Simulation of Controls for Reducing Aerosol Exposure in Educational Spaces using FaTIMA

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9/17/2020 NTAA Webinar

National Institute of Standards and Technology
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engineering laboratory

Outline

- FaTIMA (**F**ate **a**nd **T**ransport of **I**ndoor **M**icrobiological **A**erosols)
- Study objective
- Educational spaces simulated
- Simulation parameters
- Results
- Summary

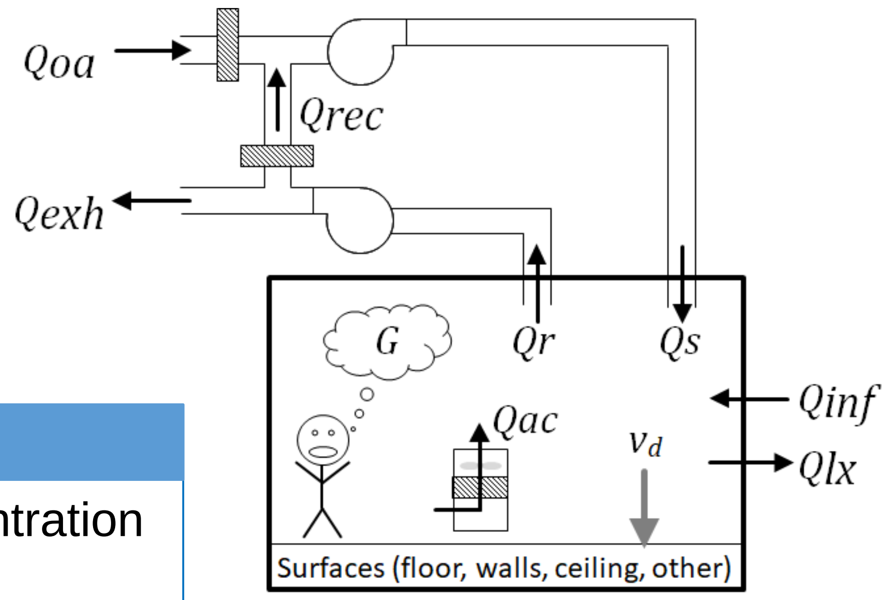
FaTIMA

- **FaTIMA: F**ate **a**nd **T**ransport of **I**ndoor **M**icrobiological **A**erosols [Ref 1]

https://www.nist.gov/services-resources/software/fatima

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

- Free online tool for evaluating aerosol exposure
  - Single-zone with uniform aerosol concentration
  - 24 h simulation



Inputs
• Room dimensions • Infiltration rate • HVAC airflow rates • Portable air cleaner specs • Aerosol characteristics • Deactivation rate • Sources • Surface deposition rates • Occupied time

→

Outputs
• Airborne aerosol concentration • Surface loading • Aerosols on filter • Occupant exposure • Numerical and graphical

FaTIMA web interface

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NIST MULTIZONE MODELING

Fate and Transport of Indoor Microbiological Aerosols (FaTIMA)

See TN 2095 - A Tool to Model the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA) for documentation of this tool.

Instructions: Set Inputs then click the RUN SIMULATION button.

Inputs

Zone Geometry	Volume 191 m³	Floor Area 74 m²	Wall Area 89 m²	Ceiling Area 74 m²	Other Surface Area 0 m²	Surface to Volume Ratio 1.2
Infiltration	Infitration 0.3 1 / h	Particle Penetration Coefficient 1				
Ventilation System	Supply Airflow Rate 413 sL/s	Outdoor Air Intake Fraction 0.3	Return Airflow Rate 371 sL/s	Local Exhaust Airflow Rate 0 sL/s		
System Filters	Outdoor Air Filter None	Recirculation Air Filter MERV 8				
Calculated Airflows	Total Outdoor Air Change Rate 2.6353 1/h	Outdoor Air Intake Rate 123.9 sL/s	Recirculation Airflow Rate 289.1 sL/s			
Room Air Cleaner	Maximum Airflow Rate 94.39 sL/s	Fan Flow Fraction 0	Filter Efficiency 0.8	CADR 0 sL/s		
Particle Properties	Name IV1	Diameter 1 µm	Density 1 g/cm³	Particle Deactivation Off	Half-life 1.1 h	Decay Rate 0.63014 1/h
Continuous Source	Source On	Generation Rate 500 #/min	Generation Time Period Start 09:00 / End 15:00			
Burst Source	Source	Burst Type	Amount per Burst	Generation Time Period	Burst Interval	

FaTIMA results

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RUN SIMULATION | Simulation Complete. | Project File | Download CONTAM Project | Report | Download CSV Report | Go back to Inputs

Results

Sources	Continuous: 180000 #	Burst: 0 #	Outdoor: 0 #	Total: 180000 #	
Airborne Concentration	Average (6 h): 34.439 #/m³	Average (24 h): 8.9546 #/m³	Maximum (24 h): 35.825 #/m³		
Airborne Exposure	Average (6 h): 34.45 #/m³	Maximum (6 h): 35.825 #/m³	Integrated Exposure: 744130 # s/m³		
Surface Loading	Floor: 26.31 #/m²	Walls: 0.26156 #/m²	Ceiling: 0 #/m²	Other: 0 #/m²	Total: 26.572 #/m²
Deposited	Floor: 1946.1 #	Walls: 23.281 #	Ceiling: 0 #	Other: 0 #	Total: 1969.4 #
Filtered	Outdoor Air: 0 #	Recirculation: 69844 #	Air Cleaner: 0 #	Envelope: 0 #	Total: 69844 #
Other	Deactivated: 0 #	Exited Zone: 108190 #	Remain Airborne: 7.1272e-14 #		

Study Objective

To evaluate the relative reduction in aerosol exposure in education spaces as a result of changes to the operation of heating, cooling and ventilation (HVAC) systems and inclusion of non-HVAC controls (e.g., wearing of face coverings) using FaTIMA

Disclaimers

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- This study characterizes the relative reduction in aerosol exposure (of individuals with face coverings) due to controls studied
- This study provides data that can help decision makers select changes to HVAC operation that may reduce aerosol exposure
- This study is for a single zone with uniform aerosol concentration and for single contagious occupant
- This study <u>does not</u> define a level of exposure that is safe or healthy
- Controls presented should be part of a larger risk reduction strategy

Educational spaces simulated

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Required outdoor air (OA)

ASHRAE 62.1-2019	L/s·person	L/s·m²	cfm/person	cfm/ft²	Default occupancy (#/100 m² or #/1000 ft²)
Classroom (ages 5-8)	5	0.6	10	0.12	25
Classroom (ages 9+)	5	0.6	10	0.12	35

Note:
Total OA required = per·person rate x #ppl + per·area rate x Area

Supply rates[Ref 2]

	L/s·m²	cfm/ft²
Classroom (ages 5-8)	5.60	1.12
Classroom (ages 9+)	7.05	1.41

Space information

Size	Dimensions (m)	Dimensions (ft)	Occupancy	Assumption/Source
Classroom (ages 5-8)	8.6 x 8.6 x 2.6	28 x 28 x 8.5	18	California Specification 01350 [Ref 3]
Classroom (ages 9+)	12.2 x 7.3 x 2.6	40 x 24 x 8.5	31	Portable classroom [Ref 4]

Simulation parameters

- Aerosol size: 1 μm
  - No virus inactivation
  - Deposition velocities

Space Type (occupant ages)	Air change rate (h^{-1}) (supply)	Deposition velocity (cm/s) [Ref 1]		
		Floors	Walls	Ceiling
Classroom (5-8)	7.8	3.40E-03	3.38E-05	0
Portable classroom (9+)	9.8		1.13E-03	1.75E-04

- Continuous source
  - Contagious person emitting 500 particles/min
- Integrated exposure evaluated between 9 am to 3 pm
- Controls simulated
  - Face coverings filter efficiency at 1 μm: 30 % [Ref 5]
  - Portable air cleaners between 1 h^{-1} and 6 h^{-1}
- All results will be normalized

FACE COVERINGS

OUTDOOR AIR (OA)

PORTABLE AIR CLEANER (PAC)

FILTER/ MERV RATING

EXHAUST FAN

Simulation of PACs

- CADR [Ref 6]: clean air delivery rate = airflow (cfm) x efficiency of particle removal of 3 test particles (i.e., smoke 0.09 µm -1.0 µm, dust 0.5 µm -3 µm and 5 µm -11 µm pollen) per ANSI/AHAM Standard AC-1
- Convert CADR to h^{-1}

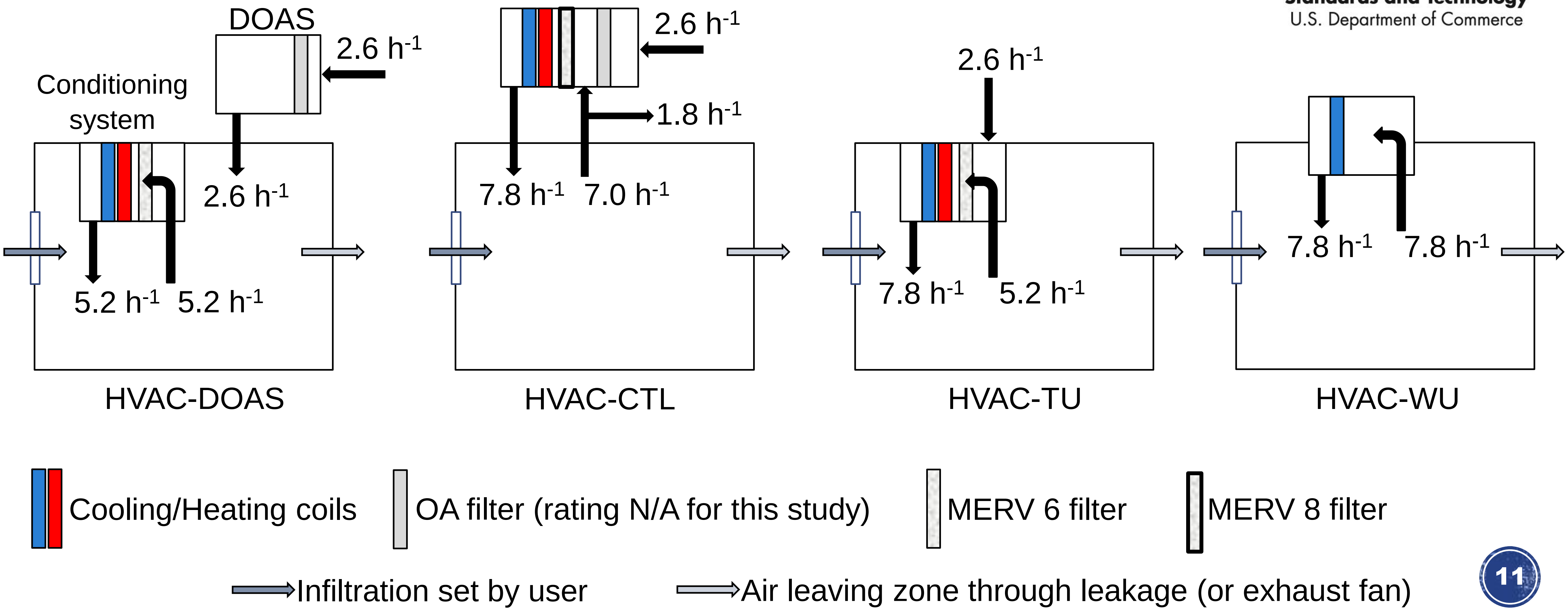
$$h^{-1} = \frac{\text{CADR} \times 60}{(\text{area x height})\ \text{ft}^3}$$

- PACs: typically 50 CADR to 400 CADR
- Simulation assumptions
  - Filter efficiency 0.99 (HEPA filter)
  - Operated at highest speed setting

Space Type (occupant ages)	Area, m^2 (ft^2)	Equivalent air changes (h^{-1}) achieved with CADR listed						
		150	250	300	350	400	2x400	3x400
Classroom (5-8)	74 (793)	1.3	2.2	2.7	3.1	3.6	7.1	10.7
Portable classroom (9+)	89 (960)	1.1	1.8	2.2	2.6	2.9	5.9	8.8

Note: classrooms ceiling height = 2.6 m (8.5 ft)

Simulated HVAC system types – classroom (5-8) values



Sensitivity analysis

	Base assumption	Uncertainty
Face coverings	30 % filtration efficiency	20 % less effective for fit
Infiltration	0.30 h^{-1}	0.1 h^{-1} and 1.0 h^{-1}
OA (HVAC-TU)	62.1-2019 rate	20 % less for performance issues
Filter	MERV 13: 90 % filtration efficiency at 1 μm	10 % less for improper installation, age, etc.
PACs	99 % effective at max setting	33 % capacity when operated at <max setting
Exhaust fan	100 % effective	10 % less for improper installation

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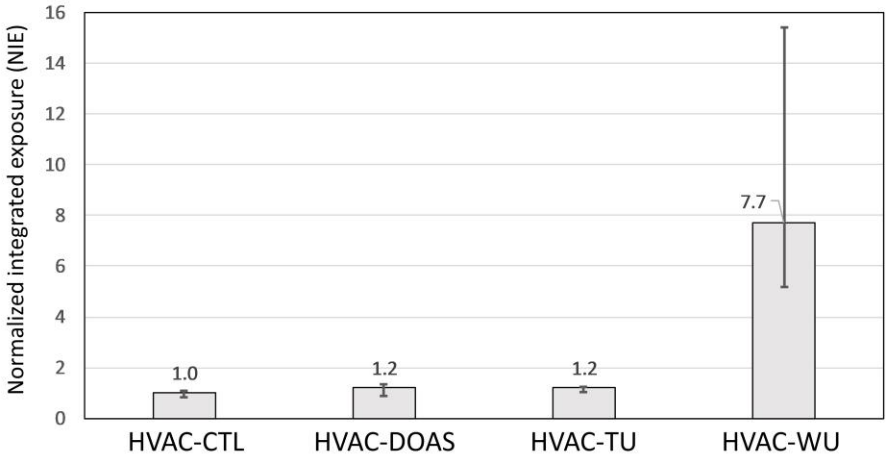
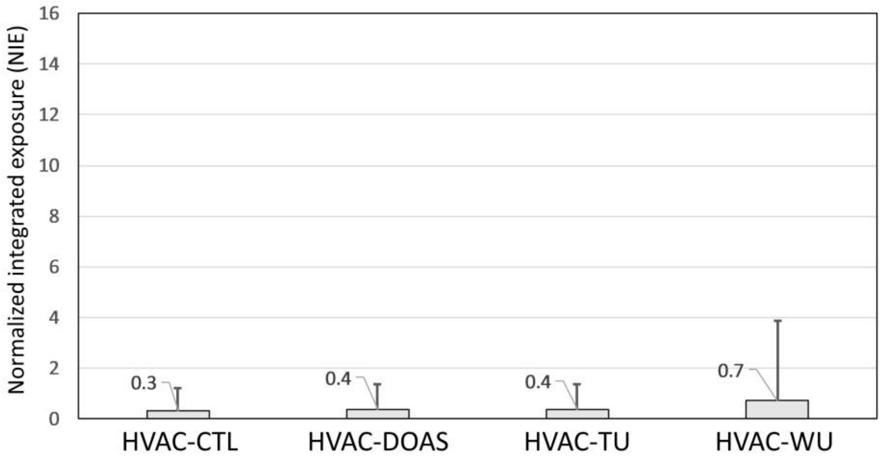
Results

With and without controls

- Integrated exposure normalized (NIE) to HVAC-CTL with:
  - One person contagious, no face coverings
- HVAC-WU systems have highest NIE and largest error bars



No controls



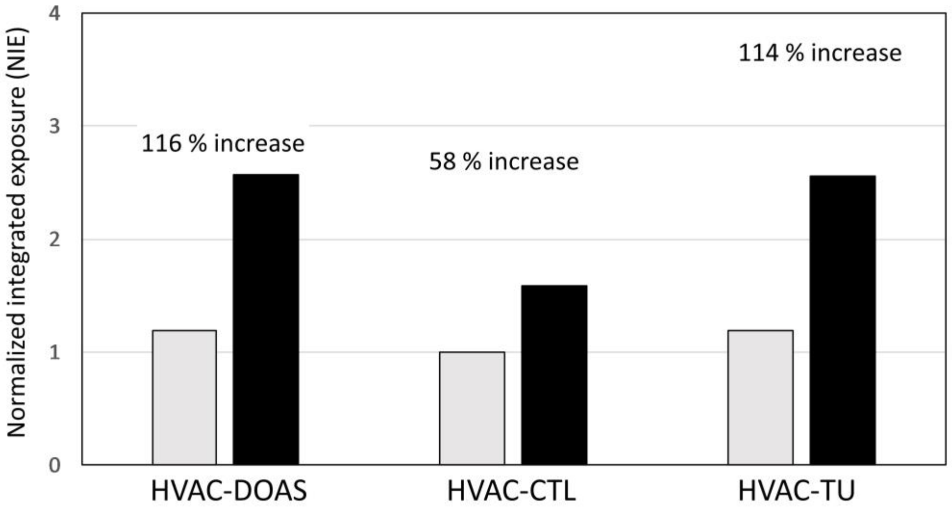
With face coverings and 300 CADR PAC

Avg 68 % reduction in NIE for HVAC-CTL, DOAS, and TU systems

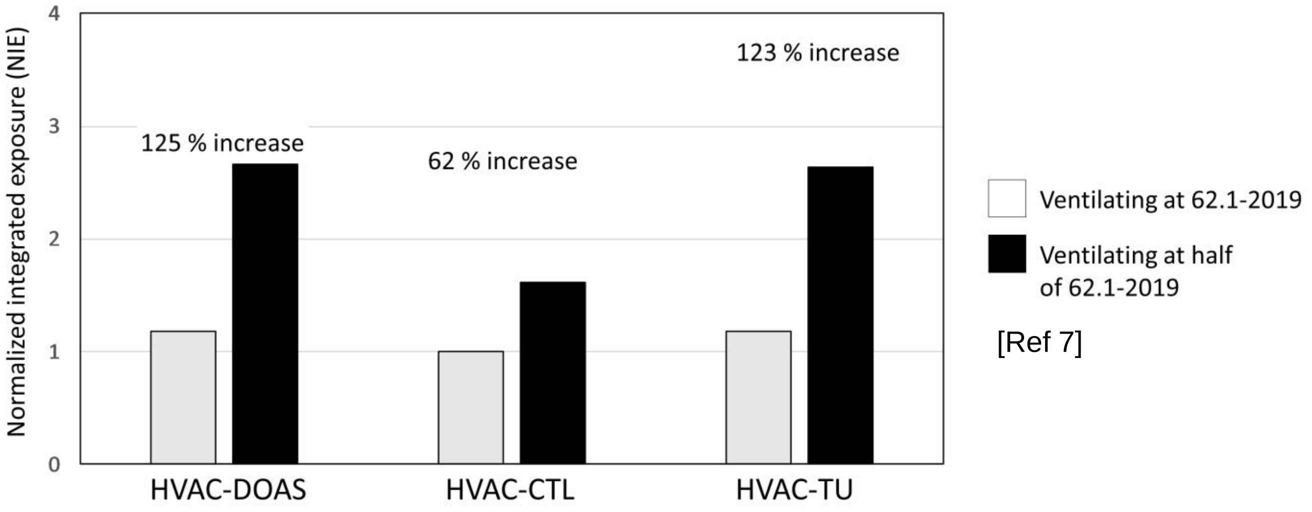
Avg 96 % reduction in NIE for HVAC-WU systems

NIE ventilating at half of OA requirement

- Integrated exposure normalized (NIE) to HVAC-CTL with:
  - One person contagious, no face coverings



Classroom (ages 5 to 8)



Classroom (ages 9+)

[Ref 7]

HVAC-CTL with controls

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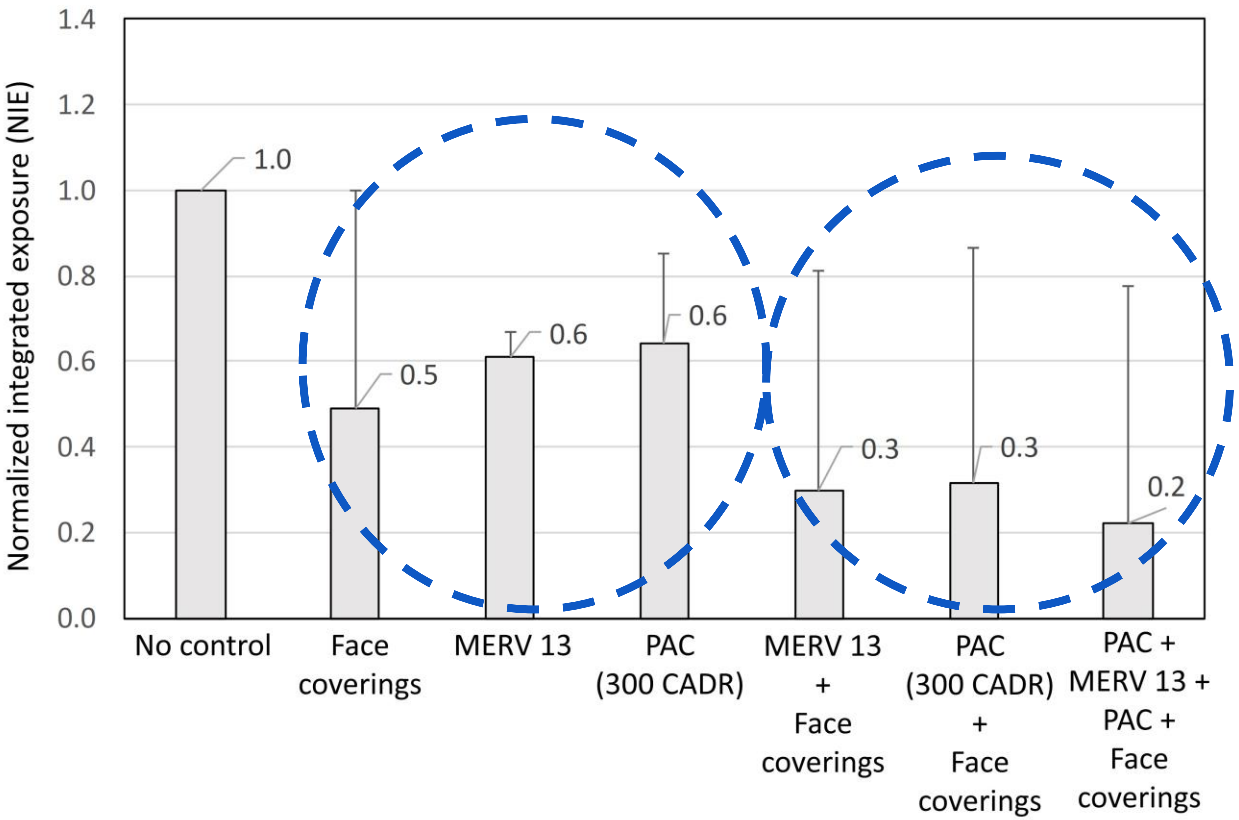
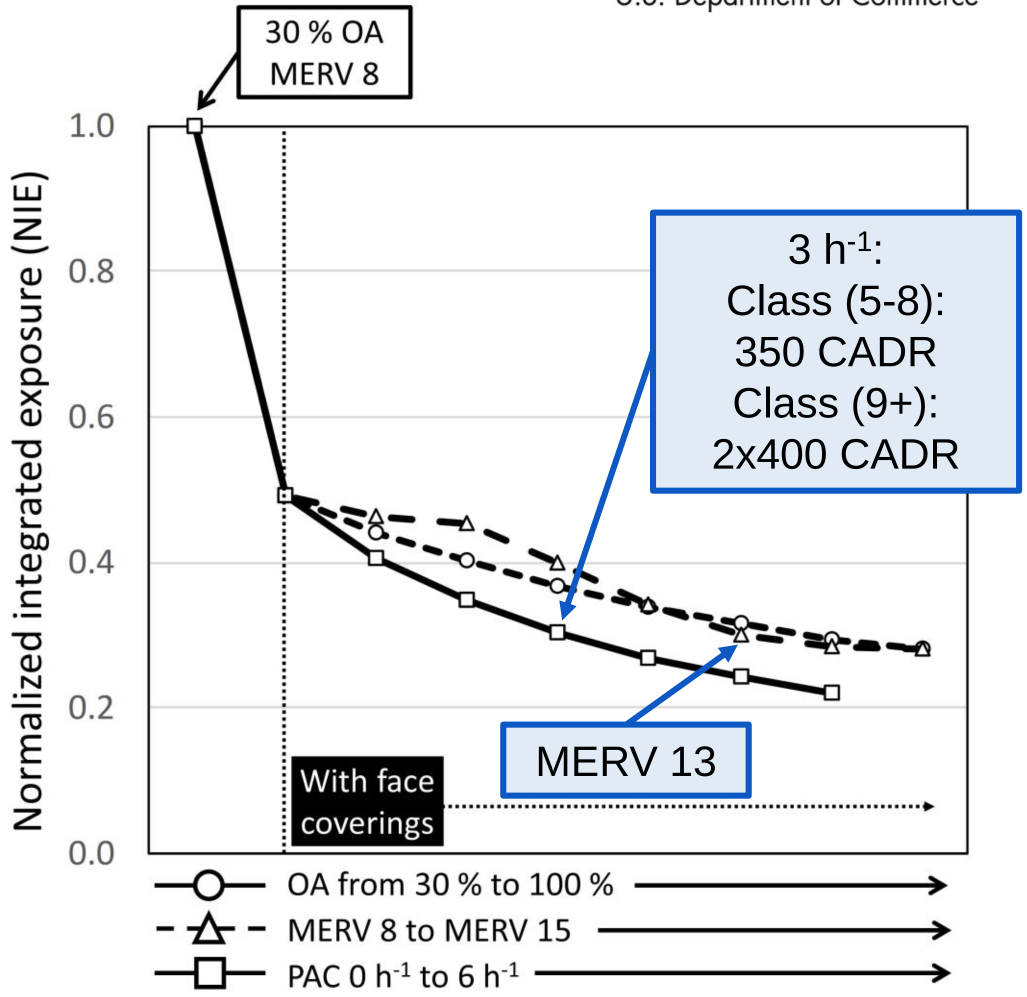
- Results similar in both classrooms and normalized to no controls
- Error bars account for uncertainty in effectiveness of filter, face coverings and/or PAC
- Face coverings, MERV-13 and PAC (300 CADR) reduce NIE to 0.5, 0.6 and 0.6, respectively
- Combined face coverings with controls have lower NIE compared with individual controls



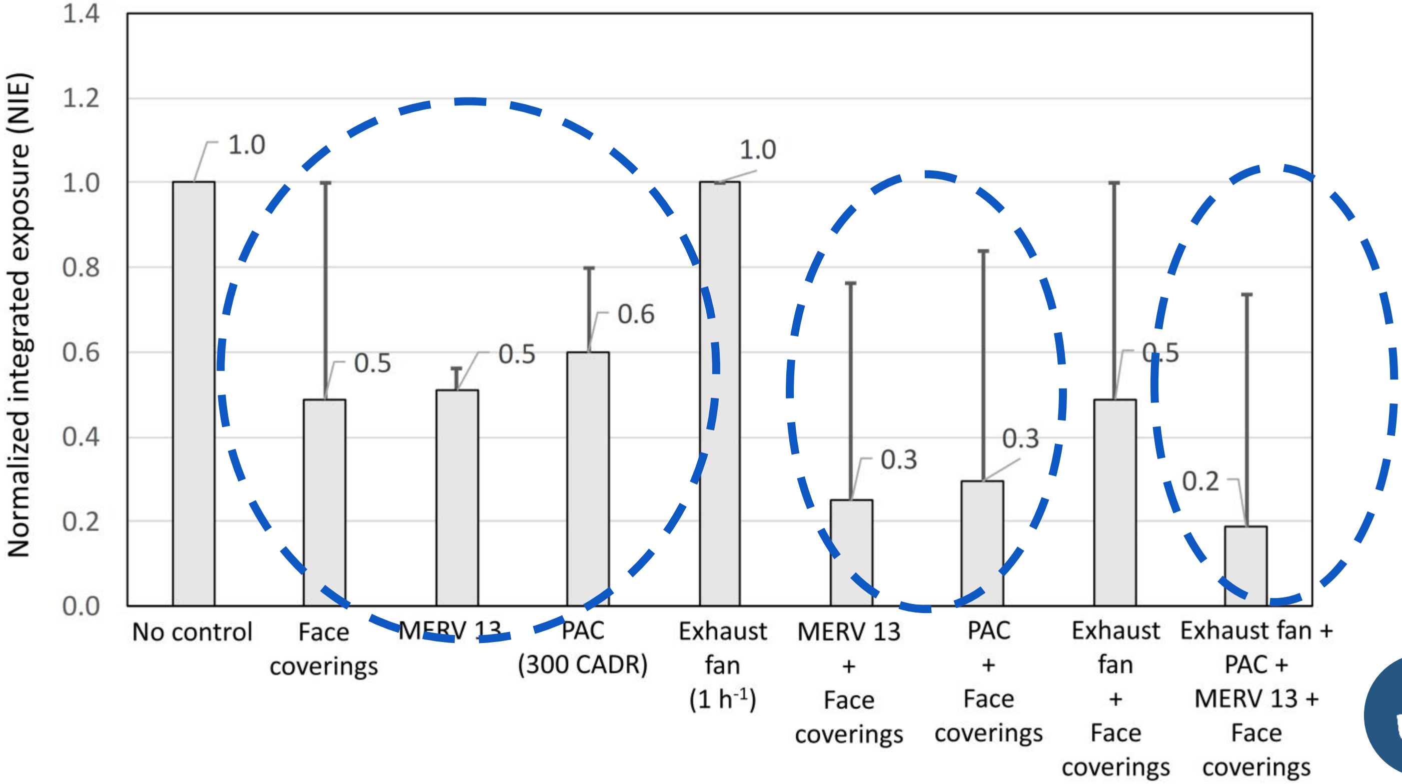
HVAC-CTL: varying controls with face coverings

- Similar for both classrooms (5-8, 9+)
- 70 % reduction in NIE at MERV 13
  - Equivalent controls: 90 % OA or 3 h^{-1} PACs
- PAC may be more effective than other controls (OA, filtration) as capacity increases beyond 1 h^{-1}
  - Assumes good fit of face coverings and PAC operated at max setting



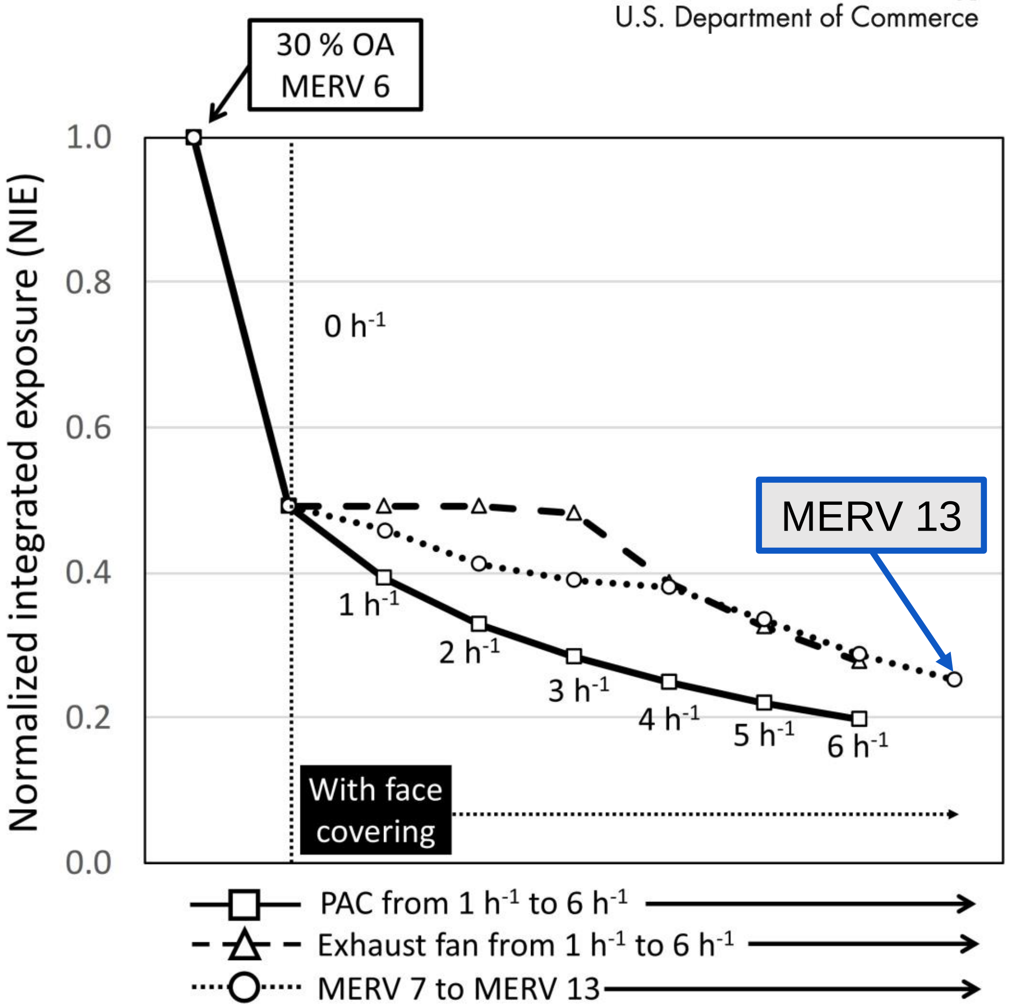
HVAC-TU with controls

- Results similar in both classrooms
- Error bars account for uncertainty in effectiveness of face coverings, filter, PAC and/or exhaust fan
  - Use of exhaust fan resulted in exposure similar to high infiltration rate
- Face coverings, MERV 13 and PAC (300 CADR) reduce NIE to 0.5, 0.5 and 0.6, respectively
- Combined face coverings with controls (except exhaust fan) have lower NIE compared with individual controls



HVAC-TU: varying controls with face coverings

- Similar for both classrooms (5-8, 9+)
- PAC reduced NIE by more than Exhaust Fan with same capacity
  - Exhaust fan (1 h^{-1} to 3 h^{-1}) had similar NIE to no exhaust fan
- 75 % reduction in NIE at MERV 13
  - Equivalent controls: 4 h^{-1} PACs (450 CADR in classroom (ages 5 to 8) or 500 CADR in classroom (ages 9+)



HVAC-WU with controls

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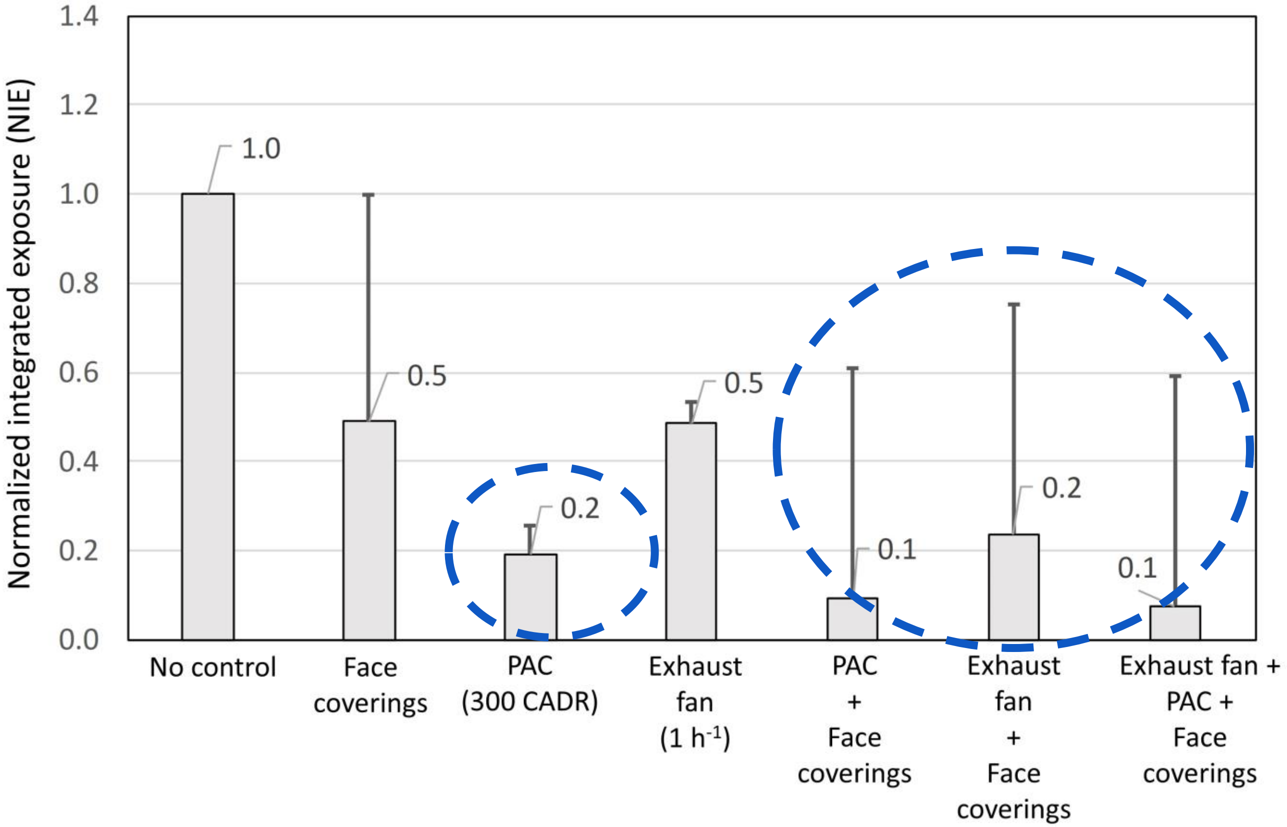
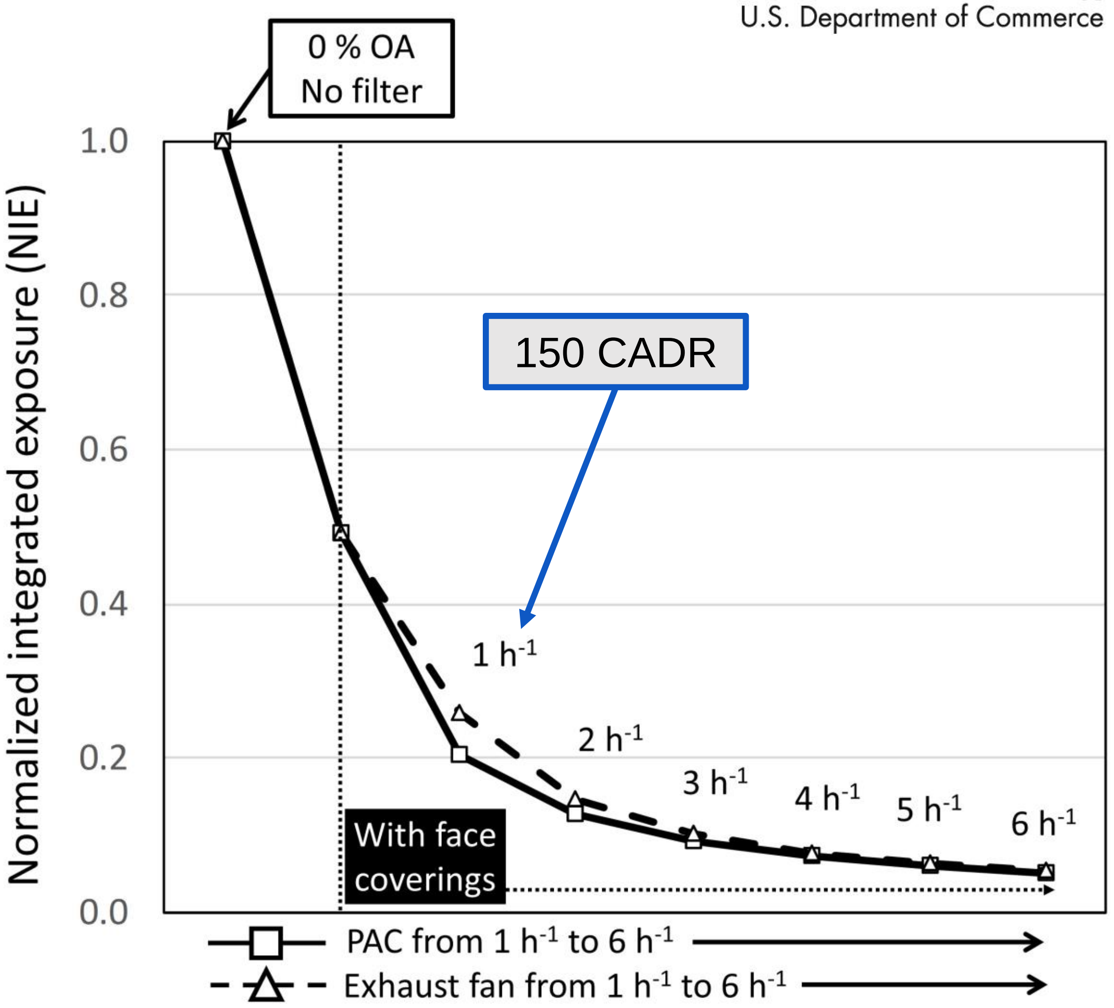
- Similar for both classrooms (5-8, 9+)
- Error bars account for uncertainty in effectiveness of face coverings, PAC and/or exhaust fan
- PAC (300 CADR) alone reduced NIE to 0.2
- Combined face coverings with PAC had lower NIE compared with individual controls



HVAC-WU: varying controls with face coverings

- Similar for both classrooms (5-8, 9+)
- PAC and exhaust fan reduced NIE by similar amounts over range of capacities
- 80 % reduction in NIE with 150 CADR
  - 90 % reduction with 300 CADR
- Note: HVAC-WU system (no controls) started with 9x exposure of HVAC-DOAS (avg both classrooms)



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Summary

Summary: comparing within each HVAC system

Average NIE across classrooms (5-8, 9+)			No face coverings			With face coverings			
System	No controls	Face coverings alone	PAC (300 CADR)	MERV 13	Exhaust fan (1 h^{-1})	PAC (300 CADR)	MERV 13	Exhaust fan (1 h^{-1})	All combined
HVAC-DOAS	1.0	0.5	0.7	N/A	N/A	0.3	N/A	N/A	N/A
HVAC-Central	1.0	0.5	0.7	0.6	N/A	0.3	0.3	N/A	0.2
HVAC-Terminal Unit	1.0	0.5	0.6	0.5	1.0	0.3	0.3	0.5	0.2
HVAC-Window Unit	1.0	0.5	0.2	N/A	0.5	0.1	N/A	0.3	0.1

- Dark cells indicate controls with lowest NIEs
- Assumes controls are performing "perfectly"
- These values are not a direct metric of infection risk
- HVAC-WU system starts out with highest exposure (9x of HVAC-DOAS)

Conclusions

- Effect of controls varies depending on HVAC system type
- Effect of controls depends on how they are implemented
  - Fit of face coverings
  - Portable air cleaner setting
  - Filter fit, sealing or condition
- While the exposure presented here are not a direct metric of infection risk, FaTIMA can be used to identify and compare possible control strategies to reduce exposure

References

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