Mitigation Strategies for Infectious Aerosols such as SARS CoV-2

Infectious Dose

The probability of getting infected depends on inhaling an “infectious dose”

- “infectious dose” = the number of viral particles needed to make infection likely

Infectious dose depends on

- where particles land in the lung, and
- the likelihood they will be deposited

Inhaling an infectious dose does not necessarily imply symptomatic Illness

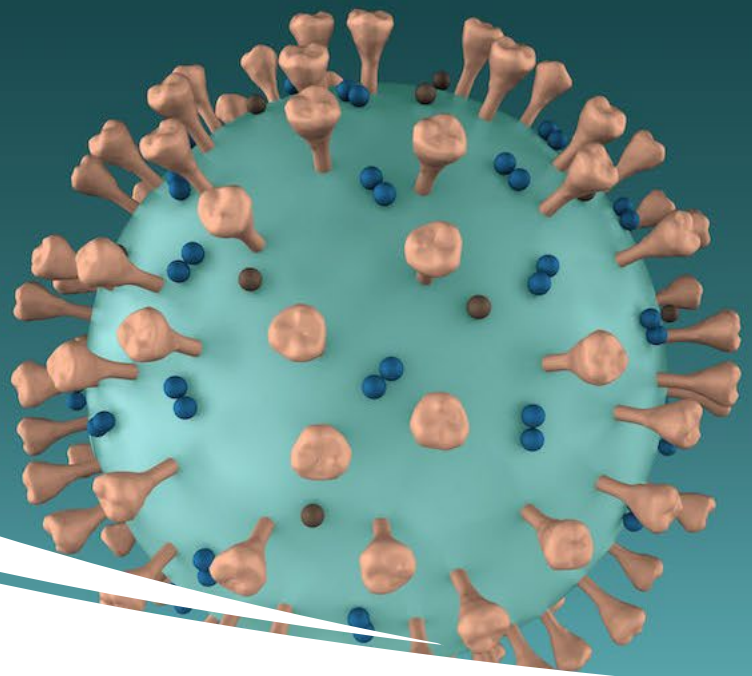
Source: Matthew Evans. Avoiding COVID-19: Aerosol Guidelines. Preprint 2020
https://www.medrxiv.org/content/10.1101/2020.05.21.20108894v2

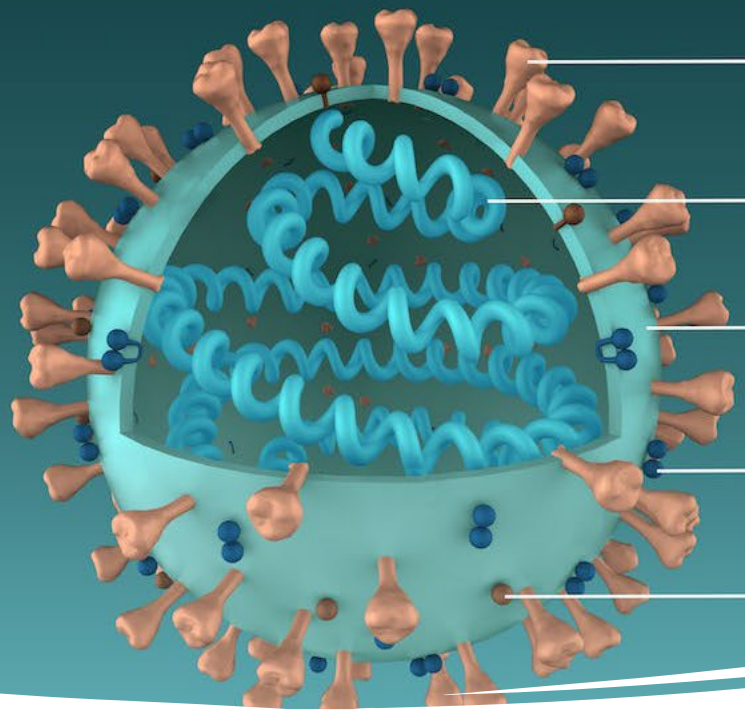
SARS CoV-2 Infectious Dose

- Infectious dose by inhalation of SARS-CoV-2 is unknown
- Some experts believe it to be 100-1000 viral particles by analogy to influenza and other coronaviruses
- Likely to influenced by factors such as
  - duration of exposure,
  - age
  - comorbidities.[1,2]
- Infectious dose for Delta and Omicron likely to be lower

1. Dabisch, PA, et. al. (2021) Seroconversion and fever are dose-dependent in a nonhuman primate model of inhalational COVID-19. *PLOS Pathogens*. 17(8): e1009865.
2. https://www.newscientist.com/article/2238819-does-a-high-viral-load-or-infectious-dose-make-covid-19-worse/

SARS-CoV-2

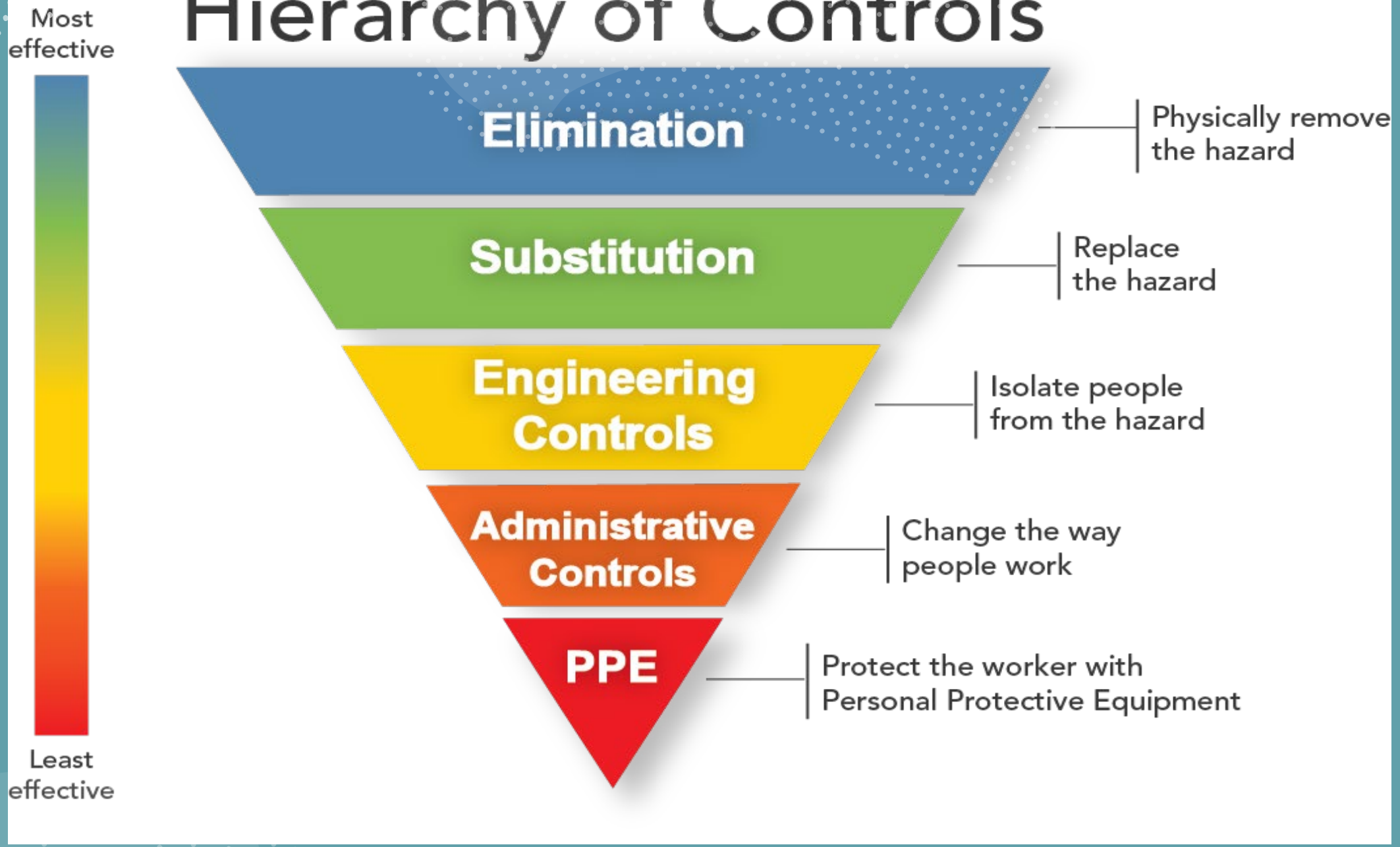




Reducing the Probability of Infection

Implement multiple mitigation strategies to reduce airborne concentrations of aerosols, including droplet nuclei that may carry the SARS CoV-2 virus

Hierarchy of Controls



Mitigation Strategies – Four Major Categories

- Vaccinations
- **Ventilation**
- Administrative controls
- Respiratory protection

Using Carbon Dioxide Levels to Assess Ventilation

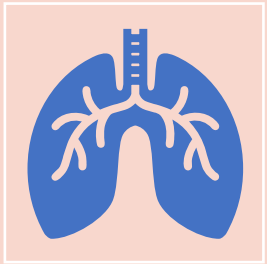
The concentration of carbon dioxide is

approximately 400 parts per million (ppm) in outdoor air

approximately 40,000 ppm in exhaled breath

Carbon dioxide levels rise in occupied spaces that are inadequately ventilated.

CO_2 as a Surrogate for Exhaled Infectious Particles



The higher the CO_2 Concentration, the more exhaled breath is retained in an indoor space.

If some of that exhaled breath contains infectious particles, those particles will be retained as well.

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Position Document on Indoor Carbon Dioxide

ASHRAE DOES NOT RECOMMEND A SPECIFIC CO_2 CONCENTRATION AS A METRIC OF INFECTION RISK.

RECOMMENDATIONS OR FOR VENTILATION RATES AND CO_2 CONCENTRATIONS TO LIMIT INFECTIOUS DISEASE TRANSMISSION HAVE BEEN SUGGESTED

BUT ARE HIGHLY UNCERTAIN GIVEN THE MANY FACTORS THAT IMPACT INFECTION RISK, INCLUDING DIFFERENCES BETWEEN PATHOGENS.

ASHRAE Position Document on Indoor Carbon Dioxide

All else equal, higher CO_2 concentrations correspond to lower outdoor air ventilation rates and the potential for an increased risk of airborne transmission.

CO_2 concentrations do not capture the impacts of reduced occupancy or of air cleaning on infection risk.

Other factors impact exposure and transmission risk

the amount of virus in the air (which does not necessarily scale with CO_2)

respiratory activity

type of pathogen.

ASHRAE Position Document on Indoor Carbon Dioxide

Several analyses of airborne infection risk have used CO_2 as an indicator of the "rebreathed fraction" of indoor air (the fraction of inhaled air that was exhaled by someone else in the space).

If the incidence of an airborne disease in the population and the infectious dose of the pathogen are known, these methods can be used to estimate the percentage of new infections for a particular scenario.

These methods rely on multiple assumptions about the distribution of indoor CO_2 and infectious aerosol, the relative significance of different infection modes, and dose-response relationships that are subject to large uncertainties.

Consequently, they may not be highly accurate predictors of risk.`

Increasing Outdoor Air (Dilution) Ventilation through HVAC System

- How much dilution ventilation is enough?
- Airborne concentrations of virus particles cannot be practically or meaningfully measured.
- Use indoor carbon dioxide (CO_2) levels as indicator of adequacy of dilution ventilation.
  - Provide dilution ventilation sufficient to maintain indoor CO_2 levels at or close to outdoor levels (400-500 ppm).[1]

1. ASHRAE Epidemic Taskforce for Schools and Universities. https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools-and-universities-c19-guidance.pdf

Increasing Outdoor Air Ventilation through HVAC System

Rooftop package air handler with fresh air intake hood. Economizer inside hood, regulated based on outdoor air temperature.

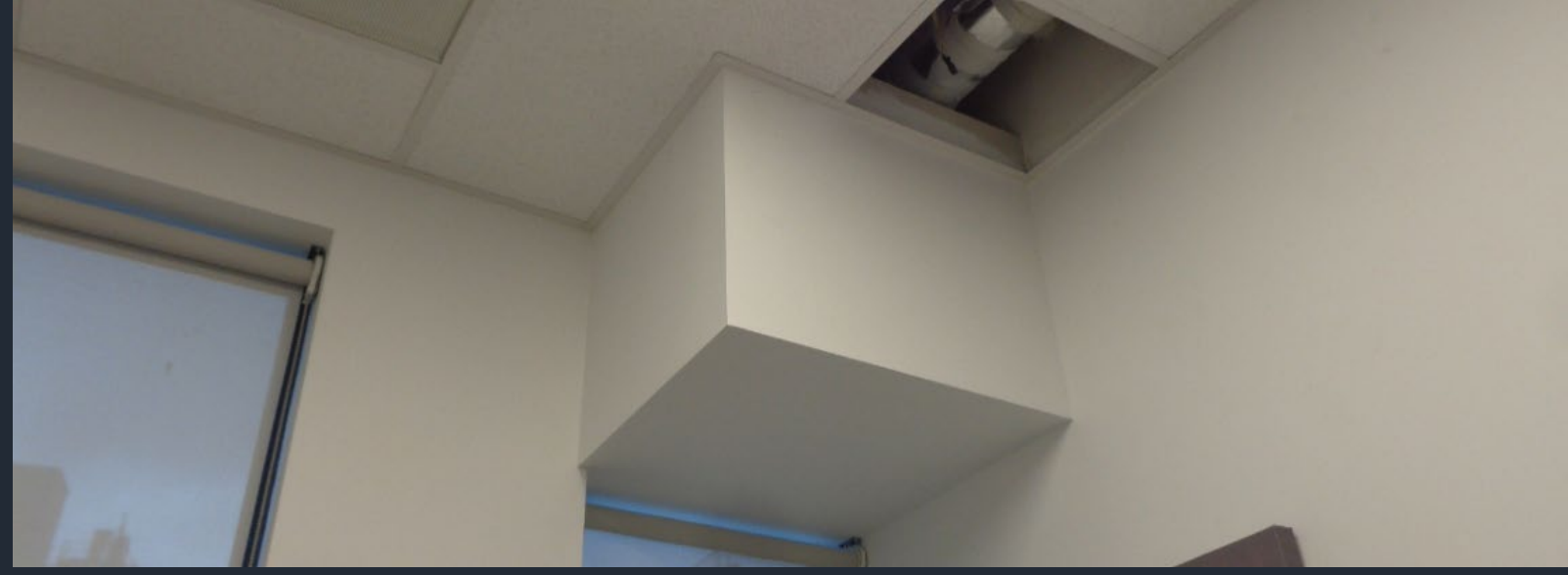
Increasing Outdoor Air Ventilation through HVAC System

Air handler in mechanical room (left). Fresh air intake fan in window (above) with air-driven fresh air dampers introducing outdoor air into room. Air handler draws air from inside room through open plenum return.

Increasing Outdoor Air Ventilation through HVAC System

- Air handler in mechanical closet (above).
- Fresh air duct with manual dampers (left) routes outdoor air from rooftop fresh air intake into closet.
- Air handler draws air from inside closet through open plenum return.

Increasing Outdoor Air Ventilation through HVAC System

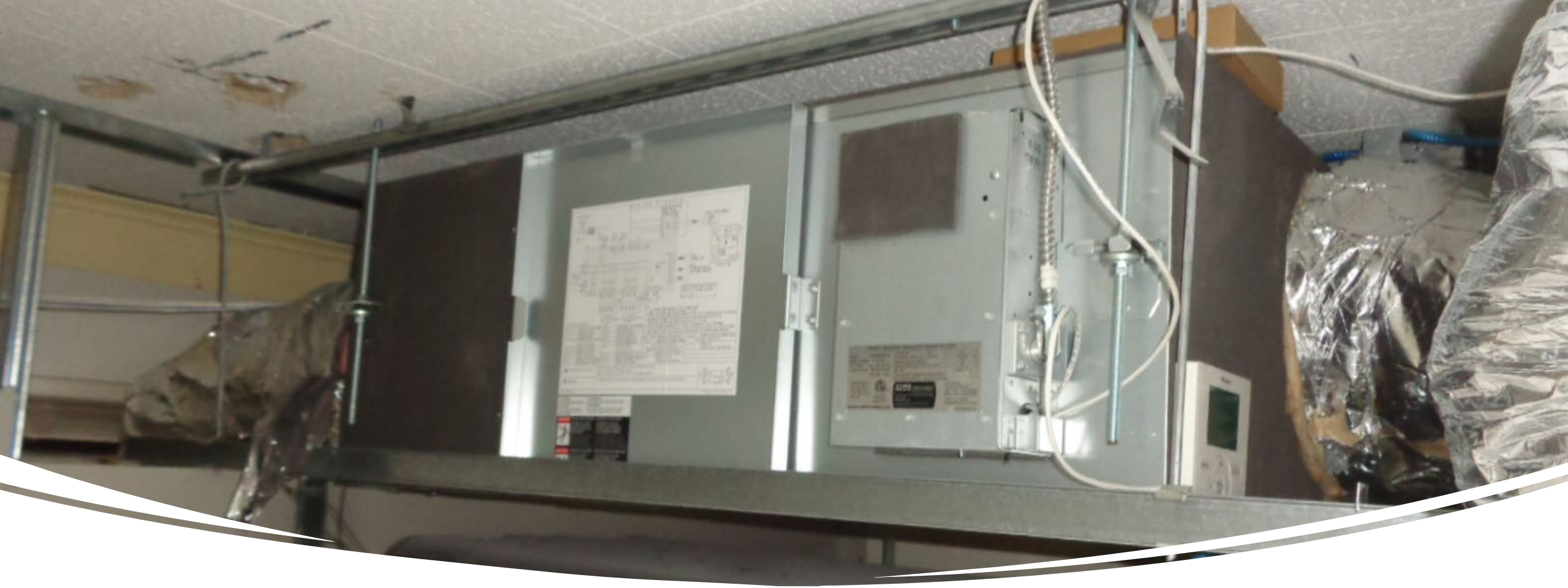


Air handler in ceiling plenum with fresh air duct (top) routing outdoor air from fan-driven fresh air intake in window (left) directly into unit.

Increasing Outdoor Air Ventilation – Negative Impacts

Increasing outdoor air ventilation on hot, cold or humid days can

- Adversely affect thermal comfort and humidity in indoor environment
- Increase cost of heating and cooling (may need supplemental heating and cooling)



Energy Recovery Ventilator (ERV)

- Provides dilution and exhaust air ventilation
- Uses outgoing air to condition incoming air (heat exchanger), addressing thermal comfort and mitigates increased cost of heating & cooling

Increasing Supply Airflow

Rebalance or adjust HVAC systems to provide sufficient airflow, taking into account room size and occupancy level.

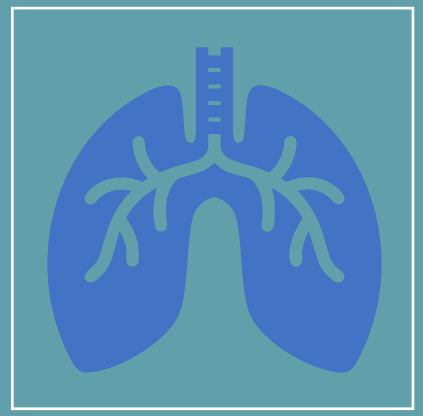
- Air dampers in supply ducts
- VAV boxes

Recommend minimum 6 ACH (air changes per hr), based on ASHRAE recommendation of 6 ACH in healthcare settings.*

Operate HVAC systems continuously to maintain supply air flow to occupied spaces irrespective of thermal demand (i.e. disable demand-controlled ventilation controls).

*ASHRAE (2020). ASHRAE Position Document on Infectious Aerosols. https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Improve Central Air Filtration



To further reduce airborne concentration levels of aerosols in indoor air, upgrade HVAC filters to minimum MERV-13 (50-74% capture efficiency in 0.3-1.0 micron size range). Ensure filters are properly sized to avoid filter bypass.

Consider upgrading to MERV-14 (75-84% capture efficiency) or MERV-15 (85-94% capture efficiency) filters, provided such filters do not significantly reduce airflow.

Improve Central Air Filtration

ASHRAE Standard 52.2 MERV Ratings (Minimum Efficiency Reporting Values)

MERV value	Particle Capture Efficiency 0.3-1.0 micron	Particle Capture Efficiency 1.0-3.0 microns	Particle Capture Efficiency 3-10 microns	Pollutants Captured Include
MERV-1	-	-	<20%	Pollen, dust mites, house dust, spray paint dust, carpet fibers
MERV-2	-	-	<20%	
MERV-3	-	-	<20%	
MERV-4	-	-	<20%	
MERV-5	-	-	20-34%	Mold spores, hair spray, fabric protector, cement dust
MERV-6	-	-	35-49%	
MERV-7	-	-	50-69%	
MERV-8	-	-	70-85%	
MERV-9	-	<50%	≥85%	Humidifier dust, lead dust, auto emissions, milled flour
MERV-10	-	50-64%	≥85%	
MERV-11	-	65-79%	≥85%	
MERV-12	-	80-89%	≥90%	
MERV-13	50-74%	≥90%	≥90%	Bacteria, tobacco smoke, droplet nuclei, viruses including SARS CoV-2
MERV-14	75-84%	≥90%	≥90%	
MERV-15	85-94%	≥90%	≥90%	
MERV-16	≥95%	≥90%	≥90%	

Exhaust Ventilation

- Provide exhaust ventilation to help prevent aerosols from lingering
- Exhaust ventilation options:
- Mechanical exhaust fan system (discharges air to outdoors)
- Open windows to provide pathway for exhaust ventilation
- ERV's
- Spill-air in rooftop return ductwork
- In bathrooms, enhance mechanical exhaust ventilation to provide minimum 6 ACH (based on ASHRAE recommendation of 6 ACH in healthcare settings*).

*ASHRAE (2020). ASHRAE Position Document on Infectious Aerosols. https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Portable Air Filtration Units

Use portable air filtration units equipped with HEPA filters (high efficiency particulate air filters that capture airborne particles as small as 0.3 micron at 99.97% efficiency).

Use portable air filtration units in shared spaces such as open office areas, waiting rooms, conference rooms, break rooms/pantries and shared offices and in bathrooms, and other high-occupancy areas.

Assessing HVAC and Ventilation Controls

Equipment Used in Ventilation Assessments

Instruments

- Flow hood balometer or anemometer
- Indoor air quality monitor (CO_2)
- Particle counter

Tools

- Screw driver
- Flashlight
- Camera/smart phone

Instruments Used in Ventilation Assessments

- **Flow hood balometer (left),**
- **Indoor air quality monitor (middle)**
- **Laser particle counter (right)**

Types of HVAC Systems in Commercial Spaces

- Package air handlers – on rooftops or in mechanical rooms
- Air handlers – in indoor space (mechanical rooms or closets, ceiling plenums) with outdoor condensers
- Fan-coil (PTAC) units – beneath windows in perimeter offices/rooms
- Mini-split units – mounted on walls or in drop ceilings

Types of HVAC Systems

- **Right: Air handler in mechanical closet with outdoor condenser unit.**
- **Below: Package air handlers on rooftop**

Types of HVAC Systems

- Fan-coil (PTAC) unit beneath window (left)
- Mini-split unit in drop ceiling (right)

Physical Assessment of HVAC Systems

- If HVAC units serving your office space are on roof or in mechanical rooms outside your office space, you will need building maintenance or management to provide access to these areas to conduct assessment.
- Contact building maintenance or management to provide access to roof or mechanical room(s).
- It is helpful to have HVAC contractor who services system onsite during assessment to open up HVAC units and answer questions about system.

Physical Assessment of HVAC Systems

- If HVAC system does not introduce fresh air, how can it be modified to do so?
- If HVAC system is capable of introducing fresh air:
  - How are fresh air dampers regulated (electronic or manual)?
  - Can electronic/automatic controls be overridden/adjusted?
  - How readily accessible are manual controls?

Physical Assessment of HVAC Systems

If HVAC system is capable of introducing fresh air:

- Is there a fresh air fan?
- How is fan operation regulated?
- Is incoming air pre-conditioned (i.e. pre-heated/pre-cooled)?
- How is fresh air routed into HVAC system (i.e. directly into HVAC units, ducted to mechanical rooms/closets)?

Physical Assessment of HVAC Systems

- Who has control of HVAC units?
- Are thermostats within office space?
- Recommend operating HVAC units continuously to maintain airflow in occupied spaces irrespective of thermal demand.

Physical Assessment of HVAC Systems

Note filter type in HVAC units:	
Have filters been upgraded to MERV-13 or better?	**Are filters properly sized to avoid filter bypass?**

Airflow Measurements

Use flow hood balometer or anemometer to measure:

- **Supply airflow at face openings of supply diffusers in drop ceilings and walls**
- **Exhaust airflow at face openings of exhaust vents in bathroom drop ceilings and walls**
- **Recommend minimum 6 ACH in any given room/area.[1]**
- **Recommend increasing airflow (>6 ACH) in high-occupancy rooms/areas (i.e. open office areas, conference rooms, waiting rooms, break rooms, etc.).**

1. ASHRAE (2020). ASHRAE Position Document on Infectious Aerosols. https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Physical Assessment of Office Space

- Are there operable windows?
- Are there pathways for exhaust ventilation (i.e. windows, passive returns)?
- Feasibility of installing fresh air intakes in windows or ERV’s in ceilings?
- Identify high-occupancy areas that would benefit from portable air filtration units (i.e. open office areas, conference rooms, waiting rooms, break rooms).

Physical Assessment of Office Space

In bathrooms

- Are there mechanical exhaust vents?
- Are there operable windows?
- Are there dividers?
- Are there toilet seat lids?
- Are air filtration units in use?

Hygienic Assessment of HVAC Systems

Visually assess hygienic condition of:

- Cooling coil (upstream side)
- Blower wheel (fan)
- Surfaces surrounding air intake areas (inside ceiling plenums and mechanical rooms/closets if open plenum return and on roof around fresh air intake)

Hygienic Assessment of HVAC Systems

If feasible, Assess hygienic condition of interior surfaces of supply ductwork (if readily accessible)

Common hygienic deficiencies: mold growth, damaged fiberglass insulation, excessive dirt/dust accumulation

Conduct Post-Intervention Assessments

Once initial assessment is completed, issue report of findings and site-specific recommendations for any mitigations.

Issue follow-up questionnaire for office manager to complete detailing status of implementation of recommendations. Following receipt of completed questionnaire, conduct post-intervention assessment to verify and make further recommendations as may be necessary.

Example

Office Space in Downtown Brooklyn NYC

(21,000 ft^2 office space on 3rd, 4th and 5th floors of 6-story building erected in 1929)

Initial Assessment Findings

- 7 air handlers in ceiling plenums, ***no fresh air intake***
- Air handler filters
  - MERV-8 and fiberglass-type
- Operable windows in all perimeter rooms
- Wide range in supply airflow, <6 ACH in many rooms, inadequate exhaust airflow in bathrooms (<6 ACH)
- No portable air filtration units

Office Space in Downtown Brooklyn NYC

(21,000 ft^2 office space on 3^{rd}, 4^{th} and 5^{th} floors of 6-story building erected in 1929)

Recommendations:

- Install ERV's
- Upgrade filters to MERV-13
- Enhance exhaust airflow in bathrooms
- Use portable air filtration units

Office Space in Downtown Brooklyn NYC

Picture Shows:

1 of 7 air handlers in ceiling plenums. No fresh air intake.

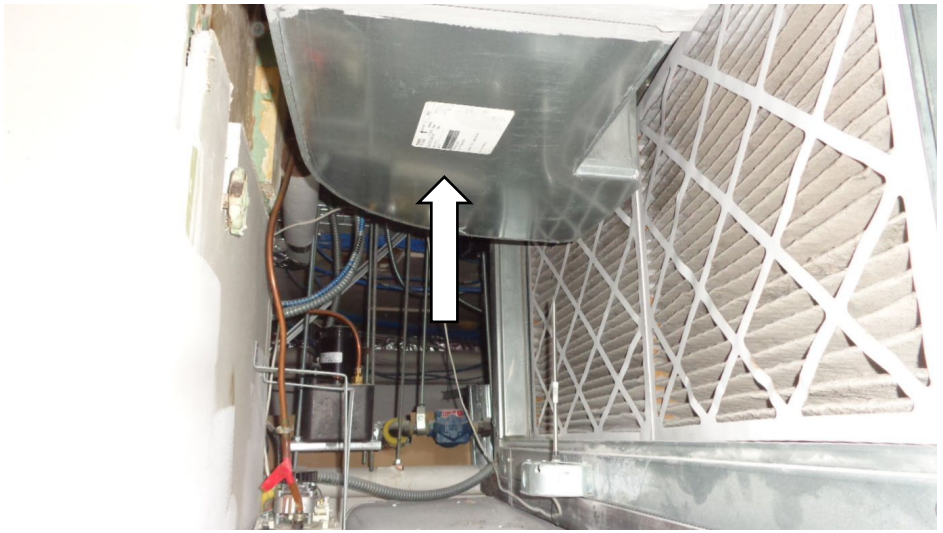
Post-Intervention Assessment Findings

- 10 ERV’s installed in ceiling plenums
- Fresh air ducted to open plenum returns of each air handler
- Exhaust air being drawn from hallways
- ERV’s operate continuously while air handlers are running

Post-Intervention Assessment Findings

- Air handler filters upgraded to MERV-13
- Supply airflow still deficient in some offices
- Still inadequate exhaust airflow in some bathrooms
- Portable air filtration units used in shared spaces, none in bathrooms

Office Space in Downtown Brooklyn NYC



Post-intervention assessment: 10 ERV's installed in ceiling plenums (top left) with fresh air ducted to open plenum returns of each air handler (top right). Exhaust vents installed in common halls, ducted back to ERV's.