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Preliminary Findings Report No. 4

NYSERDA Energy Efficient Indoor Air Quality Analysis

October 26th, 2020

Note: All *italicized* text is duplicate content from prior reports, repeated for reference

Executive Summary

Syska has been engaged by NYSERDA to evaluate the engineering feasibility, energy usage and operational cost impact of making indoor air quality (IAQ) improvements to existing buildings and spaces. The overall effort is split across two separate studies: a commercial office tenant in Manhattan and a commercial office building operator/occupier in Westchester. The studies focus on assessing COVID-mitigating improvements to building systems and operations that also incorporate energy efficiency without sacrificing safety or indoor air quality.

Existing Conditions

Below is a summary of the existing building characteristics and building systems for each project.

Study 1 – *Manhattan Commercial Office Tenant*			
Number of Floors	*6*	*Peak Occupants (pre-COVID)*	*800*
Project Gross Floor Area	*186,000 Square Feet*	*Typical Operating Hours*	*8am through 8pm*
Location	*Midtown Manhattan*	*Current Occupancy %*	*2%*
Heating System(s)	*The tenant's floors are heated by a perimeter fin-tube radiator system outfitted with new control valves supplied by the landlord. Hot water is supplied by the landlord's boilers and routed through risers located at the perimeter columns.*		
Cooling System(s)	*The tenant's floors are cooled using base building supply air from two main air risers located at the buildings core. Cooling air is supplied to these floors from two variable volume AHUs. These AHUs with VFDs each provide approximately 67,000 CFM and are the main source of cooling for half the building. Chilled water is produced by 3 Chillers located in the basement totalling approximately 2,700 Tons. This chilled water is split between the AHUs that serve the lower levels and upper floor AHUs.*		
Ventilation System(s)	*Ventilation air is introduced via the main AHUs providing supply air to the tenant floors. The actual amount of outside air varies depending on outside conditions, but the landlord estimates the OA rate to be approximately 4,500 CFM per floor.*		
Domestic Hot Water System(s)	*DHW is provided by the landlord to the main core restrooms. Additional DHW for the pantries and additional tenant restrooms is provided by the tenant under-counter instantaneous water heaters and above ceiling storage type water heaters.*		
Building Management System / HVAC Controls	*All landlord and tenant equipment is connected to the base building BMS which is a Reliable Controls system and maintained by the landlord's automated controls contractor. Each tenant has visibility to the BMS for their HVAC terminal unit setpoints, leak detectors, CRAC/AC unit failures, etc*		

Study 2 – Westchester Commercial Office Facility			
Number of Floors	*3 & Parking Garage*	*Peak Occupants (pre-COVID)*	*2,828*
Project Gross Floor Area	*627,000 Square Feet*	*Typical Operating Hours*	*5am – 6pm Mon-Fri*
Location	*Westchester*	*Current Occupancy %*	*10*
Heating System(s)	*The site is heated by (3) 300 HP boilers which provide steam and hot water to heating and reheat coils in the central air handling units and VAV/FPBs throughout the office spaces. The perimeter is heated with supplemental constant volume fans and steam coils.*		
Cooling System(s)	*The site is cooled via water-cooled chiller plant, with (3) 800-ton cooling towers and a total 2,100 tons of chiller capacity. The chiller plant provides chilled water to the cooling coils of all air handing units. The perimeter is cooled as needed with supplemental constant volume fans and chilled water coils.*		
Ventilation System(s)	*Supply and ventilation air to the occupied areas is provided by large central air handlers, some variable volume some constant volume.*		
Domestic Hot Water System(s)	*DHW is generated via heat exchangers on the steam supply from the space heating boilers which is stored in a domestic hot water tank which then supply the plumbing fixtures.*		
Building Management System / HVAC Controls	*The ventilating and air handling units are controlled via a central BMS which monitors status of all fans and coils as well as other setpoints, including OA damper open %, fan power, supply pressure and supply and return air temperatures.*		

Progress Summary

Study 1 – Commercial Office Tenant – 186,000 GSF (Manhattan, NY)		Study 2 – Large Commercial Office Facility – 627,000 GSF (Westchester, NY)	
Current Project Stage:	*Data Collection and Site Surveys*	Current Project Stage:	*Data Collection and Site Surveys*
	IAQ Measure Feasibility Analysis		*IAQ Measure Feasibility Analysis*
	Energy and Cost Impact Analysis		*Energy and Cost Impact Analysis*
	Draft IAQ and Energy Study Report		*Draft IAQ and Energy Study Report*
	Final IAQ and Energy Study Report		*Final IAQ and Energy Study Report*
	Overarching IAQ Report and Key Findings Slides		*Overarching IAQ Report and Key Findings Slides*

- Currently waiting for technical information from the manufacture to continue review of IAQ sensors to be installed for permanent monitoring.
- IAQ sensors are also being assessed for a control strategy to reduce energy usage (e.g. only turn on conference room air cleaning equipment if CO2 is above a certain ppm threshold)
- Received answers to our follow up questions sent to base building engineers regarding filtration OA and COVID measures to survey and report back, in lieu of surveying base building mechanical rooms and air handlers directly
- Preliminary energy calculations for IAQ improvement measures deemed feasible from an engineering perspective (see August Report) are complete.
- Assessed that ASHRAE-approved contamination calculation tools can provide actionable data. Calculations have been performed for a typical floor (42nd) comparing the airborne concentration, airborne exposure, and surface loading. See the *FaTIMA Reports* section in the **Appendix** for further information.

- Created and calibrated a schematic-level energy model of the whole facility to evaluate energy and utility cost impacts of IAQ measures.
- Ran 9 combinations of MERV ratings and OA% for air handlers in the whole building energy model to measure energy and cooling and heating impacts
- Performed research and calculations on the UV-C dosage required to inactivate up to 99% of SARS-CoV-2 virus and whether the dosage was feasible to achieve for an in-duct or at the coil application.
- Assessed that ASHRAE-approved contamination calculation tools can provide actionable data. Calculations have been performed for a typical AHU zone comparing the airborne concentration, airborne exposure, and surface loading under difference MERV and % OA scenarios. See the *FaTIMA Reports* section in the **Appendix** for further information.

New Findings to Date

Study 1 – Manhattan Commercial Office Tenant

- Adding in-zone local air scrubbers equipped with MERV 15 filters and UVC-emitting light fixtures to fully serve the open office and conference room areas increased the energy usage by **11%** while reducing the average number of contaminant particles occupants were exposed to by **14%**.
- The UV-C energy output standard UVGI fixtures installed within the duct or at the filter/coil is too small give the air speed to achieve enough dosage to strongly impact aerosolized SARS-CoV-2 in the air stream after a single pass, therefore UVGI systems in ductwork are only recommended for surface/fomite applications, such as filter and coil disinfection
  - Based on 500/300 FPM air speeds in the duct and at the filter, typical commercial HVAC UV-C fixture output (0.01 mW/cm^2 per linear inch of lamp) and an average of estimates of UV-C dosages required to inactivate SARS-CoV-2 (38 mWs/cm^2), it was found that 7-10 seconds of exposure would be needed to inactivate 99% of the SARS-CoV-2 virus while the supply air would only have 0.02-0.05 seconds of exposure on a single pass.
  - This will be investigated further once additional information is received from the manufacturer

Study 2 – Westchester Commercial Office Facility

- Utilizing a MERV 16 filter with 50% Outside Air in the Supply Air is comparable in IAQ performance to the ASHRAE baseline scenario of MERV 13 filtration with 80% Outside Air (full open OA dampers) while resulting in **11%** less energy increase and **6%** less utility costs increase.
- The ASHRAE baseline scenario of running central air systems with MERV 13 filtration with 80% Outside Air (full open OA dampers for this site) resulted in a **15.63%** increase in energy usage and a **9.3%** increase in energy cost.
- For the New York Climate, the increase in annual heating energy usage is significantly greater than the increase in annual cooling energy usage when increased the amount of outside air delivered by ventilation systems (**~51%** increase in heating vs a **~10%** increase in cooling when moving from 30% OA to 80% OA in the supply air).
  - This is due to the largest temperature difference between outside air and the supply air temperature in the winter months as compared to the summer months (76.5°F heating ΔT vs 31.4 °F cooling ΔT for Westchester)
- Little to no energy savings will be achieved by application of UVGI systems for well-maintained commercial AHUs with clean cooling/heating coils.

FaTIMA Study Overview

FaTIMA (Fate and Transport of Indoor Microbiological Aerosols) is a web based calculator, provided by National Institute of Standards and Technology (NIST), that determines the effectiveness of mechanical systems in reducing concentrations of airborne contaminants and potential exposure to occupants by simulating particle movements through the air over a set time period, up to 24 hours. The program analyses an enclosed zone and the system level filtration system as well as any room level filtration to determine the number of particulates that were filtered by each system, the amount of particles were deposited on surfaces, the amount of particles that were displaced outside of the zone due to dilution (from adding outside air) and the amount that remains airborne in the space.
The tool does not take into account any impact that UVGI has on inactivating the virus and it assumes a generic contaminant "particle" of a particular size, and does not model any specific bacteria or virus, such as influenza, or SARS-CoV-2.

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This tool was utilized to measure the relative impact of local in-room air cleaners, and various combinations of MERV filtration and percentages of outside air in the supply air stream on airborne contaminants and to determine IAQ performance equivalencies between different mechanical system set ups. To ensure all scenarios provided an equitable IAQ performance comparison, the assumptions regarding the generation rate and size range of contaminant particles were the same in every modeled scenario: 200,000 contaminant particles generated per minute, continuously during occupied hours (to simulate a sick person being present in the space) and 0.3 µm to 1.0 µm particle diameters (to take into account the min and max size ranges of the particles that the SARS-CoV-2 virus is estimated to attach to when aerosolized).

Study 1 – Manhattan Commercial Office Tenant – Energy Calculations Summary

Energy calculations have been performed using a typical unit for power use calculations. The unit includes a fan and MERV filter in addition to an optional UV light. Calculations were performed showing the power consumption for units with and without the UV light option. Total number of units were calculated by generating a hypothetical layout based off area and space type. Units were placed with the following conditions. See the FaTIMA Reports section in the **Appendix** for more information.

- One (1) unit per 1,000 square feet of open office, lobby, and lounge spaces
- One (1) unit per conference or meeting room

Floor	35th	36th	38th	42nd	43rd	44th	Total
# of Units	12	12	12	12	13	21	82

The below table demonstrates the total and relative annual energy and cost impacts of running all of the local air ceiling-mounted cleaners across all floors. 3 separate scenarios were investigated:

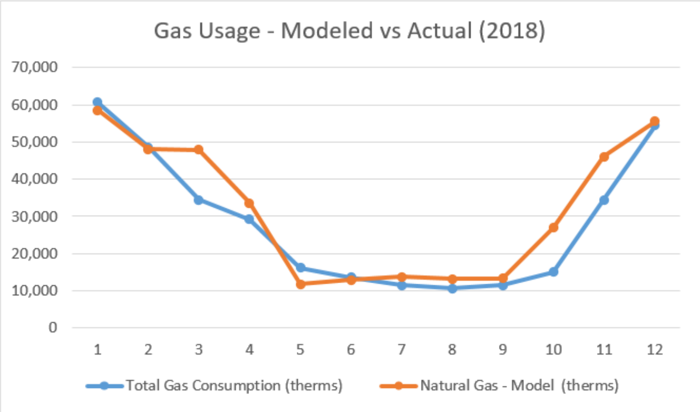
- all units on high (500 CFM) 24/7/365,
- All units on high (500 CFM) and scheduled based on office operating hours
- Units located in the open office areas are on high (500 CFM) and scheduled based on office operating hours, units located in conference rooms will be scheduled and on low (200 CFM) unless the space is occupied, then the units turn onto the highest setting (500 CFM). The this will be triggered by either a CO2 or an occupancy sensor.

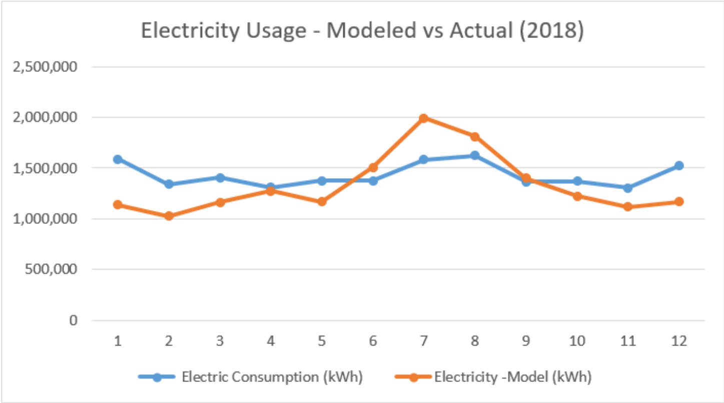
	Study 1- Manhattan Commercial Office Tenant					
	With UV			Without UV		
	kwh	% Elec. Increase	% Total Cost Increase	kWh	% Elec. Increase	% Total cost Increase
On 24/7/365	278,708.16	19%	12%	267,933.36	19%	12%
Scheduled	157,171.04	11%	7%	151,094.84	10%	7%
Scheduled with Occupancy Controls	143,193.31	10%	6%	111,478.51	8%	5%

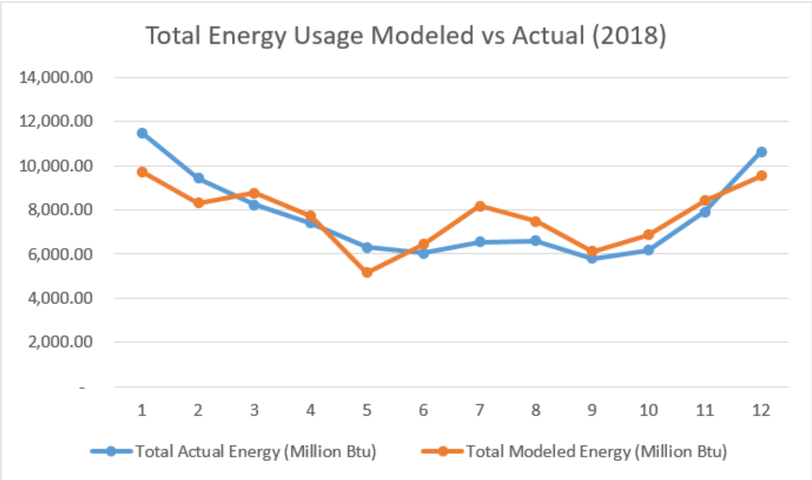
Study 2 – Westchester Commercial Office Facility – Energy Calculations Summary

A schematic-level energy model was developed of the entire building in Study 2 using the IES VE energy modeling software and then calibrated to the existing 2018 energy baseline in order to simulate ASHRAE-recommended and other IAQ improvement scenarios and provide their order-of-magnitude energy impacts. Below are charts comparing the simulated energy usage of the "baseline" scenario with MREV 8 filters and 30% outside air. The annual modeled natural gas usage was 12% higher than actual, the annual electricity usage was 7% lower than actual and the total annual modeled energy usage was only 0.1% higher than the actual utility bills.

It's important to note that this facility has a relatively constant electrical load year round due to having a higher plug load than average from IT equipment in the financial offices, a trading floor and other equipment in a gym and amenity spaces.







The outside air dampers for the AHUs in the building provide 30% OA at a minimum and provide 80% OA at full-open. Nine scenarios were modeled with varying combinations of Outside Air percentages of the subtotal supply and MERV Ratings on the filters of the main AHUs providing ventilation air and serving the VAVs. All 9 scenarios were also studied for a single AHU zone in the FaTIMA software to determine their relative IAQ performance in filtering and diluting airborne contaminants in 0.3 – 1 micron size range (representative of the range of particles SARS-CoV-2 can be found in/on). Please see the Appendix for more information on the FaTIMA calculation. The MERV 13 at 80% OA represents the ASHRAE recommendations scenario based on the minimum MERV rating recommended and to open OA dampers as much as possible. For all 9 scenarios the chilled water/steam AHU systems were operating to maintain comfortable indoor conditions (70-75 F 50% RH) in all conditioned spaces. For the purposes of the analysis it was assumed the filters would only be changed twice a year in each scenario.

The combined results of the contaminant and energy analysis are summarized in the table below. It was found that operating the systems with MERV 16 filters at 30-50% outside air achieved similar IAQ improvement performance as the ASHRAE recommendations scenario of MERV 13 at 80% outside air, but with significantly lowered energy penalty. This is due to the increased fan energy from the added pressure drop of MERV 16 filters being much less than the added energy of pre-heating and pre-cooling additional outside air year-round.

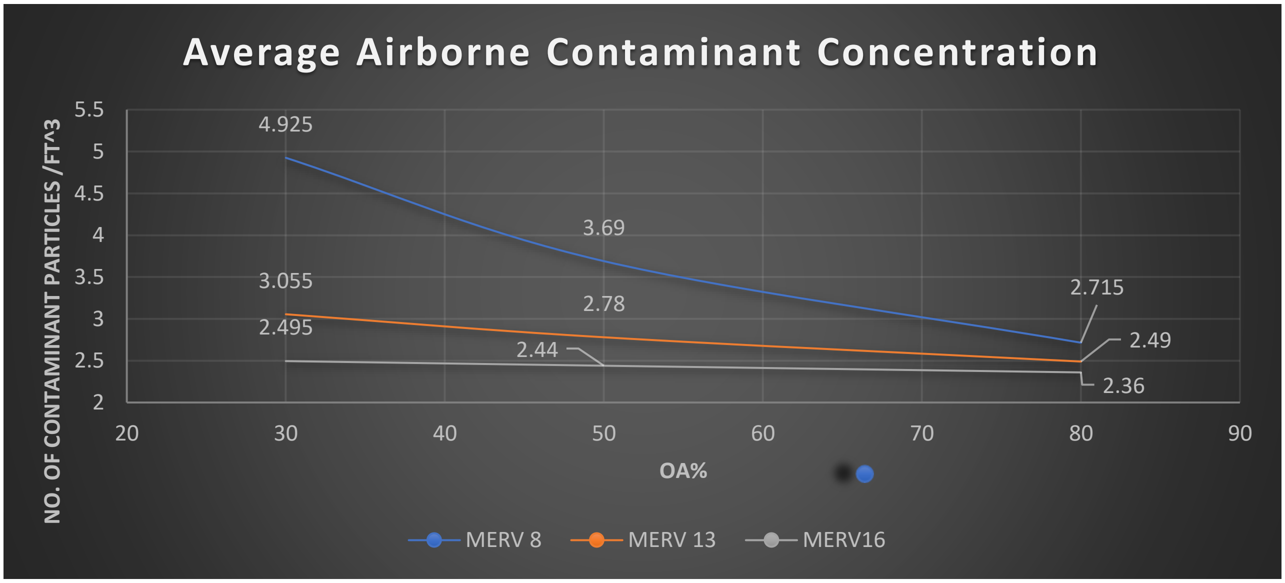
Because this facility has a higher than average plug load for a typical office building, the constant electrical load is unaffected by increases in outside air or MERV filtration, and thus the relative percentage increases in energy and cost are lower than they would be for a more typical office space. For standard offices without high IT load from financial occupancies or trading floors will likely see a higher % increase in energy cost and usage from increasing the outside air % in the supply air.

	Study 2 – Westchester Commercial Office Facility			
	OA% of Total Supply Air	30%	50%	80%
MERV 8	% Reduction in Average Airborne Particle Concentration		25.1%	44.9%
	% Increase in Total Energy Usage		3.4%	15.0%
	% Increase in Total Energy Cost		2.6%	8.8%
MERV 13	% Reduction in Average Airborne Particle Concentration	38.0%	43.6%	**49.4%**
	% Increase in Total Energy Usage	0.4%	3.7%	15.3%
	% Increase in Total Energy Cost	0.6%	3.1%	9.3%
MERV 16	% Reduction in Average Airborne Particle Concentration	**49.3%**	**50.5%**	52.1%
	% Increase in Total Energy Usage	0.6%	3.9%	15.4%
	% Increase in Total Energy Cost	0.8%	3.3%	9.5%

The below table summarizes the increase in annual space heating and space cooling energy (cooling tower energy included) for all 9 scenarios. The increase in heating energy is significantly larger than cooling due to Westchester, and New York in general, currently being a heating-dominated climate and the difference in template between the outside air and supply air is much greater in the winter than it is in the summer (76.5°F heating ΔT vs 31.4 °F cooling ΔT for Westchester). The small increase in cooling energy and decrease in heat energy as the MERV rating of the filters is increased is due to the minor amount of added heat to the air stream from the AHU supply fans working at a higher power to overcome the additional pressure drop.

	Study 2 – Westchester Commercial Office Facility			
	OA% of Total Supply Air	30%	50%	80%
MERV 8	% Increase in Heating Energy Usage (Gas)		9.5%	51.4%
	% Increase in Cooling Energy Usage (Electricity)		4.6%	9.1%
MERV 13	% Increase in Heating Energy Usage (Gas)	-0.1%	9.2%	50.9%
	% Increase in Cooling Energy Usage (Electricity)	1.1%	5.3%	9.7%
MERV 16	% Increase in Heating Energy Usage (Gas)	-0.2%	9.0%	50.5%
	% Increase in Cooling Energy Usage (Electricity)	1.3%	5.6%	9.9%

The below graph shows the results for the FaTIMA analysis alone, in units of average airborne concentration of contaminant particles 0.3-1 micron, per unit of space volume. The chart shows that effect of MERV rating on the amount of particles filtered is diminished as the volume of outside air in the supply air stream is increased (the dilution effect overpowers the filtration effect at high percentages of outside air). The results also demonstrate that as MERV rating increased, the effect of adding additional outside air on reducing the amount of airborne contaminants greatly diminishes.



Barriers Encountered

Study 1 – Manhattan Commercial Office Tenant	Study 2 – Westchester Commercial Office Facility

- There is little research of the effects of UV-C on SARS-CoV-2 specifically, and of the few studies performed on the actual virus, the majority study the virus in a liquid, on masks or on a surface. There is a large variance in the reported dosage of UV-C to inactivate 99% of the virus and a large variance in the initial concentration of the virus utilized.
  - Why is this a barrier?

    There is currently no standard, evidence based, dosage of UV-C required that can be assumed when designing and installing UVGI systems specifically to combat SARS-CoV-2.
  - Resolution/workaround

    For longer term projects, wait for additional research and formal recommendations from ASHRAE, IES and other industry bodies regarding the specific dosage for SARS-CoV-2. For short term projects, assume the worst-case scenario (highest dosage found required to inactivate 99% of the virus, about ~100-300 mJ/cm^2) or follow the radiant power recommendations of IES for room air decontamination – 17 mW /m^{3}.

Lessons Learned

Study 1 – Manhattan Commercial Office Tenant	Study 2 – Westchester Commercial Office Facility

- It is important to note the air velocity in FPM at which a specific MERV air filter tested at when looking to achieve a particular MERV rating in a system. ASHRAE Standard 52.2 allows for MERV filters to be tested and rated over a range of air velocities and typically manufacturers only select one of these speeds. If the actual design air velocity for a system is significantly higher than the test velocity at which a MERV filter was rated, then the effectiveness of that filter drops and the MERV value is effectively derated at the increased velocity. For example, a 24"x24" filter rated to achieve MERV 11 performance at 300 FPM, would be equivalent to a MERV 8 filter at 500 FPM. For this reason, filter cutsheets will often indicate a maximum air speed in FPM and it is important that the design airspeed achieved at the filters in air handlers not greatly exceed the rated speed.

Proposed Work Plan Adjustments

Study 1 – Manhattan Commercial Office Tenant	Study 2 – Westchester Commercial Office Facility

- No new adjustments to work plan

Next Steps

Study 1 – Manhattan Commercial Office Tenant	Study 2 – Westchester Commercial Office Facility
• Review all calculations and begin Final Draft Report • Investigate method to estimate % SARS-CoV-2 after a single pass under a UV-C based UVGI system in ductworks. • Anticipated final IAQ report submission date: 11/27/20	• Complete energy calculations for all calculations and begin Final Draft Report. Additional calculations to include: ○ Flushout vs 2 hrs before/after vs 3 Air Changes ○ Additional verification and development of UVGI calculations (consider volumetric radiation and energy impacts) ○ Fan energy vs pressure drop for MERV 8/13/16 ○ Higher RH setpoint as an energy saving IAQ strategy ○ Inclusion of HEPA filtration in calculations ○ Inclusion of IAQ and energy effects of in-room UVC equipped air cleaners for open offices, private offices, and conference rooms ○ Investigation of reduced occupancy (with reduced over-ventilation to match) as an energy saving IAQ strategy • Anticipated final IAQ report submission date: 11/27/20

Appendix

Resources

As introduced and endorsed by ASHRAE in the September 9th Webinar titled "Reopening Commercial Buildings: Evaluating Your HVAC System's Readiness to Mitigate the Spread of SARS-CoV-2, the following free online tools allow for additional calculations regarding the airborne spread and survivability time of SARS-CoV-2 under varying airflow, outside air, MERV filtration, temperature and relative humidity conditions:

- *NIST (National Institute of Standards and Technology) has developed an online simulation tool to compare the virus mitigation effectiveness of various filters and outside air rates:*
  - *https://pages.nist.gov/CONTAM-apps/webapps/FaTIMA/*

IES UV-C Recommendations: https://media.ies.org/docs/standards/IES-CR-2-20-V1-6d.pdf

Links to current studies on the effects of various dosages of UV-C on SARS-CoV-2:

- https://pubmed.ncbi.nlm.nih.gov/32842655/
- https://www.medrxiv.org/content/10.1101/2020.06.05.20123463v2
- https://www.biorxiv.org/content/10.1101/2020.06.06.138149v1.full
- https://www.nature.com/articles/s41598-020-67211-2
- https://www.sciencedirect.com/science/article/pii/S0196655320307562

FaTIMA Reports

Commercial Office Tenant – FaTIMA Study

Summary

FaTIMA is a web based calculator, provided by National Institute of Standards and Technology (NIST), that determines the indoor air quality by calculating the particles/ contaminant concentration after a 24h simulation. The program 11nalyses an enclosed zone and the system level filtration system as well as any room level filtration to determine the number of particulates that were filtered by each system and the amount that remains. This project encompasses multi-floor office retrofit with an additional room level UVC box.

A study was conducted in the open office area of a typical floor, five simulations were performed comparing the baseline case with no room level filtration, one (1) UVC box at 200 cfm, (1) 500 cfm, nine (9)x 200cfm, and nine (9)x 500cfm to determine the filtration efficiency and energy implications of UVC running at lowest setting at a single unit to the highest setting with all nine (9) units accounted for in the open office area.

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Project Inputs:

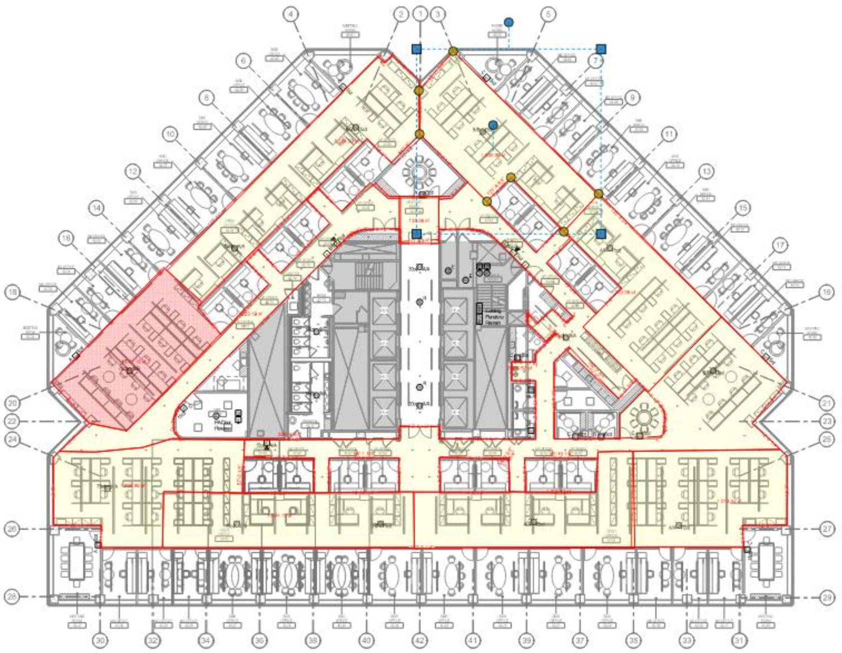

Figure 1: 42nd floor plan.

The highlighted region is the open office zone that was inputted as the zone geometry. The red region denotes (1) room level UVC box that was applied to the FaTIMA application. The yellow region was incorporated since the open office area was enclosed by all the walls and therefore deposition of particles would apply to all the highlighted surface area in question.

The existing building utilizes a main AHU serving floors 28th -44th floors. Due to multi-floor distribution, the total airflow (429,060 cfm) from the main system was split evenly between the 17 floors and utilized as the supply air flow rate The following table details the specifics of the ventilation system inputted into FaTIMA.

Existing Ventilation System	Inputs
Supply Airflow Rate	25,238 cfm
Outdoor Air Intake, %	17.6%
System outdoor Air filter	MERV 15
System Recirculation Air Filter	MERV 15

Table 1: Existing Building Ventilation System

The retrofit room level filtration system is a ceiling mounted air purifier system. LMS testing showed the unit was 99.9% efficient at a single pass for particles within the range of 0.3-0.5 microns. The yellow region shown in figure 1, has multiple room level UVC boxes rated for 1,000 square feet, however for the purpose of this study only one (1) box will be considered for the first two (2) test cases. Then a total of nine (9) units throughout the open office area is simulated.

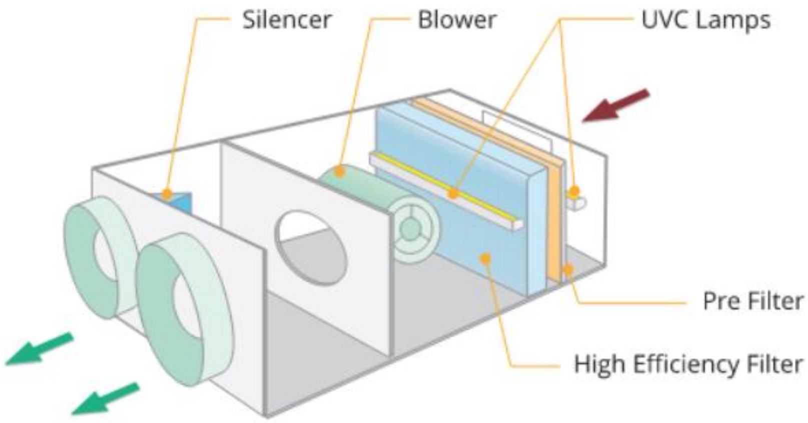

Figure 2: Air purifier diagram

The following table shows the inputs utilized for the FaTIMA simulation, with the information provided by manufacturer.

Input Categories	Inputs Values
Particle Diameter / density	0.3 microns – 1.0 microns / 1.0 g/cm^3
Room Air Cleaner airflow rate	200-500 cfm
Room Air Cleaner efficiency	99%
Contaminant Source	200,000 #/min
Generation Time	7am – 6pm
Initial Concentration	0 #/min
Occupant Exposure time	Constant / 7am -6pm

Table 2: Simulation input values

The purpose of this study is to analyze the effectiveness of the room level air filtration system therefore the initial concentration from outside air source was set to 0. The particle generation time was set to generic office hour occupancy.

Simulation Results:

The simulation over a 24 hr. period in the designated region shows a negligible number of particles that would remain airborne, however it does show a decrease in particles with additional room air filter. This is a conservative result as particle decay was not considered for this simulation. The tabulated data below summarized the filter particles and those that remain within the system for particle size of 0.3 micron and 1.0 micron.

Results	Baseline (no room filter)	Air Purifier @ 200 cfm	Air Purifier @ 500 cfm	Air Purifier @9x 200 cfm	Air Purifier @9x 500 cfm
Total Particles, #	4,889,200,000	4,889,200,000	4,889,200,000	4,889,200,000	4,889,200,000
Outdoor Air Filtered	0	0	0	0	0
Recirculation Filtered	3,621,700,000	3,587,700,000	3,538,200,000	3,338,000,000	2,987,200,000
Air Cleaner Filtered	0	45,723,000	112,750,000	382,820,000	856,610,000
Total Filtered	3,621,700,000	3,633,400,000	3,650,900,000	3,720,800,000	3,843,800,000
Integrated exposure	3848.9 # h /ft^2	3813.3 # h /ft^2	3761.0 # h /ft^2	3550.1 # h /ft^2	3179.7 # h /ft^2
Exited Zone	1,244,100,000	1,232,400,000	1,215,400,000	1,146,600,000	1,026,100,000
Remain Airborne	$1.17x10^{-18}$	$6.74x10^{-19}$	$2.94x10^{-19}$	$8.09x10^{-21}$	$4.58x10^{-24}$

Table 3: Simulation results of 5 test cases at particle size of 0.3 micron.

Results	Baseline (no room filter)	Air Purifier @ 200 cfm	Air Purifier @ 500 cfm	Air Purifier @9x 200 cfm	Air Purifier @9x 500 cfm
Filter Efficiency	74.08%	74.31%	74.67%	76.10%	78.62%
Total Air Filtered Comparison	0.00%	0.32%	0.81%	2.74%	6.13%
Integrated Exposure Comparison	0.00%	0.92%	2.28%	7.76%	17.39%

Table 4: Filter efficiency, and comparison of total air filtered, integrated exposure to baseline case, for 0.3 Micron.

The table above notes the overall filter efficiency for the five (5) different room level filtration efficiency, at a particle size of 0.3 micron, to range between 74%-78.6% of the overall contaminants filtered out. The comparison between total air filtered and integrated exposure is compared with the baseline case, showing a percentage increase for the total particles filtered ranging from 0-6.13%; and a percentage decrease in the air exposure through the 24 hr simulation ranging from 0-17.39% decrease with the addition of more room level filters.

The same five (5) room level filtration system was applied to the 1-micron particle size scenario which resulted in the following tabulated data below.

Results	Baseline (no room filter)	Air Purifier @ 200 cfm	Air Purifier @ 500 cfm	Air Purifier @9x 200 cfm	Air Purifier @9x 500 cfm
Total Particles, #	132,010,000	132,010,000	132,010,000	132,010,000	132,010,000
Outdoor Air Filtered	0	0	0	0	0
Recirculation Filtered	104,740,000	103,950,000	102,810,000	98,090,000	89,572,000
Air Cleaner Filtered	0	985,300	2,437,000	8,369,000	19,099,000
Total Filtered	104,740,000	104,940,000	105,240,000	106,460,000	108,670,000
Integrated exposure	82.946	82.331	81.426	77.723	71.016
Exited Zone	26,760,000	26,561,000	26,266,000	25,064,000	22,887,000
Remain Airborne	9.52E-27	9.52E-28	0	0	0

Table 5: Simulation results of 5 test cases at particle size of 1.0 micron.

The particle size of 1.0 Micron accounts for bioaerosol size that the filtration system design is aiming to filter out. The two particle sizes considered was averaged to formulate a more accurate result in determining the efficacy of the room filtration system in question to the overall space.

Results	Baseline (no room filter)	Air Purifier @ 200 cfm	Air Purifier @ 500 cfm	Air Purifier @9x 200 cfm	Air Purifier @9x 500 cfm
Filter Efficiency	79.34%	79.49%	79.72%	80.65%	82.32%
Total Air Filtered Comparison	0.00%	0.19%	0.48%	1.64%	3.75%
Integrated Exposure Comparison	0.00%	0.74%	1.83%	6.30%	14.38%

Table 6: Filter efficiency, and comparison of total air filtered, integrated exposure to baseline case, for 1 micron.

Based on the table above, the overall filter efficiency for the five (5) different room level filtration efficiency, at a particle size of 1.0 micron, is higher than that of 0.3 micron test cases ranging between 79.34%-82.32% of the overall contaminants filtered out. The comparison between total air filtered and integrated exposure is compared with the baseline case, showing a percentage increase for the total particles filtered ranging from 0-3.75%; and a percentage decrease in the air exposure through the 24 hr simulation ranging from 0-14.38% decrease with the addition of more room level filters.

The range varies from the test cases in 0.3 micron to 1.0-micron particle size, due to the changes in physical properties of the particulates. The rate of which the particles attach to the surface area is denoted by "surface loading" and total number of particles is recorded in the "deposited" the value of which increases with the diameter of the particles. In the baseline the deposited amount for 0.3 micron is roughly around 0.4% as opposed to 1.0 micron which increases to 3.7%.

The efficiency data in table 4 and table 6, was then utilized to formulate the efficiency of the overall filters, the percentage increase of total air filtered to the baseline case, as well as the percentage decrease of the occupant exposure rate compared to the baseline in all (5) test cases.

Averaged Results	Baseline (no room filter)	Air Purifier @ 200 cfm	Air Purifier @ 500 cfm	Air Purifier @9x 200 cfm	Air Purifier @9x 500 cfm
Filter Efficiency	76.83%	76.79%	77.20%	78.37%	80.47%
Total Air Filtered Comparison	0.00%	0.26%	0.64%	2.19%	4.94%
Integrated Exposure Comparison	0.00%	0.83%	2.06%	7.03%	15.88%

Table 7: Averaged results for filter efficiency, and comparison of total air filtered, integrated exposure to baseline case

The averaged filter efficiency ranged from 76.83%-80.47%, this is to be expected as ASHRAE research in filter efficiency increases due to increase in diameter size after 0.3 microns. However, compared to the total amount of particles filtered the overall percentage increase, declines due to changes in physical properties of the particles resulting in less total particles filtered in comparison to the baseline. The inverse is explained for the integrated exposure rate. Due to this, the overall efficiency values are lower than the ones recorded for simulations of 0.3 microns. However, the averaged results still show a significant increase to the baseline when a room filtration system is considered. The occupant exposure rate decreases up to 7.03%-15.88%. The total particles filtered increases from 0.23%-4.94%.

References:

The web based application can be found in the link below:

https://pages.nist.gov/CONTAM-apps/webapps/FaTIMA/

- "A Tool to Model the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA)",Dols et. Al. , https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2095.pdf, (10/21/2020)
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Westchester Commercial Office Facility– FaTIMA Study

Summary

FaTIMA is a web based calculator, provided by National Institute of Standards and Technology (NIST), which determines the indoor air quality by calculating the particles/ concentration following a source of contamination that is placed within the system. The program analyzes an enclosed zone, the system level filtration , as well as any room level filtration to determine the number of particulates that were filtered by each filter, a theoretical occupant exposure rate, particle airborne concentrations, and the amount of airborne particles that remains within the space in question.

This study focuses on the zone geometry determined by the enclosed spaced served, solely, by the air handler unit ***"VVH109".*** A system level analysis is completed with a range of outside air percentage (30-80%) and MERV filters (8-16) to determine the effectiveness of overall system filtration and provide recommendations for the equivalent efficiency of MERV filter to outside air design. The integrated exposure and airborne concentration of each test trial was compared to a baseline with the lowest MERV rated filter 8 and lowest outside air percentage of 30%. The 3rd floor zone in question also encompasses executive offices, conference rooms, and open office spaces, therefore a second part of this study focuses on the efficacy of room level filtration for these 3 different spaces. An additional room level UVC box, is applied to the 3 different spaces, at the lowest setting (200cfm) to the highest (500cfm). The integrated exposure and airborne concentration for each test trial was compared to a baseline where room level filtration was set to 0.

Project Inputs:

The highlighted region is the entire enclosed space that was inputted as the zone geometry for the first part of this analysis. The existing building utilizes a main AHU, ***VVH109***, serving 1/3 of the 1st floor. The following table records the input for the FaTIMA simulations.

Existing Ventilation System	Inputs
AHU System	VVH-109
Supply Airflow Rate	80000
Outdoor Air Intake, %	30%, 50%, 80%
Return Air, cfm	68000
Exhaust air, cfm	12000
System Outdoor Air filter	MERV 8, 13, 16
System Recirculation Air Filter	MERV 8, 13, 16
Ceiling Height, ft	15 FT
Particle Diameter / density	(0.3 microns / 1.0 g/cm$^{3)}$ (1.0 microns / 1.0 g/cm^3)
Contaminant Source	200,000 #/min
Generation Time	7am – 6pm
Initial Concentration	0 #/min
Occupant Exposure time	Constant / 7am -6pm
zone area, ft^2	42085.8
zone volume, ft^3	631287
zone wall Surface Area, ft^2	37245
Other Surface Area, ft^2	200000

Table 8: System level analysis inputs.

The system level inputs for the air handling unit was derived from existing schedule. A constant value of 200,000 #/ min is set to simulate a contaminated person for the duration of a generic office occupancy schedule, 7am-6pm. This is the same for the occupant exposure time. Based on the designated region the zone area, volume wall surface area, floor surface area, and ceiling surface area was measured. The zone volume was calculated with the assumption of 15 ft. ceiling height.

The purpose of this study is to determine the efficacy of filtration system with an indoor contaminating source hence the initial particle concentration and rate of infiltration was set to 0. As mentioned in the summary, the first part of the analysis was utilized to determine the MERV filter and outside air percentage that is most effective at filtering out the particles given a continuous source of particle generation. MERV filters 8, 13, and 16 were compared to an outside air percentage of 30, 50, and 80%. A total of (9) test cases was used to compare the efficiency of the occupant exposure rate & airborne concentration in a 24 hr simulation to the worse performing case (MERV 8 at 30%). The 9 test cases were simulated for particle diameters of 0.3 micron and 1.0 micron. Based on the results, (3) MERV filter and outside air scenario was selected for the second part of the simulation.

An additional set of simulations were performed to determine the IAQ impact of adding room-level air cleaners to enclosed offices, conference rooms and the open office areas that would operating simultaneously with the main building systems. The results were then averaged to account for the particle diameters ranging from (0.3-1.0 micron) that study is trying to decrease through filtration. The system level supply, return, exhaust air was derated based on the area of each space type on a typical office floor as compared to the overall area of the zone served by the AHU. The MERV filter and outside air percentage test trials were reduced to that of MERV 13 at 80%, MERV 16 at 30%, and MERV 16 at 50%. The following table shows the inputs utilized for the FaTIMA simulation, with the information provided by manufacturer for the room level filtration system.

Existing Ventilation System	Executive office Inputs	Conference Room input	Open Office Inputs
AHU SYSTEM	VVH-109	VVH-109	VVH-109
Supply Airflow Rate	380	760	9504
Outdoor Air Intake, %	30%-50%	30%-50%	30%-50%
System outdoor Air filter	MERV 13 & 16	MERV 13 & 16	MERV 13 & 16
System Recirculation Air Filter	MERV 13 & 16	MERV 13 & 16	MERV 13 & 16
Ceiling Height	15 FT	15 FT	15 FT
Particle Diameter / density	0.3 -1.0 μm	0.3 -1.0 μm	0.3 -1.0 μm
Room Air Cleaner airflow rate	200- 500 cfm	200 -500 cfm	200 - 500 cfm
Room Air Cleaner efficiency	99.9%	99.9%	99.9%
Contaminant Source	950	1901	23761
Generation Time	7am – 6pm	7am – 6pm	7am – 6pm
Initial Concentration	0 #/min	0 #/min	0 #/min
Occupant Exposure time	Constant / 7am -6pm	Constant / 7am -6pm	Constant / 7am -6pm
zone area	200	400	5000
zone volume	3000	6000	75000
zone wall Surface Area	900	1140	11385
Other Surface Area	500	1700	25000

Table 9: Simulation input values for executive office, conference room, open office space.

The contaminant source was also derated from 200,000 #/min to the values shown in the table above based on the decrease in zone area in question. The other surface area varies throughout for the different spaces as there is no definite design of the room therefore the value was set to maintain a surface area ratio to volume of 2.0 throughout all the different scenarios and match the system level simulation shown in the first part of this analysis. A room level filtration system was included for these 3 different scenarios. LMS testing showed the unit was 99.9% efficient at a single pass for particles within the range of 0.3-0.5 microns.

A single UVC fan powered box was applied to each room. The UVC box is rated for 1,000 square feet, however for the purpose of this study only one (1) box will be considered for consistency purposes. Hence for the 5000 sf open office area is expected to have a lower efficiency with the room level filtration than the other 2 office scenarios. Similar to the first part of the study, particle diameters of 0.3 and 1.0 micron were analyze for the 9 different test cases.

Project Results:

Below are the results for the primary analysis for the AHUs without in-room air cleaners.

Main AHU Filtration for 3rd floor at 0.3 micron Summary											
Results			*Total Particles, #*	*Recirculation Filtered*	*Surface Loading*	*Total Deposit-ed*	*Airborne Concent-ration*	*Integrated exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*								
Base	8	30	131,990,000	16,305,000	55.90	8,443,600	5.60	59.50	107,250,000	0.0048853
1	8	50	131,990,000	8,269,000	39.67	5,991,200	3.94	42.53	117,740,000	8.99*10^-7
2	8	80	131,990,000	2,303,100	27.64	4,173,900	2.75	27.65	125,520,000	2.85*10^-12
3	13	30	131,990,000	56,525,000	36.46	5,507,300	3.60	39.15	69,967,000	6.8*10^-8
4	13	50	131,990,000	34,583,000	31.23	4,716,700	3.10	33.62	92,700,000	3.4*10^-10
5	13	80	131,990,000	11,381,000	25.70	3,881,500	2.60	27.74	116,730,000	1.28*10^-13
6	16	30	131,990,000	76,677,000	26.71	4,035,100	2.65	28.82	51,264,000	6.88*10^-13
7	16	50	131,990,000	52,358,000	25.53	3,856,600	2.54	27.56	75,784,000	9.52*10^-14
8	16	80	131,990,000	19,636,000	23.94	3,616,200	2.38	25.87	108,740,000	4.94*10^-15

Main AHU Filtration for 3rd floor at 1 micron Summary											
Results			*Total Particles, #*	*Recirculation Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*								
Base	8	30	132,010,000	49,026,000	22.28	928,950	4.25	45.78	82,048,000	0.00000753
1	8	50	132,010,000	28,381,000	18.06	752,950	3.44	37.25	102,870,000	1.306*10^-8
2	8	80	132,010,000	8,840,700	14.06	586,240	2.68	29.11	122,570,000	1.06*10^-12
3	13	30	132,010,000	83,002,000	13.15	548,360	2.51	27.26	48,444,000	5.4*10^-14
4	13	50	132,010,000	73,392,000	12.88	537,230	2.46	26.70	73,392,000	2.23*10^-14
5	13	80	132,010,000	22,536,000	12.50	521,000	2.38	25.91	108,950,000	5.4*10^-15
6	16	30	132,010,000	86,211,000	12.29	512,540	2.34	25.50	45,277,000	2.47*10^-15
7	16	50	132,010,000	61,517,000	12.28	512,130	2.34	25.47	69,968,000	2.36*10^-15
8	16	80	132,010,000	2,458,000	12.26	511,310	2.34	25.44	10,692,000	2.2*10^-15

Below are the results for the second analysis for the AHUs combined with in-room air cleaners.

Main AHU and Room Level Filtration for Executive Office Space 0.3 micron Summary													
Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	23,222,000	13,836,000	0	13,836,000	529	135,620	100.82	1094.4	92,492,000	3.58*10^-13
1	8	50	23,222,000	2,052,000	0	2,052,000	508	130,380	96.896	1052.3	21,040,000	6.64*10^-14
2	8	80	23,222,000	9,436,100	0	9,436,100	505	129,500	96.245	1045.3	13,657,000	4.95*10^-14
3	13	30	23,222,000	8,827,800	8,403,400	17,231,000	337	86,524	64.324	701.55	5,901,200	2.57*10^-23
4	13	50	23,222,000	5,721,800	13,617,000	19,338,000	219	56,087	41.689	456.02	3,824,500	0
5	13	80	23,222,000	1,327,700	8,191,200	9,518,900	329	84,353	62.705	684.03	13,616,000	4.95*10^-24
6	16	30	23,222,000	867,920	13,397,000	14,265,000	215	55,160	41.002	448.55	8,903,300	0
7	16	50	23,222,000	6,120,700	8,155,800	14,277,000	327	83,978	62.431	681.08	8,859,100	3.72*10^-24
8	16	80	23,222,000	4,008,600	13,355,000	17,363,000	214	54,997	40.885	447.28	5,801,700	0

Main AHU and Room Level Filtration for Open Office Space 0.3 micron Summary

Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	5.81*10^8	3.46*10^8	0	3.46*10^8	529	2,918,500	100.91	1095.3	2.32*10^8	9.08*10^-12
1	8	50	5.81*10^8	51,361,000	0	51,361,000	509	2,804,800	96.979	1053.2	5.27*10^8	1.68*10^-12
2	8	80	5.81*10^8	2.36*10^8	0	2.36*10^8	50,511	2,786,100	96.327	1046.2	3.42*10^8	1.25^-12
3	13	30	5.81*10^8	3.39*10^8	12,895,000	3.52*10^8	517	2,853,900	98.668	1071.3	2.26*10^8	3.53*10^-12
4	13	50	5.81*10^8	3.28*10^8	31,194,000	3.59*10^8	501	2,761,500	95.489	1037.2	2.19*10^8	8.56*10^-13
5	13	80	5.81*10^8	50,265,000	12,400,000	62,665,000	498	2,745,300	94.908	1031	5.15*10^8	6.54*10^-13
6	16	30	5.81*10^8	48,701,000	30,041,000	78,743,000	482	2,659,600	91.963	999.39	4.99*10^8	1.59*10^-13
7	16	50	5.81*10^8	2.31*10^8	12,322,000	2.43*10^8	494	2,726,700	94.284	1024.3	3.35*10^8	4.88*10^-13
8	16	80	5.81*10^8	2.24*10^8	29,850,000	2.54*10^8	479	2,642,600	91.376	993.09	3.24*1068	1.19*10^-13

Main AHU and Room Level Filtration for Conference Office Space 0.3 micron Summary

Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	1,254,800	748,380	0	748,380	14	6570	2.7252	29.581	500,020	1.98*10^-14
1	8	50	1,254,800	110,910	0	110,910	14	6314.6	2.6191	28.444	1,137,400	3.67*10^-15
2	8	80	1,254,800	510,070	0	510,070	14	6272.2	2.6015	28.255	738,310	2.74*10^-15
3	13	30	1,254,800	582,650	277,420	860,070	11	5117.8	2.1227	23.108	389,470	1.56*10^-19
4	13	50	1,254,800	304,090	506,680	810,770	8	3739.1	1.5509	16.93	440,150	0
5	13	80	1,254,800	87,146	268,940	356,080	11	4961.4	2.0577	22.408	893,640	2.96*10^-20
6	16	30	1,254,800	65,940	508,730	574,670	8	3754	1.5571	16.998	676,240	0
7	16	50	1,254,800	401,350	267,520	667,770	11	4934.6	2.0469	22.291	580,900	2.21*10^-20
8	16	80	1,254,800	437,570	520,750	958,320	8	3843.1	1.594	17.397	292,480	0

Main AHU and Room Level Filtration for Executive Office Space 1.0 micron Summary												
Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	627,010	409,090	0	409,090	12	3,150	2.3417	25.466	214,830	1.14*10^-17
1	8	50	627,010	106,890	0	106,890	12	3,203	2.3804	25.882	516,890	2.49*10^-17
2	8	80	627,010	291,830	0	291,830	12	3,147	2.3395	25.442	331,980	1.09*10^-17
3	13	30	627,010	274,830	205690	480,520	8	2,117	1.5737	17.177	144,370	9.09*10^-28
4	13	50	627,010	184,230	344540	528,760	6	1,419	1.0548	11.542	96,764	0
5	13	80	627,010	71,448	207980	279,430	8	2,140	1.5911	17.365	345,480	1.82*10^-27
6	16	30	627,010	47,708	347210	394,920	6	1,429	1.0625	11.626	230,720	0
7	16	50	627,010	196,140	205500	401,640	8	2,116	1.5727	17.166	223,160	9.09*10^-28
8	16	80	627,010	131,530	344350	475,880	6	1,418	1.0543	11.537	149,610	0

Main AHU and Room Level Filtration for Open Office Space 1.0 micron Summary												
Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	15,682,000	10,237,000	0	10,237,000	12	67,776	2.3435	25.485	5,376,800	2.88*10^-16
1	8	50	15,682,000	2,675,700	0	2,675,700	12	68,899	2.3823	25.902	12,938,000	6.29*10^-16
2	8	80	15,682,000	7,305,200	0	7,305,200	12	67,707	2.3413	25.461	8,308,900	2.75*10^-16
3	13	30	15,682,000	10,042,000	300,420	10,342,000	12	66,490	2.2987	25.002	5,273,800	1.12*10^-16
4	13	50	15,682,000	9,761,300	729,950	10,491,000	12	64,634	2.2345	24.312	5,126,500	2.76*10^-17
5	13	80	15,682,000	2,624,100	305,200	2,929,300	12	67,568	2.3359	25.403	12,686,000	2.46*10^-16
6	16	30	15,682,000	2,549,700	741,600	3,291,300	12	65,644	2.2697	24.691	12,326,000	6.02*10^-17
7	16	50	15,682,000	7,165,800	300,040	7,465,800	12	66,422	2.2965	24.979	8,149,900	1.07*10^-16
8	16	80	15,682,000	6,965,300	729,380	7,694,600	12	64,565	2.2324	24.29	7,922,500	2.63*10^-17

Main AHU and Room Level Filtration for Conference Office Space 1.0 micron Summary													
Results			*Total Particles, #*	*Recirculation Filtered*	*Air Cleaner filtered*	*Total Filtered*	*Surface Loading*	*Total Deposited*	*Airborne Concentration*	*Integrated Exposure*	*Exited Zone*	*Remain Airborne*
Run #	*MERV*	*OA %*										
Base	8	30	33,881	22,116	0	22,116	0	152.6	0.063293	0.68829	11,613	6.29*10^-19
1	8	50	33,881	5,779	0	5,779	0	155.12	0.06434	0.69954	27,942	1.37*10^-18
2	8	80	33,881	15,777	0	15,777	0	152.45	0.063232	0.68763	17,946	6*10^-19
3	13	30	33,881	17,771	6,648	24,419	0	122.65	0.050872	0.55444	9,334	5.39*10^-24
4	13	50	33,881	13,730	12,840	26,570	0	94.76	0.039302	0.42924	7,211	0
5	13	80	33,881	4,630	6,736	11,366	0	124.28	0.051546	0.56172	22,386	1.17*10^-23
6	16	30	33,881	3,566	12,972	16,537	0	95.723	0.039704	0.43359	17,243	0
7	16	50	33,881	12,683	6,643	19,326	0	122.56	0.050833	0.55402	14,427	5.15*10^-24
8	16	80	33,881	9,801	12,832	22,634	0	94.692	0.039279	0.42898	11,148	0

The efficiency of the integrated exposure and airborne concentration were compared to the worst performing case and then averaged to show the efficiency range between particle diameters of 0.3-1.0 microns. A significant percentage decreased in integrated exposure, and airborne concentration is observed for the 3 different room scenarios with 2 different room filter speeds (200cfm and 500 cfm), compared to the baseline with the 3 different MERV filters observed in the system level analysis and no room level filter .

References:

The web based application can be found in the link below:

https://pages.nist.gov/CONTAM-apps/webapps/FaTIMA/

- “A Tool to Model the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA)”,Dols et. Al. , https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2095.pdf, (10/21/2020)
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