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The Effect of Building Fan Operation on Indoor-Outdoor Dust Relationships

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As part of an energy conservation program recently implemented by the Bell System, fans in many telephone equipment buildings now operate only when necessary to bring the temperature within allowable limits, rather than continuously. In the study reported here the effects of fan operation on indoor-outdoor dust relationships were monitored at 2 representative telephone offices. Automatic dichotomous samplers were used to collect fine and coarse aerosol particles inside telephone equipment buildings at Wichita, KS and Lubbock, TX. At both sites, outdoor samples (roof top) were collected at the same time as the indoor samples. During the tests the building fans were repetitively cycled between 2-week intervals of continuous fan operation and 2-week intervals of intermittent fan operation. The indoor dust concentrations typically increased when the fans were off. The results indicate that this increase was due to loss of constant filtration, but not due to loss of building pressurization (i.e., filtration of the recirculated air is largely responsible for the lower dust levels when the fans are running continuously). An expression is derived for the relative dust increase when the building fans are switched off. Among other factors, the relative increase is directly proportional to the efficiency of the building filters and to the rate at which air is recirculated through them. The present findings can be extended to similar buildings.

Dust contamination in telephone equipment buildings can insulate contacts from each other and block the flow of electricity completely, or bridge conductors and cause electrical shorts. It can also contribute to the corrosion or degradation of metals, plastics, and other materials. Consequently, telephone offices attempt to limit the infiltration of outdoor aerosol particles. Recently the Bell System has implemented an energy conservation program that lets the temperature in telephone equipment buildings vary over a wider range than previously allowed.[1] Under the Wide Band Temperature Control program, a building is not heated if above 65°F or cooled if below 80°F. Between these limits the temperature is allowed to drift. The building fans operate only when necessa y to bring the temperature within allowable limits, rather than continuously. Under the "wideband" program, when heating, ventilating, and air conditioning (HVAC) fans are not operating, the building has no positive pressurization. It was feared that this might lead to increased infiltration of outdoor dust. The present study was devised to assess the effect of fan operation on the infiltration of both fine and coarse particles in two representative telephone equipment buildings.

The results provide information on indoor-outdoor relationships for fine and coarse particles for a common type of office building. An expression is presented that permits the extension of these results to other buildings with similar air handling systems.

Experimental

Test Sites

Two typical telephone switching offices were selected as test sites—one in Wichita, KS and the other in Lubbock, TX. The first test series was conducted in Wichita during the fall and early winter of 1981. The second series of tests was conducted in Lubbock, TXd uring the late winter and spring of 1982. This second site was particularly severe since heavy dust storms are common in Lubbock during the spring.

The Wichita office has an 8000 cfm (227 m^3/min) air handler and a total internal volume of 68,000 ft^3 (1900 m^3) resulting in approximately 0.12 air changes/min. The Wichita office does not pre-filter the makeup air; the air handling plenum contains one inch thick polyester mat filters that have an ASHRAE Dust Spot rating[2] of 12%. (The ASHRAE Dust Spot rating is a measure of the amount of atmospheric dust removed by a filter under specified conditions). The Lubbock o fice has a 13,000 cfm (372 m^3/min) air handler and a total internal volume of 55,000 ft^3 (1500 m^3) resulting in about 0.24 air changes/min. The Lubbock office pre-filters the makeup air using two inch Farr 30-30 filters; the air handling plenum contains one inch Farr 30-30 filters followed by bag filters that have an ASHRAE Dust Spot rating[2] of 85%.

Test Procedure

General. Airborne concentrations of fine and coarse dust were simultaneously measured outdoors and indoors so that variations in outdoor dust levels could be taken into account in evaluating the effect of fan operation on indoor dust levels. The normal test procedures called for the offices to operate for 2 weeks with HVAC fans on continuously, and then 2 weeks with thermostatic fan cycling while maintaining

Table I. Average indoor temperature and relative humidity at Wichita and Lubbock.

	Wichita Aisle Temp. °F	Wichita RH %	Lubbock Aisle Temp. °F	Lubbock RH %
1st continuous fan period	78	32	84	17
1st fan cycle period	74	36	80	17
2nd continuous fan period	70	27	83	19
2nd fan cycle period	72	26	82	17
3rd continuous fan period	69	19	82	[a]
3rd fan cycle period	65	16	(end of test)	

[a] Data signal lost.

building temperatures between 65 and 80°F. The 4-week test cycle was then repeated. Environmental conditions such as temperature and humidity were also monitored throughout the test.

Dust Sampling. The concentration of airborne particulate matter, both indoors and outdoors, was determined using Sierra Automatic Dichotomous Samplers, Model No. 245. These samplers have an inlet that excludes particles larger than 15 μm in aerodynamic diameter. The entrained particles are size fractionated into fine particles smaller than 2.5 μm in diameter and coarse particles between 2.5 and 15 μm in diameter by means of virtual impaction.[3] The virtual impaction method of size fractionation eliminates the problems of particle bounce and reentrainment sometimes associated with cascade impactors. The nominal flow rate was 0.59 cfm (16.7 Lpm). The particles were collected on 2 μm pore size Teflon membrane filters (37 mm diameter) with nonwoven polypropylene backing (GHJA R2P J03725). These filters essentially function as impaction filters and are more than 99.95% efficient for particles larger than 0.035 μm diameter. The filters were precleaned using ultrasonic extractions, first with water, then with methanol. After 3 such cleaning cycles, the filters were air dried and equilibrated at least 1 day at 55% R.H. before weighing. Typical tare weights ranged from 0.088–0.103 g. The recorded weight for each filter was the average of 3 weighings to the nearest μg on a microanalytical balance.

At each location, the indoor sampler was located adjacent to the equipment frames and the outdoor sampler was located on the roof (approximately 6 m above ground). Samplers were run continuously, with 2 outdoor samples collected for every indoor sample. At Wichita, the outdoor sampling interval was 84 h, and the indoor sampling interval was 168 h. At Lubbock, the outdoor sampler was changed manually, with 2 changes every week; the indoor sampling interval was again 168 h. Typical mass gains in these intervals ranged from 0.0002–0.002 g. The present study is based on 36 sets of filters collected at Wichita and 33 sets of filters collected at Lubbock.

Environmental Data. Besides dust levels, environmental conditions were recorded during the tests in Wichita and Lubbock. Sensors were placed in and around the buildings to provide indoor and outdoor temperature and relative humidity information and to record building pressurization and on/off status of the main HVAC fan.

The data were recorded on a 10 channel A.D. Data Systems Model ML10-A data logger. The data logger records input voltage or analog signals via a built-in cassette tape recorder. These data are then displayed in graphic form using automated data processing techniques.

Results

Environmental Data

Indoor temperatures at both Wichita and Lubbock were between 65°F and 85°F for the duration of the tests. Table I lists the average indoor temperature and humidity recorded at each site.

Due to intermittent sensor problems, outdoor temperature and humidity were not recorded consistently. However, records of local outdoor conditions for the test periods were obtained from the U.S. Weather Service (Appendices A & B).†

Normal building pressurization (with fans running) in both buildings was low, generally only a few hundredths of an inch of water gauge pressure. Minor disturbances near the sensors caused large variations in recorded pressure.

The fan status indicator showed that for the major part of the tests in both Wichita and Lubbock, the HVAC fan was off virtually 100% of the time during thermostatic cycling. A listing of percent "on" time for each test phase is included in Tables II and III.

Distinctions Between Fine and Coarse Dusts

Table II lists the indoor and outdoor concentrations of fine, coarse, and total suspended particulate at the Wichita site. Table III lists the same information for the Lubbock site. The concentrations of the fine and coarse dust are actually more useful in understanding the effects of HVAC fan operation than is the total dust concentration. Not only do fine and

† Appendix A, "Climatological Data for Wichita, Kansas from October, 1981 through January, 1982," and Appendix B, "Climatological Data for Lubbock, Texas from February, 1982 through April, 1982" are available from the authors upon request.

Table II. Indoor and outdoor concentrations of fine, coarse and total suspended particulate at the Wichita site.

Date	Fan status (% on)[a]	Fine, $\mu g/m^3$ Indoor	Fine, $\mu g/m^3$ Outdoor	Coarse, $\mu g/m^3$ Indoor	Coarse, $\mu g/m^3$ Outdoor	Total, $\mu g/m^3$ Indoor	Total, $\mu g/m^3$ Outdoor
Oct. 21–Oct. 28, 1981	Continuous (100)	3.8	9.1	0.28	20.7	4.11	29.8
Oct. 28–Nov. 4, 1981	Continuous (100)	4.1	15	0.1	8.1	4.22	23.1
Nov. 4–Nov. 11, 1981	Thermostat (0)	11.1	9.6	0.13	16.1	11.24	25.7
Nov. 11–Nov. 18, 1981	Thermostat (0)	14.7	16.9	0.34	30.1	15.02	47.1
Nov. 18–Nov. 25, 1981	Continuous (100)	3.7	10.8	0.87	33.8	4.55	44.5
Nov. 25–Dec. 2, 1981	Continuous (100)	4.5	10.9	0.16	15.5	4.68	26.5
Dec. 2–Dec. 9, 1981	Thermostat (0)	11.2	8.4	0.38	20.6	11.63	29
Dec. 9–Dec. 16, 1981	Thermostat (0)	14.1	18.8	0.80	14.7	14.91	33.4
Dec. 16–Dec. 23, 1981	Continuous (100)	4.4	10.7	0.56	8.1	4.97	18.9
Dec. 23–Dec. 30, 1981	Continuous (100)	5	9.1	0.62	4.3	5.6	13.4
Dec. 30, 1981–Jan. 6, 1982	Thermostat (0)	11.8	15.3	0.4	13.4	12.24	28.7
Jan. 6–Jan. 13, 1982	Thermostat (85)	7.2	12.9	0.52	22.4	7.75	35.3

[a] The percentage of the period that the HVAC fans are on.

coarse dusts have different sources; they also settle out of the air at different rates, are filtered with different efficiencies, and even have different chemical compositions.[4,5,6]

Observations Derived from Dust Measurements

Using the data in Tables II and III, indoor-outdoor concentration ratios[7] (I/O) can be calculated for each of the sampling intervals. Table IV presents average I/O ratios for fine and coarse dust when the fans are on and when the fans are off.

A number of relationships for the Witchita site are revealed by the raw data in Table II and the average I/O ratios in Table IV. (In examining Table II it should be noted that in the first 5 periods of thermostatic fan operation the outside temperatures were such that fan operation was not required for either heating or cooling. In the final period, January 6–13, fan operation was occasionally necessary for heating.)

1) The average I/O ratio for fine dust is about 2.5 times greater when the fans are off than when the fans are running continuously. For the period January 6–13, when the fans were frequently on, the concentration of fine indoor dust was lower than during other periods of thermostatic operation.
2) The average I/O ratio for coarse dust is about the same when the fans are off as when the fans are running continuously.
3) When the fans are running continuously, the average I/O ratio for fine dust is about 15 times the average I/O ratio for coarse dust; when the fans are off this factor rises to about 40.

In examining the Lubbock raw data (Table III), it is again important to note that during the first 3 periods of thermostatic fan operation the building fans were off. However, for the period April 1–8 the fans were on for cooling 46% of the time. Acknowledging this complication in the data for April 1–8, Tables III and IV reveal relationships for the Lubbock site analogous to those enumerated for the Wichita site:

4) The average I/O ratio for fine dust is about 11 times greater when the fans are off than when the fans are running continuously. For the period April 1–8, when the fans were frequently on, the concentration of fine indoor dust was lower than during the other periods of thermostatic operation.
5) The average I/O ratio for coarse dust is about 6 times greater when the fans are off than when the fans are running continuously.
6) When the fans are running continuously, the average I/O ratio for fine dust is about 8 times the average I/O ratio for coarse dust; when the fans are off this factor rises to about 15.

Also apparent from Table III is the occurrence of 2 dust storms during the sampling periods. The HVAC fans were running continuously during the first dust storm; the fans were thermostatically controlled during the second storm. Additional observations relate to the dust storms:

7) During a dust storm most of the additional outdoor particles are coarse dust; there is little increase in the concentration of fine dust.
8) Regardless of fan status, the fraction of coarse dust that enters the building during a dust storm is very small (I/O ratio between 0.002 and 0.003).

The results presented in Tables II, III and IV can be compared to reveal some basic similarities and differences between the Wichita and Lubbock sites:

9) At both sites, the fan status has more of an effect on the concentration of indoor dust than do variations in outdoor dust levels.
10) At both sites, the concentration of coarse outdoor dust has little effect on the concentration of coarse indoor dust.
11) When the fans are running continuously, the I/O ratio for fine dust at Wichita is about 5 times the I/O ratio for fine dust at Lubbock; when the fans are off, the I/O ratios for fine dust are similar.
12) When the fans are running continuously, the I/O ratio for coarse dust at Wichita is about twice the I/O ratio for coarse dust at Lubbock; when the fans are off, the situation is reversed and the I/O ratio for coarse dust at Lubbock is more than twice that at Wichita.
13) The concentration of fine outdoor dust at Wichita is about 1.5 times the concentration of fine outdoor dust at Lubbock; the concentration of coarse outdoor dust at Wichita is about half the concentration of coarse outdoor dust at Lubbock (disregarding dust storms).

Table III. Indoor and outdoor concentrations of fine, coarse and total suspended particulate at the Lubbock site.

Date	Fan status (% on)[a]	Fine, μg/m³ Indoor	Fine, μg/m³ Outdoor	Coarse, μg/m³ Indoor	Coarse, μg/m³ Outdoor	Total, μg/m³ Indoor	Total, μg/m³ Outdoor
Feb. 4–Feb. 11, 1982	Continuous (100)	0.97	10.6	0.9	16.9	1.86	27.5
Feb. 11–Feb. 18, 1982	Continuous (100)	0.69	7.7	0.64	33.2	1.33	40.9
Feb. 18–Feb. 25, 1982	Continuous (100)	0.77	6.9	0.32	46.3	1.1	53.2
Feb. 25–Mar. 4, 1982	Thermostat (0)	7.06	8.5	2.11	65.3	9.17	73.8
Mar. 4–Mar. 11, 1982	Thermostat (0)	6.76	6	2.25	28.2	9.01	34.2
Mar. 11–Mar. 18, 1982	Continuous (100)	0.73	16.3[b]	0.65	419.3[b]	1.38	432.3[b]
Mar. 18–Mar. 25, 1982	Continuous (100)	0.67	10.3[b]	0.3	155.5[b]	0.96	165.8[b]
Mar. 25–Apr. 1, 1982	Thermostat (0)	5.29	8.3	2.85	43.5	8.14	51.8
Apr. 1–Apr. 8, 1982	Thermostat (46)	2.64	30.5[b]	4.99	1472[b]	7.63	1503[b]
Apr. 8–Apr. 15, 1982	Continuous (100)	0.84	9.5	0.05	41.2	0.89	50.7
Apr. 15–Apr. 22, 1982	Continuous (100)	0.63	8.9	0.12	60.8	0.76	69.7

[a] The percentage of the period that the heating, ventilating, and air conditioning fans are on.
[b] Dust storm.

Table IV. Average indoor/outdoor ratios for fine and coarse dust at Wichita and Lubbock.

	Fine Dust	Coarse Dust
Wichita		
Continuous (fans on)	0.4	0.026
Thermostat (fans off)	0.98	0.024
Lubbock		
Continuous (fans on)	0.08	0.012
Thermostat (fans off)	0.87	0.06

Discussion

Presentation of Model

Figure 1 is a schematic illustration of the principal sources and sinks for dust in a modern office building. When the HVAC fans are on, there are 3 major sources of indoor dust: generation of dust within the office, leakage of outdoor dust into the office, and introduction of outdoor dust with the makeup air. There are 4 major sinks for the dust: the settling of dust onto indoor surfaces, the removal by the building filters of dust suspended in the recirculated air, the leakage of indoor dust out of the office, and the expulsion of dust suspended in the air that is exhausted and replaced with makeup air. The conservation of mass requires that when the system is in a steady state, the source terms equal the sink terms.[8] Under these conditions, and assuming that there is uniform mixing within the building, the average indoor dust concentration is given by the expression:

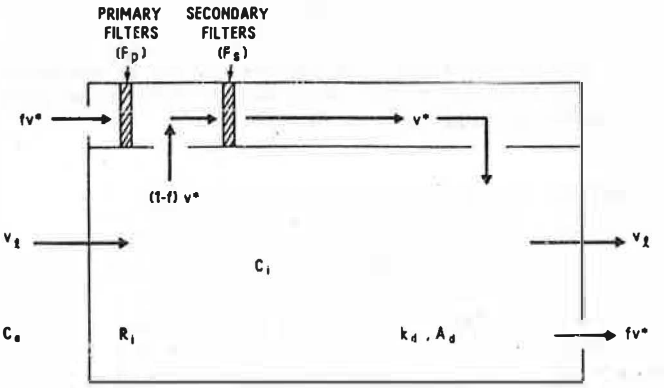

Figure 1. Principal sources and sinks for dust in a modern office building.

$$C_i = \frac{R_i + v_l(1 - F_l)C_e + v^*(1 - F_p)(1 - F_s)fC_e}{k_d A_d + v^* F_s + v^*(1 - F_s)f + v_l} \quad (1)$$

where:

C_i = average indoor dust concentration ($\mu g/m^3$)
R_i = internal rate of dust generation ($\mu g/min$)
v_l = volume of air leaking into and out of the building (m^3/min)
F_l = fractional equivalent filter efficiency of leakage paths (0–1)
C_e = average outdoor dust concentration ($\mu g/m^3$)
v^* = volume of air flow in air handling system (m^3/min)
F_p = fractional primary filter efficiency; the fraction of particles in a given size range removed by the primary filter (0–1)
F_s = fractional secondary filter efficiency; the fraction of particles in a given size range removed by the secondary filter (0–1)
f = fraction of recirculation made up with outside air (0–1)
k_d = internal dust deposition rate constant (m/min)
A_d = internal dust deposition area (m^2)

This model can be applied to the concentrations of both fine and coarse dust at the Wichita and Lubbock sites. For dust in the fine mode:

$k_d \sim 0.0012$ m/min
$F_p = 0$ (Wichita)
$F_p \sim 0.1$ (Lubbock)[9]
$F_s \sim 0.05$ (Wichita)[9]
$F_s \sim 0.74$ (Lubbock)[9]

For dust in the coarse mode:

$k_d \sim 0.06$ m/min
$F_p = 0$ (Wichita)
$F_p \sim 0.65$ (Lubbock)[9]
$F_s \sim 0.46$ (Wichita)[9]
$F_s \sim 0.995$ (Lubbock)[9]

For both fine and coarse mode dust:

$v^* \sim 227\ m^3/min$ (Wichita)
$v^* \sim 372\ m^3/min$ (Lubbock)
$A_d \sim 525\ m^2$ (Wichita)
$A_d \sim 440\ m^2$ (Lubbock)

The values substituted above for A_d, the internal dust deposition area, are simply the floor area. To a first approximation this estimate is justified, since more dust is deposited on indoor horizontal surfaces than on indoor vertical surfaces.[10] Measured or reported values for R_i, v_l, F_l, and f are not available; their values must therefore be estimated for each office.

Discussion of Results

The observations derived from dust measurements (enumerated above) can be discussed within the context of the above model. To some extent, this procedure can identify the major factors influencing indoor dust concentrations at these sites.

Observations 1, 4, and 5 report that when the fans are on, the average I/O ratios are lower than when the fans are off. The experimental data in Tables II and III can be fit relatively accurately by Eq. 1. Comparison of the terms in Eq. 1 reveals that the factor most affected by intermittent fan operation is filtration of the recirculated air (v^*F_s). When the HVAC fans are on, a large percentage of the indoor air is being recirculated through the building filters. On each pass through the filters, some dust in the air is removed. When the fans are off, this sink is lost. With the addition of outside air (makeup air) during continuous fan operation, outside dust is also brought in $[v^*(1 - F_p)(1 - F_s)C_e]$. However, the filtration of the recirculated air controls most of the dust introduced with the makeup air. Fan status (on vs. off) has a larger effect in Lubbock than in Wichita (observations 11 and 12). This is to be expected since Lubbock has both more efficient building filters (larger F_s) and twice the rate of recirculation (v^*) compared to Wichita.

The building filters remove coarse dust more efficiently than fine dust. Yet observations 1, 2, 4 and 6 indicate that the concentration of coarse indoor dust does not increase as much as that of fine indoor dust when the fan status changes from on to off. This suggests there is a source of coarse indoor dust when the fans are on that is not present when the fans are off. Perhaps more coarse dust is resuspended when the fans are on than when the fans are off. Resuspension would be a much more likely process for coarse than for fine dust.[11] Yet even for coarse dust it is questionable whether the air flows are great enough for a significant amount of resuspension.

At both locations the ratio of fine to coarse indoor dust (fans off) is greater than the ratio of fine to coarse outdoor dust. Although to some extent this may reflect different internal generation rates for fine vs. coarse, the primary causes are more likely the much larger building penetration and much slower settling rate of fine dust as compared to coarse dust. The fact that, with the fans off, the I/O ratio for fine dust sometimes exceeds unity at both Wichita and Lubbock suggests that indoor generation, as well as penetration from the outdoors, contributes to the net amount of indoor fine dust. The I/O ratios for coarse dust are always much less than unity (Table IV). Furthermore, variations in the concentration of coarse outdoor dust have little effect on coarse indoor levels (observation 10). Even during dust storms, only a very small fraction of the coarse dust penetrates the building (observation 8). These results indicate that, with the exception of dust storms, leakage of outdoor dust into the office is an insignificant source of coarse dust within the Wichita and Lubbock offices. When the fans are off, the I/O ratio for coarse dust is more than twice as large at Lubbock as at Wichita (observation 12). Apparently more coarse dust is generated within the Lubbock office than within the Wichita office.

It is evident from the above discussion that recirculation/filtration is a major factor determining the average indoor dust concentration at both Wichita and Lubbock and is responsible for most of the differences between these offices reported above. The study also demonstrates that building pressurization is of minor influence in these same areas. The values of pressurization measured at the Wichita and Lubbock offices were low (typically less than 0.05 in. of water), displayed considerable fluctuation, and occasionally went negative, even during continuous fan operation. Changes in outdoor wind speed and wind direction appeared to be primarily responsible for the last two observations. The major reason for increased dust levels during wideband was not the lack of positive pressurization, but the lack of recirculation/filtration.

Extension of Results

The previous discussion has dealt exclusively with just two buildings. However, the observations from these sites can be used in conjunction with the conservation of mass model to reach conclusions of general applicability to other similar buildings. Eq. 1, for the average indoor dust concentration, can be used to estimate the relative increase in indoor dust concentrations when the HVAC fans are turned off [i.e., the ratio $C_i(\text{off})/C_i(\text{on})$]. The indoor dust concentration with the HVAC fans on will be smallest when no outside air is being introduced (i.e., when $f = 0$). In this case, Eq. 1 simplifies to:

$$C_i(\text{on}) = \frac{R_i + \upsilon_l(1 - F_l)C_e}{k_d A_d + \upsilon^* F_s + \upsilon_l} \quad (2)$$

When the fans are off, $\upsilon^* = 0$ and

$$C_i(\text{off}) = \frac{R_i + \upsilon_l(1 - F_l)C_e}{k_d A_d + \upsilon_l} \quad (3)$$

The relative increase in indoor dust concentrations when HVAC fans are turned off is then given by:

$$\frac{C_i(\text{off})}{C_i(\text{on})} = \frac{k_d A_d + \upsilon_l + \upsilon^* F_s}{k_d A_d + \upsilon_l} \quad (4)$$

which simplifies to:

$$\frac{C_i(\text{off})}{C_i(\text{on})} = 1 + \frac{\upsilon^* F_s}{k_d A_d + \upsilon_l} \quad (5)$$

This expression indicates that the relative increase in indoor dust concentration when the HVAC fans are turned off depends directly on both the efficiency of the filters through which the air is recirculated and the rate at which the air is recirculated. It depends inversely on the rate at which dust settles out of the air and the rate at which air leaks out of the office. It is important to note that this ratio does not depend on the outdoor dust concentration. In telephone equipment buildings, there is likely to be less variation in υ^*, A_d, and υ_l (normalized for the internal office volume) than there is in F_s. Using typical values for υ^*, k_d, A_d, and υ_l one can estimate the effect of turning off HVAC fans in telephone offices with different types of filters. Such estimates indicate that for an office with glass fiber or polyester filters, the indoor concentrations of both fine and coarse dusts will most likely increase by a factor of 2–3. For an office with high efficiency filters, the indoor fine dust concentration will most likely increase by a factor of 10–15, while the indoor coarse dust concentration will likely increase by a factor of 7–10. These two extremes are represented by the offices at Wichita and Lubbock. The Wichita office has polyester filters, and the relative increase in fine dust concentration when the fans are turned off is about a factor of 3. As a result of other compensating factors, the coarse level remains virtually unchanged. The Lubbock office has high efficiency filters, and when the fans are turned off, the relative increase in fine dust concentration is about a factor of 8, while that of coarse dust is about a factor of 6. It should be noted that although a large relative increase is expected in an office with high efficiency filters, such an office can often tolerate such an increase since its indoor dust levels are normally very low when the fans are on.

Although these studies were conducted in telephone switching offices, Eq. 1 and 5 should be of general applicability for buildings whose sources and sinks are adequately described by Figure 1. The above results verify that Eq. 5 can be used to estimate the relative increase in indoor dust concentrations when HVAC fans are turned off. Differences in external environments appear to be of only secondary importance when considering the effect of intermittent fan operation on dust concentrations in well sealed office buildings.

Summary

At both of the offices examined in this study, the indoor dust concentrations increased when the building fans were turned off. The relative increase was smaller at the office with the less efficient filtration system. Analysis of the results indicates that filtration of the recirculated air is the most important factor controlling indoor dust levels when the fans are on. Lack of this constant filtration, rather than lack of pressurization, is responsible for the observed dust increase with intermittent fan operation. The results obtained at Wichita and Lubbock can be explained in terms of a conservation of mass model. The model, coupled with the results, can in turn be used to reach conclusions of general applicability to other similar offices. An expression derived from the model indicates that the relative increase in indoor dust concentration when the HVAC fans are turned off depends directly on both the efficiency of the filters through which the air is recirculated and the rate at which the air is recirculated. The relative increase does not depend on the outdoor dust concentration. Consequently, the present findings can be extended to buildings in locations outside of Wichita and Lubbock.

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