Wildfire Smoke Impacts on Residential Indoor Air Quality

Background

Wildland fires are occurring with increased frequency and intensity throughout many areas of the world and wildfire smoke exposure is becoming a seasonal event in many communities. Increases in property loss, illness, and mortality are well documented (Burke et al. 2021; Fann et al. 2018; Matz et al. 2020). In 2020, over 58,000 wildfires occurred in the U.S. alone, burning more than 10 million acres (https://www.nifc.gov/fireInfo/nfn.htm).

Wildfire smoke is a toxic mixture with as much as 90 percent of the particle mass presenting as $PM_{2.5}$ (Groβ et al. 2013; Vicente et al. 2013). Wildfire smoke also contains ultrafine particles, toxic particle-phase constituents, and many irritant gases including acrolein, formaldehyde, and organic acids (O'Dell et al. 2020). When fires reach and burn buildings, the human-produced materials add toxic constituents to the smoke, including polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs). A single wildfire event can result in a large region experiencing levels of $PM_{2.5}$ that exceed national ambient air quality standards (Nazarenko et al. 2021) over many days (Ryan et al. 2021).

Even without active filtration, sheltering in a building can lower exposure to outdoor $PM_{2.5}$ significantly as particles deposit during air infiltration through the building envelope and also deposit on surfaces inside the occupied zone. These deposition ratescan be faster than outdoor air change when mechanical ventilation is temporarily turned down or turned off for smoke protection. However even with this level of protection, the very high concentrations of outdoor $PM_{2.5}$ that occur during some smoke episodes will result in indoor concentrations greatly exceeding the 24-h WHO exposure guideline of 15 ug/m^3.

Some chronic health conditions contribute to greater susceptibility to wildfire smoke. These include respiratory conditions such as asthma, COPD, and bronchitis (U.S. EPA 2019). Diseases of the circulatory system, including high blood pressure and coronary artery disease, can be exacerbated by fine particles and other air contaminants (U.S. EPA 2019). Exposure to elevated levels of wildfire smoke specifically has been linked to many adverse health outcomes (Arriagada et al. 2020; Cascio 2018; Kunzli et al. 2006; Liu et al. 2015; Reid et al. 2019). A recent study reported that $PM_{2.5}$ from wildfires results in larger increases in respiratory hospitalization rates per 10 ug/m^3 increase in ambient concentration than non-wildfire $PM_{2.5}$(Aguilera et al. 2021).

Segments of the population in various life stages are impacted differently by wildfire smoke hazards. Children have respiratory systems that are still developing and thus more vulnerable, inhale more air per pound of body weight, and are often more active and spend more time outside than adults (Sacks et al. 2011). During pregnancy women experience higher respiratory rates; this and other physiological changes may make them and their developing fetuses more vulnerable (Holstius et al. 2012; Li et al. 2017; Melody et al. 2019). Aging adults may also be more susceptible due to higher incidence of chronic disease and natural decline in lung function as they age (U.S. EPA 2019).

The impacts of wildfire smoke are not equal across the socioeconomic spectrum. Some research has found that areas with the lowest socioeconomic status are at the greatest risk of adverse effects (Hanigan et al. 2008; Rappold et al. 2012), including indigenous populations. The reasons for this are complex, but include underlying health conditions, leakier buildings allowing more smoke infiltration, and lack of air conditioning forcing occupants to open windows for ventilation and cooling. Renters are in a particularly challenging situation because they suffer from the hazards of wildfire smoke but must rely on owners to pay for improvements to the building though some steps to reduce smoke exposure maybe within renters' control.

ASHRAE's Response to the Increasing Wildfire Smoke Hazard

In response to these concerns, ASHRAE initiated the development of Guideline 44P Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events. While Guideline 44P is still in development, the committee developed interim guidance: "Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events" (Javins et al. 2021). The scope of Guideline 44P and the Planning Framework document is primarily for commercial buildings. Since addressing wildfire smoke hazards for dwelling occupants is also critical, the ASHRAE Residential Buildings Committee (RBC) published a Residential Issue Brief (RIB) titled Wildfire Smoke Hazards for Dwelling Occupants in June 2021.

The RIB recognizes that ASHRAE is uniquely qualified to provide guidance on building performance and the design, operation, and maintenance of HVAC systems to help protect occupants from exposure to wildfire smoke. ASHRAE RBC is initiating an effort to pursue a RIB recommendation for ASHRAE to consider developing appropriate engineering interventions and operational recommendations to help protect dwelling occupants from the impacts of wildfire smoke for the building envelope, new construction practices, existing HVAC systems, existing structures in poor condition with high infiltration rates, and enhanced filtration and filter maintenance.

The ASHRAE RBC effort is expected to take the form of a best practices guide that will discuss the roles of residential building envelopes, HVAC systems, filtration, IAQ sensors and portable air cleaners in detail and provide recommendations for their design, selection, operation and maintenance in both new and existing residential buildings. The guide will also emphasize the importance of having a smoke readiness plan including having necessary supplies such as replacement filters and portable air cleaners on hand. While no such guide for dwellings currently exists, much fundamental and practical knowledge can be found in sources ranging from scientific literature (e.g., Barn et al. 2016, Rajagopalan and Goodman 2021, Delp and Singer 2020, Shum and Zhong 2022,), online resources (https://www.co.mendocino.ca.us/aqmd/wildfire-smoke-your-health.html, https://www.pscleanair.gov/525/DIY-Air-Filter, https://www.epa.gov/indoor-air-quality-iaq/wildfires-and-indoor-air-quality-iaq, https://blog.aham.org/tips-to-improve-and-maximize-air-cleaner-performance/, http://www.bccdc.ca/health-info/prevention-public-health/wildfire-smoke, https://basc.pnnl.gov/disaster-resistance/wildfires), and elsewhere. However, many of these resources do not give specific actionable recommendations, particularly for addressing a building's envelope and HVAC system. There are also specific issues which may require more research, such as the impact of exhaust ventilation on indoor-to-outdoor (I/O) ratios of $PM_{2.5}$ from wildfire smoke.

An Example from the Pacific Northwest

The Pacific Northwest (PAC) was always a predictable place: green, gray and wet. The norm here in the upper west coast used to be that summer never started until after July 4th, but that's changed in the past 20 years. The PAC now experiences short shoulder seasons and hot, dry summers with heat domes and significant wildfire events. In September 2020, the Riverside and Beachie Creek fire complexes caused significant air quality issues in Portland, OR when AQI levels far exceeded 500, and elevated $PM_{2.5}$ lasted nearly two weeks, making Portland, OR the city with the most polluted outdoor air in the world for a period of a few days.

Using low-cost sensors used in a recent DOE Building America field study, two Pacific Northwest National Laboratory researchers instrumented a leaky, 2600 sq ft home built in 1928 in Portland for a week of monitoring over September 12-19, 2020, setting up indoor and outdoor stations to collect 2-min time-resolved $PM_{2.5}$ data. Windows were kept closed and the three occupants avoided cooking or other activities likely to increase $PM_{2.5}$ from indoor sources. Peak measured concentrations during this period reached over 700 $\mu g/m^3$ outdoors and 400 $\mu g/m^3$ indoors. During the days with the highest outdoor $PM_{2.5}$ concentrations, the mean indoor-outdoor ratio (I/O) was 0.5, indicating significant penetration of $PM_{2.5}$ from outdoors. The team added a portable air cleaner (with a flow of 160 cfm through a HEPA filter and co-located in a 150 sq. ft. room with the sensor) to the room with the air quality monitor, which lowered the I/O ratio to a mean of 0.2 (Figure 1), highlighting the benefits of portable air cleaning during high smoke events. However, even with the air cleaner, the indoor concentrations of $PM_{2.5}$ were still at unhealthy levels, stressing the need for further research and development of air cleaning technologies and the application of other strategies to limit the entry of smoke. The absolute numbers reported here for the low-cost sensors are likely biased as reported in Delp and Singer 2020 and Holder et al. 2020 but agreed with data from a research instrument when seeing the same particle concentrations, so the IO ratio is considered reliable.

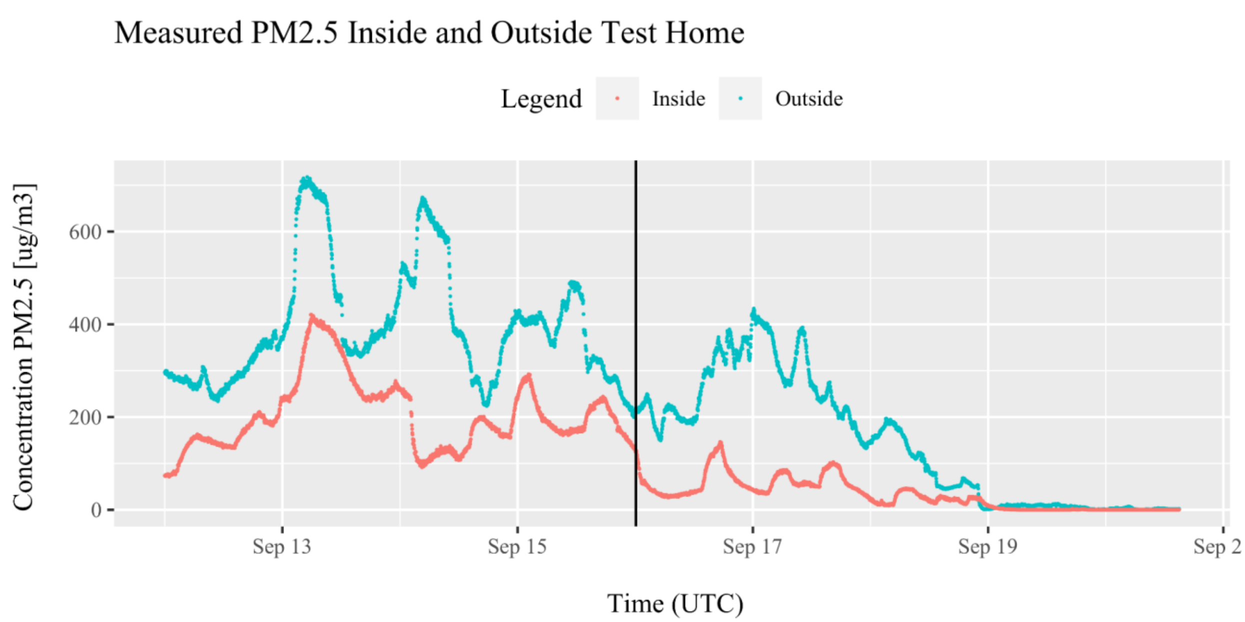

Figure 1. $PM_{2.5}$ concentrations measured with the outdoor (blue) and indoor (red). The black vertical line indicates the time when the portable air cleaner was turned on and remained on.

Figure 2. PNNL Data scientist setting up an outdoor air quality station in Portland, OR.

Wildfire smoke enters residential buildings through natural ventilation, mechanical ventilation systems and infiltration of outdoor air through the building enclosure. During high-smoke events, the U.S Environmental Protection Agency and Centers for Disease Control recommend that people stay indoors and create a “clean room” by limiting smoke entry, keeping cool and using portable air cleaners to filter the air (https://www.epa.gov/indoor-air-quality-iaq/create-clean-room-protect-indoor-air-quality-during-wildfire#how). Whole-house air filtration can be accomplished by installing a high MERV filter in a central HVAC system and ensuring the fan operates continuously. Ductless HVAC systems should be coupled with additional filtration systems or properly sized portable air cleaners. Window and portable AC should be avoided; when they are operated, it should only be in recirculation modes. Older homes with leaky enclosures have a higher risk of increased particulate matter concentrations due to infiltration (Rajagopalan and Goodman, 2021). Efforts to increase wildfire resiliency in housing can be tied to enhanced energy performance of the housing stock, particularly in low-income communities which suffer additional burdens associated with energy insecurity and exposure risk. Weatherization measures such as air sealing coupled with increased filtration efficiency can help limit particulate exposures in homes, and high-performing HVAC systems will help reduce the electricity demand during the hot summer months.

Mitigating occupant exposure to outdoor pollutants associated with wildfire smoke is an important public health issue that ASHRAE can address by the completing Guideline 44 for commercial buildings and by developing a best practices guide for residential buildings.

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