Topic B2: Particles

DUST EXPOSURE IN INDOOR CLIMBING FACILITIES

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SUMMARY

Indoor climbing gyms have very high concentrations of PM_{10}. This is because the chalk (magnesium carbonate) that rock climbers use to keep their hands dry is a significant particle source. In sufficiently polluted spaces, inhalation of magnesium carbonate has been shown to cause respiratory system irritation, cough, and pulmonary problems. This research effort consisted of baseline particulate-matter measurements and three interventions. The interventions involved placing air cleaners in various places in the gym and offices. PM_{10} concentrations of up to 597 $\mu g\ m^{-3}$ (6-hour average) were measured in the gym. Concentrations increased with occupancy when the air conditioning system was off. The highest measured 6-hour-average concentration with ventilation was 190 $\mu g\ m^{-3}$, which is approximately 70% lower than the peak value with no ventilation. Because of the large error bars on the data, we could not draw strong conclusions on reduction in PM10 in the office during the interventions.

INTRODUCTION

Numerous studies have established that particle pollution has a negative impact on human health (Pope et al., 2002, Slaughter et al., 2005, Samet et al., 2000). Respirable particles have the most significant impact on human health, because they are the only particles that are likely to reach the gas-exchange region of the lungs (Lindsay et al., 2009).

Indoor climbing gyms have very high concentrations of PM_{10} and $PM_{2.5}$. This is because the chalk (magnesium carbonate) that rock climbers use to keep their hands dry is a significant particle source (Weinbruch et al., 2005). In sufficiently polluted spaces, inhalation of magnesium carbonate has been shown to cause respiratory system irritation, cough, and pulmonary problems (Vincoli, 1996). Even though inhalation of magnesium carbonate can cause health problems, it is considered nontoxic (Kuschner et al., 1997). Therefore, general dust standards for workplaces, mandated by the Occupational Safety and Health Administration (OSHA), are used to regulate its concentration (OSHA, 2012).

Currently, there is a significant discrepancy between indoor (workplace) and outdoor PM regulations. One reason for this is that indoor regulations are designed to protect healthy adults in their workplaces, and outdoor regulations are designed to protect sensitive populations, such as children, the elderly, and asthmatics. OSHA dictates that the maximum legal level of dust in a workplace is 15 mg m^{-3} of total dust and 5 mg m^{-3} of respirable dust (OSHA, 2012). National Ambient Air Quality Standards (NAAQS) limit acceptable outdoor

$PM_{2.5}$ levels to 35 μ g m^{-3} and PM_{10} levels to 150 μ g m^{-3}, both averaged over 24 hours (Lindsay et al., 2009). OSHA standards apply to healthy adults, while NAAQs apply to the general population, including sensitive individuals.

Approximately 4.8 million Americans participated in rock climbing in 2010. This was an 11% increase over the number of participants in 2009 (Foundation, 2012). As participation increases, climbing gyms are becoming more crowded, and more people are exposed to chalk dust in climbing gyms. The growing number of children who climb indoors may warrant consideration of sensitive populations in determining air quality standards in climbing gyms.

Weinbreck et al. explored the problem of PM levels in indoor climbing facilities (Weinbruch et al., 2005). The authors measured PM_{10} concentrations of up to 4000 μ g m-3 and $PM_{2.5}$ concentrations of up to 500 μ g m^{-3} during peak hours (Weinbruch et al., 2005). The measured $PM_{2.5}$ and PM_{10} values were much higher than those of non-climbing exercise facilities, which had PM_{10} concentrations lower than 100 μ g m^{-3}.

In addition to finding particle concentrations, the authors used scanning-electron microscopy and energy-dispersive X-ray analysis to evaluate the size, morphology, and chemical composition of the particles (Weinbruch et al., 2005). They found that the particles consisted almost exclusively of magnesium alba (hydrated magnesium carbonate). They also conducted experiments that cycled humidity from 5% to 100% and back 3 times over 21 days. The particles developed a film of water, but never dissolved. Weinbruch et al. concluded that because magnesium alba particles do not dissolve, they deposit as solids in the respiratory tract.

For the reasons mentioned above, it is worthwhile to explore options for reducing particle concentrations in indoor climbing gyms. Increasing building ventilation is one solution, but heating and cooling large amounts of air can lead to very high electricity costs. A more cost-effective option is to use in-room air cleaners. Multiple studies have shown in-room air-filtration systems to be effective at reducing particle concentrations (Miller-Leiden et al., 1996, Offermann et al., 1985). Properly sized air cleaners can reduce room-average particle concentrations by up to 90% (Miller- Leiden et al., 1996).

METHODOLOGIES

Ambient particulate-matter concentrations were obtained using two instruments. A TSI Aerodynamic Particle Sizer Spectrometer 3321 (APS) provided temporal sampling of PM aerodynamic diameter distributions. The APS was positioned in the main gym at Location 1 in for the baseline sampling period and during the first intervention. It was placed in the office (Location 3) during the third intervention. 25mm filter-samplers (URG-2000-25FG) were used to measure time-averaged PM_{10} mass concentrations. It should be noted that the APS was not calibrated prior to the experiment. Still, the APS data is useful in determining trends and correlations.

This research effort consisted of baseline particulate-matter measurements and three interventions. The study began with four days of baseline sampling. Samples were collected for 6 hours each day. Specific sampling locations include: (1) the second-floor of the main gym, adjacent to the main climbing wall, (2) a second floor railing in the middle of the gym, directly above the bouldering wall and (3) the front-desk/office area. Filter samplers were at every location. Of the four sampling periods, three were conducted during the busy evening

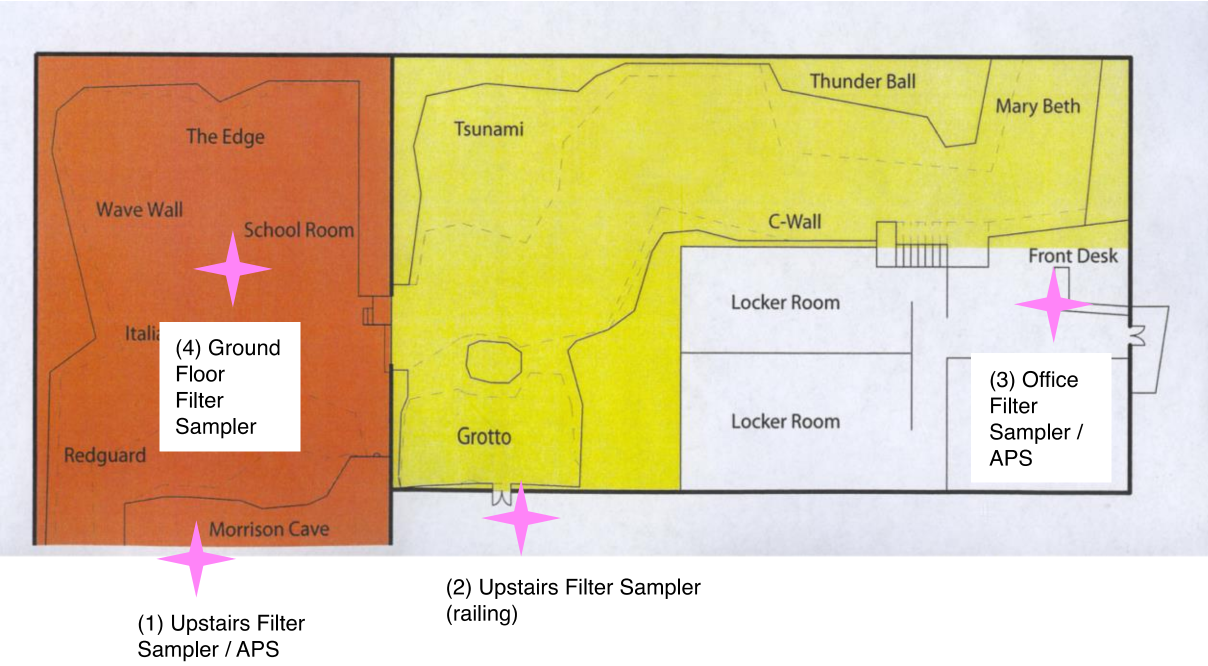

Figure 1. Diagram of the Boulder Rock Club. Pink stars indicate sampler locations 1-4.

hours of 6pm to 11pm, with the objective of acquiring worst-case datum. The fourth sampling campaign was conducted on a weekday, which provided low-occupancy data for comparison.

The next phase of the study consisted of two 6-hour days of sampling. Intervention 1 was designed to reduce employee dust exposure by placing a small HEPA air cleaner (Honeywell HHT- 011) very close to the gym employees. The Honeywell HHT-011 has a Clean Air Delivery Rate (CADR) of 93 $m^3 hr^{-1}$, which is much too small to filter the entire front office (170 m^3). Thus, the air cleaner was used as a personal air cleaner, with its outlet positioned such that the filtered air entered the employee front-desk seating area. Sampling locations were the same as for the baseline sampling.

The third phase of the study, Intervention 2, was also implemented for two 6-hour sampling days. The second intervention consisted of placing two Friedrich C90 electrostatic precipitating air cleaners, which each have a CADR of 404 $m^3 hr^{-1}$, in the office (Henderson et al., 2008). This intervention was also designed to reduce employee dust exposure, and added 4.7 air exchanges per hour to the room. Sampling locations 2 and 3 were the same as in the previous phases of the study. A new sampling location, which is approximately 0.5 m above the floor in the center of the main room of the climbing gym, was added (Location 4). The upstairs sampling locations (1 and 2), are less susceptible to point sources, since they are not near any climbers, but Location 4 is closer to where climbers spend most of their time.

The final phase of the study (Intervention 3) was designed to reduce exposure to employees and climbers, and consisted of placing five Friedrich C90 electrostatic precipitating air cleaners in the main gym. Like the previous 2 phases, this phase was implemented for 6 hours on 2 separate days. Samples were taken at locations 2, 3 and 4.

We estimated air exchange rates in the gym by performing linear regressions on the decay of the natural log of concentration after the ventilation system turned on (or when occupancy decreased, in the case when the ventilation system was not turned on).

RESULTS AND DISCUSSION

PM_{10} concentrations of up to 597 $\mu g\ m^{-3}$ (6-hour average) were measured in the gym. Concentrations increased with occupancy when the air conditioning system was off. The highest measured 6-hour average concentration on a day when the air conditioning was running was 190 $\mu g\ m^{-3}$, which is approximately 70% lower than the peak value with no ventilation. When the ventilation system is running, its effect on PM_{10} concentrations dwarfs the effect of occupancy. We estimate that the air exchange rate in the facility is 0.75 changes/hour when the ventilation system is off, and 7.1 changes/hour when the ventilation system is on.

Figure 2 displays average daily outdoor temperature versus 6-hour averaged PM_{10} concentration at locations 1 and 2. When outdoor temperature is low, the air conditioning system is off, and indoor concentrations are very high. When temperature rises, the ventilation system turns on, and PM_{10} concentration decreases. Figure 3 shows PM_{10} concentration at location 1 versus time for two different days. The bottom plot displays data from April 3, when the ventilation system was off, and the top plot represents April 4, when the ventilation system was running. On April 3, there were some fluctuations in concentration, but once the concentration exceeded 200 $\mu g\ m^{-3}$, it never dropped back below that value. On April 4, the concentration peaked at approximately 400 $\mu g\ m^{-3}$, and rapidly dropped to less than 50 $\mu g\ m^{-3}$ three different times. This can be explained by the fact that location 1, where the APS was located, was about 3 m an air conditioning vent, so when the ventilation was operating, PM_{10} concentrations dropped to nearly outdoor levels.

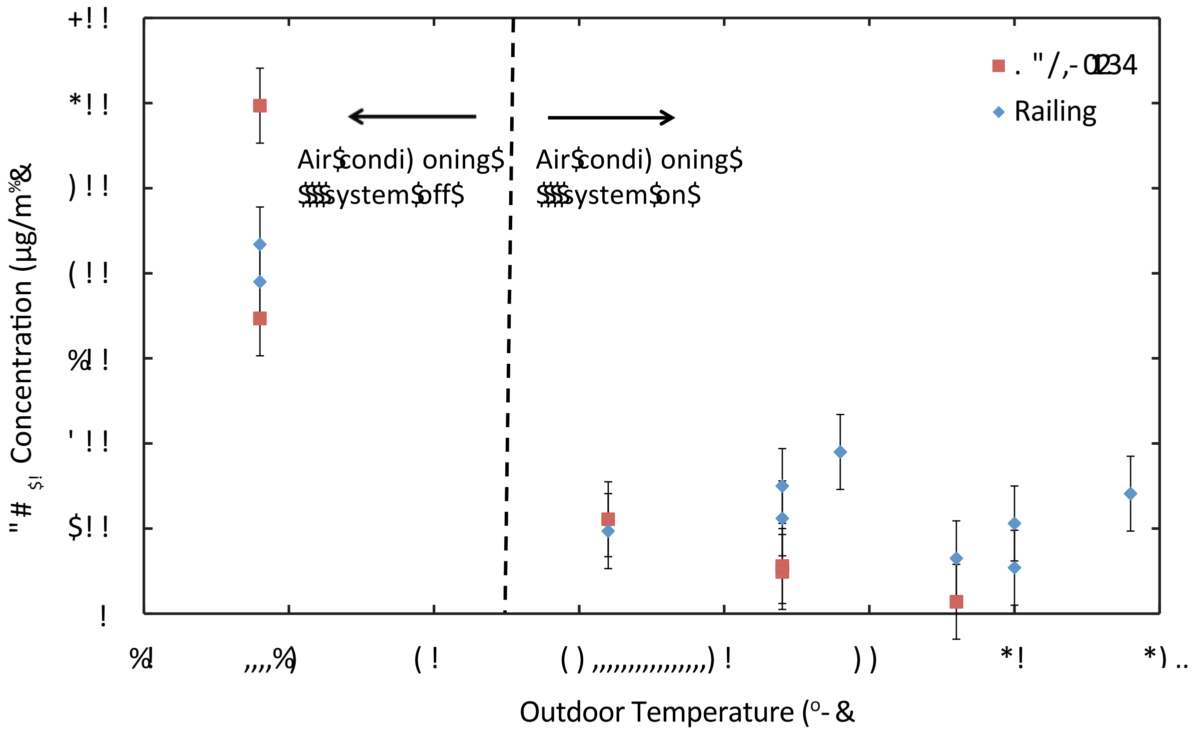

Figure 2. PM_{10} versus outdoor temperature. When temperature rises, the ventilation system turns on, and PM_{10} concentration decreases.

Figure 4 displays PM_{10} concentrations at locations 2 and 3 (railing and office) for the baseline scenario and the three interventions. Two days of data are presented for the following scenarios: no ventilation, A/C in the main gym with no intervention, A/C in the main gym and personal samplers placed in the front office, A/C in the main gym and appropriately-sized samplers at the front office, and A/C and air filters placed in the main gym.

The first thing worth noting in Figure 4 is that when the ventilation system is off, the wall

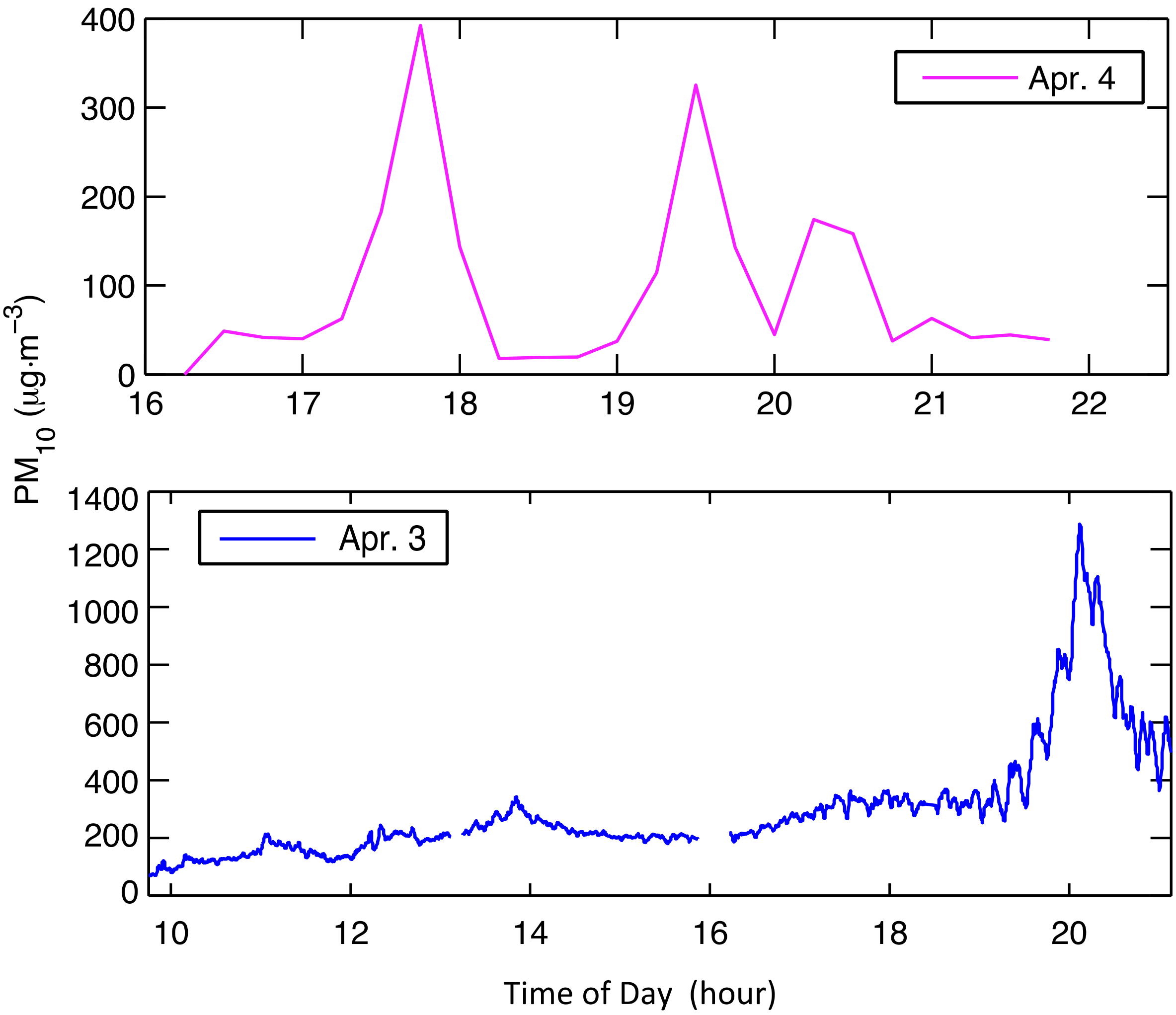

Figure 3. PM_{10} versus time on 3 days. When the ventilation system turns on, PM_{10} values drop dramatically.

between the front office and the gym partially shields the office from PM_{10} (40-50% reduction). The next two sets of data, labeled, “A/C Only”, show a significant decrease in PM_{10} concentrations in the gym compared with the “no ventilation” scenario.

It is not possible to draw strong conclusions about the effectiveness of the interventions because the error bars are large compared to the data. In order to do statistical analysis, we need longer sample times, which would both reduce the uncertainty and increase the concentration values.

While more data is needed to draw strong conclusions, some observations can be made based on Figure 4. The air cleaners did not seem to make a significant difference in office PM_{10} concentrations for either of the scenarios where air cleaners were placed in the office. We can infer that the reason the "properly sized" office air cleaners did not significantly reduce PM_{10} was that the door to the gym is opened about once a minute when the gym is busy. Because the door is opened so frequently, the office is infiltrated with PM_{10} from the gym at a very high rate.

Perhaps the most interesting result that can be inferred from Figure 4, is the fact that PM_{10} concentrations in the office were reduced the most compared to PM_{10} in the gym in the

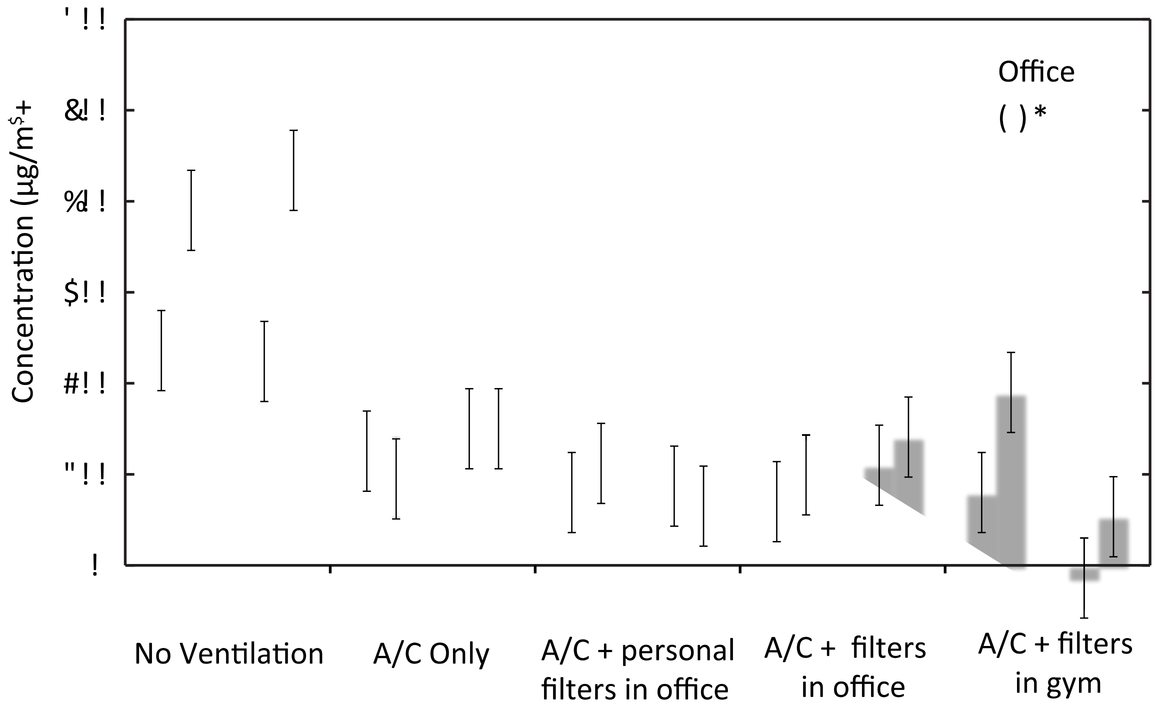

Figure 4. Ventilation type versus PM_{10} concentrations for the office and railing (main gym).

"A/C + filters in gym" scenario. We suspect that this is because 2 air cleaners were placed in the narrow part of the gym, near the doors that connect the office to the gym. Since concentrations in the gym (near the door to the office) were reduced, less PM_{10} infiltrated the office each time the door opened, and the filters acted as a source control for the office.

CONCLUSIONS

Rock climbing facilities have high PM_{10} concentrations. In the facility studied in this research effort, the ventilation system reduced particle concentrations dramatically when it was in operation. When the ventilation was not running, as is frequently the case in colder months, the concentration is highly dependent on occupancy. However, when the ventilation is on, it has a much greater effect on PM_{10} concentration than occupancy. As a result, it is recommended that the ventilation system be programmed to be turned on when the gym is open and occupancy is high, regardless of temperature. Another potential solution would be to install a new air filtration system in the gym, but this solution is currently cost prohibitive.

Because of the large error bars on the data, we could not draw strong conclusions on reduction in PM_{10} in the office during the interventions. Nevertheless, full-time employees spend much of their time in the office, and it is therefore important to ensure good air quality. Adding small air cleaners to the office is inexpensive, so, even with inconclusive data, we still recommend running small air cleaners in the office areas. Finally, adding air filters to the front portion of the gym was effective at reducing PM_{10} in the office. Therefore, adding air cleaners to that area should also be considered.

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