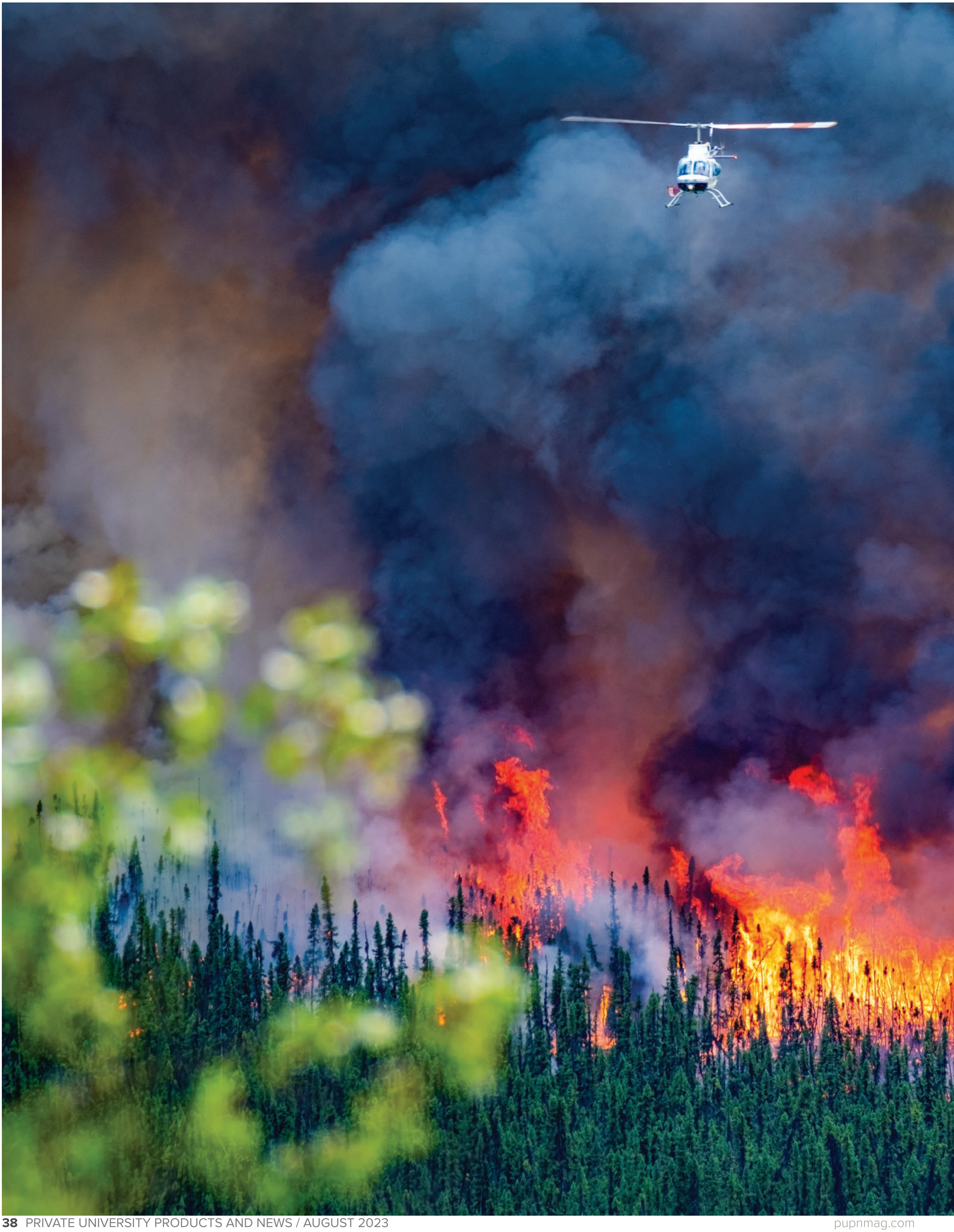
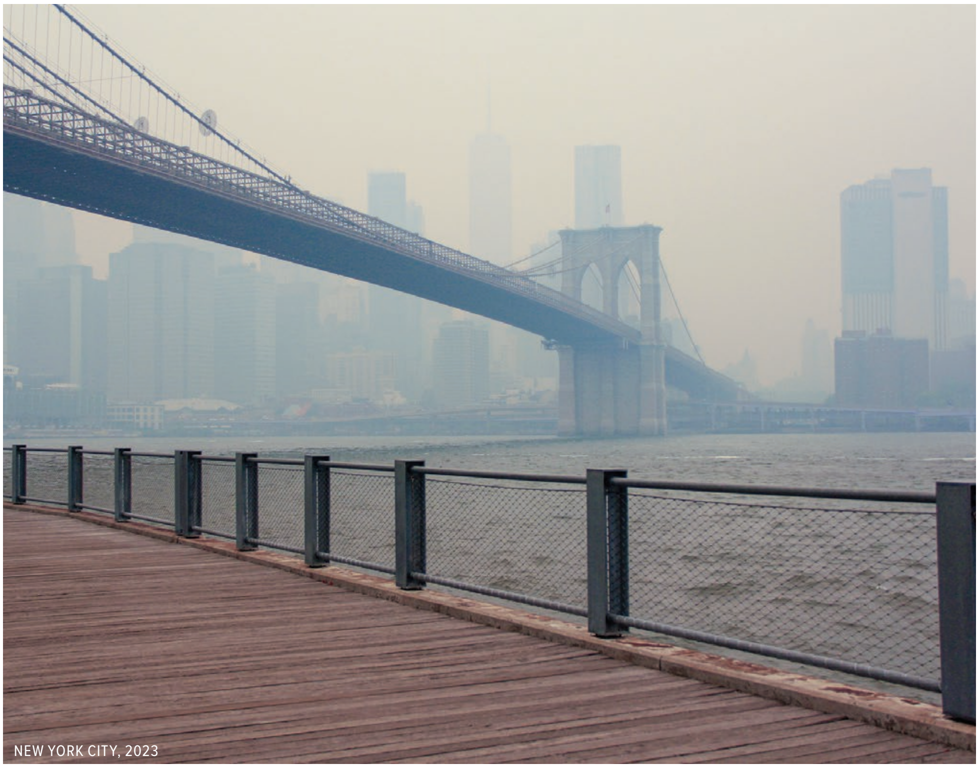


REMOVING PARTICULATES FROM

The Air You Breathe, Smoke Included

Wildfires have emerged from a localized nuisance to an annual problem that affects millions. They generate a wide range of gas phase and particulate contaminants. The smoke composition varies based on the heat and relative completeness of the combustion and the great variety of material that can burn in the path of a wildfire. Wildfire smoke changes rapidly and significantly with time and distance as most gas phase contaminants disperse and larger particulates settle. When not immediately near the fire, VOCs have not been found in high concentrations. Weather and wind patterns also play important roles in where and how long the smoke remains.



NEW YORK CITY, 2023

In general, indoor air quality (IAQ) is directly linked to outdoor air quality. Since most buildings depend on bringing in outdoor air to dilute indoor contaminants and maintain a positive pressure, unacceptably contaminated outdoor air can be a real problem. With the increased incidence of fire, especially at the WUI, the impacts of those fires are felt in more places by more people in more buildings. One of the most noticeable, hazardous, and lingering effects is the generated fine particulate haze that can spread hundreds of miles from the source and impact entire regions. Effectively removing these contaminants from the indoor and outdoor air is critical for both occupants and processes. The first step in dealing with an air quality issue is to determine as specifically as possible what the issue is and which technologies need to be brought to bear to effectively deal with it.

Smoke Composition

Wildfire smoke is a complex mixture of airborne particulate matter (PM), as well as vapors and gases produced by incomplete combustion. These include volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), inorganic gases, and water vapor.

The composition of wildfire emissions is impacted by a wide variety of factors that include the biomass (fuel) conditions, its structure, mass, and moisture content; the ecosystem type; and the fire weather (cumulative temperature, relative humidity, wind speed, and precipitation)—all of which drives fire intensity. Smoke also evolves quickly with time as it diffuses and interacts with atmospheric trace gases and sunlight, undergoing photochemical reactions. The photochemical processing includes the rapid conversion of short-lived reactive trace gases and the production of ozone (O3) and secondary organic aerosols.

When wildfire perimeters include the WUI, there is additional complexity as the burning fuels can include building materials, consumer products, vehicles, plastics, waste products, and other materials not typically found in the woods.

Particulate Matter (PM)

In terms of outdoor air, airborne particulate is typically discussed in mass/volume v. count/volume. This convention follows industrial hygiene standards which were developed before the advent of laser particle counters, and the nomenclature has survived. There are three standard categories:

PM10 (particles <10 µm—generally referred to as large particle pollution), PM2.5 (particles <2.5 µm – generally referred to as small or fine particle pollution), and PM1 (particles <1 µm – generally referred to as ultra-fine particle pollution). PM from wildfires is comprised of a complex mixture of soot, tars, and organic substances and can be directly emitted from fires or formed through secondary processes that can involve gas phase contaminants. PM2.5 and the ultra-fine fraction PM1 are formed in smoke and within the smoke plume from chemical reactions and physical processes in the plume. The differences in the particle size depend on the type of fuels burned, combustion phase, and aging of the smoke. PM10 particles will settle quickly and are more likely to contain contaminants like heavy metals, whereas fine PM2.5 and PM1.0 particles stay suspended, carry adsorbed gas phase contaminants, and have significant health impacts.

Fresh smoke particles have been found to be composed of ~50-60% soot and 5-10% black carbon, with count median diameters in

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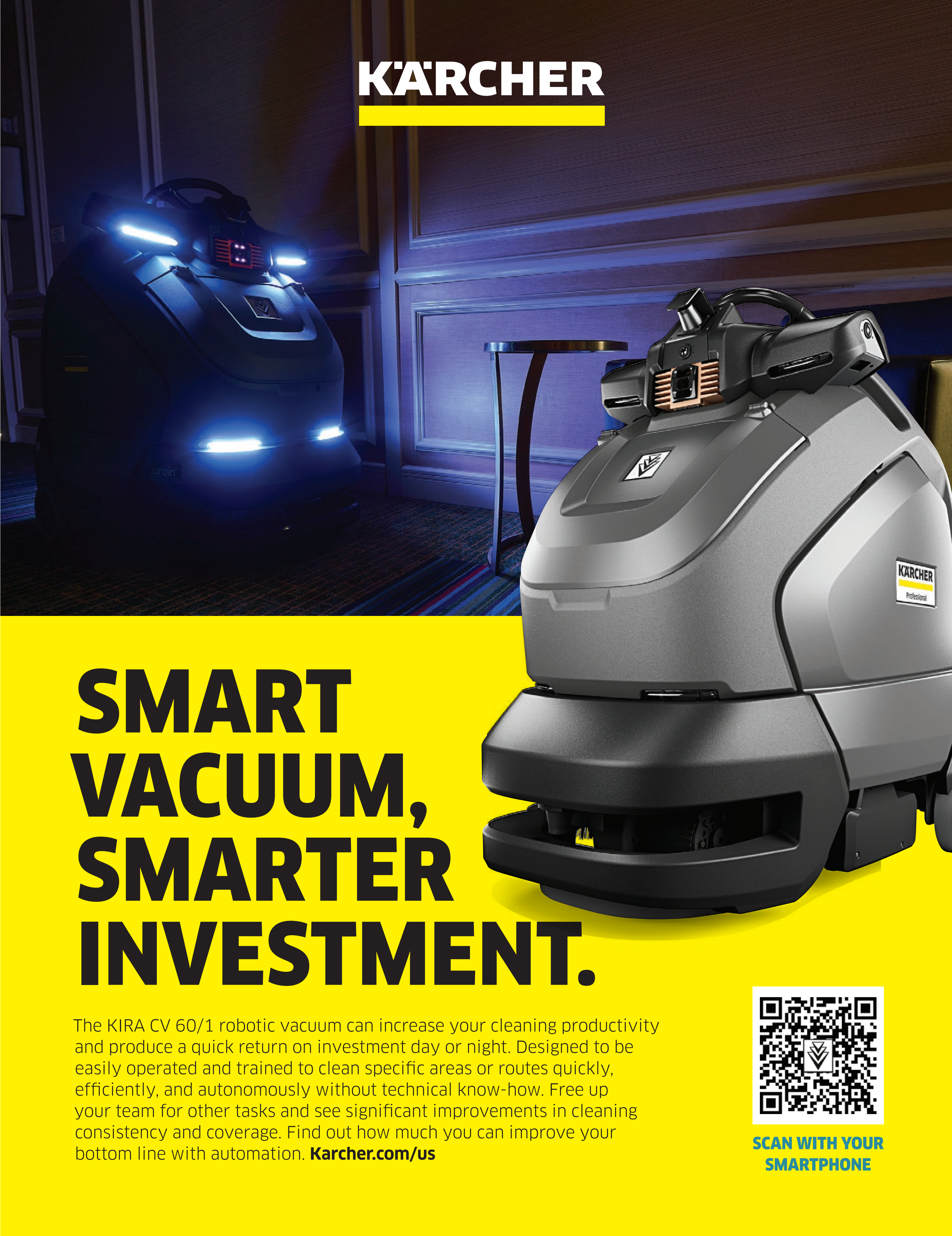
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the range of 0.1-1.6 μm peaking at 1.30 μm and volume median diameters in the range of 2.5-3.0 μm. Another study found biomass burning usually produces fine particles less than 2.5 μm in aerodynamic diameter (PM2.5), with a peak in the size distribution between 0.15 and 0.4 μm. Particulate in this size range will stay suspended for days or weeks and will disperse far more slowly than gas phase contaminants. PM2.5 and especially PM1 will also carry odors, with some gases adsorbed to particles.

Health Impacts

Particle diameter and composition are important factors to consider for health effects, as the size defines where the particles deposit in the lungs, and the composition defines what type of toxic effect they can exert. For example, the soot particle fraction generated by smoldering, incompletely combusted biomass has been reported to contain several known toxins and carcinogenic PAHs.

Exposure to wildfire smoke pollutants has negative impacts on human health, with adverse respiratory, cardiovascular, and cerebrovascular events in the general population. Specifically, PM2.5 from wildfire smoke has been strongly associated with respiratory effects (exacerbations of obstructive lung disease, bronchitis, and pneumonia) in several epidemiological studies.

A recent 2021 toxicological study suggested that PM2.5 from wildfires is more toxic per unit mass than PM2.5 from other sources. Beyond these general health impacts are the IAQ requirements of medical, laboratory, pharmaceutical, and clean manufacturing facilities. Increases in outdoor contaminants will lead directly to increases in indoor contaminants—potentially to unacceptable levels.

Wildfire Smoke Monitoring Case Studies

Wildfires impact the air quality not only in rural and WUI regions adjacent to the fire, but also in urban and suburban area hundreds or thousands of miles away. The size of emitted smoke particles is wide-ranging: larger particles (> 5.0 μg) are often deposited in the near-field (~1–2 miles), whereas small particles are injected high into the atmosphere can remain suspended for weeks to months. To address the problem of the impacts of wildfires on IAQ, it is important to know what contaminants at what levels need to be removed. The following studies are a wealth of information and help to define the problem.

Missoula, Montana Study 2000

A robust air quality study was conducted in Missoula, Montana that coincided with the 2000 wildfire season and the Bitterroot Fire. The year 2000 was the worst fire season in Montana history up until that time (it has been surpassed nine times since). This study monitored PM, and a wide array of VOCs and SVOCs while there were two active wildfires. One fire burned approximately sixty miles south and the second about sixty miles west, resulting in smoke build up in the Missoula Valley. Missoula is the only city completely surrounded by the Rockies, and the Missoula Valley tends to concentrate pollutants. Monitoring was performed at various sites around the valley, some of which were immediately adjacent to active fires.

For the entire month of August, PM2.5 concentrations were above the then annual PM2.5 ambient air quality standard of 15 μg/m3. On only two occasions did the monitoring sites exceed the then 24-hour PM2.5 standard of 65 μg/m3. There were two occasions, August 10th and 22nd, 2000, with PM2.5 concentrations reaching over 300 μg/m3 at Hamilton both days and 165 μg/m3 the 10th at Boyd Park, followed by 83 μg/m3 on the 22nd.

There were no strong correlations between the VOC level and the active fires, demonstrating that most VOCs generated by the wildfire dissipate and do not stay concentrated or travel long distances in the smoke plume. The most abundant VOCs measured were toluene, benzene, and 1,4-dimethylbenzene, all of which were attributed to gasoline-powered automobile emissions. The study did find that along with PM, there was a large spike of SVOCs measured during the fire season with the prevalence being phenolic compounds: phenol, 2-methylphenol (o-cresol), 4-methylphenol cresol), and 2,4-dimethylphenol.

Rim Fire, California 2013

Another study used measurements from a variety of monitoring sites to collect data about the 2013 Rim Fire in California and Western Nevada. The Rim Fire burned a total of 257,314 acres (402 square miles) and, as of 2016, it was the largest wildfire recorded in the Sierra Nevada Mountain range and third largest in California history.

The study covered fourteen counties that were near the Rim Fire or reported air quality impacts from the fire's smoke. Daily twenty-four-hour average PM2.5 concentrations measured by the twenty-two air monitors ranged from 0 to 450 μg/m3. Rim Fire data shows that not only distance from the fire impacts the PM2. concentrations, but also the location relative to the fire and the wind direction. Several of the locations over 100 km away had the same or similar PM2.5 concentrations compared to sites 10-20 km away.

Monitoring sites in Rim Fire Camp, Tuolumne City, Groveland, Pollock Pines, and Gardnerville experienced the highest mean twenty-four-hour average concentrations of PM2.5 (121, 70, 42, 31, 35 ug/m3 respectively), of which Rim Fire Camp, Tuolumne City, and Groveland were within 20 km from the fire origin. The Rim Fire Camp monitoring site (7 km from the fire origin) reported the highest mean and maximum 24-h average PM2.5 concentration (121 and 450 μg/m3). Carson City also had a high maximum of 170 ug/m3 even though it was 146 km away from the fire's origin.

Camp Fire, 2018, San Francisco Bay Area Study

In 2018, the San Francisco Bay Area (SFBA) experienced a period of heavy smoke due to the Camp Fire, approximately 150 miles Northeast. During the wildfire, a stagnant weather system trapped the smoke in the Bay Area, increasing ground-level PM concentrations. Passive PM samples were measured at three sites during the wildfire period, and all sites recorded elevated PM2.5, PM10-2.5, and PM10 compared to samples from the non-wildfire period. The mean fraction of submicron PM (PM1.0/PM2.5) was significantly higher during the wildfire period (0.80) compared to the non-wildfire period (0.52).

The submicron particles were dominated by carbonaceous, nearly spherical, single particles 0.15-0.45 μm in diameter, referred to as "tar balls." In contrast, particles collected at the same sites during the non-wildfire period were mostly crustal particles, spores, salts, and vehicle emissions. Over time, these small tar balls agglomerate and form large clusters that are roughly ten times larger than the 0.2 μm

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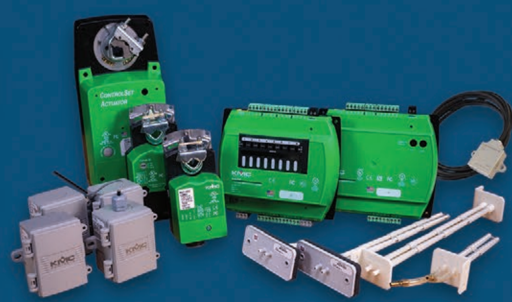

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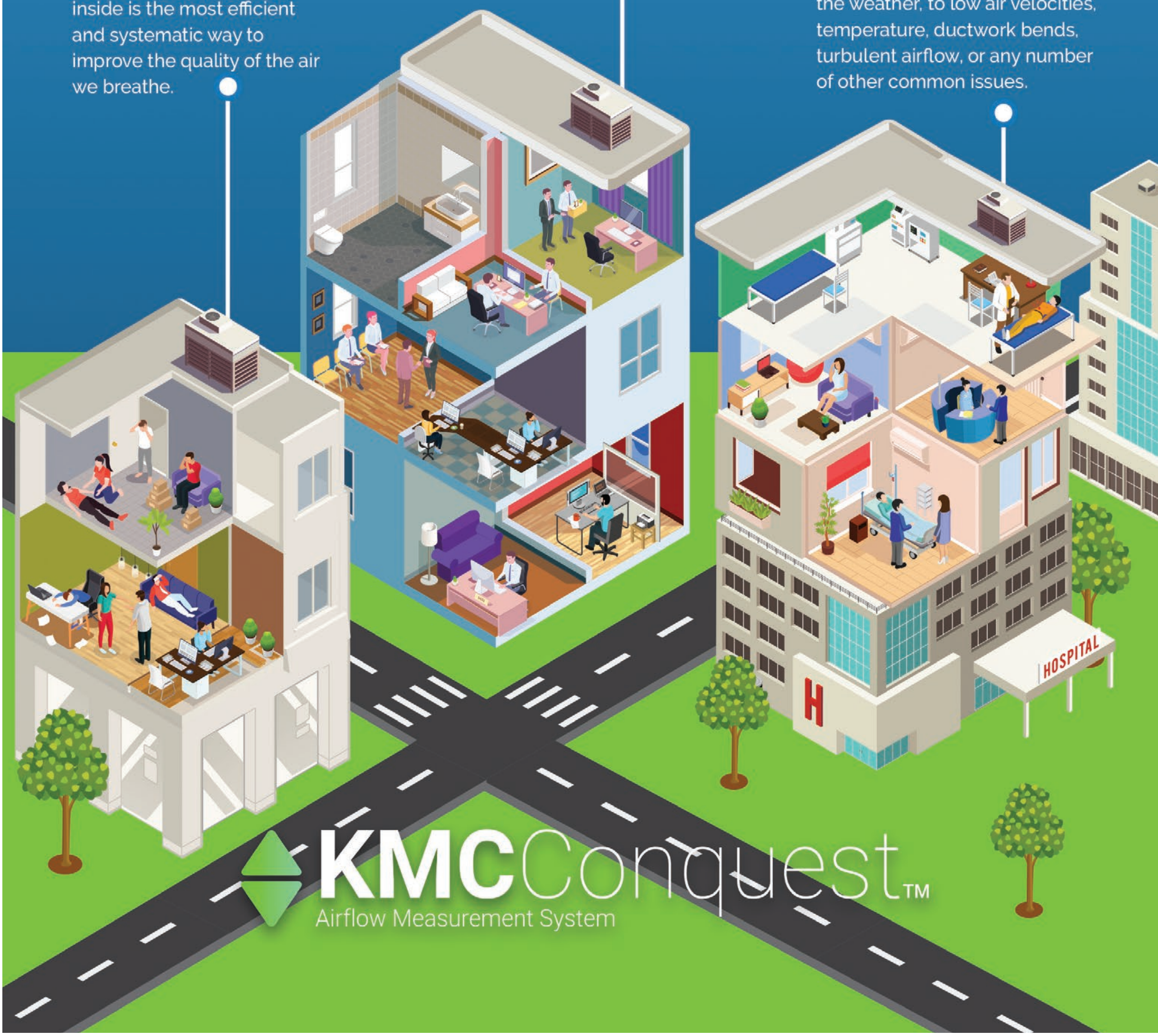

primary spheroids in typical vehicle emission soot agglomerates. The study concluded that, due to these significant differences in size and composition, the tar balls may be associated with different lung retention and health effects than demonstrated by vehicle-emitted soot health studies.

The SFBA study observed particle size dependence of smoke penetration indoors with an abundance of tar balls in the indoor samples, implying that wildfire tar balls are more likely than coarse wildfire ash to be found indoors. In the study, a house intermittently running active ventilation with MERV 11 furnace filters encountered penetration ratios as high as 0.8 for submicron tar balls (i.e., 80% went through the filter).

Smoke Mitigation: Filtration And Improving IAQ

As shown in the studies above, the primary contaminants of concern from a wildfire are PM2.5 and PM1 (i.e., fines and ultra-fines) and the potential for elevated SVOCs. These are the contaminants that must be brought down to acceptable levels. There are currently no PM1 or PM2.5 standards or maximums for indoor air concentrations; therefore, the outdoor maximums are typically applied as a minimum target. The National Ambient Air Quality Standard (NAAQS) and the California Ambient Air Quality Standard (CAAQS) have set an annual maximum of 12 µg/m3 PM2.5 for outdoor air, with the NAAQS with the outdoor twenty-four-hour average maximum of 35 µg/m3.

Particulate filters are tested according to ASHRAE standard 52.2 “Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size” and given a minimum efficiency rating value (MERV). Upstream/downstream particle counts are taken in 12 size ranges from 0.3 to 10 µm; these are then put into three groups and averaged: Range 1:- 0.3-1.0 µm; Range 2:- 1.0-3.0 µm; and Range 3:- 3.0 to 10 µm.

A new 2022 ASHRAE guideline “Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events” recommends upgrading filtration to MERV 13 or higher, especially during smoke events. Additional recommendations include ensuring equipment is well maintained, filters are installed properly and sealed, and buildings maintain positive pressure.

Translating that target of 92-97% efficiency for removing PM2.5 to a MERV rating is a little tricky ,as Standard 52.2 uses particle counts (v. mass) and does not look at anything smaller than 0.3 µm. As noted, smoke contains a lot of particles smaller than 0.3 µm. Further, for particles of a given range, there is an inverse relationship between count and weight. For example, in typical atmospheric dust, 95% of the mass is greater than 3.0 µm, but 95% of the count is less than 0.5 µm. Historically, smoke capture systems for power plants, incinerators, restaurants, and casinos have employed some form of active electrostatic

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capture mechanisms versus high-efficiency passive/barrier filtration. The movement, agglomeration, attraction, and capture of ultra-fine particles is greatly influenced by these active mechanisms. Passive filters do not make much use of these; therefore, passive filters of sufficient efficiency to capture ultra-fine particulate are unacceptably airflow-restrictive and have service lives that are too short for most applications.

Gas Phase And Svocs

As found in the studies mentioned above, VOCs are not found at elevated levels, even in close proximity to a fire. SVOCs, however, may linger and attach themselves to small particles and/or become small particles themselves. While the V8 can put a significant dent in moderate levels of VOCs, there are certain buildings that need more precise control. For these, Dynamic EDGE Activated Carbon Panels can provide precise control of gas phase contaminants at extremely low (<0.25" w.g.) pressure drops. These can be installed seasonally or year-round to maximize IAQ.

Conclusions

Wildfires have emerged as an annual air quality issue for a far greater area than that affected directly by the fires themselves. Poor air quality resulting from wildfires is an issue that must be dealt with for both the people and the processes in buildings. Smoke composition can vary greatly due to incomplete combustion and the wide range of material that can burn in the path of a wildfire. The most lingering and critical components of wildfire smoke to remove from the air entering a building, however, are PM1 and PM2.5, due to their potential health impacts. In addition, by removing these particulates from the air, the attached SVOCs and odors are also removed.

ABOUT THE AUTHOR: Published from materials supplied by Dynamic Air Quality Solutions and Caitlin D Naske Lead chemical Engineers. Go to www.dynamicaqs.com to see more information on how Dynamic Air Quality can help you with Air Filtration for your multiple building facilities.

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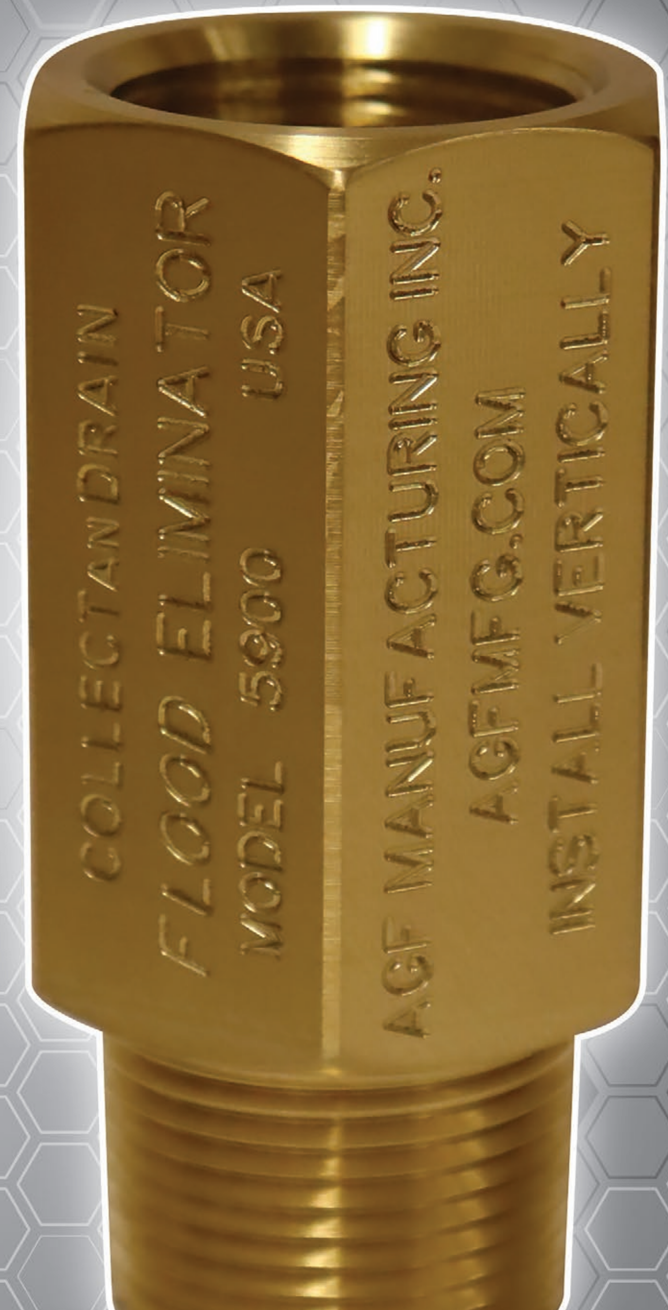

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