A STUDY OF LOCAL ELECTROSTATIC FILTRATION AND MAIN PRE-FILTRATION ON AIRBORNE AND SURFACE DUST LEVELS IN AIR-CONDITIONED OFFICE PREMISES

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ABSTRACT

The impact of electrostatic precipitation as a useful form of particulate filtration in the breathing zone is investigated in an intervention study in an air-conditioned commercial office in central London. Surface dust deposition and airborne dust levels are measured in the open plan zones of two floors - a control floor and a floor where the intervention is effected. The intervention consists of a sequence of weekly scenarios where the main pre-filters of the air-handling unit are switched between new and old filters, and where the electrostatic filters, located as uniformly as practicable on the open plan areas, are switched on or off. This 2x2 set of interventions is repeated over 4 cycles. It was found that the breathing zone filtration (BZF) by electrostatic precipitators reduces airborne dust significantly and appears to be more efficient in reducing smaller sized particles. No significant effect of BZF filters in reducing surface dust deposition was detected.

KEYWORDS

Deposition, dust, breathing zone filtration, particle size distribution, suspended particles (TSP)

INTRODUCTION

There is increasing evidence that indoor particulate matter is a significant contributor to sick building syndrome (SBS). In a cross-sectional epidemiological study of a problem high-rise building Armstrong et al. [1] found that SBS symptoms were significantly associated with total suspended particulate levels, while Hodgson et al. [2] concluded from a similar study that respirable suspended particulates was the strongest predictor of SBS symptoms. Kjaergaard and Brandt [3] reported a very strong correlation between dust sedimentation rates at workplace desks and eye symptoms. In double-blind studies on the impact of surface dust cleaning regimes on SBS symptoms, Raw [4] concluded that indoor surface pollution by particulate dust is a major risk factor for SBS symptoms.

Among methods suggested for the alleviation of indoor particulate contamination, breathing zone filtration has been proposed as an effective form of source control by localized air filtration in each worker's breathing zone. Using such a system comprising a three-layer filter (polymer pre-filter, activated carbon polymer filter, and a HEPA filter) integrated into the office furniture, Hedge et al. [5] reported a substantial reduction in dust exposure of desk-bound office workers. The system however suffers an energy penalty in that a large pressure drop occurs across the composite filter. Electrostatic precipitation has been developed as an energy efficient alternative.

This paper reports findings from the first phase of a larger study aimed at examining the impact of electrostatic precipitation units (located within the occupied space) on airborne and desk-top settled dust and SBS reporting. Results on surface and airborne dust reduction effectiveness by electrostatic precipitation is discussed while the SBS study will be reported separately.

METHODOLOGY

Building description

The subject building is a six storey deep plan, mechanically cooled and ventilated office building in central London surrounded by busy roads, and hence, potentially, a polluted site. Fresh air is drawn in via an air-handling unit located at the topmost (6^{th}) floor. It is treated sequentially by a set of pre- and main-filters before being distributed through a ceiling duct system, and finally supplied to the office premises via induction units located at the perimeter of the building and in island units in the open plan spaces.

Two floors of the deep building were selected for the study: one (Floor 2) to serve as a control and the other (Floor 3) for assessing the impact of the breathing zone filtration (BZF) units. A total of 15 BZF units, which operate on the principle of electrostatic precipitation, were located as uniformly as practicable on the open plan areas of each floor studied.

Intervention Design

Two different interventions were scheduled: alternating between a set of new and old (used) pre-filters in the main building air-handling unit, and switching on and off the operation of the electrostatic filtration panels within the BZF units. Note, the BZF unit fans were left continuously running in order to keep the occupants 'blind' to the interventions. Therefore in the remaining text where the term "BZF units off" is used it refers to only the electrostatic element of the units being off – the fans are always on and air is always drawn through the units. This generates a set of 4 scenarios, and 3 such sets were executed sequentially. However, the order of the scenarios within each set is randomly assigned. Once a scenario is established, the conditions are maintained for a week before the next scenario is implemented. The schedule of scenarios is given in table 1.

For each scenario, the airborne dust and surface dust deposition levels were measured by techniques described below. The subjective response of the occupants in terms of SBS intensity was procured with a weekly questionnaire, and the results of this work will be the subject of another paper.

Particulate Sampling and Measurement

Two categories of sampling locations were selected for particulate sampling based on office configuration, dust generation and deposition characteristics: workstations and thoroughfare areas. For each category, sampling locations were determined weekly on a random basis to provide unbiased samples. On the study floor (Floor 3), a total of 9 workstation and 5 thoroughfare locations were determined; while 3 workstation and 1 thoroughfare locations were selected for the control floor (Floor 2).

Surface dust deposition was measured by means of a standardised technique [6] which involved removing a sample of deposited dust with a forensic (fingerprint) tape, and measuring the light scattered from a laser beam passing through the tape before and after exposure with a commercially available instrument (DustDetector). The unit of measurement is the percentage of light scattered. These samples of deposited dust were measured at the end of each scenario so that the full impact of the scenario was monitored.

Airborne dust was measured at one-minute intervals throughout each scenario with a single Grimm Dust Monitor which measures particle numbers in several size ranges based on a light scattering technique [7]. The particulate measurements utilised in this study are Total Suspended Particulates (TSP), PM10 and PM2 and have been expressed in units of $\mu g/m^3$. A multiplication factor is used by the Grimm to convert numbers of particles to a mass measurement, this multiplication factor is derived from a calibration using standard Arizona road dust. Because of this difference in measurement technique there may be differences in readings when compared with background measurements from the National Automatic Urban Monitoring Network (AUN). The measurement method for the AUN network is based on the use of Tapered Element Oscillating Microbalances, (TEOM's), elevated background levels of PM10 particles measured using TEOM's have been linked with an elevated risk of mortality [8].

RESULTS

In addition to the internal surface and airborne dust measurements, the external background levels of PM10 and PM2.5 measured at the Bloomsbury monitoring site in central London [9] are presented. Firstly we present results from the surface dust measurements, comparing readings taken when the Breathing Zone Filtration units were on or off, and when the pre-filters were new or old.

We then present the measurements of internal airborne dust levels which were made using the Grimm monitor. External levels of particulate are then considered and their effect on internal levels.

Surface dust measurements

Since surface dust samples were taken from random locations on the second and third floors, the randomisation of the locations mean that spatial analysis of the measurements is not possible. The analysis is therefore based on averages taken from all locations on each floor for each week and thus compares how each floor's surface dust differs from week to week and from scenario to scenario.

When the mean of all readings are compared for periods which have the same filter states, BZF units are on or off, and main supply pre-filters old or new, the differences seen are not statistically significant. The results are presented in table 2. In the table the p-value is a measure of how likely the result seen could have arisen by chance. A p-value of <0.05 is generally taken as being "statistically significant" and means that there is a 5 in 100 likelihood of that result happening by chance. The DF is the degrees of freedom associated with the relationship. The t-value is a measure of how important a variable is in determining the result seen. A large positive or negative number is associated with a high importance.

The difference in dust deposition between the states for floor 2 and floor 3 workstations, measured in terms of percentage of light scattered, are shown in figures 1a and figure 1b. In figure 1a it can be seen that there is no systematic difference in surface dust levels seen when the BZF units are on or off which could be used to analyse any differences that might be seen in the deposited dust levels on the third floor. By comparing levels of surface dust seen on the 2nd floor, the effect of the supply filters without the BZF filters can be examined, again no significant effect is seen. In figure 1b there is a large difference in levels seen for the scenarios with BZF off and new or old supply pre-filters but it is not significant. None of the differences seen in surface dust levels are significant.

Airborne particulate measurements

Measured data from the Grimm has been averaged to give weekly figures to allow comparison with the surface dust measurements. The differences in airborne dust levels between weeks with different filter states are shown in table 3. In all cases the levels of airborne dust are significantly lower with the BZF units on ($P < 0.0001$), and these are shown as shaded cells. The levels of TSP and PM10 do not vary significantly whether the supply pre-filters are old or new. However, there is a significant reduction in the PM2 levels when the pre-filters are new, the reason for this is not clear but may be that the new filters are effective at removing PM2 and the old ones are not.

In figures 2a, 2b and 2c, the effects on each of the size fractions of airborne dust of each scenario is shown. In each case the levels with the BZF unit on are lower than with it off. The supply pre-filter seems to effect the levels of TSP and of PM2 but not the PM10 levels. From these graphs the effects of the BZF filter are clearly seen as being greater than any effects of the supply pre-filter.

The ratios of on:off dust levels for the BZF unit are plotted for each size fraction in figure 3 and expressed as a percentage. In figure 3 it can be seen that for the BZF unit the smaller the size fraction, the larger the difference between on and off mean values of airborne dust. The dust levels with the BZF unit on are 50% of the level with it off for the PM2 fraction. The suggestion is therefore that the BZF units are more effective at removing the smaller particles than the larger particles. There is no such relationship seen with the supply pre-filter.

External Particulate Levels

External levels of particulates are measured at the nearby Bloomsbury monitoring site in central London. This is classed as an urban background site and as such is comparable to the levels expected outside the study building at the roof top level, which is where the main air intakes for the building are situated.

Figures 4a and 4b show the levels of external levels of particulates split by the state of the internal filters. These figures are included to show the external levels during the times that each scenario was being tested. From these it can be seen that when the BZF units were on the external particulate levels happened to be higher than when they were off. The external levels were also higher when the pre-filters were new. The assumption that outdoor particulate levels (PM10) affect indoor levels of particulates (PM10 Grimm) is examined and the results are presented in figures 4c and 4d, these show that there is no consistent relationship between internal and external particulate levels. In figure 4c it can clearly be seen that when the Breathing Zone Filtration units are on, the levels of indoor airborne dust are always lower than when the units are off. Figure 4d shows how there is no consistent relationship that is due to the state of the supply pre-filters.

CONCLUSIONS

Internal levels of both surface and airborne dust are unrelated to external particulate levels. This suggests that the supply pre-filters are effective at removing the majority of dust when either new or old ones were used.

The implication of this is that a major proportion of the internal dust is generated by indoor office activities. The different levels of surface dust seen on the 2nd and 3rd floors back up this supposition. A reason may be that floor 3 has different activity and occupancy levels than floor 2. There is a also a possibility that some of the increase seen between 2nd and 3rd floors is due to the continuous running of the BZF fans.

The study has not shown that the BZF units are effective in reducing desktop dust deposition.

The study has shown that electrostatic precipitation at the breathing zone level using BZF filtration units is effective in reducing airborne dust. Measurements of internal levels of 3 size fractions of airborne dust show also that the BZF units appear to remove smaller size fractions more effectively than larger fractions. TSP, PM10 and PM2 dust levels are reduced to 63%, 54% and 51% respectively, when compared to the levels when the BZF electrostatic filtration is turned off, see figure 3.

That the BZF units seem more efficient in removing smaller sized particles is potentially useful in mitigating SBS symptoms caused by particulate contamination. Smaller sized particles, particularly those nearer the sub-micron range have a deeper penetration in the human breathing system, notably to the alveolic region, where it is recognised that the greatest harm is done. It is also notable that this is achieved without the need to resort to HEPA filters, thus providing a potentially energy efficient method of removing smaller sized particles in the indoor environment. The relative performance of electrostatic precipitation and other forms of BZF filtration, including energy consumption, needs to be further explored.

ACKNOWLEDGEMENTS
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List of captions
Table 1. Schedule of the scenarios used in the study. No data was taken for week 11, and airborne dust measurements using the Grimm monitor started with week 5.

Table 2. Differences in surface dust levels measured during the intervention study

Table 3. Differences in airborne dust levels measured during the intervention study

Figures 1a and 1b. Deposited surface dust on workstation desktops on both floors over the entire period, split by whether the BZF units were on or off, and whether the main supply pre-filters were new or old. (Units: % light scattered)

Figure 2. Comparison of external PM2.5 and PM10 readings for periods with the BZF unit on and off (left) and for periods with new or old main supply pre-filters (right).

Figure 3. Reduction in airborne dust levels for three size fractions with the BZF units on or off.

Figure 4a. Levels of external PM10 measurements during each scenario.

Figure 4b. Levels of external PM2.5 measurements during each scenario.

Figure 4c. Comparison between internal and external PM10 levels showing measurements taken when the BZF units were on or off.

Figure 4c. Comparison between internal and external PM10 levels showing measurements taken when the supply pre-filters were old or new.

Table 1

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Scenario	D	B	A	C	A	B	D	C	C	D	-	B	A	B	A	C	D

Notes: Scenario A = Old pre-filter, BZF Off; Scenario B = Old pre-filter, BZF On;
Scenario C = New pre-filter, BZF Off; Scenario D = New pre-filter, BZF On

Table 2

Floor	Generic Location	Filtration Status	Mean Diff.[a]	DF	t-value	p-value
3rd Floor	Workstation	BZF(Off,On)	0.039	16	0.118	0.9076
		Pre-filter(Old,New)	-0.462	16	-1.490	0.1557
	Thoroughfare	BZF(Off,On)	0.062	16	0.130	0.8984
		Pre-filter(Old,New)	-0.499	16	-1.082	0.2952
2nd Floor	Workstation	Pre-filter(Old,New)	-0.190	16	-0.395	0.6980
	Thoroughfare	Pre-filter(Old,New)	-0.255	16	-0.297	0.7703
3rd and 2nd Floor	W/S & Thoroughfare	BZF(Off,On)	0.063	16	0.099	0.922

[a] denotes the difference in mean values (% of light scattered) between the BZF off and on states or between the pre-filter old and new states

Table 3

			Mean Difference[a]	DF	t-value	P-value
BZF	TSP	Total	4.301	1690	7.200	<0.0001
		Occupied[b]	9.863	490	9.518	<0.0001
		Unoccupied	20021	1198	5.098	<0.0001
	PM10	Total	3.765	1690	10.004	<0.0001
		Occupied	8.151	490	11.601	<0.0001
		Unoccupied	1.967	1198	7.108	<0.0001
	PM2	Total[c]	0.805	1549	15.768	<0.0001
		Occupied	0.882	449	7.597	<0.0001
		Unoccupied	0.774	1098	14.385	<0.0001
Pre-filter	TSP	Total	1.230	1690	2.031	0.0424
		Occupied	2.704	490	2.412	0.0163
		Unoccupied	0.626	1198	1.564	0.1180
	PM10	Total	-0.150	1690	-0.388	0.6978
		Occupied	-1.139	490	-1.439	0.1509
		Unoccupied	0.255	1198	0.902	0.3670
	PM2	Total	0.232	1549	4.250	<0.0001
		Occupied	0.361	449	2.957	0.0033
		Unoccupied	0.180	1098	3.077	0.0021

[a] denotes the difference in mean values between the BZF off and on states or between the pre-filter old and new states

[b] occupied hours are between 0900 and 1900 hours, Mondays to Fridays

[c] Data for PM2 was not recorded during the first week, and hence the corresponding number of hours are less than that for TSP and PM10

Figure 1a

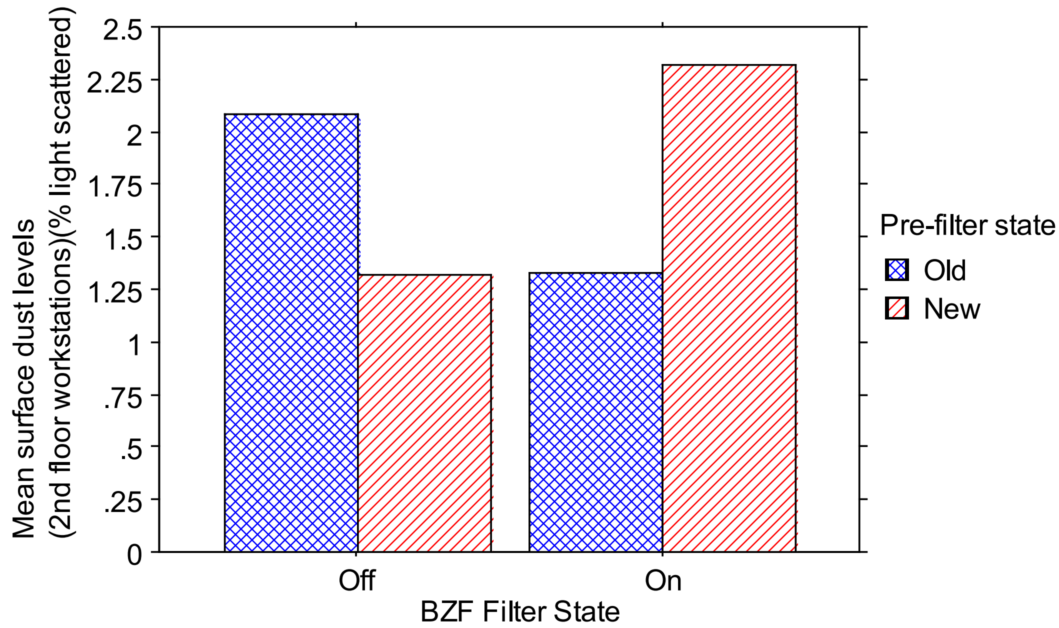


Figure 1b

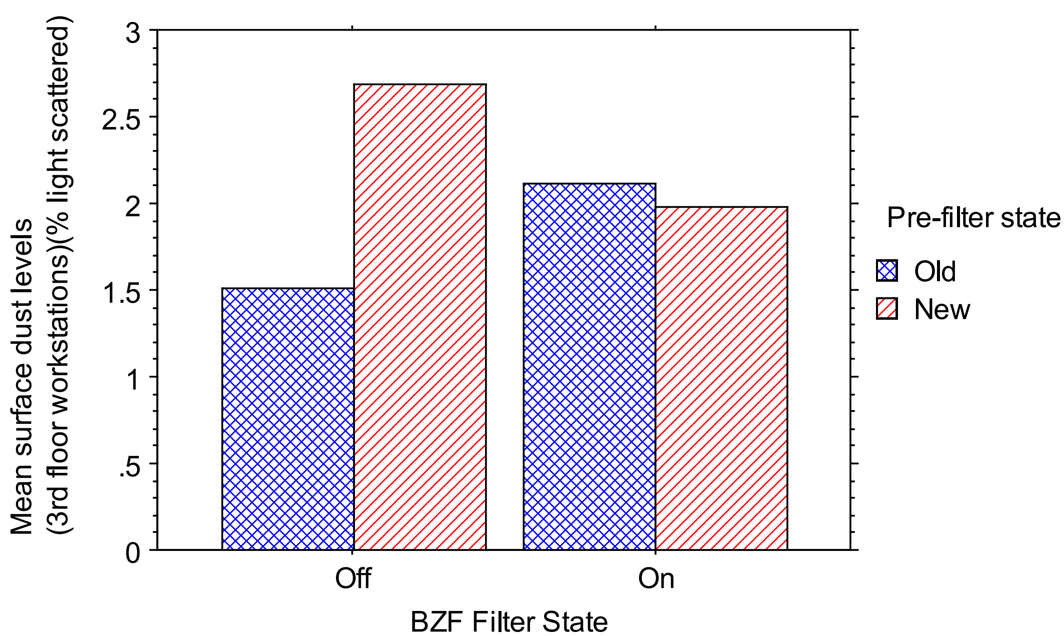


Figure 2a

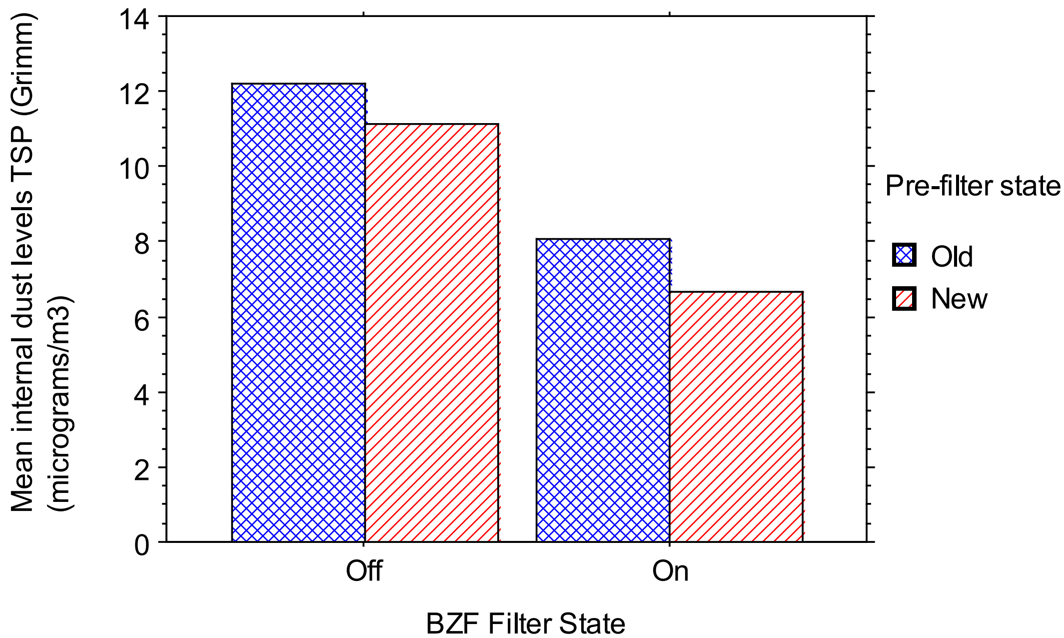


Figure 2b

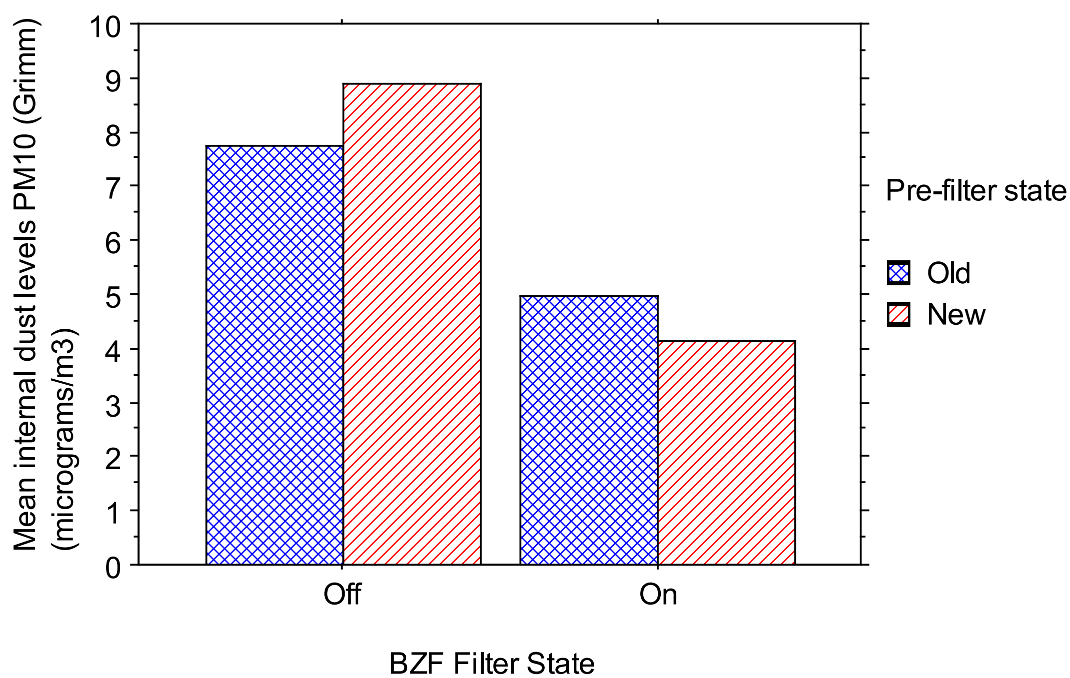


Figure 2c

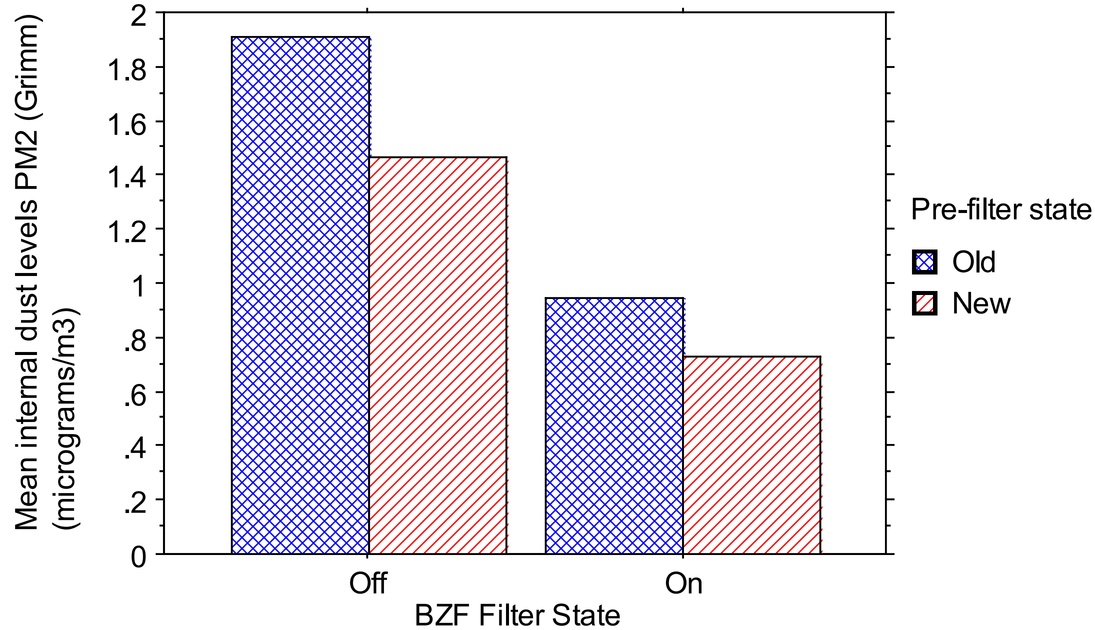


Figure 3

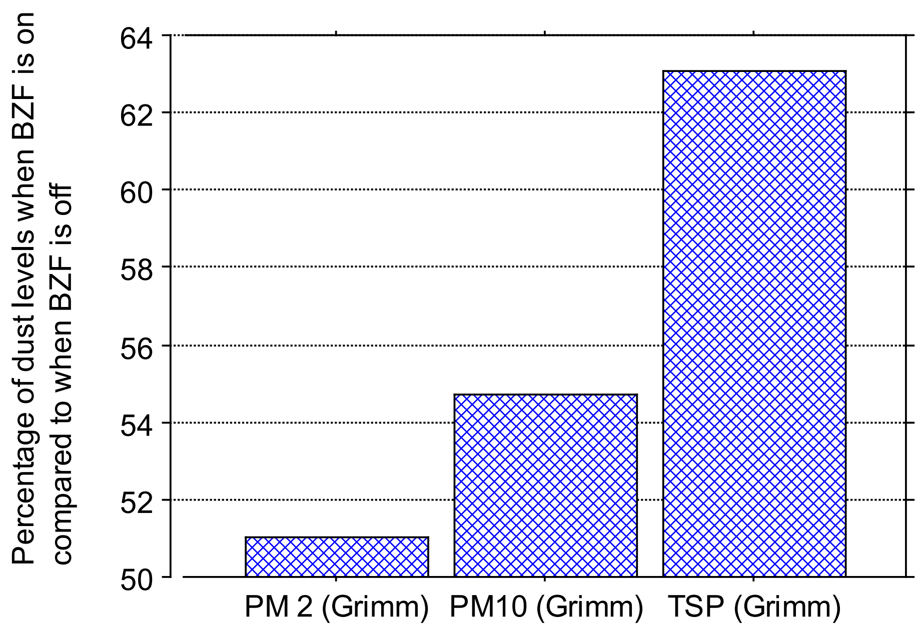


Figure 4a

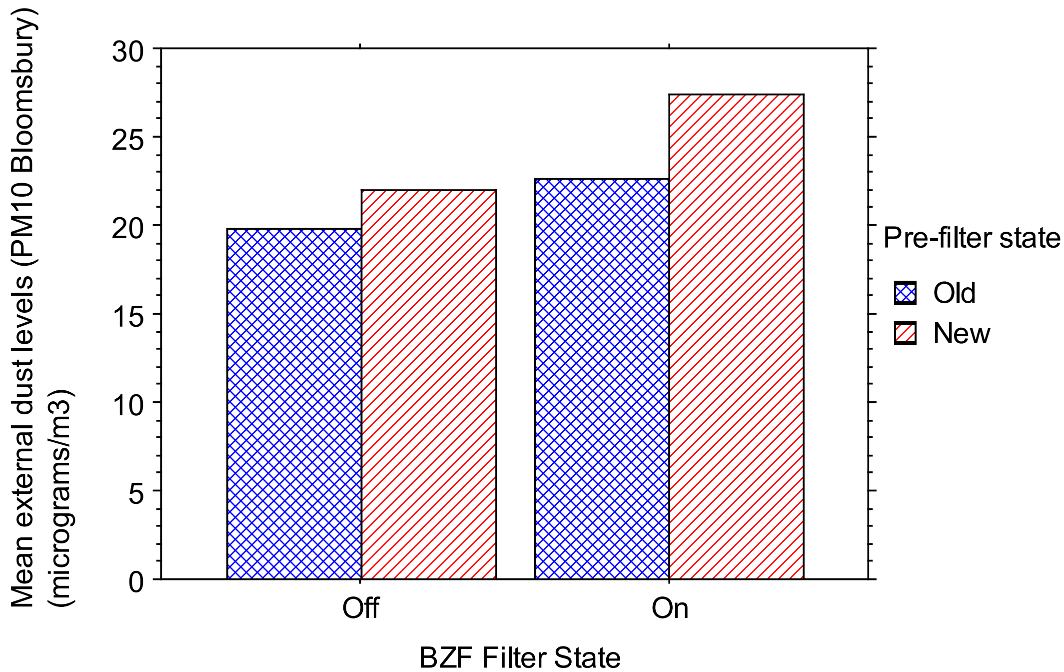


Figure 4b

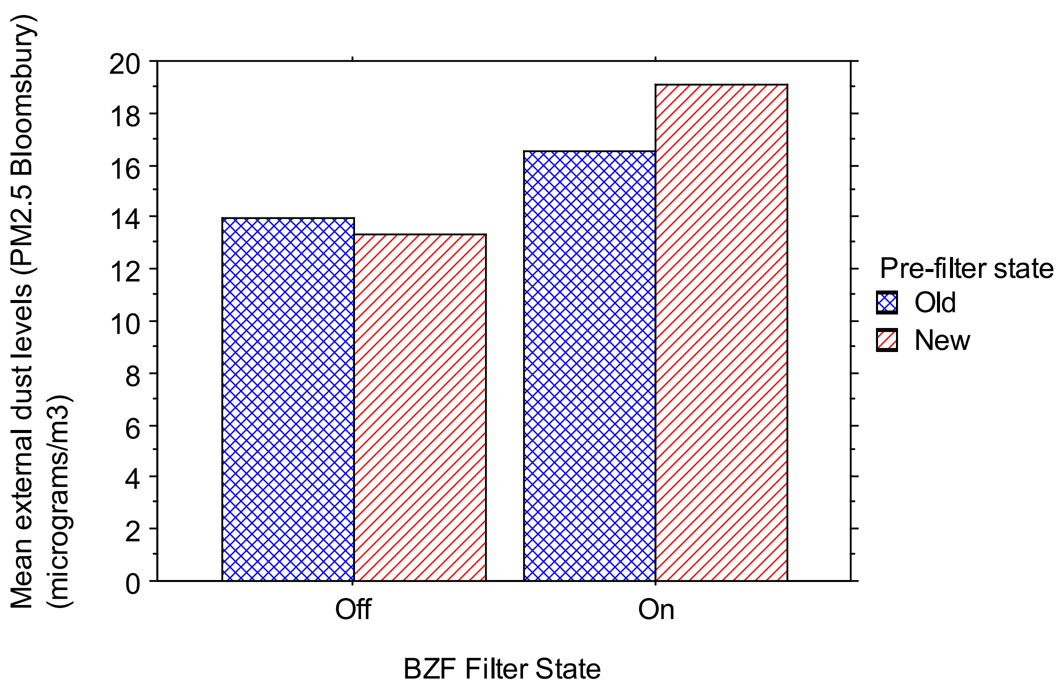
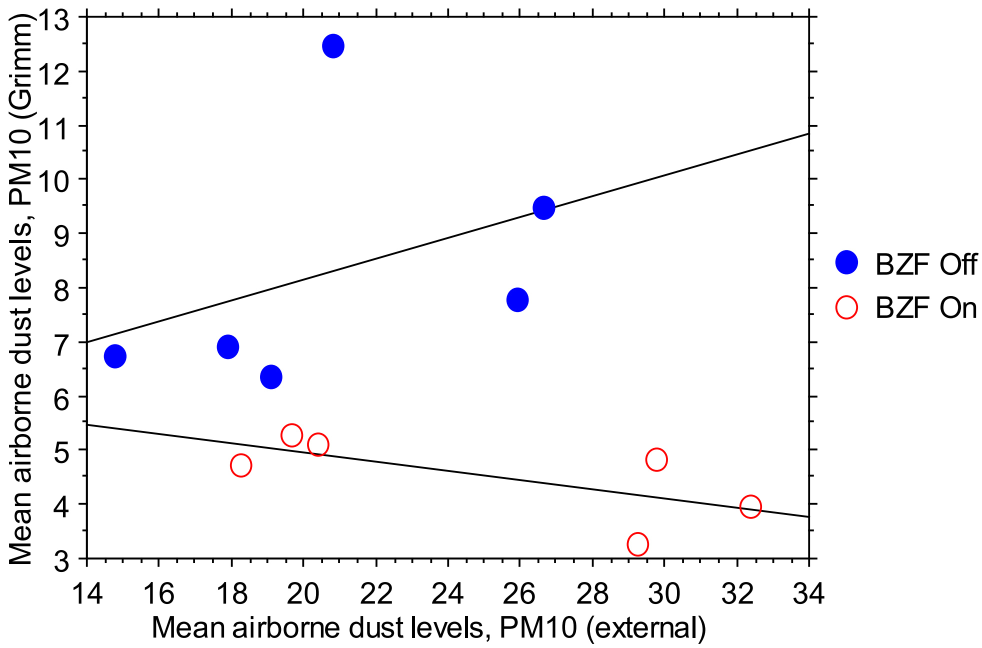
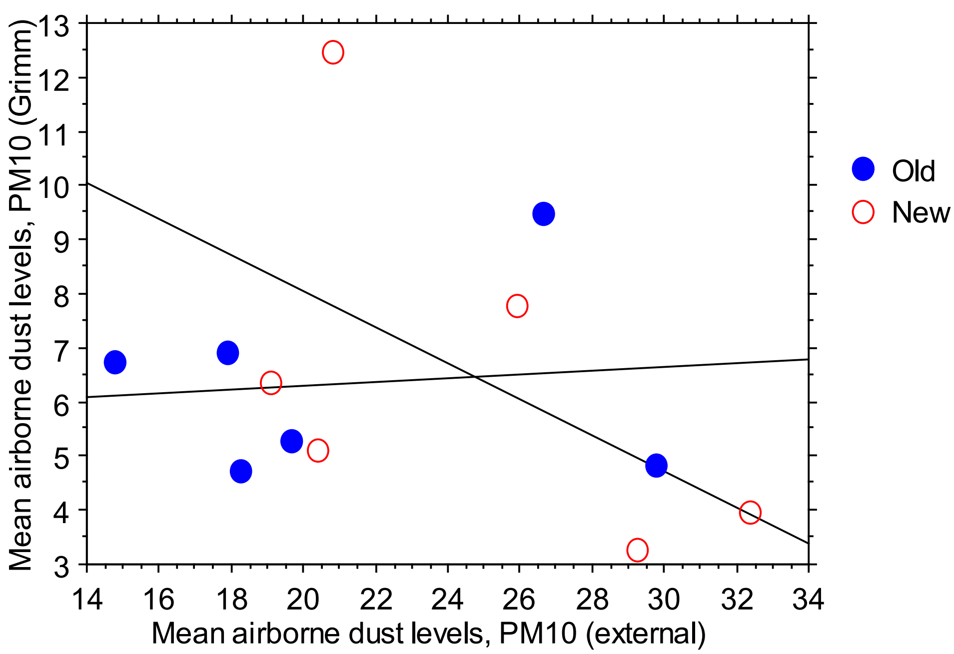


Figure 4c



PM10 (Grimm) = 6.667 - .085 * PM10 (external); R^2 = .466 (On)
PM10 (Grimm) = 4.267 + .194 * PM10 (external); R^2 = .15 (Off)

Figure 4d



PM10_Grimm = 14.749 - .335 * PM10Blooms; R^2 = .294 (New)
PM10_Grimm = 5.606 + .035 * PM10Blooms; R^2 = .012 (Old)