FLEXTECH
ENERGY EFFICIENT INDOOR AIR QUALITY STUDY

FINAL CONCLUSIONS REPORT

For

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Joint Statement from NYSERDA and ASHRAE on the Energy Efficient Indoor Air Quality Study Conclusion Reports

The Energy Efficient Indoor Air Quality Study Conclusion Reports summarize the findings from individual studies conducted under the FlexTech Energy Efficient Indoor Air Quality Pilot. NYSERDA presented this offering in May 2020 in response to a two-fold call from commercial market building owners and managers of New York to better understand:

1. the energy impact of the COVID-19 response guidance that was emerging in the market between March and May of 2020, and
2. how energy efficiency goals could be achieved in conjunction with reducing the risk of building occupants transmitting and contracting COVID-19 in the built environment.

When reading these reports and contemplating the conclusions drawn, it is important to consider the context of the time period in which these studies were conducted and the uniform parameters by which the consultants were bound. NYSERDA directed the consultants to use the building readiness guidance that was in the market when the studies commenced in June 2020. The ASHRAE Epidemic Task Force (ETF) guidance available to the market at the time consisted of the following document versions:

Building Readiness v.5-21-2020
Commercial v.4-20-2020
Schools & Universities v. 5-5-2020
Healthcare v. 6-17-2020
Filtration & Disinfection v. 5-27-2020
ERV Practical Guide v. 6-9-2020

While a benefit of this approach is to allow for a comparative analysis across all the studies under the initiative to explore overarching conclusions applicable to the broader market sector, a drawback emerged when ASHRAE guidance evolved significantly while the studies were underway. As a result, some of the guidance that formed the basis of the studies is no longer advocated as best practices by leading authorities in the market, including the ASHRAE ETF. Current ASHRAE ETF guidance is summarized in its Core Recommendations (1/6/2021). The concise guidance in the Core Recommendations is reflected in more recent versions of the guidance documents noted in the table above. To provide the reader a side-by-side account of the changes to the ASHRAE ETF's guidance, the table below compares guidance available to the market at the time the studies commenced to the current ASHRAE Core Recommendations and the resulting energy implications.

ASHRAE Epidemic Task Force Guidance

	THEN **Building Readiness Guidance *version 5.21.2020*** and/or **Commercial Guidance *version 4.20.2020***	**NOW** **Core Recommendations *version 1.6.2021*,** **Building Readiness *version 4.27.2021,*** and/or **Commercial Guidance *version 3.22.2021***	**Energy Impact Takeaways**
Outdoor airflow rate	• Increase system outdoor air ventilation as much as the system and or space conditions will allow to reduce the recirculation air back to the space during occupied hours • Open windows where appropriate during occupied hours. • For HVAC system that use Demand-controlled ventilation sequences we recommend disabling this feature for the duration of the crisis.	• Provide and maintain at least required minimum outdoor airflow rates for ventilation as specified by applicable codes and standards • Maintain equivalent clean air supply required for design occupancy whenever anyone is present in the space served by a system • Evaluate the use of additional outdoor air as a mitigation strategy compared to other items, such as filters or air cleaners[1]. • For HVAC system that use Demand-controlled ventilation sequences we recommend disabling this feature for the duration of the crisis[2]	It is more energy and cost efficient to operate systems with less outdoor air
Filtration	Update or replace existing HVAC air filtration to a minimum of MERV 13 (MERV 14 preferred) or the highest compatible with the filter rack	Achieve MERV 13 or better levels of performance for air recirculated by HVAC systems by using a combination of filters and air cleaners[3]	Depending on the performance of the current filtration system, higher MERV filter ratings might increase system pressure drop, leading to increased energy use and cost. Using carefully selected filters, or the appropriate combination of MERV filtration and air cleaners, could mitigate a negative energy impact.
Air Cleaners	• Where there can be a large assembly of people, consider air treatment, e.g. upper-room UVGI lamps. • Consider adding air treatment and cleaning devices such as UVGI in duct, plenums and air handling units and on the face of cooling coils[4]. • If an increase in filter MERV level cannot be accommodated using the existing air handling equipment fans and motors, consider using In Room portable HEPA filter units in high occupancy or high bioburden (such as the building entry) spaces.	• Only use air cleaners for which evidence of effectiveness and safety is clear. Per the CDC, consumers should match any specified claims against the consumer's intended use, request efficacy performance data that quantifies a protective benefit under conditions consistent with the intended application of the technology, and look for multiple sources including independent, third-party sources that conclude the same performance data. • Consider adding air treatment and cleaning devices such as UVGI in duct, plenums and air handling units and on the face of cooling coils[4]. • If the outdoor air, filter or air cleaner in the HVAC system is not achieving the desired exposure reduction, consider adding In Room portable HEPA filter units[1].	No impact in the context of these studies. Only air cleaners with a proven track record of safety and effectiveness were allowed in the NYSERDA studies. UVGI and HEPA filtration are considered safe technologies by ASHRAE if applied correctly and the appropriate safeguards are put into place.

[1] ASHRAE ETF Core Recommendations, v.1.6.21, item 2.4
[2] ASHRAE ETF Core Recommendations, v.1.6.21, item 4.2
[3] ASHRAE ETF Building Readiness Guidance v.4.27.21, Equivalent Outdoor Air section
[4] ASHRAE ETF Commercial Guidance v.4.20.20

	THEN **Building Readiness Guidance *version 5.21.2020*** and/or **Commercial Guidance *version 4.20.2020***	**NOW** **Core Recommendations *version 1.6.2021*,** **Building Readiness *version 4.27.2021,*** and/or **Commercial Guidance *version 3.22.2021***	**Energy Impact Takeaways**
Building Flush	Flushing sequence or mode may be implemented to operate the HVAC system with maximum outside airflows for two hours before and after occupied times.	When necessary to flush spaces between occupied periods, operate systems for a time required to achieve three air changes of equivalent clean air supply. Use the Equivalent Outdoor Air Calculator to determine the flush time required to achieve 3 equivalent changes of space volume based on the outdoor air levels, filtration levels, and/or efficacy of air cleaners in use OR use a 2-hour flush period.	• Depending on the system configuration, achieving three air changes of equivalent clean air supply could be less energy intensive than conducting a two-hour flush. • Performing only one flush between building occupancy will be more energy efficient than conducting a flush both pre- and post-occupancy of the building.
Air Distribution	Check that air handling systems are providing adequate airflow, there are no blockages in the duct system (for example – closed fire/smoke dampers) and air from the air handling system is reaching each occupied space.	Where directional airflow is not specifically required, or not recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person-to-person	Both sets of guidance could have an increased impact on energy use if deficiencies in airflows levels require corrective action.
Contaminated Air Re-entry	• Well-designed and well-maintained air-to-air energy recovery systems should remain operating in residences, commercial buildings and medical facilities during the COVID-19 pandemic. • Heat wheels may continue operation if the unit serves only one space.	• Evaluate the operation of your energy recovery devices to determine that they are well-designed and well-maintained and fix them if there are issues[5]. • Limit re-entry of contaminated air that may re-enter the building from energy recovery devices, outdoor air, and other sources, such as relief air from patient rooms to acceptable levels	No substantial change in guidance
Setpoints	• Maintain dry bulb temperatures within the comfort ranges indicated in ANSI/ASHRAE Standard 55-2017 • Consider adjusting the space comfort setpoints to increase the system's ability to use more outside air. • Maintain relative humidity between 40%-60% • Prioritize increasing outside air over humidity[6]	Maintain temperature and humidity design set points	The current guidance will likely result in less energy use compared to the prior guidance.
System Performance	Verify that equipment and systems are properly functioning	Verify that HVAC systems are functioning as designed	No substantial change in guidance

[5] Practical Guidance for Epidemic Operation of Energy Recovery Ventilation Systems

[6] ASHRAE ETF Commercial Guidance v.4.20.20

It is also important to understand the basis of the package groupings in these reports.

Pre-COVID energy use establishes the typical energy use baseline prior to any impacts resulting from COVID-19

ASHRAE guidance measures include the HVAC-related guidance from the ASHRAE Epidemic Task Force documents that are feasible in the subject building(s)

Energy Efficient measures include Ultraviolet Germicidal Irradiation (UVGI), air filtration strategies, and building operation optimization solutions that perform equally on the basis of COVID-19 risk of infection to the ASHRAE guidance package of measures

ASHRAE has recommended UVGI since the inception of the Epidemic Task Force as a potential mitigation strategy. NYSERDA chose to use UVGI in the Energy Efficiency package because of its potential to reduce the energy impact of risk mitigation.

One final note is that major mechanical capital improvements were intended for exclusion from analysis under these studies.

For more information, the NYSERDA-issued mini-bid for the Energy Efficient Indoor Air Quality studies can be found here and the current ASHRAE ETF Core Recommendations can be found here.

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NYSERDA Energy Efficient Indoor Quality (IAQ) Analysis

CUMULATIVE RESULTS

STUDY OVERVIEW

On behalf of the New York State Research and Development Authority (NYSERDA), LaBella Associates Partnered with (6) organizations and (8) facilities across New York State to perform indoor air quality studies in response to the COVID-19 pandemic. As a part of this investigation, existing HVAC systems, equipment, and controls were analyzed to identify ways to mitigate the spread of pathogens through the building's HVAC systems as well as opportunities for energy conservation. The analyses focused on determining feasible indoor air quality measures according to industry guidance alongside an energy and economic analysis evaluating the energy, maintenance, and capital costs for each.

For all reports, the recommendations were grouped in two "packages". The 'ASHRAE Recommendations Package' included all pathogen mitigation procedures outlined by industry guidance at the time of this study that limit significant capital investments to meet the recommended safety measures. The "Energy Efficiency Package" incorporated industry-recommended safety measures as well as opportunities for energy efficiency improvements.

For each package the clean air percent was evaluated to quantify the effectiveness of each approach and determine the most cost-effective solutions for each facility. As a result of the recommendations made in the studies, the average existing system effectiveness of 37% was increased to 95.4% for the ASHRAE Packages and 98.3% for the Energy Efficiency Packages.

The most common recommendations included upgrading filtration levels to MERV-13 or greater, the implementation of UVGI in the airstream and on the cooling coil, pre/post-occupancy purges, and increases in outdoor air ventilation rates. The application of UVGI lighting in the air stream as well as on the cooling coil provided a significant opportunity in most facilities to reduce the outdoor air ventilation rates relative to the ASHRAE package recommendations while still providing an equal or greater effectiveness in reducing the amount of airborne pathogens circulating throughout the building. Since the conditioning of outside air is one of the largest costs associated with the operation of the building HVAC systems, the energy savings from reducing outdoor air ventilation rates proved to be significant in comparison to the increase in energy consumption from the operation of UVGI lighting systems.

DEFINITIONS & ACRONYMS

Definitions

Site Energy	Energy measured at the site of consumption
3-log Inactivation	Corresponds to a 99.9% inactivation of a virus or particle.
Equivalent Effectiveness	Metric used to quantify the supply air cleanliness (first pass percentage) of a particular system.

Commonly-Used Acronyms & Abbreviations

AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigeration, & Air-Conditioning Engineers
AQM	Air Quality Measure
BCA	Blue Cross Arena
BNIA	Buffalo Niagara International Airport
BTU	British Thermal Unit
CBECS	Commercial Building Energy Consumption Survey
CO_2	Carbon Dioxide
COVID-19	CO rona VI rus D isease
DCV	Demand Control Ventilation
DHW	Domestic Hot Water
DX	Direct Expansion
ECiP	Epidemic Conditions In-Place
ECM	Energy Conservation Measure
EUI	Energy Utilization Index
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IRR	Internal Rate of Return
kBtu	kilo-British Thermal Unit (1,000 BTU)
kW	kilo-Watt (1,000 W)
kWh	Kilo-Watt hours
MERV	Minimum Efficiency Reporting Value
MTC	Metropolitan Transportation Center
NPV	Net Present Value
NTI	North Tonawanda Intermediate (School)
NYSERDA	New York State Energy Research & Development Authority
OA	Outdoor Air
P-ECiP	Post-Epidemic Conditions In-Place
RH	Relative Humidity
RNA	Ribonucleic Acid
RTU	Rooftop Unit
SARS	Severe Acute Respiratory Syndrome
SF	Square Foot
UV	Ultraviolet
UVGI	Ultraviolet Germicidal Irradiation
WHO	World Health Organization
100 GO	100 Great Oaks
299 ONR	299 Old Niskayuna Road

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STUDY APPROACH

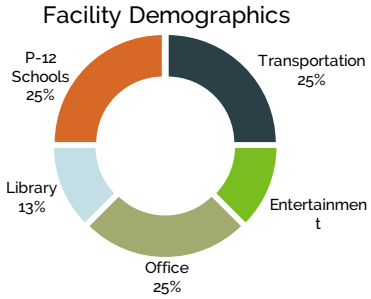
For all reports, the recommendations were grouped in two "packages". The 'ASHRAE Recommendations Package' included all pathogen mitigation procedures outlined by industry guidance at the time of this study that limit significant capital investments to meet the recommended safety measures. In other words, measures recommended under this package are meant to maximize the current building's performance in terms of pathogen mitigation, without significant capital upgrades for measures such as UVGI in air handling units. In some instances controls/HVAC upgrades were required to enable increased ventilation.

Conversely, the second package termed the "Energy Efficiency Package" incorporated industry-recommended safety measures as well as opportunities for energy efficiency improvements. In addition to traditional energy efficiency measures related to the operation of HVAC systems, the use of UVGI in air streams and on the cooling coil of air handling units acted as an energy efficiency improvement – where it could provide an equal or greater equivalent level of safety to the occupants as a more energy-intensive approach such as increasing the outdoor air ventilation rates.

All proposed packages in each study were evaluated for their equivalent effectiveness based on the first pass effectiveness of each individual measure– which quantifies the effectiveness a system has in removing pathogens from the air stream for the combined measures for each package. This, in combination with the calculated energy and cost impacts to the facility, provides the owners of the facility with concrete evidence on what the most effective pathogen mitigation measures are in relation to their building's operation as well as the associated costs of implementing those measures.

Overview of Facilities

Eight facilities across New York State were analyzed as a part of this study. The facility types ranged from P-12 schools, to office spaces, to major public transportation hubs. The graphics below indicate the locations of the facilities as well as the facility types and sizes.



Facility No.	Name	Demographic	Size (SF)
1	Buffalo Niagara International Airport	Transportation	462,251
2	Blue Cross Arena	Entertainment	259,000
3	100 Great Oaks Boulevard	Office	90,000
4	Metropolitan Transportation Center	Transportation	99,000
5	Rundel Library	Library	191,000
6	Webster Dewitt Elementary School	P-12 Schools	73,394
7	299 Old Niskayuna Road	Office	210,000
8	North Tonawanda Intermediate School	P-12 Schools	164,163

Research Conducted

Upon the arrival of the COVID-19 pandemic, the ASHRAE Epidemic Task force published a series of industry guidance informing engineers and building owners on how to most effectively mitigate the spread of pathogens in facilities. The versions of the guidance used for these studies are listed below:

- Building Readiness v.5-21-2020
- Commercial v.4-20-2020
- Schools & Universities v. 5-5-2020
- Healthcare v. 6-17-2020
- Filtration & Disinfection v. 5-27-2020
- ERV Practical Guide v. 6-9-2020

In addition to ASHRAE's 2020 guidance published after the onset of the pandemic, other publications from ASHRAE and third-party studies alike were used to gather information on the applications and effectiveness of various technologies and building operation strategies. The following resources were used to gather information:

- Italian National Institute for Astrophysics, *UV-C irradiation is highly effective in inactivating SARS-CoV-2 replication* (2020)
- Office of Research and Development National Homeland Security Research Center, Biological *Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems* (2006)
- 2019 ASHRAE Handbook, Chapter 62
- ASHRAE Position Document on Infectious Aerosols
- ANSI/ASHRAE Standard 52.2 (2017)

Further detail into the findings from the industry guidance is outlined in Appendix B of this report.

Methodology

The process for developing the recommended air quality measures at each facility started with site walkthroughs with facility personnel. During the initial walkthroughs, information was collected on building occupancy, existing mechanical infrastructure, existing building controls, filtration levels, ventilation rates, and general operation characteristics of the building.

Using this information in conjunction with industry guidance, individual measures were evaluated first for technical feasibility, safety, and then for energy and cost impacts. In instances where vendors had information available on the existing units, simulations were run with varying ventilation rates to determine the maximum amounts of outdoor air that the facility can bring in. Other coil capacity calculations were used when vendor simulations were not available, in addition to feedback from operating staff to determine maximum ventilation rates that the existing infrastructure can handle.

Similarly, air handling unit drawings, submittals, and field measurements were used to determine the feasibility and scalability of applying UVGI lighting inside the air handling units, within the air stream, as well as upper-room applications. In some instances, such as schools, the use of UVGI systems was not permitted in areas where there are occupants.

Information on the existing filtration levels, humidity control, and building purges was collected as well. Where feasible, these improvements were included in the appropriate recommendation package.

The calculation methodology used for evaluating the energy and safety impacts varied based on each facility and the information made available. Most analyses were conducted using Excel spreadsheet calculations, in addition to some vendor modeling software where available. Energy impacts were calculated and evaluated for cost impacts based on the facility's most recent utility rates, estimated maintenance costs, and vendor-quoted costs of installation.

Equivalent effectiveness of measures, also referred to as the equivalent safety, was evaluated by calculating the amount of "clean" air provided with each air change within the spaces. Using outdoor air percentage, rated filter effectiveness for particles small enough to carry the SARS-CoV-2 virus, and UVGI effectiveness determined by the intensity and time of exposure, the net effectiveness of each proposed system was evaluated.

When developing these calculations, it is assumed that all outside air is 100% clean and free of contaminants. In addition, it is assumed that the SARS-CoV-2 virus has the same levels of ultraviolet light susceptibility as other SARS virus strains.

Bianco et al. (June, 2020) proves the virucidal effectiveness of UV-C lighting on the SARS-CoV-2 virus is consistent with similar viruses used to develop ASHRAE guidance, and indicate a 3-log inactivation at an irradiance of 3.7 mJ/cm^2 and complete inhibition at an irradiance of 16.9 mJ/cm^2. From the 2019 ASHRAE Handbook (Ch. 62) it is stated that the UV effectiveness is dependent on dose, which is a direct function of irradiance (W/cm^2) and time of exposure. Combining the ASHRAE guidance and knowledge of UV's effectiveness on the covid-19 virus, it is reasonable to conclude that the previous ASHRAE guidance (before 2020 pandemic) on UVGI systems is applicable in this case – specifically the guidance in the 2019 ASHRAE Handbook, Chapter 62.

OVERALL FINDINGS

Using the approach outlined above for each facility, the recommendations that were made are outlined in the table below. This shows the facility's current operation (baseline), ASHRAE Package, and Energy Efficiency Package recommendations.

	Indoor Air Quality Measures	Buffalo Niagara International Airport	Blue Cross Arena	100 Great Oaks Boulevard	Metropolitan Transportation Center	Rundel Library	Webster Dewitt Elementary School	299 Old Niskayuna Road	North Tonawanda Intermediate School
Baseline Operation	Outdoor Air %	17%	25%	5%	25%	12%	34%	14%	25%
	Filtration	MERV-15	MERV-8	MERV-8	MERV-8	MERV-8	MERV-8	MERV-8	MERV-8
	Cooling Coil UVGI	-	-	-	-	-	-	-	-
	In-Duct UVGI	-	-	-	-	-	-	-	-
	Upper-Room UVGI	-	-	-	-	-	-	-	-
	Portable Filtration Units	-	-	-	-	-	-	-	-
	Humidity Control	✓	-	-	-	-	-	✓	-
	Pre/Post Occupancy Purge	-	-	-	-	-	-	-	✓
	First Pass Equivalent Effectiveness	91.7%	25%	24%	40%	12.0%	47.2%	31.2%	25.0%
Energy Efficiency Package	Outdoor Air %	37%	27%	15%	25%	28%	54%	14%	70
	Filtration	MERV-15	MERV-9	MERV-13	MERV-13	MERV-14	MERV-13	MERV-13	MERV-9
	Cooling Coil UVGI	✓	✓	✓	✓	✓	-	-	✓
	In-Duct UVGI	✓	-	-	✓	-	✓	✓	-
	Upper-Room UVGI	-	-	-	-	-	-	-	-
	Portable Filtration Units	-	-	-	-	-	✓	-	-
	Humidity Control	✓	-	-	✓	-	-	✓	-
	Pre/Post Occupancy Purge	-	✓	✓	-	✓	✓	✓	✓
	First Pass Equivalent Effectiveness	99.9%	98.0%	99.8%	99.4%	96%	100%	98.7%	99%
ASHRAE Package	Outdoor Air %	17%	100%	30%	70%	100%	34%	34%	100%
	Filtration	MERV-15	MERV-13	MERV-13	MERV-13	MERV-14	MERV-13	MERV-13	MERV-13
	Cooling Coil UVGI	-	-	-	-	-	-	-	-
	In-Duct UVGI	-	-	-	-	-	-	-	-
	Upper-Room UVGI	-	-	-	-	-	-	-	-
	Portable Filtration Units	-	-	-	-	-	-	-	-
	Humidity Control	✓	-	-	✓	-	-	✓	-
	Pre/Post Occupancy Purge	✓	✓	✓	-	✓	✓	✓	✓
	First Pass Equivalent Effectiveness	91.7%	100%	89.5%	95.5%	100%	93.1%	89.5%	100%

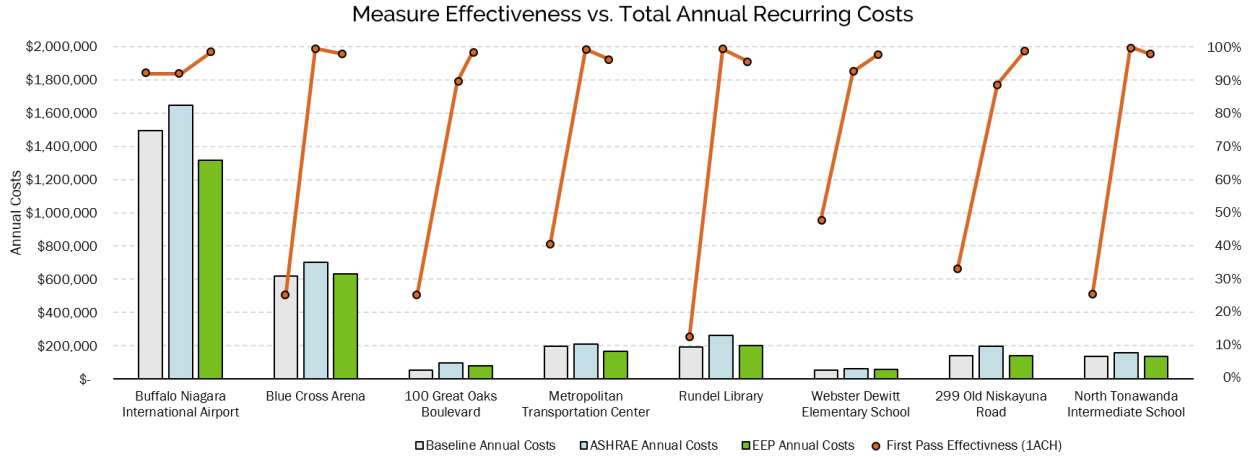
Green highlighted box indicates measures meeting or exceeding ASHRAE-recommended values, or upgraded from baseline

A more detailed breakdown of each individual measure and their associated energy impacts is shown in Appendix A.

One of the key aspects of this study and where it differs from the ASHRAE guidance is where the facilities can apply UVGI lighting, or other measures, as a means of energy reduction. Some ASHRAE-recommended measures such as increasing outdoor air ventilation rates as much as the system can handle are particularly energy-intensive and can significantly increase the utility expenditure of a facility. In addition, if increased ventilation is not paired with other measures such as increased filtration, this can potentially have a limited impact on indoor air quality improvement due to the limitations of many systems. The application of UVGI in the cooling coil and/or air stream allows the facilities to keep their ventilation rates at normal levels while still maintaining an equal or greater level of safety in comparison to the ASHRAE package. This leads to a slight increase in energy consumption from the baseline usage due to the energy impact of the UVGI lights, but results in significant avoided energy usage from not maximizing outdoor air ventilation rates.

The table and figure below illustrate the net utility costs for the baseline, ASHRAE Package, and Energy Efficiency Package for each facility, as well as their associated equivalent effectiveness in removing pathogens from circulation in the air stream.

	Buffalo Niagara International Airport	Blue Cross Arena	100 Great Oaks Boulevard	Metropolitan Transportation Center	Rundel Library	Webster Dewitt Elementary School	299 Old Niskayuna Road	North Tonawanda Intermediate School
Baseline Annual Costs	$ 1,495,467	$ 620,113	$ 53,698	$ 198,427	$ 191,016	$ 51,823	$ 138,567	$ 134,945
ASHRAE Annual Costs	$ 1,647,798	$ 702,817	$ 96,461	$ 210,110	$ 259,954	$ 60,792	$ 194,689	$ 157,400
EEP Annual Costs	$ 1,315,642	$ 634,022	$ 76,658	$ 168,051	$ 201,080	$ 57,195	$ 140,696	$ 136,364
Baseline Effectiveness	91.7%	25.0%	24.0%	40.0%	12.0%	47.2%	31.2%	25.0%
ASHRAE Effectiveness	91.7%	100.0%	89.5%	99.4%	100.0%	93.1%	89.5%	100.0%
EEP Effectiveness	99.9%	98.0%	99.8%	95.5%	96.0%	99.6%	98.7%	99.0%



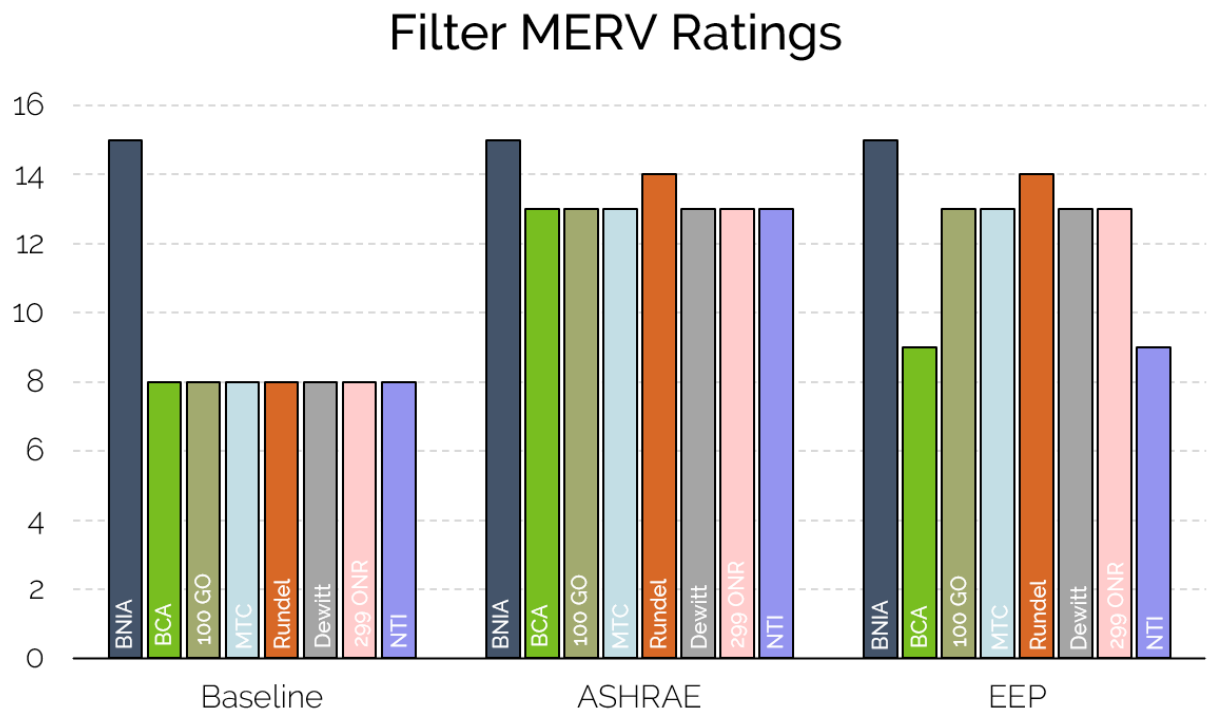
As indicated in these figures, the recommendations made in both packages see significant increases in effectiveness. The baseline average effectiveness of the facilities is 37%, whereas the ASHRAE Package effectiveness averages 95.4% and the Energy Efficiency Package averages 98.3%. Utility costs are also reflected in these figures – indicating an average increase of 15.5% in energy costs for the ASHRAE package compared to the baseline. The Energy Efficiency Packages averaged an 18% reduction in costs compared to the ASHRAE Package and 5.3% reduction in costs compared to the baseline. From these numbers, it is evident that

the use of UVGI lighting is a generally more effective and cost-efficient means of pathogen mitigation in facilities compared to other mitigation strategies. Strategies such as 100% outdoor air may have a higher safety level than increased filtration and UVGI, however, this has a significant energy impact associated with conditioning large amounts of additional outside air that exceeds the cost of implementing UVGI technologies, which generally have a similar level of first-pass effectiveness.

STUDY COMPARISONS

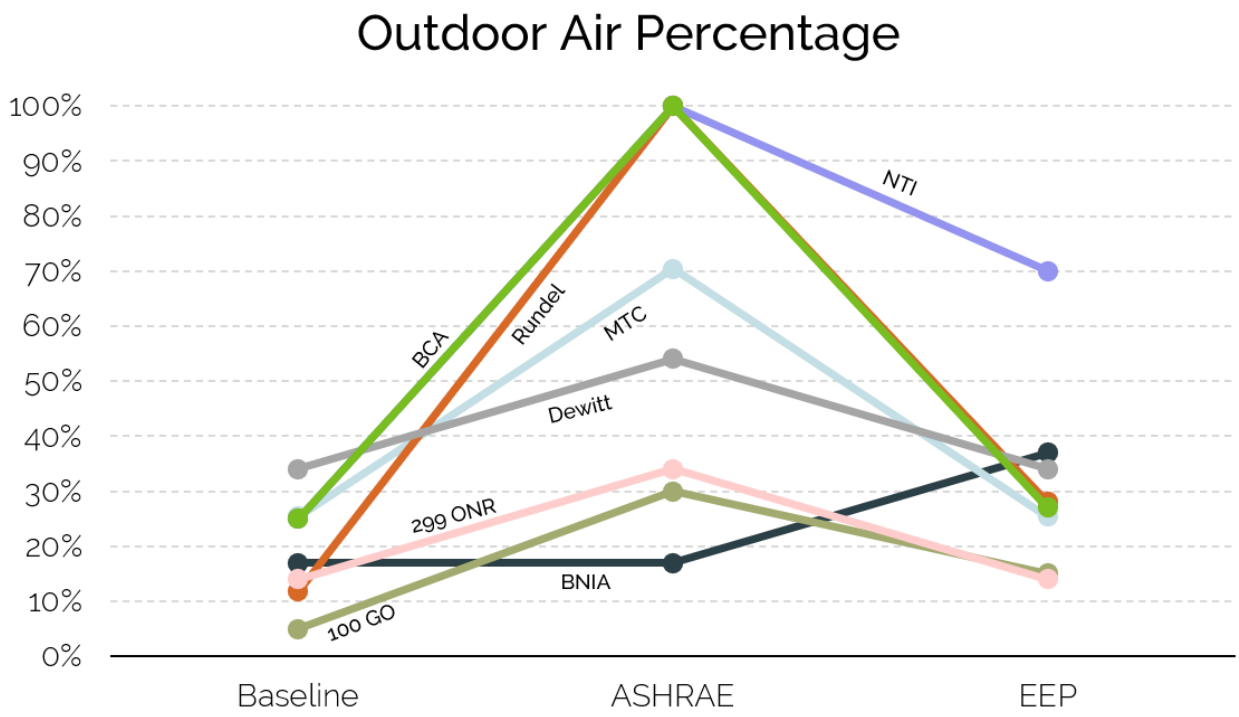
Recommended Measures

Across all of the studies, the recommended measures were compiled into the figures below for each package. In general, higher-rated MERV filters were recommended for both ASHRAE and Energy Efficiency Packages (EEP). In some facilities, increased-efficiency MERV-9 filters were recommended for the EEP where it did not have a significant impact on the safety of the facility.



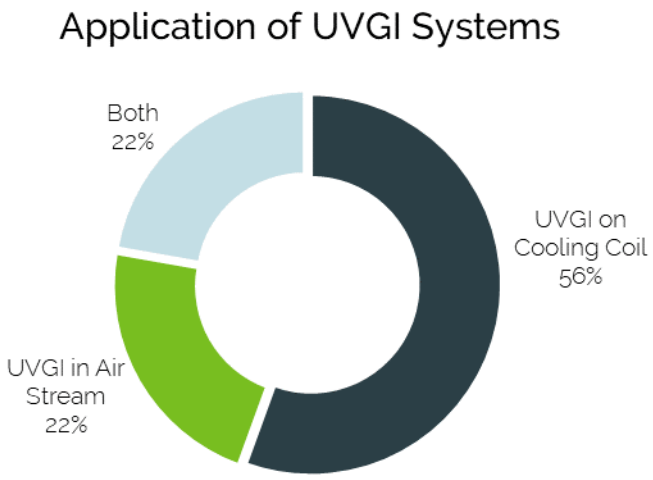
Taking a similar approach comparing outdoor air percentages in the figure below, all facilities (with the exception of one that did not have the capacity) were recommended to increase outdoor air ventilation as much as the existing system can allow, and then back-off the ventilation rates for the EEP as long as the UVGI was able to maintain the equivalent level of safety.

There were some instances where facilities were not meeting current code-required ventilation rates. In those cases, an increase to the code-minimum ventilation rates was included in the recommended outdoor air percentage number.



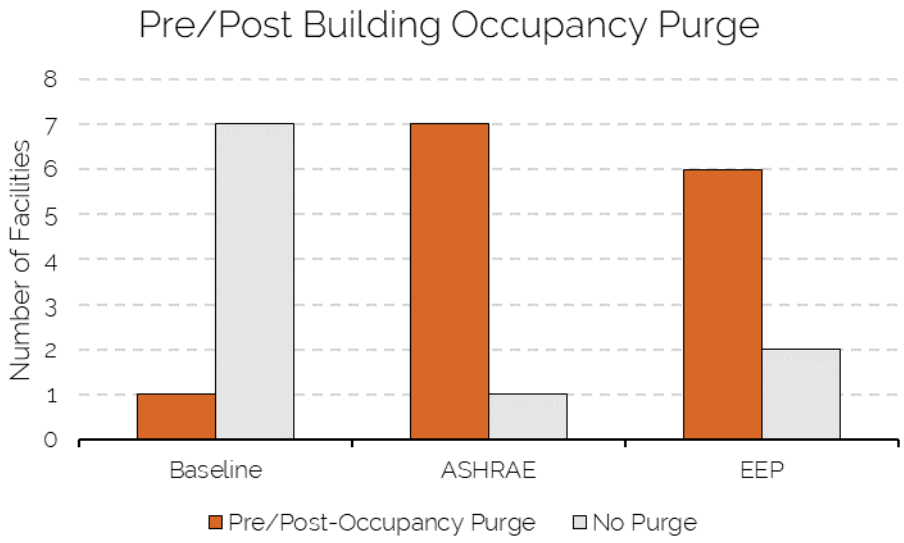
The application of UVGI systems in the facilities was highly dependent on the space available in the air handling units as well as in the main branches of ductwork. In some facilities, there was not enough space available in the rooftop packaged units for UVGI to be applied to the cooling coil. In these instances, UVGI was recommended in the air stream where there was more room available.

There were some additional facilities that benefitted from the application of UVGI on both the cooling coil and in the air stream – maximizing the time of exposure that the particles in the air stream are subjected to due to an increased distance in the air stream where the particles are subjected to UVGI light.



Finally, all but one facility was recommended for a pre/post-occupancy building purge in the ASHRAE Package. In that one instance, the facility is already occupied 24/7.

The Energy Efficiency Package still had a pre/post occupancy purge recommended in (6) of the (8) total facilities – however, many of the building purges were recommended to be run for a reduced amount of time to achieve the equivalent effectiveness as the ASHRAE-recommended (3) air changes before and after occupancy.



Measures not Recommended

Six of the eight facilities had no existing form of humidity control. Of the six, five had concerns over implementing such control including issues of condensation forming in the building or significant cost upgrades to incorporate it into the system. For that reason, it was not recommended in those reports.

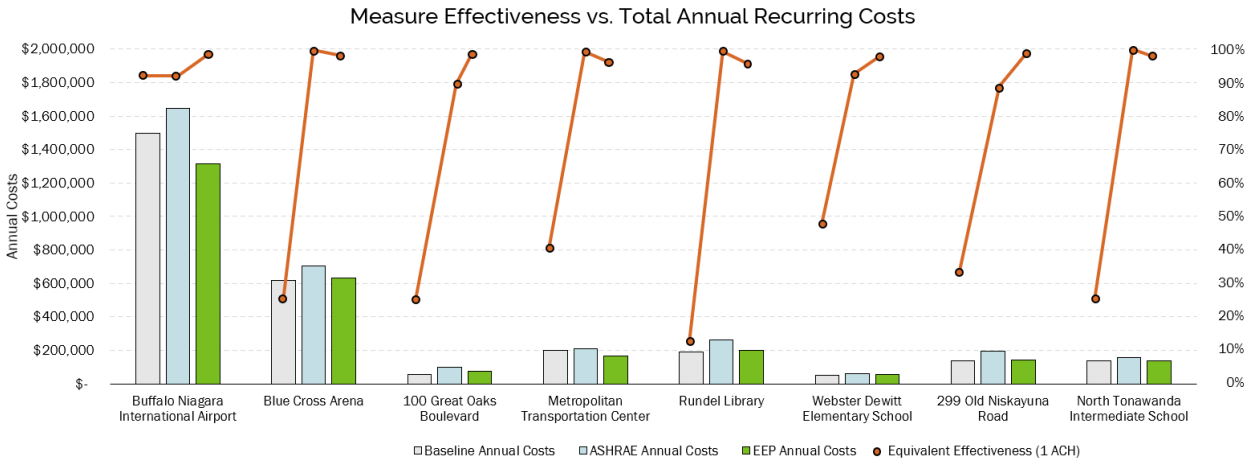
Additionally, as previously mentioned, some facilities did not have space for UVGI on the cooling coil section of the air handling unit. For these facilities, in-duct applications were recommended.

In some instances, upper-room UVGI was evaluated where there was not the possibility of applying UVGI in the duct or air handling unit, but it was ultimately not recommended due to the high upfront cost and high cost of operation for units that are able to effectively disinfect a large, mostly unoccupied space. Since it was such low-occupancy and a low-level of concern, inclusion of UVGI elsewhere in the more densely occupied areas was evaluated.

Current guidance from the NYSED prohibits the use of UVGI systems in areas where students or faculty are present. This limits the application potential of UVGI systems to in the AHUs or in the ductwork. In nurses offices, where the highest risk of infectious persons is, portable filtration units were recommended to increase the amount of air passing through a filter in that space. In addition, an emphasis was placed on maintaining a negative pressure differential in the nurses office in order to prevent the spread of potential contaminants.

Energy & Safety Impacts

Based on the results of the proposed measures and their corresponding safety levels, the following figure is shown again to illustrate the evolution of energy performance relative to the effectiveness of the systems in capturing particles as they pass through the building HVAC systems.



The safety of a measure was evaluated based on the percentage of particles captured or inactivated by the system with each air change. Each recommended air quality measure has a corresponding percentage of particles captured or inactivated. For instance, a MERV-13 filter has an effectiveness of 85% based on ASHRAE 52.2, and the UVGI effectiveness of a particular system, assuming the SARS-CoV-2 virus has a UV-C susceptibility in-line with other SARS viruses, is calculated to be 90% based on the light intensity and air speed (time of exposure). This combined with the outdoor air percentage can be used to qualify the net amount of particles captured/inactivated by the system with each air change.

Expressed mathematically, the effectiveness can be calculated as follows:

$$System\ Effectiveness = 1 - (((1 - OA\%) * 100) * (1 - Filter\ Effectiveness\ \%)) * (1 - UVGI\ Effectiveness))/100$$

In other words, the system effectiveness is 100% minus whatever is not captured by filtration or deactivated by UVGI from the recirculated air. As outdoor air, filtration levels, and irradiance increases, so does the net system effectiveness.

OVERARCHING TAKEAWAYS

Conclusive Findings

Based on the study results from all (8) facilities, the following measures were deemed effective in improving indoor air quality and reducing the spread of pathogens, in various combinations:

- Increase outdoor air ventilation rates (in scenarios where UVGI and increased filtration are not used)
- Increase filtration levels (recommended MERV-13 or greater)
- Maintain humidity levels between 40-60%
- Apply UVGI lighting in the cooling coil and in the air stream
- Run a pre and post-occupancy purge for 3 air changes (or equivalent)

Based on the energy analysis, it was deemed that the use of UVGI systems in the air stream and/or on the cooling coil in addition to MERV-13 or greater filtration levels provided a level of effectiveness that met or exceeded the effectiveness of just increasing outdoor air ventilation rates. Since treating outdoor air is the most energy intensive and it may limit the comfort levels of the occupants where there is not enough cooling capacity, it was more economically attractive to substitute increases in outdoor air percentage with the use of UVGI systems and increased filtration in the air stream.

Best Practices

In accordance with ASHRAE's building readiness guide, the best practice should be for facilities to implement the recommended measures and have a plan in-place for future pandemic responses. This includes the use of a 'pandemic mode' in building operation systems for immediate responses to future pandemics and/or health-related emergency events.

Each measure, as recommended above, should be evaluated for feasibility at each facility to determine the most cost-effective way of mitigating the spread of pathogens through the building HVAC systems. These measures can in turn be implemented into regular building operation or only during 'pandemic mode' operation.

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APPENDIX A: PROJECT SUMMARY TABLES

WP#	Building Name and Address, Campus or Complex	Measure Description	Measure Category	Measure Sub-Category	Measure Application	Package	Feasible?	Barrier(s) to Feasibility	Evaluated?	Barrier(s) to Evaluation	Measure Status	Barrier(s) to Recommendation	Product/Manufacturer/Model Analyzed	Risk Reduction/ Safety Impact			Outdoor Air	Energy Use Impact			Energy Cost Impact[1]				Maintenance Cost	First Cost
														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	MERV 15 Filters	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	No	MERV 15 already in use	NR	Not evaluated	N/A	90%	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	Cooling Coil UVGI (EEPA, EEPB, EEPC)	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Biowall UVGI	99%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	293,552.0	402.1	0.0	$14,114.50	$2,965.56	$0.00	$17,080.06	$12,325.00	$362,500.00
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	Air Stream UVGI (EEPA, EEPB, EEPC)	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Biowall UVGI	99%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	208,649.0	285.9	0.0	$10,032.21	$2,108.57	$0.00	$12,140.78	$12,325.00	$217,500.00
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	Increased Outdoor Air (EEPB)	Ventilation	Increased OA%	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	NR	Increased OA only possible with capital improvement project	N/A	37%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	240056	18,038.0	0.0	26,559.0	$867.30	$0.00	$118,759.55	$119,626.85	$0.00	$0.00
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	Retrofit AHUs with CHW Loop (EEPB)	Other	Non IAQ Measure	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	ME	Measure selected under Energy Efficiency Package C	Mammoth AHU Components / York Air Cooled Screw Chillers	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-2,091,177.0	-4,431.2	-22,137.0	-$100,547.49	-$32,680.94	-$98,986.41	-$232,214.85	$93,500.00	$21,818,008.00
WP-01	Buffalo Niagara International Airport 4200 Genesee Street, Buffalo, NY 14225	Retrofit AHUs with CHW Loop (EEPC)	Other	Non IAQ Measure	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Mammoth AHU Components / York Air Cooled Screw Chillers	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-2,735,916.0	-6,684.4	-14,937.5	-$131,547.68	-$49,298.72	-$66,793.58	-$247,639.99	$93,500.00	$21,818,008.00

WP#	Building Name and Address, Campus or Complex	Measure Description	Measure Category	Measure Sub-Category	Measure Application	Package	Feasible?	Barrier(s) to Feasibility	Evaluated?	Barrier(s) to Evaluation	Measure Status	Barrier(s) to Recommendation	Product/Manufacturer/Model Analyzed	Risk Reduction/ Safety Impact			Outdoor Air	Energy Use Impact			Energy Cost Impact[1]				Maintenance Cost	First Cost
														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Humidity Control	Humidifcation	Increased RH	Central System	ASHRAE	No	Infeasible due to equipment limitations and building envelope condition	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Differential Space Pressures	Other	Space Pressurization	Central System	ASHRAE	No	Infeasible due to equipment limitations and open space layout	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Increase Economizer Window	Controls	Control Optimization	Central System	ASHRAE	No	Minimal impact on the total hours the unit operates in econornizer mode	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Filter Upgrades - MERV-9	Filtration	Recuded MERV rating	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	AAF Flanders / MEGApleat M9 Filters	63%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	-8,182.0	-14.1	0.0	-$564.56	-$205.94	$0.00	-$773.00	$166.00	$13,800.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Filter Upgrades - MERV-13	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	AAF Flanders / PREpleat M13 Filters	89%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	-6,236.2	-9.7	0.0	-$430.30	-$141.68	$0.00	-$574.00	$836.00	$10,600.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	OA Ventilation Improvements	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	27%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	243174	0.0	0.0	5.3	$0.00	$0.00	$90.90	$90.00	N/A	$9,400.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Air Handler Repair	Other	Retrocommissioning	Central System	ASHRAE	Yes	N/A	Yes	N/A	RS	Further study needed to confirm exact cause of current LWCO alarms.	N/A	25%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	298.3	0.5	138.8	$20.58	$7.30	$2,425.67	$2,454.00	N/A	$16,300.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Purge Fan Exhaust	Ventilation	Exhaust System	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	25%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-11,510.4	-13.6	0.0	-$794.22	-$198.64	$0.00	-$996.00	N/A	$25,600.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Suite AHU Controls Modifications	Controls	Control Optimization	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	25%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	1,924.7	11.2	6.8	$132.80	$163.59	$131.12	$428.00	N/A	$3,700.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	UVGI on Cooling Coils with Reduced Outdoor Air	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	RLM Xtreme,UV Resources	95%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	10,887.0	18.1	-2,342.2	$751.20	$264.37	-$37,412.97	-$36,394.00	$1,728.00	$131,400.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Pre & Post Evnet Purge (2.5 hr.)	Ventilation	Institute 3 ACH Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to 0.75 hr. purge	N/A	98%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	186,805.3	397.5	1,463.8	$12,889.57	$5,805.89	$25,147.76	$43,889.00	N/A	$0.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Pre & Post Evnet Purge (0.75 hr.)	Ventilation	Institute 3 ACH Building Air Flush	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	25%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-130,763.7	-397.5	-1,024.6	-$9,022.70	-$5,805.89	-$17,603.45	-$32,432.03	N/A	$0.00
WP-02	Blue Cross Arena 100 Exchange Blvd., Rochester, NY 14614	Maximum Outdor Air	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	100%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	359500	0.0	0.0	2,341.9	$0.00	$0.00	$37,412.97	$37,413.00	N/A	$12,900.00

WP#	Building Name and Address, Campus or Complex	Measure Description	Measure Category	Measure Sub-Category	Measure Application	Package	Feasible?	Barrier(s) to Feasibility	Evaluated?	Barrier(s) to Evaluation	Measure Status	Barrier(s) to Recommendation	Product/Manufacturer/Model Analyzed	Risk Reduction/ Safety Impact			Outdoor Air	Energy Use Impact			Energy Cost Impact[1]				Maintenance Cost	First Cost
														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-03	100 Great Oaks Blvd., Albany, NY 12203	UVGI in Duct Return	UVGI	In-Return Duct UVGI	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	Biowall UVGI	99%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	3,744.0	1.0	0.0	$389.38	$10.64	$0.00	$389.38	$1,466.00	$17,159.00
WP-03	100 Great Oaks Blvd., Albany, NY 12203	Reduced Ventilation (30% to 15%)	Ventilation	Reduced OA%	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	15%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	9750	-28,153.0	0.0	-2,012.0	-$2,927.91	$0.00	-$22,215.00	-$25,142.91	N/A	$1,200.00
WP-03	100 Great Oaks Blvd., Albany, NY 12203	Increased Ventilation (5% to 30%)	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to Reduced Ventilation	N/A	25%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	19500	46,922.0	0.0	3,354.0	$4,879.89	$0.00	$37,025.00	$41,904.89	N/A	$10,200.00
WP-03	101 Great Oaks Blvd., Albany, NY 12203	Increased Filtration	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	85%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	9,269.0	3.0	0.0	$963.98	$31.40	$0.00	$963.98	$4,990.00	$0.00
WP-03	101 Great Oaks Blvd., Albany, NY 12203	Purge (3 ACH)	Ventilation	Institute 3 ACH Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to 1 ACH Purge	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	81300.7	0	110.2	$5,365.85	$0.00	$912.79	$6,278.63	N/A	$0.00
WP-03	101 Great Oaks Blvd., Albany, NY 12203	Purge (1 ACH)	Filtration	Institute 3 ACH Building Air Flush	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-54418.1	0	-91.9	-$3,591.59	$0.00	-$761.21	-$4,352.80	N/A	$0.00

WP#	Building Name and Address, Campus or Complex	Measure Description	Measure Category	Measure Sub-Category	Measure Application	Package	Feasible?	Barrier(s) to Feasibility	Evaluated?	Barrier(s) to Evaluation	Measure Status	Barrier(s) to Recommendation	Product/Manufacturer/Model Analyzed	Risk Reduction/ Safety Impact			Outdoor Air	Energy Use Impact			Energy Cost Impact[1]				Maintenance Cost	First Cost
														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14203	UVGI on Cooling Coil + Airstream of AHUs	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Biowall UVGI	99%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	8,340.0	22.8	0.0	$341.94	$257.82	$0.00	$599.76	$595.00	$21,751.89
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14203	Filter Upgrades	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	85%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	1,978.0	0.0	0.0	$81.10	$0.00	$0.00	$81.10	N/A	$4,374.61
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14204	Increased Ventilation	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to Reduced Ventilation	N/A	45%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	51680	43,018.0	0.0	864.0	$1,763.74	$0.00	$3,550.18	$5,313.91	N/A	$6,730.17
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14205	Tower Steam Humidification	Humidifcation	Increased RH	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	DriSteam	0%	N/A	N/A	Measure does not dictate outdoor air rates.	151,004.0	0.0	0.0	$6,191.16	$0.00	$0.00	$6,191.16	N/A	$56,775.67
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14206	Aerosealing of AHU-3 and AHU-4 ductwork	Other	Non IAQ Measure	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Aeroseal	0%	N/A	N/A	Measure does not dictate outdoor air rates.	-202,910.0	0.0	-53.9	-$8,319.31	$0.00	-$221.48	-$8,540.79	N/A	$21,751.89
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14207	Chiller Upgrade	Other	Non IAQ Measure	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Trane RTAF Air-Cooled Screw Chiller	0%	N/A	N/A	Measure does not dictate outdoor air rates.	-174,404.0	-131.5	0.0	-$7,150.56	-$1,487.00	$0.00	-$8,637.57	-$500.00	$748,976.63
WP-04	Niagara Frontier Transportation Authority Metropolitan Transportation Center 181 Ellicott Street, Buffalo, NY 14204	Reduced Ventilation	Ventilation	Reduced OA%	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	0%	N/A	N/A	18600	-43,018.0	0.0	-864.0	-$1,763.74	$0.00	-$3,550.18	-$5,313.91	N/A	$0.00

WP#	Building Name and Address, Campus or Complex	Measure Description	Measure Category	Measure Sub-Category	Measure Application	Package	Feasible?	Barrier(s) to Feasibility	Evaluated?	Barrier(s) to Evaluation	Measure Status	Barrier(s) to Recommendation	Product/Manufacturer/Model Analyzed	Risk Reduction/ Safety Impact			Outdoor Air	Energy Use Impact			Energy Cost Impact[1]				Maintenance Cost	First Cost
														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Humidity Control	Humidifcation	Increased RH	Central System	ASHRAE	No	Infeasible due to zones and the building envelope not well sealed. Equipment is not set up for humidity control.	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Airflow Pattern Adjustments	Other	Airflow Pattern	Central System	ASHRAE	No	No relevant spaces for this measure	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Differential Space Pressures	Other	Space Pressurization	Central System	ASHRAE	No	No relevant spaces for this measure	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Provide VFDs to fans to reduce fan speed	Other	Non IAQ Measure	Central System	ASHRAE	No	No relevant spaces for this measure	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Increase Economizer Window	Controls	Control Optimization	Central System	ASHRAE	No	Minimal impact on the total hours the unit operates in economizer mode	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Filter Upgrades - MERV 9	Filtration	Increased MERV rating	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Mega Pleat MERV 9	56%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	-3,356.5	-1.3	0.0	-$278.59	-$18.41	$0.00	-$968.00	-$671.00	$8,400.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Filter Upgrades - MERV 11	Filtration	Increased MERV rating	Central System	None	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	Fiberbond Polysheild XI Media	82%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	6,019.1	2.3	0.0	$499.59	$32.57	$0.00	$1,844.00	$1,312.00	$4,800.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Filter Upgrades - MERV 14	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	MERV 14 basis of design not defined in report	91%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	9,028.7	3.5	0.0	$749.38	$49.56	$0.00	$1,076.00	$278.00	$8,800.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Filter Upgrades - MERV 13	Filtration	Increased MERV rating	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	Camfil MERV 13	87%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	10,031.9	3.8	0.0	$832.65	$53.81	$0.00	$1,757.00	$870.00	$4,400.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	OA Quality Improvements (Code Required OA)	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	18%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	15344	2,177.4	1.6	105.6	$180.72	$22.66	$2,270.81	$2,474.00	$0.00	$1,000.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	UVGI on Cooling Coils (NR)	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Steril-Aire	91%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	5,787.9	2.2	0.0	$480.40	$31.15	$0.00	$853.00	$341.00	$16,900.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Maximum OA Emergency Pandemic Mode	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to UVGI measure (that includes reduced OA)	N/A	100%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	54800	49,273.5	0.0	2,228.7	$4,089.70	$0.00	$47,925.74	$52,016.00	$0.00	$15,100.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Pre & Post Purge (2 hr)	Ventilation	Institute 2 hr. Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	MR to 1 hr. Purge	N/A	30%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	29,685.7	20.3	300.1	$2,463.91	$287.45	$6,453.32	$9,204.00	$0.00	$11,170.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Pre & Post Purge (1 hr)	Ventilation	Institute 3 ACH Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	RME	N/A	N/A	57%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	26,290.8	20.5	73.9	$2,182.14	$290.28	$1,589.14	$4,061.00	$0.00	$0.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Additional Mechanical Ventilation	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	100%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	30,995.5	25.7	45.6	$2,572.63	$363.91	$980.58	$4,168.00	$251.00	$918,000.00
WP-05	Rundel Library 115 South Ave, Rochester, NY 14604	Portable HEPA Filtration	Filtration	HEPA Filtration	Local In-Room	None	Yes	N/A	Yes	N/A	NR	Too costly to impleent across all spaces and will not meet requirements for mechanical ventilation as compared to adding mechanical ventilation.	N/A	100%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	55,147.3	21.2	0.0	$4,577.23	$300.19	$0.00	$34,977.00	-$30,100.00	$276,900.00

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														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	MERV-13 Filtration	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	AAF PrePleat 13	85%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	56.0	0.0	0.0	$3.30	$0.00	$0.00	$3.30	$157.00	$2,300.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Maximize OA Ventilation	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to UVGI measure (that includes reduced OA)	N/A	54%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	35172.9	2,497.6	4.1	1,236.0	$147.36	$67.49	$6,290.33	$6,505.17	$0.00	$7,800.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Portable Filtration Unit	Filtration	HEPA Filtration	Local In-Room	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Healthway 950P Purifier portable units	99%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	2,898.9	1.1	0.0	$171.04	$18.11	$0.00	$189.14	$0.00	$3,800.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Increased Ventilation	Ventilation	Increased OA%	Local In-Room	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	34%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	172.8	-0.2	19.1	$10.20	-$3.29	$97.20	$104.11	$0.00	$14,500.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	MERV-9 Filtration	Filtration	Reduced MERV rating	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	AAF MegaPleat MERV 9	35%	N/A	ASHRAE 52.2 compliant performance data	22145.9	-447.9	-0.2	0.0	-$26.43	-$3.29	$0.00	-$29.72	$80.00	$2,400.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	UVGI at Air Handlers	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Sanuvox Biowall air purification unit	99%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	3,890.4	-1.7	-1,236.0	$229.53	-$27.98	-$6,290.33	-$6,088.78	$350.00	$32,400.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Pre/Post-Purge (2 hr)	Ventilation	Institute 2 hr. Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to 45 min purge	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	34,298.8	7.0	927.5	$2,023.63	$115.22	$4,720.29	$6,859.14	$0.00	$0.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Pre/Post-Purge (45 min)	Ventilation	Institute 3 ACH Building Air Flush	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	Sanuvox Biowall air purification unit	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-27,867.8	0.0	-753.6	-$1,644.20	$0.00	-$3,835.27	-$5,479.47	$0.00	$0.00
WP-06	Webster Central School District 722 Dewitt Road, Webster, NY 14580	Upper Room UVGI	UVGI	Upper Room UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	High level evaluation due to SED not currently allowing the technology in schools	NR	Technology not allowed in schools by SED currently & further airflow modeling of the individual spaces may present more refined time of exposure estimate that can be used to calculate the exact effectiveness of the UVGI in each room	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	4,857.1	1.9	0.0	$286.57	$31.27	$0.00	$317.84	$500.00	$134,300.00

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														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	UVGI in Return Ducts	UVGI	In-Return Duct UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	Biowall UVGI	90%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	5,256.0	14.4	0.0	$283.82	$152.93	$0.00	$436.75	$298.00	$57,900.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Outside Air Ventilation Improvements (Minimum Code OA in select areas)	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	30%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	25480	0.0	0.0	0.0	$0.00	$0.00	$0.00	$0.00	$0.00	$35,100.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Decrease Outside Air Ventilation	Ventilation	Reduced OA%	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	14%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	-222,583.6	0.0	-6,049.6	-$12,019.51	$0.00	-$29,454.07	-$41,473.59	$0.00	$0.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Disable DCV	Controls	Disable DCV	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	0%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	159,715.0	0.0	512.9	$8,624.61	$0.00	$2,497.19	$11,121.80	$0.00	$0.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Increase Outside Air Ventilation	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to Reduced Ventilation	N/A	14%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	54,600	222,583.6	0.0	6,049.6	$12,019.51	$0.00	$29,454.07	$41,473.59	$0.00	$0.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Building Purge (2 ACH)	Ventilation	Institute 2 hr. Building Air Flush	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to 1 ACH Purge	N/A	0%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	40,801.5	0.0	0.8	$2,203.28	$0.00	$3.90	$2,207.18	$0.00	$0.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Building Purge (1 ACH)	Ventilation	Institute 3 ACH Building Air Flush	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	0%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	20,400.7	0.0	0.2	$1,101.64	$0.00	$0.97	$1,102.61	$0.00	$0.00
WP-07	NY State Tax and Finance Building 299 Old Niskayuna Rd., Latham, NY 12110	Increase Filtration	Ventilation	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	85%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	22,115.4	0.0	0.0	$1,194.23	$0.00	$0.00	$1,194.23	$0.00	$0.00

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														Supply Air Cleanliness (First Pass %)	Probability of Infection	Risk Reduction Method of Analysis	CFM	kWh	kW	MMBtu	kWh ($)	kW ($)	MMBtu ($)	Total ($)		
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Disable DCV	Controls	Disable DCV	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	0%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	0.0	0.0	127.4	$0.00	$0.00	$655.93	$656.00	$0.00	$2,900.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Filter Upgrades - MERV 9	Filtration	Reduced MERV rating	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	AAF MegaPleat MERV 9 Filter	35%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	0.0	0.0	0.0	$0.00	$0.00	$0.00	$0.00	$96.00	$4,400.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Filter Upgrades - MERV 13	Filtration	Increased MERV rating	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to MERV 9 measure	AAF MegaPleat MERV 13 Filter	85%	N/A	ASHRAE 52.2 compliant performance data	Measure does not dictate outdoor air rates.	3,289.5	1.3	0.0	$220.40	$13.65	$0.00	$234.05	$295.00	$3,700.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	UVGI for Air Handlers	UVGI	In-AHU UVGI	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	R	N/A	UVR - SLX Single Lamp High Output Fixture	90%	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	5,068.3	2.0	0.0	$339.58	$21.00	$0.00	$360.58	$455.00	$23,200.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Upper Room UVGI in Classrooms	UVGI	Upper Room UVGI	Local In-Room	Energy Efficiency	Yes	N/A	Yes	N/A	NR	Not allowed by NYSED while classrooms are occupied	UVR - SLX Single Lamp High Output Fixture	N/A	N/A	Calculated UVGI effectiveness based on ASHRAE Handbook Chapter 62 (2019) methodology	Measure does not dictate outdoor air rates.	11,962.8	4.8	0.0	$801.51	$50.40	$0.00	$851.91	$3,547.00	$298,100.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Max OA - All units	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	ME	ME to Max OA Unit Ventilators	N/A	100%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	97800	3,858.9	0.0	3,677.0	$258.55	$0.00	$18,931.29	$19,189.84	$0.00	$8,800.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Max OA - Unit Ventilators	Ventilation	Increased OA%	Central System	Energy Efficiency	Yes	N/A	Yes	N/A	RME	N/A	N/A	70%	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	68460	0.0	0.0	2,195.6	$0.00	$0.00	$11,304.20	$11,304.20	$0.00	$3,900.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Utilize MAU-2	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	6,765.0	2.6	296.6	$453.26	$27.30	$1,527.07	$2,007.62	$0.00	$0.00
WP-08	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14120	Supply Fresh Air to Room 234	Ventilation	Increased OA%	Central System	ASHRAE	Yes	N/A	Yes	N/A	R	N/A	N/A	N/A	N/A	Spreadsheet calculations using calculated and rated effectiveness of measures.	Measure does not dictate outdoor air rates.	483.1	0.2	4.8	$32.37	$2.10	$24.71	$59.18	$16.00	$24,900.00
WP-09	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14121	Humidity Control	Humidifcation	Increased RH	Central System	ASHRAE	No	Infeasible due to there being no existing humidification or dehumidification equipment. Additionally most spaces are served by single zone equipment making it difficult to incorporate a humidity control system.	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-10	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14122	Differential Space Pressures	Other	Space Pressurization	Central System	ASHRAE	No	No practical spaces to implement this measure due to space zoning and equipment limitations	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-11	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14123	Provide VFDs to fans to reduce fan speed	Other	Non IAQ Measure	Central System	ASHRAE	No	No practical spaces to implement this measure due to space zoning and equipment limitations	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WP-12	North Tonawanda Intermediate School 1500 Vanderbilt Ave, North Totawanda, NY 14124	Increase Economizer Window	Controls	Control Optimization	Central System	ASHRAE	No	Minimal impact on the total hours the unit operates in economizer mode	No	Not Feasible	NR	Not evaluated	N/A	N/A	N/A	N/A	Measure does not dictate outdoor air rates.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

APPENDIX B: INDUSTRY GUIDANCE

Defined as a biological agent that causes disease or illness to its host, pathogens can be transmitted from one body to another in a number of ways through direct and indirect methods of exposure. A number of viruses, bacteria, and microorganisms fall under this classification such as influenza, the common cold, and more lethal strains such as the SARS outbreak in 2003 and the ongoing COVID-19 pandemic in 2020. Despite their varying in severity and infectiousness, a number of strategies exist that can be used to help mitigate the spread of pathogens through both direct and indirect exposure.

The SARS-CoV-2 virus, short for severe acute respiratory syndrome coronavirus 2, is a RNA virus with a lipid envelope with a size of approximately 120 nm. Common symptoms include fever, coughing, fatigue, shortness of breath, and loss of taste and smell. Studies have indicated that the virus is capable of surviving hours in the air and up to days on surfaces. The World Health Organization and other research institutions are still researching the virus shedding rate and infectious dosage, as that is not known at this time.

Transmission Modes & Non-HVAC Mitigation

Common transmission modes according to the World Health Organization includes direct or indirect contact with an infected person, through food or water, insect or animal vector, fomite- meaning intermediate surfaces, or through airborne particles such as large droplets or aerosols. For the purpose of this study, methods of mitigating the spread of pathogens, specifically COVID-19, can be separated into "HVAC" methods of mitigation and "Non-HVAC" methods of mitigation. Both categories play an essential role in maintaining a safe environment for occupants in buildings.

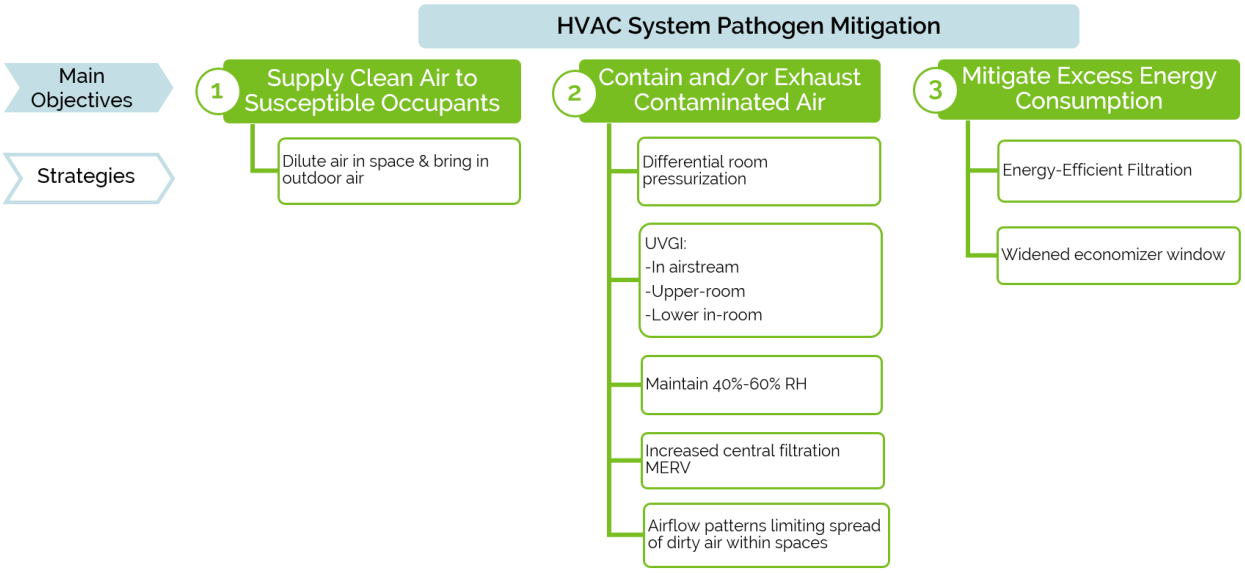
The graphic shown on the right highlights common non-HVAC methods of mitigating the spread of pathogens and are paramount to the stop of the spread of the virus. These measures help limit direct exposure between occupants and helps maintain clean surfaces to limit fomite transmission.

HVAC Mitigation

In addition to limiting direct exposure between occupants, there are several ways in which the operation of buildings plays a critical role in limiting the spread of contaminants from one occupant to another. Indoor air quality control is a key element in controlling transmission, specifically impacting aerosol and fomite transmission.

The flowchart below outlines the three main objectives of the building systems within its role in pathogen mitigation and a variety of means to accomplish these goals. The two primary objectives are to supply clean air to occupants while containing and/or exhausting contaminated air out of the occupied spaces. The third objective, after taking appropriate

safety precautions, is to mitigate excess energy consumption in a way that does not negatively impact building safety.



A number of variables impact the feasibility of these indoor air quality strategies that are unique to each facility. In general, current industry guidance states that it is recommended to ventilate as much outdoor air as possible, with a MERV-13 filter or higher, while incorporating ultraviolet germicidal irradiation (UVGI) to disinfect surfaces in the airstream. The following sections take a closer look at each of the recommended strategies to pathogen mitigation with respect to the HVAC system as well as potential limiting factors in existing facilities and possible alternatives.

Filtration

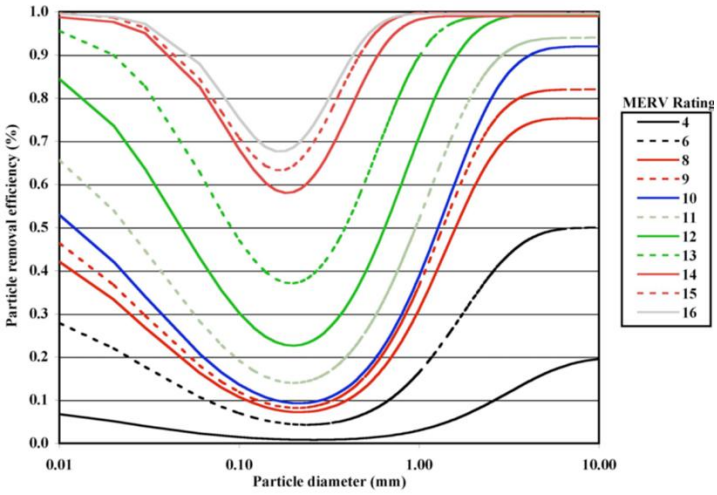
Recommended Action	• MERV-13 or higher filter
Limiting Factors	• Supply fan power great enought to overcome ΔP

Filtration plays a key role in limiting the spread of the virus through the HVAC system. Most commonly located centrally in the HVAC system, mechanical filters are evaluated by the minimum efficiency reporting value (MERV), which is based on a scale is 1-16. The higher the MERV rating, the better the filter is able to remove particles in the air ranging in sizes from 0.3 microns to up to 10 microns.

ASHRAE recommends that the mechanical filter efficiency has a minimum MERV rating of 13, and preferably higher to better limit the spread of the virus. Since many existing systems were designed with a MERV rating of 6-8, the unit's fan power and capacity must be taken into consideration to ensure it is still able to effectively meet indoor temperature and humidity requirements.

The graph to the right illustrates the particle removal efficiency for different rated filters. In general, higher-rated filters are more effective at removing particles from the air, however they often require more energy to overcome the increased pressure drop across the filter. In

addition, frequency of filter changes should be taken into consideration, as dirty filters result in additional pressure drop. Note this is in generality – pressure drops are to be evaluated on a filter-by-filter basis as it is known that the MERV rating is not always proportional to the pressure drop.



(Kowalski and Bahnfleth 2002)

Ventilation

The current industry guidance encourages building operators to increase outdoor air ventilation to reduce recirculation air back to the space as much as possible. By doing this, fresh air is brought into the space and dirty air can be exhausted, limiting spread from one person to another via airborne particles.

Recommended Action	• Increase OA intake as much as system allows
Limiting Factors	• HVAC system capacity • Ability to meet setpoints

Two main strategies are used to increase the amount of outdoor air ventilation from code minimum include:

1) Control OA intake based on heating/cooling coil control valve position and discharge air temperature
2) Control OA intake based on space conditions inside the space

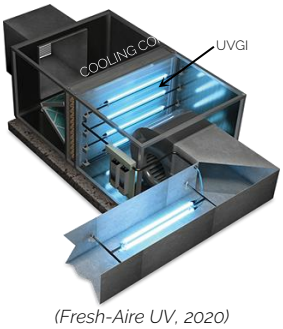
Both strategies allow the system to intake as much outdoor air as the system design allows, while maintaining indoor temperature and humidity setpoints.

In addition to increased ventilation during occupied hours, performing pre and post-occupancy purges of the system, where the HVAC system is run at the maximum amount of outdoor air changes per hour is another effective measure to dilute the air in the space. For most mixed air spaces, this equates to approximately three full air changes of outside air immediately after occupants leave for the night and again before occupants return in the morning. According to ASHRAE guidance, this strategy can reduce the concentration of airborne particles by up to 95%.

Ultraviolet Germicidal Irradiation

Ultraviolet Germicidal Irradiation (UVGI) is defined as the use of UV lighting to kill or inactivate viral, bacterial, and fungal species. Current industry guidance recommends UVC lighting (200-280 nm wavelength) used on the cooling coil, upper-room, and lower in-room applications, depending on the application.

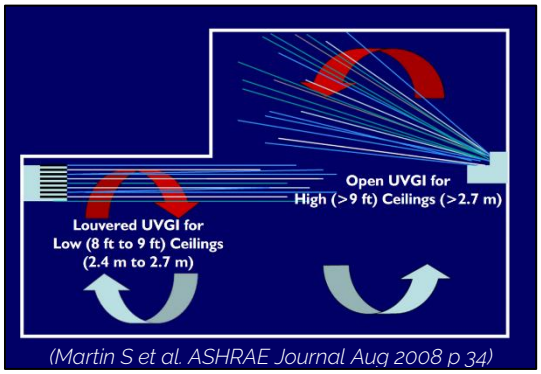
Recommended Action	• UVGI downstream of Cooling Coil • Upper-room UVGI • Surface UVGI
Limiting Factors	• Space in AHU cooling coil section • Materials susceptible to UV degradation



(Fresh-Aire UV, 2020)

Industry best practices indicate that in-duct UVGI downstream of the cooling coil is the most effective application of UVGI to reduce or eliminate microbial growth on the cooling coil and drain pan. While the exact mounting location of the lamps is dependent on the AHU design and lamps used, the UV lamps are typically mounted within 3 feet of the coil and are generally on 24/7.

In instances where in-duct UVGI is not possible and there is ample overhead room in the spaces, upper-room UVGI is also an effective means of disinfecting air. As shown in the image below to the right, the UVGI lamps are mounted on the wall and shine UV light across the room, above the heads of the occupants. These fixtures inactivate airborne microorganisms by irradiating them as air moves through the path of the UV lights. Some louvered fixtures use small fans to enhance air mixing. A rule of thumb for upper air installations, according to the 2019 ASHRAE Handbook, is one 30W fixture for every 200 sf of room area in order to maintain an intensity of between 30-50 $\mu W/cm^2$ in the upper part of the room.



(Martin S et al. ASHRAE Journal Aug 2008 p 34)

In addition to upper-room and in-duct UVGI, UV light can be used to disinfect commonly touched surfaces such as busses, public waiting spaces, and sports arenas. Similar to the UV lighting used on the cooling coil, the UV light is required to be shined on surfaces at a prescribed intensity and length of time in order to effectively disinfect the surfaces. The use of UVGI on lower room surfaces is required to be during unoccupied hours.

Humidity Control

Research links air between 40% and 60% relative humidity (RH) with less effective aerosol travel, shorter airborne and surface survival times, lower transmission rates, and more effective patient lung repair functions. It is recommended that the HVAC system is controlled to maintain the indoor temperature setpoints as well as the relative

Recommended Action	• Maintain RH between 40% to 60%
Limiting Factors	• HVAC system capacity • Humidification capability in AHU • HVAC controls

humidity between 40% and 60%, if possible. Potential limiting factors include insufficient cooling capacity in the HVAC system, building envelope, no humidification inside the HVAC unit, or inadequate controls that are not capable of monitoring humidity within the spaces.

Additional Considerations

In-room airflow should be directed away from occupants in order to limit instances where contaminated air is being blown across other occupants. These airflow strategies are typically most effective when incorporated into the HVAC system design.

An additional method of conserving energy that is not included in this report is to reduce filtration levels with the use of UVGI to reduce pressure drop while still maintaining an equivalent safety level.

Differential Room Pressurization can be an effective way of mitigating spread from one room to another by creating a positive or negative room pressure to prohibit airflow in or out of a room. This is typically applied in healthcare or educational settings. Limiting airflow between one room and another helps discourage the spread of contaminated air.

Modes of Building Operation

The intent of this study is to identify operational strategies to mitigate the spread of pathogens during normal operation as well as during pandemics. ASHRAE recommends the following operational settings for the building management system:

Epidemic Conditions in Place (ECiP)

- Occupied at pre-epidemic capacity
- Occupied at reduced capacity
- Unoccupied temporarily
- Unoccupied for indefinite period

Post-Epidemic Conditions in Place (P-ECiP)

- Prior to occupancy
- Occupied

The Epidemic Conditions in Place (ECiP) setting includes all of the pathogen mitigation measures listed above – with pre-programmed settings accounting for varying levels of occupancy and building closure. In addition to mitigating the spread of the COVID-19 virus, this will allow the systems to have an already built-in epidemic mode in the event of future epidemic/pandemic events.

The Post-Epidemic Conditions in Place (P-ECiP) measure includes a normal building operation setting as well as a post-epidemic, pre-occupancy setting or protocol is in-place to ensure all systems are in good working condition, all necessary filters and maintenance supplies are confirmed for delivery, and all safety measure protocols are in-place.