Ventilation Improvement Feasibility Study

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I. Executive Summary

This report provides suitable solutions for improving ventilation rates at the University of Manitoba Fort Garry campus for a list of spaces outlined by the U of M. A suitable metric for minimum ventilation rates based on relevant codes and standards is developed, existing air handling system conditions are assessed, and a set of solutions for obtaining proposed minimum ventilation rates is provided for both short and long-term implementation.

The Ventilation Rate Procedure (VRP) from ASHRAE 62.1 2022 is used to determine acceptable minimum outdoor air flow rates for each space. A method for calculating effective ventilation rates is proposed to calculate additional ventilation from air cleaning devices. Additionally, a minimum air change rate of 3 ACH is set based on the recommended minimum in the Harvard T.H. Chan School for Public Health report.

The supply air to each space in the study has been measured by air balancers, outdoor airflow percentages are determined using a mass balance equation with air temperatures measured at each air handler, and existing filtration is documented, resulting in an overall understanding of existing ventilation. Lastly, control programs are reviewed to understand minimum flow rate conditions and evaluate systems under conditions where overall air flow and outdoor air supply is minimized.

Existing conditions are assessed in Section V for each air handler, identifying concerns with air flow below design conditions, VAV minimum flow rates, humidity issues, and maintenance concerns with regards to cleaning and filter replacements.

In Section VI, a set of potential solutions for improving ventilation rates are outlined. Short-term recommendations (0-6 months) are then proposed for achieving target clean air ventilation rates using data provided by U of M and data acquired through system assessments. Short-term recommendations include air-handler filter upgrades, control sequence modifications, and outdoor air percentage increases.

Long-term recommendations (1-3 years) are provided in Section VIII. A list of high-risk spaces outlines air handlers serving spaces that are below 80% of original design flow rates and processes are proposed to investigate these systems. Humidifier installation is recommended for air handlers without existing humidifiers. A list of air handlers that are compatible with V-bank and pocket style filters is provided with a test method to determine the most cost-effective filter setup for each air handler. Control system updates are recommended for improved energy efficiency and more consistent outdoor airflow. Lastly, computerized documentation of air handler maintenance is suggested.

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II. Summary

The University of Manitoba has developed a list of highly utilized spaces at their Fort Garry campus (shown in APPENDIX H) that require ventilation rate improvements to maintain acceptable indoor air quality. The purpose of this study is to provide U of M with suitable solutions for improving ventilation rates in these spaces.

Condition assessments are conducted on existing air handling systems. A suitable metric for minimum ventilation rates is developed based on relevant codes and standards. Lastly, a list of solutions for short-term (0-6 month) and long-term (1-3 year) timelines is proposed. Suitable solutions will have low sound levels, will be economical, and will be feasible within either the short or long-term timelines provided. Additional consideration will be made for tamper-proof solutions, and solutions that maintain accessibility for occupants within the spaces.

III. Scope

The scope of this feasibility study is limited to the list of 95 spaces provided by U of M for the Fort Garry campus. Recommendations in this report provide space level solutions that improve ventilation, are feasible and economical, and can be implemented in 1-2 years as per the Request for Quote. The effective clean air ventilation requirements applied in this report do not guarantee that the outdoor air requirements of ASHRAE 62.1 are satisfied.

IV. Metrics

A. Outdoor Air Ventilation Metric

ASHRAE 62.1 outlines 2 methods that can be used (either independently or in combination) to determine acceptable outdoor air ventilation rates. These methods are:

- Ventilation Rate Procedure (VRP): Determines required outdoor air ventilation based on space type/application, occupancy level, and floor area.
- Indoor Air Quality Procedure (IAQP): Determines required outdoor air ventilation based on analysis of contaminant sources and concentration limits.

VRP will be used to calculate the required outdoor air ventilation rates (V_{ot}) for each space in this study as shown in ASHRAE 62.1 equations below:

$$V_{ot} = V_{ou}/E_v \quad \text{Equation 6.2.5.4}$$

$$V_{ou} = D * (R_P * P_z) + (R_a * A_z) \quad \text{Equation 6.2.5.3}$$

$$A_z = Zone\ floor\ area$$
$$P_z = Zone\ peak\ occupancy$$
$$D = Occupant\ Diversity$$
$$R_p = Outdoor\ air\ flow\ required\ per\ person$$
$$R_a = Outdoor\ air\ flow\ required\ per\ unit\ area$$
$$E_v = System\ Ventilation\ Efficiency$$
$$V_{ou} = Effective\ zone\ outdoor\ airflow$$

IAQP can be used when there is a known source for contaminants within a space. This method is consistent with the Alternative Ventilation Metric defined below, relying on air cleaning in addition to dilution from the Ventilation Rate Procedure.

B. Alternative Ventilation Metric

Our recommendation is to follow ASHRAE 62.1 Ventilation Rate Procedures to calculate minimum outdoor air ventilation rates, however we understand the limitations with budget and existing equipment at the U of M. For this study, a method will be used to calculate an effective air cleaning ventilation rate that will contribute to the ventilation rate required by *ASHRAE 62.1*.

The effective clean air ventilation rate for an air cleaning device will be determined using Equation 1 and Equation 2.

$$V_{eff} = V_{act} + \sum (E_f * V_f) \qquad \text{Equation 1}$$

$$eACH = (Vol * 60)/V_{eff} \qquad \text{Equation 2}$$

$$V_{eff} = Effective\ ventilation\ flow\ rate$$
$$eACH = Effective\ Air\ changes\ per\ hour$$
$$Vol = Room\ volume$$
$$V_{act} = Ventilation\ flow\ rate$$
$$E_f = Percent\ efficiency\ of\ air\ cleaning\ device$$
$$V_f = Flow\ rate\ of\ unclean\ air\ travelling\ through\ the\ device$$

For MERV rated filters, the percent efficiency (E_f) is an average efficiency based on the removal rate of a given MERV rating at each of the particulate size ranges. The method is based on ASHRAE's Epidemic Task Force's Building Readiness Guidelines for calculating Equivalent Outdoor Air. The result of this calculation is shown in APPENDIX E.

C. Space Air Change Rate

A report by Harvard T.H. Chan School for Public Health classifies air change rates above 3 air changes per hour (ACH) as the minimum recommended air change rate for schools[6]. A minimum of 3 ACH of total effective ventilation air will be targeted for all spaces where minimum ASHRAE 62.1 outdoor air flow rates are lower than 3 ACH.

V. Assessment of Existing Conditions

A. Measuring Space Flow Rates and Outdoor Air Percentage

Flow rates were obtained by AHS Testing & Balancing in June/July of 2022 for several spaces at U of M. The air balancers documented minimum and maximum flow rates for pneumatic VAV systems. Control programs were reviewed to determine minimum and maximum setpoints for electronically controlled VAV systems.

Air temperatures are used in a mass balance calculation to determine the percentage of outdoor air supplied by each air handler as shown in Equation 3. This percentage is then multiplied by the total flow rate to a given space served by the air handler to determine the outdoor air flow rate to the space.

$$OA\,\% = \frac{MAT - RAT}{OAT - RAT} \qquad \text{Equation 3}$$

$$OA\,\% = Pecentage\ of\ supply\ air\ that\ is\ outdoor\ air$$
$$MAT = Mixed\ air\ temperature$$
$$RAT = Return\ air\ temperature$$
$$OAT = Outdoor\ air\ temperature$$

B. Calculating Minimum Outdoor Air Flow Rates

The outdoor air damper control sequence was documented for each air handler. This control sequence is used to determine percent outdoor air during shoulder seasons and worst-case winter and summer conditions. APPENDIX F shows how worst-case summer and winter outdoor air percentages are calculated.

C. Control Sequence Observations

The following observations were made while analyzing control sequences for air handlers in this study:

- Outdoor air damper position appears to be controlled based on combinations of the following:
    - Ramp function (to slowly open outdoor air damper during startup)
    - Minimum damper position
    - Target mixed air temperature (calculated based on return air temperature)
- The formula for target mixed air temperature appears to have the same format with different variables for each air handler.
- Some air handlers had a so-called ‘economizer’ mode to set the outdoor air damper to a minimum position when outdoor air temperature rises above 24°C. Note that ‘economizer’ modes usually refer to systems that conserve energy by increasing outdoor air intake while this 'economizer' mode reduces outdoor air intake.
- There were portions of code that had been commented out (such as demand control ventilation).

D. Measured Versus Design Airflow Rates

A list of spaces that were measured below design flow rates are show in APPENDIX A. Airflow rates below design conditions can result in low outdoor air flow, low air change rates, and air stratification.

1. Outdoor Air Flow

Outdoor air is critical in maintaining indoor air quality. Introducing clean outdoor air results in the dilution of contaminants within the space including odors, viruses, bacteria, mold, VOCs, irritants, and other contaminants. Outdoor air also dilutes CO2 which filtration devices cannot. CO2 measurements alone do not properly reflect the overall air cleaning efficiency of the ventilation system.

2. Air Change Rates

Higher air changes results in more recirculated air passing through filters and other air cleaning devices. This removes airborne contaminants such as airborne pathogens (viruses, bacteria, mold, etc.) and other particulates but does not directly influence CO2 levels.

3. Air Stratification

Most ventilation systems in this study are mixed air systems which rely on having enough airflow to fully mix air within each space. The purpose of a mixed air system is to ensure the air temperature and air quality is uniform throughout the space. Low air change rates can cause air stratification in a mixed air system resulting in ventilation air not properly mixing throughout the space.

E. Air Handler Condition Assessments

1. VAV Minimum Airflow

VAV minimum airflow setpoints for several spaces in this study were observed to be well below the effective clean air ventilation requirement. VAV systems typically vary supply air volumes based on cooling demand. When a space requires cooling the airflow increases and when the space requires heating the airflow decreases. The VAV has a minimum setpoint to prevent airflow from dropping below a certain flow rate. The image below for a typical VAV system shows the change in air volume versus change in room temperature.

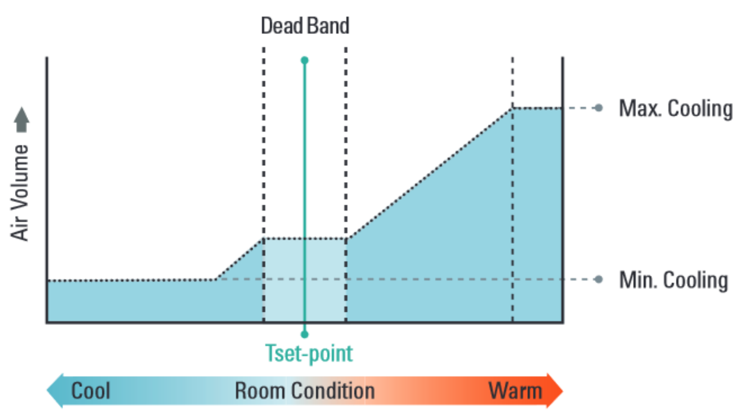

Figure 1. VAV system airflow versus room temperature.[8]

Controlling air volume based on temperature may result in reduced air flow during occupancy. ASHRAE outlines a method for calculating minimum acceptable flow rates which ensures ventilation rates are met when cooling demand is at a minimum.

2. Humidity

Studies have shown that higher humidity levels, not exceeding 60% and ideally between 40-60%, minimizes the survival and infectivity of bacteria and viruses while reducing reactions to allergens.[2] Low humidity can be an issue in colder months when the ventilation systems are heating cold outdoor air that naturally has low moisture levels. Some air handlers in this study were observed to have either broken or no humidifiers (shown in APPENDIX C).

3. Filter Maintenance

The process for filter replacement appears to be based mainly on visual inspection without the use of pressure drop measurements across the filter banks. Without using pressure sensors, the process of changing filters is subjective and can result in filters being changed too frequently or too infrequently.

Air handler filter ratings in some buildings were observed to have been upgraded from MERV 8 to MERV 13 between inspections in July and November 2022. Air handlers with MERV 13 replacements are being monitored by U of M for motor data and pressure drops where possible.

4. Air Handler Maintenance & Cleanliness

Many air handlers were observed to have dust and generally dirty surfaces in the air stream after pre-filtration (see table in APPENDIX B). Dust was frequently found on the intake side of the heating/cooling coil fins. Unclean surfaces can host unwanted contaminants that can be re-introduced into the air. Dirty coil fins can also increase pressure drop and can be a sign for dirty coils resulting in reduced heating and cooling capacities.

VI. Ventilation Improvement Solutions

The following solutions are split up into high, medium, and low priority categories. High priority solutions are recommended wherever possible within the scope of this study. Medium priority solutions are recommended where high priority solutions are not feasible. Lastly, low priority solutions are recommended for energy cost savings.

A. System Level Analysis

***High Priority Solution**: Increases air changes and restores proper air mixing in more than just the prioritized space. Increases effectiveness of AHU filtration and other filtration systems.*

Airflow rates are recommended to be restored to original design conditions for the air handlers serving spaces that are below design conditions.

The following process will allow for a better understanding of overall systems supplying the spaces in this study with low air flow rates. The system information can then be used to provide a solution for improving system air flow rates.

1. Analyzing System Design Condition

The overall system needs to be assessed to determine the cause of the low air flow rates. This includes analyzing spaces outside of the scope of this study. Record drawings are required to assess which spaces are served by each air handler, and the air flow rates required for each of space served by that air handler. Additionally, record drawings showing air handler design conditions can be referenced (e.g. fan schedules, coil schedules, air balancing reports, etc.).

Design conditions can be approximated through calculations where record drawings are not available. Coil loads can be approximated using the size of the coil, number of coils, and flow rate through the coil. Airflow can be approximated using the size of the installed ductwork.

2. Measuring Existing System Condition

The existing condition of the system should be measured and compared to the observed or calculated design conditions. The information required to properly assess the system would be:

- Air handler flow rate
- Coil size, number of coils, and pressure drop across the coil
- Motor RPM, amp draw, and VFD setpoint
- Motor and blower name plates
- Pulley sizes
- Supply and return fan pressure

Additionally, fan curves for any motor/blower assembly should be acquired where possible.

3. Potential Air Handler Issues

The following are some potential issues with the system that can be diagnosed by comparing the existing and measured conditions.

Problem	Solution
Un-balanced system	Air balancing required at room level
Plugged or dirty coils	Clean or replace coils
Bad motor	Replace motor
Incorrect pulley size	Replace pulleys
Room-level issue	Fix or replace room-level equipment

B. Air Handler Filtration Upgrades

***High Priority Solution**: Improves air quality in more than just the prioritized space. Proven method for ventilation air cleaning.*

Minimum Efficiency Removal Rating (MERV) quantifies a filter's ability to capture particles between 0.3 and 10 microns in diameter. Filters with MERV 13 or better are recommended by the ASHRAE Epidemic Task Force for removal of biological contaminants due to the contaminants typical particle sizes[3].

The consequence of increasing filter ratings without changing filter depth or air velocity is an increase in pressure drop. A higher rated filter also removes more particulate from the air which can result in the filter becoming dirty faster. APPENDIX E shows the overall efficiency of each MERV rating for removing particulate in the 0.3 to 10 micron diameter range.

The air handlers that were assessed in this study consist of either angled or flat filter bank styles as shown in Figure 2. The angled filter bank (or V-bank housing) has the filters at approximately 45 degrees. This layout increases the filter surface area to reduce pressure drop across the filter bank, but is only suitable for panel style filters. The flat filter banks allow for the installation of V-bank style filters or pocket filters when there is adequate space on the downstream side. Filter bank style for each air handler can be found in APPENDIX D.

Figure 2. V-bank housing aka angled filter bank (left). Flat filter bank (right)

The following table shows various filter options from Camfil and Filtration Group, both filter manufacturers that are currently used by U of M. The table shows the filter style, depth, MERV rating, and initial pressure drop for a 24”x24” filter.

Table 1
Camfil and Filtration Group 24x24" Filters

Manufacturer	Model	Style	MERV Rating	Media Depth	Pressure Drop @ 500 FPM [in w.g.]
Camfil	Farr 30/30	Panel	8	2"	0.31
	AeroPleat		13		0.41
	Durafil-ES	V-Bank	11	12"	0.22
			14		0.29
	Hi-Flo-ES	Pocket	11	12"	0.24
			13		0.38
Filtration Group	EnduroPleat	Panel	8	2"	0.20
	Green Pleat		13		0.39
	Aerostar FP	V-Bank	11	12"	0.18
			14		0.28
	Fiberflass	Pocket	11	22"	0.27
			13		0.37

*Listed pressure drop is for clean filters. V-Bank and Pocket style filters should be used with additional MERV 8 pre-filter.

Some air handling units in this report have pressure sensors installed to measure pressure drop across filter banks as shown in APPENDIX D. Digital pressure sensors are recommended for all air handlers as they will allow for a consistent process by the maintenance team for replacing filters. This will have an added advantage as higher rated filters that are more expensive get installed across campus. See Section VI.H for further discussion on filter replacement maintenance.

C. Room Level Filtration Devices

***Medium Priority Solution**: Required where spaces do not meet design flow rates and the central system cannot accommodate increased flow rates. Potential for added noise.*

Room level filtration devices filter additional recirculated air from the space. This is considered where air handler filtration upgrades and control sequence changes cannot satisfy clean air ventilation rate requirements.

Noise levels and maintenance are a concern with localized filtration units. Noise levels are recommended to remain below 30 NC for classrooms according to the ASHRAE HVAC applications handbook[7]. Corridor or utility room ceiling spaces adjacent to lecture rooms are recommended for housing the unit to reduce radiated noise into the space. Attenuators are also recommended in all room level fan applications to reduce discharge noise. Lastly, room-level filtration devices are recommended to operate below maximum rated flow rates to further reduce noise.

The height of these units must be considered for each application. Low profile options are available going as low as 10.5 inches. The largest units considered in this report are 17.5 inches tall without the low-profile option. Demand Control Ventilation (DCV) is recommended to control room level filtration devices to ensure the spaces are getting the required clean air when occupied. See Section VI.E.

1. Parallel Fan Powered Terminal Unit

Parallel fan powered terminal units (Parallel FPUs) use a blower to supply additional recirculated air to existing air handler supply air as shown in Figure 3. The blower can stage on and off based on air recirculation demand. Using a MERV 13 filter or alternative air cleaning method on a parallel fan powered terminal unit will result in additional air changes to a space allowing spaces to meet design flow rates where the central system is not capable. The additional airflow can restore design flow rates and proper air mixing in spaces below design conditions.

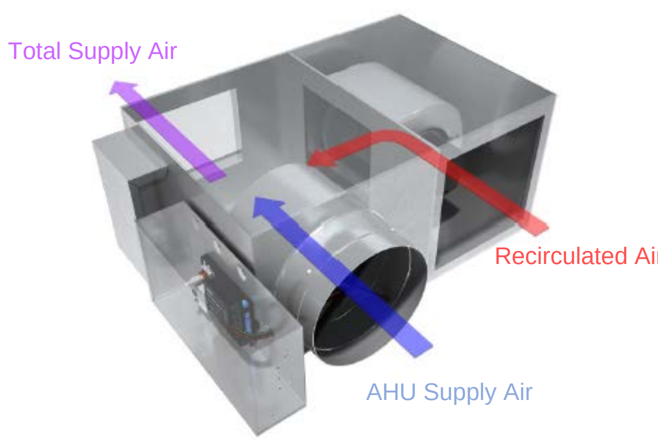

Figure 3. Parallel Flow Fan Powered Unit (Parllel FPU).[8]

2. Series Fan Powered Terminal Unit

Series fan powered terminal units (Series FPUs) differ from parallel FPUs by pulling both supply air and recirculated air through the blower as shown in Figure 4. The Series FPU requires the fan to be running to provide air to the space and operates at a constant flow rate.

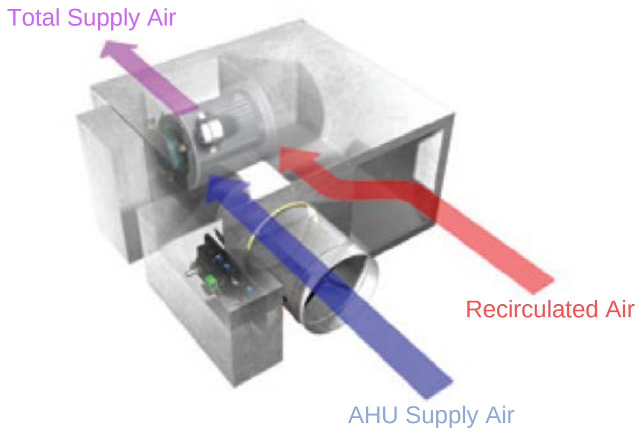

Figure 4. Series Flow Fan Powered Unit (Series FPU).[8]

The series FPU can be used for the sole purpose of recirculating and filtering room air without the need for modifications to existing ductwork. Overhead air purifiers (OAPs) are designed specifically for the purpose of filtering and recirculating air. These units pull in room air, clean the air with MERV 13 filters, and supply the clean air back into the space. The sizing is limited for these units, so they are only used in certain series FPU applications.

D. Alternate Air Cleaning Devices

Medium Priority Solution*: Low pressure drop compared to traditional filtration. Can be used in parallel with any other solutions to increase air quality. Requires testing to confirm benefits.*

The following alternate air cleaning devices were reviewed for this ventilation study. However, these devices were not considered to contribute toward clean air ventilation rates since there is no standardized method for calculating the air cleaning efficiency of these devices.

- Needlepoint Ionizers
- UVGI
- Hydrogen Peroxide
- Hydroxyl Radicals
- Activated Carbon Filters

E. Demand Control Ventilation (DCV)

Medium Priority Solution*: Can be used in parallel with space flushing. Lowers energy costs. Can be used to meet ventilation requirements for VAV systems.*

Demand control ventilation (DCV) is recommended for certain spaces with VAV systems to ensure the minimum effective clean air requirement is achieved under high occupant loads. DCV can also be used on a system level to lower the required outdoor air during low occupancy periods. CO2 monitors, occupancy sensors, or other means of measuring occupancy can be used to implement DCV. Energy savings will be realized by using DCV and can counteract some of the increase in energy use from increasing ventilation rates.

1. Demand Control Ventilation Sensors

Occupancy sensors can be used to reduce outdoor air during unoccupied periods. This will result in energy savings for air handlers serving frequently unoccupied spaces and would prevent excessive ventilation outside of operating hours. Occupancy sensors cannot determine the number of occupants in a space and must be placed appropriately to ensure occupancy is detected accurately.

CO2 sensors are a common method for DCV since the level of CO2 within a space is proportional to the occupancy of that space. However, there is a delay between when occupants enter a space and when the CO2 monitor registers the occupants. A recommended method for using CO2 sensors for DCV can be found in ASHRAE Guideline 36[10].

2. System Level Demand Control Ventilation

Air handlers with CO2 sensors installed on the main return duct can switch to unoccupied mode to close off the outside air dampers once carbon dioxide levels approach atmospheric CO2 levels. Atmospheric CO2 is normally averaged at 400 ppm and it is reasonable to close outside air dampers at conditions lower than 425 ppm. Digital CO2 sensors are recommended where there are no existing sensors. ASHRAE recommends restarting the HVAC system 1 hour prior to expected occupancy to flush contaminants built up during the unoccupied period.

3. VAV Space Level Demand Control Ventilation

The recommendation for demand control ventilation on VAV systems is to increase the VAV airflow to 100% when CO2 levels rise above a certain ppm level (called the CO2 setpoint). The recommended CO2 setpoint is based on peak CO2 measurements taken prior to implementing VAV demand control ventilation.

Table 2.
Recommended VAV system demand control ventilation CO2 setpoints

Peak CO2 Measurement	DCV CO2 Setpoint
< 800ppm	600 ppm
800-900 ppm	700 ppm
900-1000 ppm	800 ppm
1000-1300 ppm	900 ppm
> 1300 ppm	1000 ppm

The VAV runs at 100% until CO2 levels drop 100ppm below the CO2 setpoint at which point the VAV will return to normal operation. For systems with no room level reheat device, if room temperature drops more than 1 degree Celsius below the room temperature setpoint then the VAV is recommended to return to normal operation until the temperature setpoint is restored.

VAV spaces were observed to have low or even zero airflow at the minimum VAV setpoint. This could result in no air supply to these spaces during low occupancy. VAV minimums are recommended to be increased to account for low occupancy levels immediately once the occupancy sensor is triggered.

Data logs and monitoring of spaces with VAV demand control ventilation is recommended to ensure the control sequence operates properly and the room temperature remains at reasonable levels.

F. Space Flushing

***Low Priority Solution**: Allows for nighttime setback mode with no outdoor air. Lowers energy costs.*

Flushing spaces before and after occupancy will ensure contaminants are diluted before occupants enter the space. Flushing is recommended on a fixed schedule before occupancy. Spaces can also be flushed for a fixed amount of time after occupancy with the use of occupancy sensors.

Equation 4 is used to calculate the time in hours required to fully flush a space based on the cleaning efficiency of the ventilation system.

$$t = \frac{3}{eACH * E_V} \qquad \text{Equation 4}$$

The maximum time required to flush a space will be approximately 1 hour for spaces with 4 eACH considering the lowest ventilation effectiveness (E_v) observed in the analyzed spaces. Therefore, 1 hour is recommended for flushing time before and after occupancy in locations where effective clean air ventilation rates are reduced during non-occupied periods.

G. General Air Handler Maintenance

***High Priority Solution**: Basic requirement for maintaining indoor air quality. Improves performance of heating/cooling coils.*

As discussed in Section V.E.4, the cleanliness and maintenance of some observed air handlers in this study is a concern for maintaining performance and air quality.

Dirty coil fins may reduce coil efficiency and increase pressure drop resulting in increased energy usage and reduced ventilation. A review is recommended for coil cleaning maintenance schedules to ensure consistent cleaning is taking place and that no air handlers are being overlooked. Air handlers are also recommended to be shut off during filter replacements to prevent debris from by-passing the filter bank during maintenance.

Bipolar ionizers and UV-C systems are useful for keeping air handlers clean. Implementing these devices more frequently in U of M air handlers will help keep them clean over years of use.

H. Filter Replacement Maintenance

***Low Priority Solution**: Prevents issues that can cause low ventilation. Lowers energy and maintenance cost.*

Filters that are not replaced frequently enough will cause adverse effects on the ventilation system due to an increase in pressure drop. The increased pressure can cause reduced airflow and can increase energy costs. However, changing filters too frequently will also increase costs. A cost that will be compounded with the integration of more expensive MERV 13 filters.

Filters are recommended to be replaced based on a pre-determined allowable pressure drop using installed pressure monitors that are connected to the building management system (BMS) and can be visually confirmed by maintenance. Using pressure measurements will ensure a consistent approach for filter replacements without excess waste or adverse effects on ventilation systems. Consistent labels that specify the type of filter that needs to be installed are also recommended.

Installing a pressure sensor on an air handler filter bank requires purchasing the device, installing the device, and setting up the controls. APPENDIX D shows existing pressure gauges for each air handler.

The last date of calibration for each installed pressure sensor should be verified and referenced against the manufacturer's recommendations. Each pressure sensor is recommended to have a schedule for calibration to ensure that the data used for filter replacements is accurate.

VII. Short Term Solution Implementation (0-6 Months)

Solutions from Section VI are recommended for each of the priority spaces in this section for short-term applications. The outdoor airflow percentage used in these calculations is the worst-case scenario taken from the lowest calculated percentage in winter or summer conditions based on analysis of air-handler control sequences.

A. Definitions

- **Existing Airflow**: Airflow calculated from measurements taken by AHS Testing & Balancing
- **Effective Clean Airflow**: Represents effective clean air ventilation calculated as shown in Section IV.B Alternative Ventilation Metric, units are eCFM or eACH

B. Room-Level Recommendations

			Existing Minimum Effective Clean Airflow		Required Effective Clean Airflow		
Bld #	Building Name	Room #	[eCFM]	[eACH]	[eCFM]	[eACH]	Recommendation
12	Agricultural and Civil Eng	A205	60	0.4	749	5.6	DCV + Central MERV 13
11	Agriculture Building	130	864	3.8	1040	4.6	Parallel FPU
11	Agriculture Building	172	2884	5.3	2265	4.2	-
11	Agriculture Building	343	1290	4.8	1067	4.0	-
14	Agriculture Lecture Block	101	211	1.6	530	4.0	OAP
151	Allen Building	403	850	2.6	1527	4.6	Central MERV 13
151	Allen Building	405	834	3.0	1122	4.0	Central MERV 13
151	Allen Building	519	1245	5.6	893	4.0	Central MERV 13
151	Allen Building	521	938	4.5	826	4.0	Central MERV 13
261	Architecture 2	110	301	2.7	449	4.1	Parallel FPU
261	Architecture 2	116	228	1.7	552	4.0	Parallel FPU
152	Armes Lecture Theatre	200	1986	3.5	2262	4.0	Central MERV 13, BI
152	Armes Lecture Theatre	204	2058	3.6	2260	4.0	Central MERV 13, BI
152	Armes Lecture Theatre	205	2153	5.5	1566	4.0	Central MERV 13, BI
152	Armes Lecture Theatre	208	2052	3.6	2274	4.0	Central MERV 13, BI
343	Art Lab	136	889	2.1	1664	4.0	DCV
191	Biological Science	211	574	3.3	870	5.0	Central MERV 13
191	Biological Science	305	759	3.2	1115	4.8	Central MERV 13
157	Buller	207	438	2.3	1403	7.3	DCV
157	Buller	215	276	1.4	779	4.0	DCV
157	Buller Biological Building	204	1318	7.2	1100	6.0	DCV
157	Buller Biological Building	302	1196	6.7	876	4.9	DCV
157	Buller Biological Building	306	1101	5.9	889	4.8	DCV
157	Buller Biological Building	312	1755	5.8	1484	4.9	DCV
157	Buller Biological Building	314	1250	6.3	1040	5.3	DCV

Bld #	Building Name	Room #	Existing Minimum Effective Airflow		Required Effective Clean Airflow, Veff		Recommendation
			[eCFM]	[eACH]	[eCFM]	[eACH]	
28	Dairy Art	230	3121	3.4	2757	3.0	Balance
117	Drake Centre	115	992	3.1	962	3.0	-
117	Drake Centre	105	412	1.7	1003	4.2	Digital VAV + DCV
117	Drake Centre	107	480	2.0	1003	4.2	Digital VAV + DCV
117	Drake Centre	117	530	2.3	916	4.0	Digital VAV + DCV + AHU Analysis
117	Drake Centre	122	1629	4.0	1638	4.0	DCV
117	Drake Centre	343	499	0.7	2911	4.0	AHU Analysis
167	Duff Roblin	P210	318	1.3	926	4.0	Digital VAV + DCV
167	Duff Roblin	W232	673	3.3	821	4.0	Central MERV 13
211	Education	290	4012	5.8	2819	4.1	-
211	Education	325	496	2.4	911	4.4	Central MERV 13
211	Education	326	630	2.8	668	4.0	Central MERV 13
211	Education	327	529	2.3	678	4.0	Central MERV 13
211	Education	342	726	2.1	1043	4.0	Central MERV 13
211	Education	366	1105	5.6	594	4.0	-
211	Education Building	222	338	1.6	848	4.0	OAP
211	Education Building	224	647	1.8	1805	5.0	OAP + Central MERV 13
211	Education Building	226	424	2.4	698	4.0	Central MERV 13
231	EITC-1	E1-225	864	3.9	918	4.1	DCV + Central MERV 13
231	EITC-1	E1-422	0	0.0	1016	3.1	DCV + Central MERV 13
231	EITC-1	E1-473	851	3.6	957	3.0	DCV + Central MERV 13
232	EITC-2	E2-105	57	0.1	1448	3.0	DCV
232	EITC-2	E2-110	77	0.2	1556	3.0	DCV
232	EITC-2	E2-125	0	0.0	997	3.1	DCV
232	EITC-2	E2-130	0	0.0	1122	3.0	DCV
232	EITC-2	E2-150	106	0.3	1126	3.0	DCV
232	EITC-2	E2-155	64	0.2	997	3.1	DCV
232	EITC-2	E2-160	0	0.0	1122	3.0	DCV
232	EITC-2	E2-165	146	0.5	964	3.0	DCV
232	EITC-2	E2-320	35	0.1	1046	3.0	DCV
232	EITC-2	E2-330	24	0.1	1046	3.0	DCV
232	EITC-2	E2-350	152	0.4	1046	3.0	DCV
233	EITC-3	E3-270	3034	3.5	2638	3.0	-
310	Extended Ed	160	554	2.6	920	4.3	Digital VAV, Balance
310	Extended Ed	198	377	1.6	972	4.0	Digital VAV, Balance
111	Fletcher Argue	100	1846	4.5	1929	4.7	Central MERV 13
111	Fletcher Argue	200	4200	7.2	2780	4.8	-
309	Frank Kennedy	130	1799	6.4	1014	4.0	-
309	Frank Kennedy	136	1502	6.7	1845	8.3	Balance

Bld #	Building Name	Room #	Existing Minimum Effective Airflow		Required Effective Clean Airflow, Veff		Recommendation
			[eCFM]	[eACH]	[eCFM]	[eACH]	
283	Helen Glass	260	738	2.5	1195	4.1	DCV + Central MERV 13
283	Helen Glass	460	634	1.8	1078	3.0	DCV + Central MERV 13
283	Helen Glass	470	716	2.0	1063	3.0	DCV + Central MERV 13
81	Human Ecology	206	124	0.4	1851	5.5	DCV + Central MERV 13
113	Isbister	137	1150	5.1	868	4.0	Verify airflow in winter
113	Isbister	231	5365	9.8	2617	4.8	-
113	Isbister	235	1554	7.8	1015	5.1	Verify Winter Airflow
37	J.H. Ellis Building	241	481	2.3	849	4.0	Series FPU
37	JH Ellis	245	1006	4.8	735	4.0	-
142	Robert Schuller	172	2299	2.7	3018	3.5	DCV
251	Robson Hall	200A	1309	4.6	1105	4.0	Balance
251	Robson Hall	200B	941	3.3	977	4.0	Balance
201	Russel	211	365	2.0	743	4.0	OAP + Central MERV 13
201	Russel	214	701	2.5	1528	5.4	OAP + Central MERV 13
146	Sinnot	101	205	2.5	386	4.6	OAP
141	St. Johns College	118	1106	3.7	1330	4.4	Balance
145	St. Pauls College	100	1583	3.9	1932	4.8	Central MERV 13
145	St. Pauls College	258	1411	5.3	797	4.0	-
145	St. Paul's College	225	175	1.0	685	4.0	DCV
145	St. Paul's College	318	1152	5.7	908	4.5	-
238	Stanley Pauley Eng Building	SP124	464	1.8	1035	4.0	Balance, Revise DCV
341	Tache Arts Complex	450	948	2.1	1791	4.0	MERV 13 @ Fan Coil Unit
339	Tache Arts Complex - T2	T2-166	1097	4.0	1100	4.0	-
339	Tache Arts Complex - T2	T2-266	2190	1.7	5021	4.0	MERV 13 @ Fan Coil Unit
339	Tache Arts Complex - T2	T2-272	948	2.1	1791	4.0	MERV 13 @ Fan Coil Unit
115	Tier	206	2648	6.6	1533	4.0	-
115	Tier	306	3103	7.2	1590	4.0	-
115	Tier	408	1823	4.3	1679	4.0	-
131	University College Lecture	233	1192	5.5	912	4.2	DCV
156	Wallace	221	-	-	1462	4.0	Replace VAV, Balance
156	Wallace	223	-	-	1534	4.0	Replace VAV, Balance

VIII. Long-term solutions (1-3 Years)

The following solutions are for further ventilation and air quality improvements after short-term solutions have been implemented. The priority system from the short-term solutions section is used on these solutions as well.

A. System Level Solutions

***High Priority Solution**: Increases air changes and restores proper air mixing in more than just the prioritized space. Increases effectiveness of AHU filtration and other filtration systems.*

The air handlers in Table 3 serve spaces that have been measured below 80% of design flow rates based on record drawings provided by U of M. These air handlers are recommended for system level analysis as per Section VI.A.

Table 3
Air handlers recommended for system analysis

Bld #	Building Name	AHU #
11	Agriculture Building	AH-1
14	Agriculture Lecture Block	AH-1
151	Allen Building	AH-1, SF-77
261	Architecture 2	AH-1
117	Drake Centre	SF-12
117	Drake Centre	SF-16
211	Education Building	AH-1
211	Education Building	AH-2
310	Extended Ed	AH-1
309	Frank Kennedy	AH-1
113	Isbister	AH-1
37	J.H. Ellis Building	AH-3
115	Tier	AH-1
115	Tier	AH-2

B. Air Handler Control Sequence

***Low Priority Solution**: Improves control sequence clarity, may help with future control modifications.*

Observations from air handler control sequence analysis are outlined in Section V.C. Specific recommendations are outlined below and ASHRAE guideline 36 is recommended for standardization of controls across the U of M campus[10].

1. Documentation

Changes appear to have been made in the control sequence without documentation on the date or reason for the change. There is also very little explanation or commenting in the control sequence for the intended purpose of each section of code. Each section of control sequence is recommended to have comments that describe the intent of that section. Any changes to the control sequence are recommended to be documented with a reasoning for the change.

2. Mixed Air Temperature Formulas

Small variations were observed in almost every air handler's target mixed air temperature formula. Increasing outdoor air intake is important for improving indoor air quality and requires an understanding of existing control sequences. Consider an investigation into the reasoning for the variations in these formulas and consider consolidating formulas.

3. Outdoor Air Minimums

The minimum outdoor air percentages in this report are estimated based on control sequences and observed data. The actual minimums and the variation of outdoor air throughout the day are not fully known. An analysis for outdoor airflow percentages provided by U of M air handlers in both hot and cold outdoor air conditions is recommended. The analysis would provide valuable information to ensure minimum outdoor air volumes are being met and show which air handlers would require control sequence modifications or damper air balancing.

C. Humidification

***Medium Priority Solution**: Directly impacts air quality. Proper humidity levels are proven to lower infection rate and survivability of bacteria and viruses[2].*

Humidifiers are recommended to be installed in air handlers to maintain the recommended relative humidity levels. Observed humidifier conditions for the air handlers in this report are listed in APPENDIX C. While a range of 40% to 60% is a typical recommendation for relative humidity in some climates, high humidity levels during the winter in Winnipeg's climate can result in building envelope deterioration in older buildings. In winter, the recommended relative humidity level for older buildings is 30% while newer buildings are recommended to target 40% relative humidity. In summer, a target of 40-60% relative humidity is recommended.

ERVs are recommended for current and future systems to allow for humidity to be recovered from exhaust air. ERV systems allow for optimal relative humidity levels on cold days when outside air moisture content is low by recovering humidity from exhaust air.

D. V-Bank & Pocket Style Filters

***Low Priority Solution**: May lower costs, lower filter pressure-drop, and allow for widely adopted higher rated filters.*

V-bank and pocket style filters were not recommended in the short-term due to the higher initial costs shown in Table 2. However, V-bank or pocket style filters have a longer lifespan. The trade-off for pricing depends on how fast filter loading occurs based on site conditions.

APPENDIX D lists the air handlers that can accept the deeper V-bank or pocket style filters by labeling the filter bank as 'Spacious'.

The following approach is recommended to compare the cost of V-bank filters, pocket filters, and MERV 13 panel filters. A decision can be made on implementing a certain filter type on a larger scale once the annual cost for each option is obtained.

1. Install V-bank or pocket style filters with MERV 8 pre-filters.

2. Document pressure drop and replace MERV 8 pre-filters as required until the V-bank or pocket filters have reached the manufacturer's maximum recommended pressure drop.

3. Repeat the test with each filter types.

4. Calculate the average annual cost of each filter type.

E. Filter Replacement Maintenance

***Low Priority Solution**: Improves maintenance efficiency.*

Filter replacements, filter upgrades, bearing replacements, and bearing maintenance appear to be documented on paper in each mechanical room. An example is shown below in Figure 5.

A computerized method is recommended to be implemented for any air handler maintenance to allow for a centralized system that is remotely accessible. This will help maintain a consistent approach to air handler maintenance while maximizing maintenance efficiency. Documenting data will also help with future troubleshooting and consultant reviews.

Maintenance documentation is recommended to include all necessary information for proper replacements including frequency of service, required filter rating/style, and type of filters used.

Figure 5. Physical notes for filter and bearing maintenance in building 117 – Drake, mechanical room for F-12.

I. REFERENCES

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[3] ANSI/ASHRAE. (2021) *ASHRAE Position Document on Filtration and Air Cleaning*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

[4] Timothy Leach and Dr. Robert Scheir. (2014) *Ultraviolet Germicidal Irradiation (UVGI) in Hospital HVAC Decreases Ventilator Associated Pneumonia*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

[5] U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention (1994) *NIOSH pocket guide to chemical hazards*. National Institute for Occupational Safety and Health., Cincinnati, Ohio.

[6] Harvard T.H. Chan School for Public Health. (2020) *Schools for Health: Risk Reduction Strategies for Reopening Schools*. Harvard T.H. Chan School for Public Health Healthy Buildings, https://schools.forhealth.org/

[7] ANSI/ASHRAE Handbook (2019) *Heating, Ventilating and Air-Conditioning Applications*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

[8] Price Industries (2014) *Engineering Guide – Terminal Units*. Price Industries Limited, Winnipeg, Manitoba.

[9] ANSI/ASHRAE. (2021) *ASHRAE Position Document on Indoor Carbon Dioxide*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

[10] ANSI/ASHRAE Guideline 36. (2018) *High-Performance Sequences of Operation for HVAC Systems*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

II. APPENDIX A – DESIGN VS ACTUAL MAX FLOW RATES

The table below contains the spaces in this study that have been measured below 80% of design flow rates taken from record drawings. A percentage is shown comparing measured air flow to design airflow. The columns on the right show the required outdoor air as a percentage of total air flow for both measured and design conditions.

Bld #	Building Name	Room #	AHU #	Measured Minimum Airflow [CFM]	Design Supply Airflow [CFM]	% Measured vs. Design Airflow
11	Agriculture Building	130	AH-1	1081	1617	67%
14	Agriculture Lecture Block	101	AH-1	463	775	60%
151	Allen Building	403	AH-1, SF-77	1989	3920	51%
151	Allen Building	405	AH-1, SF-77	1952	3120	63%
261	Architecture 2	116	AH-1	475	1240	38%
261	Architecture 2	110	AH-1	627	1280	49%
191	Biological Science	211	AH-1	1985	2920	68%
117	Drake Centre	105	SF-12	522	1830	29%
117	Drake Centre	107	SF-12	609	1830	33%
117	Drake Centre	117	SF-12	672	1532	44%
117	Drake Centre	343	SF-16	1154	4172	28%
211	Education Building	222	AH-1	850	1477	58%
211	Education Building	224	AH-2	1510	2250	67%
310	Extended Ed	160	AH-1	1425	2790	51%
310	Extended Ed	198	AH-1	983	2650	37%
309	Frank Kennedy	130	AH-1	2283	2880	79%
309	Frank Kennedy	136	AH-1	1879	2680	70%
113	Isbister	137	AH-1	1463	2340	63%
113	Isbister	235	AH-1	1978	2910	68%
37	J.H. Ellis Building	241	AH-3	605	1290	47%
115	Tier	206	AH-1	2986	4600	65%
115	Tier	306	AH-1	3500	4600	76%
115	Tier	408	AH-2	2048	4600	45%

III. APPENDIX B – EQUIPMENT DEFICIENCIES FROM SITE VISIT

Bld #	Building Name	System	Observed Deficiency
11	Agriculture Building	AH-1	Dirty coils
11	Agriculture Building	AH-3	Dirty coils, rusty condensate pan
11	Agriculture Building	AH-5	Dirty coils
14	Agriculture Lecture Block	AH-1	Dirty coils, worn out V-belt
152	Armes Lecture Theatre	AH-1	Dirty coils, rusty condensate pan, dirty blower wheel
191	Biological Science	AH-1	Dirty coils
28	Dairy Art	AH-1	Dirty coils
211	Education	AH-1	Rusty condensate pan
211	Education	AH-2	Dirty coils
111	Fletcher Argue	AH-1	Dirty coils
309	Frank Kennedy	AH-1	Rusty condensate pan
283	Helen Glass Centre	AH-2	Dirty coils
113	Isbister	AH-1	Rusty moisture eliminators
201	Russell	AH-4	Dirty coils, rusty condensate pan
141	St. Johns College	AH-1	Dirty coils

IV. APPENDIX C – AIR HANDLER HUMIDIFIER STATUS

Table 4
System Humidifier and Humidity Sensor Status

Bld #	Building Name	Air Handler Tag	Spaces Served	Humidifier		Humidity Sensor	
				(Yes/No)	Status	(Yes/No)	Reading
343	Art Lab	AH-1	136	☑	Functional	☑	45%
157	Buller	AH-1	207, 215	☐	Disconnected	☑	20%
28	Dairy Art	AH-1	230	☐	-	☐	
117	Drake	SF-12	115	☐	Broken	☑	16%
167	Duff Roblin	AH-1	W232	☑	Functional	☑	32%
167	Duff Roblin	AH-2	P210	☐	-	☑	20%
211	Education	AH-2	325, 326, 327, 342	☐	Disconnected	☑	24%
211	Education	AH-3	366	☐	-	☐	
211	Education	ERV-1	290	☑	Energy Recovery	☑	20%
231	EITC-1	AH-1	E1-422	☐	-	☑	19%
233	`-3	AH-3	E3-270	☐	De-activated	☐	
111	Fletcher Argue	AH-1	100	☐	-	☑	28%
111	Fletcher Argue	AH-2	200	☐	-	☑	24%
81	Human Ecology	AH-1	206	☑	Functional	☑	20%
113	Isbister	AH-1	137, 235	☐	Removed	☐	19%
113	Isbister	AH-2	231	☑	Functional	☑	60%
37	JH Ellis	AH-3	245	☐	-	☐	
142	Robert Schuller	AH-3	172	☑	Functional	☑	29%
251	Robson Hall	AH-1	200A, 200B	☐	-	☐	
141	St. Johns College	AH-1	118	☐	Removed	☐	
145	St. Pauls College	AH-1	100	☐	-	☐	
145	St. Pauls College	AH-6	258	☐	-	☐	
115	Tier	AH-1	206, 306	☐	-	☐	

Table 42
System Humidifier and Humidity Sensor Status (Cont'd x 1)

Bld #	Building Name	Air Handler Tag	Spaces Served	Humidifier		Humidity Sensor	
				(Yes/No)	Status	(Yes/No)	Reading
11	Agriculture Building	AH-1	130	☑	Functioning	☑	38%
11	Agriculture Building	AH-5	172	☐	Disconnected	☑	21%
11	Agriculture Building	AH-3	343	☐	-	☑	12%
14	Agriculture Lecture Block	AH-1	101	☐	-	☐	
261	Architecture 2	AH-1	110, 116	☐	-	☐	
157	Buller Biological Building	AH-1	204, 302, 306, 312, 314	☐	Disconnected	☑	20%
117	Drake Centre	SF-12	105, 107, 117	☐	Broken	☑	16%
117	Drake Centre	SF-11	122	☐	-	☐	
117	Drake Centre	SF-16	343	☐	Broken	☑	21%
211	Education Building	AH-1	222	☐	Disconnected	☑	18%
211	Education Building	AH-2	224, 226	☐	Disconnected	☑	24%
231	EITC-1	AH-1	E1-225, E1-473	☐	-	☑	19%
283	Helen Glass	AH-2	260, 460, 470	☐	-	☑	33%
37	J.H. Ellis Building	AH-3	241	☐	-	☐	
146	Sinnot Building	AH-2	101	☐	-	☐	
145	St. Paul's College	AH-5	225	☐	-	☐	
145	St. Paul's College	AH-6	318	☐	-	☐	
238	Stanley Pauley Engineering Building	HRV-1	SP124	☐	-	☑	16%
341	Tache Arts Complex	ERV-X	450	☑	Energy Recovery	☑	58%
339	Tache Arts Complex - T2	ERV-1	T2-166, T2-266, T2-272	☑	Energy Recovery	☑	46%

Table 43
System Humidifier and Humidity Sensor Status (Cont'd x 2)

Bld #	Building Name	Air Handler Tag	Spaces Served	Humidifier		Humidity Sensor	
				(Yes/No)	Status	(Yes/No)	Reading
12	Agriculture and Civil Engineering	AH-2	A205	☐	-	☑	26%
151	Allen	AH-1	403, 521	☐	-	☐	
152	Armes Lecture Theatre	AH-1	200, 204, 205, 208	☐	-	☐	
191	Biological Science	AH-1	211, 305	☑	Functional	☑	59%
232	EITC-2	AH-2	E2-105, E2-110, E2-125, E2-130, E2-320, E2-330, E2-350	☐	-	☑	25%
232	EITC-2	AH-2	E2-150, E2-155, E2-160, E2-165	☐	-	☑	21%
310	Extended Ed	AH-1	160, 198	☐	-	☐	
309	Frank Kennedy	AH-1	130, 136	☑	Functional	☑	40%
201	Russel	AH-4	211, 214	☐	-	☐	
115	Tier	AH-2	408	☐	-	☐	
131	University College Lecture	AH-5	233	☐	-	☐	
156	Wallace	AH-1	221, 223	☑	Functional	☑	21%

V. APPENDIX D – AIR HANDLER INSTALLATION DATE, FILTER, AND DAMPER INFO

Table 44
Air Handler Information

Bld #	Building Name	Air Handler Tag	Est. Unit Install Year	Damper Control	Filter Pressure Gauge	Filter Bank Layout
157	Buller	AH-1	2006	Pneumatic	Digital	Flat, spacious
343	Art Lab	AH-1	2009	Digital	Digital	Flat with V-Bank filters
28	Dairy Art	AH-1	1998	Pneumatic	None	Flat, no space
117	Drake	SF-12	1987	Pneumatic	Digital	Flat, no space
167	Duff Roblin	AH-1	2009	Pneumatic	None	Flat, spacious
167	Duff Roblin	AH-2	2009	Pneumatic	None	Flat, spacious
211	Education	AH-2	1965	Pneumatic	None	Flat, spacious
211	Education	AH-3	1968	Pneumatic	Magnehelic	Flat, spacious
211	Education	ERV-1	Unknown, newer	Digital	Digital	Flat, no space
231	EITC-1	AH-1	2005	Digital	Magnehelic	Flat, no space
232	EITC-2	AH-2	2005	Pneumatic	Magnehelic	Flat, no space
233	EITC-3	AH-3	1967	Pneumatic	None	Flat, spacious
111	Fletcher Argue	AH-1	1967	Pneumatic	None	Flat, no space
111	Fletcher Argue	AH-2	1967	Digital	Digital	Flat, no space
81	Human Ecology	AH-1	2002	Pneumatic	None	Flat, spacious
113	Isbister	AH-1	1961	Pneumatic	Magnehelic	Flat, spacious
113	Isbister	AH-2	1961	Pneumatic	Magnehelic	Flat, no space
37	JH Ellis	AH-3	1969	Pneumatic	None	Flat, spacious
142	Robert Schuller	AH-3	Unknown, newer	Pneumatic	Magnehelic	Flat, spacious
251	Robson Hall	AH-1	1971	Pneumatic	Magnehelic	Flat, spacious
141	St. Johns College	AH-1	1971	Pneumatic	None	Flat, spacious
145	St. Pauls College	AH-1	1971	Pneumatic	None	Flat, no space
145	St. Pauls College	AH-6	1961	Pneumatic	None	Flat with V-Bank filters
115	Tier	AH-1	1966	Pneumatic	Magnehelic	Flat, spacious

Table 45
Air Handler Information (Cont'd x 1)

Bld #	Building Name	AHU	Unit Install Year	Damper Control	Filter Pressure Gauge	Filter Bank Layout
11	Agriculture Building	AH-1	1996	Pneumatic	None	Angled
11	Agriculture Building	AH-3	1996	Pneumatic	None	Angled
11	Agriculture Building	AH-5	1996	Pneumatic	Magnehelic	Angled
14	Agriculture Lecture Block	AH-1	1998**	Pneumatic	Magnehelic	Flat, no space
37	J.H. Ellis Building	AH-3	1969*	Pneumatic	None	Flat, spacious
117	Drake Centre	SF-11	1987*	Pneumatic	Unknown	Flat, no space
117	Drake Centre	SF-12	1987*	Pneumatic	Digital	Flat, no space
117	Drake Centre	SF-16	1987*	Pneumatic	Digital	Flat, no space
145	St. Paul's College	AH-5	1968	Pneumatic	None	Angled
145	St. Paul's College	AH-6	1961	Pneumatic	None	Flat with V-filters, MERV 14
146	Sinnot Building	AH-2	1982	Pneumatic	None	Flat, no space
157	Buller Biological Building	AH-1	2006	Pneumatic	Digital	Flat, spacious
211	Education Building	AH-1	1961*	Pneumatic	None	Flat, spacious
211	Education Building	AH-2	1965*	Pneumatic	None	Flat
231	EITC-1	AH-1	2005**	Digital	Magnehelic	Flat, no space
238	Stanley Pauley Engineering Building	HRV-1	2019	Digital	Digital	Flat
261	Architecture 2	AH-1	1964*	Pneumatic	Magnehelic	Flat, spacious
283	Helen Glass	AH-2	1999*	Pneumatic	Unknown	Angled
339	Tache Arts Complex - T2	ERV-1	2017	Digital	Digital	Flat
341	Tache Arts Complex	ERV-X	2017	Digital	Digital	Flat

**Assumed based on building construction date*
*** Assumed based on mechanical renovation date*

Table 46
Air Handler Information (Cont'd x 2)

Bld #	Building Name	Air Handler Tag	Est. Unit Install Year	Damper Control	Filter Pressure Gauge	Filter Bank Layout
12	Agricultural and Civil Eng	AH-2	2002	Pneumatic	None	Flat, minimal space
151	Allen	AH-1	1961	Pneumatic	None	Flat, spacious
152	Armes Lecture Theatre	AH-1	1961	Pneumatic	None	Flat, spacious
191	Biological Science	AH-1	2011	Digital	Digital	Flat, spacious
232	EITC-2	AH-1	2003	Pneumatic	Magnehelic	Flat, no space
232	EITC-2	AH-2	2003	Pneumatic	Magnehelic	Flat, no space
310	Extended Ed	AH-1	1972	Pneumatic	None	Flat, spacious
309	Frank Kennedy	AH-1	1970	Pneumatic	Magnehelic	Flat, spacious
201	Russel	AH-4	1959	Pneumatic	None	Flat, no space
115	Tier	AH-2	1966	Pneumatic	Magnehelic	Flat, spacious
131	University College Lecture	AH-5	1964	Pneumatic	None	Flat, minimal space
156	Wallace	AH-1	1985	Digital	Magnehelic	Angled

VI. APPENDIX E – EFFECTIVE VENTILATION PERCENT CALCULATION (MERV)

The following table shows the percent efficiency of each MERV rating in 3 ranges of particulate matter diameters. A formula is used to calculate the overall percent efficiency for each rating by multiplying each efficiency by the percentage of particulate assumed to be in that particulate diameter range. The equation assumes that 30% of particulate is in the 10-3 micron diameter range, and 30% of particulates are in the 1.0-3.0 and the 0.3-1.0. The percent efficiencies for each particulate diameter range are also the absolute minimum for that MERV rating resulting in a more conservative approach.

MERV Rating	4	5	6	7	8	9	10	11	12	13	14	15	16
% Efficiency @ 10.0 - 3.0 Microns	10%	20%	35%	50%	70%	75%	80%	85%	90%	90%	95%	95%	95%
% Efficiency @ 3.0 - 1.0 Microns	0%	0%	0%	0%	20%	35%	50%	65%	80%	85%	90%	90%	95%
% Efficiency @ 1.0 - 0.3 Microns	0%	0%	0%	0%	0%	0%	0%	20%	35%	50%	75%	85%	95%
Overall Percent Efficency	**4%**	**8%**	**14%**	**20%**	**34%**	**41%**	**47%**	**60%**	**71%**	**77%**	**88%**	**91%**	**95%**

VII. APPENDIX F – WORST-CASE MINIMUM OUTDOOR AIR PERCENTAGES

Equation 5 shows an example from Buller building air handler AH-1 of how the mixed air temperature setpoint (MAT_{SP}) is calculated during heating. The MAT_{SP} determines how much outdoor air is introduced to the air handler. The equation also has a maximum and minimum setpoint for the mixed air temperature, in this case 4°C and 15°C respectively. As the return air temperature (RAT) decreases, the MAT_{SP} increases, with the goal of maintaining a RAT of 22°C and a MAT of 5°C.

$$MAT_{SP} = 5 + (22 - RAT) * 2.25 \quad \text{Equation 5}$$

Plugging in a RAT of 21°C to the above equation results in a MAT of 7.25°C. The percentage of outdoor air can now be calculated using Equation 3 with a MAT of 7.25°C, a RAT of 21°C, and an OAT of -30°C. The worst-case outdoor air percentage in this scenario during heating in the winter would be 19%.

A worst-case scenario of 21°C RAT was used to calculate the outdoor air percentage on a -30°C winter day. The exception is the air handlers that have a minimum damper position well above 20% where the minimum outdoor air percentage was based on the minimum possible damper position.

The control sequence for summer conditions favors a higher outdoor air percentage due to the lower temperature differential at high outdoor air temperatures. In these cases, the minimum damper position in the control sequence was used.

VIII. APPENDIX G – ASHRAE 62.1 REQUIRED OUTDOOR AIR VENTILATION

Table 47
Input Data for ASHRAE 62.1 Outdoor Air Ventilation Requirement

Bld #	Building Name	Room Type	Room #	Area [ft^2]	CFM Per Person	CFM Per Sqft	Ad Astra Capacity	Required OA [CFM]
12	Agricultural and Civil Eng	Computer Lab	A205	912	10	0.18	36	749
151	Allen Building	Computer Lab	403	2,241	10	0.12	80	1527
151	Allen Building	Computer Lab	405	1,803	10	0.12	40	881
151	Allen Building	Computer Lab	519	1,462	10	0.12	40	822
151	Allen Building	Computer Lab	521	1,352	10	0.12	20	517
152	Armes Lecture Theatre	Classroom	200	2,627	7.5	0.06	180	2154
152	Armes Lecture Theatre	Classroom	204	2,625	7.5	0.06	182	2175
152	Armes Lecture Theatre	Classroom	205	1,819	7.5	0.06	111	1345
152	Armes Lecture Theatre	Classroom	208	2,641	7.5	0.06	182	2176
191	Biological Science	Laboratory	211	1,163	10	0.18	40	870
191	Biological Science	Laboratory	305	1,558	10	0.18	50	1115
232	EITC-2	Classroom	E2-105	2,264	7.5	0.06	114	1293
232	EITC-2	Classroom	E2-110	2,401	7.5	0.06	126	1421
232	EITC-2	Classroom	E2-125	1,509	7.5	0.06	81	910
232	EITC-2	Classroom	E2-130	1,579	7.5	0.06	81	916
232	EITC-2	Classroom	E2-150	1,580	7.5	0.06	81	917
232	EITC-2	Classroom	E2-155	1,509	7.5	0.06	81	910
232	EITC-2	Classroom	E2-160	1,580	7.5	0.06	81	917
232	EITC-2	Classroom	E2-165	1,508	7.5	0.06	76	862
232	EITC-2	Classroom	E2-320	1,550	7.5	0.06	81	914
232	EITC-2	Classroom	E2-330	1,550	7.5	0.06	81	914
232	EITC-2	Classroom	E2-350	1,550	7.5	0.06	81	914
310	Extended Ed	Laboratory	198	1,377	7.5	0.06	30	439
309	Frank Kennedy	Classroom	136	1,340	10	0.18	105	1845
201	Russel	Classroom	211	942	7.5	0.06	60	724
201	Russel	Classroom	214	1,574	7.5	0.06	130	1528
115	Tier	Classroom	408	1,865	7.5	0.06	170	1541
131	University College Lecture	Computer Lab	233	1,319	10	0.12	48	912
156	Wallace	Classroom	221	1,923	7.5	0.06	160	1462
156	Wallace	Classroom	223	2,023	7.5	0.06	160	1468

Table 48
Input Data for ASHRAE 62.1 Outdoor Air Ventilation Requirement (Cont'd x 1)

Bld #	Building Name	Room Type	Room #	Area [ft^2]	CFM Per Person	CFM Per Sqft	Ad Astra Capacity	Required OA [CFM]
343	Art Lab	Classroom	136	1916	7.5	0.06	140	1664
157	Buller	Classroom	207	1371	7.5	0.06	120	1403
157	Buller	Laboratory	215	1252	10	0.18	32	779
28	Dairy Art	Laboratory	230	2595	10	0.18	40	1239
117	Drake	Classroom	115	1343	7.5	0.06	58	737
167	Duff Roblin	Computer Lab	P210	1316	10	0.12	49	926
167	Duff Roblin	Laboratory	W232	1360	10	0.18	33	821
211	Education	Classroom	290	3134	7.5	0.06	238	2819
211	Education	Classroom	325	1211	10	0.18	42	911
211	Education	Classroom	326	1293	7.5	0.06	47	614
211	Education	Classroom	327	1312	7.5	0.06	45	595
211	Education	Classroom	342	1971	7.5	0.06	35	544
211	Education	Classroom	366	1320	7.5	0.06	40	542
231	EITC-1	Laboratory	E1-422	1951	10	0.18	40	1073
233	EITC-3	Classroom	E3-270	3044	7.5	0.06	215	2564
310	Extended Ed	Classroom	160	1354	10	0.18	40	920
111	Fletcher Argue	Classroom	100	2754	7.5	0.06	158	1929
111	Fletcher Argue	Classroom	200	3305	7.5	0.06	233	2780
309	Frank Kennedy	Laboratory	130	1746	10	0.12	50	1014
81	Human Ecology	Classroom	206	1840	7.5	0.06	158	1851
113	Isbister	Classroom	137	1381	7.5	0.06	70	868
113	Isbister	Classroom	231	2786	7.5	0.06	222	2617
113	Isbister	Classroom	235	1211	7.5	0.06	85	1015
37	JH Ellis	Classroom	245	1326	7.5	0.06	58	735
142	Robert Schuller	Classroom	172	3958	7.5	0.06	250	3018
251	Robson Hall	Classroom	200A	1644	7.5	0.06	90	1105
251	Robson Hall	Classroom	200B	1647	7.5	0.06	78	977
141	St. Johns College	Classroom	118	1640	7.5	0.06	111	1330
145	St. Pauls College	Classroom	100	2285	7.5	0.06	162	1932
145	St. Pauls College	Classroom	258	1406	7.5	0.06	59	753
115	Tier	Classroom	206	1866	7.5	0.06	169	1533
115	Tier	Classroom	306	1854	7.5	0.06	176	1590

Table 49
Input Data for ASHRAE 62.1 Outdoor Air Ventilation Requirement (Cont'd x 2)

Bld #	Building Name	Room Type	Room #	Area [ft^2]	CFM Per Person	CFM Per Sqft	Ad Astra Capacity	Required OA [CFM]
11	Agriculture Building	Classroom	130	1,379	7.5	0.06	86	910
11	Agriculture Building	Classroom	172	2,549	7.5	0.06	191	1982
11	Agriculture Building	Laboratory	343	1,433	10	0.18	36	772
14	Agriculture Lecture Block	Classroom	101	802	7.5	0.06	40	435
261	Architecture 2	Classroom	110	733	7.5	0.06	36	392
261	Architecture 2	Classroom	116	920	7.5	0.06	35	397
157	Buller Biological Building	Laboratory	204	1,167	10	0.18	56	963
157	Buller Biological Building	Laboratory	302	1,184	10	0.18	40	766
157	Buller Biological Building	Classroom	306	1,371	7.5	0.06	72	778
157	Buller Biological Building	Laboratory	312	1,993	10	0.18	68	1298
157	Buller Biological Building	Laboratory	314	1,267	10	0.18	50	910
117	Drake Centre	Classroom	105	1,448	7.5	0.06	82	877
117	Drake Centre	Classroom	107	1,448	7.5	0.06	82	877
117	Drake Centre	Classroom	117	1,335	7.5	0.06	68	738
117	Drake Centre	Classroom	122	2,137	7.5	0.06	104	1135
117	Drake Centre	Classroom	343	3,493	7.5	0.06	240	2512
211	Education Building	Classroom	222	1,231	7.5	0.06	35	420
211	Education Building	Classroom	224	2,055	7.5	0.06	152	1579
211	Education Building	Classroom	226	1,163	7.5	0.06	51	565
231	EITC-1	Laboratory	E1-225	1,349	10	0.18	40	804
231	EITC-1	Laboratory	E1-473	1,196	10	0.18	35	707
283	Helen Glass	Classroom	260	1,790	7.5	0.06	108	1147
283	Helen Glass	Laboratory	460	2,175	10	0.12	40	826
283	Helen Glass	Laboratory	470	2,143	10	0.12	40	821
37	J.H. Ellis Building	Laboratory	241	1,341	10	0.18	25	614
146	Sinnot Building	Classroom	101	625	7.5	0.06	31	338
145	St. Paul's College	Classroom	225	1,197	7.5	0.06	48	540
145	St. Paul's College	Classroom	318	1,339	7.5	0.06	74	794
238	Stanley Pauley Engineering Building	Computer Lab	SP124	1,165	10	0.12	50	800

Table 505
Input Data for ASHRAE 62.1 Outdoor Air Ventilation Requirement (Cont'd x 3)

Bld #	Building Name	Room Type	Room #	Area [ft^2]	CFM Per Person	CFM Per Sqft	Ad Astra Capacity	Required OA [CFM]
341	Tache Arts Complex	Classroom	450	535	7.5	0.06	21	237
339	Tache Arts Complex - T2	Classroom	T2-166	1,500	7.5	0.06	75	816
339	Tache Arts Complex - T2	Classroom	T2-266	2,798	7.5	0.06	80	768
339	Tache Arts Complex - T2	Classroom	T2-272	1,289	7.5	0.06	30	302

IX. APPENDIX H – SPACE LIST PROVIDED BY U OF M

Table 516
List of Spaces in Scope by Building & Room Number

Bld #	Building Name	Priority Spaces
12	Agriculture and Civil Engineering	A205
11	Agriculture Building	130, 172, 343
14	Agriculture Lecture Block	101
151	Allen	403, 405, 519, 521
261	Architecture 2	110, 116
152	Armes Lecture Theatre	200, 204, 205, 208
343	Art Lab	136
191	Biological Science	211, 305
157	Buller	207, 215
157	Buller Biological Building	204, 302, 306, 312, 314
28	Dairy Art	230
117	Drake	115
117	Drake Centre	105, 107, 117, 122, 343
167	Duff Roblin	W232
167	Duff Roblin	P210
211	Education	325, 326, 327, 342
211	Education	366
211	Education	290
211	Education Building	222, 224, 226
231	EITC 1	E1-225, E1-473
231	EITC-1	E1-422
232	EITC-2	E2-105, E2-110, E2-125, E2-130, E2-150, E2-155, E2-160, E2-165, E2-320, E2-330, E2-350
233	EITC-3	E3-270

Table 52
List of Spaces in Scope by Building & Room Number (Cont'd)

Bld #	Building Name	Priority Spaces
310	Extended Ed	198
310	Extended Ed	160
111	Fletcher Argue	100
111	Fletcher Argue	200
309	Frank Kennedy	136
309	Frank Kennedy	130
283	Helen Glass Centre	260, 460, 470
81	Human Ecology	206
113	Isbister	137, 235
113	Isbister	231
37	J.H. Ellis Building	241
37	JH Ellis	245
142	Robert Schuller	172
251	Robson Hall	200A, 200B
201	Russell	211, 214
146	Sinnott Building	101
141	St. Johns College	118
145	St. Pauls College	100
145	St. Pauls College	258
145	St. Paul's College	225, 318
238	Stanley Pauley Engineering Building	SP124
341	Tache Arts Complex	450
339	Tache Arts Complex - T2	T2-166, T2-266, T2-272
115	Tier	408
115	Tier	206, 306
131	University College Lecture	233
156	Wallace	221, 223