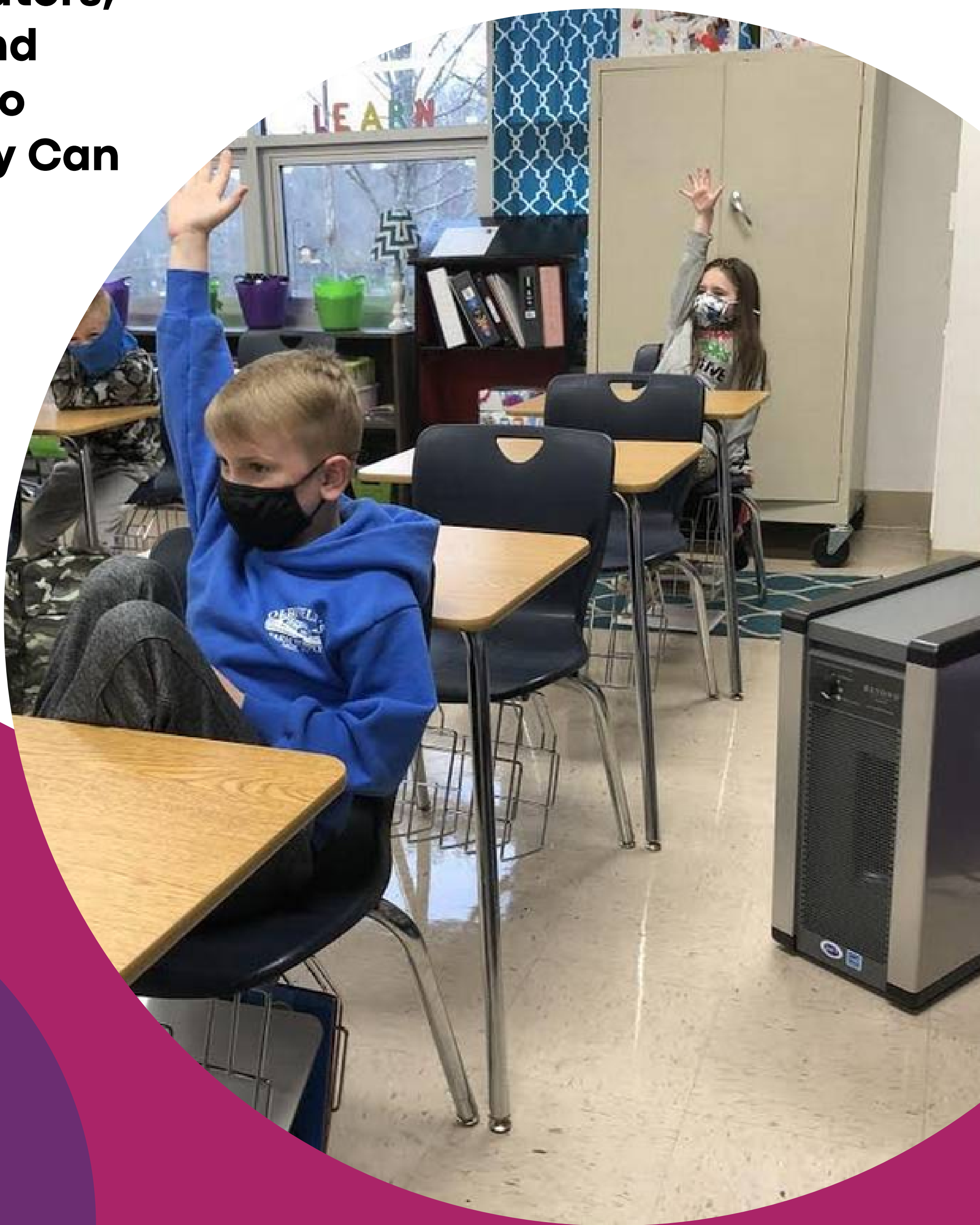
Ventilation for Coronavirus in Schools

What Schools, Educators, Students, Parents and Communities Need to Know and What They Can Do



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The pandemic made visible the inequities of our health and the health risks we face, and the inadequacy and inequities of healthcare in our country in shocking clarity (Ref 1). The gross inequity in our nation is also reflected in our schools, especially since in much of the country, a large part of public school funding comes from property taxes. This system of funding public schools guarantees more funding for high income neighborhoods than lower income ones and helps to preserve and reproduce inequalities of race and class. [On a national basis in the school year 2017–18, revenues from local property taxes comprised 37 percent of total revenues for public school districts, even as federal revenues declined from 13% to 8% during the eight years preceding 2017-18 (Ref 2).] Under-resourced schools are more likely to have broken-down, unmaintained ventilation systems, or to lack ventilation systems altogether and to lack air conditioning altogether.

A recent study showed that temperatures above 80 degrees resulted in lower scores on standardized tests. Another study showed that Black and Hispanic students in the US are disproportionately subjected to such temperatures both at school and at home because of lack of air conditioning (Ref 3).

According to an article in the Philadelphia Inquirer in July of 2020, schools in Philadelphia–where one in four families lives below the poverty line (Ref 4)–need a lot of help with old ventilation systems (Ref 5). “The average life expectancy for commercial heating, ventilation and cooling (HVAC) units is 15 to 20 years,” the article states, while “The average age of public school buildings in Philadelphia is 75 years.”

Similar problems are common to many school systems: A June 2020 study released by the Government Accounting Office (GAO) showed through sampling of 55 schools (in 16 districts across 6 states) that an estimated 41% of districts need to update or replace HVAC systems in at least half of their schools; this translates to about 36,000 schools across the nation in need of updates to or replacement of their HVAC systems (Ref 6).

Some HVAC repairs cost up to a million dollars per building. In addition, upgrading HVAC systems alone is often not enough. Like any other mechanical system with many parts, HVAC systems must be properly installed and periodically monitored and maintained to ensure adequate classroom ventilation. All of these processes are expensive.

Air quality matters

Air quality in schools is an important piece of the puzzle for protecting the health of students, educators and staff. The purpose of a ventilation system is to provide clean air at a comfortable temperature and humidity. A broken or inadequate ventilation system can result in air that is polluted by both indoor and outdoor pollutant sources and/or at uncomfortable temperatures and humidity. People experiencing unhealthy air quality know (and many studies have confirmed) that poor air quality has serious consequences for student performance, absenteeism, and even teacher retention (Ref 7, 8 and 9).

Ventilation improves air quality in two ways: **diluting** the virus and other pollutants with fresh air and **filtering** the air. Indoor air may contain many more pollutants than the Coronavirus, including indoor sources, such as asbestos, mold, dust from renovation and cleaning supplies, as well as outdoor sources, such as pollutants from vehicles, wildfire smoke, pesticides used on the grounds and construction debris.

This article is addressing primarily the COVID virus–and any future respiratory viruses**.** The virus is different from all the other pollutants, in that infected building *occupants are the source* of pollution, and the virus-containing droplets are much smaller than most pollutants, requiring better filters and more dilution. If ventilation is upgraded to address the virus, it will address other pollutants as well.

We now know that social distancing is not enough to protect people from the virus – the CDC recommendation for social distancing of 6 feet was based on early confusion about how the virus moves in air. While it is true that large virus-containing droplets produced by coughing and sneezing do fall to the floor on average within about 6 feet from an infected person, they can be projected much further (Ref 10). But later it became clear that much smaller droplets, called aerosols, are produced just by breathing (and more are produced by talking, singing and laughing, as well as sneezing or coughing). The aerosols are so lightweight that they don't fall to the ground.

Rather, they can float in the air for hours (Ref 11), unless diluted with outside air or trapped in a filter. In addition, a 2021 study showed that the greatest amount of viruses emitted by infected people are contained in the smallest aerosols (Ref 12) That makes both filtration and dilution with fresh air more important than ever.

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Types of ventilation systems in schools: HVAC, unit ventilators or a combination

Some schools have a heating, ventilation and air conditioning (**HVAC**) system that delivers air to rooms throughout a building via ducts. The HVAC system is supposed to filter as well as heat or cool the air and address humidity before blowing it into rooms. Some percent of the air delivered should be outside air, and the rest is recirculated room air. *It is very important that a large portion of the air be outside air.* Other schools have **unit ventilators**, which are heating/air conditioning units in each room. Many schools have combinations of HVAC and unit ventilators. (See **Appendix 1** for diagrams of these two types of ventilation.) Some schools rely on windows. Issues with all of these are discussed below.

Problems with school ventilation systems

1) HVAC systems may be poorly designed, operated and/or maintained. A properly designed and properly functioning HVAC system both filters air and dilutes pollutants, and provides heating/cooling and humidity control. But poor design, operation issues and/or lack of maintenance are common. In fact, it is rare that school HVAC systems operate according to design, even when they are well designed (Ref 13).

Common design issues include:

- *Demand-control* ventilation that automatically reduces the amount of outdoor air that is pulled into a building, often in response to temperature control or carbon dioxide monitors in ventilated rooms.[1] This is common in newer schools.
- Outdoor air intakes are sometimes too close to exhaust outlets (from the HVAC, plumbing, kitchen, toilets or labs) or to other pollutant sources and draw exhaust or other pollutants in with the outside air.
- The HVAC system can't handle filters that capture virus-containing particles.

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Common <u>operational</u> issues include:

- Filters don't fit tightly and may allow air to bypass them.
- Reducing outside air when the weather is very hot or cold, in order to reduce heating and cooling costs. Outside air dampers may be closed entirely, especially in cold weather when they may need to be closed *only in the coldest hours* to prevent pipes from freezing. Some buildings don't have enough personnel to monitor the dampers.
- Finally, HVAC systems, like any mechanical systems, must be kept clean and in working order. Some employers do not budget enough to pay for skilled personnel or maintenance costs.

2) Unit ventilators cannot be considered ventilation, if they do not filter air or attend to its humidity. They are heating/cooling units only, except some newer models that can house good filters. For those lacking adequate filters, their one helpful function is that they are designed to bring in fresh air (though not very much) through the wall behind them, but many are installed without attaching to the outside. You can tell by looking for louvers on the outside wall. Unit ventilators can be set with dampers for anywhere from 0 to 100% outdoor air.

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Just as with HVAC outside air dampers, there may not be personnel to open and close them daily to avoid keeping them open at night in freezing weather. Many unit ventilators are old and malfunction. Their outdoor air louvers may be stuck shut, and they may be dirty and/or moldy. The filters in older units are useless for removing virus-containing particles–similar to those in a window-installed room air conditioner. The filter is just there to protect the heating/cooling coils from dust and debris. So unless they are clean and bringing in 100% outside air, they are just recirculating contaminated room air, and in some cases further contaminating room air with dirt and mold. Even if the unit runs at 100% outdoor air, it usually provides only about 1 to 2.5 air changes per hour (ACH). The recommended air change rate for virus contamination is 6 to 12 ACH. (See **Appendix 2** for an explanation of ACH and other ventilation measures). Also, incredibly, though air comes out the top of the unit, there are many classrooms with books and debris on top of the units, blocking the air flow!

Sometimes desks or other items are backed against the units, blocking the exit of room air into the unit. **Even an operable, clean unit ventilator bringing in 100% outside air must be supplemented with HEPA air purifiers in the classroom!**

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3) Problems with windows. In buildings which lack an HVAC system, you hear a lot that opening windows is a quick fix solution. They can help, but they are a limited solution and ***never* should be relied upon by themselves for ventilation** for COVID**.** The primary reason is that they do not provide filtration. Several additional reasons include: they can only be used if outdoor temperatures are moderate, and their effectiveness depends on weather conditions, such as wind; if a school is located among streets with heavy traffic or other pollution sources, opening windows may bring in pollution and noise; if the windows lack screens mosquitoes may enter, which could be a public health concern in some areas. Finally, open windows without bars may be a security or a falling concern.

Many schools have windows that do not open. A helpful fix for those schools might be to get the windows made openable, but keeping in mind that windows are never a solution by themselves.

Bear in mind that the International Mechanical Code requires all occupied spaces be served by natural or mechanical ventilation that includes providing outside air (Ref 15). Sometimes rooms are "created" where they were not intended to be (like basements or supply closets), and thus have no ventilation, but these should not be occupied.

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Do-it-yourself filtration units are a last resort with many drawbacks

Some scientists have developed a DIY unit created by taping together filters in a box formation with one face of the box a fan. Building managers need to add filtration in the form of professionally designed and tested portable units with HEPA (high efficiency particulate air) filters. HEPA filters capture virtually all viral particles, whereas the DIY unit can capture as little as 50% of the most hazardous aerosols; because they are not enclosed, replacing filters may be hazardous, labor intensive and expensive. (Please see Appendix 3 for details on problems with DIY units.)

The path to excellent ventilation

For schools, parents, students, educators and others in the community who want to work to improve ventilation in their schools, here are some steps to take on that path. Note, whenever the word “you” appears, it is referring to you as a group, because, as you know, it’s hard to win any changes as an individual!

- Educate yourselves about good ventilation by reading this document and related references.
- Learn about the status of ventilation in your schools. You probably already have an idea from the experiences of students and educators. Ask for a meeting with the person(s) who maintains and operates the ventilation system. You can also request a walkthrough of the school and ask the same person to respond to your questions where possible. Appendix 4 lists what to look for on a walkthrough and questions to ask at a meeting.

- Prioritize the improvements that are needed, using the recommendations in this document as a guide, get more people together in the community interested in advocating for adequate ventilation in schools, and present your priorities to the administration, school board or other individuals and bodies who control school funding.

Recommendations

1. Top priority: Ensure that the Ventilation System in combination with HEPA filtered air purifiers provides 6 air exchanges per hour of outside air plus HEPA filtered air, in order to be effective at reducing the spread of the COVID-19 by aerosols produced by an infected person.

2. Seek to maintain relative humidity between 40 and 60%, which may reduce the potential for airborne viral transmission.

3. School systems should install mechanical ventilation systems where none exist and upgrade those that do not meet current standards. If schools rely only on natural ventilation (open windows and doors), HVAC systems should be installed. Upgrades to facilities will take time but will improve ventilation in schools for the long term and will pay off in terms of improved health and classroom outcomes and teacher retention.

4. **For all schools:** In almost every school, all classrooms and other occupied spaces should be provided with portable air purifying units with HEPA (high efficiency particulate air) filters. Only if an HVAC can use HEPA filters (which very few can) *or* provide at least 6 air changes per hour of 100% outside air, are the HEPA air purifying units not needed. (See **Appendix 2** for details on filters and air changes.) One CAVEAT: these units can be noisy, causing educators to sometimes turn them off. Shop for the quietest units.

   a. Inspect and maintain *exhaust* ventilation in areas such as kitchens, cooking areas, and especially where exhaust exists in high risk areas such as nurse's office and isolation rooms, and medium risk areas such as special needs classrooms. Operate these systems any time these spaces are occupied. Operating them even when the specific space is not occupied will increase overall ventilation within the occupied building.
   b. Ensure that restrooms are under negative pressure—that is, air always flows into the restroom and is exhausted to the outside of the building. The exhaust fan should be on all the time. Be sure airflow into the restroom does not interfere with the ventilation of adjacent spaces.

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c. Ensure that any free-standing fans or air purifying units are not blowing air from one person's breathing zone directly into the breathing zones of other persons nearby. Having the purifying unit blow upwards accomplishes this.

5. **For schools with HVAC systems**.
    a. Ensure that the HVAC system is working as designed. Ensure that the HVAC system complies with or exceeds appropriate codes, standards, guidelines, and supplier instructions.
    b. Schools should provide spaces with ventilation and HEPA filters where students can eat unmasked, possibly including outdoor tents when weather permits.
    c. Disconnect from the HVAC system any device that operates the fan or outdoor air louvers in response to CO2 levels or temperature. Instead, operate outdoor air louvers manually or remotely. Alternatively, it may be possible to set the louvers to deliver a set minimum of outside air.

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d. In buildings where the HVAC fan operation can be controlled at the thermostat, set the fan to the "on" position instead of "auto," to operate the fan continuously, even when heating or air-conditioning is not required.
e. Ensure that the ventilation system brings in as much outdoor air as the HVAC system will safely allow. Ensure that the HVAC system uses the highest efficiency filters the system can handle (MERV 13 or higher, if possible). The outside air setting should compensate for having MERV 13-16 filters, by adding 20 to 40% outside air, preferably 40%. If HEPA filters are used, outside air can be set at 20% for comfort.
f. Ensure that filters are sealed in place using tape, clamps, gasket or other methods, to prevent contaminated air from leaking around the filter, and test for air leaking around them.
g. Start the ventilation system at nominal speed at least 2 hours before the building usage time and switch to lower speed 2 hours after the building usage time. This will help flush any contaminants before and after occupants enter the building (Ref 16).

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h. Ensure that the HVAC system is checked, inspected, cleaned, and maintained on a regularly scheduled basis. System performance (for example, airflow rates) should be checked regularly. Filters should be changed about every 3 months. For further guidance, consult Ref 16. Consider checking airflow regularly, perhaps weekly, either by occupants using the tissue test or by facilities personnel. If handheld CO2 monitors are used, consider that they cannot prove good HVAC function: Since CO2 is produced by room occupants, a low reading may reflect few people in the room, rather than HVAC function. Airflow measurements are a much more reliable measure of HVAC function.

i. Ensure that air supply and return louvers in the rooms, as well as outdoor air intake louvers are open, clean, and operating properly.

j. Take steps to ensure that outdoor air sources are not located near sources of contamination, including exhaust from the HVAC, kitchens, toilets or labs, stored chemicals or very dirty areas.

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6. **For schools relying on windows**
    a. Ensure that windows alone are not relied upon as the sole source of ventilation. **Windows should be used in conjunction with portable HEPA air purifiers.**
    b. Consider how best to use windows to contribute to ventilation.
    c. When windows are used for ventilation, they are most useful if two windows on two different walls are used, providing cross ventilation. Similarly, opening a window and a door on an opposite wall can improve circulation (depending on whether the door opens into a space with clean, circulating air).
    d. If a room has windows on only one wall, you can experiment with different arrangements of intake fans (blowing into the room) and exhaust fans (blowing out). Opening two windows at a distance from each other and providing an intake fan in one and an exhaust fan in the other is sometimes recommended. But they can easily short circuit each other–circulate air between the fans and not the room. You could check this with tissues to see where air is flowing. Or you could open two windows, and put an exhaust fan in one, and allow outside air to be drawn into the other.

d. If there is an open door in the room that might draw unclean air into the room, as for example, from a bathroom or lab with a malfunctioning exhaust fan, it might be better to put an intake fan in one window.
e. If you're using pedestal or free-standing fans to increase circulation within the room, be sure to avoid blowing air from the face area of one student toward the face area of another student.
f. If windows are jammed or designed not to open, ventilation must be achieved with one or more portable air purifiers with HEPA filters. If possible, consider repairs that allow windows to open.

7. **For schools relying on unit ventilators.**
    a. If the ventilators have openings to the outside, ensure that maximum outside air is used.
    b. Ensure that all elements of the ventilators are maintained in clean and operable condition
    c. Since most ventilators have neither adequate filters nor capacity for adequate air changes, ensure that they are supplemented by portable air purifiers with HEPA filters, and ideally, by an HVAC system providing maximal outside air.

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8. **Avoid barriers as a protection measure.** Some schools put up barriers between students to reduce the spread of infection. However, if you consider that aerosols containing COVID behave like smoke–they will find a route over the top, under and around barriers. You would need floor-to-ceiling barriers to prevent this. But even that is not a good idea, because any barrier is likely to interfere with the ventilation system and reduce its effectiveness in replacing contaminated air.

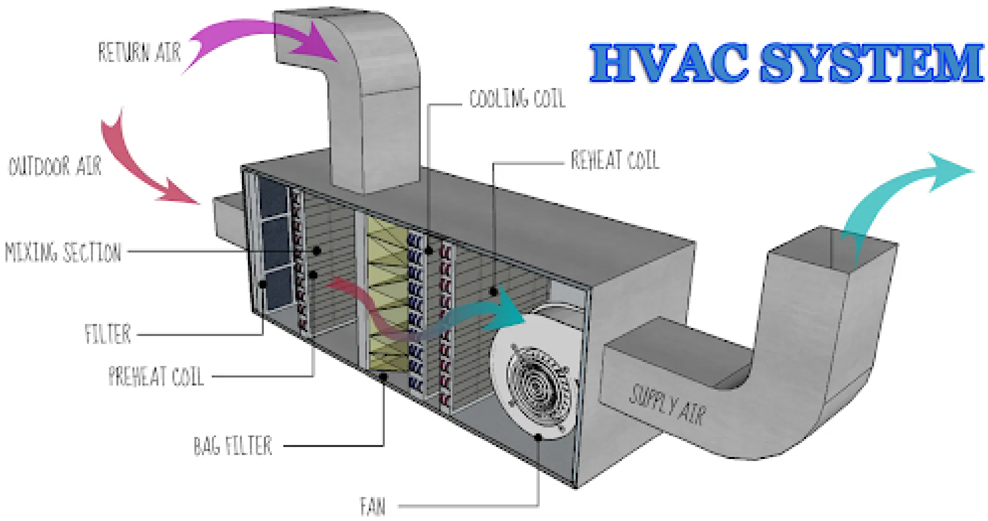
9. **Avoid hazardous air cleaning methods.** School systems should use only proven technologies for improving indoor air quality: appropriate ventilation and HEPA filtration. They should not use chemical foggers or misters or any ”air cleaner” other than filtration. School systems should not use unproven technologies such as ozone generators, ionization, plasma, and air disinfection with chemical foggers and sprays. They are ineffective and the effect of these cleaning methods on children has not been tested and may be hazardous to their health.

The primary aim for improving air quality should be to remove contaminants and impurities from the air and not to introduce new substances into the air.

Appendix 1

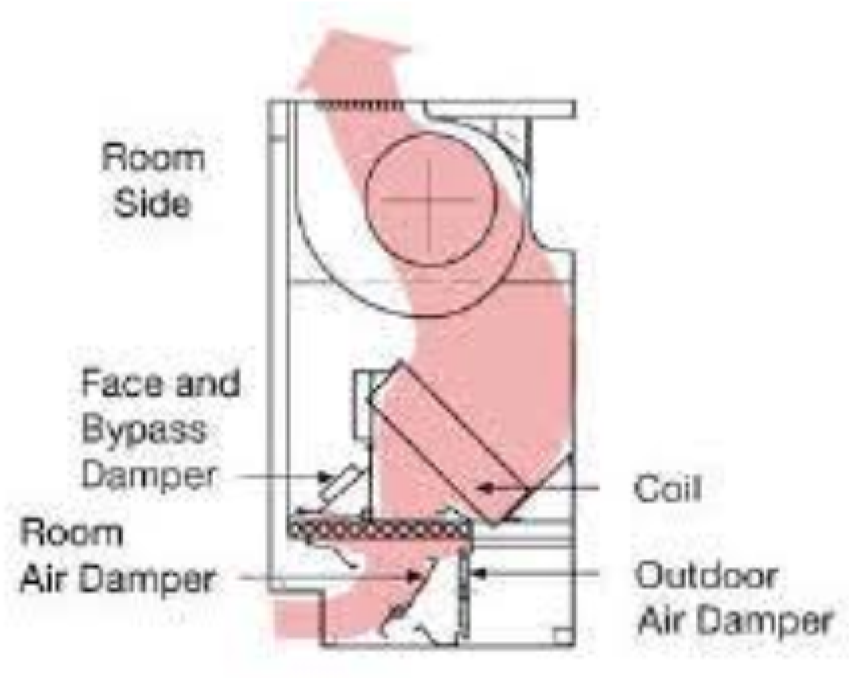
Diagram of HVAC System

Below is a diagram of the basic elements of an HVAC system. The air handling unit takes in a mixture of room (return) air and outside air and passes it through a filter. There are louvers somewhere on the outside air and recirculated air ducts which govern the proportion of each entering the mixing section. Then a fan sends the mixed, filtered air through heating/cooling coils and out to the rooms to be ventilated. **Note the HVAC in this picture has a bag filter, not a MERV 13 or higher filter recommended for virus protection.**



Appendix 1 (cont)

Below is a diagram of a classroom unit ventilator. The perimeter wall is on the right. At the bottom there are places for recirculated room air and outdoor air to enter. Note the diagram shows the outdoor air damper fully closed, and the recirculated air damper fully open– just the opposite of what you want. The big circle with a plus sign is on the fan; the coil is a heating or cooling element; the crosshatched horizontal thing is the filter.



Appendix 2

Actual ventilation numbers: How much filtration? How many air changes? How much outside air? And how do you measure airflow?

What filters should be used?

Filters are rated on their ability to capture particles by a system called MERV, or minimum efficiency reporting value, on a scale of 1 to 20. The higher the MERV rating, the better the particle capture. Ideally, HVAC systems would use MERV 17 filters, which are equivalent to HEPA, or high efficiency particulate air filters. However, HVAC systems may not be capable of using that level filter. In that case, the administration should use a minimum of MERV 13 filters, if the HVAC system can accommodate them. They can remove >50% in the particle size range of 0.3 to 1 micron and >85% of 1 to 3 micron particles. COVID aerosols are in both those ranges (Ref 21). HEPA (or MERV 17) filters remove 99.97% of particles in that range.

Appendix 2 (cont)

How many air changes (ACH) are needed in a room?

Engineers use air changes per hour, or ACH, to measure the amount of clean air (in the case of virus, this means outside air plus HEPA-filtered air) flowing through a space. If a room is 20 ft wide, 30 ft deep and 8 feet high, the total volume of the room is 20 X 30 X 8, or 4800 cubic feet. One ACH would mean 4800 cubic feet (filtered + outside) of air supplied to the room per hour.

So how many ACH are enough? The group which creates ventilation guidelines respected throughout the country is ASHRAE, the American Society of Heating, Refrigeration and Air-conditioning Engineers. As of August, 2021, ASHRAE recommends for places that may contain viruses, 6 to 12 ACH. The two groups which provide guidelines for workplace ventilation, the American Industrial Hygiene Association, AIHA, and the American Conference of Governmental Industrial Hygienists, ACGIH, both say that at least 6 ACH is needed to control bioaerosol pollutants.[2]

Appendix 2 (cont)

How much outside air or HEPA-filtered air is needed?
The volume or clean air needed in a room is the sum of outside air (unmixed with recirculated room air) and air delivered by portable HEPA air purifier units in the room. To calculate how much is needed, we use CADR, or clean air delivery rate. This is just the room volume X the desired ACH. For the room described above and 6 ACH, the CADR is

4800 cubic feet X 6 ACH = 30,800 cubic feet per hour

CADR is a common metric for rating portable air purifiers.

Another way to look at outside air is to consider what percentage of the delivered air should be outside air, and then consider how long it will take each MERV rated filter to change the air:

1. AIR CHANGES PER HOUR (ACH). The minimum ACH should be 6, which can at best provide a replacement (purge) of 99% of the air in the room in 46 minutes. The more ACH, the better. An ACH of 12, for example, can at best provide a purge in 23 minutes. (Note: purge time depends on how well air coming in is mixed with air already in the room.)

Appendix 2 (cont)

2. FILTER GRADE (MERV RATING). The minimum grade of filter should be a MERV 13 with the MERV 17 (HEPA) being ideal. (If the system will not operate with a MERV 13, the only options are to run the system at 100% outdoor air or supplement with HEPA air purifiers.)

3. THE PERCENTAGE OF OUTDOOR AIR. The percentage of fresh air should be as high as possible with minimums in the following table:

Suggested Minimum Outside Air (OA) at 6 ACH[3]

MRV#	Minimum OA
17 (HEPA)	20%
16	25%
15	30%
14	35%
13	40%
<13	100%*

*Resetting the HVAC system's fresh air intake to 100% will improve protection but can raise heating and cooling costs unsustainably. Even then, the system must provide at least 6 ACH to provide adequate protection. If the HVAC system cannot deliver 100% outside air, or cannot deliver at least 6 ACH of outside air, then HEPA filtered air purifiers are necessary in the classrooms and other occupied spaces. Unit ventilators, even when set for 100% outside air, are not powerful enough to deliver 6 ACH. They deliver 1 to 2.5 ACH, so they too must be supplemented with HEPA filtered air purifiers.

Appendix 2 (cont)

Summary recommendations

- **Filters MERV 13-17**
- **Highest percent of outside air possible from HVAC system and unit ventilators, ideally conforming to the table above of MERV/Minimum OA**
- **Minimum of 6 Air Changes per Hour (ACH), counting only HEPA-filtered and outside air**

A note on measuring airflow

Airflow from a diffuser should be measured with an instrument called a **balometer**, which covers the diffuser with a sort of tent, and measures all the air coming through. It looks like this:

Appendix 2 (cont)

Some people measure air flow with an anemometer. This instrument is NOT useful for measuring airflow from a wide area like a diffuser, because it just measures air velocity at a single point. That won't tell you the flow over the whole surface of a diffuser. It looks like this

You can find detailed instructions for measuring airflow in a guide from the Harvard T.H. Chan School of Public Health (Ref 19)

Request the engineers conduct a study of airflow in rooms served by an HVAC. The data sheet can look like this:

Room #	Room vol cubic feet	Supply air design, CFM	Actual Supply Air CFM	OA CFM	%OA to room	Min required ACH	Atual ACH of OA
Room 1	23,142	3,150	3,188	**956**	30%	6.00	**2.5**
Room 2	11,306	2,900	2,944	**677**	23%	6.00	**3.6**

CFM = cubic feet per minute
OA = outside air

Note: The ACH of outside air is very low. There is no point in calculating the ACH base on supply air, because most of the supply air is recirculated. For example, in Rehearsal room 1, only 30% is outside air, so 70% is recirculated from the room, and can't be considered part of an air change.

Appendix 3

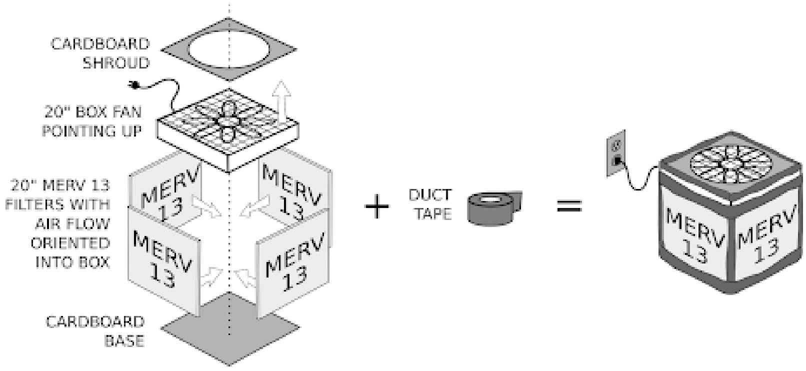
The Corsi/Rosenthal DIY Air Purifier Design–to use or not to use?

Corsi/Rosenthal boxes have gotten a lot of press as an affordable alternative to HEPA air purifying units where resources are limited. We do not recommend it for the reasons described below, and we urge building occupants to push hard for commercial HEPA units.

Here's what the designers say[4]

Several researchers and practitioners, working together and in parallel, have come up with a design for an in-room air purifier which can remove a significant amount of COVID-19 virus from the air. The design involves making a 'box' out of four 20" MERV-13 (or HEPA) filters (the 'sides' of the box), a 20" box fan (the 'top' of the box), and a cardboard (the 'bottom' of the box'). Air flows in through the filter sides, removing particulates of the sizes that can transport COVID-19 particles, and then flows out through the fan at the top.
These devices can be built from parts that cost less than $100 USD, without any special tools.

Appendix 3 (cont)



Here are reasons *not* to use these DIY units

Below, are listed a summary of all the reasons that this system should not be used. This list may make it easier for readers to facilitate a discussion with employers and experts who advocate its use.

#1. MERV 13 CAPTURE EFFICIENCY. The MERV 13 filter captures only some of the aerosols in the size range of 0.3 to 3 microns in diameter (Ref 21).[5] These particles are the most hazardous because 1) they stay airborne the longest, 2) the have a much higher virus load than larger particles (Ref 12) and 3) medical data and an animal study have shown that these smaller particles are also associated with more severe diseases, presumably because the small particles deposit deep in the lung (the alveoli) (Ref 22). HEPA filters capture virtually all of the aerosols in that hazardous size range.

Appendix 3 (cont)

#2. CONTAMINATED FILTERS. If there is an infected person in the room, the filter will capture the larger particles and some of the smaller virus-containing particles. However these particles are now captured on, and in, the MERV 13 filters. Unlike commercial air purifiers whose filters are inside the unit, a person who touches or who moves a DIY purifier will physically contact these filters. Filters are a reservoir for all sorts of particulate contaminants besides virus-containing particles. They may house, for example, dust, mold, allergens, asbestos, or lead dust. Any of these contaminants may be dislodged and shed into the air when the DIY air purifiers are moved around, touched, bumped into, etc. While no study has demonstrated the seriousness of the risk from such shedding, it is something to bear in mind.

#3. CHANGING CONTAMINATED FILTERS. The person breaking down the box and rebuilding the DIY air purifier may be handling four contaminated filters every 3 to 6 months, and thus may be exposed to multiple contaminants. Here are some precautions: The person should carefully bag the whole device in the room and take it outside, while wearing protective equipment. (ASHRAE recommends N95 respirators, eye protection–safety glasses, goggles, or face shields–and disposable gloves). They should then take the unit apart and dispose of the filters and tape in a bag, seal the bag and dispose of it outside. Then they can dispose of the gloves and respirator, thoroughly wipe down the fan.[6]

Appendix 3 (cont)

#4. TIME AND COST. Time must be spent periodically breaking down the old air purifier, disposing of these filters, and constructing a new one from four unused MERV 13 filters and a lot of tape. The cost of a commercial HEPA air purifier and it's filter replacement should be compared to the time and money to replace four MERV 13 filters.

#5. VARIABILITY OF THE FANS. There is no data on the variability of the output of the box fans themselves. These are inexpensive, mass-produced, often imported units that are unlikely to be uniform in output unless each individual unit is tested.

#6. THE CADR OF THE DIY PURIFIER MAY BE UNRELIABLE. The Corsi/Rosenthal box is a recent invention and continues to be developed and studied. Early measurements used an anemometer to measure/calculate CADR, rather than the appropriate tool, a balometer (see Appendix 2). A very recent study (Ref 23) measured the rate of particle removal, which is a better measure of efficacy. The study found the CR boxes had a high rate of particle clearance, but with many serious omissions and other problems in their presentation that make it impossible to evaluate their results. As of this writing, that study is the only peer reviewed study of CR box efficacy in the literature.

Appendix 3 (cont)

CONCLUSION
Buy properly manufactured and tested HEPA filter units, appropriately sized for the room they will be used in. These will capture virus-containing particles safely inside the unit and their contaminated filter can be removed and replaced with minimum contact.

Appendix 4

What to look for on a walkthrough and what to ask

Exterior of the building

1. View the outside air intakes of HVAC system(s) and note if they are close to exhaust (plumbing, kitchen, toilet, labs), or other sources of contaminants or excessive dirt, and clear of obstructions, debris or covers.
2. If there are individual room heating/cooling units, check the outside wall behind each of them to see if there is an opening, and if possible, to see if the outside air louvers are open. If you have access to chemical smoke tubes use them. If not, just use a piece of tissue, to see if air is entering the intakes (if air is entering, the tissue will be sucked against the louvers).

Interior of the building

Most of what you need to know about the ventilation system you will need to ask about, using the guide below. However there are a few things you can check yourself.

1. If there is an HVAC system, look at all supply and return louvers (also known as registers, grilles, and vents) to see if they are clean, open and operable. Check with a piece of tissue whether air is flowing into the room from supply vents and out of the room at return ones when the system is on.
2. Check whether bathrooms, kitchens and labs are at negative pressure. This means that airflow is inward through the doors, and that windows are closed. You can check this with a tissue.

Appendix 4 (cont)

Document your walkthrough

Keep good documentation of your walkthroughs, correlating your findings to a map or spreadsheet, so that if certain areas are consistently not functioning properly, those areas can be more frequently checked in the future.

Questions for HVAC and unit ventilator engineers and operators

1. Describe the building's ventilation: what buildings have an HVAC system and which rooms does it serve? Where are room ventilation units used, and are windows ever used for ventilation?
2. For HVAC systems:
    a. What MERV filters are used? (Should be 13 or as high as HVAC can handle)
    b. Outside air:
        i. What percent of delivered air is from outside? (Should be as high as possible, 100% is desirable, but may drive heating and cooling costs too high). Can you verify this with an engineering report?
        ii. Is it a demand system, that is, is it varied according to inside and/or outside temperature or indoor carbon dioxide levels? Demand or trigger systems should be disabled.
        iii. How many air changes per hour (ACH) of **outside air plus HEPA-filtered air** are provided by the HVAC system? (should be at least 6 ACH)

People's CDC

Appendix 4 (cont)

c. Is regular cleaning, inspection and maintenance performed? How often? Is it in compliance with ANSI/ASHRAE 180-2018, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems (Ref 24)? Can you provide us with your preventive maintenance plan?
d. How often are filters changed?
e. Has a check been carried out to make sure the filters are sealed into place to prevent leaks of air around them?
f. Are all supply and return louvers (also known as registers, grilles, and vents) open, operable, and is air flowing through them when the system is on?
g. Is the relative humidity in the building maintained at 40 to 60%?
h. Is ventilation operated at low speed for 2 hours before the building is occupied and for 2 hours after people have left?
i. Are you willing to do an airflow study using a balometer? (show the sample Airflow Data Sheet in Appendix 2)

3. For unit ventilators:
   a. What percent of delivered air is outside air?
   b. Is regular maintenance performed? How often?
   c. Are the inside components clean?
   d. Are the top surfaces maintained clean and free of books, plants and other materials?
   e. Are the sides free of furniture or other obstructions to room air flowing into the ventilator?

Resources

These 3 resources are helpful guides written in non-technical language:

1. D. Jeff Burton, **A Ventilation Checklist: Helping Control Airborne Disease Transmission in Non-Healthcare Facilities**, https://synergist.aiha.org/202012-a-ventilation-checklist

2. Harvard T.H. Chan School of Public Health, **5-Step Guide to Measuring Ventilation Rates in Schools,** https://schools.forhealth.org/wp-content/uploads/sites/19/2020/08/Harvard-Healthy-Buildings-program-How-to-assess-classroom-ventilation-08-28-2020.pdf

3. **Foundations for students success: how school buildings influence student health, thinking and performance**, Harvard T.H. Chan School of Public Health, updated Jan 2021, https://forhealth.org/wp-content/uploads/2020/02/Schools_ForHealth_UpdatedJan21.pdf.

References

1. **COVID-19 and Inequality**, Inequality.org, 2021
https://inequality.org/facts/inequality-and-covid-19/

2. National Center for Education Statistics, **Public School Revenue Sources**, May 2021,
https://nces.ed.gov/programs/coe/indicator/cma

3. C. Flavelle, **Hotter Days Widen Racial Gap in U.S. Schools, Data Shows,** New York Times, Oct 2020,
https://www.nytimes.com/2020/10/05/climate/heat-minority-school-performance.html

4. **Philadelphia's Poor, a report from the Pew Charitable Trusts**, Nov 2017,
https://www.pewtrusts.org/-/media/assets/2017/11/pri_philadelphias_poor.pdf

5. Philadelphia Chalkbeat, **Is it possible to make school ventilation safe enough to open this fall?** Jul 2020,
https://philadelphia.chalkbeat.org/2020/7/27/22186772/is-it-possible-to-make-school-ventilation-safe-enough-to-open-by-september

6. U.S. Government Accountability Office, **School Districts Frequently Identified Multiple Building Systems Needing Updates or Replacement**, June 2020, https://www.gao.gov/assets/gao-20-494.pdf

7. J M Daisey 1, W J Angell, M G Apte, **Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information**, Indoor Air. Mar;13(1):53-64.2003 https://pubmed.ncbi.nlm.nih.gov/12608926/

8. Mendell, M, **Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature, Indoor Air,** 01 Feb 2005, https://europepmc.org/article/MED/15660567

9. Ehsan Majd, et al, **Indoor air quality in inner-city schools and its associations with building characteristics and environmental factors**, Environ Res. 2019 Mar; 170: 83–91
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6360122/

10. A. Issakov, et al, **A numerical assessment of social distancing of preventing airborne transmission of COVID-19 during different breathing and coughing processes,** Nature, May 2021,
https://www.nature.com/articles/s41598-021-88645-2

11. Wang, C. *et al,* Science vol 373, No. 6558, Aug 27, 2021, **Airborne transmission of respiratory viruses,**
https://www.science.org/doi/10.1126/science.abd9149

12. K.K. Coleman, et al, **Viral Load of SARS-CoV-2 in Respiratory Aerosols Emitted by COVID-19 Patients while Breathing, Talking, and Singing,** Clin Infec Disease, August 2021,
https://pubmed.ncbi.nlm.nih.gov/34358292/

13. CA Energy Commission, **Improving Ventilation and Indoor Environmental Quality in California Schools, 2020** https://www.energy.ca.gov/publications/2020/improving-ventilation-and-indoor-environmental-quality-california-schools

14. Centers for Disease Control and Prevention, **Ventilation in Buildings**, June 2021,
https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html

People's CDC

15. **2018 International Mechanical Code (IMC)**, chapter 4 Ventilation, https://codes.iccsafe.org/content/IMC2018P4/chapter-4-ventilation

16. ASHRAE Epidemic Task Force Schools & Universities, **Reopening Schools and Universities Guidance**, Updated 5-14-2021 https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools-and-universities-c19-guidance.pdf

17. American Industrial Hygiene Association (AIHA), **Reducing the Risk of COVID-19 Using Engineering Controls Guidance Document**, Sept 2020, https://aiha-assets.sfo2.digitaloceanspaces.com/AIHA/resources/Guidance-Documents/Reducing-the-Risk-of-COVID-19-using-Engineering-Controls-Guidance-Document.pdf

18. American Conference of Governmental Industrial Hygienists (ACGIH), and the Industrial Ventilation Committee of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) jointly written **White paper: Ventilation for Industrial Settings during the COVID-19 Pandemic,** July 2021, found in ACHIG document, COVID-19 References, https://www.acgih.org/covid19/

19. J. Allen, et al, **5-step guide to checking ventilation rates in classrooms**, Harvard T.H. Chan School of Public Health, https://schools.forhealth.org/wp-content/uploads/sites/19/2020/08/Harvard-Healthy-Buildings-program-How-to-assess-classroom-ventilation-08-28-2020.pdf

20. An informal collection of information, references and Tweets, https://edgecollective.io/airbox/

21. MERV/ASHRAE 52.2 Vs ISO 16890 Efficiency Charts, https://www.energysmartfilters.com/merv-ashrae-52-2-vs-iso-16890-efficiency-charts/

22. C.C. Wang, et al, **Airborne Transmission of Respiratory Viruses**, Science, Aug 2021, https://www.science.org/doi/10.1126/science.abd9149

23. R. Dal Porto, et al, **Characterizing the performance of a do-it-yourself (DIY) box fan air filter**, Aerosol Science and Technology, April 2022, https://www.tandfonline.com/doi/pdf/10.1080/02786826.2022.2054674

24. ANSI/ASHRAE 180-2018, **Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems**
https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/previews_2016639_pre.pdf

Notes

1. Carbon dioxide (CO_2) is a gas we exhale. As it builds up, it can be harmful itself, and the buildup also indicates that other pollutants–including the Coronavirus–are building up too. Problems with CO_2 monitors connected to an HVAC include: they are expensive and require expertise to set up and maintain; and they are often in a fixed location which is unlikely to read the CO_2 level representative of where the people in the room are. CDC recommends using a (cheaper) hand-held CO_2 monitor to check HVAC performance in many rooms (Ref 14). CO_2 levels should not exceed 800 PPM, but 600 PPM is preferable. However, since CO_2 is produced by room occupants, a low reading may reflect few people in the room, rather than good HVAC function. Airflow measurements are a much more reliable measure of HVAC fu[redacted]
2. The guidance docu[redacted]r decades, ASHRAE 62.1, Ventilation for Acce[redacted]ecommends 5 ACH for schools. However, t[redacted]mmendation is not designed to control bioaeroso[redacted] we need to turn to recent guidance document[redacted]ygiene groups offering guidance on workpl[redacted]ng bioaerosols during the pandemic: Refs 16, 1[redacted]
3. These recommenda[redacted]y industrial hygiene expert, Monona Rossol, and[redacted]een Actors Guild-American Federation of Television and Radio Artists (SAG-AFTRA), published in their October 2020 ACTS FACTS, and were later adopted by other unions.
4. This document was found in an informal collection of information on the Corsi/Rosenthal Box, (Ref 20)
5. This comparison of MERV and International Standards Institute data from April 7, 2021 points out that the ASHRAE 52.2 chart of capture efficiency for the MERV 13 is >50% in the particle size range of 0.3 to 1 micron and >85% of 1 to 3 micron particles. COVID virus aerosols fall in both those ranges.
6. The ASHRAE- ACGIH White Paper, Ventilation for Industrial Settings during the COVID-19 Pandemic, (in Ref 9 suggests): "While we did not identify any studies that suggest re-aerosolization of SARS-CoV-2 particles from filters is likely, it is best to be prudent and take precautions. Wearing an N95 or higher respirator, gloves, and safety glasses or goggles is recommended."