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INDOOR/OUTDOOR POLLUTANT RELATIONSHIPS IN AN AIR-CONDITIONED ROOM DURING AND AFTER THE 2013 HAZE IN SINGAPORE

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INTRODUCTION

Indoor air quality is important to human health because people spend significant amount of time indoors (Klepeis et al., 2001). In addition to provide adequate air exchange for the indoor environment, air-conditioning and mechanical ventilation (ACMV) system in office building also helps to protect indoor occupants from exposing to air pollutants originated from both indoor and outdoor sources. This study aims to understand the level of protection provided by the ACMV system during both hazy and clear outdoor conditions. The indoor and outdoor particle concentrations were monitored simultaneously to evaluate the impacts from the ACMV system.

METHODOLOGIES

Simultaneous monitoring of outdoor and indoor particles was conducted on Nanyang Technological University (NTU) campus. The outdoor monitoring station was on the covered balcony that was about 12 m above the ground. The indoor sampling was carried out in an unoccupied office, which was about 20 m away from the outdoor monitoring station and 9m above the ground. The office had an area of about 300 m^2 and equipped with basic office furniture with no obvious indoor particle sources. The office was served by an independent air-handling unit (AHU) system. There were two monitoring campaigns in the present study, which were the hazy day monitoring campaign and the clear day monitoring campaign. Indoor and outdoor particles (11.5nm to 10μm) were concurrently monitored continuously for multi-days. The haze day monitoring campaign lasted from 14 to 28 June 2013 and the clear day sampling campaign lasted from 14 to 28 August 2013. Particles with the size range of 11.5nm to 273.8nm were monitoring by the TSI Nanoscan SMPS Nanoparticle Sizers (Model 3910, TSI Inc., Shoreview, USA). The TSI optical particle sizers (Model 3330) were used to monitor particles of 0.3μm to 10μm in 16 channels. An InfraRan Specific Vapor Analyzer of SF6 gas (Wilkes Enterprise Inc., East Norwalk, USA) was used to measure the air exchange rates (ACH) in the studied room based on tracer gas decay method.

RESULTS AND DISCUSSION

Particle number size distributions of outdoor submicron particle number concentrations in selected hazy and clear days were illustrated in Figure 1. The results showed that for particles of 0.3-10μm, the outdoor particle volume concentrations in the most polluted day (21 June 2013) were about 8-10 times higher than those in a typical clear day (19 August 2013). However, for ultrafine particles (UFPs) of 11.5-278.4nm, their number concentrations were comparable in the two days, although the size-distributed number concentration profiles were different. The phenomenon might be attributable to growth of ultrafine particles to larger particles during their long-distance transport from the sources to the Singapore city.

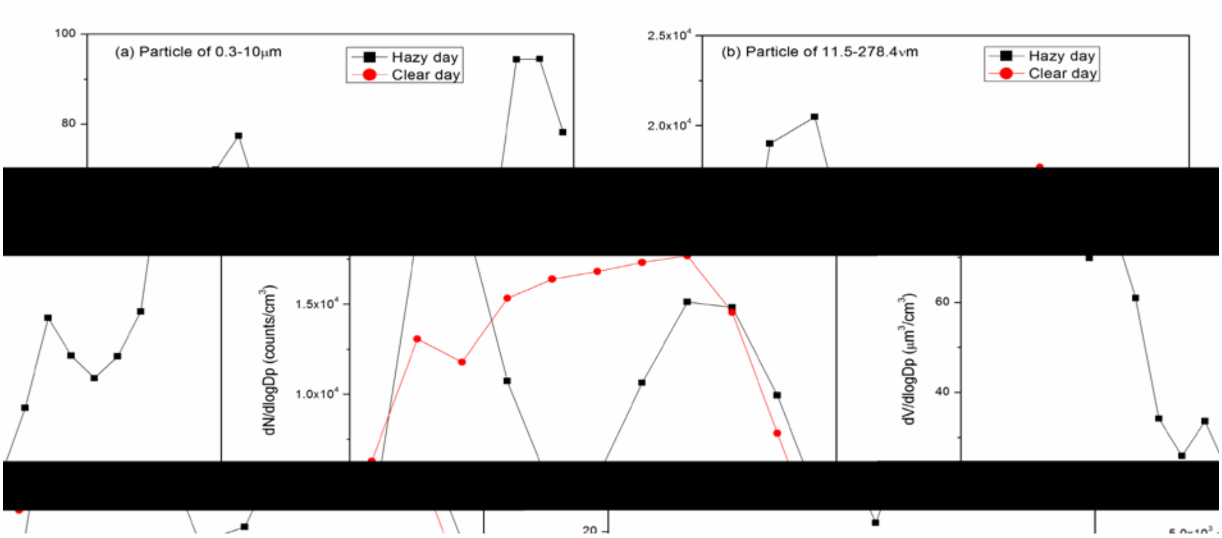

Figure 1. Size-resolved outdoor submicron particles number concentrations in selected hazy and clear days.

As shown in Figure 2 (a), in the most polluted day, the indoor volume concentrations of particles of 0.3-1.117μm correlated closed with those of outdoor particles with slight delay in time. The finding indicated that the contribution from outdoor to the indoor environment is significant for this size range. However, for larger particles (Figure 2 (b) and (c)), similar trend was not observable. Further interpretations found that the indoor/outdoor PM ratios (I/O) for particles of 0.3-1.117μm, 1.117-2.685μm and 6.451-10μm were 0.49, 0.09 and 0.03, respectively. The lower I/O ratios of large particles were mainly because of the removal effects of the ACMV system since the ACH of the studied room was considerably larger than their indoor deposition rates (ACH: 4 h^{-1} *versus* deposition rates for particles of 1-10μm: 0.25-1.78 h^{-1}) (Thatcher and Layton, 1995). The results therefore implied that the filtration system of the ACMV system could remove particles > 1.117μm effectively, but not so for the particles <1.117μm. This is because that fibrous filters cannot effectively capture particles of 0.1-1.0μm, since they are too large to diffuse and yet too small for either impaction or interception (Hinds, 1999; Nazaroff, 2004). In combination with the much higher outdoor volume concentrations of particles <1.117μm in the most polluted day, indoor occupants were expected to expose to much higher concentrations of particles <1.117μm in the most polluted day than in a clear day.

In the hazy days, the ACMV system for the indoor environment was operated in ACMV on mode and AC off mode (without cooling but the MV was on) for daytimes and nighttimes, respectively. The I/O ratios for particles larger than 0.2μm were lower when there was cooling in the ACMV system (Figure 3). The elevated filtration efficiency might be due to the wet surface of the cooling coil. The appearance of water film on cooling coil surface would change the gravimetric settling and inertial impaction processes and consequently increased the filtration efficiency. It has been recognized that the cooling coil does contribution to the particle removal in the ACMV system (Jamriska et al., 2000; Siegel and Nazaroff, 2003); however, a better understanding on its role and efficiency is desirable.

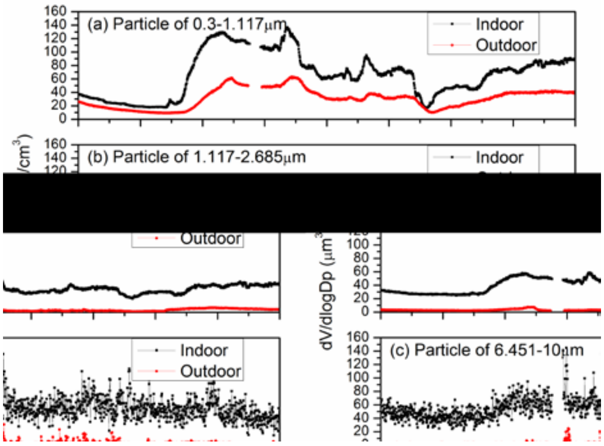

Figure 2. Time-resolved indoor and outdoor particle volume concentrations in the most polluted day.

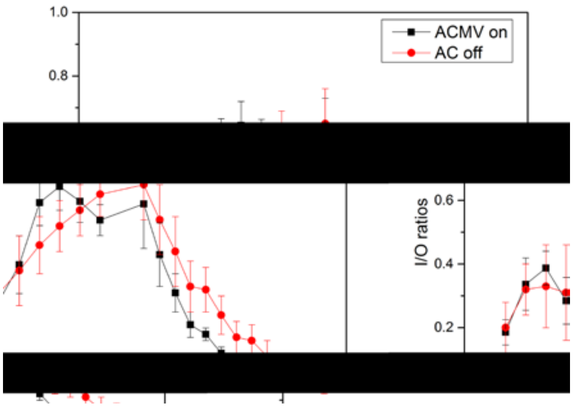

Figure 3. I/O ratios of submicron particles during the hazy days.

CONCLUSIONS

The ACMV system mitigates migration of outdoor originated particles into indoor environments. The removal efficiency is size dependent and is more effective for the larger particles. The protection effect provided by the building is not satisfactory for the particles <1.117μm during the haze episode.

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