Environmental Protection Agency
National Health and Environmental Effects Research Laboratory

Particulate Exposure Control Assessment

For Room B467

Building B, EPA, RTP
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Durham, North Carolina 27711

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Executive Summary

Background

On September 20th, 2011 air sampling was performed to assess the bioaerosol exposure control in room B467 of the Environmental Protection Agency's (EPA) Main Building at Research Triangle Park. This assessment was performed in preparation for the re-occupancy of an employee who has experienced health symptoms while occupying the test space (room B467).

The engineering controls implemented in B467 in an attempt to reduce particulate concentration were positively-pressurizing the room air relative to surrounding spaces and installing a household air filter over the supply duct. The adjacent room, B468, had the same controls implemented but additionally employed an in-room HEPA filtration unit.

Methods

Nine different hypotheses were developed to test particulate and viable fungal spore concentrations and counts. Comparisons of the means and medians were performed between each of the spaces. The assessment was conducted during a single day for three time periods: morning, mid-day, and afternoon. An Andersen N6 single-stage slit sampler was used to sample total viable fungal spores. TSI® Dust-Traks and P-Traks were used to sample particulate matter from 0.1 – 10.0 and 0.02 – 1.0 µm, respectively, in diameter. Dust was reported as mass concentration (mg/m^3), and ultra-fine particulates were reported as counts per cubic meter (pt/m^3).

Results

Fungal Concentration

Results of total viable (culturable) fungal concentration (CFU/m^3) were as follows:

1. Lower in B467 than the adjacent hallway (34.1-93.3%) (tests of difference in log-scale means: *t* test, *p*, 0.0015; Wilcoxon test, *p*, 0.0041).
2. Insignificant between B468 and B467 (tests of difference in log-scale means: t test, *p*, 0.1794; Wilcoxon test, *p*, 0.1747).
3. Lower in B468 than the hallway (-0.05 – 85%) (tests of difference in log-scale means: t test, *p*, 0.0198; Wilcoxon test, *p*, 0.0431).

Ultra-fine Particulate Concentration

Results of ultra-fine particulate concentrations were as follows:

4. Lower in B467 than the adjacent hallway (56.6 – 60.0%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.05125; AR (1) ANOVA, *p*, <0.0001).
5. Lower in B468 than in B467 (51.4 – 56.2%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.06527; AR (1) ANOVA, *p*, <0.0001).
6. Lower in B468 than in the adjacent hallway (80.0 – 81.6%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, <0.0001; AR (1) ANOVA, *p*, <0.0001).

Dust Concentration

Results of dust concentrations were as follows (note: a percentage was not provided since some median values were zero, thus the zeros were replaced with minimum value divided by square root of 2 prior to log transforming):

7. Lower in B467 than the adjacent hallway (tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.0004).
8. Insignificant between B468 than B467 (tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.2481).

9. Lower in B468 than the adjacent hallway (tests of difference in log-scale means: ARMA (1,1) ANOVA, p, <0.0001).

Discussion

The engineering controls were effective in lowering particulate concentrations; however, the in-room HEPA filter did not make a difference in lowering total viable fungal spore concentrations. Genus and species did not provide insight into the possible origination of the fungal spores.

Conclusion

The implementation of positive-pressurization and supply air filtration has been shown to be effective in reducing the concentration of particulates ranging from 0.02 – 10.0 µm and in reducing the concentration of viable fungal spores. An in-room HEPA filtration unit provided additional reduction in the 0.02 – 1.0 µm diameter range, but had no significant effect on particulates in the 0.1 – 10 µm diameter range or on the fungal spore concentration.

These engineering controls should be considered for rooms whose occupants are displaying health symptoms coincident with room occupancy.

Background

An employee occupying room number B467 presented to the on-site health unit multiple times complaining of health symptoms temporally consistent with room occupation. Under a reasonable accommodation request the employee was given authorization to work from home until the problem was resolved.

The employee's symptoms may have been related to allergens in the indoor air. Many airborne allergens are biogenic whose origination may include the following sources: pollen (soluble antigens), bacteria (organisms, soluble antigens), amoebae (soluble antigens), fungi (organisms, spores, fragments, soluble antigens), dust mites (fecal pellets, dried body fragments), cockroaches (fecal particles, saliva, dried body fragments), birds (dried eggs, droppings, serum), cats (skin dander, saliva), dogs (skin dander, saliva, urine), and rodents (urine). Allergens in general do not demonstrate a dose-response curve that can be considered when assessing risk to susceptible individuals. Furthermore, and related to the lack of dose-response, an occupational exposure limit has not been determined for biogenic allergens.

While numerous and significant limitations in air sampling impedes efforts to identify a specific substance causing the employee's distress, efforts to control potential bioaerosol allergens were implemented as a general particulate control strategy. Two particulate exposure controls were implemented in the office: 1) positive-pressurization of the office space air relative to adjacent spaces through the removal of a passive exhaust vent, and; 2) the installation of a Filtrete® residential air filter over the supply vent. The office immediately adjacent, B468, employed an Austin Air HealthMate Plus portable air cleaner with high-efficiency particulate air (HEPA) filter and granular activated carbon and zeolite impregnated with potassium iodide as well as the two controls implemented in B467. This study was designed to assess the comparative effectiveness of the particulate exposure controls.

Methods

Equipment Used:

Table 1. Industrial Hygiene Sampling Instrumentation

Make/Model	Test ID	Measures	Serial Number	Calibration Date
Andersen N6 single stage slit sampler (400 hole)	1	Viable fungal spores	N/A	N/A
Andersen N6 single stage slit sampler (400 hole)	2	Viable fungal spores	N/A	N/A
Andersen N6 single stage slit sampler (400 hole)	3	Viable fungal spores	N/A	N/A
TSI P-Trak/8525	1	0.02 – 1.0 µm particulates	8525-05001018	4/18/2011
TSI P-Trak/8525	2	0.02 – 1.0 µm particulates	8525-1108003	11/5/2010
TSI P-Trak/8525	3	0.02 – 1.0 µm particulates	8525-01100003	1/7/2011
TSI Dust Trak/8530	1	0.1 – 10 µm particulates	85300111703	8/30/2011
TSI Dust Trak/8530	2	0.1 – 10 µm particulates	85300111611	4/15/2011
TSI Dust Trak/8530	3	0.1 – 10 µm particulates	8530101514	9/7/2011
Gast High-Flow Pump/1532-101-G557X	1	N/A	1007600028	N/A
Gast High-Flow Pump/1532-101-G557X	2	N/A	1007600049	N/A
Gast High-Flow Pump/1532-101-G557X	3	N/A	1007600007	N/A
Quest AQ-5001 Indoor Air Quality Meter	N/A	Temperature, humidity, CO2	2087	9/15/2010

Sampling Plan: The building is divided longitudinally with laboratories and offices on one side and administrative offices on the other side. The particulate controls tested were on the laboratory side of the building.
Nine hypotheses were developed as follows:
1) There was a lower total culturable fungal concentration (colony forming units (CFU))/m^3 in B467 than in the adjacent hallway ($H_ø$: $C_{B467} = C_{hallway}$);
2) There was a lower total culturable fungal concentration in B468 than in B467 ($H_ø$: $C_{B468} = C_{B467}$);
3) There was a lower total culturable fungal concentration in B468 than in the adjacent hallway ($H_ø$: $C_{B468} = C_{hallway}$);
4) There was a lower concentration (particles (pt)/cm^3) of ultra-fine particulates (0.02 – 1.0 µm) in office B467 than in the adjacent hallway ($H_ø$: $C_{B467} = C_{hallway}$);
5) There was a lower concentration of ultra-fine particulates in B468 than in office B467 ($H_ø$: $C_{B468} = C_{B467}$);
6) There was a lower concentration of ultra-fine particulates in B468 than in the adjacent hallway ($H_ø$: $C_{B468} = C_{hallway}$);
7) There was a lower concentration (mg/m^3) of dust (0.1 – 10.0 µm) in B467 than in the adjacent hallway ($H_ø$: $C_{B467} = C_{hallway}$);
8) There was a lower concentration of dust in B468 than in B467 ($H_ø$: $C_{B468} = C_{B467}$); and,
9) There was a lower concentration of dust in B468 than in the adjacent hallway ($H_ø$: $C_{B468} = C_{hallway}$).

Sampling for total culturable fungi were performed concurrently between three spaces (B467, B468, and hallway) during three time periods throughout a single day. The three sampling time periods were morning (approximately 6:00am); mid-day (approximately 11:00am); and afternoon (approximately 3:00pm). Particulate sampling was performed concurrently between the same three spaces and the samples were collected and data-logged throughout the entire day, from 6:00am until all sampling was completed at approximately 3:30pm.

Prior to each sampling period, percent relative humidity and temperature were recorded using a Quest AQ-5001 IAQ meter.

Fungal Sampling Collection Methods: Total culturable fungal concentration sampling was conducted using an Anderson N6 single-stage (400 hole) slit impactor and a Gast model 1532-101-G557X High-Flow Pump. Pumps were calibrated the night before the sampling day and re-calibrated after sampling was completed. Malt extract agar with chloramphenicol (MEA/chlor) was used as the growth media.

The spaces were sampled concurrently, three periods during the day: morning, mid-day, and afternoon. Three sequential samples were taken during each time period in each space. Samples were collected at an airflow rate of 28.1 l/min for five minutes each.

Particulate Sampling Collection Methods: Particulate sampling was performed concurrently in rooms B467, B468, and the hallway. The samples were collected and data-logged throughout the entire day, from 6:00am until all sampling was completed at approximately

3:30pm. Prior to each sampling period, percent relative humidity and temperature were recorded using a Quest AQ-5001 IAQ meter.
Ultra-fine particulates: The TSI® P-Trak, model 8525 particle counter was used to sample and enumerate particles in the 0.02 – 1.0 µm range using the principle of condensation nuclei concentration whereby particles are "grown" using alcohol that adheres to the particle. The enlarged particle is then counted by passing through a laser beam. The Data Log Mode was used which has a flow rate of 700 cm^3/min.
Dust: The TSI® Dust-Trak II, model 8530, was used to sample and calculate mass concentration of particles in the 0.1 - 10 µm. This unit is a light-scattering laser photometer.

Viable Fungi Sampling Analysis Methods: Culture plates were sent to EMSL Analytical, Inc. for viable fungi identification and enumeration to include speciation of *Penicillium, Aspergillus, Cladosporium, and Stachybotrys* (EMSL Method M005). The culture plates were incubated at 25°C for 5 days. Each sporulating colony was identified to genus or species and colonies were counted by generic or speciational category or as non-sporulating.

Data Analysis Methods:
Viable Fungal Analysis: Counts were converted for multiple impactions using the positive-hole correction values published by the American Conference of Governmental Industrial Hygienists (ACGIH) [Burge, et al. 1999]. Each corrected count was divided by the volume of air sampled to produce data expressed as Colony Forming Units (CFU)/m3 of air. The MEANS Procedure was performed using SAS; Geometric Means were calculated using SUDAAN; and *t* tests and (nonparametric) Wilcoxon Tests for Difference of log-scale Means were performed using R and their p-values reported.
Dust: The MEANS procedure was performed using SAS. Modeling that accounted for the highly-correlated time-series nature of these data was performed. ARMA (1,1) ANOVA in R was used to test for Difference of log-scale Means; corresponding p-values were reported. Zeros were replaced by minimum value divided by square-root of 2 before log transforming.
Fine Particulates: The MEANS procedure was performed using SAS. ARMA (1,1) ANOVA in R was used to test for Difference of Means in log-scale. Modeling that accounted for the highly-correlated time-series nature of these data was performed. ARMA (1,1) ANOVA in R was used to test for Difference of log-scale Means; corresponding p-values were reported. Zeros were replaced by minimum value divided by square-root of 2 before log transforming. Additionally, AR(1) ANOVA was used to include model smoothing terms for observed downward trend over time; corresponding p-values were reported.

Results
The reported d50 (particle diameter collected at 50% efficiency) for the Andersen N6 single-stage sampler is 0.67µm [Andersen, 1958].

Descriptive statistics for these data are presented in Tables 2 - 4. Figures 1 - 12 display changes in concentrations over time for the sampled spaces. The analysis findings provide species and genus of successfully germinated spores (see Appendix A).

Hypothesis 1: Total culturable fungal concentrations in B467 were significantly lower than those in the hallway (34.1-93.3%) (tests of difference in log-scale means: *t* test, *p*, 0.0015; Wilcoxon test, *p*, 0.0041).

Hypothesis 2: Total culturable fungal concentrations in B468 not significantly lower than B467 (tests of difference in log-scale means: t test, *p*, 0.1794; Wilcoxon test, *p*, 0.1747). These tests failed to disprove the null hypothesis ($H_{ø}$).

Hypothesis 3: Total culturable fungal concentrations in B468 were significantly lower than the hallway (tests of difference in log-scale means: t test, *p*, 0.0198; Wilcoxon test, *p*, 0.0431).

Table 2. Total Viable Fungal Concentration Results

Room	N observed	Geometric Mean	95 % C.I.	Comparison (log-tranformed data)	p-value	
					t-test	Wilcoxon
Hallway	9	57.5	(32.3, 82.7)	467 vs. Hallway	0.0015	0.0041
B467	8	13.4	(5.5, 21.3)	467 vs. 468	0.1794	0.1747
B468	5	23.2	(12.5, 33.9)	468 vs. Hallway	0.0198	0.0431

Figure 1. Boxplot for Andersen recoveries (CFU/m3), untransformed

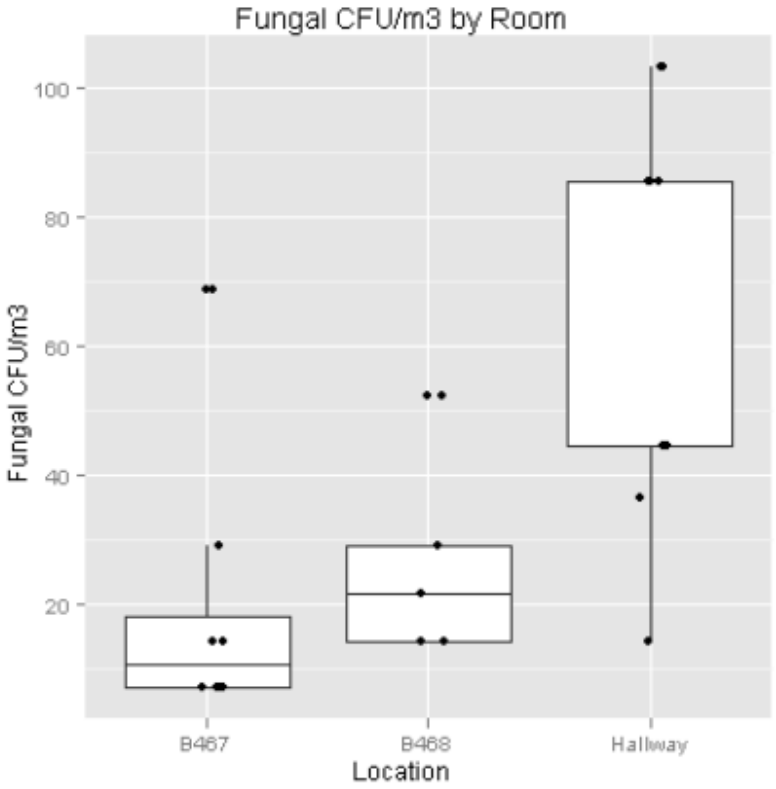


Figure 2. Histogram for Andersen recoveries (CFU/m3), untransformed

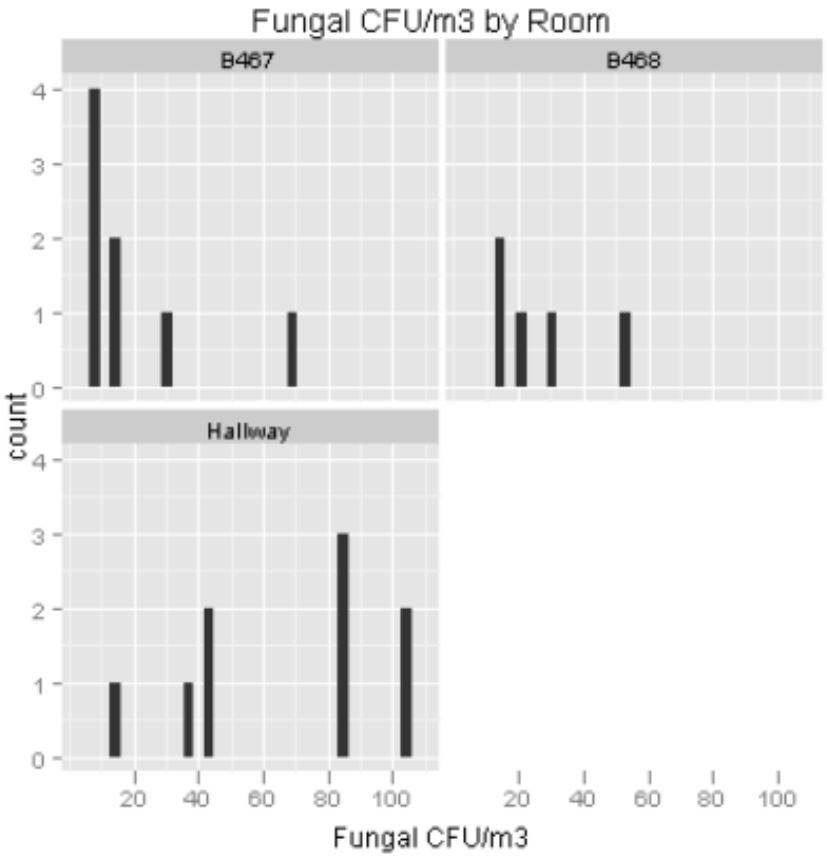


Figure 3. Boxplot for Andersen recoveries (CFU/m3), log transformed

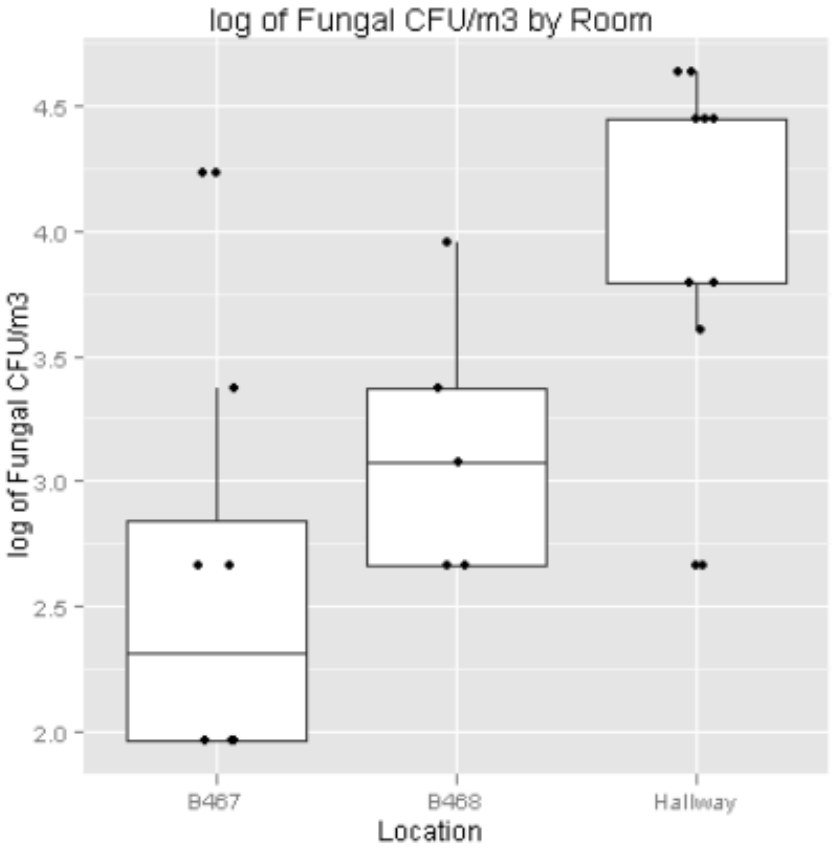
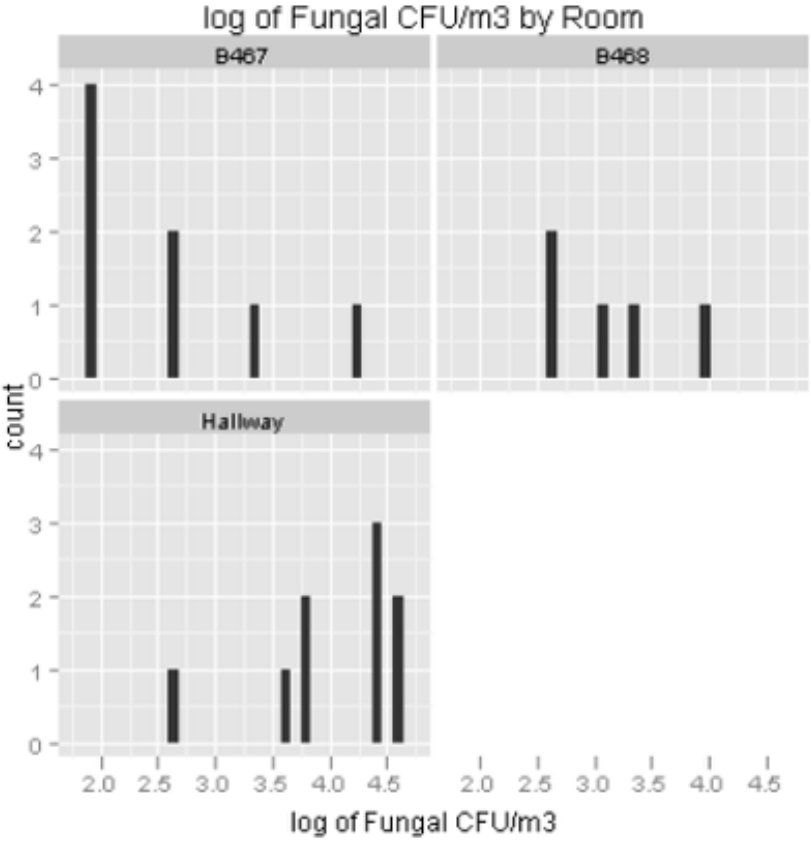


Figure 4. Histogram for Andersen recoveries (CFU/m3), log transformed



Hypothesis 4: There was a lower concentration of ultra-fine particulates in B467 than in the Hallway (56.6 – 60.0%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.05125; AR (1) ANOVA, *p*, <0.0001).

Hypothesis 5: There was a lower concentration of ultra-fine particulates in B468 than in B467 (51.4 – 56.2%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.06527; AR (1) ANOVA, *p*, <0.0001).

Hypothesis 6: There was a lower concentration of ultra-fine particulates in B468 than in the Hallway (80.0 – 81.6%)(tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, <0.0001; AR (1) ANOVA, *p*, <0.0001).

Table 3. Ultra-Fine Particulate Count Results

Room	N observed	Geometric Mean	95 % C.I.	Comparison (log-transformed data)	p-value	
					ARMA (1,1) ANOVA	AR (1) ANOVA
Hallway	565	1224	(1204.2, 1243.2)	467 vs. Hall	0.05125	<0.0001
B467	560	511	(498.9, 522.8)	468 vs. 467	0.06527	<0.0001
B468	546	236	(229.0, 242.5)	468 vs. Hall	<0.0001	<0.0001

Figure 5. Boxplot for Ultra-Fine Count Comparisons, untransformed

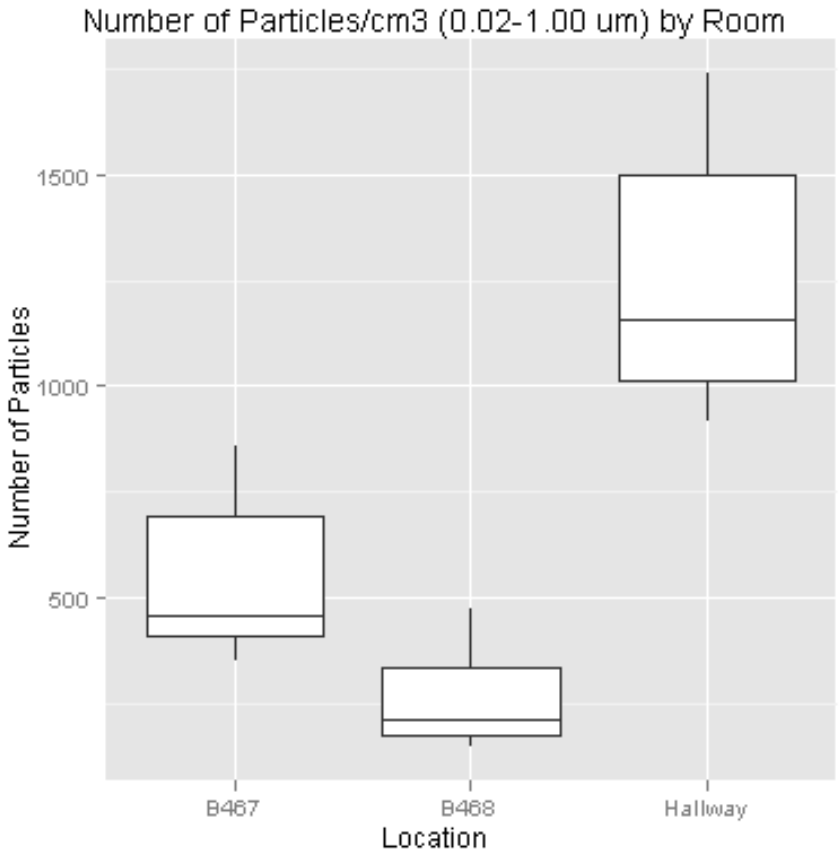


Figure 6. Histogram and times series plot for Ultra-Fine Count Comparisons, untransformed

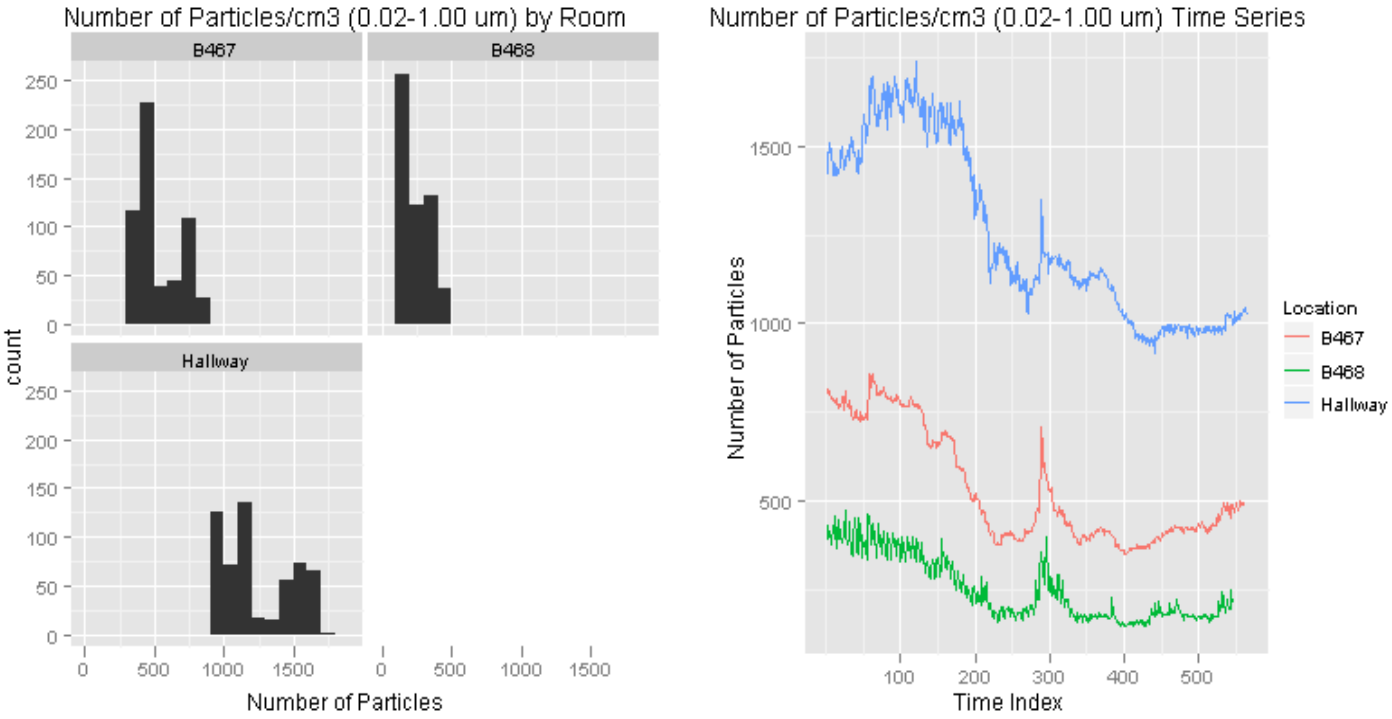


Figure 7. Boxplot for Ultra-Fine Count Comparisons, log transformed

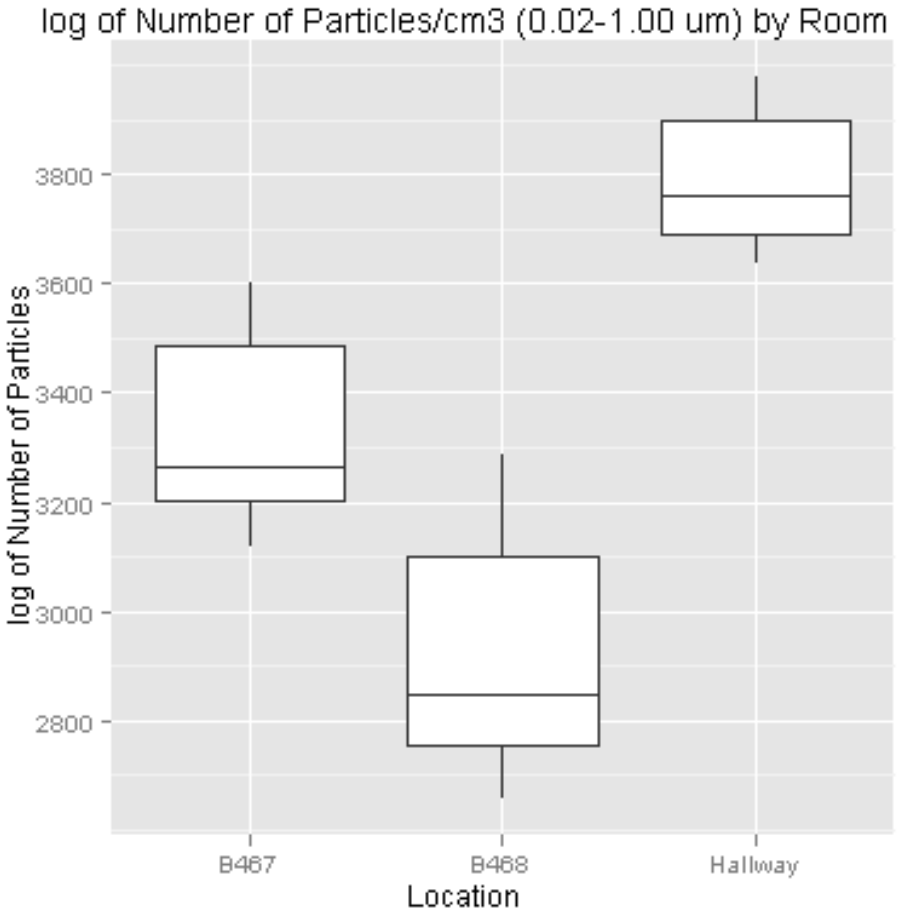
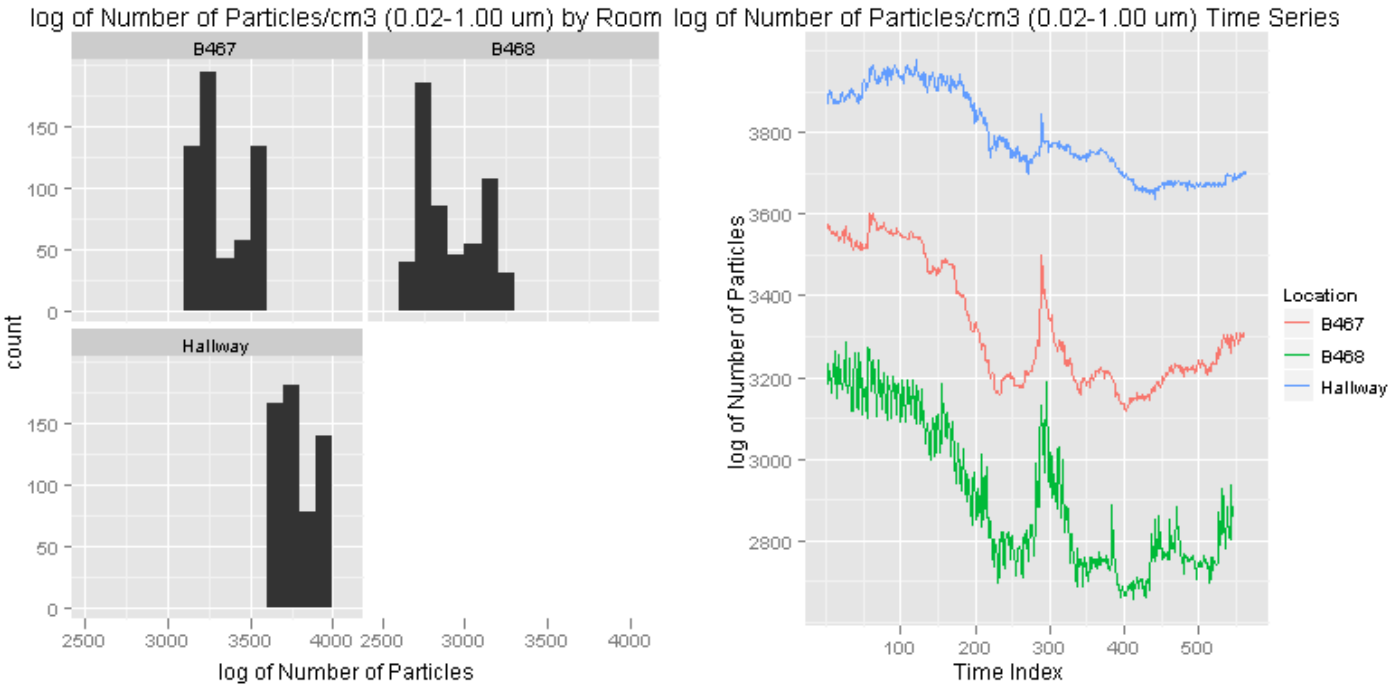


Figure 8. Histogram, and times series plots for Ultra-Fine Count Comparisons, log transformed



Hypothesis 7: There was a lower concentration of dust in B467 than in the Hallway (tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.0004).

Hypothesis 8: There was a lower concentration of dust in B468 than in B467 (tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, 0.2481).

Hypothesis 9: There was a lower concentration of dust in B468 than in the Hallway (tests of difference in log-scale means: ARMA (1,1) ANOVA, *p*, <0.0001).

Table 4. Dust Concentration Results

Room	N observed	Geometric Mean	95 % C.I.	Comparison (log-transformed data)	p-value
					ARMA (1,1) ANOVA
Hallway	540	0.01	(0.01, 0.01)	467 vs. Hall	0.0004
B467	540	0		468 vs. 467	0.2481
B468	415	0		468 vs. Hall	<0.0001

Figure 9. Boxplot for Dust Particulate Mass, untransformed

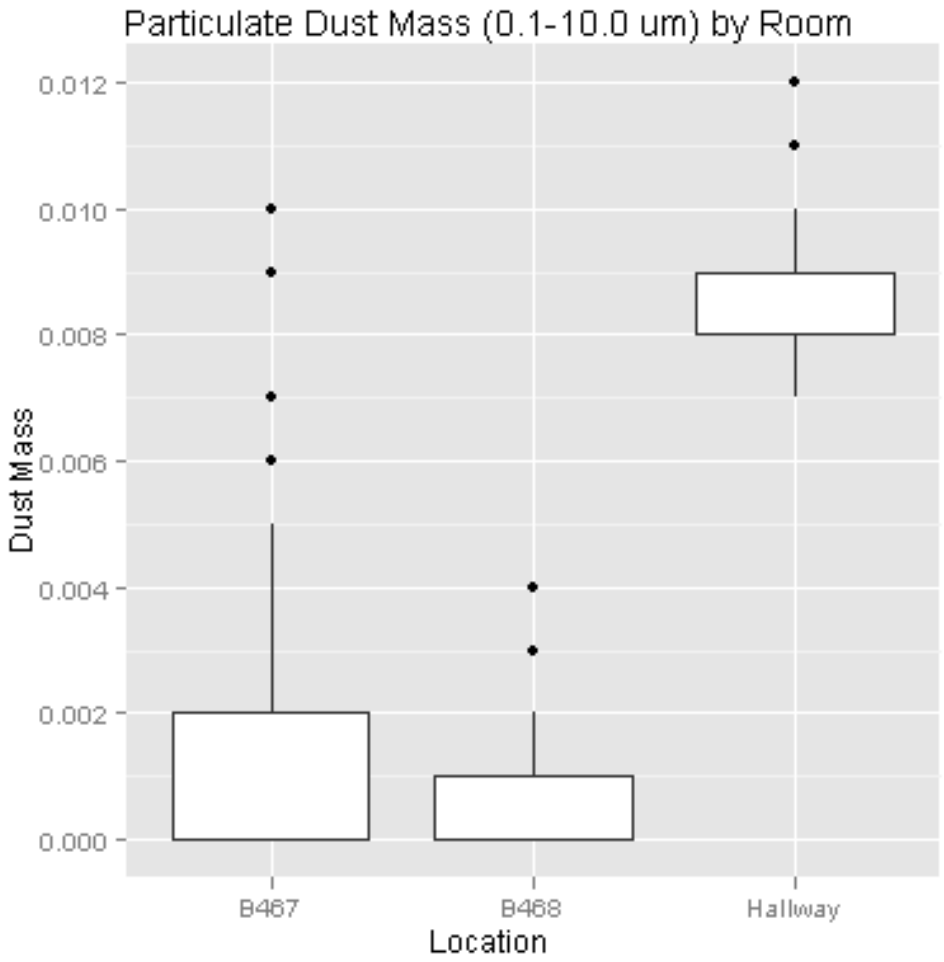


Figure 10. Histogram and times series plots for Dust Particulate Mass, untransformed

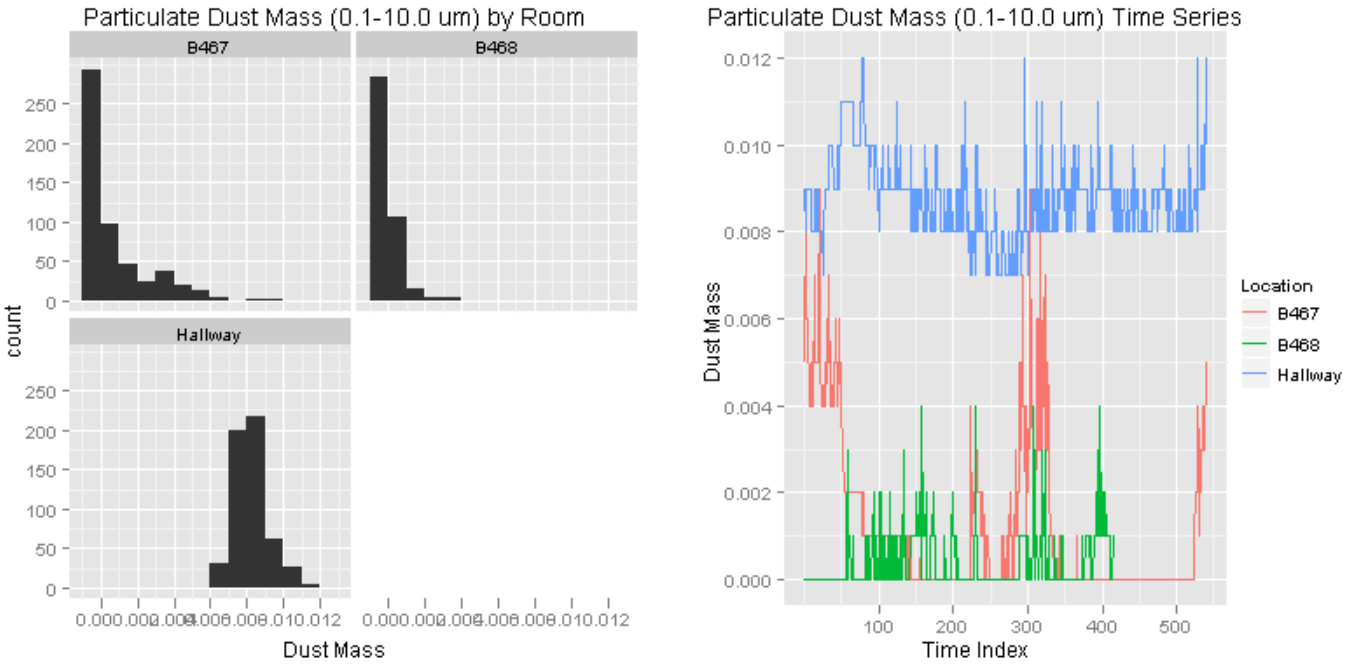


Figure 11. Boxplot for Dust Particulate Mass, log transformed

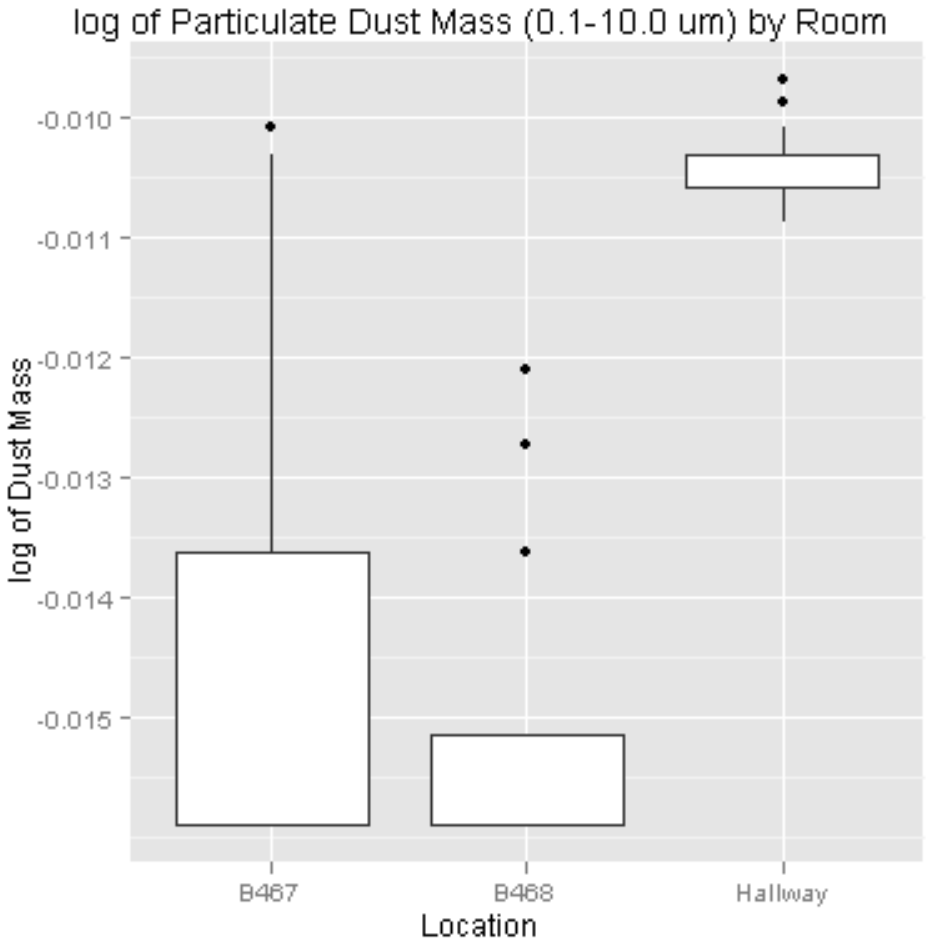
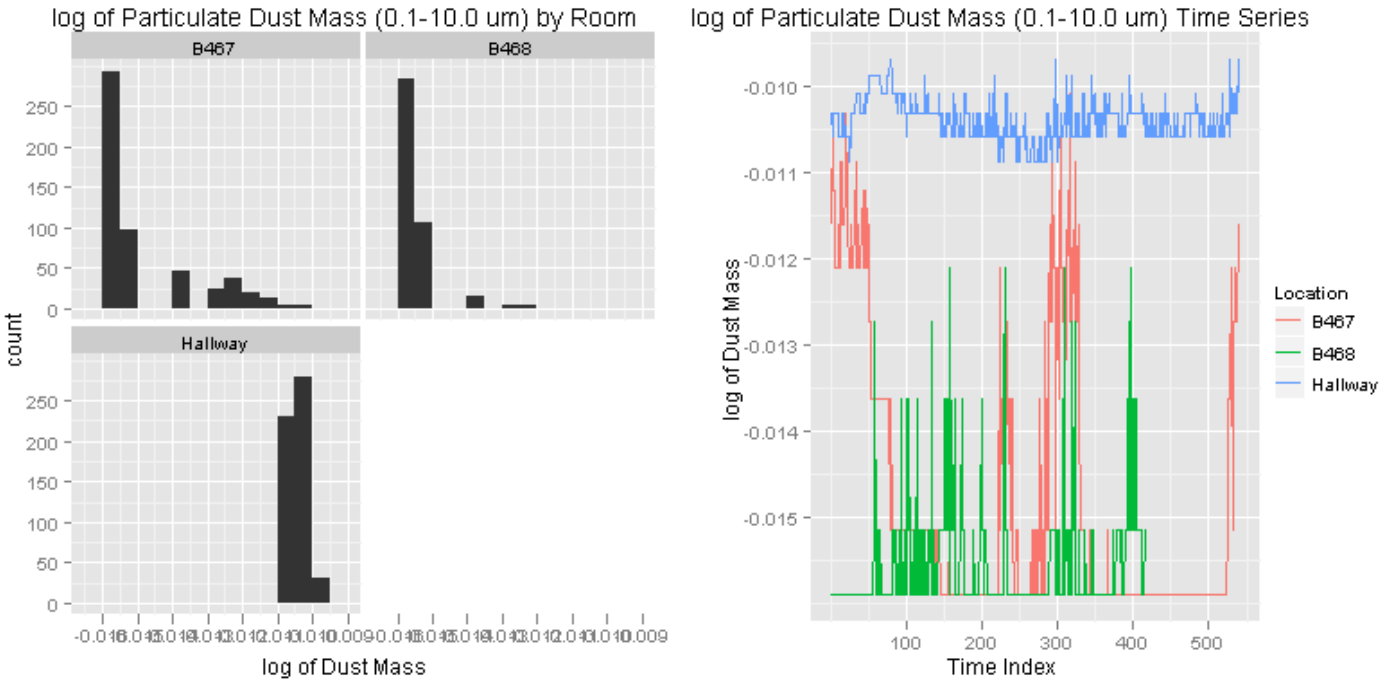


Figure 12. Histogram and times series plot for Dust Particulate Mass, log transformed



Note 2: These Dust time series are not coincident in time; the hallway and B467 starts at approximately 6:20am and B468 starts at approximately 8:54am.

Discussion

The engineering controls employed to control particulates in rooms B467 and B468 were positive-pressurization of room air and installation of a household Filtrete® air filter over the supply ducts. Room B468 also used an in-room HEPA filtration unit to reduce the particulate load even further.

The engineering controls implemented in rooms B467 and B468 were shown to effectively control viable fungal spore concentrations, ultra-fine particulates, and dust as compared to concentrations in the adjacent hallway. However, when B468 was compared to B467 for viable fungal concentration reduction and dust concentration (0.1 – 10 µm), no statistical difference was shown.

The in-room HEPA filtration unit was successful in lowering particulate concentrations to very low levels, which is important in lowering risk to individuals susceptible to allergic reactions to airborne biogenic allergens. Since biogenic allergens have no known dose-response curve, the levels should be kept as low as reasonably achievable to prevent highly susceptible persons from experiencing allergic reactions.

The genus and species of germinated fungal spores did not provide meaningful insight into the possible origination of the fungal spores.

Conclusion

The implementation of positive-pressurization and supply air filtration has been shown to be effective in reducing the concentration of particulates ranging from 0.02 – 10.0 µm and in reducing the concentration of viable fungal spores. An in-room HEPA filtration unit provided additional reduction in the 0.02 – 1.0 µm diameter range, but had no significant effect on particulates in the 0.1 – 10 µm diameter range or on the fungal spore concentration.

These engineering controls should be considered for rooms whose occupants are displaying health symptoms coincident with room occupancy.

Further work should be conducted to assess the fungal aspect of occupant particulate exposures. A statistically valid comparison of the concentration and speciational make-up of fungal spores indoors and outdoors can provide information helpful in tracing and controlling fungal allergens. Due to extremely large variability, especially among outdoor microbiology, such a study would require numerous samples to be taken during different times of the day, during different weather patterns, throughout the weeks and extending across the four seasons to achieve statistical validity.

Signature:

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Appendix A

Data Collected and Analysis Results