TECHNICAL BRIEF

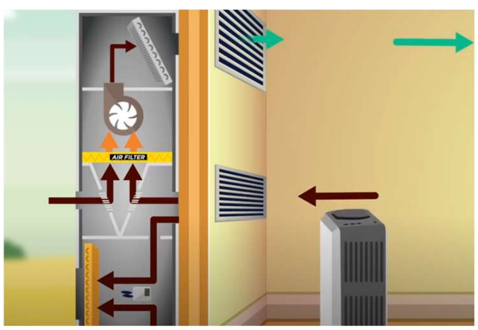
WHAT UPGRADES TO VENTILATION SYSTEMS STILL NEED TO BE DONE TO PROVIDE SAFE INDOOR AIR IN BRITISH COLUMBIA'S SCHOOLS?

March 2023

1. The Basics of Ventilation and Air Filtration for Classrooms

Two short videos produced by the University of California Davis provide an excellent overview of this subject which it would take many pages to achieve here. Watching these is the recommended start point[1].

Towards the end of the video on Filtration the point is made that portable air cleaners may also be needed in addition to the upgrades to the mechanical ventilation system described earlier in the video.



This point is also made by Dr William Bahnfleth, the Chair of ASHRAE's Epidemic Task Force, in a January 7 2022 letter to the Alberta Chapter of ASHRAE[2].

> "….Even when minimum outdoor air requirements are met and recirculated air is filtered by MERV 13 filters, the total clean air delivery rate to most spaces does not reach recommended levels and should be supplemented by in-room air cleaners. HEPA filter units are a good way to do this. By analogy to the levels of clean air delivery found in healthcare ventilation standards, a goal of six air changes per hour of outdoor and filtered air is a widely accepted guideline."

This Technical Brief explores the question of **how to ensure the total and the fractions of outdoor air and filtered air is enough to provide safe indoor air in schools**. It then looks at what this means for upgrades needed for the types of ventilation systems used in schools in British Columbia.

---

[1] Downloadable from https://wcec.ucdavis.edu/improving-indoor-air-quality-in-california-schools/

[2] ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers which is the authoritative body that creates the ventilation standards that governments use in their local building codes.

2. Latest thinking by experts on needed ventilation rates

In November 2022 the Lancet COVID-19 Commission Task Force on Safe Work, Safe School, and Safe Travel published a report on **Proposed Non-infectious Air Delivery Rates (NADR) for Reducing Exposure to Airborne Respiratory Infectious Diseases**. In this report is the following table:

	Volumetric flow rate per volume	**Volumetric flow rate per person**		**Volumetric flow rate per floor area**	
	ACHe	cfm/person	L/s/person	cfm/ft^2	L/s/m^2
Good	4	21	10	0.75 + ASHRAE minimum outdoor air ventilation	3.8 + ASHRAE minimum outdoor air ventilation
Better	6	30	14	1.0 + ASHRAE minimum outdoor air ventilation	5.1 + ASHRAE minimum outdoor air ventilation
Best	>6	>30	>14	>1.0 + ASHRAE minimum outdoor air ventilation	>5.1 + ASHRAE minimum outdoor air ventilation

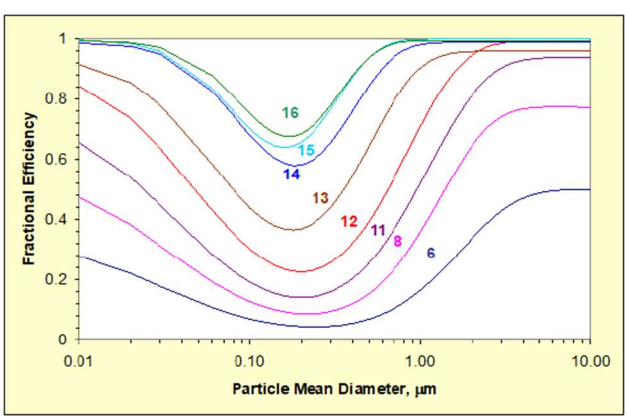
The terms "non-infectious air rate" or "equivalent outdoor air rate" have become prominent in technical literature during the COVID-19 pandemic. There are multiple facets to what is meant by, and how to calculate, these rates that need to be clearly understood.

In simple terms what is meant is the sum of outdoor air (assumed to be non-infectious) plus recirculated air that has been filtered to remove infectious particles. An important point is that filtered air cannot replace all the functions of outdoor air. To maintain carbon dioxide (CO_2) levels below about 1,100 ppm (700 ppm plus outdoor air 400 ppm) requires about 3 ACH of outside air. This has been the basis of minimum ventilation rates in ASHRAE's 62.1 ventilation standard prior to the concerns of infectious air raised in the COVID-19 pandemic.

Taking the numbers in the table above, what is meant in practice is that at least another 3 ACHe are needed by filtering recirculated air to be in the better-best categories. This is consistent with Dr Bahnfleth's "six air changes per hour of outdoor and filtered air".

3. How to calculate 'equivalent air' rates

The efficiency of air filters depends on the particle sizes. Below are curves that show the performance of commercial air filters routinely used in HVAC systems. The numbers in the graph represent Minimum Efficiency Reporting Values. (MERV)



It can be seen from this graph that no single number represents the efficiency of a given filter. MERV ratings for filters are created by looking at efficiencies in three different particle size ranges: **E1** (0.30-1.0 µm), **E2** (1.0-3.0 µm) and **E3** (3.0-10.0 µm). The latest ASHRAE guidance provides the following efficiencies for different MERV rated filters:

MERV Rating (Based on 52.2-2017)	E1 (%)	E2 (%)	E3 (%)
4	10.3	29.9	11.9
5	8.0	28.0	33.0
6	7.8	30.0	43.5
7	10.8	36.6	55.6
8	15.1	51.6	73.7
9	17.8	52.4	84.8
10	16.6	59.0	86.7
11	33.9	69.4	90.1
12	37.6	86.1	99.8
13	66.3	92.4	97.8
14	81.4	96.6	99.3
15	86.4	97.8	99.1
16	95.0	98.0	98.0

Another variable in the calculation is the percentage of the infectious particles in the different size classes. Based on some early studies for the SARS-CoV-2 virus ASHRAE suggests a starting point for anticipated distribution of virus to be per the following table[3]:

Filter Ranges (Particle Size)	Anticipated Distribution of Virus
E1 (0.3 um to 1 um)	30%
E2 (1um to 3 um)	30%
E3 (3 um to 10 um)	40%

ASHRAE notes, however, "The most conservative approach for the distribution would be for the E1 range to be 100% of the particles."

The method used by ASHRAE to create a single overall efficiency rating for a filter across all the particle sizes is then to apply the formula:
Efficiency = E1 efficiency x E1 distribution + E2 efficiency x E2 distribution + E3 efficiency x E3 distribution

If done using the values in the above two tables, the result is shown in the table below. The result is called the Filter Droplet Nuclei Efficiency.

[3] ASHRAE Epidemic Task Force – Building Readiness 5-17-2022.

MERV Rating (Based on 52.2-2017)	Filter Droplet Nuclei Efficiency
4	16%
5	24%
6	28%
7	36%
8	49%
9	54%
10	57%
11	67%
12	77%
13	86%
14	93%
15	94%
16	97%

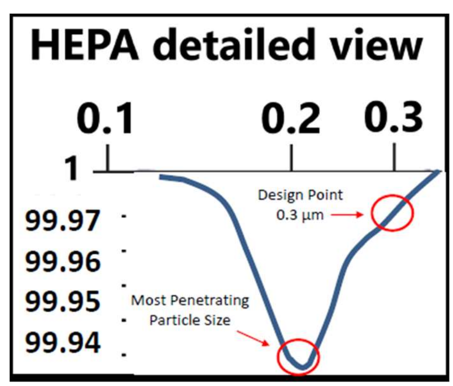
Note again that the above table does not use the more conservative approach suggested where the E1 range has 100% of the particles. As an example, if this were done for the **MERV13** filter the value would drop from 86% to **66%**.

An even more conservative approach would be to use the minimum efficiency that occurs in the efficiency vs particle size curve shown above, which for a MERV13 filter is about **40%**. A point to be made is that the science about this issue can be seen as still evolving. For example, there is no consideration given in these formulas to the infectivity of the SARS-CoV-2 virus in different particle sizes. An application of the **precautionary principle,** which some recommend as appropriate given the morbidity and mortality risk, could suggest the use of the lowest (most conservative) efficiency value until such time as the science is more established.

The critical point about what efficiency value is selected is that the value for the **equivalent airflow rate** is then calculated as this **efficiency value times the airflow rate**. Using the example of a 1000 CFM airflow rate for the air recirculated through a MERV13 filter, this calculates as **860 CFM** in the base calculation, **660 CFM** in the more conservative calculation and **400 CFM** in the most conservative calculation. The significance of this choice of which efficiency to use becomes starkly apparent. The **most conservative** efficiency value is used in our analysis in section 6.

4. Achieving high equivalent air change rates with HEPA and UV-C technologies

Shown here is the efficiency versus particle size curve for a **HEPA filter**. HEPA filters provide very high efficiency, **at least 99.97% at 0.3 microns**. The most penetrating particle size (MPPS) is smaller, so the efficiencies will be a bit less. Different classes of HEPA filter are rated for efficiency at their MPPS.



HEPA class:	H-12	H-13	H-14
MPPS removal efficiency	99.5%	99.95%	99.995%

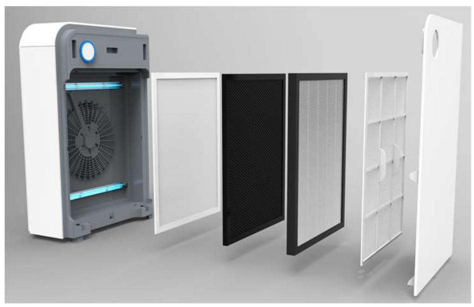
The key point is that for practical purposes **the equivalent air flow rate is the same as the actual flowrate**.

However, ASHRAE notes that it is usually not feasible to retrofit existing HVAC systems with HEPA filters due to high pressure drops and the likelihood that systems will need new filter racks to allow sufficient sealing to prevent filter bypass. HEPA filters are therefore normally found in the form of standalone air purifiers, including portable and fixed wall mount or ceiling mount models.

Another high efficiency technology is **Ultraviolet Germicidal Irradiation** (UVGI). This is a chemical-free disinfection method that uses UV-C light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions. UV-C radiation has been scientifically proven over many decades in hundreds of studies to kill and inactivate harmful microbiological pathogens including, most recently, the SARS-CoV-2 virus. For in-duct air disinfection systems involving banks of UV-C lamps ASHRAE suggests a conservative minimum UV-C dose value of 1,500 µJ/cm2 for 99% inactivation of SARS-CoV-2 in air. Standalone HEPA room air cleaners can also include UV-C lamps to enhance the efficiency achieved by the mechanical filters.

Examples of UV-C technologies are shown below:

In-duct UV-C system



HEPA air purifier with final stage UV-C

Ceiling mount UVGI model

5. Latest ASHRAE Guidance for schools

At the end of January 2023 ASHRAE published the new Design Guidance developed by its TC9.7 Technical Committee. This reflects the work of ASHRAE's Epidemic Task Force and the new focus on equivalent air change rates and the need for >6 ACHe.

The TC9.7 Guidance recommends the use of best practice technologies to achieve **Advanced Indoor Air Quality** (AIAQ). These include HEPA/UV machines in classrooms and UVGI systems in wellness/nurse suites and restrooms.

A key aspect of the use of high efficiency air filtration and disinfection technologies to supplement the existing HVAC systems is that this can most effectively achieve the high ACHe rates without the energy penalties of increasing outdoor air supplies beyond that needed to maintain CO_2 levels to below 1,100 ppm.

6. Applying the latest guidance to BC's schools

In August 2022 the BC Ministry of Education and Child Care (MoECC) released a document titled *Guidance for HVAC Systems.* A second edition of this was released in December 2022. It is important to know that **this document does not reflect the Advanced Indoor Air Quality elements of this latest ASHRAE TC9.7 guidance for schools**. But it does note:

"… Beyond the pandemic, providing enhanced amounts of outdoor air runs counter to energy targets. It is anticipated, however, that ASHRAE will be publishing updated standards for classroom ventilation in Fall 2022, which may recommend increasing the capacity of ventilation systems to a level greater than pre-pandemic levels."

The *Guidance for HVAC Systems* document categorises all the types of ventilation systems found in BC schools and comments on steps that may still be needed to upgrade these. Below we use these categories to add a further level of analysis which reflects the ASHRAE TC9.7 guidance. This is done in the reverse order to the MoECC document, so **starts with the categories most likely to need further upgrade**.

CATEGORY 4(B): **Schools with heating but no mechanical ventilation.** Typically, with operable windows for ventilation – It is rare to find these in districts that qualify for mechanical cooling, which by default use ventilation air as the cooling medium.
MoECC comment on Enhancement: Category 4(b) systems should be considered as the least effective. An upgrade of the heating plant will also likely be required as part of such an HVAC upgrade, since no capacity for heating of ventilation air would have been included in the original design. Funding was provided by government to school districts during the pandemic to purchase HEPA filter units for all classrooms that don't have mechanical ventilation systems.
Comment reflecting ASHRAE TC9.7: Upgrades are likely needed to address both outside air needs to maintain CO_2 levels below 1,100 ppm and to achieve >6 ACHe. The outside air part could be done with an HRV unit capable of >3 ACH. Note that the HEPA filter units provided to such classrooms during the pandemic would need to be checked in terms of their flowrate and noise specifications. If they are unable to provide the 3 ACHe required in ASHRAE TC9.7 when meeting these specifications, additional HEPA/UV units could be added.

CATEGORY 4(A): **Schools designed to use Natural Ventilation.** These utilize windows or other means of introducing outdoor air, such as trickle vents. Air is diverted to the highest level(s) of the building, where it is expelled. If these are operating as intended, then no upgrades to these are necessarily required.
MoECC comment on Enhancement: None required unless the natural ventilation system is not providing an adequate quantity of outdoor air or maintaining indoor thermal comfort. Funding was provided by government to school districts during the pandemic to purchase HEPA filter units for all classrooms that don't have mechanical ventilation systems.
Comment reflecting ASHRAE TC9.7: If testing shows that CO_2 levels **are** being maintained below 1,100 ppm then all that is required is to check the HEPA filter units provided to such classrooms during the pandemic in terms of their flowrate and noise specifications. If they are unable to provide the >3 ACHe required in ASHRAE TC9.7 when meeting these specifications, additional HEPA/UV units could be added. If testing shows that CO_2 levels **are not** being maintained below 1,100 ppm then upgrades are likely needed to address both outside air needs and to achieve >6 ACHe. The outside air part could be done with an HRV unit capable of >3 ACH. Note that the HEPA filter units provided to such classrooms during the pandemic would need to be checked in terms of their flowrate and noise specifications. If they are unable to provide the 3 ACHe required in ASHRAE TC9.7 when meeting these specifications, additional HEPA/UV units could be added.

CATEGORY 3(A): Mixing systems with capacity to provide 1-5 ACH of TOTAL supply air. Common in older schools. These likely do not have capacity to meet the current ASHRAE standard of 3 ACH of OUTDOOR air.
MoECC comment on Enhancement: Consider new equipment with increased ventilation capacity.
Comment reflecting ASHRAE TC9.7: These systems need an upgrade to address both outside air needs to maintain CO_2 levels below 1,100 ppm and to achieve >6 ACHe. There are a number of ways to achieve this, including: (i) Replace the existing air handling units with units capable of 6 ACH total air and at least 3 ACH outdoor air. Use MERV8 filters in the air handling units. Supplement the new air handling units with in-room HEPA/UV units meeting the specifications in ASHRAE TC9.7 to provide the additional >3 ACHe required. (ii) Replace the existing air handling units with units capable of at least 6.5 ACH total air and at least 3 ACH outdoor air. Use MERV8 filters in the air handling units. Install a UV-C lamps system in the ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency (so able to provide the additional >3 ACHe required). (iii) Replace the existing air handling units with units capable of 10 ACH total air and at least 3.5 ACH outdoor air. Use MERV13 filters in the air handling units. The logic for this option is that 6.5 ACH of recirculation air filtered with MERV13 filters can achieve the extra 2.5 ACHe needed (using the 40% most conservative efficiency rating of MERV13 filters discussed in section 3.) (iv) Add to the existing air handling units an HRV unit capable of providing 6 ACH. This value could be reduced by the amount of outdoor air known to be provided by the existing air handling units at minimum, plus the amount of recirculated air filtered by MERV13 filters (if installed) x 40%. The system would need to be professionally designed to ensure that the outdoor air provided by the HRV is added to the supply air to the space without interfering with the supply air coming from the existing air handling units.

CATEGORY 2(B) TYPE 1: Outdoor air systems with capacity of 3 ACH of OUTDOOR air. Common in schools that qualify for full cooling, where make-up units deliver outdoor air to modular heat pumps or fan coil units.
MoECC comment on Enhancement: When upgrades are carried out, an increase of airflow capacity of the make-up air unit(s) should be considered, along with appropriate amounts of pre-heating and/or pre-cooling capacities. This will also allow replacement of the make-up equipment and the modular indoor units independently, allowing HVAC capital funding to be carried out over multiple years, with a clear delineation between phases.
Comment reflecting ASHRAE TC9.7: These systems seemingly provide enough outside air to maintain CO_2 levels below 1,100 ppm. But this could have been reduced if these systems have had their original filters upgraded to MERV13. They could be returned to their original filters, and supplementary in-room HEPA/UV units could be provided with a capacity of >3 ACHe while meeting the noise specification of ASHRAE TC9.7.

CATEGORY 2(B) TYPE 2: Outdoor air systems with capacity of 3 ACH of OUTDOOR air. These systems are also common where DOAS ventilation systems are installed, where providing code minimum outdoor air was done strategically to minimize energy use. These systems were designed to minimize energy use and are NOT viewed as wrongly designed. These schools will likely be equipped with newer equipment, which should not yet need renewal based on age or condition. These sometimes include Heat Recovery Ventilators (HRVs),

which although typically not providing any more outdoor air than code minimum, do have the benefit that they do not re-circulate any room air. Such designs often are also associated with terminal heating/cooling equipment, such as fan coils, heat pumps, chilled beams and/or radiant floors

MoECC comment on Enhancement: It is expected that ASHRAE will be recommending increased minimum ventilation rates for Classrooms. Considering the current pandemic, and potential for future events of concern, increasing outdoor air capacity in future should be considered.

Comment reflecting ASHRAE TC9.7:
As for TYPE 1, these systems seemingly provide enough outside air to maintain CO_2 levels below 1,100 ppm. But this could have been reduced if these systems have had their original filters upgraded to MERV13. They could be returned to their original filters, and supplementary in-room HEPA/UV units could be provided with a capacity of >3 ACHe while meeting the noise specification of ASHRAE TC9.7.

CATEGORY 2(A): Outdoor air systems with capacity of 4-5 ACH of OUTDOOR air. Where outdoor air systems are sized for at least 4 ACH of outdoor air, these already have ability to deliver enhanced amounts of outdoor air, if required for any future events of concern.

MoECC comment on Enhancement: None necessary

Comment reflecting ASHRAE TC9.7:
These systems should provide enough outside air to maintain CO_2 levels below 1,100 ppm. Supplementary in-room HEPA/UV units meeting the noise specification of ASHRAE TC9.7 could be provided with sufficient capacity to achieve the balance of the needed >6 ACHe.
If the outdoor air systems do not have heat recovery, there is an energy cost to operate these at >3 ACH during the heating season even if they have capacity to do so. It may be more cost effective to operate them at 3 ACH and provide supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 for the additional >3 ACHe.

CATEGORY 1(D): Mixing systems with capacity to provide a total air flow (combination of outdoor and recirculated) of 6-8 ACH, but with restricted OUTDOOR AIR paths. Often seen with furnaces provided for classrooms and portables.

MoECC comment on Enhancement: Consider replacement of outdoor air ducts, with larger ducts capable of delivering 100% outdoor air. This would not only allow increased amounts of outdoor air as a response to future periods of increased respiratory illness transmission, but would also allow the ventilation system(s) to be operated in free cooling mode when outdoor temperatures are suitable (for climatic areas that do not have mechanical cooling).

Comment reflecting ASHRAE TC9.7:
If the restricted outdoor air paths mean these units are not capable to provide 3 ACH of outdoor air, then these will not be capable of maintaining CO_2 levels to below 1,100 ppm. Larger outdoor air ducts could be the best solution to this problem. If it is then possible to achieve 100% outside air and >6 ACH these systems have the capacity needed to address both the outside air and total ACHe objectives. However, there is an energy cost to operate these systems at >3 ACH outside air during the heating season, even if they have capacity to do so. Note also that the systems need to have the capacity to provide sufficient heat on the coldest day to ensure thermal comfort (temperature and relative humidity). During the heating season, it may be more cost effective to operate them at 3 ACH and provide supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 for the additional >3 ACHe.

A different option for the additional >3ACHe would be to add a UV-C lamps system in the supply air ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency. One factor to be considered in this choice of options is the extent to which wildfire smoke is also a concern. Where it is, this may mean that outdoor air rates may need to be reduced to 3 ACH during such events. Note that UV-C lamps have no effect on wildfire smoke. HEPA air filters have a >99.5% efficiency. MERV13 filters have a 40% efficiency (using the most conservative efficiency rating).

CATEGORY 1(C): Mixing systems with capacity to provide a total air flow (combination of outdoor and recirculated) of 6-8 ACH, **but with non-functional outdoor dampers.** Where damage or component failure has occurred, resulting in non-functional dampers due to broken linkages, seized actuators or dampers being out of alignment. Also, with older unit ventilators, outdoor air dampers are sometimes controlled in an “either/or” manner in parallel with heating valves, as with some older unit ventilators.

MoECC comment on Enhancement: Consider replacement or repair of failed or damaged dampers and/or damper actuators.

Comment reflecting ASHRAE TC9.7:
If, even with the non-functional outdoor dampers, the systems are able to provide 3 ACH of outdoor air and maintain CO_2 levels to below 1,100 ppm, this objective is met. (Note that if these systems have been upgraded with MERV13 filters, these could be changed back to MERV8 filters if this enables the systems to achieve 3 ACH of outdoor air.) With the outdoor air objective met, the issue then is just achieving the balance needed of >3 ACHe. Providing supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 could be the most cost effective solution for this.
However, this solution does not address the issue of ‘free cooling’ using outdoor air noted in Category 1(D), if this is also an objective in the climate zones in BC where these systems exist. In this case, replacement or repair of failed or damaged dampers and/or damper actuators to achieve the capacity of providing 100% outdoor air is a solution. The systems would need to have the capacity to provide sufficient heat on the coldest day to ensure thermal comfort (temperature and relative humidity.) During the heating season, it may be more cost effective to operate them at 3 ACH outdoor air and provide supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 for the additional >3ACHe.
A different option for the additional >3ACHe would be to add a UV-C lamps system in the supply air ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency. One factor to be considered in this choice of options is the extent to which wildfire smoke is also a concern. Where it is, this may mean that outdoor air rates may need to be reduced to 3 ACH during such events. Note that UV-C lamps have no effect on wildfire smoke. HEPA air filters have a >99.5% efficiency. MERV13 filters have a 40% efficiency (using the most conservative efficiency rating).

CATEGORY 1(B): Mixing systems with capacity to provide a total air flow (combination of outdoor and recirculated) of 6-8 ACH, **but without digital controls**. No associated digital controls. Enhanced outdoor air can be provided, but potentially in a manner not controlled as to time of day and/or maintaining interior comfort. Excessive energy use could potentially be an unintended consequence.

MoECC comment on Enhancement: Consider upgraded or new digital control system.

Comment reflecting ASHRAE TC9.7:
These systems have the capacity needed to address both the outside air and total ACHe objectives using outside air. However, there are potential drawbacks to utilise the full outside air capacity: (1) when outdoor

air temperatures are too high to provide free cooling, and (2) during the heating season. In the first case having outside air >3 ACH can lead to thermal discomfort or excessive energy costs if cooling is provided. In the second case having outside air >3 ACH can lead to excessive energy costs for heating. It may therefore be more cost effective to operate them at 3 ACH and provide supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 for the balance of the >3 ACHe. In this case, MERV13 filters can be changed back to MERV8.
A different option for the additional >3ACHe would be to add a UV-C lamps system in the supply air ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency. One factor to be considered in this choice of options is the extent to which wildfire smoke is also a concern. Where it is, this may mean that outdoor air rates may need to be reduced to 3 ACH during such events. Note that UV-C lamps have no effect on wildfire smoke. HEPA air filters have a >99.5% efficiency. MERV13 filters have a 40% efficiency (using the most conservative efficiency rating).

CATEGORY 1(A): Mixing systems with capacity to provide a total air flow (combination of outdoor and recirculated) of 6-8 ACH, and equipped with digital controls.

MoECC comment on Enhancement: None necessary. The optimal category for pandemic operation, with ability to provide greater amounts of outdoor air than code requirement, as well as digitally programmed operation that does not compromise occupant comfort or risk damage to heating equipment during colder weather.

Comment reflecting ASHRAE TC9.7:
These systems have the capacity needed to address both the outside air and total ACHe objectives using outside air. However, there are potential drawbacks to utilise the full outside air capacity: (1) when outdoor air temperatures are too high to provide free cooling, and (2) during the heating season. In the first case having outside air >3 ACH can lead to thermal discomfort or excessive energy costs if cooling is provided. In the second case having outside air >3 ACH can lead to excessive energy costs for heating.
Given the digital control systems it seems likely that the outside air may only be provided at >6 ACH during the periods of time when free cooling is called for. At other times it may be reduced to 3 ACH to maintain CO_2 levels to <1,100 ppm. In these circumstances the system would be relying on MERV13 filtered recirculation air to achieve the balance needed of >3 ACHe. However, the systems would not be capable of achieving this using the most conservative efficiency values for MERV13 filters as set out in section 3. If using the more conservative efficiency value, the recirculation air would need to be 5 ACH. This totals the full 8 ACH capacity of the systems, which may not be being achieved in practice, e.g. because of the higher pressure drop of loaded MERV13 filters and/or any bypass air due to leakage around the filters.
Given these uncertainties that the system performance will meet the safe indoor air objectives, it may therefore be more appropriate (and cost effective) to operate them at 3 ACH and provide supplementary in-room HEPA/UV units meeting the specification of ASHRAE TC9.7 for the balance of the >3 ACHe. In this case, MERV13 filters can be changed back to MERV8.
A different option for the additional >3ACHe would be to add a UV-C lamps system in the supply air ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency. One factor to be considered in this choice of options is the extent to which wildfire smoke is also a concern. Where it is, this may mean that outdoor air rates may need to be reduced to 3 ACH during such events. Note that UV-C lamps have no effect on wildfire smoke. HEPA air filters have a >99.5% efficiency. MERV13 filters have a 40% efficiency (using the most conservative efficiency rating).

SUMMARY

The above analysis for each category shows that there may be a role for the use of in-room HEPA/UV machines in all categories of ventilation systems found in BC schools.[4] This is consistent with the ASHRAE TC9.7 guidance, which also notes:

> …The "advanced IAQ" recommendations are generally believed to represent best practices that may not be appropriate for all applications but are worth consideration for adoption to improve beyond the base minimum recommendations.

In those categories where the air flowrate capacity is 6-8 ACH an alternative to using in-room HEPA/UV machines could be to add a UV-C lamps system in the supply air ductwork of the HVAC system capable of achieving at least a 90% single-pass efficiency. This alternative would not be appropriate in regions where wildfire smoke is a concern.

It is important to note that even the Category 1(A) type systems, which are referred to as "the optimal category for pandemic operation", for energy efficiency reasons would normally operate for much of the school year in a manner where they are **not** able to provide the total of >6 ACHe being called for to help ensure safe indoor air.

The above analysis sets out options for ventilation system upgrades needed to achieve >6 ACHe and maintain CO_2 levels to under 1,100 ppm. It also shows that objectives such as the utilisation of outdoor air for free cooling and dealing with wildfire smoke events may need to be considered when reviewing options. More generally an overarching objective is also to minimise energy use as part of climate change considerations. But this should not be at the expense of providing safe indoor air.

The choice of what options should be used in further upgrades of the ventilation systems in BC schools should be based on a full understanding of all the objectives and a comparative multi-year systems cost analysis including design and engineering fee costs, equipment capital costs, installation costs and operating costs. The operating costs should include the cost of filters, including the labour costs of their routine replacement, and the overall energy costs to operate the systems.

[4] Note that ventilation systems for wellness/nurse suites and restrooms, included in the ASHRAE TC9.7 guidance document, are not included in the MoECC guidance document, so are not included in this analysis.