FLEXTECH
ENERGY EFFICIENT INDOOR AIR QUALITY STUDY

FINAL CONCLUSIONS REPORT

For

Jaros, Baum & Bolles Consulting Engineers, LLP (JB&B)

New York State Energy Research and Development Authority
17 Columbia Circle
Albany, New York 12203-6399

Date: October 21, 2021

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.

NYSERDA IAQ Study Conclusion Report

October 5, 2021

JB&B | 80 Pine Street | New York NY 10005 | 212.530.9300 | www.jbb.com

Table of Contents

NYSERDA IAQ Study Conclusion Report

1 Study Overview

In response to the COVID-19 global pandemic, building operations staff across New York made operational changes to the existing HVAC systems to improve indoor air quality per guidance and recommendations from the CDC, ASHRAE and World Health Organization. Many building sector Stakeholders, including Owners, operators, solution providers and government agencies, were interested in understanding the energy, carbon and cost impacts resulting from the specific recommendations by these organizations. Through a NYSERDA-funded mini-bid process, JB&B was selected to study these energy, carbon and cost impacts for approximately 8,200,000 sq.ft. of space across a diverse selection of building types, geographic locations, ownership structures, space programs/occupancies and HVAC systems.

2 Study Objective

In accordance with the NYSERDA mini-bid solicitation, there were four (4) primary study requirements:

- Evaluate opportunities to improve indoor air quality including feasibility of implementation.
- Analyze the energy and cost impacts of minimum IAQ recommendations identified by the ASHRAE Pandemic Task Force.
- Evaluate possible alternatives to the ASHRAE minimum recommendations that improve indoor air quality with less impact to energy and cost.
- Provide industry guidance and thought leadership around technologies, strategies and operating principles to improve indoor air quality and prepare buildings for safe operation as occupants return.

3 Study Approach

3.1 Overview

The JB&B study team approached ten (10) buildings across three (3) New York boroughs and three (3) building sectors to participate in the study. The following buildings included in this study represent a broad spectrum of project types and ownership structures that provided a robust dataset in the wider NYSERDA effort to understand the impacts to energy as a result of IAQ enhancement.

A list of participating properties is shown below:

NYSERDA IAQ Mini-Bid Participating Properties

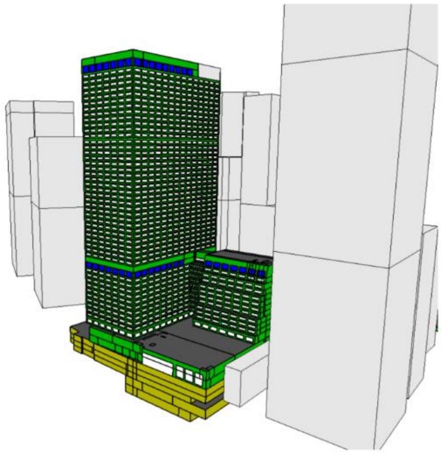
Building	Location	Sector
55 Water Street	Manhattan	Commercial
345 Park Avenue	Manhattan	Commercial
3 Times Square	Manhattan	Commercial
80 Pine Street	Manhattan	Commercial
Museum of Modern Art (MoMA)	Manhattan	Cultural
Museum of Modern Art Queens (MoMA QNS)	Queens	Cultural
Horace Mann School (four [4] Buildings)	Bronx	K-12 School

NYSERDA IAQ Mini-Bid Participating Properties

3.2 Three (3)-Phase Approach

The study team approached the project in three (3) steps as detailed below.

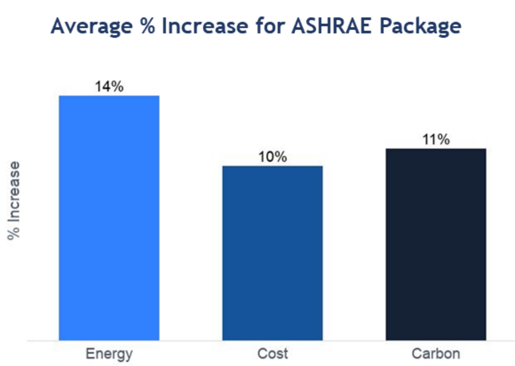
3.2.1 Step 1: Understand Each Building's Existing Energy and Carbon Profile



Determine the baseline energy, cost and carbon profile for each participating site before COVID. Building baselines were determined using either spreadsheet or simulation-based energy models.

Example: 55 Water Street's simulation-based energy model rendering shown at left.

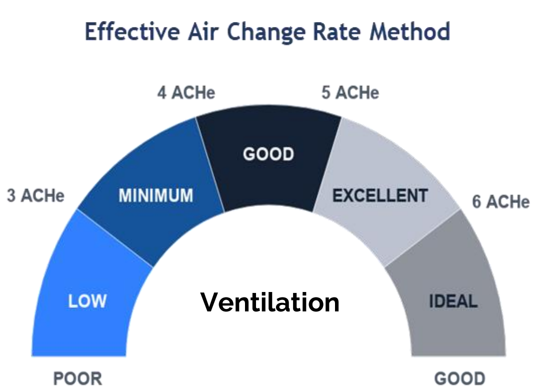
3.2.2 Step 2: Study the Impacts of ASHRAE Recommended Measures



Evaluate energy, carbon and cost impacts of implementing feasible ASHRAE recommendations from April and May 2020, including:

- Minimum of MERV 13 filtration (MERV 14 preferred).
- Maximum possible outside air for ventilation during occupied hours.
- Pre-and-post occupancy flushing sequence.
- Disable demand-controlled ventilation (DCV).
- Disable energy-recovery ventilation (ERV).
- Humidification control between 40% - 60% relative humidity.

3.2.3 Step 3: Evaluate Other IAQ Recommendations with the Goal of Maintaining Effectiveness of the Solution, but with Less Energy, Carbon and Cost Impact



Study IAQ enhancement strategies beyond ASHRAE recommendations to improve IAQ, but with less energy, carbon and cost impacts. Use the Effective Air Change Rate methodology to ensure "packages" of "energy-efficient" IAQ enhancements were also effective from a safety perspective.

3.3 Key Commonalities in Study Approach across Participating Buildings

- All project locations first evaluated potential IAQ strategies based upon feasibility. Each strategy has criteria and restrictions for successful implementation that must be considered. Feasibility criteria are discussed in depth in Section 4.4.
- IAQ improvement strategies were categorized into three (3) tiers. All projects studied the impacts of feasible recommendations and packages of feasible recommendations combined with other ASHRAE alternatives. The tier system used throughout the study by the study team is discussed in Section 4.1.
- Combined packages were evaluated using an effective air change rate methodology with a target of 5 ACHe in design condition. This methodology and the assumptions used in ACHe analysis are discussed in Section 4.6.

3.4 Key Differences in Study Approach across Participating Buildings

- Some projects used spreadsheet-based energy models to evaluate energy, carbon and cost impacts, while others used previously developed calibrated simulation-based energy models.
- Simulation-based energy models had more accurate results that were able to account for interactive effects and more complex control schemes.
- Spreadsheet-based energy models were faster to work with and required less technical modeling experience. Spreadsheet models were based on the DCAS Ventilation Increase Impacts Calculator. Modeling approaches are discussed in Section 4.5.

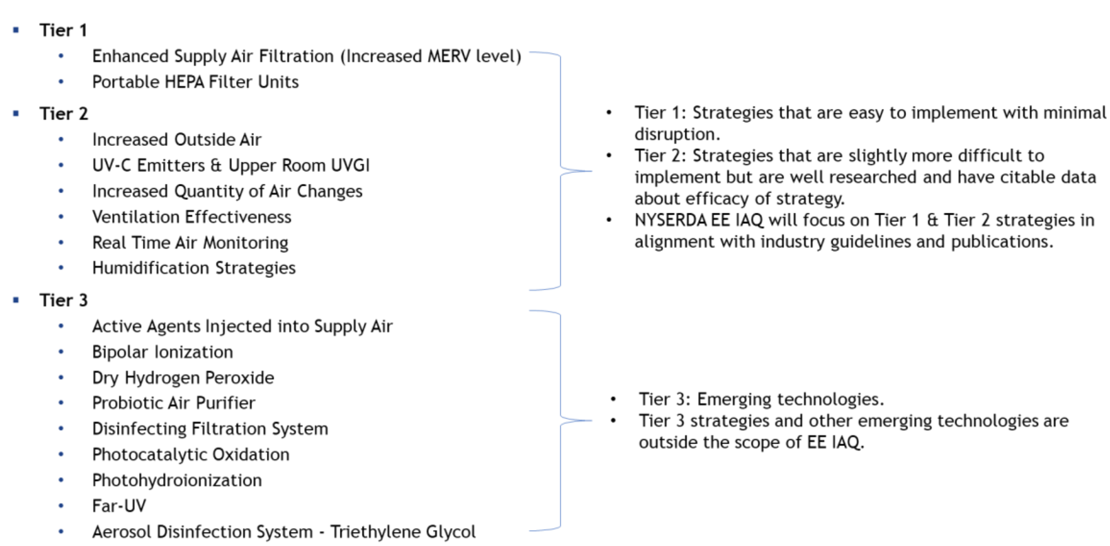
4 Methodology

4.1 Approaching Indoor Air Quality (IAQ)

Available IAQ strategies, products and technologies vary greatly. For the purposes of this study, JB&B characterized the various IAQ improvements/technologies into the following three (3) tiers:

- Tier 1: Strategies and technologies that are easy to implement with minimal disruption to building operations.
- Tier 2: Strategies that are more difficult to implement but are well researched and have citable data about the efficacy of strategy.
- Tier 3: Emerging technologies that lack a sufficient quantity of citable data and scientific support of efficacy.

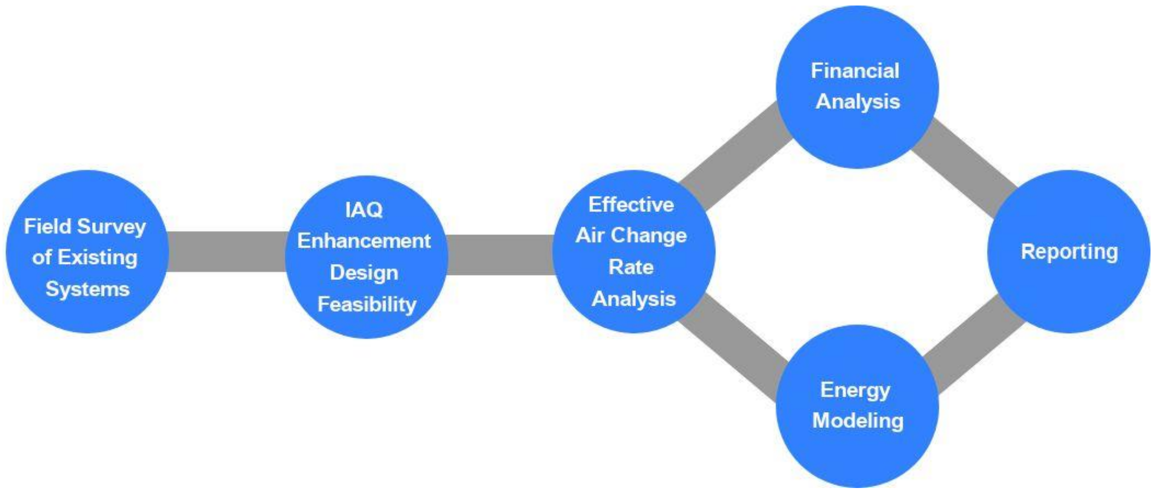
IAQ Enhancement Tier System Used by the Study Team



The study focuses on Tier 1 and Tier 2 IAQ enhancements. While many Tier 3 emerging technologies show promise, they were considered to be outside of the scope of this project.

4.2 Study Process Overview (Each Building)

The IAQ study process conducted at each participating building included five (5) phases as described below:



Phase 1: Onsite survey efforts collected existing systems information needed to advance the project.

Phase 2: The feasibility evaluation included a criteria matrix to level-set on the definition of "feasible" across the various IAQ strategies.

Phase 3: Feasible measures were then evaluated for their "effectiveness" through an effective air change rate analysis. Measures deemed to be feasible and that achieved a target of five (5) effective air change rates within served spaces were then analyzed for potential energy, carbon and cost impacts to the facility.

Phases 4.1 and 4.2: If available, a whole-building calibrated energy model that had been previously developed was utilized to analyze the energy, carbon and cost impacts of feasible IAQ packages. If a calibrated energy model was not available, a spreadsheet-based energy modeling tool was developed and utilized to analyze the impacts of feasible IAQ packages.

Phase 5: The results of each study were shared with each building's management team and NYSERDA.

4.3 Phase 1: Onsite Survey

The study team conducted a survey of all central air handling units serving occupied spaces including Office Floors, retail spaces and common areas at each participating property. Units serving Mechanical Rooms or other unoccupied areas were not surveyed as part of this scope of work.

The study team surveyed airside systems and equipment to develop an Equipment and Air Filtration Log for each participating building. This log included make and model of the airside equipment, currently installed air filtration media, a condition assessment of airside equipment and filter media, and miscellaneous observations related to IAQ.

The onsite survey at each building spanned multiple days and formed the foundation of the design feasibility analysis conducted by the design team. Equipment information captured in the

Equipment and Air Filtration Log allowed the design team assigned to each participating property to evaluate the feasibility of implementing IAQ enhancement strategies, including:

- Increased air filtration
- Ultraviolet germicidal (UV-C) emitters (duct-mounted or upper-room)
- Portable air cleaners
- Operational adjustments including disabling of DCV or ERV, increased outside air change rates and flushing procedures

4.4 Phase 2: Feasibility Assessment

4.4.1 Approach to Feasibility

IAQ enhancement strategies were evaluated based on equipment conditions, space availability and operational considerations. The study team developed a feasibility criteria matrix for possible IAQ enhancements based upon the assumption that a measure is considered "feasible" if it can be accomplished without making major changes to the existing facility. Feasibility criteria for each possible IAQ enhancement is listed below:

Feasibility Criteria Matrix

IAQ Measure	Feasible	Not Feasible	Other Assumptions
Increased Air Filtration	• If additional motor capacity is available. **AND** • If only alternation needed is changing out the filter rack. **AND** • If there is space in the unit to increase the filter rack size.	• If a new fan motor is required. **OR** • If modifications to the existing AHU casing are required. **OR** • If there is not enough room in the unit to replace the filter rack.	Evaluation is based on the pressure drop of a dirty filter. Increased air filtration may also be feasible if the initial pressure drop increases, but final pressure drop does not increase. Filter replacement would be more frequent in this case.
Increase in OA %	• If physical size and configuration of ductwork and louvers support an increase in OA%. **AND** • If only required change to existing system is controls-related programming.	• If alterations to ductwork would be required. **OR** • If alterations to OA dampers or louvers would be required. **OR** • If there are very strict temperature or humidity requirements that could be impacted by an increase in OA% (example: museum)	Evaluation of increasing OA% will be based on the notion of "weather permitting". To avoid complex analysis around existing coil capacities, OA% will only be increased when outdoor air conditions allow for it.
UV-C in Central AHUs	• If AHU has 30 inches of space between fan inlet and cooling coil. **OR** • If return air duct has 5 ft. of accessible straight run.	• If AHU does NOT have 30 inches of space between fan inlet and coil. **OR** • If return air duct DOES NOT have 5 ft. of accessible straight run.	Current electrical distribution has capacity for inclusion of UV-C where "feasible".

IAQ Measure	Feasible	Not Feasible	Other Assumptions
Upper Room UV	• If space is an enclosed area with minimal air circulation and people tend to be static (corridors or seating areas) **AND** • Architectural wall and ceiling finishes are UV tolerant or are not particularly important.	• If space has adequate air circulation and people tend to be moving around. **OR** • If ceiling heights are atypically high. **OR** • Architectural wall and ceiling finishes are NOT UV-tolerant or are important (example: museum)	Current electrical distribution has capacity for inclusion of UV-C where "feasible". If space has adequate air circulation and people tend to be moving around, upper-room UV is not necessary if the AHU serving the space has been provided with adequate filtration at the unit.
Portable Air Cleaners	N/A	N/A	Portable air cleaners are assumed to always be feasible and that outlets are available to plug them in.

4.5 Phase 3: Effective Air Change Rate Methodology

4.5.1.1 Approach to IAQ Enhancement Comparisons

Comparing the "effectiveness" of various combined IAQ enhancement strategies is a challenging task due to limited research and guidance in this area. For the purposes of this study, the study team selected a specific effective air change rate approach that was discussed by Dr. William Bahnfleth[1] during his presentation entitled *ASHRAE's COVID-19 Mitigation Recommendations for HVAC Systems.*

The approach is based on a study published by Harvard and the University of Colorado, Boulder to identify effective air changes in schools and to determine whether these air changes were adequate for the spaces included in the study. Through this study, the research team identified that five (5) effective air changes per hour is the recommended target for occupied spaces.

An effective air change rate considers the amount of "clean air" delivered to a space. Outdoor air is considered 100% clean because there is no human contact with the air. Return air that passes through a filter is considered cleaned by a factor of the filter's nuclei-weighted effectiveness, which has been published by ASHRAE. At a minimum, this approach recommends that the design minimum outdoor air, per ASHRAE 62.1, be introduced to every space and that, where feasible, MERV 13 filters are installed in air handling units.

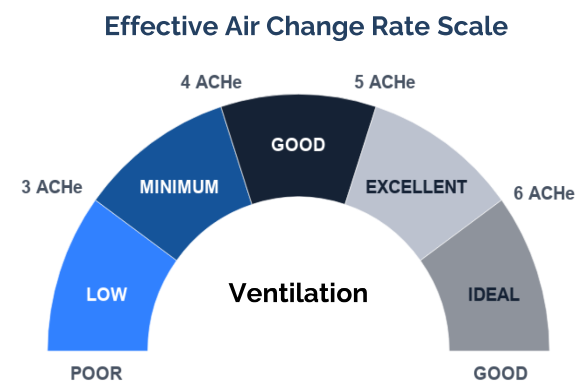
If the ACHe in a space still does not meet the target five (5) ACHe with design minimum outdoor air and MERV 13 filters, ASHRAE recommends that additional filtration or other air cleaners, such as UV-C in the unit, upper room UV-C, or portable air cleaners, are used to raise the ACHe value.

In summary, the formula and methodology presented in the Harvard and University of Colorado, Boulder study is as follows:

$$Effective\ ACH = ACH\ Outside\ Air + ACH\ Filtration + ACH\ In-room\ Air\ Cleaning$$

The following graph demonstrates the prescribed categories for different ACH values:

[1] Presentation is titled *ASHRAE's COVID-19 Mitigation Recommendations for HVAC Systems,* by Dr. William Bahnfleth, P.E., FASHRAE, FASME, FISIAQ, given on October 22, 2020. https://enverid.com/watch-dr-william-bahnfleth-ashraes-covid-19-mitigation-recommendations-for-hvac-systems/



By utilizing the ACHe approach, the study team was able to target IAQ enhancement opportunities to specific space types and compare the "effectiveness" of these solutions in a common metric. A sample ACHe calculation is shown below:

Sample Effective Air Change Rate Calculation

Room Size

sqft	205,890
ceiling	10
volume	2,058,900

Design OA	26%
Practical OA	30%
Max OA	63%

Goal Clean ACH	**5**

		Phase 1		***Phase 2***									***Phase 3***			***Total***	***Phase 4***	
	AHU Air	**OA**		**MERV 13**			**MERV 15**			**MERV 16**			**UV-C**			**Clean CFM Central AHUs**	**Portable Air Cleaner**	
		CFM	Clean	Yes/No	CFM	Clean	Yes/No	CFM	Clean	Yes/No	CFM	Clean	Yes/No	CFM	Clean		Yes/No	
ASHREA Minimum Recommendation	356,460	224,570	224,570	yes	131,890	114,744	no	0	0	no	0	0	no	0	0	339,314	no	9.89
ASHREA Min Recs + MERV-15	356,460	224,570	224,570	no	0	0	yes	131,890	118,701	no	0	0	no	0	0	343,271	no	10.00
ASHREA Min Recs + MERV-16	356,460	224,570	224,570	no	0	0	no	0	0	yes	131,890	125,296	no	0	0	349,865	no	10.20
Min OA + MERV-13	356,460	92,680	92,680	yes	263,780	229,489	no	0	0	no	0	0	no	0	0	322,169	no	9.39
Min OA + MERV-15 (MoMA Standard)	356,460	92,680	92,680	no	0	0	yes	263,780	237,402	no	0	0	no	0	0	330,082	no	9.62
Min OA + MERV-16	356,460	92,680	92,680	no	0	0	no	0	0	yes	263,780	250,591	no	0	0	343,271	no	10.00
Min OA + MERV-13 + UV-C	356,460	92,680	92,680	yes	263,780	229,489	no	0	0	no	0	0	yes	34,291	32,577	354,745	no	10.34
Min OA + MERV-15 + UV-C	356,460	92,680	92,680	no	0	0	yes	263,780	237,402	no	0	0	yes	26,378	25,059	355,141	no	10.35
Min OA + MERV-13 + Portable Air Cleaner	356,460	92,680	92,680	yes	263,780	229,489	no	0	0	no	0	0	no	0	0	322,169	yes	11.99
Min OA + MERV-15 + Portable Air Cleaner	356,460	92,680	92,680	no	0	0	yes	263,780	237,402	no	0	0	no	0	0	330,082	yes	12.22
Practical OA + MERV-13	356,460	106,938	106,938	yes	249,522	217,084	no	0	0	no	0	0	no	0	0	324,022	no	9.44
Practical OA + MERV-15	356,460	106,938	106,938	no	0	0	yes	249,522	224,570	no	0	0	no	0	0	331,508	no	9.66
Practical OA + MERV-16	356,460	106,938	106,938	no	0	0	no	0	0	yes	249,522	237,046	no	0	0	343,984	no	10.02

Effectiveness	
MERV 13	87%
MERV 15	90%
MERV 16	95%
UV-C	95%
Portable Air Cleaner	99.9%
OA	100%

Notes:

- IAQ enhancement opportunities are based upon a targeted 5 ACHe at design airflow. In certain spaces, the original design condition may meet this threshold without additional IAQ enhancement strategies.
- Strategies that meet the target 5 ACHe were cross-referenced with feasibility study results for implementation to select final energy efficient IAQ package(s).
- Filter effectiveness values are from October of 2020.

Disclaimer: The effective air change rate methodology described above is one possible approach to compare the effectiveness of various IAQ enhancement strategies; however, the science on COVID-19 is still developing and research/methodologies for evaluating the comparative benefits of IAQ strategies is subject to change. Additionally, the methodology outlined by the referenced Harvard and University of Colorado, Boulder study is targeted for schools; however, in the absence of sector-specific guidance for commercial or cultural institutions, this equivalent air change rate methodology and the target of 5 ACHe was deemed appropriate for this study. It must be noted that effective air change rate calculations are based on design airflow and do not account for airflow reductions that would naturally occur as a result of low loads in buildings with variable air volume air distribution systems. With this in mind, industry guidance and recommendations should be revisited for the most up-to-date information frequently and building owners should carefully review all assumptions made over the course of this study before implementing IAQ enhancements that differ from the latest ASHRAE guidance.

4.6 Phase 4.1: Energy Analysis

4.6.1 IAQ Enhancement "Packages"

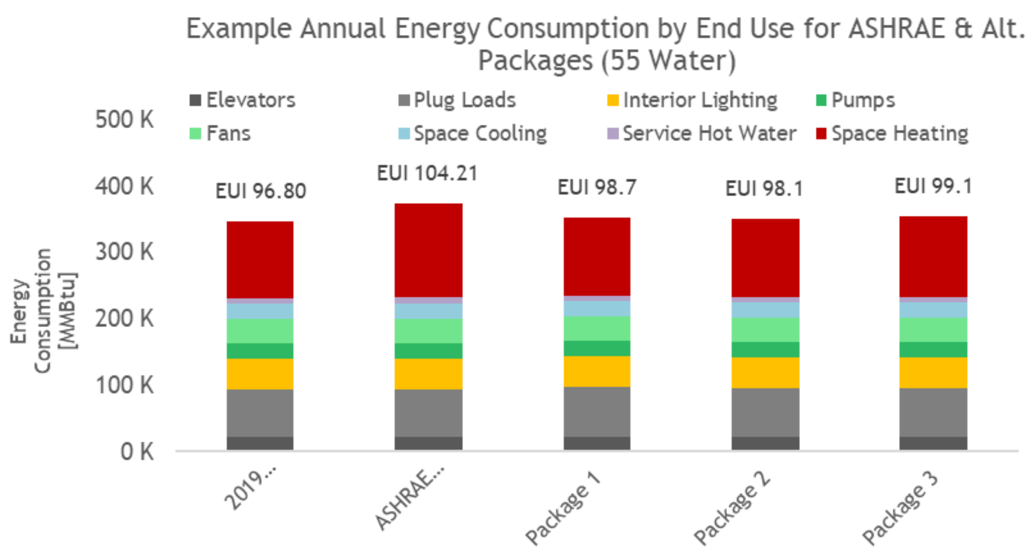
Effective air change rate analysis and the feasibility analysis of various IAQ enhancement strategies were used to select energy efficient IAQ enhancement packages at each building. IAQ enhancement packages "stack" multiple IAQ strategies or technologies with the intent of providing a target of five (5) effective air change rates in each space type while reducing potential energy impacts[2]. Packages that successfully achieved 5 ACHe with less energy, carbon and cost impacts than the ASHRAE recommendations package were recommended to participating properties.

Sample Comparison Between ASHRAE Measures and Energy Efficiency "Packages"

Strategy	ASHRAE Measures	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Filtration	MERV 13	MERV 16	MERV 13	MERV 13	MERV 13
Average OA%	Max OA%	Design OA%	Design OA%	Design OA%	"Practical" OA%
Flushing	2 Hours Before/After Occupancy	3 OACH	3 OACH	3 OACH	3 OACH
UV	--	--	In-Unit	--	--
Portable Filtration	--	--	--	3-6 Additional ACH	--
DCV	Disable	Disable	Disable	Disable	Disable
ERV	Disable	Disable	Disable	Disable	Disable

Core Recommendations

Alternate Packages



Energy impacts of IAQ enhancement strategies were analyzed with either an existing simulation-based energy model calibrated to the building's operations or a spreadsheet-based energy model

[2] Effective air change rate calculations are based upon a methodology from the "Harvard-UC Boulder Portable Air Cleaner Calculator for Schools, v1.3", which was presented during a presentation entitled, "ASHRAE's COVID-19 Mitigation Recommendations for HVAC Systems." COVID-19 & Indoor Air Quality: New Best Practices Webinar Series. Effective air change rate calculations are outlined in Section 4 and can be found in Appendix B. These calculations are based upon design airflow conditions. Calculations specifically related to the UV-C system can be found in Appendix G.

that used the Airborne Infection Risk (AIRC) and Ventilation Increase Impact (VII) Calculator v1.0 (07/2020) calculator as a foundation:

Summary of Modeling Approach Taken for Each Project

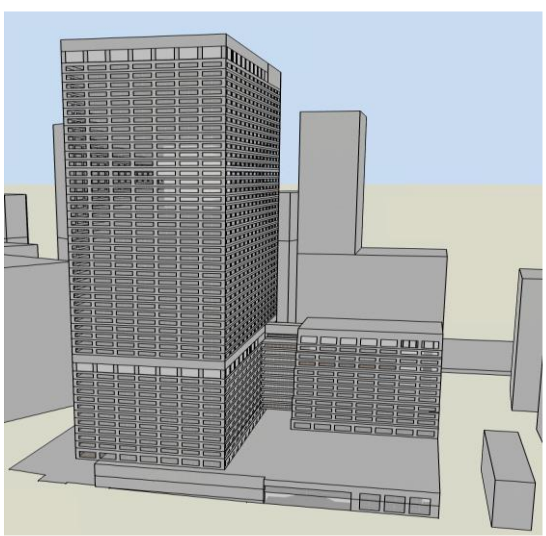
Building	Energy Analysis Method
55 Water Street	Calibrated Simulation-Based Energy Model
345 Park Avenue	Spreadsheet-Based Energy Model
3 Times Square	Calibrated Simulation-Based Energy Model
80 Pine Street	Calibrated Simulation-Based Energy Model
Museum of Modern Art (MoMA)	Spreadsheet-Based Energy Model
Museum of Modern Art Queens (MoMA QNS)	Spreadsheet-Based Energy Model
Horace Mann School (four [4] Buildings)	Spreadsheet-Based Energy Model

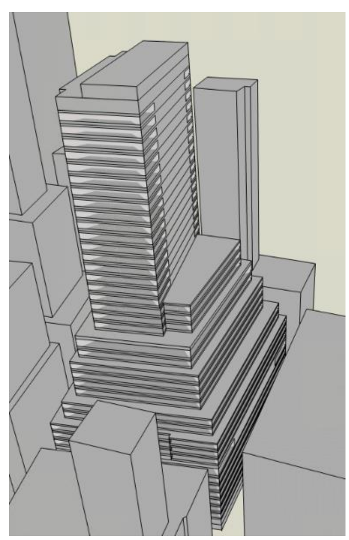
4.6.2 Calibrated Simulation-Based Energy Modeling

Calibrated simulation-based energy models that were developed for participating buildings prior to this study were used where available. Calibrated simulation-based models are able to account for interactive effects and more complex control schemes. Energy models that were developed prior to 2019 were updated to include 2019 pre-COVID utility data.

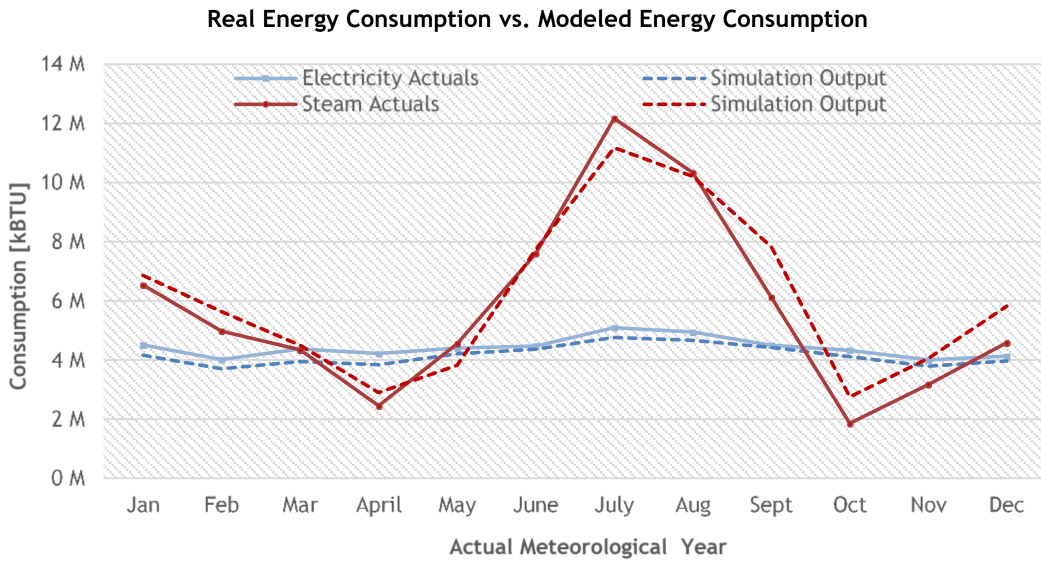
All existing building energy models were developed by JB&B prior to this study using the graphical interface DesignBuilder with EnergyPlus as the calculation and simulation engine, respectively. Building attributes such as floor dimensions, lighting, plug loads, HVAC layouts and detailed schedules were included in the model to reflect the general parameters of the existing building conditions. A sample of an energy model is shown below.

Sample Design Builder Renderings





Sample Design Builder Calibration to Existing Building Data



After the feasibility of different IAQ enhancement strategies were determined at each building, feasible enhancement "packages" were modeled into that building's existing calibrated energy model to evaluate energy, carbon and cost impacts.

4.6.3 Spreadsheet Energy Modeling

Where existing calibrated energy models were not available, the study team developed spreadsheet-based energy models to create a 2019 pre-COVID baseline and evaluate IAQ enhancement strategies. Spreadsheet-based models were created using audit information collected during site visits, 2019 utility data, weather data and operational parameters.

Sample 8,760 Spreadsheet Model

					24% OA, DCV Operation												
Date & Time	Time	Day	OAT	OA RH	OAD	MAT (eq. 40)	dT (eq. 41)	Qs dot (eq. 31)	Qs (eq. 42)	Qs, edited	W_ MA (eq. 37)	dW	QL dot (eq. 33)	QL (eq. 38)	QL, edited	Qtotal	Qtotal - Cooling Capacity (BTU/h)
5/31/20XX 12:00:00 AM	0.00	5	65.9	72.5	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 1:00:00 AM	0.04	5	64.9	73.8	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 2:00:00 AM	0.08	5	64.2	74.8	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 3:00:00 AM	0.13	5	64.2	73.2	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 4:00:00 AM	0.17	5	63	75.7	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 5:00:00 AM	0.21	5	63.1	76.2	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 6:00:00 AM	0.25	5	64.4	73.1	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 7:00:00 AM	0.29	5	65.8	70.7	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 8:00:00 AM	0.33	5	67.5	69.1	0	0	0	0	0	0	0	0	0	0	0	0	0
6/1/20XX 9:00:00 AM	0.38	5	69.4	64.5	0.24	70	14.9712	5,763,403	5,763,403	5,763,403	58	10	2,469,579	2,469,579	2,469,579	8,232,982	8,232,982
6/1/20XX 10:00:00 AM	0.42	5	71.6	60.7	0.24	70	15.0768	5,804,055	5,804,055	5,804,055	58	10	2,532,103	2,532,103	2,532,103	8,336,159	8,336,159
6/1/20XX 11:00:00 AM	0.46	5	74.3	55.9	0.24	71	15.8256	6,092,318	6,092,318	6,092,318	58	11	2,572,058	2,572,058	2,572,058	8,664,376	8,664,376
6/1/20XX 12:00:00 PM	0.50	5	76.7	52.7	0.24	71	16.2864	6,269,710	6,269,710	6,269,710	59	11	2,663,485	2,663,485	2,663,485	8,933,195	8,933,195
6/1/20XX 1:00:00 PM	0.54	5	76.7	51.8	0.24	71	16.2864	6,269,710	6,269,710	6,269,710	59	11	2,590,054	2,590,054	2,590,054	8,859,765	8,859,765
6/1/20XX 2:00:00 PM	0.58	5	76.5	52.5	0.24	71	16.248	6,254,928	6,254,928	6,254,928	59	11	2,618,753	2,618,753	2,618,753	8,873,680	8,873,680
6/1/20XX 3:00:00 PM	0.63	5	75.5	53.8	0.24	71	16.056	6,181,014	6,181,014	6,181,014	58	11	2,580,864	2,580,864	2,580,864	8,761,878	8,761,878
6/1/20XX 4:00:00 PM	0.67	5	75.3	55.1	0.24	71	16.0176	6,166,231	6,166,231	6,166,231	59	11	2,653,774	2,653,774	2,653,774	8,820,005	8,820,005
6/1/20XX 5:00:00 PM	0.71	5	74.4	56.3	0.24	71	15.8448	6,099,709	6,099,709	6,099,709	59	11	2,616,400	2,616,400	2,616,400	8,716,109	8,716,109
6/1/20XX 6:00:00 PM	0.75	5	73.2	59.1	0.24	70	15.1536	5,833,621	5,833,621	5,833,621	59	11	2,649,792	2,649,792	2,649,792	8,483,413	8,483,413
6/1/20XX 7:00:00 PM	0.79	5	71.5	61.3	0.24	70	15.072	5,802,208	5,802,208	5,802,208	58	11	2,558,841	2,558,841	2,558,841	8,361,048	8,361,048
6/1/20XX 8:00:00 PM	0.83	5	70.2	64.5	0	0	0	0	0	0	0	0	0	0	0	0	0

After the feasibility of different IAQ enhancement strategies were determined at each building, feasible enhancement "packages" were modeled into that building's spreadsheet-based energy model to evaluate energy, carbon and cost impacts.

4.7 Phase 4.2: Financial Analysis

Cost estimates were developed for each feasible strategy through discussions with applicable Contractors and equipment manufacturers to develop the implementation cost for each package. Each building's 2019 utility bills were utilized to approximate the energy costs associated with implementing each measure. The ten-year cost of ownership was determined as an appropriate metric for evaluating IAQ enhancement packages, which summed ten years of utility costs against the implantation cost of the package.

4.8 Phase 5: Reporting

Study results were presented to each building's management team through an executive summary and full report detailing the impacts to energy, cost and carbon for each of the feasible strategies.

5 Overall Findings

5.1 Recommended Measures

Participating Building	Outside Air	Filtration	UV-C	Flushing (Before and After Occupancy)	DCV/ERV	Portable Air Cleaners	Energy Savings
MoMA Main	Design	MERV 15 (Existing)	No	3 OACH	Disable	No	89%
MoMA QNS	Design	MERV 15 (Existing)	No	3 OACH	Disable	No	-28%*
3 Times Square	Design	MERV 16 (If desired to increase ACHe)	No	3 OACH	Disable	No	80%
80 Pine Street	Design	MERV 15 (Existing)	No	3 OACH	Disable	Yes (Exterior Offices)	-35%**
345 Park Avenue	Practical (Upper Floor Interior Offices) Design (All Other Spaces)	MERV 16 (Increased from MERV 15 on Upper Floor Interior Offices)	No	3 OACH	Disable	Yes (All Spaces *excluding* Upper Floor Interior Offices)	65%
55 Water Street	Design	MERV 15 (Increased from MERV 13)	Yes (AHUs providing primary air to the North and West of Floors 4-13 and 16-33)	3 OACH	Disable	Yes (Concourse North)	82%
Horace Mann Campus	Design	MERV 16 (Increased from MERV 13 for Science Building AHU)	No	3 OACH	Disable	Yes (Pforzheimer Hall)	84%

*Increase in energy due to additional time required to flush building to three (3) outdoor air changes (2 hours 10 mins).
** Increase in energy due to plug load impacts of portable filtration, which was the only strategy that would bring building to target 5 ACHe.

5.2 Measures Not Recommended

Measure Not Recommended	Location	Reason
2-Hour Pre-/Post-Occupancy Flush	All Participating Buildings	In all locations, flushing to 3 OACH required less time, energy, carbon and cost than flushing for 2 full hours.
Increasing Outside Air % (Max)	All Participating Buildings	High-efficiency filtration + design OA values had comparable ACHe, but with much less energy, carbon and cost impact.
Increasing Outside Air % (Practical)	MoMa Main, MoMA QNS, 3 Times Square, 80 Pine, 55 Water Street, Horace Mann	Listed buildings were able to achieve the target 5 ACHe without increasing OA% above design values.
Increasing Filter Efficiency to MERV 16	MoMA Main, MoMA QNS, 3 Times Square, 345 Park Avenue (in Interior Offices Only)	Listed buildings/spaces were able to achieve the target 5 ACHe with existing filtration in combination with other strategies.
UV-C (In-Unit or Duct-Mounted)	MoMA Main, MoMA QNS, 3 Times Square	Listed buildings were either unable to feasibly install UV-C or there were more energy, carbon and cost-efficient strategies to achieve the target 5 ACHe.
Upper-Room UV	All Participating Properties	In all locations, widespread use of upper-room UV was not feasible due to concerns with finishes, occupant exposure and ceiling-mounted equipment.
Portable Filtration Units	MoMa Main, MoMA QNS, 3 Times Square, 55 Water (Outside of Concourse North), Horace Mann (Outside of Science Building), 345 Park Avenue (Outside of Interior Offices Only)	Listed buildings/spaces were able to achieve the target 5 ACHe with other more energy, carbon and cost-efficient strategies.

5.3 Conclusions from Recommended Measures

- High-efficiency filters (MERV 13 and above) in combination with design OA % is more energy, carbon and cost-efficient than increasing OA% to maximum values year-round. The effectiveness of each strategy is comparable.
- Flushing to 3 OACH is a more energy-efficient approach than a forced 2-hour pre-/post-occupancy flush.
- DCV should be disabled until vaccination rates rise. The time lag between a rise in occupancy and an increase in delivered air may allow concentrations of harmful airborne particles to increase to an unfavorable level.
- Portable air cleaners are an effective strategy for specific spaces that have limited options to increase ACHe. Deployment should be targeted to avoid significant increases to building plug loads.
- In-unit UV-C can be an effective strategy for buildings that have additional space within units or straight runs of return duct at least five (5) feet in length, allowing for the required minimum air velocity (approx. 500 fpm) and exposure time needed to deactivate virus. A high dosage of UV-C is required to inactivate airborne virus particles as they pass through the irradiated zone of ductwork or air handlers, due to limited exposure time. To be effective at deactivating COVID-19, UV-C technology requires an emitter intensity that will achieve a minimum dosage of 1,300 microJ/cm2 at “end of life”.

5.4 Conclusions from Measures Not Recommended

- Increasing OA% year-round has significant energy, carbon and cost impacts. Where possible, alternate strategies should be considered.
- In-unit UV-C can be challenging and expensive to implement and does not significantly increase ACHe compared to alternatives. Where possible, buildings should consider increasing their filter efficiency before considering UV-C.
- Wide use of upper-room UV is not feasible due to concerns with finishes, occupant exposure and ceiling-mounted equipment.

5.5 Key Commonalities/Differences in Measure Recommendations

5.5.1 Commonalities

- LL97-compliance and annual cost concerns for ASHRAE core recommendations were consistent across all project locations.
- Upfront capital costs for ASHRAE core recommendations were typically low, but the 10-year cost of ownership was substantial.
- Guidance on how to compare effectiveness or safety of combined IAQ strategies was minimal at project onset.
- Most sites were able to achieve the target 5 ACHe with design OA% in combination with other measures such as improved filter efficiency or targeted deployment of portable filtration units.
- Most project sites already had MERV 13 or higher filtration.
- Buildings with perimeter induction units required additional strategies to meet 5 ACHe in perimeter zones. While perimeter induction units often have 100% OA primary supply, a large portion of delivered air is induced from the occupied zone.
- Portable filtration units were found to be feasible at all project sites but were generally not recommended for large-scale deployment due to cost and energy impact.
- Upper-room UV was found to be infeasible at all project sites.

5.5.2 Differences

- Increasing OA% in MoMA Main and MoMA QNS was not recommended as a result of feasibility constraints associated with duct size and upstream pre-treatment units. Increased

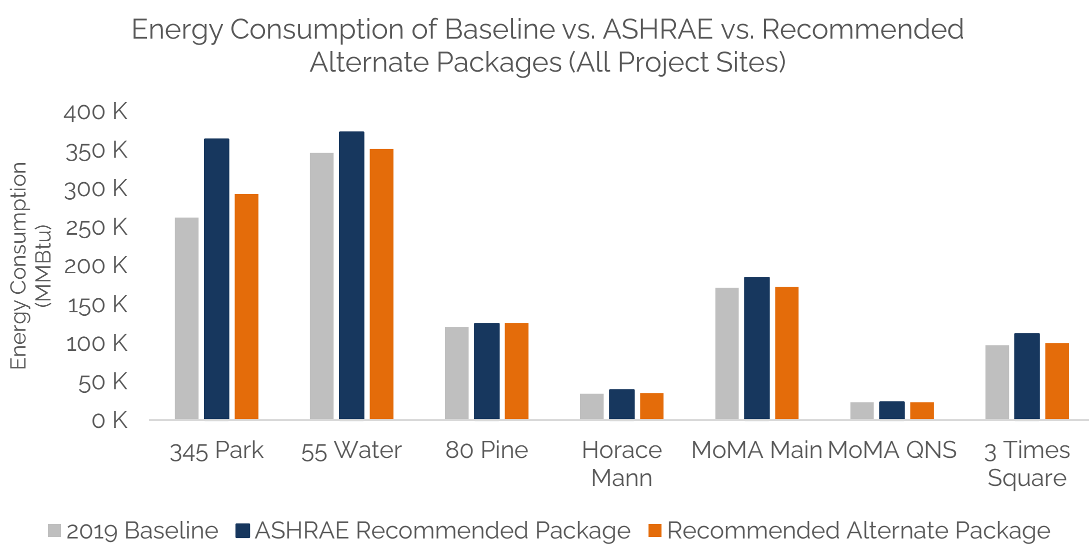
OA% was not recommended in most other sites due to energy, carbon and cost impacts instead of feasibility.

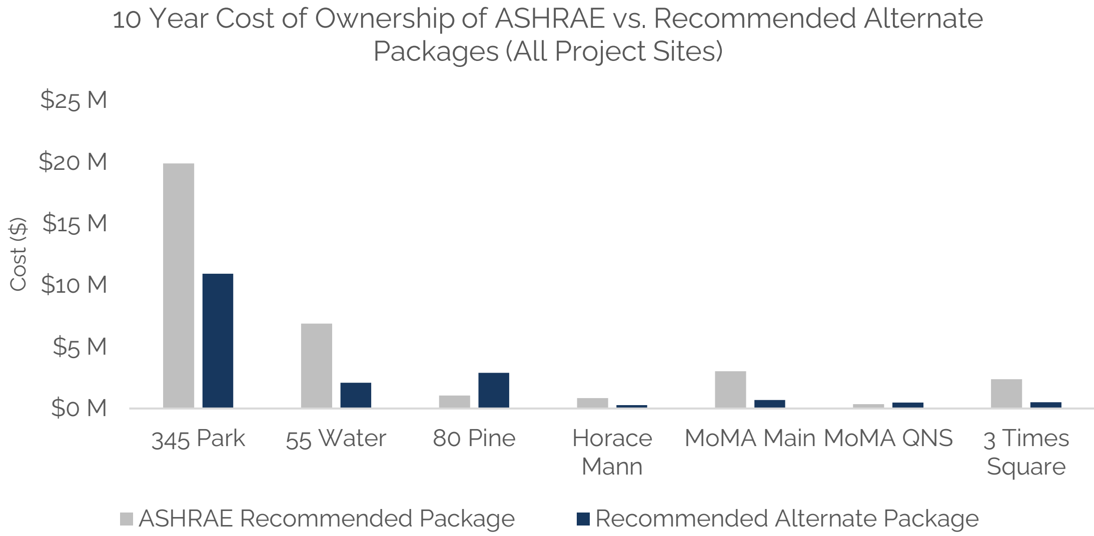
- While most sites were able to achieve the target 5 ACHe with design OA% in combination with other measures, the specific alternate strategies were unique to each building.

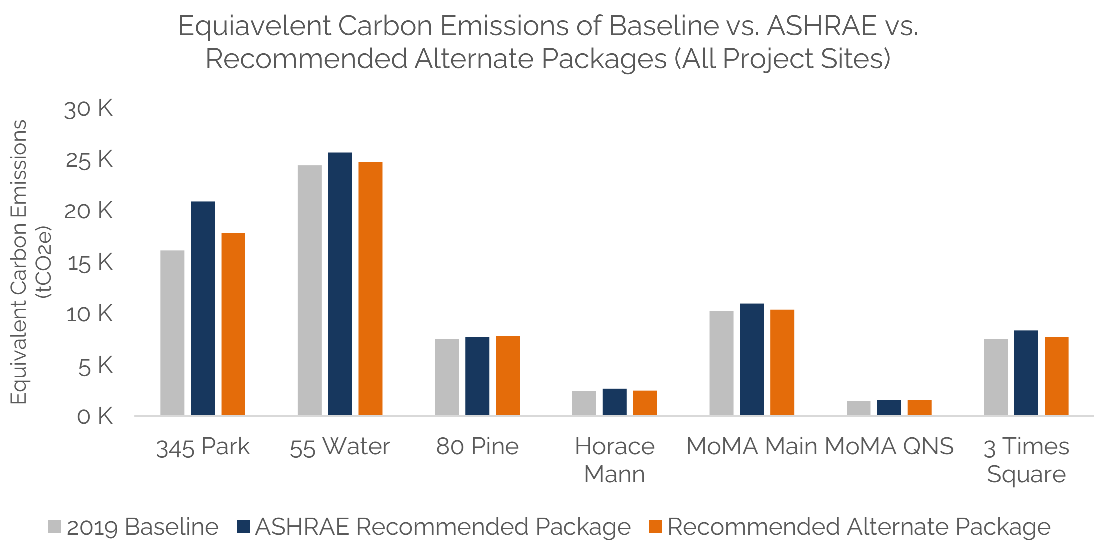
5.6 Key Commonalities/Differences in Energy Impacts of Measure Recommendations

- ASHRAE recommendations (including increasing OA% to the maximum feasible amount) resulted in substantial energy, carbon and cost impacts at all facilities.
  - Increasing in OA% and pre-/post-flushing was the primary driver of energy, cost and carbon increases.
  - Heating was the largest end-use impacted by the core ASHRAE recommendations.
- Only two (2) buildings were projected to have more energy, carbon and cost impact by pursuing an Alternate Package of measures (MoMA QNS and 80 Pine Street) instead of the ASHRAE recommendations package.
- Facilities with larger coil capacities or free-cooling capabilities had higher energy, cost and carbon impacts if OA% increases are pursued (55 Water and 345 Park Avenue).
- Facilities that used steam for cooling were projected to have increased energy, carbon and cost impacts (345 Park Avenue).
- The quantity of required portable filtration units to achieve 5 ACHe across an entire facility was found to be too costly and too energy-intensive. A targeted approach to deployment of these units in high-occupancy areas, including Conference Rooms, was found to be more feasible.
  - Plug loads were the end-use most impacted by portable filtration.

5.7 Result Visualizations







6 Overarching Takeaways

6.1 Conclusive Items and Lessons Learned

- Improving IAQ and maintaining energy and carbon reductions goals do not have to be mutually exclusive.
- While increasing outside air above minimum design requirements is an effective strategy for improving IAQ, alternate combined strategies, such as maintaining design OA with increasing filter efficiency, can lessen energy, cost and carbon impacts.
- A common metric to compare the effectiveness/safety of combined IAQ enhancements is a valuable tool for decision-making, but more guidance from industry and health organizations is needed:
  - What is an appropriate effective air change rate to target in each building typology?
  - When should that target rate be met? i.e., in the design condition, in typical operating conditions year-round? etc.

- A data-driven approach to improving IAQ with real-time monitoring should be considered when developing an IAQ improvement strategy. Monitoring sensors can provide transparency to Tenants and enable early action by building operation teams.
- Occupant perception is critical to successful implementation of IAQ enhancement measures. Strategies that result in an acceptable effective air change rate may not be successful if occupants do not *feel* safe once that strategy is in place.
- Each facility is different and an evaluation of feasible IAQ enhancements should be conducted by a professional to determine the most energy-efficient and effective strategy.

6.2 Best Practices by Sector

6.2.1 Commercial Offices

Lessons Learned from 55 Water Street, 345 Park Avenue, 3 Times Square and 80 Pine Street

- Offices should consider increasing filter efficiency above MERV 13 as a first step. Commercial office buildings typically already have a filter maintenance/replacement protocol in place. If existing air handling units can accommodate higher efficiency filtration, buildings can improve IAQ with minor impacts to operations and budgets.
- Offices served by perimeter induction units should verify adequate IAQ at perimeter zones. While some induction unit systems use 100% outside air as primary air, the % breakdown of primary air to induced space air may result in low effective air change rates in perimeter zones.
- Good filter and coil maintenance is critical to improved IAQ and can reduce energy, carbon and cost impacts. Operations teams should also inspect gaskets and sealing within air handling equipment to ensure air is not escaping from unwanted areas.
- If UV-C is pursued, building operations staff should understand the bulb intensity, maintenance and 24/7 operational requirements of the equipment. This may lead to additional maintenance and operational costs.
- Spaces with high occupant density may benefit from increases in ACHe through implementing portable air cleaners or utilizing other localized IAQ improvement methodologies.

6.2.2 Art Museums

Lessons Learned from MoMA Main and MoMA QNS

- High-efficiency filtration is already typically installed for art preservation purposes. As a result, art museums are well positioned for good IAQ and higher effective air change rates.
- Tight temperature and humidity control is typical for art preservation purposes. These requirements are aligned with the desired humidity ranges for virus mitigation.
- HVAC infrastructure designed to meet strict temperature and humidity requirements for art preservation may not have enough heating and cooling capacity to appropriately treat additional outside air (above design criteria).
- Portable air cleaners are not feasible in galleries and other public spaces due to aesthetic or noise-related concerns.

6.2.3 K-12 Schools

Lessons Learned from Horace Mann School

- Lower-efficiency filtration (MERV 8) is more common in K-12 schools. Increasing filter efficiency to a minimum of MERV 13 should be considered as a first step.
- Deploying portable air cleaners is an easy-to-implement, cost-efficient and non-disruptive strategy within Classrooms.
- Parent perception of portable air cleaners in individual Classrooms was overall positive.

7 Accuracy of Results

We have endeavored to closely approximate the projected energy use of each participating building as well as the energy impacts associated with individual IAQ enhancements and interactive IAQ enhancement packages; however, there will be variances based on atypical weather, changes in occupancy, changes in building operation or changes in energy rates that will affect the results.

8 Bibliography

The bibliography for this study is included below.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 55-2013: *Thermal Environmental Condition for Human Occupancy*. New York: The Society, 2013.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 62.1-2019: *Ventilation for Acceptable Indoor Air Quality*. New York: The Society, 2019.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 90.1-2016: *Energy Standard for Buildings Except Low-Rise Residential Buildings*. New York: The Society, 2018.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 211-2018: *Standard for Commercial Building Energy Audits*. New York: The Society, 2018.

ASHRAE, "Building Readiness" *ASHRAE Website,* https://www.ashrae.org/technical-resources/building-readiness#increasedvent

Azimi P, Stephens B. HVAC filtration for controlling infectious airborne disease transmission in indoor environments: Predicting risk reductions and operational costs. *Build Environ*. 2013;70:150-160. doi:10.1016/j.buildenv.2013.08.025

Bahnfleth, William. "ASHRAE's COVID-19 Mitigation Recommendations for HVAC Systems." COVID-19 & Indoor Air Quality: New Best Practices Webinar Series. enverid.com/watch-dr-william-bahnfleth-ashraes-covid-19-mitigation-recommendations-for-hvac-systems/.

"Air Filtration Standards." Association of Home Appliance Manufacturers, ahamverifide.org/ahams-air-filtration-standards/.

"Building Technologies Program: Demand Control Ventilation." *Department of Energy Building Energy Codes Program*, Department of Energy, Aug. 2012, www.energycodes.gov/sites/default/files/documents/cn_demand_control_ventilation.pdf.

"Coronavirus Disease (COVID-19): Ventilation and Air Conditioning in Public Spaces and Buildings." World Health Organization, 29 July 2020, www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-ventilation-and-air-conditioning-in-public-spaces-and-buildings.

"Guide to Air Cleaners in the Home." United States Environmental Protection Agency, 2018.

"Ventilation in Buildings." Center for Disease Control and Prevention, 21 Dec. 2020, www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html.

"Ventilation Increase Impacts (VII) Calculator." *Cunybpl.org*, 1.0, CUNY BPL and NYC Department of Citywide Administrative Services Energy Management Load Management, www.cunybpl.org/resources/ventilation-increase-impacts-calculator/.

Zaatari, Marwa. "New Methods for Modeling COVID Mitigation Approaches." COVID-19 & Indoor Air Quality: New Best Practices Webinar Series. https://enverid.com/awards/webinar-new-methods-for-modeling-covid-mitigation-approaches-with-dr-marwa-zaatari-p-e/

r:\projects\26782.r.001-iaq mini bid\wp\reports\2021-08-11_nyserda iaq study conclusion report_draft_mhd-dp.docx