Exclusive Content

Beyond Ozone: Cleaning Outdoor Air for Improved Indoor Air Quality

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An overview of the current status of ozone control in outdoor and indoor air.

The U.S. Environmental Protection Agency (EPA) recognizes six "criteria pollutants" as indicators of outdoor air quality and has established for each of them a maximum concentration above which adverse effects on human health may occur.[1] Of the six pollutants—carbon monoxide, lead, nitrogen oxides, particulates, sulfur dioxide, and ozone—ground-level ozone (commonly called, smog) has been suggested as being the most widespread health threat.

Although outdoor ozone is a major global concern and there have been concerted efforts to reduce its concentration, Weschler[2] reports that, "Indeed, '… there have been enormous increases in background ozone concentrations over the past half-century' and projections are that this trend will continue." This is what has been observed and is of special concern in less developed countries.[3-5]

Peak levels of ground-level ozone are substantially lower than in the past, however, long-term average and background values were seen to increase in many sites.[6] This has led to ozone levels being unhealthy in many regions globally and in numerous areas of the United States. In October 2015, EPA strengthened the air quality standards for ground-level ozone based on extensive scientific evidence about ozone's effects, in part, in response to concerns for acute and chronic health effects among the general population.[7]

As of September 2018, EPA has identified part or all of 200 counties in 22 states and the District of Columbia as exceeding the current federal air standard for ozone.[8] These areas encompass a total population of almost 125 million people or more than 38 percent of the population. Air monitoring data for ozone and other criteria pollutants is available in many countries and can be used to determine compliance with national ambient air quality standards (NAAQS) and the potential risks. Table 1 shows a comparison of international air quality standards and guidelines for ozone. With levels of ground-level ozone continuing to increase, a discussion on the control of ozone in both outdoor and indoor air is a timely topic due to the potential adverse health effects in the general population.

OZONE AND HEALTH

Ozone is not emitted directly into the air, but is formed by nitrogen oxides (NOx) and volatile organic compounds (VOCs) that in the presence of heat and sunlight react to form ozone. NOx is emitted from motor vehicles, power plants, and combustion sources. VOCs are emitted from sources, including motor vehicles, chemical plants, refineries, and other industries. The reactivity of ozone causes health problems because, if breathed in, it can damage lung tissue, reduce lung function, and sensitize the lungs to other irritants. Ambient levels of ozone not only affect people with impaired respiratory systems, but healthy adults and children as well.

Even with the acute health effects attributed to ozone, controversy remains regarding the relationship between ambient ozone and mortality worldwide.[9] Although many studies have linked ozone to adverse health outcomes, the effect of long-term exposure to ozone and air pollution-related mortality remains uncertain. However, as more data become available, definite links are being established.

For example, an 18-year study in the United States shows that people who live in areas with high ground-level ozone face a 30-percent greater risk of death due to respiratory problems.[10] A study of four years' worth of data for Shanghai, China, concluded that an independent association exists between ozone and total and cardiovascular mortality.[11] It was further concluded that current levels of ozone had an adverse effect on the health of the general population. Other studies have reported that an increase of 10 parts per billion (ppb) outdoor ozone concentration has been linked to an increased mortality rate.[12]

OZONE AND INDOOR AIR QUALITY

In addition to direct exposure from ozone, there is also the potential for exposure to ozone reaction byproducts, as reactions with ozone have the potential to be quite significant as sources of compounds that are potentially damaging to human health. Weschler[13] estimates that the average daily indoor intakes of ozone oxidation byproducts are roughly one third to two times the indoor inhalation intake of ozone itself. These oxidation byproducts include formaldehyde, acrolein, hydroperoxides, and ultrafine particles. Studies of ozone reactions with typical indoor surfaces reported byproducts such as organic acids and carbonyls.[12] A multitude of unstable products and secondary organic aerosols can also form. Minimizing indoor ozone concentrations reduces the generation of these harmful byproducts, as well as ozone exposure.

Several studies have pointed to ambient ozone entrained into ventilation systems as a health risk factor to building occupants. A statistical analysis of an EPA study of 100 randomly selected large U.S. office buildings showed that ozone in the outdoor air was significantly associated with increased upper respiratory, dry eye, neurological, headache and other building-related symptoms (BRS).[14] In buildings with very low ozone in the outdoor air, on average, BRS was found to be up to 45-percent less prevalent. None of the buildings in this study had extremely high ozone levels, and only one building was in an area that exceeded the 8-hr federal air standard for ozone.

Ozone and Building Ventilation

Ground-level ozone enters buildings through ventilation systems and infiltration. It negatively impacts the indoor environment and its removal is required by some building standards. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) Standard

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62.1-2016, "Ventilation for Acceptable Indoor Air Quality," specifies minimum ventilation rates and indoor air quality (IAQ) that is acceptable to the human occupants of a building.[15] However, acceptable IAQ may not be achieved when meeting the requirements of the standard, especially in non-attainments area for one or more of the criteria pollutants. Meeting minimum ventilation requirements in these areas increases the likelihood of BRS and there is growing concern about simply ignoring outdoor air quality when used for ventilation. If the outdoor air does not meet NAAQS, it must be treated before being introduced into a building.

Table 1. International ambient air quality standards for ozone (mg/m^3).

Averaging Time	USA	WHO	EU	Australia	Canada	China	Hong Kong	Indonesia	Japan	Korea	Netherlands	Philippines	Seoul	Sri Lanka	Surabaya	Taiwan	Thailand	Viet Nam
1 hr	—	0.15	—	0.24	0.10	0.16	0.24	0.24	0.14	0.20	0.12	0.14	0.20	0.20	0.24	—	0.20	0.20
8 hr	0.07	0.12	0.12	0.10	—	—	—	—	—	0.12	—	0.06	0.12	—	—	0.12	—	—
Annual	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	0.05	—	—	0.06

Sources:
"Beyond Professional Engineers"; CEI Seminar, CEI Co., Ltd. Bangkok, September 2006. Clean Air Initiative for Asian Cities; CAI-Asia (2018); **http://cleanairasia.org/node2288/**. National Ambient Air Quality Standards; U.S. Environmental Protection Agency (2018); **https://www.epa.gov/criteria-air-pollutants/naaqs-table.**

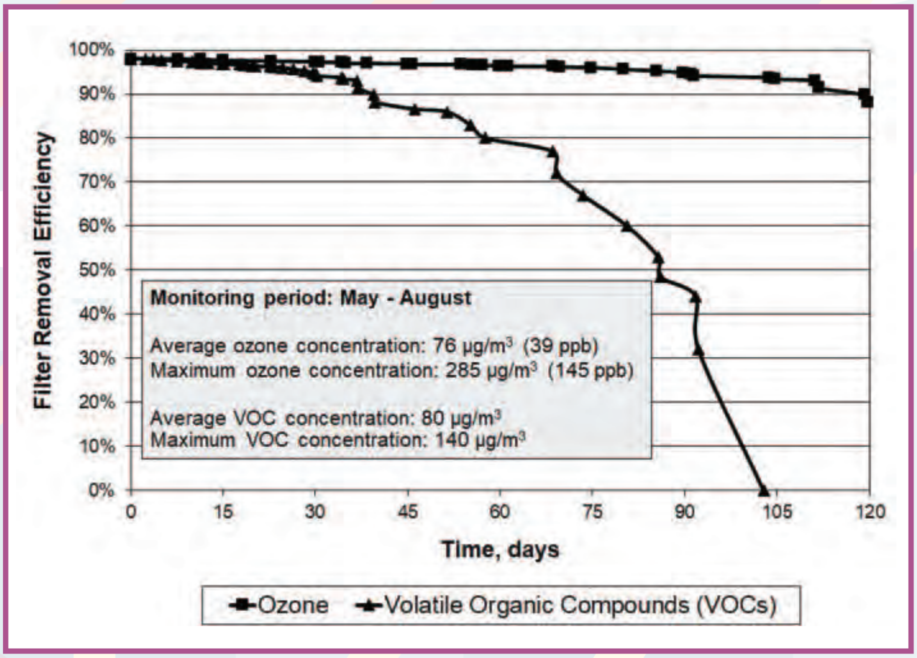

Figure 1. Combination particulate + chemical performance against ozone and VOCs. *Source: **https://airgeorgia.org**.*

As a compromise to requiring air cleaning for all areas where outdoor air may be deemed "objectionable" or "unacceptable" ASHRAE approved a change to the standard that requires air cleaning requirements for ozone under certain conditions. While reducing ozone levels indoors may have a beneficial health effect, this requirement was mainly intended to reduce discomfort.

As a standard looking toward net-zero buildings and sustainability, ASHRAE Standard 189.1 "Standard for High-Performance Green Buildings"[16] was first published with the purpose to provide requirements for the siting, design, construction, and plan for operation of green buildings. It also provided criteria that address indoor environmental quality (IEQ).

Provisions of Standard 189.1 address indoor air quality whereby the building must comply with specific sections of ASHRAE Standard 62.1 and have made air cleaning for ozone mandatory under certain conditions (i.e., when the building is in an area that is designated "non-attainment" for ozone). In these locations, air cleaners shall be provided to clean outdoor air prior to its introduction to occupied spaces. Standard 189.1 strengthens the requirements to investigate and address outdoor air quality that began with Standard 62.1 and mandates remedial actions for the benefit of building occupants.

Air Cleaning

Since essentially every building's heating, ventilation, and air conditioning (HVAC) system already has particulate filters, they should be able to address most particulate contamination issues. However, when it comes to ozone, this requirement has been almost universally ignored. Primary excuses include the high cost of installing, operating, and maintaining air cleaning systems. Mandatory air cleaning for ozone is appropriate because of the substantial number of people living in non-attainment areas, and the negative impact ozone has on IAQ and occupant wellbeing. Many experts are endorsing the use of air cleaning for ozone.

For example, Weschler[13] states, "Indoor exposure to ozone and its oxidation products can be reduced by filtering ozone from ventilation air and limiting the indoor use of products and materials whose emissions react with ozone. Such steps might be especially valuable in schools, hospitals, and day care centers in regions that routinely experience elevated outdoor ozone concentrations."

While Apte[14] considers, "If the observed ozone-BRS associations are confirmed as causal, ventilation system ozone removal technologies could improve building occupant health when higher ambient ozone levels are present.

If one is required to apply air cleaning for compliance with ASHRAE standards 62.1 or 189.1, or any other standard or building code for that matter, the next step is to evaluate and select the appropriate control technology. The most common air cleaning technology in use for outdoor air employs various adsorbent media incorporated as an integral part of an HVAC system. Properly designed, gas-phase air filtration systems can effectively reduce ozone and many other gaseous pollutants to well below regulatory levels and below those considered objectionable by most building occupants.

It is not always simple to incorporate a gas-phase air filtration system into an existing HVAC system. Retrofit applications present challenges to the building engineer due to physical limitations or budgetary constraints. However, there are many filter options that can be used in existing air handlers with little or no additional equipment or retrofit costs.

Air Cleaning Systems for Ozone and Outdoor Air

Air cleaning for ozone typically involves the use of a virgin activated carbon in granular form (GAC). Air cleaning systems with a 1-in (25-mm) bed of carbon can provide the required level of protection over an extended period.

Filters employing an adsorbent-loaded non-woven fiber matrix or extruded carbon composite media can be used as alternative to packed-beds of GAC. These provide much more flexibility in design and are available in all standard filter sizes. True combination particulate + chemical filters are available that can replace existing particulate filters to provide for efficient and economical control of both ozone and particulates.

Generally speaking, a properly designed, installed, and maintained gaseous air cleaning system will be able to remove significantly more than just ozone from the outdoor air. Even in non-attainment areas, the resulting indoor air quality will be improved to the point that BRS are effectively eliminated for the building occupants.

Air Cleaning Case Study

An office building located in the southeastern United States was going "green" to attract and retain tenants. Part of this effort included the use of enhanced air cleaning for both indoor and outdoor air. The primary contaminants of concern in the outdoor air were ozone and VOCs, which peaked in the "ozone season" during the months of May to September.[17]

Particulate filters were already in use the ventilation system and there was no room for additional hardware, so combination particulate + chemical filters were employed as replacements. Upstream and downstream ozone and VOC concentrations were measured nearly daily from May to September to gauge the efficiency of these combination filters. At the end of 90 days, the VOC efficiency had dropped to approximately 45 percent, but the ozone removal was above 95 percent (see Figure 1). This convinced the building's owner that these combination filters were effective, and their use would improve IAQ. The very high effectiveness of these filters against ozone—even as the effectiveness for VOCs approached zero—meant that the potential for adverse respiratory health effects due to ozone would be significantly reduced or eliminated. Also, the formation of new highly irritating or harmful chemical species due to reactions between VOCs and ozone, would be similarly reduced or eliminated.[18,19]

CONCLUSION

Several studies point to ambient ozone introduced into HVAC systems as a health risk factor to building occupants. Ozone in the outdoor air has been associated with an increase in BRS and buildings with very low ozone in the outdoor air were found to have up to 45 percent less prevalence of BRS.

In contrast to particle filters, gas-phase air filters are used in only a small minority of buildings because of a lack of strong and enforceable requirements for cleaning outdoor air. Combination filters have been shown to provide the ability to effectively and economically control both particulate and gaseous contaminants, and even when the filter is effectively spent with regard to other gaseous contaminants, ozone removal efficiency remains high.

Although requiring the use of air cleaning systems for ozone is an important first step in addressing the quality of the outdoor air being used for ventilation purposes, a requirement for ozone air cleaning in all areas of non-attainment should be considered as mandatory given the current level of understanding regarding ozone and its impact on IAQ and health. We must acknowledge that adding a requirement in ventilation standards and codes to control ozone will bring us a closer to the goal of assuring and providing acceptable indoor air quality. **em**

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