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Building Protection Factor

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The recent wild fires in California have a lot of people asking how much protection is afforded by avoiding outdoors and staying indoors (i.e. "sheltering in place").

The answer is that it depends on the building and the ventilation system.

To help answer this question, we developed a building metric called the Building Protection Factor (BPF), which describes how much protection is provided from the outdoor air concentrations of $PM_{2.5}$ particulate matter.

$$BPF = \frac{C_{outdoors}}{C_{indoors}}$$

where:

BPF – Building Protection Factor
$C_{outdoors}$ = outdoor $PM_{2.5}$ concentration ($\mu g/m^3$)
$C_{indoors}$ = indoor $PM_{2.5}$ concentration ($\mu g/m^3$)

A building's BPF can be calculated directly from measurements the $PM_{2.5}$ concentrations in the indoor and outdoor air.

A building's BPF can also be calculated from information regarding the building and the ventilation system, for either existing buildings or during building design. The model inputs include the following:

- outdoor air ventilation rate
- air filter efficiency
- air recirculation rate
- air recirculation filter efficiency
- building envelope particle penetration factor

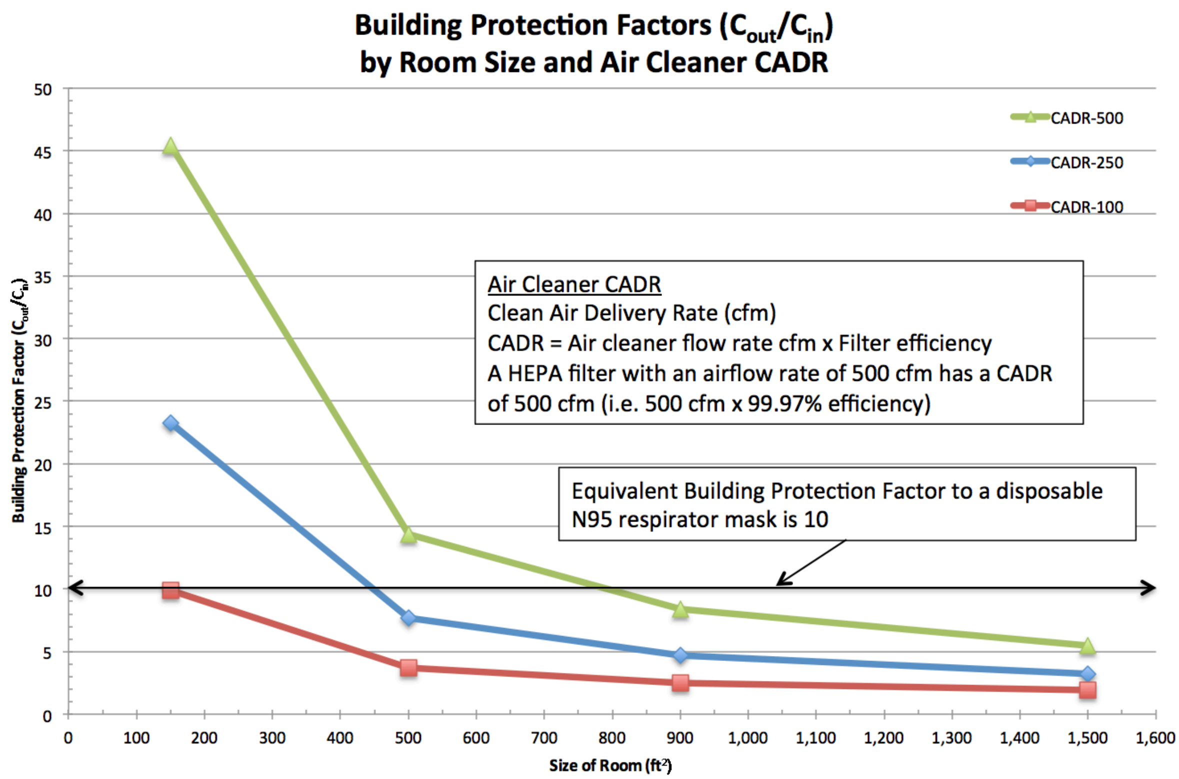
The indoor concentrations of outdoor $PM_{2.5}$ particles can be calculated by dividing the outdoor air concentration by the BPF.

<u>Portable Air Cleaners</u>. To assess the impact of portable air cleaners on the BPF for a residence, the following plot shows the BPF for different room sizes and different air cleaner Clean Air Delivery Rates (CADR). The CADR is the "air cleaning power," the combination of filter efficiency and airflow rate, and is often included in the specifications of portable air cleaners, and is calculated as the product of the airflow rate through the air cleaner and the efficiency of the air filter. So an air cleaner with an airflow rate of 500 cfm and a true HEPA (i.e. 99.97% efficiency) has a CADR of 500 cfm (i.e. 500 cfm times 99.97%), while the same air cleaner with a 50% efficient filter has a CADR of 250 cfm.

The following Energy Star link has the CADRs for many air cleaners https://www.energystar.gov/productfinder/product/certified-room-air-cleaners/results.

The AHAM AC-1 air cleaner certification program measures the CADR for 3 different aerosols, tobacco smoke, dust, and pollen, but the one that matters is the tobacco smoke CADR, as this represents the minimum CADR for all size particles (i.e. particles larger than smoke particles such as dust, or particles smaller than smoke particles such as viruses, will be removed at a higher rate). The tobacco smoke CADR in the Energy Star link above is called the "smoke-free air delivery rate".

The calculation for this plot assumes a room with a 9 ft ceiling, an air infiltration rate of 0.5 air changes per hour (i.e. average, not exceptionally tight or loose), a conservative penetration factor of 1.0 for infiltrating outdoor $PM_{2.5}$ particles, and all windows and doors closed.



As can be seen in this plot, higher CADRs provide higher BPFs and larger room sizes result in lower BPFs. To achieve a BPF of 10, similar to the protection provided by an N95 disposable respirator mask with a good fit, a CADR equal to 0.68 times the floor rate of the room is required (i.e. a 250 cfm bedroom requires a CADR of 170 cfm). For an outdoor $PM_{2.5}$ concentration of 300 $\mu g/m^3$, as has been seen during the recent wild fires, a BPF of 10 will provide an indoor concentration of outdoor $PM_{2.5}$ particles equal to 30 $\mu g/m^3$, which is less than the EPA NAAQS 24-hour exposure guideline of 35 $\mu g/m^3$.

Central Forced Air Heating/Cooling Systems. For residences that have central forced air heating/cooling systems, these systems can be set to operate with the fan running continuously by setting the fan switch on the thermostat from "auto" to "on". The CADR for the forced air heating/cooling systems can be calculated from airflow rate of the system and efficiency of the filter. The airflow rate of residential forced air heating/cooling systems typically ranges from 0.3 to 0.9 cfm/ft^2, with an average of approximately 0.6 cfm/ft^2.

Most air filters for forced air heating/cooling systems have a Minimum Efficiency Reporting Value (MERV) that can be found on the air filter label or at the manufacturers web site. The following are the approximate $PM_{2.5}$ removal efficiencies for different MERV filter ratings and the BPFs assuming a forced air heating/cooling system airflow rate of 0.6 cfm/ft^2 and the same assumptions used for the above portable air cleaner scenarios.

MERV Rating	$PM_{2.5}$ Filter Efficiency (%)	Building Protection Factor
8	15	2.2
10	25	3.0
13	65	6.2
15	95	8.6

Some residential ventilation systems provide mechanically supplied outdoor air to the home (e.g. heat/energy recovery systems, HRVs, ERVs), so it is important that during extremely high outdoor air contaminant levels that these systems be turned off (see CAUTIONARY NOTE below regarding turning outdoor air systems off.).

<u>Office and School Ventilation Systems</u>. For office and school spaces, the mechanical ventilation systems typically filter both the outdoor and recirculated air.

The following are the approximate $PM_{2.5}$ removal efficiencies for different MERV filter ratings and the BPFs assuming a forced air heating/cooling system airflow rate of 0.75 cfm/ft^2 (offices) and 1.0 cfm/ft^2 (schools), 20% outdoor air (offices) and 25% outdoor air (schools), a 9 ft ceiling, an air infiltration rate of 0.1 air changes per hour, a conservative penetration factor of 1.0 for infiltrating outdoor $PM_{2.5}$ particles, and all windows and doors closed.

MERV Rating	$PM_{2.5}$ Filter Efficiency (%)	Building Protection Factor
8	15	1.8
10	25	2.5
13	65	8.2
15	95	33.7

As many ventilation systems in office and school buildings have outdoor air economizers that vary the percentage of outdoor air depending on the outdoor air temperature, it is important that when there is very poor outdoor air quality, such as during the recent California wild fires, that the economizer controls be set to provide just the minimum amount of air, or during extremely high outdoor air contaminant levels, set for zero outdoor air.

CAUTIONARY NOTE. Setting the ventilation systems for zero outdoor air should be only done for emergency protection from extremely high outdoor air contaminant levels as this allows other air contaminants generated indoors by the building occupants and furnishings (e.g. VOCs and human bio-effluents) to accumulate to higher than normal concentrations.