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Managing Indoor Concentrations of Wildfire Smoke in Classrooms During the COVID-19 Pandemic

August 19, 2020

Managing indoor concentrations of wildfire smoke during the COVID-19 pandemic presents a unique challenge to building operators/engineers.

Wildfires produce high outdoor concentrations of $PM_{2.5}$, small particles with diameters less than 2.5 μm that can penetrate deep into the human lungs.

To minimize indoor concentrations of wildfire smoke, it is desirable to minimize the amount of outdoor air delivered to a classroom.

However, to minimize indoor concentrations of the COVID-19 virus, SARS-CoV-2, it is desirable to maximize the outdoor air delivered to a classroom.

To investigate this conflict regarding the amount of outdoor air ventilation that should be delivered to an indoor space to control the concentrations of both wildfire smoke and SARS-CoV-2, we used a mass balance model to calculate the indoor concentrations for three ventilation scenarios and three air filtration efficiencies.

Conclusions

1. Outdoor air ventilation rates should be set to the code-required minimum and NOT to zero ventilation (which would occur if the outdoor air dampers were closed or the outdoor air inlet was sealed or obstructed).

2. The air filters in the ventilation systems should be rated at least MERV 13. Installing MERV 13 air filters should not be a problem for most systems as manufacturer's have learned how to produce MERV 13 filters with sufficient pleats that the pressure drop across the filter is low and does not significantly impede the ventilation system's airflow rate. Also, the cost of MERV 13 filters are typically less than $50 per system and filter replacement is generally one or two times per year.

3. For ventilation systems with outdoor air economizers, these controls need to be disabled during times with wildfire smoke. Outdoor air economizers save heating/cooling energy use by automatically adjusting the percentages of outdoor and recirculated air in delivered supply air depending on the outdoor air temperature. These controls automatically set the ventilation system dampers to

provide 100% outdoor air when outdoor air temperature is between approximately 55°F and 74°F, which is most of the time in many California climate zones. For these systems, the economizer dampers need to be set to maintain just the minimum code-required outdoor air ventilation.

4. Portable air cleaners can be used to assist in controlling the indoor air concentrations of wildfire $PM_{2.5}$ and SARS-CoV-2, especially in spaces without mechanical outdoor air ventilation systems and with just openable windows. Use only air cleaners with an AHAM Clean Air Delivery Rate (CADR) for tobacco smoke equal to at least 2/3 of the square feet of floor area [1]. Do not use air cleaners that use ozone, ionization, bipolarization, electrostatics, photo-catalytic oxidation (PCO), or ultraviolet (UV) radiation, as many of these devices many have unproven efficacy and may even produce harmful air contaminants.

In conclusion, schools should be prepared to ensure that the ventilation systems operate with just the minimum code-required ventilation during periods of wildfire smoke and that the systems have at least MERV 13 air filters. Also, if occupants wear N95 respirators, then an additional personal protection factor of 10 (i.e., the inhaled concentrations will be 10 times less than indoor concentrations) can be achieved for both wildfire-smoke $PM_{2.5}$ and SARS-CoV-2.

Ventilation and Air Filtration Analyses – Classroom Scenario

The following are the model inputs we used for our analyses of a typical classroom with a 960-ft^2 floor area, a 10-ft ceiling, 27 occupants, and a mechanical ventilation system that delivers a total of six air changes per hour (ach) of supply air consisting of a percentage of outdoor air with the balance of recirculated air. We assumed that the mechanical ventilation system has air filters that are located, as they are in most systems, to filter the mixed incoming outdoor and recirculated air.

<u>Modeled Mechanical Outdoor Air Ventilation Rates</u>

- 0% mechanical outdoor ventilation, outdoor air inlet closed to exclude wildfire smoke (0 ach)
- 42% mechanical outdoor air, code minimum ventilation (2.52 ach)
- 100% mechanical outdoor air (6 ach)

In addition to the mechanical outdoor air ventilation, we assumed 0.2 ach of air infiltration with 100% penetration of $PM_{2.5}$ through the building envelope. We also assumed that all windows are closed.

<u>Modeled Air Filtration Rates</u>

- low efficiency, MERV 4 (0% and 5% of wildfire $PM_{2.5}$ and SARS-CoV-2, respectively)
- medium efficiency, MERV 8 (15% and 46%, respectively)
- high efficiency, MERV 13 (65% and 87%, respectively)

For SARS-CoV-2 we used one individual generating 1 quantum of infection per hour (q/h), an indoor surface deposition rate of 0.57 ach, and a five-hour exposure period. The q for SARS-CoV-2 is unknown and expected to vary widely depending on the viral load in an infected person's respiratory fluids and their activities (e.g., breathing or talking normally, singing, sneezing, coughing, etc.) which impacts the emission rate of respiratory droplets.

For wildfire smoke we assumed an outdoor $PM_{2.5}$ concentration of 250 μg/m^3 (the highest 24–hour average outdoor air concentrations monitored by the ARB AQMIS [2] during the California Camp Fire, November 10-21, 2018, ranged from 250-263 μg/m^3,) and an indoor $PM_{2.5}$ surface deposition rate of 0.2 ach.

The following charts show the wildfire smoke and SARS-CoV-2 indoor concentrations for each of the modeled ventilation and filtration scenarios.

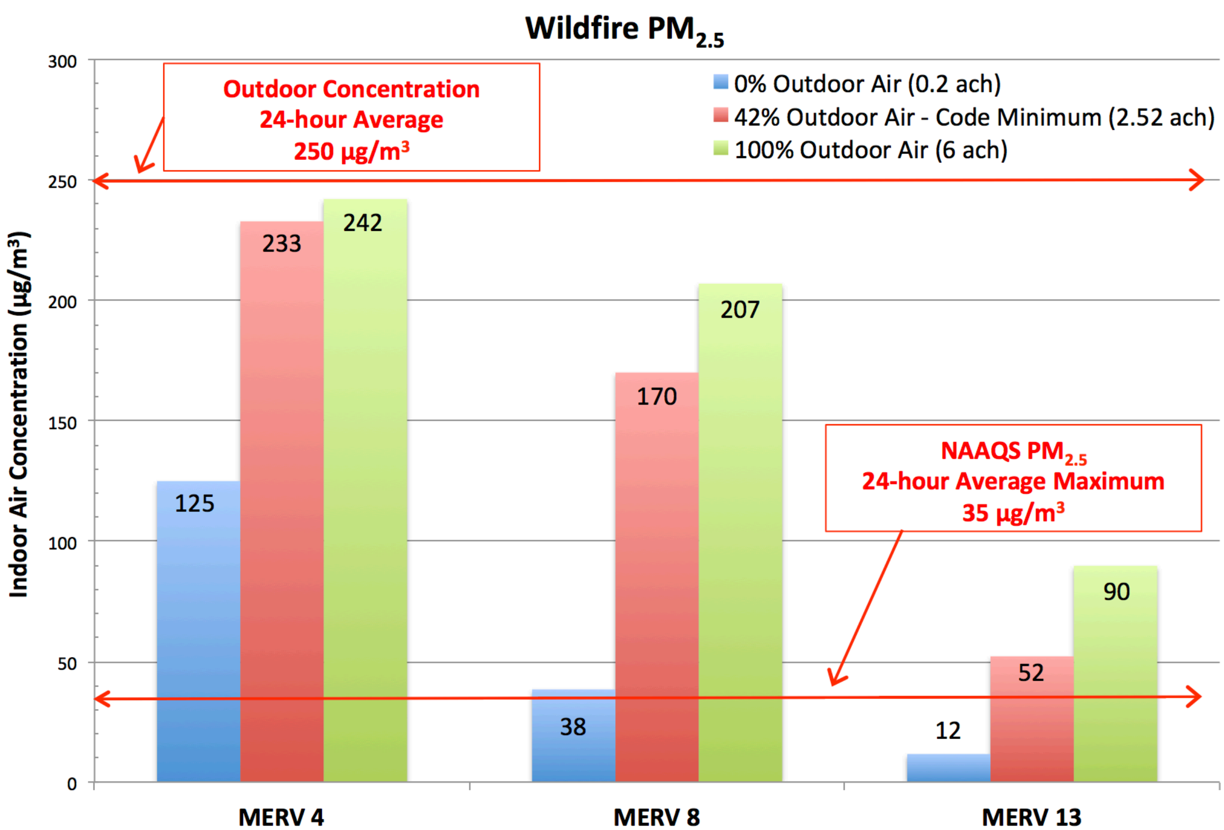

Figure 1. Modeled indoor wildfire $PM_{2.5}$ concentrations for three ventilation and three air filtration scenarios.

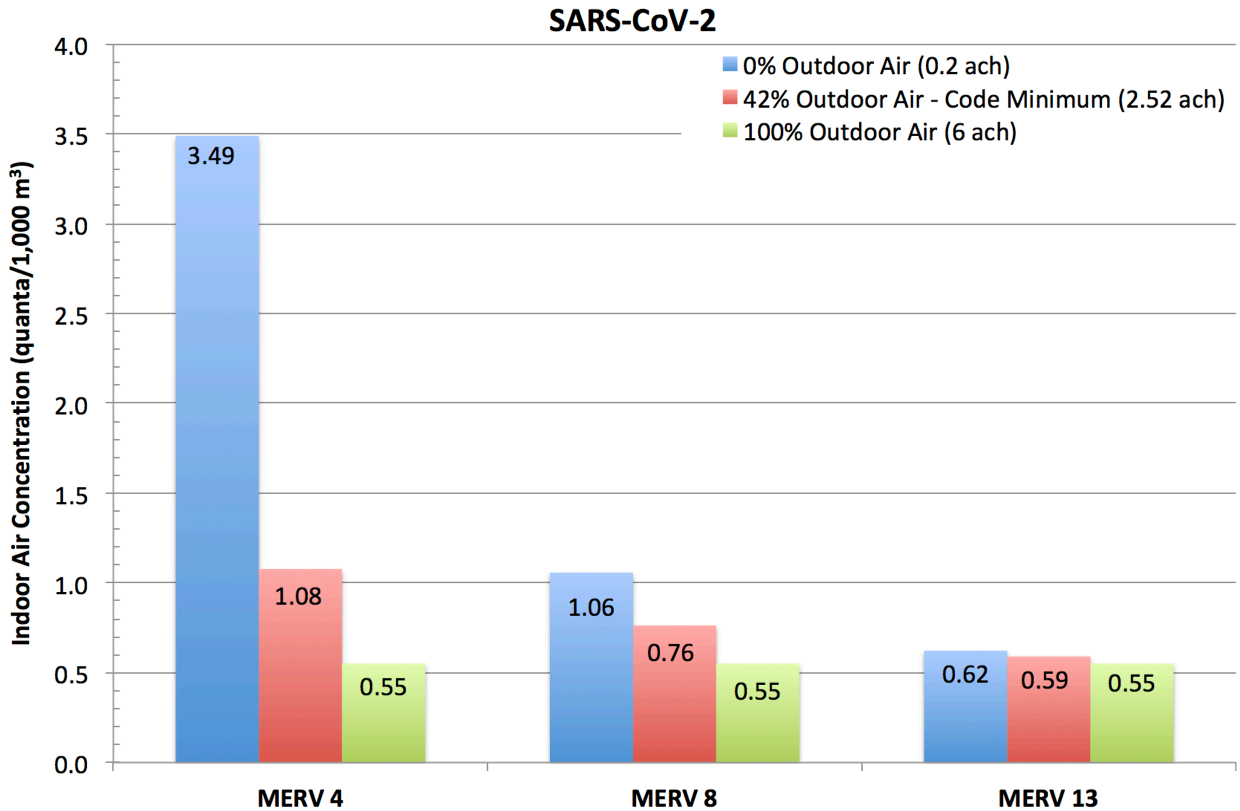

Figure 2. Modeled indoor SARS-CoV-2 concentrations for three ventilation and three air filtration scenarios.

A couple of points worth noting emerged from these analyses.

1. Air filtration matters. If ventilation system filters are MERV 13, then for indoor-generated SARS-CoV-2 it makes little difference how much outdoor air is delivered to the classroom (the indoor concentration varies from 0.55 q/1000 m^3 with 100% outdoor air to 0.59 q/1000 m^3 with the code minimum 42% outdoor air, and to 0.62 q/1000 m^3 with 0% outdoor air).

2. Outdoor air economizer controls need to be disabled. Outdoor air economizers automatically set the ventilation system dampers to provide the minimum code-required amount of outdoor air when outdoor air is warmer than 74°F, the middle bars in Figures 1 and 2.

For ventilation systems with outdoor air economizer controls, when the systems are operating at 100% outdoor air (e.g., when outdoor air temperatures are between approximately 55°F and 74°F) the indoor concentrations of wildfire-smoke $PM_{2.5}$ are quite high even with MERV 13 filters (i.e., 90 µg/m^3). So during periods with high outdoor wildfire smoke concentrations, it is important to disable outdoor air economizers so that just the code-required minimum outdoor air is delivered, by either programming the control system or disconnecting the dampers from the damper actuators and manually setting them to maintain the minimum code-required ventilation. It is important to NOT seal the outdoor air inlets of these systems shut, not only because without the minimum code-required ventilation the concentration of indoor-generated gas-phase air contaminants will accumulate to high concentrations (see point 5), but doing so also may damage the system if the controls attempt to provide 100% outdoor air and the outdoor air inlet is sealed.

3. Wildfire indoor $PM_{2.5}$ concentrations. With MERV 13 air filters and the code minimum outdoor air ventilation rate, the indoor concentration of wildfire smoke is estimated to be 52 $\mu g/m^3$, which is 4.8 times lower than the assumed 250 $\mu g/m^3$ outdoor concentration. While there are no specific exposure guidelines for wildfire smoke, the EPA NAAQS 24-hour maximum $PM_{2.5}$ concentration for outdoor air is 35 $\mu g/m^3$ [3].

4. SARS-CoV-2 indoor concentrations. There are no exposure guidelines for safe indoor concentrations for SARS-CoV-2. Thus, we may consider a goal of achieving exposures no more than those associated with ventilation systems providing the code-required minimum ventilation rate with MERV 13 filters. For this scenario (i.e., one individual generating 1.0 *q*/h), the indoor concentration is 0.59 $q/1000\ m^3$, which is a concentration 5.9 times lower than the concentration of 3.49 $q/1000\ m^3$ for a system with MERV 4 filters and 0% outdoor air (outdoor air dampers closed for wildfire smoke) and 1.8 times lower than the concentration of 1.08 $q/1000\ m^3$ for a system with MERV 4 filters and the code minimum 42% outdoor air.

5. Formaldehyde, Volatile Organic Compounds (VOCs), and Carbon Dioxide (CO_2). With respect to the 0% outdoor air mechanical ventilation scenarios with just 0.2 ach of outdoor air infiltration (outdoor air intakes sealed during periods of wildfire smoke), we also need to consider the gas-phase air contaminants generated indoors that air filtration will not remove and which will accumulate to high indoor concentrations. The continuous emissions of formaldehyde and VOCs from building materials and furnishings will result in indoor concentrations being more than 13 times higher than with the code-required minimum ventilation. Also, the indoor concentration of occupant-generated CO_2 will increase to very high concentrations: 6,000 ppm for a five-hour period of continuous occupancy, which is more than five times higher than the 1,150 ppm for a classroom with the code minimum outdoor air and an outdoor air concentration of 450 ppm and the ASHRAE 62.1 human carbon dioxide emission rates for sedentary occupants (1.2 met) [4]

1. AHAM. *Air Filtration Standards, Follow the 2/3 Rule*. 27 June 2020; Available from: https://ahamverifide.org/ahams-air-filtration-standards/

2. ARB. Air Quality & Meteorological Information System (AQMIS).

3. 40 CFR Parts 50, 52, 53 and 58,, *National Ambient Air Quality Standards for Particulate Matter.* Federal Register, 2013. **78**(10): p. 3086-3287.

4. ASHRAE 62.1. 2013. Ventilation for Acceptable Indoor Air Quality, Informative Appendix C – Rational for Minimum Physiological Requirements for Respiration Air Based on CO_2 Concentrtions.