HEALTHY TEACHING RECOMMENDATIONS

IN-PERSON TEACHING IN TIMES OF COVID-19

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As students and teachers prepare to go back to school, a comprehensive and integrated ***People-Air-Surface-Space (PASS)*** approach is needed to minimize risk of exposure and SARS-CoV-2 transmission, while maximizing in-person presence and space usage. This approach requires one to think about both the near-field (breathing/exhalation zone) and far-field (room scale) contaminations and pathogen dispersal over seconds to hours from a potentially infected individual [Fig. 1]. Here we feature such an *integrated approach* that accounts for interactions among people and interactions of people with their surrounding spaces. We also review modifiable features of the built environment.

DEFINITIONS

Pods (or bubbles) – Group of students/teacher that can intermix but do not or only minimally mix with other groups, either via physical distancing or time-staggering of usage of common areas in the school. **Surfaces** – Hard (desk, door knobs, faucet handles, supplies such as pens) and soft (hands) surfaces. **Grade of mask** – Material's ability to filter the air passing through.

PEOPLE MANAGEMENT

• Within a few seconds, uncovered exhalation clouds can reach 7-8 m for sneezes, 4-6 m for coughs, and 1-3 m for normal tidal exhalation [Fig. 2]. To reduce the range of contamination, masks should be worn by all (age permitting) and at all times, except when eating or drinking. *High-grade and well-fitting masks provide the highest level of protection [Fig. 3] and should ideally be made available upon entrance into the building if students do not come with one.* These should be tight, well-fitted masks made of high grade filter materials. In resource limited times, double cotton masking with a layer of filter material in between (*e.g.,* coffee filter) well sealed around the face can also be effective.

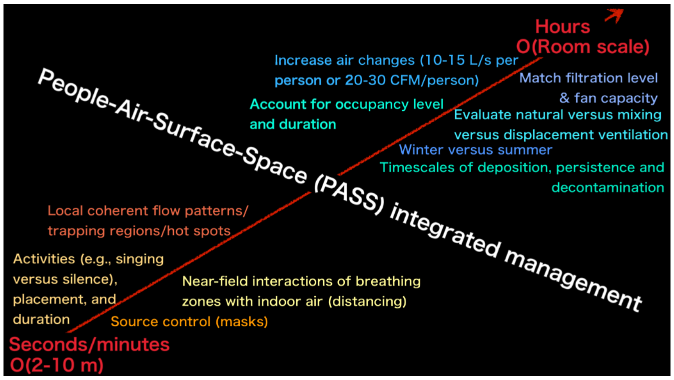

Figure 1 – Framework of People-Air-Surface-Space (PASS) integrated infection control approach for re-opening of society in time of pandemic, requiring a holistic approach of risk management both at the individual level (bottom left) and building/indoor space level (top right). The individual level involves contamination over short timescales, order of seconds to minutes, that can range from 2 m to 10 m, depending on activities and exhalation types **[**Fig. 2**]**. The management of the indoor space involves strategies to mitigate contamination over longer timescales, order of minutes to hours, and involves room and building scales (venting system, etc.). Source: Bourouiba (2021) ARBME, 23:547-77.

• Use of masks is particularly important in common areas, such as classrooms, corridors, breakrooms, restrooms, or even outside in crowded courts or playgrounds during if close interactions take place. *Training should be provided on the importance and proper usage and handling of masks*.

• Hand-washing stations, including non-contact soap dispensers and hand sanitizers, should be available, and training should be provided on proper hand washing and disinfection. *Favor non-contact, such as foot-activated water or soap dispensers.* Ensure frequent cleaning of the common contact surfaces and minimize their use, e.g., avoid sharing pens.

• Where appropriate, introduce ***gamification*** (development of games) and reward systems around usage of masks and hand-washing, possibly including competitions and point systems for making most original well-fitted masks or for teams/pods with most consistent adherence to hygiene requirements.

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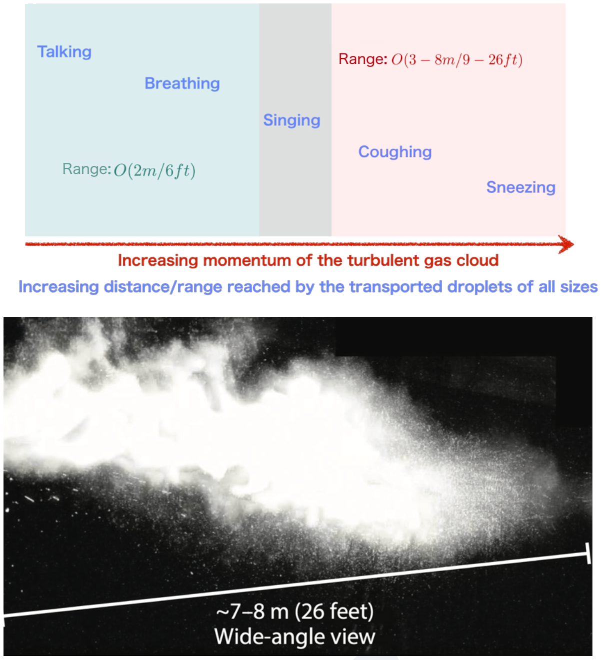


Figure 2 – Top: Uncovered (without mask) exhalations can easily range from 2 to 8 m within seconds to minutes due to the force of the exhalation itself. Source: [Bourouiba (2021) ARBME, 23:547-77](). Bottom: Time-lapse of an exhalation cloud and the droplet payload within it, here shown for a sneeze of an adult, reaching up to 7-8 m. Coughs can reach up to 4-6 m, and normal tidal breathing can reach 1-3 m. Masks reduce the range of the cloud, limiting it to the vicinity (1-2 m) of the exhaler. [See Video illustration to use for educational material in JAMA 2020.]() Source: [Bourouiba (2020) JAMA, 323(18):1837-1838.]()

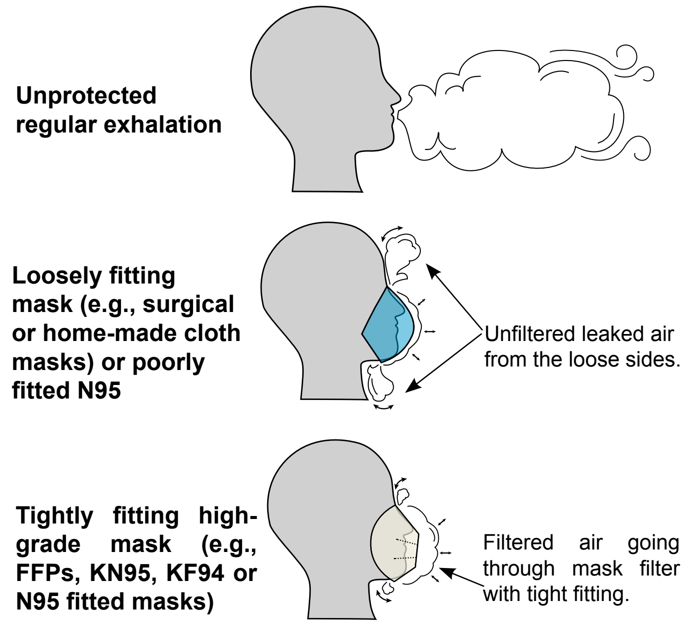


Figure 3 – Masks reduce the forward momentum – and range – of the exhalation cloud and its droplet payload. This is called *source control* as it controls what the exhaler emits into the environment. Two characteristics of masks are important to reduce transmission: 1) filtration; and 2) seal. **Top**: uncovered exhalation. **Middle**: exhalation covered by a mask with loose seal (this can be either a low or high grade mask that is not well fitted), with a larger portion of air coming out from the sides unfiltered. **Bottom**: exhalation covered by a mask that is better sealed (this can be either a high grade respirator, such as N95, or multi-layer masks as long as it is well sealed around the edges). *In the sealed case (bottom) a larger fraction of the exhaled air is forced through the filter of the mask than in the loose case (middle).* For the protection of the inhaler (receiver) of potentially contaminated air, similarly more inhaled air goes through the filter of the mask in the sealed case (bottom) compared to the loose case (middle). Hence, the *tightly fitted mask (bottom) provides better personal protection for the inhaler as well*. Appropriately sized masks for children, whenever possible, should be used to ensure propper fit and seal when age permits.

PEOPLE-SPACE INTERACTION MANAGEMENT

- Whenever possible, assign students into distinct groups (pods/bubbles) that consistently perform activities together and that do not mix with other pods/groups.
- Separate areas of the school by pods/age group, including playgrounds, as much as possible. This is to limit mixing and common space usage between age groups/students from different pods.
- If multiple entrances to a building are available, assign consistent usage of a given entrance to a given pod, ideally minimizing distance indoors from building entrance to the target classroom. Use tape on the ground or doors and in classrooms to guide consistent usage of such entrances and paths.
- Stagger start and end times (5-30 mins or more) and breaks to limit crowding and mixing of pods/age groups, particularly in common areas, including dining halls, restrooms, and corridors.
- Have each pod consistently use the same classroom, and have each student in the pod consistently assigned the same desk/chair to ensure rapid identification of contamination location and range, and for contact tracing if a student or teacher contracts COVID-19 at any point.
- *To reduce risk of transmission, separate and stagger desks **[[Fig. 4]()]***. This is to avoid that the concentrated freshly exhaled respiratory cloud in the near-field of one student to reach the breathing zone of another student sitting in front of them.
- *Consider usage of large extension spaces, as long as they are well ventilated* **(see dedicated section on Air Management)**, such as libraries, gym halls, dining halls, or nearby community halls for pod-based indoor classroom teaching.
- Educate and use colored tape or markers to help maintain staggering of desks/chairs by the students and distance when walking in and out of classroom to other locations (break or meal space).

• Departure from and entrance into classrooms should ideally be conducted by row: the row closest to the exit leaves first; the row farthest from the exit enters first **[Fig. 5]**.

• *For meals, weather permitting, it is always preferable to eat outdoors, maintaining each pod separate and engaging in decontamination of surfaces and hand-washing prior to and after eating. Staggered mealtimes and hence staggered use of corridors and entrances are important to limit direct or indirect interactions across pods. Ensure highest possible ventilation of all spaces during transitions, including corridors, restrooms and all spaces that may be used sequentially by various pods.*

• *Sitting during meals should ideally be side-by-side, with students looking in the same direction at a given table **[Fig. 6]**. If this is impossible, ensure staggered and distanced seating rather than students facing each other directly. The goal is to avoid having one student inhaling the air right at the breathing/exhalation zone of another while masks are off, and that continues to be true even when outdoors.*

• If eating has to be done indoors, using a screen separation for each seat while maintaining seating assignments and increasing air intake during this unmasked period can help limit the range of the exhaled cloud during eating. It is preferable to use the same screen consistently for the same location **[see Air and Surface Management sections for cautions when using screens]**. *If indoor meals have to occur, they should involve as few people possible in the largest and best ventilated space possible for the shortest time possible.*

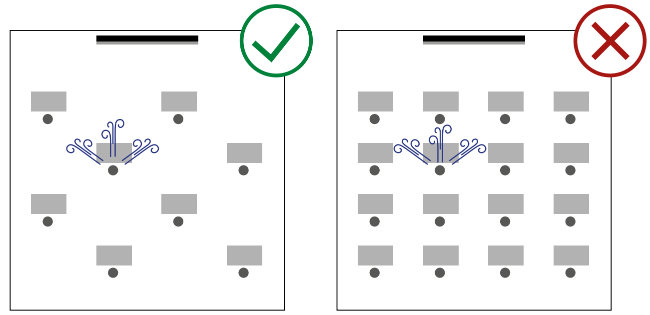


Figure 4 – Staggering of desks (left) enables to extend the distance between one student and the one in front of them. *It is particularly important to avoid continuous exposure to the exhalate of one individual in the region where the cloud exhaled remains highly concentrated in virus (for uncovered normal breathing the exhalation zone is within 2-3 m).*

• Consider limiting or eliminating direct drinking from water fountains; encourage use of washable personal water bottles and non-contact faucets.

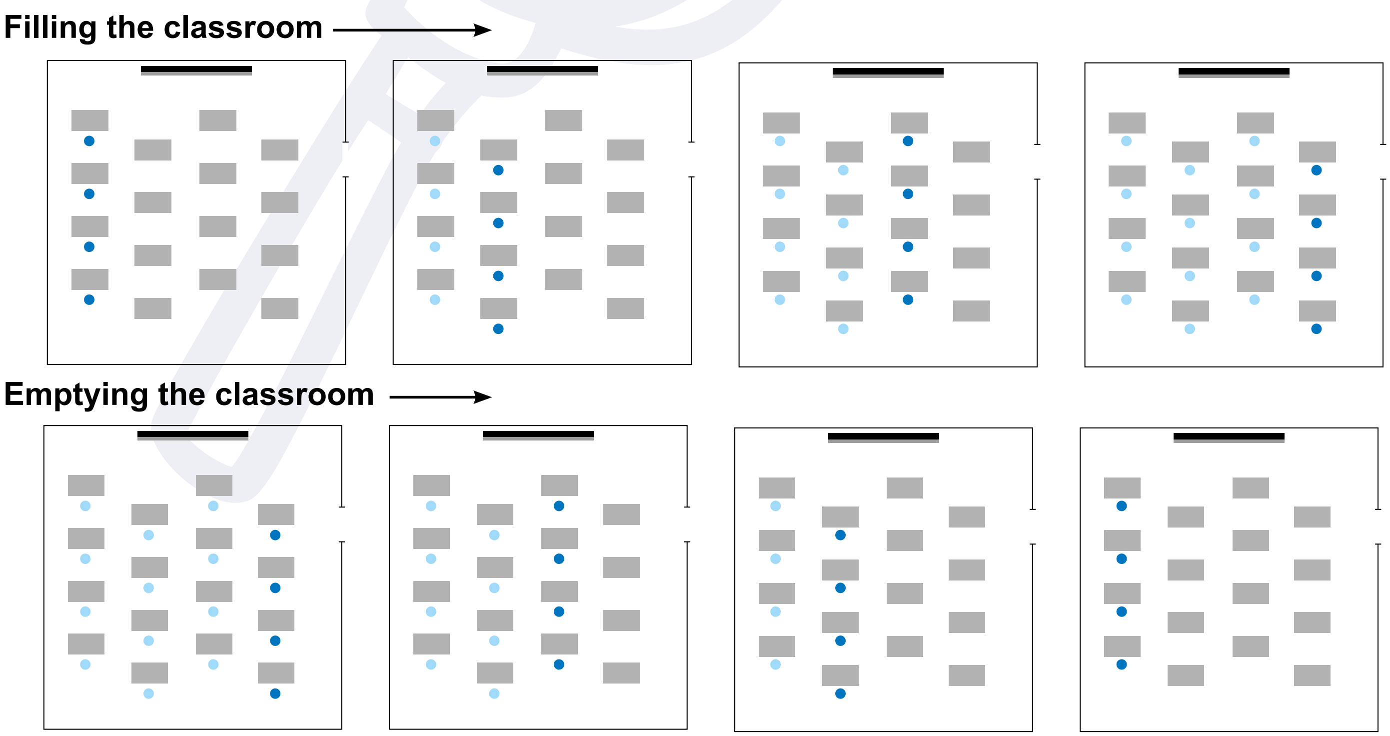


Figure 5 – If possible, entrance into (top row) and departure from (bottom row) classroom would be done by rows. Those seated farthest from the door enter first and those closest to the door leave first to avoid those seated closest to the door being exposed to the concentrated fresh exhalation cloud of all those needing to pass by.

Air management

Typically, an adult inhales/exhales about 0.5 L of air per breath during normal tidal breathing. This results in about 6 L/min, 360 L/hour or about 2500 L/workday of 7h (2.5 m^3/workday). If the shedding is 1000 viral particles per breath (a possible low estimate for SARS-CoV-2), this would result in a cumulative inhaled exposure of about 12500 viral particles/hour or 88000 viral particles per workday, assuming no ventilation. At this time, we do not know the dose required to cause infection (the *infectious dose*) for COVID-19, particularly with the new variants. However, these simple very low bound estimates illustrate the competition between 1) *the duration of occupancy* of the indoor space; 2) *the level of shedding* from the infected asymptomatic occupant; 4) *the removal or deactivation rates* of viral particles via localized or room-scale air management modalities. They all compete to determine *exposure* from such shedding, in addition to whether inhalations occur in the near-field versus the more dilute far-field **[Figs. 1 and 7]**. *In this section, we now focus on air management to promote increase in removal of viral particles and limit exposure from inhalation.*

Infectious dose – amount of live virus that needs to be inhaled in order to cause an infection. **Exposure –** cumulative amount of live viruses inhaled over a certain activity or presence in a given space over a given time. If the exposure exceeds significantly a person's infectious dose the **risk of infection** is high.

Air handling systems vary (HVAC). Some inject only outdoor fresh air, some partially recirculate used air before re-injecting it. Where and how the air is injected at inlets and removed at outlets also differ. Some are based on mechanical mixing (injection and removal from the top of the room), others on displacement ventilation (injection from the bottom of the room and removal from the top), and yet others on natural ventilation. *It is important to evaluate what system is in place in schools to optimize and improve what is available.*

Average versus localized transient flow patterns. Average (in space and time) indoor air conditions are important to assess (*e.g.,* ACH), but transient localized flow patterns are equally as important to assess when planning space usage and seating arrangements indoors with respect to venting.

Overall, aim to increase the ACH, but avoid the creation of strong localized flow patterns as they can transport contaminants in a directed manner to others ***[Fig. 8]****. They can also create trapping regions of contaminants that can remain sheltered from removal, even if the ACH estimation is thought to be high.*

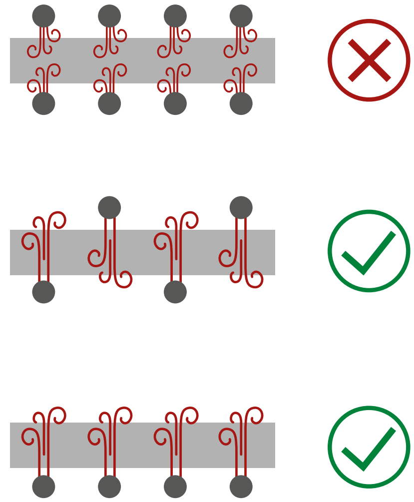


Figure 6 – Seating arrangements during meals or unmasked activities should avoid face-to-face configurations (top). This can be achieved with staggered seating (middle) or single-side seating (bottom) if space allows. All activities that require unmasking (including eating) should, to the extent possible, be performed outdoors and be staggered in time or take place with as few people as possible in the largest space possible and for the shortest time possible.

Hence, the contamination distribution and exposure risk in an indoor space are shaped by *both* the steady-state (ACH) and the localized transient flow patterns. Localized strong consistent air flow patterns are particularly important to avoid when planning seating arrangements or adding ventilation sources (*e.g.,* opening windows or addition of localized air filters).

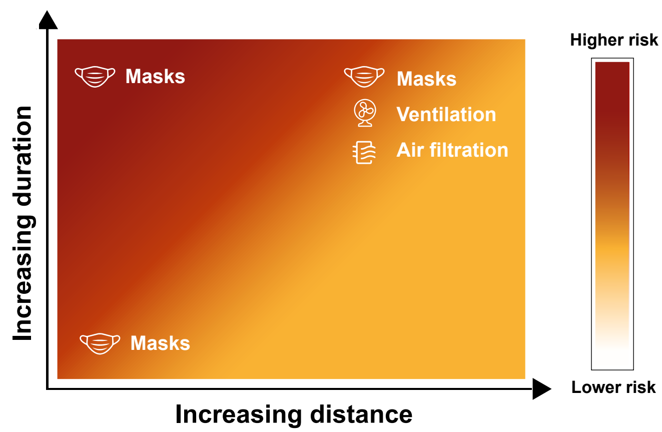
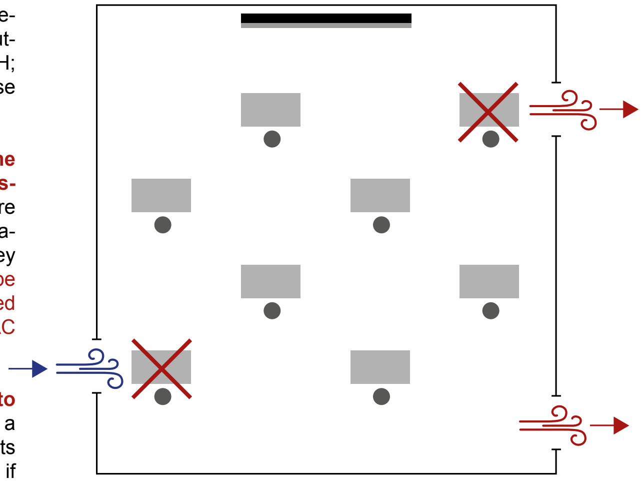


Figure 7 – *Illustrative rendering of the contributions of duration and distance to exposure and risk of infection to viral particles from a virus-shedding individual. For a given infectious dose, exposure (and hence risk of infection) can be equally high if one is present for a short duration in close proximity (near field; bottom left) of a virus-shedding individual or for a longer duration further away of fresh and dense exhalate (far field; top right). Mitigation strategies, such as well-sealed, high-grade masks* ***[Fig. 3, bottom]****, increased clean air injection via ventilation, and high grade air filtration reduce exposure to viral particles in the air and hence reduce risk of infection.*

Avoid seating a person right at the fresh air inlet (within 2 m). An inlet can be a diffuser for HVAC mechanical mixing or displacement ventilations; the outlet of a portable air-purifier added to enhance the ACH; or a window/door used (with or witout fan) to increase natural fresh air *intake*, for example.

Avoid seating individuals right at (within 2 m) the air outlet/exhaust, where contaminated air is flushed out. Individuals positioned in such a manner are exposed to a higher amount of virus particles cumulatively over time than those seated further away: they would be at a higher risk of infection. An outlet can be the suction part of a portable air-purifier, wall-mounted suctions of mixing or displacement mechanical HVAC systems, or a window/door used for air flushing.

Avoid placing localized fans close (within 2m) to a person upstream of all others. If placed in such a way, the fan extends their exhalation zone and directs it effectively to others. Note also that fans alone – if not combined with filters – only recirculate and mix air: they do not clean it.



Avoid placing students right at (within 2 m) air purifiers, like for other inlets/outlets.

Avoid creating one strong dominant flow pattern with air purifiers: prefer multiple smaller capacity purifiers in various locations in the room to one large-capacity unit. They should add up to reach the desired ACH in the room. Keep in mind the selection of low noise level units for occupied spaces.

Figure 8 – Avoid 1) creating strong directed flows and 2) seating students right (within 2 m) at air intake/inlet and exhaust/outlet locations (*e.g.,* a diffuser from the HVAC mechanical ventilation, a window for natural ventilation, or a air purifier inlet/outlet for enhanced ventilation).

Heating, Ventilation, and Air Conditioning (HVAC) – Ventilation system in a building. **Minimum Efficiency Reporting Value (MERV)** – Rating system of a filter's ability to capture particles; higher values indicate better ability to capture/filter particles. **High Efficiency Particulate Air (HEPA)** filter – filters at least 99.97% of particles of size 0.3 µm. **ACH** – number of Air Changes per Hour. **CFM** – Cubic Feet per Minute. **Clean Air Delivery Rate (CADR)** – CFM of air that had all particulate matter of a given size removed.

Evaluation of ventilation performance. Evaluate building air handling systems for both winter (heating) and summer (cooling) conditions and assess presence of used air-recirculation (often used for energy efficiency purposes):

• Ensure (not just assume) that maximum system design ACH capacity is reached. Adjustments are often needed to *maintain maximum ACH*.

• Engage with Testing, Adjusting, and Balancing (TAB) engineering services to evaluate suction capability and ensure proper calibration of air vents and highest MERV grade compatible with fan/exhaust system installed. If resources allow, upgrade fan/exhaust system to enable higher MERV grade filtration.

Ventilation systems should ensure a minimum ventilation of 10-15 L/s/person (20-30 CFM per person) in indoor spaces.

• *If air recirculation (of used air) is built into the Heating, Ventilation, and Air Conditioning (HVAC) system, assess feasibility of revision to limit such recirculation to maximize injection of outdoor fresh air. Ensure that inlets bringing in outdoor fresh air are not close to the exhaust outlets.*

• *If recirculation has to be maintained, ensure that filtration of recirculated air is possible with usage of the maximum MERV grade filters that the ventilation system can handle. A HEPA, or MERV of 13 or 14 is preferred for virus filtration. However, increasing filtration levels can lead to significant pressure drop across the filter (increase in resistance). As a result, choose filters that do not limit air-changes, which can occur, if the suction/vent system in place cannot withstand the pressure drop induced by a high-grade filter.*

• Ensure that air handling and filter systems are checked regularly and up to specified and required performance prior to start of school year. If resources allow, and when needed, upgrade the mechanical ventilation system to higher capability. Again, the ideal clear air supply to minimize airborne disease transmission due to buildup of contaminants would be a minimum of 10-15 L/s per person, or 20-30 CFM per person in a space.

• After full check and upgrade/rebalancing, a regular schedule should be established for all air handling (including roof-top) units to check filters for clogging and to detect and address deterioration in performance early to ensure highest level of air changes the air handling system allows. *An increase in noise, vibrations, CO_2 or particle levels can be a sign of clogged filters or more generally of deteriorating performance. Adding monitoring devices to check for these metrics for warning is advised.*

*• Identify where HVAC intake and exhaust are installed in classrooms and common areas: use such information to map occupancy of the space, for example position the desks to ensure that no student or staff is sitting right at the source of incoming fresh air distributed to the full class, nor that one is sitting right at the outlet of the outgoing, potentially contaminated air **[Fig. 8]**.*

Air management considerations

*• If mechanical ventilation and filtration are sub-optimal or sub-standard, natural ventilation should be considered, such as opening windows and the addition of local (low cost) window fans to force air from the outside into and out from the classroom. However, here even more caution is needed: 1) the exhaust fan should not blow out onto a common occupied area (e.g., hallway or outdoor eating area) unless it is appropriately filtered; 2) When positioning such localized airflow sources at the same height as the occupants' breathing zone (e.g., window/door level), it is critical to ensure that no individual is sitting right at the outlet of air from the class **[Fig. 8]**.*

• Between classroom usage or during breaks, open windows and classroom doors for as long as possible and use fans as much as possible to help provide fresh air. Also consider opening windows and doors before room usage in the mornings and after room usage in the evenings.

*• Screens should be used judiciously as they can partially trap the exhaled gas cloud, thus creating pockets/zones of concentrated and recirculating contamination that require an increase in time and overall airflow to clear **[Fig. 9]**. It is thus preferable to maintain separation screens only for a very short period if no additional localized air filtration systems are deployed with them.*

• Particularly when natural ventilation is difficult to use (*e.g.,* very cold or very hot days) consider having contingency localized portable air filtration systems added in the classrooms to increase the ACH using their additional mechanical filtration. These units should be high-rate recirculation units with HEPA-level filtration. For selection, the units have to be evaluated with respect to square footage of the classroom and duration of use. For example, a 600 CFM unit would cover the minimal 15 L/s/person for 20 individuals in a space. Here too, the airflow patterns created by the portable air filters/cleaner/purifiers have to be managed: minimize 1) localized strong flows, and 2) seating at the inlet/outlet of the units **[Fig. 8 and see section on Air Purifiers]**.

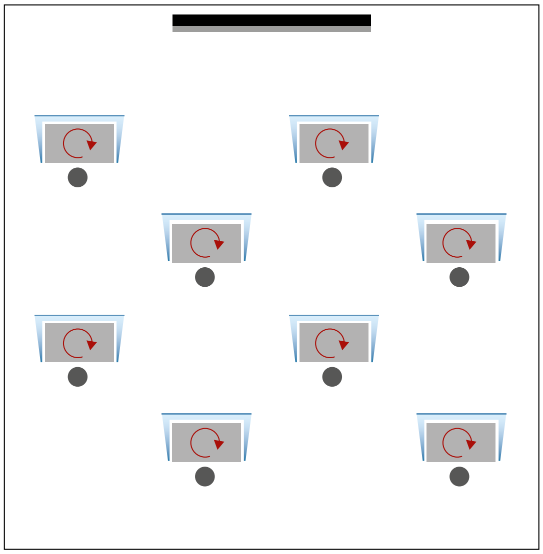


Figure 9 – Screens limit the range of exhalaed large projectile emissions and slow down and divert the exhalation cloud. They do not prevent the cloud to eventually seep past. Depending on their design, they can result in pockets of concentrated recirculating contaminants that may take longer to clear through room-level ventilation and air filtration systems.

Displacement ventilation. Displacement ventilation is an effective manner of utilizing natural buoyancy (formed by natural heat generated from occupants and devices such as computers) to concentrate the heat and the contaminants shed from breathing/exhalation at upper levels of a room where an exhaust is typically located. This air is replaced slowly by colder and cleaner air injected from the lower levels of the room (floor or desks). This ventilation type is energetically effective as it leverages the natural buoyancy generated by occupants. *When optimized, displacement ventilation can also be more effective than mixing ventilation at reducing exposure to built-up contaminants from occupants and can ensure a cleaner breathing zon*e. Institutions are encouraged to evaluate the possibility of usage and installation of localized displacement ventilation solutions, particularly important for summer/fall months. Such solutions involve a range of local air injection diffusers that ought to be installed at lower levels.

Certain caveats apply for displacement ventilation to be optimal:

• The rate of injection of clean and cool air at lower levels need to be matched to room occupancy, which driving the upward flow and stratification.

• Rooms need to be of sufficient height (typically at least 8 feet) to ensure that the contaminated and warmer air layer is high enough to be outside of the occupants' breathing zone.

• *Special consideration must be given to slanted amphitheater-style auditoriums so the upper, warmer, contaminated layer is not in the breathing zone of students sitting in the upper back rows.*

Air purifiers. When injection of clean outdoor air is harder to achieve, air purifiers can be added locally to each classroom to filter and recirculate local air. Several characteristics ought to be kept in mind when choosing air purifiers.

• As with other ventilation approaches, the capacity (in terms of CADR or ACH) and number of air purifiers should be matched to the size of the room and occupancy or to complement the existing HVAC ACH parameters.

• *As some air purifiers have 360-degree suction configurations while others have unidirectional inlets, the inlet/outlet configurations should be kept in mind when considering placement of the units to not create strong directional airflows **[Fig. 8]**. To mitigate strong directional currents, one may prefer a few small units distributed in the indoor space over one large one.*

• To enable normal conversational teaching, the overall noise level should remain below about 60 dB if the air purifiers are to be used while classes are in session. For reference, a modern refrigerator produces about 50 dB of background noise.

• Ideally consider mechanical filters in which particles are removed by attaching to the filter, and particularly HEPA filters or high level filtration that removes particle sizes in the 0.1-1 μm range effectively.

• *Filters clog easily, which is the desired outcome if they work, particularly when air purifiers are in constant use. Hence, they require maintenance. A regular testing and maintenance schedule should be established, according to the manufacturer's recommendation or more frequently if a unit's noise or vibration level increase.*

• Be aware of ozone-generating systems or other emerging technologies that do not have data available to back up claims. In particular ozone should not be used in occupied spaces. Ionization technology claims should ensure that no derivatives such as ozone are produced. The EPA suggests looking for UL 2998 standard certification. The EPA designates an ozone limit of 0.08 parts per million.

SURFACE MANAGEMENT

• Increase frequency of cleaning of bathrooms, classrooms, and common areas (corridors) to multiple times a day and particulalry between usage by different age groups/pods if a common space is used.

• High-frequency cleaning should include door handles, faucets, handrails, light switches, common teaching equipment, or soap dispenser/hand sanitizer handles [prefer foot or non-contact knobs].

• *If screen separators have to be used **[Fig. 9]**, thorough decontamination of screens, after meals for example, is required. Again, it is important to plan for air flushing of the room (while wearing masks) with increased natural or mechanical ventilation after cleaning and removal of the screens or their usage. The goal is to ensure reduction of contaminant build-up due to local air stagnation **[Fig. 9]**.*

• Engage students in surface decontamination with safe cleaning supplies (*e.g.,* wipes) for decontamination of their dedicated and consistently assigned desk and chair upon entrance into and departure from the classroom for the period, and/or prior to usage of that space by another pod.

• As outlined in the context of mask wearing, ***gamification*** and rewards can be considered to incentivize students to participate in regular surface decontamination, including hand washing (*e.g.,* team/pod reward point system).

RESOURCES

• EPA resource on MERV filter rating.

• EPA resource on HEPA filter.

• ASHRAE on Mechanical filtration.

• Technical ASHRAE resource for building management.

• Online resource for converting CFM to L/s (to estimate the L/s/person needs of a space).

• Online tool to compute noise pollution from different noise sources (*e.g.,* multiple air-filters in an occupied space).

• *Other resources and illustrations of concepts can be found at healthy-teaching.org.*

DISCLAIMER

This document seeks to address the many questions the author has received frequently over the past 18 months from parents, educators, school administrators, supply managers, or industry around the world. It seeks to succinctly synthesize information from the research literature, ongoing research, and standard documents from a range of public health agencies and professional societies. It also aims to complement guidance provided by the U.S. Centers for Disease Control & Prevention and the World Health Organization in particular for programs of regular testing and vaccination.

Given the dynamic nature of the pandemic, some of the work highlighted is very much in flux, and new insights will be added to this document as they become available. Refer to healthy-teaching.org for updates.

PARTNERS

Fields Institute for Research in Mathematical Sciences – COVID-19 Task Force. The Fields Institute COVID-19 Task Force mobilizes a network of infectious disease modelers and public health experts to assess transmission risk, predict outbreak trajectories, evaluate the effectiveness of COVID-19 countermeasures, and guide production of policy recommendations.

Prof. Chappell Lawson and Dr. Dan Pomeroy, MIT Policy Lab. The mission of MIT's Policy Lab at the Center for International Studies is to develop and enhance connections between MIT research and public policy, in order to best serve the nation and the world in the 21st century.

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