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Ozone removal efficiency and surface analysis of green and white roof HVAC filters

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ABSTRACT

Heating, ventilation, and air-conditioning (HVAC) system filters from a commercial building were tested for their ability to remove ozone from intake air. Filters were taken from rooftop HVAC systems installed for two months: one located on a white membrane roof and the other on a vegetated green roof. One new, unused filter sample was tested as a reference. Samples from these filters were exposed to ozonated air streams at 40 and 120 ppb and relative humidity levels of 30% and 70%. Filter surfaces were analyzed with a scanning electron microscope to observe the structure and composition of the materials loaded on each filter before and after exposure to ozone. The results show that for all samples tested, the ozone removal efficiency decreases with continued O_3 exposure. Removal efficiencies of 5–15% for white roof and unused filter samples, and 10–25% for green roof filter samples were observed after 5 h of exposure to O_3. Filters taken from HVAC units located in the green roof area showed more ozone removal than unused filters or those taken from white membrane roof area. Unexpectedly, the unused filter samples had slightly higher ozone removal than the white roof filter. The data also show that the ozone removal percentage is higher when tested with 40 ppb ozone inlet concentration than at 120 ppb. SEM images show deposits of biotic material that are present on green roof samples, ostensibly explaining the greater ozone removal efficiency of filters from vegetated roofs.

1. Introduction

The heating, ventilation, and air-conditioning (HVAC) system is central to ensuring the comfort and health of occupants of built environments. In commercial buildings, an HVAC system modulates the temperature, relative humidity, and levels of air pollutants in the indoor space via a combination of recirculation, filtration, and outdoor air ventilation. The intended role of an HVAC filter in a ventilation system is to trap particulate matter in the air supply system, for the protection of both occupants and downstream HVAC equipment. However, some research suggests that HVAC filters contribute to the removal of other air pollutants, including ozone [31]. Ground level ozone is a contaminant that forms outdoors as a result of a photochemical reaction between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight [20]. Ozone is an oxidant gas that has adverse effects on human health, including contributing to acute mortality [11] and lung function disorders [16]. The US EPA National Ambient Air Quality Standard for ozone is 70 ppb averaged for eight hours [10]. However, much higher levels, in exceedance of 100 ppb, especially in summer, are observed in many cities [7,24,27].

Outdoor ozone is transported indoors through the ventilation system and via infiltration across the building envelope. Outdoor ozone is removed by buildings through reactions with the building envelope [13,26], HVAC system components like ducts and filters [18], and interior surfaces [1,21]. Some HVAC filters are made of fibers with carbon-containing compounds, which may provide surface reaction sites where ozone chemistry can occur [29]. However, the removal efficiency of unused filters is generally low for filters not specifically targeting ozone (e.g., [25,28]. For instance [31], compared ozone removal of filters made from synthetic fiberglass materials that were either unused or used in residential or commercial buildings. The results show low ozone removal values of 0–9% for unused filters and values ranging between 10 and 41% for used filters [14]. tested the ozone removal efficiency of ten commercial filters that include granular activated carbon in their composition. The test results show that ozone removal efficiency of activated carbon filters varied over a broad range, from 4.6% to 98% based on filter type. These results imply filter composition can substantially affect O_3 levels in ventilation air.

While ozone removal is beneficial, reaction products may form due

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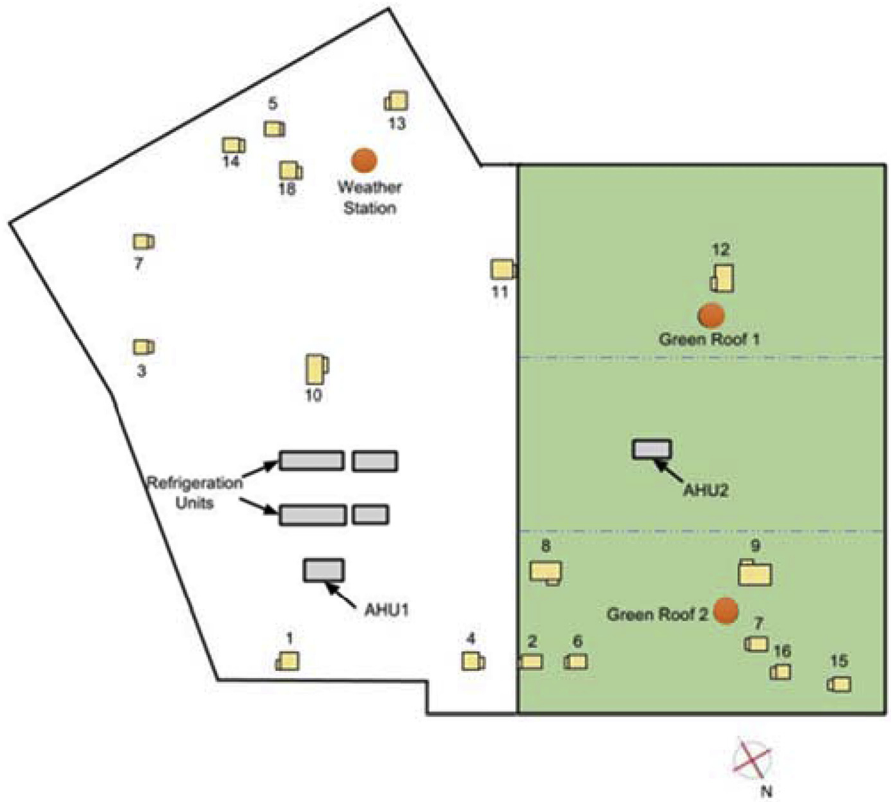

Fig. 1. Plan view for the roof of the commercial building. The green section shows the green roof, and the white section shows the white membrane roof. AHU1 and AHU2 refer to locations where filters are sampled. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

to ozone chemistry on filters. For instance [15], have studied ozone removal and carbonyl generation from HVAC filters taken from different buildings; their results show low ozone removal percentage (less than 10%) for non-activated carbon containing filters. However, for used filters, ozone removal ranged between 10 and 92%. Carbonyl concentrations resulting from ozone reactions with filters or material deposited on filters ranged between 2 and 20 $\mu g\,m^{-3}$ except for the tested activated carbon filter, which was $\sim 90\,\mu g\,m^{-3}$ [12]. conducted a study of ozone removal and VOC emissions from dusty, clean, and sooty filters taken from different buildings with variable deployment time. The effect of dust load, diesel soot, relative humidity and time of exposure were studied. Samples were tested in a small laboratory scale test apparatus with inlet ozone concentration ranged from 22 to 77 ppb. The results show differences in ozone removal among filter types where no ozone removal was observed from unused polyester filters, and higher ozone removal (25–30%) with higher TVOC emissions from in soot loaded filters. From these studies, it is clear that the loading of HVAC filters impacts both ozone removal and byproduct formation, with consequences for indoor air quality.

Many commercial HVAC units are installed on rooftops of buildings; rooftop HVAC consume substantial energy while affecting indoor air quality [30]. At the same time, two increasingly popular sustainable building practices affect the nature of the rooftop surface: installation of vegetated green roofs and white membrane roofs. Green roofs, also known as ecoroofs or vegetated roofs, are roofs containing a substrate layer that serves as a medium for growing plants [22]. It has been suggested that green roofs increase building energy-efficiency, improve storm water management, and reduce the urban heat island effect [4], although outcomes vary as a function of specific design criteria like extent of vegetative cover [23]. White membrane roofs include as the outermost layer a thin high albedo (white) membrane that contributes to reductions in roof surface temperature, increasing building thermal efficiency and mitigating the urban heat island effect [6,19]. Given that outdoor ventilation air intakes are frequently sited on building rooftops, it is possible that the nature of the rooftop surface immediately surrounding the ventilation air intake affects the quality of air entering the HVAC system. This may be due to fluxes of gases [5]) and/or re-suspended particles [17] from the rooftop that are transported into the HVAC system by wind or heat induced vertical mixing.

The objective of this research is to investigate the ozone removal efficiency of HVAC filters installed in air handling units located on green and white roof areas of a single commercial building and to compare results to a new, unused filter. We propose that the differences in fluxes of gas and/or particle-phase pollutants from either vegetated or white membrane roofing materials affects the amount and type of HVAC filter loading, in turn impacting ozone removal by HVAC filters. We apply scanning electron microscopy (SEM) imaging and chemical analysis to analyze the surface deposit composition of new and used filters, pre and post-ozonation. These data provide insights as to the mechanisms by which filter fouling, ozone removal, and byproduct formation are related in filters taken from a location with two increasingly common roofing types.

2. Methodology

2.1. Materials

In this research, three identical HVAC filters (Purolator, CLARCOR Air Filtration Products, Inc.) with dimensions of 24″ × 24″ × 2” (609 mm × 609 mm x 50 mm) with a high capacity MERV 8 rating were used in tests. Filters were made of a mixture of polyester and polyolefin fabric as confirmed by the manufacturer. Two filters were taken from air handling units situated in green roof and white roof sections of a commercial building in Portland, Oregon, USA. Each filter had been installed and in service on the rooftop for a period of two months (September–October 2015). The test field site is further described in Section 2.2. A new, unused filter was also tested to both evaluate ozone removal to unused filters and to provide a reference for comparison of SEM images and ozone removal by used filters. All filters were sampled from the field, wrapped with aluminum foil and stored in the original