Characteristics of Ambient Toner Particle Concentrations in a Printing Plant

Derek Gosman
Department of Technology
Ball State University
Muncie, IN 47306
USA

Renmei Xu
Department of Technology
Ball State University
Muncie, IN 47306
USA

Juan Carlos Ramirez-Dorronsoro
Department of Natural Resources and Environmental Management
Ball State University
Muncie, IN 47306
USA

Abstract

Dry toner is a common printing substance used in a wide variety of printing settings – e.g., residential, office, and industrial.The current study investigated the characteristics of ambient particles in a small printing facility.Ambient particles of various sizes, ranging from 0.3µm to >5.0 µm, were sampled usinga CLiMET Model CI-154 Airborne Particle Counter prior to the initiation of printing operations and during peak production hours. Samples were collected at various distances from the printing operations. The results indicate a greater number of particles adjacent to printing operations when compared to baseline samples and those taken farther away from the press. These findings suggest toner-based printers are emitting ultra-fine particles into ambient air.

Keywords*:*toner, particle, emission, electrophotography, printing press

1.Introduction

Dry toners are among the most widely used printing substances in contemporary electrophotography (EP; Tolliver-Nigro, 2006). They are readily found in printers and copy machines employed in a variety of settings, including offices, industrial settings, and households. The use of toners in these settings has seen widespread propagation. This increase has been especially prominent within the printing industry, which has benefitted from the expanding applications of production EP presses as a consequence of higher demands of short-run or print-on-demand and variable data printing jobs (Loutfy, 2002; Cleary, 2006).

During the EP printing process, fine toner particles, approximately 8 µm in size, are attracted to a photoconductive surface by electrostatic forces to form an image and then transferred to asubstrate such as paper (Kipphan, 2001). Melting and consequent fixing of the toners on the substrate take place by heat application and contact pressure, but not all toner particles become successfully fixed; some are displaced while being transferred from the photoconductive surfaceto the substrate.

Chronic exposure to elevated ambient concentrations of these substances could culminate in serious health complications (Morawska et al., 2009). The potential of these adverse health effects has two primary sources of support in the respective literature: (1) regular contact with printing equipment predicts a greater risk for respiratory health complications and (2) ambient perfusion of toner particles in offices and industrial settings during working hours can exceed the threshold for acceptable health risks (Hänninen et al., 2010).

Previous findings indicate common printing apparatuses, such as LaserJet office printers, can emit substantial quantities of ultrafine particles (UFPs) from toner cartridges(Khatri et al., 2013). The contents of these cartridges are constituted of complex chemical compositions, including toxic and volatile organic compounds (VOCs). A recent study showed six-hour exposure to modest particle levels (i.e., 5,000-30,000 particles/cm^3 per day) in a photocopying facility lead to a significant elevations in upper-airway inflammation (assessed through multiple biomarkers, including as cytokines expression, protein levels in nasal lavages, andneutrophil recruitment) and oxidative stress (assessed measurements of 8-OH-dG in urine samples) in exposed volunteers compared to healthy controls (Khatri et al., 2012). Damages from oxidative stress and inflammation have been suggested to be among the primary mechanisms of inimical health effects from respirable particles.

The foregoing findings were further supported by a follow-up toxicology study that examined the effects of copy machine UFP emissionson cell cultures(Khatri et al., 2013). Particles samples from the aforementioned photocopying facility were introduced to three types of cell lines (i.e., monocyte, small airway epithelial, and primary nasal) that would come in direct contact with inhaled UFPs. Introduction of UFPs into the cell culture medium was followed by modest cytoxicity, apoptosis, and pro-inflammatory cytokines in all three cell lines. The researchers concluded photocopier UFPs were the source of airway inflammation seen in human volunteers.

Hänninen et al. (2010) reviewed the existing epidemiological findings related to dry toner exposure and concluded the number of ambient toner particles in tested printing sites was positively associated with risk for respiratory illness. Epidemiological estimates of annual mortality rates linked with toner exposure ranged from 4-34 deaths per million, a statistic exceeding the commonly accepted definition of acceptable risk (i.e., $1{:}10^6$). These conclusions are supported by more recent research indicating the concentrations of toner emissions from office printers can reach levels that are threatening to pulmonary health (Wang et al., 2011). Similar studies conducted in office settings have yielded comparable conclusions (He et al., 2007; Betha et al., 2011; Tang et al., 2012).

Multiple longitudinal investigations found long-term employment in commercial printing facilities was associated with a greater frequency of reported respiratory symptoms, such as sputum and coughing, compared to non-printing occupations (Kitamura et al., 2009; Kocki et al., 2011). This association is further supported by correlational studies showing a higher abnormal cell count in the lung tissue of printing workers compared to well-matched controls (Balakrishnan& Das, 2010; Gadhia, Patel, Solanki, Tamakuwala, &Pithawala, 2005). Similar cell abnormalities have been observed in rats following controlled exposure to low concentrations of ambient toner particles (Morimoto et al., 2009).

Taken together, the sum of previous findings indicates toner particles emitted from EP printing presses and office printers are inimical to human health. However, information relative to the specific risk of toner emissions in discreet printing environments is obscured by the limited number and homogeneity of settings investigated thus far. Further investigations are needed to acquire an adequate understanding oftoner emission characteristics in a variety of printing sites. Such information will be required for the generation of any site-based quantitative risk estimates of chronic exposure to toner emissions. The current investigation was a pilot study of toner emissions at a local printing facility. The purposes of the study were (1) to collect preliminary data for a subsequent investigation of multiple printing sites of discreet types (i.e., industrial, office, residential) and (2) to evaluate the chosen research protocol for any needed refinements. Given that toner particles are of relatively large size (approximately 8µm), it was hypothesized that particle concentration numbers for particles of sizes greater than 5.0µm would be greater in particle samples taken in the immediate proximity of EP printing presses than in any other sampling contexts.

2. Methods

2.1. Apparatus

A CLiMET Model CI-154 Airborne Particle Counter was used to collect UFP samples from the ambient air. The device counts ambient particles at sizes of >0.3µm, >0.5µm, >1.0µm, and >5.0µm. UFPs are sampled from the ambient air at a rate of one ft^3 per minute. The device includes a hose attachment that enables sampling of out-of-reach locations (e.g., ceiling vents).

2.2. Procedures

Ambient UFPs were sampled on two separate sessions at a local printing shop. On both instances of data collection, sampling for comparison conditions was based around a single Konica Minolta C6000 press, and was the only press in operation during sampling. During Session 1 data collection, samples were taken in three conditions: (1) nearthe printer (labeled as *near*), (2) far from the printer (labeled as *far*), and (3) adjacent to the ventilation fan (labeled as *vent*). Thirty high resolution 5Lsamples were collected for each condition. In the first condition, the particle counter was positioned adjacent to the printer during sampling. The particle counter's sampling port was 2ft 9in from the press's maintenance panel. These sampling procedures were repeated in the second condition except the particle counter was positioned 13ft 6in from the press. In the third condition, the particle counter's extension hose was used to collect samples from a ventilation fan in the ceiling above the press.The air flowing through the vent is conditioned and distributed throughout the building via an air handling unit. Printing operations were continuous throughout Session 1 sampling, during which time 2,231 single-sided, colored pages were printed on standard 8½x11 paper.

The sampling conditions of Session 2 overlap with those of Session 1: (1) near the printer (labeled as *near*), (2) far from the printer (labeled as *far*), (3) adjacent to the ventilation fan (labeled as *vent*), and (4) prior to the initiation of daily printing operations (labeled as *off*). Session 2 samples were measured in ft^3 instead of 5L. Sampling procedures for the first three conditions were identical to their counterparts in Session 1. Printing operations were continuous throughout the first three conditions, during which 988 double-sided colored pages were printed on standard 8½x11 paper. Sampling procedure for the fourth condition were identical to those of the near condition, with the exception that daily printing operations were not initiated until all 30 samples were collected. At the onset of sampling, printing operations had been suspended for approximately 15 hours.

3.Results and Discussion

All data analyses were performed using SPSS. For the data collected in Session 1, a one-way between groups ANOVA, accompanied by planed contrasts within each size category, was conducted to examine the effect of sampling context on the particle counts of each particle size, in which a significant effect was identified[$F(11, 348) = 514.83$, $p < 0.001$]. Among >0.3µm particles, the count of thenearcondition was significantly greater than that of the far or ventilation condition [$t(43) = 4.676$, $p < .001$]. The count of >0.3µm particles was significantly greater in the ventilation condition compared to that of the far condition [$t(48) = -3.843$, $p < .001$]. Among >0.5µm particles, the near condition showed a significantly greater particle count than the far or ventilation condition [$t(31) = 6.756$, $p < .001$]. The count of >0.5 µm particles in the far condition was significantly greater than that of the ventilation condition [$t(29) = 2.827$, $p < .01$]. Among>1.0µm particles, particles counts in the near condition were significantly higher than that of the far or ventilation condition [$t(29) = 3.666$, $p < .005$]. The count of >1.0µm particles in the far condition was significantly greater than that of the ventilation condition[$t(35) = 3.183$, $p < .005$]. Among the largest particle size, i.e.,>5.0µm, the near condition showed a significantly higher count than the far or ventilation condition [$t(36) = 15.252$, $p < .001$].

Planned contrasts of Session 2 data indicated the ventilation condition showed significantly fewer particles than the near, far, and off conditions for particles >0.3 µm [$t(91) = 17.049$, $p < .001$], >0.5µm [$t(91) = 7.005$, $p < .001$], and >5.0µm [$t(91) = 4.636$, $p < .001$]. Compared to the near and far conditions, the off condition exhibited a significantly greater number of particles >0.3µm [$t(91) = -28.048$, $p < .001$] and significantly fewer particles, >0.5µm[$t(91) = 12.194$, $p < .001$], >1.0µm[$t(91) = 19.216$, $p < .001$], and >5.0µm[$t(91) = 9.378$, $p < .001$].Compared to the far condition, the near condition showed a significantly greater number of particles >0.3µm [$t(91) = -19.893$, $p < .001$], >0.5 µm [$t(91) = -10.440$, $p < .001$], >1.0 µm [$t(91) = -10.378$, $p < .001$], and >5.0 µm [$t(91) = -5.158.$, $p < .001$].

4.Conclusions

Overall, these findings suggest that UFPs were emitted during the operation of toner-based printing presses. Greater numbers of UFPs were observed, generally, when printing processes were in operation instead of being suspended. Sampling closer to the printing press led to greater particle counts. Particle counts were lowest when taken in proximity of the minimally contaminated air from the ventilation duct. A larger-scale study is needed to further understand toner emission characteristics in printing plants, which would also consider the effects of press type and condition, toner type, pressroom temperature and humidity, etc.

5. References

Balakrishnan, M., & Das A. (2010). Chromosomal aberration of workers occupationally exposed to photocopy machines in Sular, south India. International Journal of Pharma and Bio Sciences, 1(3), 304–307.

Betha, R., Selvam, V., Blake, D. R., &Balasubramanian, R. (2011).Emission characteristics of ultrafine particles and volatile organic compounds in a commercial printing center. Journal of the Air and Waste Management Association, pp. 1093-1101.

Cleary, N. (2006).Digital presses.Printing World, 2/23/2006, pp. 22-23.

Gadhia, P. K., Patel, D., Solanki, K. B., Tamakuwala, D. N., &Pithawala, M. N., (2005). Apreliminary cytogenetic and hematological study of photocopying machine operators. IndianJournal of Occupational and Environmental Medicine 2005, 9(2), 22–25.

Hänninen, O., Brüske-Hohlfeld, I., Loh, M., Stoeger, T., Kreyling, W., Schmid, O., & Peters, A.(2010). Occupational and consumer risk estimates for nanoparticles emitted by laser printers.Journal of Nanoparticle Research, 12(1), 91-99.

He, C. R., Morawska, L., & Len, T. (2007).Particle emission characteristics of office printers.Environmental Science Technology, 41(17), 6039-6045.

Khatri, M., Bello, D., Gaines, P., Martin, J., Pal, A., Gore, R., &Woskie, S. (2012). Nanoparticlesfrom photocopiers induce oxidative stress and upper respiratory tract inflammation inhealthy volunteers. Nanotoxicology, 7(1), 1014-2017 2012.

Khatri, M., Bello, D., Pal, A. K., Cohen, J. M., Woskie, S., Gassert, T., & Gaines, P. (2013).Evaluation of cytotoxic, genotoxic and inflammatory responses of nanoparticles fromphotocopiers in three human cell lines.Particle and Fibre. Toxicology, 10(1), 42-49.

Kipphan, H. (Ed.) (2001). Handbook of Print Media, Springer-Verlag Berlin Heidelberg, pp. 60-61.

Kitamura, H., Terunuma, N., Kurosaki, S., Hata, K., Ide, R., Kuga, H., & Higashi, T. (2009).Cross-sectional study on respiratory effect of toner-exposed work in manufacturing plants,Japan: pulmonary function, blood cells, and biochemical markers. Human & Experimental Toxicology, 28(6-7), 331-338.

Kochi, T., Kitamura, H., Terunuma, N., Kurosaki, S., Hata, K., Osato, A., & Higashi, T. (2011). Epidemiology of respiratory symptoms and changes in biological parameters over 5 years in Japanese workers engaged in toner manufacturing. Epidemiology, 22(1), 274-284.

Loutfy, R. (2002). Digital color printing: the new business of printing. Proceedings of NIP18, IS&T, Springfield, VA, p. 5.

Morawska, L., He, C., Johnson, G., Jayaratne, R., Salthammer, T., Wang, H., Uhde, E. L.,Bostrom, T., Modini, R., Ayoko, G., McGarry, P. L., &Wensing, M. (2009).An investigation into the characteristics and formation mechanisms of particles originating from the operation of laser printers. Environmental Science Technology, 43(4), 1015-1022.

Morimoto, Y., Hirohashi, M., Kasai, T., Oyabu, T., Ogami, A., Myojo, T., & Tanaka, I. (2009).Effect of polymerized toner on rat lung in chronic inhalation study. Inhalation Toxicology,21(11), 898-905.

Nel, A., Xia, T., Mädler, L., & Li, N. (2006).Toxic potential of materials at the nanolevel. Science, 311(5761), 622-627.

Tang, T., Hurra J., Gminski, R., &Mersch-Sundermann, V. (2012). Fine and ultrafine particles emitted from laser printers as indoor air contaminants in German offices. Environmental Science and Pollution Research, 19(9), 3840-3849.

Tolliver-Nigro, H. (2006). Is the future of ink making … toner?Ink Maker, September2006, p. 35.

Wang, Z. M., Wagner, J., & Wall, S. (2011). Characterization of laser printer nanoparticle andVOC emissions, formation mechanisms, and strategies to reduce airborne exposures.AerosolScience and Technology, 45(9), 1060-1068.

Wikina, S. B., Thompson, C. C., & Blackwell, E. (2010). Resourceful thinking about printing and related industries: economic considerations and environmental sustainability. Journal of Technology Studies, 36(2), 55-60.

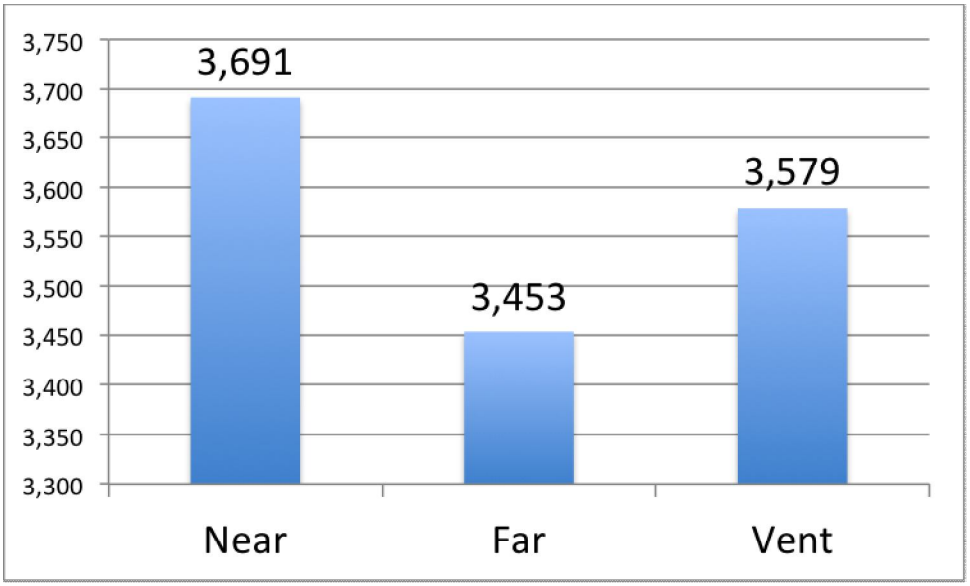

Figure 1: Mean Count of Particles >0.3 µm by Condition for Session 1

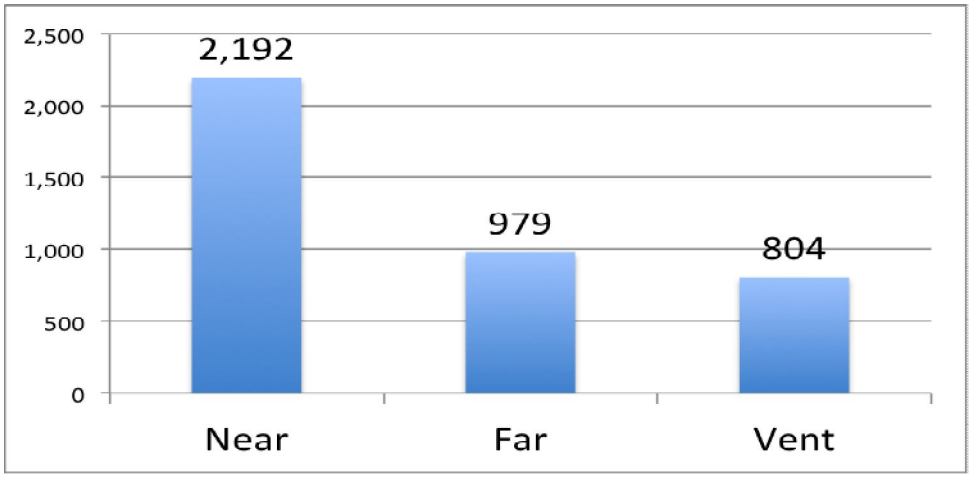

Figure 2: Mean Counts of Particles >0.5µm by Condition for Session 1

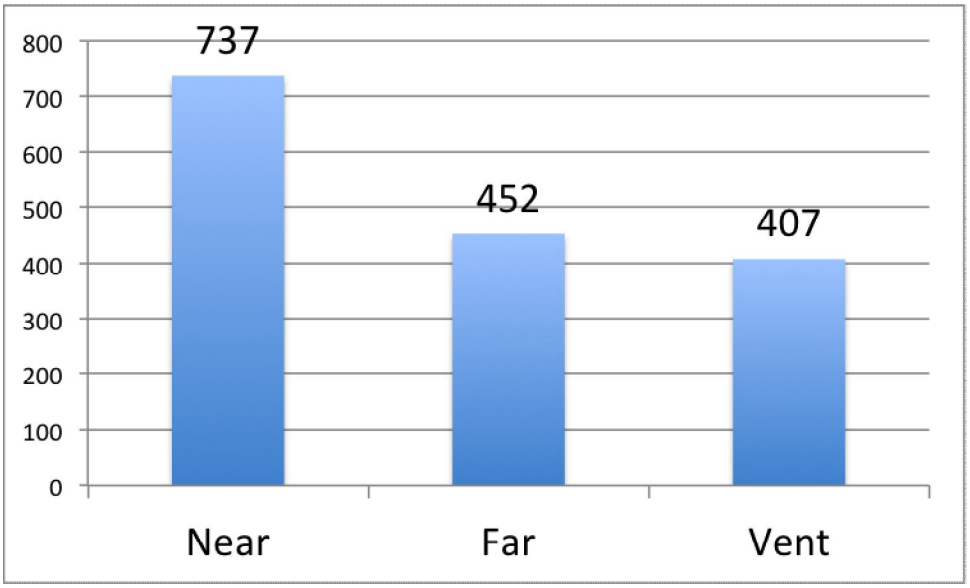

Figure 3: Mean Counts of Particles >1.0µm by Condition for Session 1

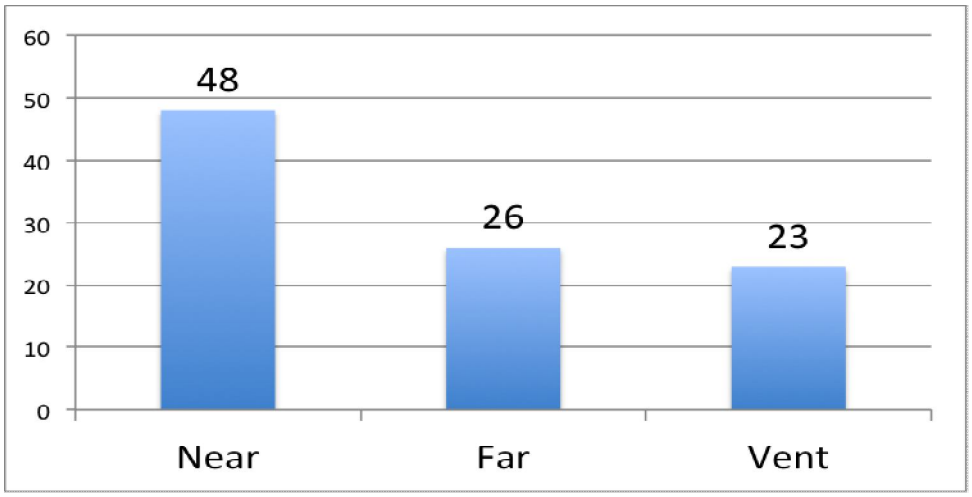

Figure 4: Mean counts of Particles >5.0µm by Condition for Session 1

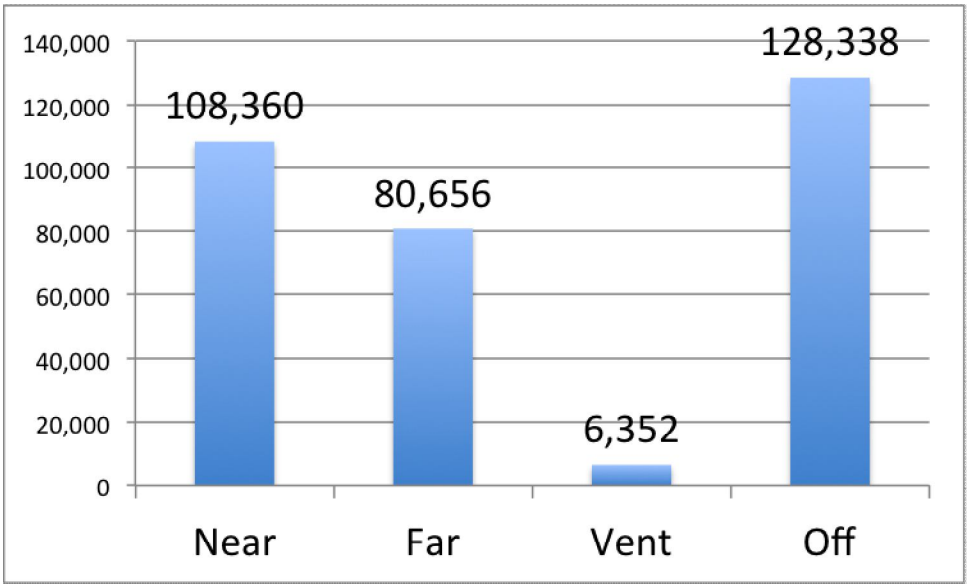

Figure 5: Mean Counts of Particles >0.3µm by Condition for Session 2

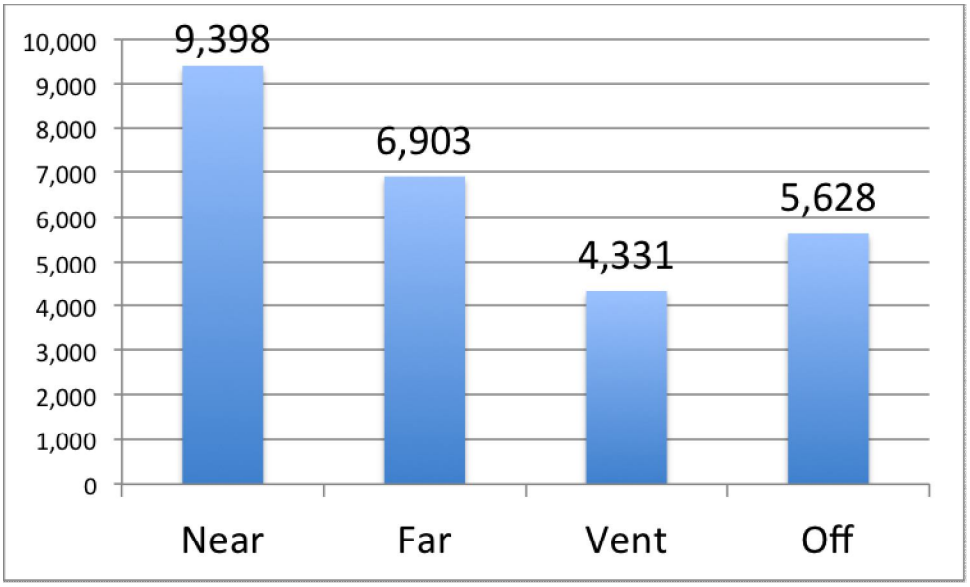

Figure 6: Mean Counts of Particles >0.5µm by Condition for Session 2

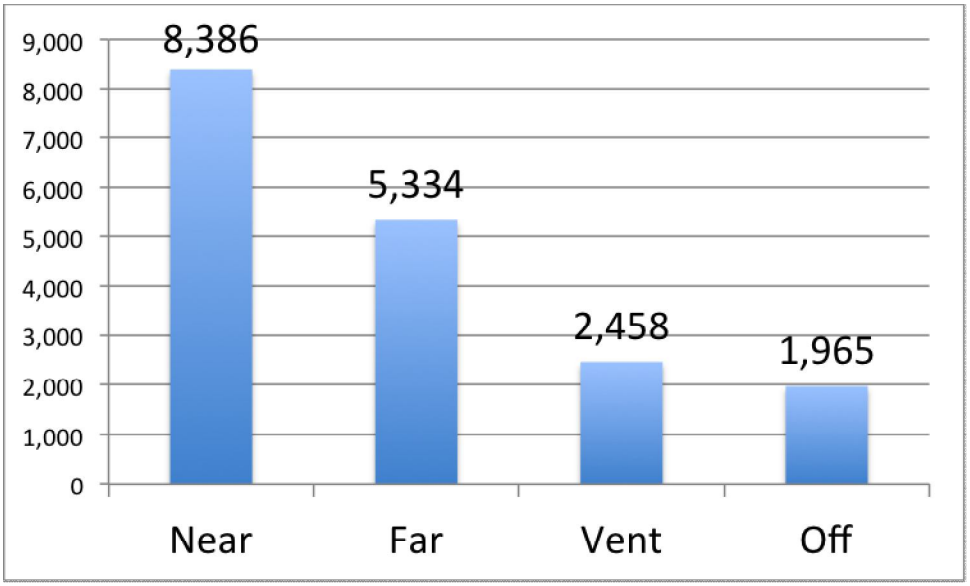

Figure 7: Mean Counts of Particles >1.0µm by Condition for Session 2

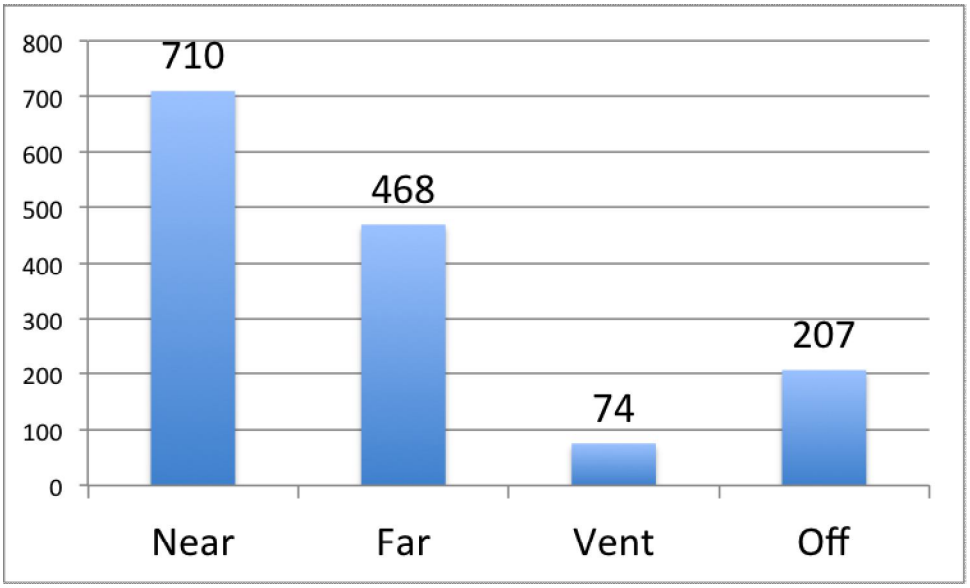

Figure 8: Mean Counts of Particles >5.0µm by Condition for Session 2