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EFFECT OF AIR DIFFUSER LAYOUT ON THE VENTILATION CONDITIONS OF A WORKSTATION—PART II: AIR CHANGE EFFICIENCY AND VENTILATION EFFICIENCY

C.Y. Shaw, Ph.D., P.E.
Member ASHRAE

J.S. Zhang, Ph.D.
Associate Member ASHRAE

M.N. Said, Ph.D., P.E.

F. Vaculik, P.E.
Member ASHRAE

R.J. Magee

ABSTRACT

Tests were conducted in an enclosed room fitted with a mock-up workstation to determine the effect of air diffuser types and layouts on the ventilation condition of the workstation. Seven different layouts including two types of air diffusers were tested. For each air diffuser layout, tracer gas tests were conducted to measure air distribution patterns, air change efficiency, and ventilation efficiency within the workstation, the surrounding area, and in the return air duct. Additional tests were also conducted to investigate the effect of gap heights at the base of workstation partitions and the supply air rate on the air distribution pattern within the workstation and its surrounding area. The results are presented in two papers. Part I presents the results of air distribution patterns and the effects of gap heights at the base of workstation partitions and airflow rates on these patterns. Part II, this paper, presents the results of air change efficiency and ventilation efficiency.

INTRODUCTION

For office buildings with open-floor layouts, some workstations may be overventilated and others may be inadequately ventilated, even though the total ventilation (outdoor air supply) rate is adequate. This is because the designer seldom knows the workstation layout when designing the ventilation system. Also, workstation layouts may be changed as the use of the space changes.

Several parameters have been proposed for assessing the performance of a ventilation system. They include air change efficiency, ventilation efficiency, and air change rate together with air distribution pattern (Skaret and Sandberg 1985; AIVC 1990, 1991; Anderson 1988; Shaw et al. 1991). The air change efficiency (or air exchange efficiency) is a measure of how quickly the air in a space is replaced. European researchers (Skaret and Sandberg 1985) define the air change efficiency as the ratio between the nominal time constant and the air exchange time for a ventilated space. The ventilation efficiency (or contaminant removal effectiveness) is defined as the ratio between the steady-state concentration of contamination at the exhaust duct and the steady state mean concentration of the room (Skaret and Sandberg 1985; AIVC 1991). The air distribution pattern (Shaw et al. 1991) is a measure of how quickly the supply air from the supply air registers reaches various locations in a room. It also shows how uniformly the supply air is distributed within the room, an indication of how efficiently a heating, ventilating, air-conditioning (HVAC) system distributes the supply air.

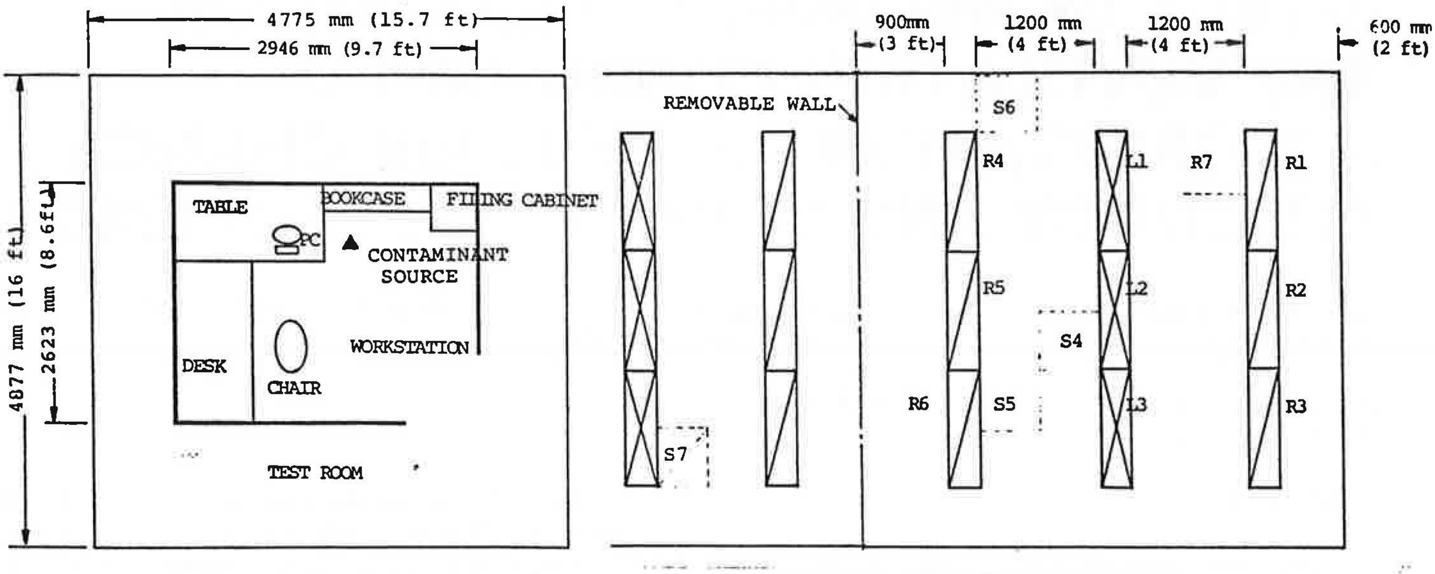
Tests were conducted in one of two interconnected ventilation test rooms to measure air distribution patterns, air change efficiency, and ventilation efficiency within and around a mock-up workstation for seven different layouts of supply air registers and return air grilles. The results are presented in two papers. The first paper (Shaw et al. 1993) reports the air distribution measurements. The results indicate that all seven diffuser layouts distributed the supply air within the workstation and in the surrounding area equally well. The presence of a workstation had no significant effect on the air distribution patterns. No evidence was found to indicate that one diffuser layout was better than another. The results also indicate that the effect of gap heights at the base of workstation partitions on the air distribution patterns was minimal. The time required by the supply air to mix with the air inside the workstation increased as the supply airflow rate decreased.

This paper presents the results of air change efficiency and ventilation efficiency measurements.

TEST SETUP

Figure 1 shows the test rooms. The dimensions of each room are 4.9 m by 4.8 m by 2.9 m high (16 ft by 15.7 ft by 9.4 ft). Each room is equipped with an independent HVAC system. Dampers and orifice plates have been installed in the supply, return, outdoor air supply, and exhaust ducts to control and measure the airflows though

C.Y. Shaw is a senior researcher, **J.S. Zhang** is a research associate, **M.Nady A. Said** is a research officer and **Robert J. Magee** is a technical officer at the Institute for Research in Construction, the National Research Council of Canada and **Frantisek Vaculik** is a manager in Building Performance, Public Works Canada, Ottawa, Ontario.



A. Layout of workstation. *B. Layout of supply air registers.*

Figure 1 *Test set-up.*

these ducts. As shown in Figure 1, the rooms are equipped with two basic designs of supply air outlets and return air inlets: recessed air-light fixtures (slot diffusers, 1.2 m [4 ft] long) and square ceiling diffusers. The air-light fixtures are fixed, but the square diffusers can be moved from one location to another. Using combinations of these diffusers, seven layouts of supply air inlets and return air outlets were tested.

A 2.9 m by 2.6 m (9.7 ft by 8.6 ft) mock-up workstation was placed inside the test room (Figure 1). The height of the partition was 1.9 m (6.3 ft). The furniture, as shown, included a desk, a 60-W desk lamp, a chair, a table, a bookcase, a computer, and a file cabinet. In addition, two light bulbs, one 60-W and one 10-W, were placed on the chair to simulate the sensible heat of an office worker.

Tracer gas sampling stations were installed at a total of 15 locations within the test room, including 9 locations within the workstation, and 4 locations around and 2 locations above the workstation. The supply, return, and outdoor air supply ducts were also sampled. In addition, sampling tubes were installed in the areas surrounding the test room. The workstation was divided into eight volumetrically equal regions with a sampling station installed in each region. As shown in Figure 2, sampling stations 1, 2, and 5 were at the breathing height of a seated adult and the others were at the center of each region (sampling stations 6, 7, 8, and 9 were approximately at the nose height of a standing adult). Sampling stations 10, 11, 12, and 13 were placed at the breathing height of a seated adult outside the workstation near the center of the space between the partition and the wall of the test room, and sampling stations 14 and 15 were placed above the workstation.

Each sampling station consisted of three sampling tubes. Of the three tubes, one could be used to inject tracer gas into the room; the second one was used to collect the tracer gas sample at that location. The third tubes from locations 1 through 9 were connected to a manifold to produce an "average" sample for the workstation; those from 10 through 15 were manifolded to produce an "average" sample for the area outside the workstation. Two automated sampling systems, each with a 16-port multiposition sampling valve, were used for collecting tracer gas samples: one for collecting individual samples from the 15 locations inside the test room (one port was used to sample the outdoor air) and the other for collecting samples from the manifolds, the HVAC system, and the locations outside the test room.

MEASUREMENT METHODS

The methods used to measure air change efficiency and ventilation efficiency are described below.

Test 1, Air Change Efficiency

For measuring the air change efficiency, a small amount of SF_6 (14 mL) was injected through eight injection tubes into the test room at sampling locations 1, 2, 3, 4, 10, 11, 12, and 13. Four small (box) fans were used to assist in mixing the tracer gas with the room air. About five minutes after tracer gas injection, the mixing fans were turned off and tracer gas samples, both individual and manifold, were taken (at four-minute intervals for about three hours) at all sampling locations. The results obtained

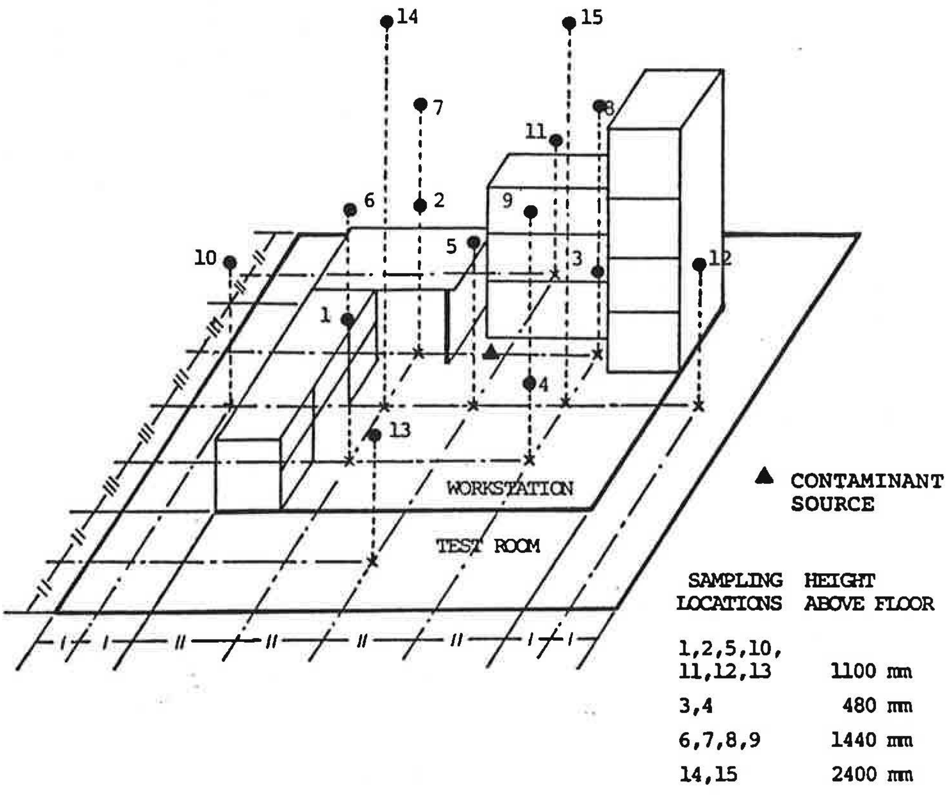


Figure 2 Locations of sampling stations.

were used to calculate (1) the local mean age of air at each of the 9 locations within the workstation (Skaret and Sandberg 1985; *NTVVS019* 1983), (2) the local mean age of air at each of the 6 locations around the workstation, and (3) the local mean age of air in the return air duct. In addition, the room mean age of air for the workstation was calculated (1) based on the concentrations measured at the manifold using the Nordtest method and (2) by calculating the average value of the local mean ages of air of the 9 locations inside the workstation. Also, the mean age of air for the test room was calculated (1) based on the concentrations measured in the return air duct (*NTVVS019* 1983) and (2) by calculating the average value of the local mean ages of air at the 16 locations. The air change efficiency was evaluated from the equations

$$e_{rm} = \frac{t_n}{2 < t >_{rm}} \tag{1}$$

$$e_{ws} = \frac{t_n}{2 < t >_{ws}} \tag{2}$$

where

t_n = nominal time constant, the volume of the test room divided by the outdoor air supply rate, and

$< t >$ = room mean age of air, the average value of the local mean ages of air for all points in a room (the local mean age of air is the average time it takes for air to travel from the supply air register to any point in a room).

The subscripts *rm* and *ws* indicate room and workstation, respectively.

Test 2, Ventilation Efficiency (Skaret and Sandberg 1985)

For measuring ventilation efficiency, 111 mL/min of CH_4 was injected continuously into the workstation (the injection rate was reduced to 90 mL/min after Case 03 to achieve a more appropriate peak concentration). The injection point was located on the floor near the corner of the worktable and the bookcase to simulate a point source. Tracer gas samples were taken (at four-minute intervals for about four hours) at the two manifolds (one for the workstation and the other for the space around the workstation) and in the supply air and the return air ducts. The ventilation efficiency was calculated from the equation

$$E = \frac{C_{ra}(oo) - C_s}{< C_{ws}(oo) > - C_s} \tag{3}$$

where,

$C_{ra}(oo)$ = steady-state concentration at the exhaust air duct,

$< C_{ws}(oo) >$ = steady-state mean concentration of the workstation, and

C_s = steady-state concentration at the supply.

RESULTS AND DISCUSSION

Experiments were conducted to measure the air change efficiency and ventilation efficiency of a workstation with different supply air diffuser layouts. As mentioned in "Test Setup," tracer gas samples were taken at 9 locations in the workstation and six locations in the surrounding area. In addition, the samples from the workstation were fed to a manifold to produce an "averaged" sample, as were the samples from the surrounding area. The results are discussed below in terms of air, change efficiency, room mean age of air, and ventilation efficiency.

Types and Layouts of Supply Air Diffusers (Cases 00 through Case 07)

Tests were conducted on seven supply air diffuser layouts including either air-light fixtures (slot diffusers) or square ceiling diffusers (Figure 1b). Details are given in Table 1. One of them, Case 00, which had three air-light fixtures for supply and six fixtures for return but no workstation (i.e., an empty room), was used as the base case for comparison. For this series of tests, the gap height at the base of the workstation partitions was 152 mm (6 in.). The supply air temperature was set at 23°C (73°F) and the supply airflow rate was controlled at 100 L/s (212 cfm), including 20 L/s (42.4 cfm) outdoor air. The airflow rates at the outdoor air supply, main supply air, return air, and exhaust air ducts were monitored continuously during the test.

Air Change Efficiency Table 2 lists the average values of the air change efficiency for the workstation, the surrounding area, and the room as a whole. Table 3 gives the air change efficiencies and the local mean ages of air for each of the 15 sampling locations. Also included in Table 2 are the air change efficiency and the local mean age of air values for the return air duct (see also Figure 3). For the base case (Case 00), Table 3 shows that the air change efficiency varied from 0.64 to 0.68 within the workstation and from 0.68 to 0.70 in the surrounding area. The local mean age of air varied from 41.6 to 44.6 minutes within the workstation and from 40.9 to 42.0 minutes in the surrounding area. For each of the seven diffuser layouts (Cases 01 through 07), the air change efficiency and the local mean age of air varied from location to location within a range similar to that of the base case.

In Figure 3a, the average of the local mean ages of air measured throughout the room (room mean age of air) and the local mean age of air in the return duct are each plotted against the average of the local mean ages of air within the workstation only. The average of the local mean ages of air within the workstation only was almost identical to the average of the local mean ages of air measured throughout the room and it was within 5% of the local mean age of air in the return air duct. This deviation was within the measurement error.

Figure 3b shows that the average values of air change efficiency for the workstation only agreed closely with those for the room as a whole. The agreement between these two and the air change efficiency in the return air duct was within 5%. It also shows that the average air change efficiency decreased linearly as the average mean age of air for the workstation increased.

To interpret the result, Cases 00 and 01 were examined. These two cases had the same diffuser layout except

TABLE 1
Experimental Conditions

Case No.	Arrangement of Air Diffusers		Work Station	Height Bottom Gap	Supply Air Rate
	Supply	Return		mm (in)	L/s (cfm)
00 (Base)	L1,L2,L3	R1,R2,R3,R4,R5,R6	No	152mm (6")	100 (212)
01	L1,L2,L3	R1,R2,R3,R4,R5,R6	Yes	152mm (6")	100 (212)
02	L1	R7	Yes	152mm (6")	100 (212)
03	L2	R7	Yes	152mm (6")	100 (212)
04	L3	R7	Yes	152mm (6")	100 (212)
05	S6	R7	Yes	152mm (6")	100 (212)
06	S5	R7	Yes	152mm (6")	100 (212)
07	S4	R7	Yes	152mm (6")	100 (212)
08	S4	R7	Yes	76mm (3")	100 (212)
09	S4	R7	Yes	0	100 (212)
10	L1,L2,L3	R1,R2,R3,R4,R5,R6	Yes	76mm (3")	100 (212)
11	L1,L2,L3	R1,R2,R3,R4,R5,R6	Yes	0	100 (212)
14	L1,L2,L3	R1,R2,R3,R4,R5,R6	Yes	152mm (6")	50 (106)
15	L1,L2,L3	R1,R2,R3,R4,R5,R6	Yes	152mm (6")	25 (53)

TABLE 2
Summary of the Test Results

Test Code	$<t>_{ws}$ (min)	E_{ws}	e_{ws}	e_{srd}	e_{rm}	Test Set-up
00	42.8	0.61	0.66	0.69	0.67	w0 L123 R1...6
01	46.2	0.56	0.62	0.61	0.61	w1 L123 R1...6 g6"
02	46.7	1.22	0.61	0.61	0.61	w1 L1 R7 g6"
03	45.3	0.97	0.63	0.63	0.63	w1 L2 R7 g6"
04	43.6	0.57	0.65	0.64	0.65	w1 L3 R7 g6"
05	50.6	0.51	0.56	0.58	0.57	w1 S6 R7 g6"
06	46.4	0.64	0.61	0.60	0.61	w1 S5 R7 g6"
07	45.9	0.56	0.62	0.62	0.62	w1 S4 R7 g6"
08	47.4	0.53	0.60	0.58	0.59	w1 S4 R7 g3"
09	40.0	0.60	0.71	0.65	0.69	w1 S4 R7 g0"
10	40.7	0.65	0.70	0.72	0.71	w1 L123 R1..6 g3"
11	40.6	0.70	0.70	0.68	0.69	w1 L123 R1..6 g0"
14	68.7	0.67	0.83	0.84	0.83	w1 L123 R1..6 g6" Q50L
15	105.3	0.84	1.08	1.07	1.07	w1 L123 R1..6 g 6" Q25L

Symbols:
- C = Gas concentration;
- e = Air change efficiency, $t_n/2<t>$;
- E = Ventilation efficiency, $(C_{ra}-C_{sa})/(C_{ws}-C_{sa})$;
- t_n = Nominal time, V/Q;
- Q = Supply airflow rate;
- V = Room volume;
- $<t>$ = Mean age of air.

Subscript:
- ra = Return air;
- rm = Room;
- sa = Supply air;
- srd = Surrounding area;
- ws = Within the workstation;

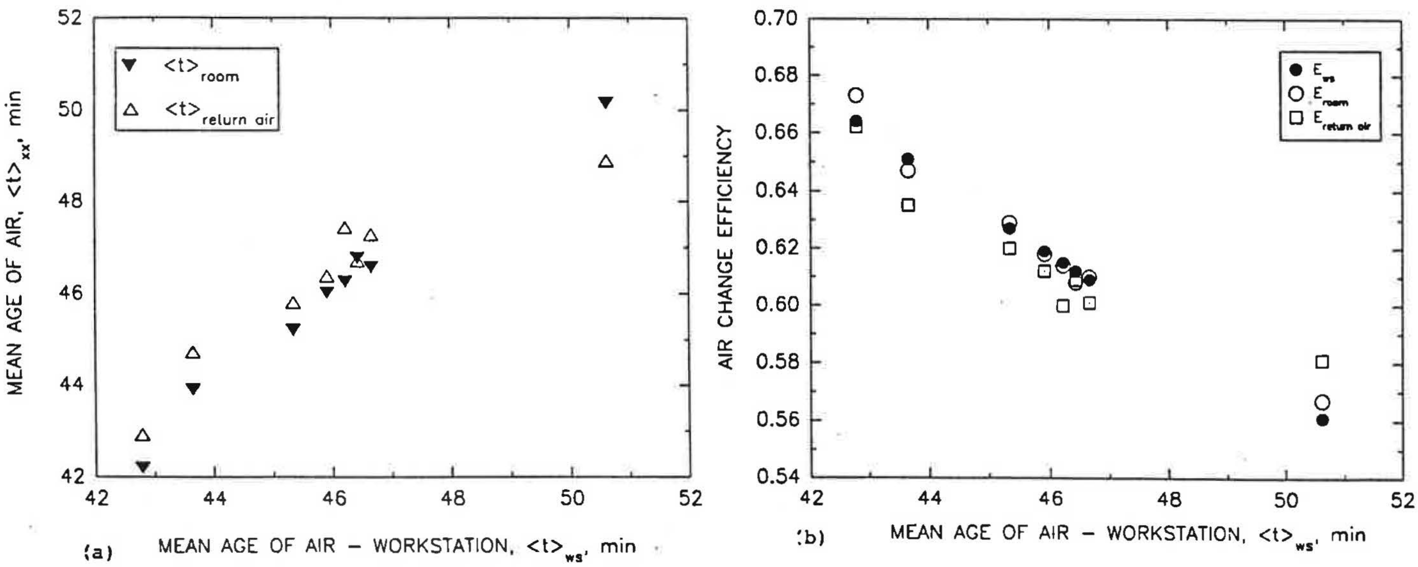


Figure 3 *Average of local mean ages of air, air change efficiency vs average of local mean age of air within the workstation for cases 00 through 07.*

TABLE 3
Measured Mean Age and Air Change Effectiveness

Location	Case 00: <t>	Case 00: e	Case 01: <t>	Case 01: e	Case 02: <t>	Case 02: e	Case 03: <t>	Case 03: e	Case 04: <t>	Case 04: e	Case 05: <t>	Case 05: e	Case 06: <t>	Case 06: e
1	41.6	0.683	44.86	0.633	46.23	0.615	45.93	0.619	43.48	0.654	50.35	0.565	45.63	0.623
2	41.64	0.682	45.51	0.624	45.77	0.621	44.65	0.637	43.74	0.65	51.09	0.556	46.46	0.612
3	42.39	0.67	48.07	0.591	46.92	0.606	45.75	0.621	43.85	0.648	50.82	0.559	46.11	0.616
4	41.93	0.678	46.13	0.616	47.31	0.601	45.24	0.628	43.02	0.661	51.46	0.552	47.3	0.601
5	42.67	0.666	46.38	0.613	46.32	0.614	45.64	0.623	43.44	0.654	51.18	0.555	46.63	0.609
6	44.64	0.637	45.99	0.618	46.66	0.609	45.28	0.628	43.73	0.65	50.45	0.563	46.46	0.612
7	42.81	0.664	46.16	0.616	46.18	0.615	45.15	0.629	43.62	0.652	50.64	0.561	46.6	0.61
8	42.93	0.662	46.62	0.61	47.23	0.602	45.05	0.631	44.01	0.646	50.51	0.563	46.22	0.615
9	44.5	0.639	46.25	0.615	47.3	0.601	45.33	0.627	43.95	0.647	49.08	0.579	46.46	0.612
10	40.86	0.695	45	0.632	46.06	0.617	45.62	0.623	43.47	0.654	49.73	0.572	47.91	0.593
11	40.9	0.695	45.45	0.625	46.06	0.617	44.79	0.635	44.29	0.642	49.49	0.574	46.96	0.605
12	41.54	0.684	47.48	0.599	46.19	0.615	43.85	0.648	44.85	0.634	49.98	0.569	47.64	0.597
13	40.55	0.701	46.06	0.617	46.42	0.612	44.85	0.634	45.06	0.631	49	0.58	46.93	0.606
14	42	0.677	47.25	0.601	47.35	0.6	45.54	0.624	44.22	0.643	49.33	0.576	47.1	0.603
15	42.04	0.676	46.68	0.609	46.5	0.611	45.46	0.625	43.75	0.65	49.24	0.577	47.07	0.604
ws_avg	42.79	0.664	46.22	0.615	46.66	0.609	45.34	0.627	43.65	0.651	50.62	0.561	46.43	0.612
srd_avg	41.32	0.688	46.32	0.614	46.43	0.612	45.02	0.631	44.27	0.642	49.46	0.575	47.27	0.601
room_avg	42.2	0.673	46.26	0.614	46.57	0.61	45.21	0.629	43.9	0.647	50.16	0.567	46.77	0.608
return_a	42.92	0.662	47.43	0.600	47.28	0.601	45.81	0.62	44.73	0.635	48.89	0.581	46.71	0.609
U_rm	0.945		0.963		0.978		0.978		0.976		0.969		0.975	
U_ws	0.951		0.965		0.977		0.984		0.987		0.974		0.982	
S_rm	0.097		0.069		0.034		0.046		0.046		0.049		0.049	
S_ws	0.071		0.069		0.033		0.028		0.023		0.047		0.036	

Location	Case 07: <t>	Case 07: e	Case 08: <t>	Case 08: e	Case 09: <t>	Case 09: e	Case 10: <t>	Case 10: e	Case 11: <t>	Case 11: e	Case 14: <t>	Case 14: e	Case 15 <t>	Case 15 e
1	46.91	0.606	49.24	0.577	39.7	0.716	38.68	0.735	38.62	0.736	68.47	0.83	108.3	1.05
2	45.75	0.621	47.57	0.597	37.6	0.756	40.22	0.707	39.09	0.727	69.12	0.822	104.6	1.087
3	45.63	0.623	47.69	0.596	38.14	0.745	39.83	0.714	41.74	0.681	73.56	0.773	106.2	1.071
4	44.79	0.635	45.54	0.624	37.98	0.748	44.59	0.637	40.91	0.695	74.05	0.768	110.5	1.029
5	46.13	0.616	45.62	0.623	39.42	0.721	40.64	0.699	41.73	0.681	66.42	0.856	103.3	1.101
6	46.29	0.614	47.55	0.598	40.34	0.704	39.92	0.712	39.51	0.719	68.29	0.832	106.4	1.068
7	46.03	0.617	47.85	0.594	42.26	0.673	40.97	0.694	41.22	0.689	65.86	0.863	102.4	1.11
8	45.89	0.619	48.01	0.592	41.52	0.684	41.3	0.688	41.59	0.683	67.81	0.838	101.7	1.118
9	45.75	0.621	47.57	0.597	42.29	0.672	40.55	0.701	41.32	0.688	64.41	0.883	104.1	1.092
10	46.05	0.617	48.99	0.58	46.07	0.617	38.96	0.729	39.55	0.719	69.63	0.816	113.6	1.00
11	45.52	0.624	49.42	0.575	43.53	0.653	39.08	0.727	42.04	0.676	70.3	0.809	108.1	1.052
12	46.68	0.609	48.52	0.586	42.95	0.662	38.73	0.734	40.85	0.696	68.38	0.831	104.2	1.091
13	46.35	0.613	47.92	0.593	43.44	0.654	38.94	0.73	41.72	0.681	65.79	0.864	103.2	1.101
14	46.1	0.617	48.23	0.589	42.35	0.671	41.01	0.693	42.46	0.669	67.27	0.845	102.7	1.107
15	46.4	0.612	48.6	0.585	42.74	0.665	41.1	0.691	44.64	0.637	66.79	0.851	107.3	1.059
ws_avg	45.91	0.619	47.4	0.6	39.92	0.712	40.74	0.698	40.64	0.699	68.66	0.828	105.3	1.08
srd_avg	46.18	0.615	48.61	0.585	43.51	0.653	39.64	0.717	41.88	0.679	68.02	0.836	106.5	1.067
room_avg	46.02	0.618	47.89	0.593	41.36	0.687	40.3	0.705	41.13	0.691	68.41	0.831	105.8	1.075
return_a	46.38	0.612	53.21	0.534	47.79	0.595	51.71	0.55	54.28	0.524	70.06	0.811	107.8	1.055
U_rm	0.979		0.955		0.887		0.928		0.929		0.924		0.939	
U_ws	0.977		0.954		0.914		0.925		0.943		0.91		0.949	
S_rm	0.046		0.081		0.205		0.146		0.147		0.141		0.113	
S_ws	0.046		0.078		0.117		0.145		0.077		0.14		0.084	

that Case 00 had no workstation and, hence, the air distribution was not affected by office furniture. For Case 00 (no workstation), the average values of the local mean age of air in the workstation and in the surrounding area were 42.8 and 41.3 minutes, respectively. The local mean age of air in the return air duct was 42.9 minutes. The corresponding values for Case 01 (with a workstation) were 46.2, 46.3, and 47.4 minutes, respectively.

The greater age of air for Case 01 than Case 00 could be interpreted as being due to the dead air spaces in Case 01 created by the furniture and partitions. However, a closer examination of the results reveals that such an explanation may be too simplistic. The presence of a workstation could cause a change in the mean age of air in the workstation. Since the outdoor air, supply air, and return air rates were each the same for both cases, a decrease in the mean age of air at one location had to be accompanied by an increase in the mean age of air somewhere else. For example, assuming that the presence of a workstation would prevent the ventilation air from moving from the workstation to its surrounding area (because the supply air diffusers were located directly above the workstation), a decrease in the mean age of air in the workstation would be expected. This would also cause an increase in the mean age of air in the surrounding area. The mean age of air in the return duct would probably be between the two. This was not observed. In fact, the results indicate that the mean age of air increased in all 3 locations uniformly. Such an observation was also true for all other cases.

Furthermore, the air distribution tests (Shaw et al. 1993) suggest that all seven diffuser layouts distributed the ventilation air equally well. Although in theory the mean age of air and, hence, air change efficiency may be a reasonable ventilation index because of the possible error associated with the measurement technique, a small difference, say 10%, in the mean age of air (and, hence, the air change efficiency) may not be sufficient to indicate that one layout would provide better ventilation for a space than another layout. This also suggests that further work is needed to interpret the result.

Ventilation Efficiency The values of ventilation efficiency for the workstation are given in Table 2 and shown in Figure 4 as a function of the average local mean age of air for the workstation. The results indicate that of the seven diffuser layouts tested with the workstation (Cases 01 through 07), two cases had much greater ventilation efficiency (1.22 and 0.97 for Cases 02 and 03, respectively) than the others (ventilation efficiency was typically about 0.57).

To determine the possible reason for the difference, Cases 03 and 07 were examined. Case 03 (similar to Case 02) had one air-light fixture type of supply air diffuser (L2) and one square return air grille (R7). The supply air diffuser was much closer to the contaminant source than other cases (Figure 1). Case 07 had a similar design except that the supply air slot diffuser was replaced with a square

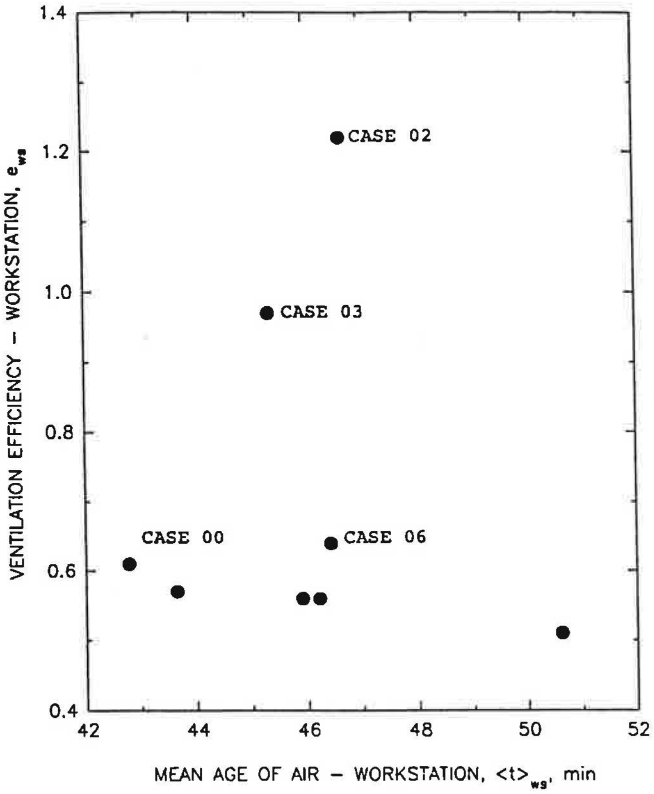


Figure 4 *Ventilation efficiency for the workstation vs. average of local mean age of air within the workstation for cases 00 = 07.*

diffuser (S4). The supply air for Case 03 was discharged in two directions, while the supply air for Case 07 was discharged in four directions. Therefore, for Case 03, about one-half of the supply air was directly discharged into the area where the contaminant source was located, while for Case 07, about one-fourth of the supply air was aimed at the contaminant source. Consequently, although the total supply air rate was identical, there was more air in Case 03 than in Case 07 to stir the contaminant for mixing. As a result, more contaminant was removed through the return air and hence higher ventilation efficiency was achieved in Case 03 than in Case 07.

Figures 5 and 6 show the concentration profiles for Cases 03 and 07, respectively. As shown for Case 03, the concentrations in the workstation, its surrounding area and, the return air were indistinguishable, while for Case 07, the concentration in the workstation was greater than that in the surrounding area and the return air. Also, the concentration profile in the workstation for Case 03 was smoother than that for Case 07, another indication that better mixing was achieved in Case 03 than in Case 07.

Furthermore, similarly to Case 03, Case 04 also had a single air-light fixture type of supply air diffuser. Because the diffuser was further away from the contaminant source, the contaminant source was not directly stirred by the air jets. As a result, the concentration in the workstation was

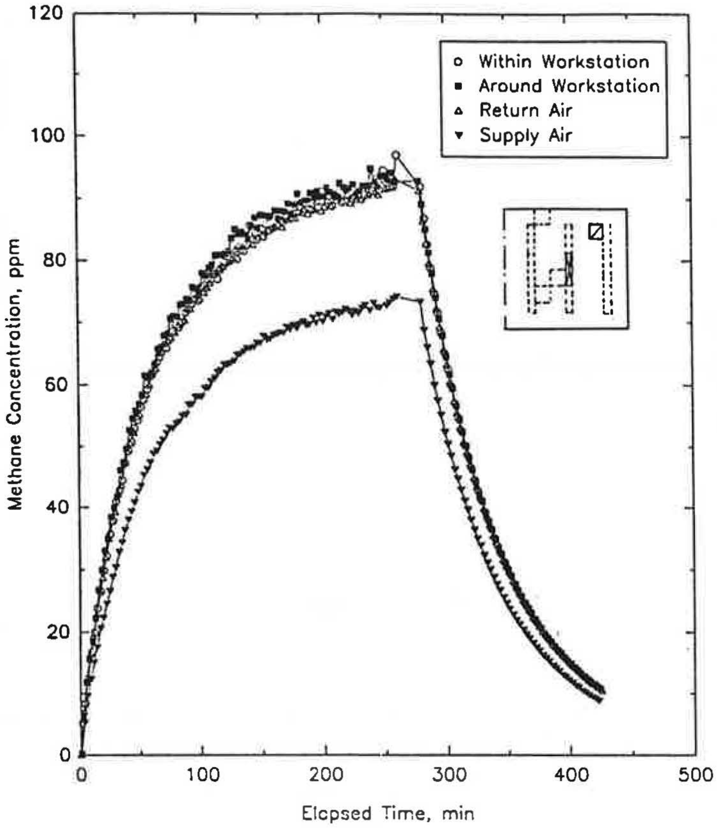


Figure 5 *Contaminant concentration profiles for case 03.*

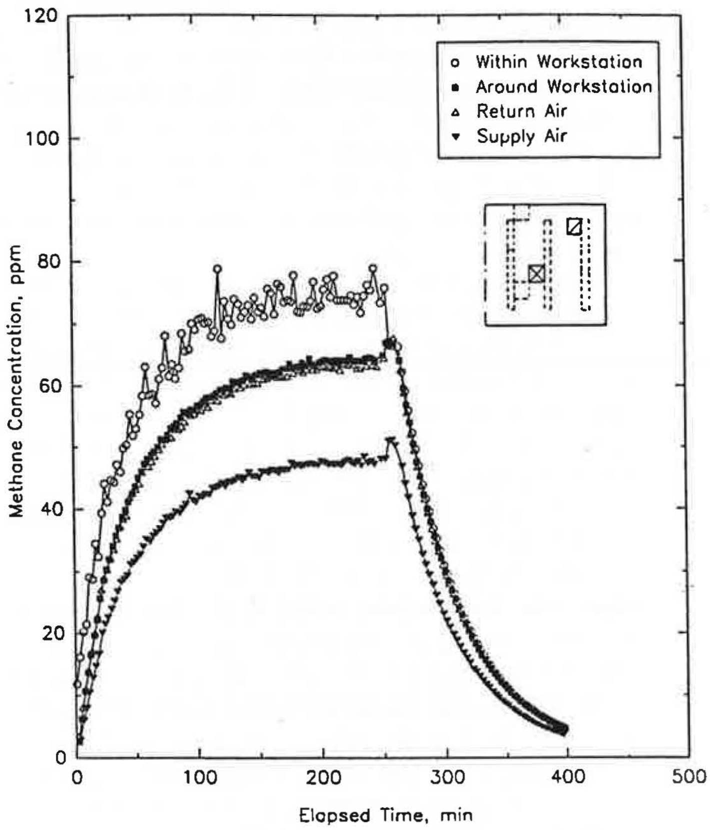


Figure 6 *Contaminant concentration profiles for case 07.*

greater than in the surrounding area and the return air (Figure 7). The ventilation efficiency of Case 04 was, therefore, also lower than that of Case 03.

Effect of Gap Heights at the Base of Workstation Partitions (Cases 01, 07, 08, 09, 10, and 11)

To determine the effects of gap heights on air change and ventilation efficiencies, Cases 01 and 07 were each tested three times, each time with a different gap height. The three gap heights were 152 mm (6 in.), 76 mm (3 in.), and 0 mm. The results are summarized in Table 2.

Air Change Efficiency For the air-light fixture type of diffuser, the air change efficiencies were 0.62 (Case 01), 0.70 (Case 10), and 0.70 (Case 11) for gap heights of 152 mm, 76 mm, and 0, respectively. For square diffusers, the corresponding air change efficiencies were 0.62 (Case 07), 0.60 (Case 08), and 0.71 (Case 09). The results indicated that the air change efficiency could either remain unchanged or increase as the gap height decreased. As the increase was only slightly greater than the uncertainty of such measurements (about 10%, as suggested previously), it may not be sufficient to suggest that workstation partitions with no bottom gaps performed better than those with bottom gaps, especially where the air distribution patterns for the three gap heights were similar (Shaw et al. 1993).

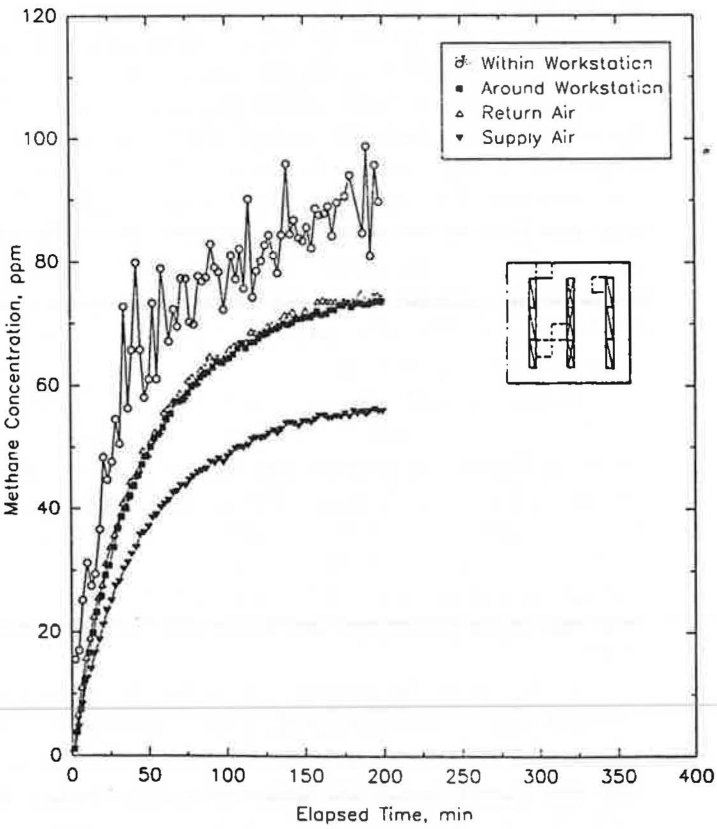


Figure 7 *Contaminant concentration profiles for case 01 (supply airflow rate, 100 L/s).*

Ventilation Efficiency For the air-light fixture type of diffuser, the ventilation efficiencies were 0.56 (Case 01), 0.65 (Case 10), and 0.70 (Case 11) for gap heights of 152 mm, 76 mm, and 0, respectively. For square diffusers, the corresponding ventilation efficiencies were 0.56 (Case 07), 0.53 (Case 08), and 0.60 (Case 09). The results indicate that a workstation with no bottom gap in the partitions had a higher ventilation efficiency than with a 152-mm or 76-mm bottom gap. As air distribution patterns were not affected by gap heights (Shaw et al. 1993), similarly to air change efficiency, the increase in the ventilation efficiency may be insufficient to suggest that workstation partitions with no bottom gaps performed better than those with bottom gaps.

Effect of Supply Airflow Rate (Cases 01, 14, and 15)

To determine the effect of supply airflow rates on the air change efficiency and ventilation efficiency, Case 01 was tested two additional times, each with a different supply airflow rate (the return airflow rate was always equal to the supply airflow rate). The results are given in Table 2.

Air Change Efficiency The air change efficiencies were 0.62 (Case 01), 0.83 (Case 14), and 1.08 (Case 15) for supply air rates of 100 L/s (212 cfm), 50 L/s (106 cfm) and 25 L/s (53 cfm), respectively. Contrary to the general belief that the ventilation provided by a ventilation system deteriorates as the outdoor air supply rate decreases, the results indicate that the air change efficiency increased as the supply airflow rate and, hence, the outdoor air supply rate decreased.

As the supply air rate decreased from 100 L/s to 25 L/s, the outdoor air supply rate decreased from 20 L/s (42.4 cfm) to 5 L/s (10.6 cfm). The nominal time constant (defined as the volume of the test room divided by the outdoor air supply rate), therefore, increased fourfold from 55.7 min to 222.7 min. The average mean age of air for the workstation (Table 3) increased only twofold, from 46.2 min to 105.3 min (the corresponding room mean ages of air for the room were 46.3 min and 105.8 min, respectively). Equation 1 indicates that such a disproportionate increase in the two parameters will lead to a large increase in the air change efficiency.

The results reveal that the air change efficiency failed to show that the ventilation provided by a ventilation system worsened as the supply airflow rate (outdoor air supply rate) decreased. Room mean age of air, on the other hand, appears to be a better indicator than air change efficiency to appropriately reflect changes in supply air rate. The results also suggest that air change efficiency may not be suitable for comparing ventilation systems with different ventilation rates (air change rates).

Ventilation Efficiency Table 2 shows that the ventilation efficiencies were 0.56 (Case 01), 0.67 (Case 14), and 0.84 (Case 15) for supply air rates of 100 L/s, 50 L/s, and 25 L/s, respectively. Similar to the air change efficiency discussed above, these results indicate that the ventilation efficiency increased instead of decreased as the supply airflow rate and, hence, the outdoor air supply rate decreased.

All three cases had three air-light fixture types of diffusers for supply air and six identical diffusers for return air. Since the supply air diffusers extended beyond the full depth of the workstation, the supply air was discharged through two air jets, which, because of the partitions, produced six recirculation airflow cells: two main ones inside and two small ones outside each end of the workstation. As the contaminant moved upward from its source, it merged and mixed with the recirculation flows inside the workstation. Because the size and strength of the recirculation airflow is proportional to the supply air rate, the turbulence and momentum associated with the recirculation airflow would be stronger for the 100-L/s supply airflow rate than the 25-L/s one. As indicated in Figures 7 and 8, because of a stronger turbulence and the workstation partitions, the average contaminant concentration within the workstation therefore fluctuated more rapidly for the 100-L/s than for the 25-L/s supply air rate.

Furthermore, Figures 7 and 8 suggest that the effects of the recirculation flows on the mixing between the

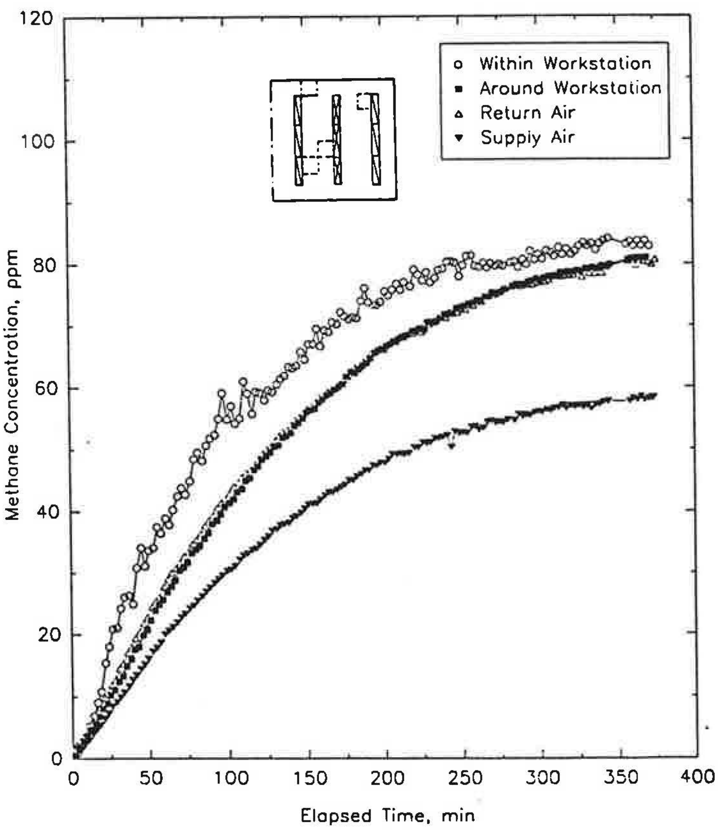


Figure 8 *Contaminant concentration profiles for case 15 (supply airflow rate 25 L/s).*

contaminant and the air in and around the workstation were different, depending on the strength of the air jet. For the 100-L/s supply air rate, the jet penetrated deep into the workstation and the main recirculation flows were strong enough to disrupt the upward motion of the contaminant and circulate it within the workstation for mixing. This air inside the workstation was then distributed to the surrounding area through the HVAC system. On the other hand, for the 25-L/s supply air rate, the jet would not penetrate deeply down into the workstation so the recirculation flows helped promote mixing only near the top of the workstation. Their effect was essentially to sweep the contaminant directly to the return air. As a result, the average contaminant concentration within the workstation was closer to the concentration in the return duct for the 25-L/s supply air rate than for the 100-L/s supply air rate. As indicated in Equation 3, this led to a greater ventilation efficiency for the 25-L/s supply air rate. This is evident from Figures 7 and 8, which indicate that the average concentrations within the workstation approached their steady-state values in about 200 and 300 minutes for the 100- and 25-L/s supply air rates, respectively. They also show that even though the contaminant release rate for the 25-L/s supply air rate was about 50% of the 100-L/s supply air rate, the peak concentrations in the return air and supply air for the two supply air rates were about the same. The results suggest that if the same contaminant release rate were used, the peak contaminant concentrations within the workstation and in the surrounding area would be lower for the 100- L/s supply air rate than for the 25-L/s rate.

For this particular diffuser/grille layout, the results show that the ventilation efficiency failed to indicate the fact that the average concentration within the workstation (or the test room) was lower and, hence, the ventilation was better for the 100-L/s supply air rate than the 25-L/s rate. Similarly to air change efficiency, the results suggest that ventilation efficiency may not be suitable for comparing ventilation systems with different ventilation rates (air change rates).

SUMMARY

Seven different diffuser layouts were compared for their ability to distribute the supply air to a workstation located inside an enclosed room. They were also compared for their ability to remove a contaminant from a source located in the workstation. The results are summarized as follows

For the same supply air rate and gap height, the air change efficiencies differed from design to design by about 10%. Because of the possible error associated with the measurement technique, such a small difference may not be sufficient to indicate that one layout would provide better ventilation for a space than another. The ventilation efficiency was improved for layouts that directed the supply air toward the contaminant source.

The effect of gap heights at the base of workstation partitions on the air distribution patterns was minimal.

For the layout with three air-light fixture types of diffusers for supply air and six identical diffusers for return air, which is commonly used for office buildings, both the air change efficiency and ventilation efficiency decreased as the supply air rate increased. This is contrary to the fact that for a properly designed ventilation system, the ventilation condition improves as the ventilation rate increases. Further work is needed to verify that this conclusion is also applicable for other commonly used diffuser/grille layouts for office buildings. This example suggests that both air change efficiency and ventilation efficiency may not be suitable for comparing ventilation systems with different ventilation rates (air change rates).

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