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Ozone Removal by Filters Containing Activated Carbon: A Pilot Study

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SUMMARY
This study evaluated the ozone removal performance of moderate-cost particle filters containing activated carbon when installed in a commercial building heating, ventilating, and air conditioning (HVAC) system. Filters containing 300 g of activated carbon per 0.09 m^2 of filter face area were installed in two "experimental" filter banks within an office building located in Sacramento, CA. The ozone removal performance of the filters was assessed through periodic measurements of ozone concentrations in the air upstream and downstream of the filters. Ozone concentrations were also measured upstream and downstream of a "reference" filter bank containing filters without any activated carbon. The filter banks with prefilters containing activated carbon were removing 60% to 70% of the ozone 67 and 81 days after filter installation. In contrast, there was negligible ozone removal by the reference filter bank without activated carbon.

KEYWORDS
activated carbon, air cleaning, effectiveness, filter, ozone

INTRODUCTION

Ozone is an air pollutant produced in the lower atmosphere by photochemical reactions. Higher outdoor ozone concentrations have been linked to asthma exacerbation, respiratory symptoms, reduced lung function in children, hospital visits, heart attacks, and premature death (EPA, 2008). Recently, increases in sick building syndrome symptoms among office workers were also associated with higher outdoor ozone concentrations (Apte et al., 2008; Buchanan et al., 2008). In buildings, the outdoor air is normally the dominant source. In addition to the direct health risks of ozone, pollutants created as ozone reacts chemically indoors (Weschler, 2006) may pose risks.

In 2008, the U.S. primary eight-hour National Ambient Air Quality Standard for ozone (EPA, 2008) was changed from 0.08 to 0.075 ppm. While this change appears small, the number of U.S. counties out of compliance with the standard increased from 85 to 345 (http://www.epa.gov/air/ozonepollution/actions.html). The current ventilation and indoor air quality standard for commercial buildings by the American Society for Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE, 2007) requires air cleaning for ozone when the second highest one hour average ozone concentration exceeds 0.160 ppm, but the standards committee is considering more stringent ozone air cleaning requirements.

Limited prior research has demonstrated that granular beds of activated carbon (Weschler et al., 1992) or filters containing activated carbon (Gundel et al., 2002; Beko et al., 2008) can be highly effective in removing ozone from an airstream for an extended period. In addition, research has shown that the addition of activated carbon in at least one type of bag filter that also removes particles can improve perceptions of air quality (Beko et al., 2008). Most major particle filter manufacturers now market filters that contain some activated carbon while also

using fibrous media to remove particles. These filters are marketed primarily to remove volatile organic compounds from air, not for ozone removal. However, the previously cited tests demonstrating that filters with activated carbon can be highly effective in removing ozone have been performed only for very expensive filter systems (Weschler et al., 1992; Beko et al., 2008) or for a filter unit designed for installation in a luxury automobile (Gundel et al., 2002). No data were identified on the ozone removal performance of a practical–cost particle filter containing activated carbon for general commercial building applications. The key performance questions are as follows: What is the ozone removal efficiency? Is the ozone removal efficiency maintained over the usual deployment period for the filter?

The objective of this study was to obtain limited data on the ozone removal performance of a single type of moderate-cost particle filter containing activated carbon. This was a small study intended to determine the merits of future related research.

METHODS

Filters containing a layer of activated carbon were installed in two "experimental" filter banks in an office building located in Sacramento, CA. The ozone removal performance of the filters was assessed through periodic measurements of ozone concentrations in the air upstream and downstream of the filters. For reference, ozone concentrations were also measured upstream and downstream of a "reference" filter bank containing filters without activated carbon. The two experimental filter banks treated the air provided to a single building zone while the reference filter bank treated the air provided to another isolated zone. The carbon-containing filters selected for study were 5.1 cm thick synthetic-media filters with a particle removal efficiency rating (ASHRAE, 1999) of MERV 8, with 300 g of activated carbon per 0.09 m^2 of filter face area, and with a cost of $U.S. 29 for a 61 cm by 61 cm filter. The manufacturer's reported pressure drops for these filters are 58 and 138 Pa with face velocities of 1.5 and 2.5 m/s, respectively. Although filters with a MERV 8 efficiency are often used as the only filter in a HVAC system, in this building these carbon-containing filters were used as pre-filters located immediately upstream of 38 cm deep pleated bag filters with a "dust spot" particle removal efficiency (ASHRAE, 1992) rating of 85%. The reference filter bank was identical to the experimental filter banks except that it contained 5.1 cm thick MERV 8 pleated synthetic-media pre-filters containing no activated carbon.

Ozone concentrations were measured using the 2B Technologies Model 202 Ozone Monitor. Concentrations were logged every 10 seconds to the instrument's internal memory for at least 5 minutes each upstream and downstream of both the experimental filter banks and the reference filter banks. The technician walked into the appropriate rooms of the air handlers to access locations upstream and downstream of filter banks and held the instrument at least three feet above the floor at a central location (several feet upstream or downstream of the filter bank) while data were logged. Because accurate measurements of low ozone concentration with portable instruments are very difficult, the measurements occurred mid-to-late afternoon when outdoor air concentrations were expected to be highest. Our prior experience showed that relative humidity above approximately 65% could lead to significant measurement errors and that passing the instrument's inlet air sample through moisture-permeable Nafion® tubing located in a lower humidity environment greatly reduced such errors. Consequently, in our study the ozone-containing air sample was passed through Nafion® tubing coiled inside a container containing silica gel desiccant. The air sample passed through two sections of 0.5 m long tubing (internal and external diameter were 1.06 and 1.35 mm, respectively) installed in parallel.

Measurements were performed on seven days between August 8, 2008 and October 28, 2008. In the first five measurement periods, the air handlers operated without intervention and most of the air entering the filter banks was recirculated indoor air. During these five measurement periods, the concentrations of ozone entering and exiting the filter banks were too small (e.g., 5 ppb) to allow an accurate determination of the ozone removal efficiency of the filters, given that the ozone instrument's output signal fluctuated substantially at these concentrations. The moderate-to-low concentrations of ozone in outdoor air (typically about 20 ppb), the high proportion of recirculated air in the airstream entering the filters, and the low concentration of ozone in recirculated air, presumably because of indoor ozone chemical reactions, explain the low ozone concentrations at the inlet of the filters. Consequently, for the last two measurement periods, the air handler was operated with 100% outdoor air supply (no recirculation) during the periods of data collection. In addition, a different ozone monitor (same brand and model), with a more stable output signal was utilized.

RESULTS

Table 2 provides the upstream and downstream ozone concentrations and the percentage ozone removal from the final two measurement periods when the air handlers were operated with 100% outdoor air. Data from the prior measurement periods was not used for the reasons described previously. The ozone removal percentages have been rounded to the nearest 10%.

Table 2. Ozone removal performance of the filter banks.

Days After Filter Installation	Filter Bank	Activated Carbon in Prefilters	Upstream Ozone (ppb)	Downstream Ozone (ppb)	% Ozone Removal*
67	EFB 1	Y	27	8	70%
67	EFB-2	Y	22**	8	60%
67	RFB	N	21	21	0%
81	EFB 1	Y	23	8	70%
81	EFB-2	Y	22	10	60%
81	RFB	N	23	22	0%

*rounded to nearest 10% **Excluding the two 80 ppb data points during a spike in instrument output. The remaining 29 data points were all near to 21 ppb. Without excluding the two data points, the calculated ozone removal efficiency is 70%. Other users of these instruments have reported similar unexplained and unrealistic spikes in output signal.

DISCUSSION

The experimental results indicate that the filter banks with pre-filters containing activated carbon were removing 60% to 70% of the ozone 67 and 81 days after filter installation. In contrast, there was negligible ozone removal by the reference filter bank which had no activated carbon in the filter media. Given that pre-filters are often changed every three to four months, these results are highly encouraging – suggesting that moderate cost activated-carbon-containing filters can be effective in ozone removal over their service life. Due to the low ozone concentrations at the filter inlets and ozone measurement imprecision, the study did not determine if the ozone removal efficiency during earlier periods of filter deployment were substantially higher than 60% to 70%. In addition, because of the onset of cool weather after 81 days of filter deployment and the reductions in outdoor ozone production with cooler temperatures, the study was unable to determine if these filters are able to maintain moderate to high ozone removal efficiencies for more than 81 days. Conceivably, filters of this type might be deployed for more than the 81 day test period, particularly when used as a main filter in contrast to deployment as a pre-filter.

For a number of reasons, the ozone removal efficiencies reported in this study should be considered only approximate values. The results are based on only two periods of short term measurements made at single locations upstream and downstream of each filter bank. In addition, the concentration measurement uncertainties are likely to be 10 to 20 percent at the low ozone concentrations encountered. It is encouraging that despite these sources of uncertainty the four measured ozone removal efficiencies of the experimental filter banks all fall within the 60% to 70% range

CONCLUSIONS

Despite the limitations noted above, the study determined that the magnitude and duration of ozone removal from a set of moderate-cost filters is clearly sufficient to justify and enable future research. Longer term studies of the ozone removal performance of a variety of practical-cost filters containing activated carbon are desirable.

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