COVID-19 Mechanical Engineering Recommendations for School Buildings

by Roy Swain, P.E.

July 23, 2020

Version 2.0

1 Introduction

This report introduces COVID-19 ventilation design principles and applies them to school buildings**.** Please note that following all the recommendations of this report will NOT guarantee complete safety. There is no guaranteed level of safety except for complete quarantine.

Following these recommendations will ensure that existing HVAC systems are performing in accordance with existing best practices. Depending on the system type, the amount of fresh air ventilation may be able to be increased fairly easily, with existing equipment.

There is no single standard in this report for how much fresh air ventilation is needed. More is better, and fresh air is one factor that can be combined and traded off with other COVID-19 safety measures.

In addition to general ventilation, for new COVID-19 patient isolation rooms, and for general health office areas, we have specific ventilation recommendations that apply no matter what are the general ventilation levels.

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2 Principles and General Guidance

2.1 Provide satisfactory or better levels of fresh air ventilation and balanced exhaust air as follows:

2.1.1 As a minimum, provide a satisfactory level of fresh air ventilation, generally 15 cfm (cubic feet per minute) per person for classrooms and other large rooms, and 20 cfm per person for offices, with balanced exhaust air.

2.1.2 If possible, provide improved classroom and general occupied ventilation to meet a goal of 30 cfm per person of outside air and exhaust air. (This is my prediction of what may emerge as a new standard within the next five years.) Note that fresh air ventilation is just one factor in the mix of measures for COVID-19 risk management. If a school's mechanical ventilation system cannot meet the 30 cfm/person goal, one can compensate via other factors, such as better-performing masks, more opening of windows, more social distancing, or lower room occupant densities.

2.1.3 CO2 levels in occupied spaces are a proxy for fresh air ventilation, because people breathe out CO2 at a constant rate given their age, metabolism, and level of physical activity. The exhaled air with the elevated CO2 mixes with the room air and the incoming fresh air (at about 400 ppm CO2) and levels out to a new steady-state concentration that can be calculated mathematically.

Fifteen cfm/person corresponds to about 1100 ppm of CO2 (Note 1) and 20 cfm/person is about 925 ppm (rounded to the nearest 25 ppm). Thirty cfm per person is equivalent to about 750 ppm of CO2, while 60 cfm is about 575 ppm.

In some buildings, the CO2 is measured through the Direct Digital Control (DDC) computer-based system controlling the HVAC equipment. For all others, you can spot check it with a hand-held CO2 meter (Note 2). Measure each room after it has been occupied for an hour. A reading of 750 ppm shows you are at the 30 cfm/person goal. A higher ppm reading indicates a lower ventilation rate. A lower ppm reading shows a higher ventilation rate, which is fine in mild weather but may strain boiler capacity and fuel budgets as the weather gets colder.

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2.1.4 Health office/triage rooms with 6 ACH (Air Changes per Hour) of supply air and exhaust air. Negative air pressurization is preferable, as is having the ducted supply air be 100% outside air.

2.1.5 Isolation rooms with 12 ACH exhaust air, 100 cfm of negative pressurization, and a balanced amount of supply air. A minimum of 50 cfm of ducted supply air is best, again, 100% outside air.

2.1.6 Restroom ventilation should already be well above 30 cfm/person if the equipment is working. A desired level of 60 cfm/person should be achievable, and should already exist, since Code requirements are 75 cfm per toilet or urinal, and the requirements have been at this level for several decades.

2.1.7 If students eat together inside the building (without masks), there is no amount of fresh air ventilation that can duplicate the great outdoors. Just as with restaurant re-openings, the safest place for mealtimes is outside. For indoor dining, increase the ventilation as much as is practical, to 60 cfm/person or above. Anything that increases the cfm/person by reducing the number of people at any one time is equally effective as increasing the total cfm.

I have heard that some schools are having the teachers continue to wear their face coverings during the student's meals, and I think this is an excellent idea since it is the adults who are at higher COVID-19 risk. (Of course, KN95 masks for teachers are even better, assuming they are plentiful and available – Note 3).

2.1.8 If Energy Recovery Ventilators (ERVs) are used (recommended where new ventilation equipment is needed), design and/or balance systems so any (slight) air leakage is from supply air to exhaust air. This prevents any possible cross-contamination.

2.2 Wherever room air is recirculated, replace existing filters with MERV-13 filters. These are the best compromise between virus filtration efficiency (35-40%) and increased pressure drop. Too much pressure drop lowers overall airflow or could even

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cause system failure if too high. Note that these filters should be ordered right away, as they will have long lead times. (Note 4).

2.3 Where there is a choice with existing or replacement equipment, avoid recirculating air from one room to another.

2.4 Where bathroom exhaust is via separate exhaust fans or separate ERV system, run these fans 24/7 on school days or start four hours prior to first daily occupancy.

2.5 Note that these increased ventilation rates will require more heating energy in cold weather. There should be enough boiler capacity in most school buildings. However, if some of the boilers are out of service, or there is difficulty heating the building, then these increased ventilation rates can only be maintained if the building occupancy is reduced.

2.6 Especially with increased ventilation levels, it is usually worth the up-front costs to have systems that automatically vary the fresh air amount based on the number of people in the room. This is achieved by having the DDC system measure the CO2 levels and automatically adjust the damper positions. Providing this “demand controlled ventilation” achieves the desired fresh air level at the least possible heating energy cost.

2.7 References – selected portions of:

2.7.1 Vermont Guidance for Reopening Schools.

2.7.2 Best practices for hospital patient care rooms and isolation rooms.

2.7.3 ASHRAE Epidemic Task Force Guidance.

Footnotes:

(1) CO_2 calculations based on adults, outdoor CO_2 concentration of 400 ppm, and with a "light work" activity level of 1.2 Met. (I used the adult rate as a proxy for children at a higher level of activity than "light work".) Because good CO_2 measurement and control have a variability of plus-or-minus 50 ppm, use the following DDC setpoints:

CFM	CO2 ppm setpoint
15	1050
20	875
30	700
60	525

(Note that if a room has a local source of CO_2 other than people, such as an operating gas range or science burner, the CO_2 levels will be high and no longer are an indicator of fresh air.)

(2) There are many CO_2 meters available for under $150. The one I use is AMTAST AMF-102, which also measures temperature and RH, and can do data logging.

(3) Currently available retail for $3.50 or less from many sources including Ocean State Job Lot and W.B. Mason.

(4) One unconventional source I have used personally is "Aerostar MERV 13" via Amazon. I ordered six for my office on July 12 and received them July 21. Many common sizes available, but not to fit unit ventilators.

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COVID-19 Mechanical Engineering Recommendations for Specific HVAC System Types

by Roy Swain, P.E.

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Version 2.0

Short Term Actions

The general report has sections numbered 1 and 2, so this report commences with section 3.

Introduction

This report takes the general ventilation design principles of my report "COVID-19 Mechanical Engineering Recommendations for School Buildings" and applies them to form recommended specific actions for the short-term (before the school year starts), medium-term (before cold weather commences in late October), and long term.

This report applies to buildings with Unit Ventilators (UVs), Energy Recovery Ventilators (ERVs), Air Handling Units (AHUs), Roof Top Units (RTUs), and Exhaust Fans (EFs), and for pneumatic, electric and Direct Digital Control (DDC) control systems.

Please note that following all the recommendations of this report will NOT guarantee complete safety. There is no guaranteed level of safety except for complete quarantine.

3 Short Term Actions

3.1 All HVAC System Types

3.1.1 Use the DDC system to review the ventilation equipment to be sure it is working properly. For DDC systems that you don't entirely trust or that do not have real "status" feedback from equipment, and for non-DDC systems, conduct a

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physical inspection, and make sure that fans are running and energy recovery wheels are rotating.

3.1.2 Set time schedules to run all ventilation systems beginning four hours before scheduled occupancy, until four hours after occupancy ends.

3.1.3 Order MERV-13 filters for all ventilation units that have recirculated air. There will probably be long lead times. There is no need for expedited shipping. The filters should be installed promptly once they come in, and checked monthly until you learn the new filter change frequency. (These filters will need to be changed more often than normal filters.)

3.1.4 Ventilate health office/triage rooms with 6 ACH (Air Changes per Hours) of exhaust air, as a minimum action, as per paragraph 2.1.4 of the general report. This work is best done with a specific design by a mechanical engineer, based on the building's existing HVAC systems.

3.1.5 Ventilate COVID-19 isolation rooms with 12 ACH of exhaust air, as a minimum action, and 100 cfm of negative air pressurization, as per paragraph 2.1.5 of the general report. This work is best done with a specific design by a mechanical engineer, based on the building's existing HVAC systems.

3.2 Unit Ventilators

3.2.1 For DDC systems: Set all UV outside air damper minimum positions to 100%. For pneumatic or electric controls, do the same if this adjustment is available, otherwise, disconnect the outside air damper actuator and move the damper to the 100% outside air position and wire or screw it to keep it in that position.

3.2.2 If there are variable-speed relief air fans for the UV rooms, set the fans to run at full speed, and on the same time schedule as the UVs.

3.3 AHUs and RTUs with Outside Air (OA) and Return Air (RA)

3.3.1 For DDC systems: Set all AHU/RTU outside air damper minimum positions to 100%. For pneumatic or electric controls, do the same if this

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adjustment is available, otherwise, disconnect the outside air damper actuator and move the damper to the 100% outside air position and wire or screw it to keep it in that position.

3.3.2 For variable fan speed AHUs/RTUs, set at 100% speed or as high as practical if the full-speed noise level interferes with teaching.

3.4 Energy Recovery Ventilators

3.4.1 As noted above, MERV-13 should be phased in. These are not critical for ERV units in order to remove virus from the air people breathe, but to protect the heat exchanger core to minimize its virus contamination.

3.4.2 For ERVs with simple adjustment of their fan speeds via the existing motor speed controls, set at 100% speed or as high as practical if the full-speed noise level interferes with teaching. For ERVs with separate motors for the two fans, consult the balance report or existing dial settings and keep the same ratio between the supply and exhaust fan speeds. For example, if the existing supply fan is at 85% speed and the exhaust fan at 70% speed, the maximum increased speeds would be supply 100% and exhaust 82%.

3.4.3 Encourage people to open windows, especially whenever there is a gathering of people in a room where the ventilation system is not providing at lease 30 cfm/person. (Consult as-built ventilation drawings for the airflow rates for each room. Determine the maximum reasonable number of occupants.)

3.4.4 If meals are to be eaten inside the building, open all the windows during mealtime, in addition to the fan-forced ventilation. (You can check the effectiveness of this measure by looking at the CO2 levels.)

3.4.5 After you have calculated the ventilation rates, consider limiting the number of people in a room to no more than one per 30 cfm of fresh air if they are going to be in the room for 15 minutes or more.

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COVID-19 Mechanical Engineering Recommendations
for Specific HVAC System Types

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Version 2.0

Medium and Long Term Actions

The general report and Short Term Actions report have sections numbered 1, 2 and 3, so this report begins with an introduction, and then section 4.

Introduction

This report takes the general ventilation design principles of my report "COVID-19 Mechanical Engineering Recommendations for School Buildings" and applies them to form recommended specific actions for the medium-term (before cold weather commences in late October), and long term (next summer, and subsequent years.)

This report applies to buildings with Unit Ventilators (UVs), Air Handling Units (AHUs), Roof Top Units (RTUs), Energy Recovery Ventilators (ERVs), and Exhaust Fans (EFs), and for pneumatic, electric and Direct Digital Control (DDC) control systems.

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4 Medium Term Actions

4.1 All HVAC System Types

4.1.1 Be sure that all Short Term Actions have been completed.

4.2 Unit Ventilators

4.2.1 For DDC systems without CO2 control, consider adding a CO2 sensor for each UV: Vaisala GMW86P.

4.2.2 For DDC systems with CO2 control: with the advent of cold weather, it is time to reduce the UV outside air amount (which has been set at 100%). Via the DDC system, adjust the minimum outside air setting to 10%, and adjust the normal CO2 setpoint to 700 ppm.

4.2.3 For DDC systems, provide a minor software change to go to 100% outside air for all rooms that are used for meal time, when occupants will not be wearing masks. Implement the 100% outside air either via pushing the override button on the room temperature sensor (which would go to 100% outside air for one hour, or another selectable amount of time), or via preprogrammed time schedule – this choice should be made district-wide.

4.2.4 For electric or pneumatic controls, and for DDC systems without CO2 sensors, set the minimum outside air damper position to 2/3 open (during occupied hours for DDC systems). Unless you have a pneumatic pilot positioner at each UV, you may have to make this a manual positioning of the damper. The 2/3 setting is of course an approximation. If you are having other balancing work done in the school, consider having the balancer determine a more exact damper position to deliver 30 cfm/person of outside air. The balancer can use the mixed air temperature method (which requires an outside air temperature of 40F or below for best accuracy). Test a representative sample of UVs if the number of UVs is large. You can also use a portable CO2 meter in a fully-occupied room to help set or check the ventilation rate, but this would be time-consuming. Consider a CO_2 reading in the range of 700-800 ppm to be satisfactory.

4.2.5 If there are variable-speed relief air fans for the UV rooms, set the fans to run at a partial speed to match the fresh air cfm. If there is not an exact match, it is better to have the building at a slight negative air pressure. Set all relief air fans to run on the same time schedule as that for the UVs.

4.2.6 Install MERV-13 filters in all unit ventilators, which will now be partially recirculating room air. This will slightly reduce airflow and increase noise.

4.3 AHUs and RTUs with Outside Air (OA) and Return Air (RA)

4.3.1 For units serving multiple rooms: check the engineering data for each AHU/RTU to see whether an OA damper position of 100% will allow the heating coil to provide adequate heat on the coldest design day. "Adequate" would be 70F leaving air temperature if the AHU/RTU service area has independent heating in each room, or 90F if the AHU/RTU provides the room heating. If needed, reduce the maximum outside air damper position accordingly. This maximum OA damper position may be reduced by other recommendations.

4.3.2 Examine the room-by-room outside air ventilation levels compared to the room occupancy and determine if more fresh airflow is needed to achieve the 30 cfm per person goal through the winter when opening windows is not an option on most days. Determine whether AHU/RTU total airflow can be increased, and then provide the needed balancing adjustments both at the AHU/RTU and at the branch ducts. [Same as 4.4.2.]

4.3.3 Where you determine that there will be occupied rooms with fresh air ventilation rates less than the recommended 30 cfm/person, consider adding a portable HEPA air filter unit to each room to make up the difference. For example, if a 20-person room has an OA rate of 400 cfm (20 cfm/person), add a minimum of 200 cfm (10 cfm/person) of portable filtration. Operate the portable unit(s) on the same time schedule as that for the room's ventilation system. Use the unit's

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built-in time clock, or use a digital plug-in time switch. See Note 5 for recommended air filter selection criteria and sample units. [Same as 4.4.3.]

4.3.4 For AHUs and RTUs that serve a single room, follow the recommendations for Unit Ventilators.

4.4 **Energy Recovery Ventilators**

4.4.1 For cold weather, it is time to reduce any excess outside air amount for variable-speed ERVs with CO2 control. Via the DDC system adjust the CO2 setpoint to 700 ppm.

4.4.2 Examine the room-by-room outside air ventilation levels compared to the room occupancy and determine if more fresh airflow is needed to achieve the 30 cfm per person goal through the winter when opening windows is not an option on most days. Determine whether ERV total airflow can be increased, and then provide the needed balancing adjustments both at the ERV and at the branch ducts. [Same as 4.3.2.]

4.4.3 Where you determine that there will be occupied rooms with fresh air ventilation rates less than the recommended 30 cfm/person, consider adding a portable HEPA air filter unit to each room to make up the difference. For example, if a 20-person room has an OA rate of 400 cfm (20 cfm/person), add a minimum of 200 cfm (10 cfm/person) of portable filtration. Operate the portable unit(s) on the same time schedule as that for the room's ventilation system. Use the unit's built-in time clock, or use a digital plug-in time switch. See Note 5 for recommended air filter selection criteria and sample units. [Same as 4.3.3.]

5 **Long Term Actions.**

5.1 If new fresh air ventilation standards are updated, and are more stringent than those followed herein, make revisions as needed for full compliance. More stringent would be higher than 30 cfm/person, or lower than 750 ppm of CO_2.

5.2 Replace all ventilation equipment more than 35 years old, in order to provide reliable fresh air ventilation and in the proper amounts.

5.3 If UVs lack DDC controls, replace all UVs (no matter their age) with DDC-ready units, and provide a DDC system for them.

5.4 If not already present, install a DDC system for the entire facility, including CO_2 measurement for all rooms with code occupancies of eight or more people (except CO_2 measurement is not needed for restrooms, kitchens, and similar rooms where exhaust air rates exceed 60 cfm/person.)

5.5 Replace any DDC system more than 20 years old, or one that lacks a web browser user interface.

5.6 Provide complete duct cleaning every 20 years. Note that Personal Protective Equipment may be needed for work on exhaust ducts, which might contain COVID-19 virus particles – comply with applicable regulations.

Footnotes

(Notes 1-4 are used in the earlier reports)

(5) **HEPA Air filtration Unit Selection Guide**

The COVID-19 pandemic has made air filtration units very popular, with some models hard to get. And it has led to a confusing cacophony of products and claims. Here is a simple guide to sensible selection of filtration units. While the guide is simple, the selection of the units is not simple, due to many misleading claims and unnecessary bells and whistles.

We suggest four criteria:

(1) Be big enough – 100 cfm minimum.

(2) Have true HEPA filtration.

(3) Be quiet enough for a classroom.

(4) Be a mechanical filter only – no snake oil.

1. **Be Big Enough – 100 cfm Minimum**

Manufacturers misleadingly claim large airflow rates that are possible only with noise levels comparable to those of a window air conditioner. And the actual airflow rates at lower fan speeds are usually not listed and not available. A rule of thumb is to assume that the actual usable airflow rate is a third to a half of the advertised rate.

Unless you are getting a unit for a small office, a flow rate of 100 cfm is a good minimum. If first cost is paramount, then you may find that multiple 100-cfm units will have the lowest cost.

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2. **Have True HEPA Filtration**

HEPA (High Efficiency Particulate Air) filtration removes at least 99.9% of airborne particles of a wide range of sizes (0.01 – 10 microns, a range that includes the size of COVID-19 viruses). Lesser filtration efficiency also would be acceptable, but HEPA filtration is such a popular standard that more filtration units are available with it than without it.

3. **Be Quiet Enough for a Classroom**

We suggest a maximum noise level of 45 dBA. For most brands, compliance with this criterion is difficult to pin down prior to purchasing a filtration unit, due to the lack of published data. (However, see our Recommended Selections, below.) An ideal classroom will have even lower noise levels of 40 dBA or less, but this level is not achievable with HEPA filtration units except at very high cost per cfm, and background noise levels may be this high anyway.

4. **Be A Mechanical Filter Only – No Snake Oil**

With a 99.9% efficient filter, why would you need anything more? Answer: you don't. You don't need an air ionizer – or if your selected unit comes with one, just turn it off. Be aware that some units do not let you turn it off, so avoid these units. You don't need Microban, silver nano-particles, or any other anti-bacterial treatment of the filters or any part of the unit. (The federal government rightly is discouraging the use of this class of products.) They have no effect on viruses in any case. You don't need ultraviolet light, or photo electrochemical oxidation, or plasmawave technology, etc. You don't need an "air quality sensor" measuring particles or Volatile Organic Compounds.

A carbon prefilter is fine – this removes gaseous organic chemicals, including odors.

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Recommended Selections

Here are recommended selections that meet all four criteria. All of them have been widely available lately, and current shipping estimates are shown below.

- Honeywell HPA300, 100 cfm (our measurement) at 45 dBA (our measurement at 3 feet) on "Germ" (lowest speed), about $300, Energy Star Rated. (Ships in 7 days at Amazon)
- Blueair Classic 205, 140 cfm at 44 dBA on medium speed, about $400, Energy Star Rated. (Ships in 7 days at Amazon)
- Blueair Classic 605, 275 cfm at 44 dBA on medium speed, about $850, Energy Star Rated. (Ships in 5 days at Amazon)

Choice of Fan Speed

Use the selected quiet speed during normal operation. During mealtimes, when most masks are off, and the room is already noisy, run the unit at maximum speed = maximum airflow. (Notes on masks: KN95 masks offer much better protection than cloth or fabric face coverings, and we have heard from teachers who keep their masks on while the students are eating.)

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