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EFFECT OF AIR DIFFUSER LAYOUT ON THE VENTILATION CONDITIONS OF A WORKSTATION - PART I AIR DISTRIBUTION PATTERNS

by

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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, this paper, presents the results of air distribution patterns, and the effects of bottom gap heights and airflow rates on these patterns. Part II presents the results of air change efficiency and ventilation efficiency.

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INTRODUCTION

For office buildings with open-floor layout, some workstations may be overventilated and others may be inadequately ventilated, even though the total ventilation (outdoor air supply) rate may be 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. To ensure that every workstation is adequately ventilated, building managers and designers need some guidelines for planning workstation layouts. To develop such guidelines, it is necessary to know the influence of various design parameters, such as the types and design layouts of supply air registers and return air grilles on the performance of a HVAC system in a workstation.

Tests were conducted in one of two interconnected ventilation test rooms to measure air distribution patterns, air change efficiency (or air-exchange efficiency, as used by other researchers), and ventilation efficiency (or contaminant removal efficiency) within and around a mock-up workstation for various layouts of supply air registers (Shaw et al 1991, Skaret and Sandberg 1985). This is the first of two papers reporting the results. This paper 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. A second paper discusses the results of air change efficiency and ventilation efficiency.

TEST SET-UP

Tests were conducted in one of two interconnected ventilation test rooms in a laboratory-office building. As shown in Figure 1, the dimensions of each room are 4.9 m x 4.8 m x 2.9 m high (16 ft x 15.7 ft x 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 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 or 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 x 2.6 m (9.7 ft x 8.6 ft) mock-up workstation was placed inside the test room (Figure 1a). 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 book case, 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, 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 centre 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 centre of the space between the partition and the wall of the test room, and sampling stations 14 and 15 were placed above 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 HVAC system, and the locations outside the test room.

MEASUREMENT METHODS

ASHRAE Standard 62 defines ventilation as "the process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned" (ASHRAE 1989). One direct way of assessing the performance of a ventilation system is to measure the supply air distribution pattern (Shaw et al 1991). Sixteen experiments were conducted. The experimental conditions are listed in Table 1. Each experiment was carried out by injecting a small amount of SF_6 (14 ml) into the supply air duct. Immediately following injection, tracer gas samples were taken (at approximately 4-minute intervals) at 9 locations within the workstation, at 6 locations around the workstation, and in the supply air and return air ducts. The measured tracer gas concentrations of each sampling location were then plotted against time. The time at which the concentrations at all locations reach a single level can be used to assess the effectiveness of a HVAC system in distributing the ventilation air.

RESULTS AND DISCUSSION

Experiments were conducted to determine the influence of various factors on the performance of a ventilation system for a workstation. These factors included types and layouts of supply diffusers, gap heights at the base of workstation partitions, and supply airflow rates. As mentioned in the "Test Set-Up", tracer gas samples were taken at nine locations in the workstation and six locations in the surrounding area. The samples were also taken from the supply and return ducts. The results are discussed below.

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

Tests were conducted on seven supply air diffuser layouts including either air-light fixtures (slot diffusers) or square ceiling diffusers (Figure 1). Details are given in Table 1. One of the seven layouts, Case 00, which included 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.

Figures 3 and 4 show the air distribution patterns with (Case 01) and without (Case 00) a workstation for the base air diffuser layout (three supply air light fixtures and six return air light fixtures). Figures 5, 6 and 7 show the air distribution patterns for three other air diffuser layouts: a supply air-light fixture near the center of the workstation (Case 03), a square supply air diffuser outside the workstation (Case 05) and a square supply air diffuser near a corner of the workstation Case 06. For all the three cases, the return air was through a single grille located near another corner of the workstation. The results indicate that the tracer gas concentrations in the occupied zones inside and outside the workstation were almost indistinguishable. Similar results were obtained for the other two diffuser layouts. No apparent short circuiting between the supply and return air was detected as evident by the fact that the tracer gas concentration in the return duct was either slightly different from or equal to those in the workstation and surrounding area.

The air distribution profiles for the seven diffuser layouts were further compared with that of the base case in Figure 8 in terms of spatial uniformity and relative spread. The uniformity and relative spread of tracer gas concentrations at time t were calculated from the equations,

$$U_{rm}(t) = 2 * C_{std}(t) / C_{avg}(t)$$

and

$$S_{rm}(t) = [C_{max}(t) - C_{min}(t)] / C_{avg}(t)$$

where,

$U_{rm}(t)$ = Uniformity of tracer gas concentration at t;
$C_{std}(t)$ = Standard deviation of tracer gas concentration at t, ppb;
$C_{avg}(t)$ = Average tracer gas concentration at t, ppb;
$S_{rm}(t)$ = Relative spread of tracer gas concentration at t;
$C_{max}(t)$ = Maximum tracer gas concentration at t, ppb;
$C_{min}(t)$ = Minimum tracer gas concentration at t, ppb;
t = Time after the tracer gas injection, min.

Figure 8 indicates that except for Case 01, the uniformity and relative spread of tracer gas concentrations for all diffuser layouts were similar. A close examination of the air distribution patterns (Figures 3 and 4) indicates that the differences in the tracer gas concentrations at various sampling locations were slightly greater in Case 01 than Case 00, but the magnitude was within the measurement error. The results further suggest that all diffuser layouts distributed the tracer gas, and hence the ventilation air, inside and outside the workstation equally well. No evidence was found to indicate that one diffuser layout was better than the others. This further suggests that, for the seven diffuser layouts, the presence of a workstation had no significant effect on the air distribution patterns within and around the workstation.

Effect of Test Room Walls (Cases 01, 12 and 13)

Air-light fixture type diffusers All the above tests were conducted in one test room with the workstation located almost at the centre. The distance between each workstation partition and the nearest test room wall was about 1 m. To determine the wall effect, Case 12 which had the same diffuser layout as Case 01 (see Figure 1) was tested with the wall separating the two test rooms removed. Figure 9 shows the air distribution patterns. As the same amount of supply air was discharged into two rooms of identical size instead of one, the concentrations at all sampling locations were lower than those for Case 01. Except for sampling locations 10 and 11 (both were outside the workstation), the concentrations at other sampling locations were almost identical, indicating that the supply air was well mixed within the workstation. This suggests that the effect of the test room wall on the air distribution pattern within the workstation was minimal.

Square diffusers A second test was conducted with the wall between the two test rooms removed. In this case (Case 13), the supply air diffuser (indicated as S7 in Figure 1) was located outside the workstation and the airflow rates were the same as all other tests. The air distribution patterns as shown in Figure 10 again suggest that the supply air was well mixed within the workstation.

Effect of gap heights at the base of workstation partitions (Cases 01, 07, 08, 09, 10, and 11)

To determine the effect of gap heights at the base of workstation partitions on air distribution patterns, for air-light fixture type diffusers, Case 01 was 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. As an example, Figure 11 shows the air distribution patterns for the gap height of 0 mm (Case 11) (see Figure 4 for the 152 mm gap height). Figure 11 indicates that the supply air was well mixed within the workstation as well as in its surrounding area, suggesting that the effect of gap heights on the air distribution patterns was minimal. Similar results were obtained for the case with a gap height of 76 mm (3 in).

For square diffusers, a similar series of tests was conducted using the diffuser layout of Case 07. A similar conclusion was reached.

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

To determine the effect of supply airflow rates on the air distribution patterns, Case 01 was tested two additional times, each with a different supply air flow rate (the return air flow rate was always equal to the supply air flow rate). The supply air flow rates tested were 100 L/s, 50 L/s and 25 L/s. As an example, Figure 12 shows the air distribution patterns for the supply air flow rates of 25 L/s (the results for the 100 L/s supply air rate is show in Figure 4). The results reveal that the scatter in the measured concentrations increased as the supply air flow rate decreased. For a supply air flow rate of 100 L/s (Figure 4), 20 to 40 minutes would be required for the supply air to be well mixed within the workstation. The mixing time increased to more than 240 minutes for the 25 L/s (Figure 12) supply air rate.

SUMMARY

Seven different diffuser layouts were compared for their ability to distribute the supply air into a workstation located inside an enclosed room. The results, as indicated by the air distribution tests, under the conditions and diffuser/grille layouts studied are summarized as follows:

All diffuser/grille 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. For the seven diffuser/grille layouts studied, no evidence was found to indicate that one diffuser layout was significantly better than another.

With all other test conditions unchanged, adding additional space to one side of the room reduced the amount of supply air to the workstation, but had no significant effect on the air distribution pattern within the workstation.

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 air flow rate decreased.

Further study under field conditions would be needed to confirm these findings for offices with single and multiple workstations.

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TABLE 1 Experimental Conditions

Case No.	Arrangement of Air Diffusers Supply	Return	Work Station	Height Bottom Gap mm (in)	Supply Air Rate 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)
12*	L1,L2,L3	R1,R2,R3,R4,R5,R6	yes	152mm (6")	100(212)
13*	S7	R7	yes	152mm (6")	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)

* With the room divider removed

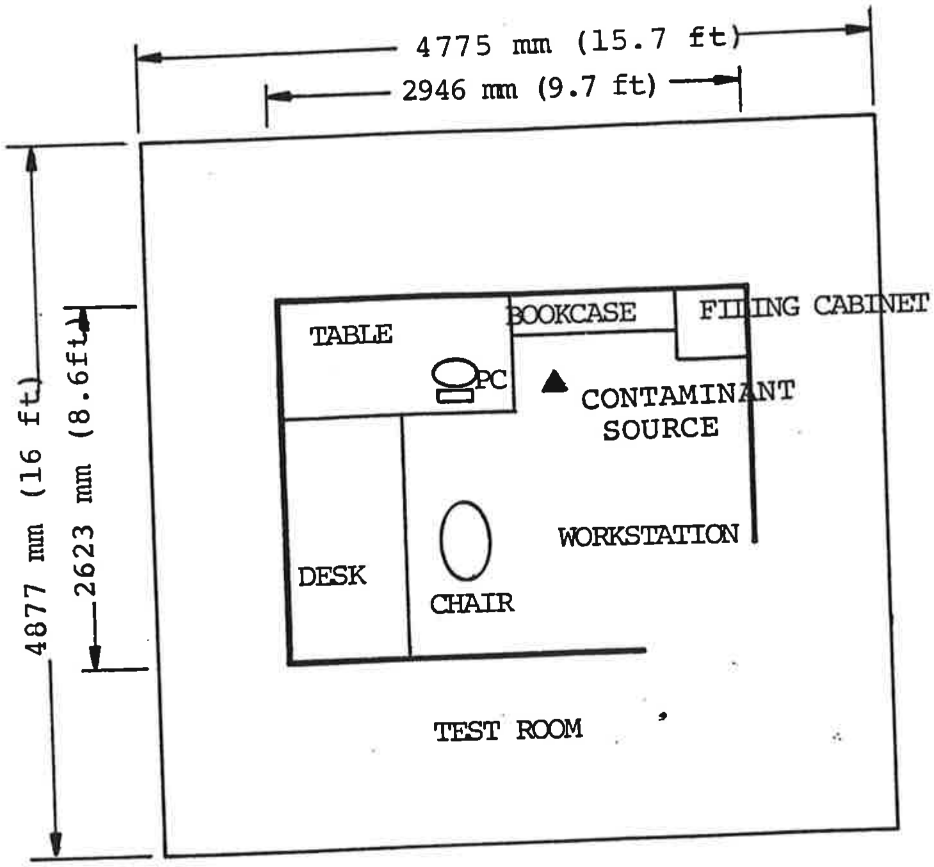


Figure 1 a Layout of Workstation

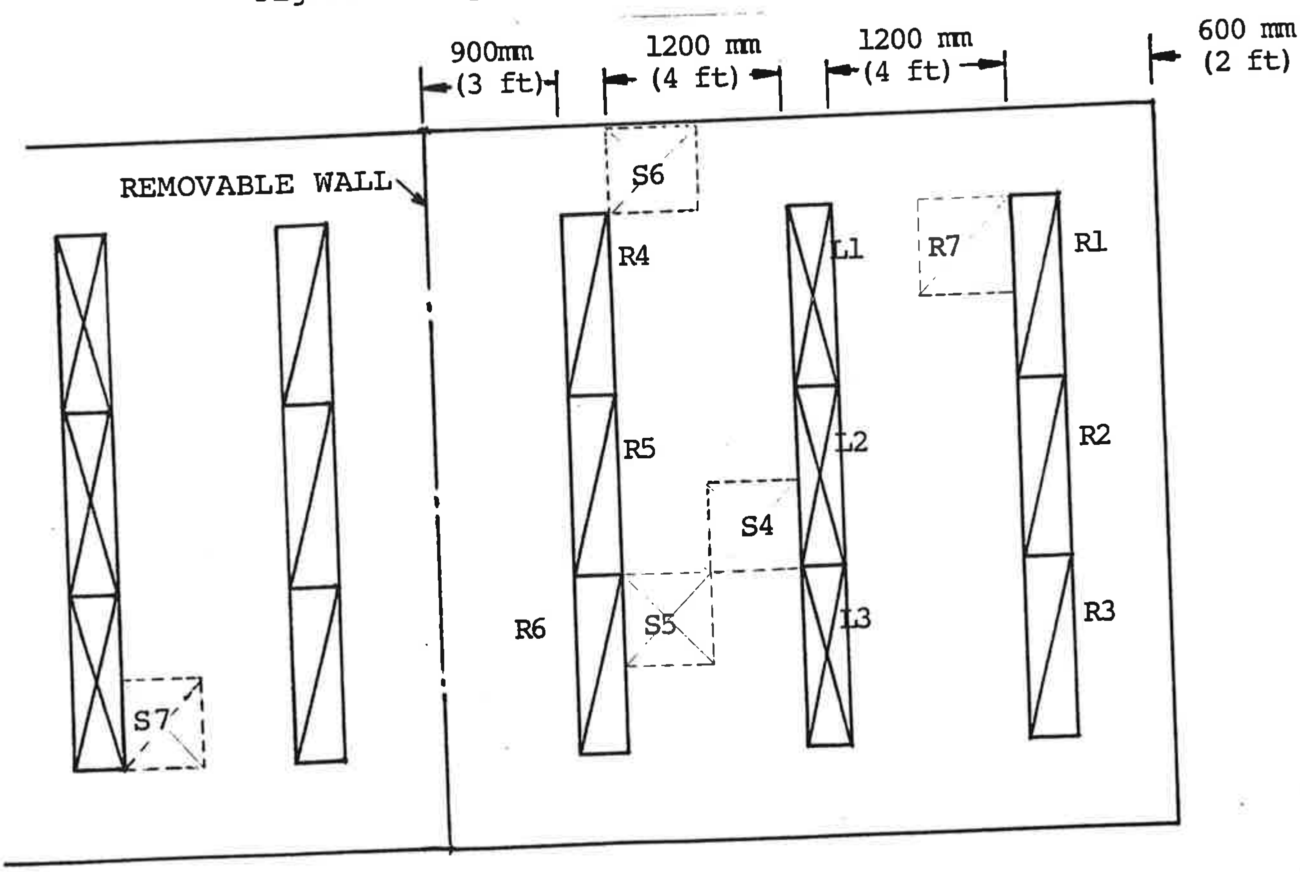
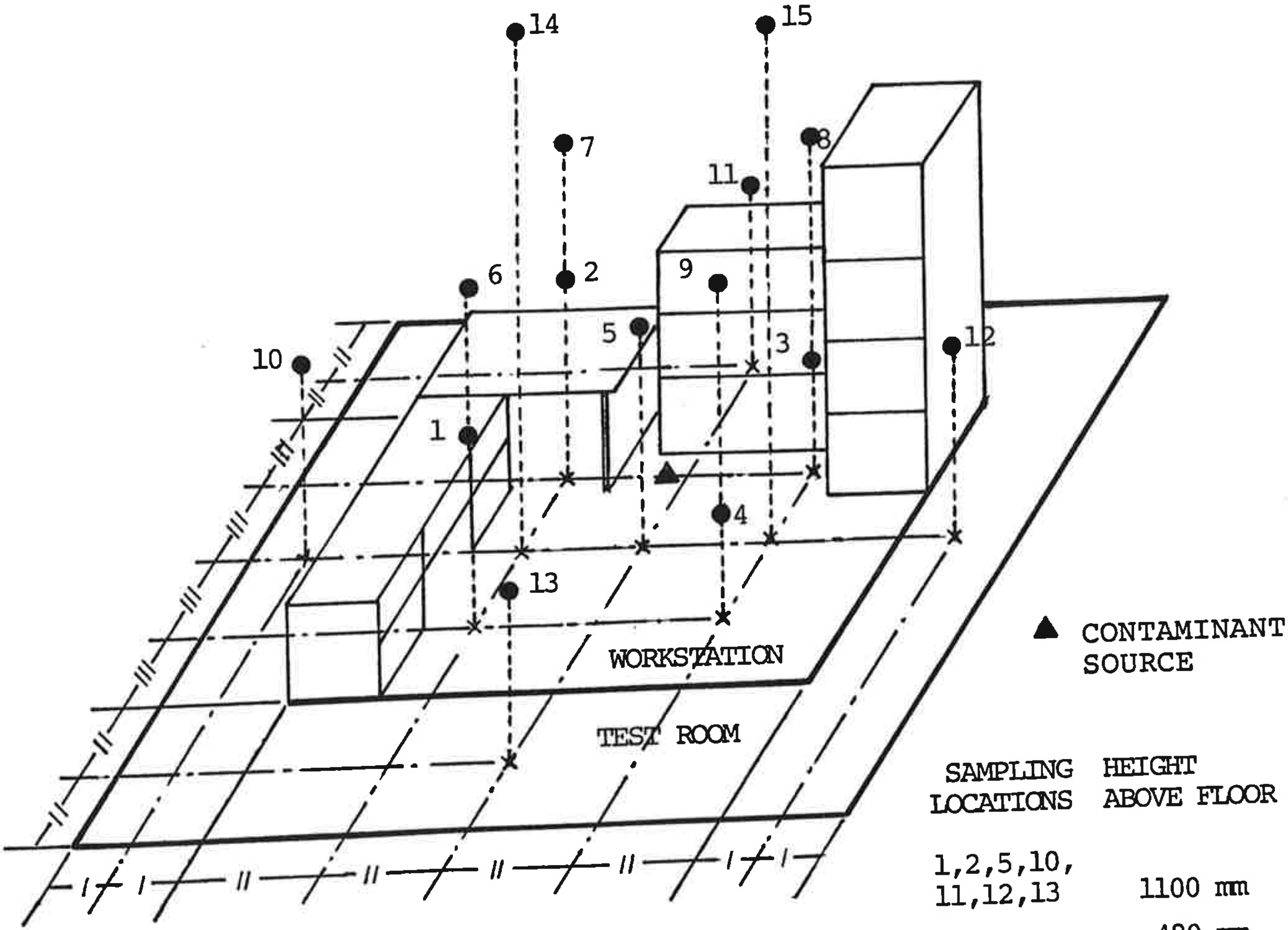


Figure 1b Layout of Supply Air Registers

Figure 1 Test set-up



SAMPLING LOCATIONS	HEIGHT ABOVE FLOOR
1,2,5,10, 11,12,13	1100 mm
3,4	480 mm
6,7,8,9	1440 mm
14,15	2400 mm

Figure 2 Locations of sampling stations

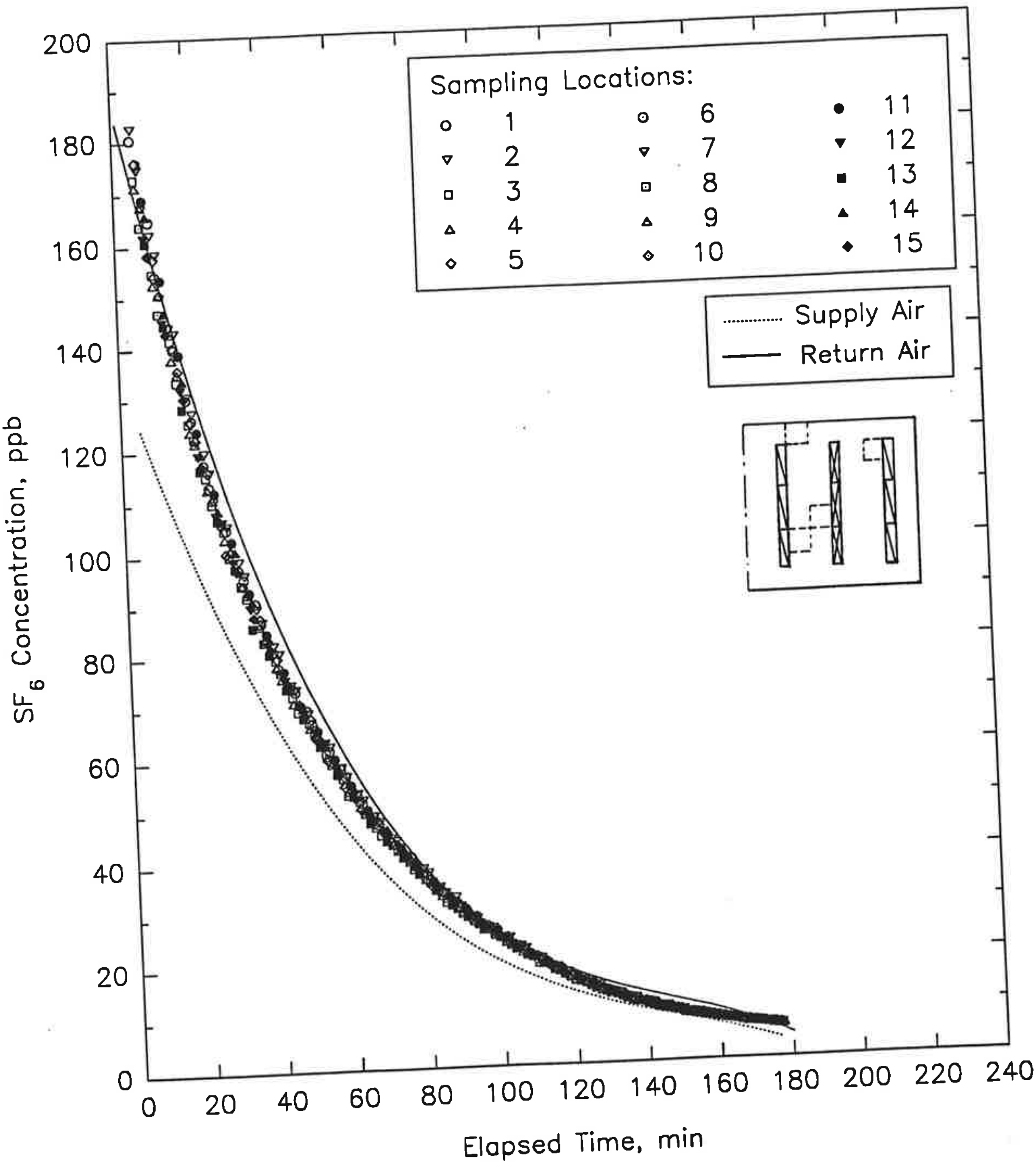


Figure 3 Air distribution patterns for Case 00 (base case, no workstation)

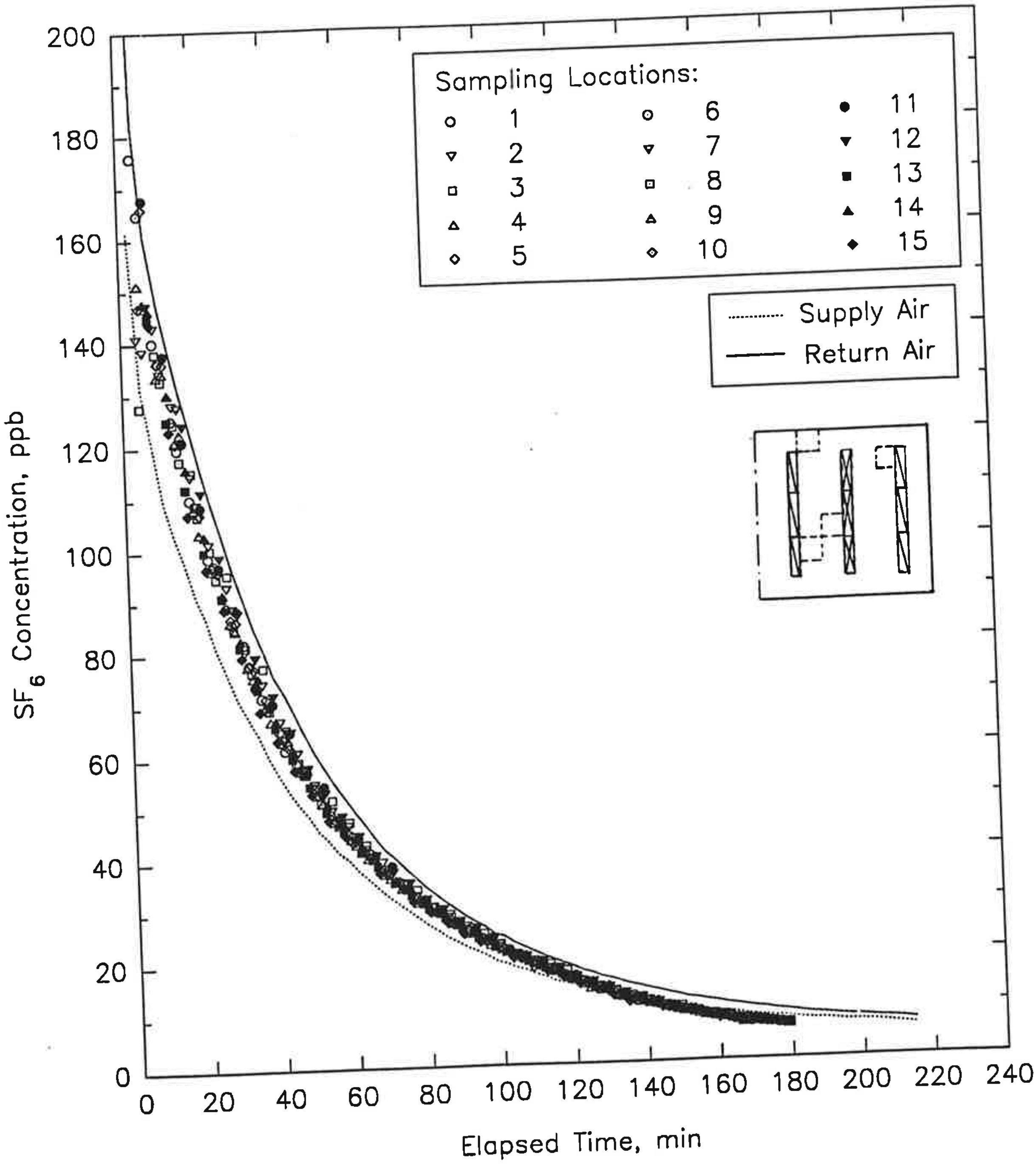


Figure 4 Air distribution patterns for Case 01 (gap height at base of workstation, 152 mm)

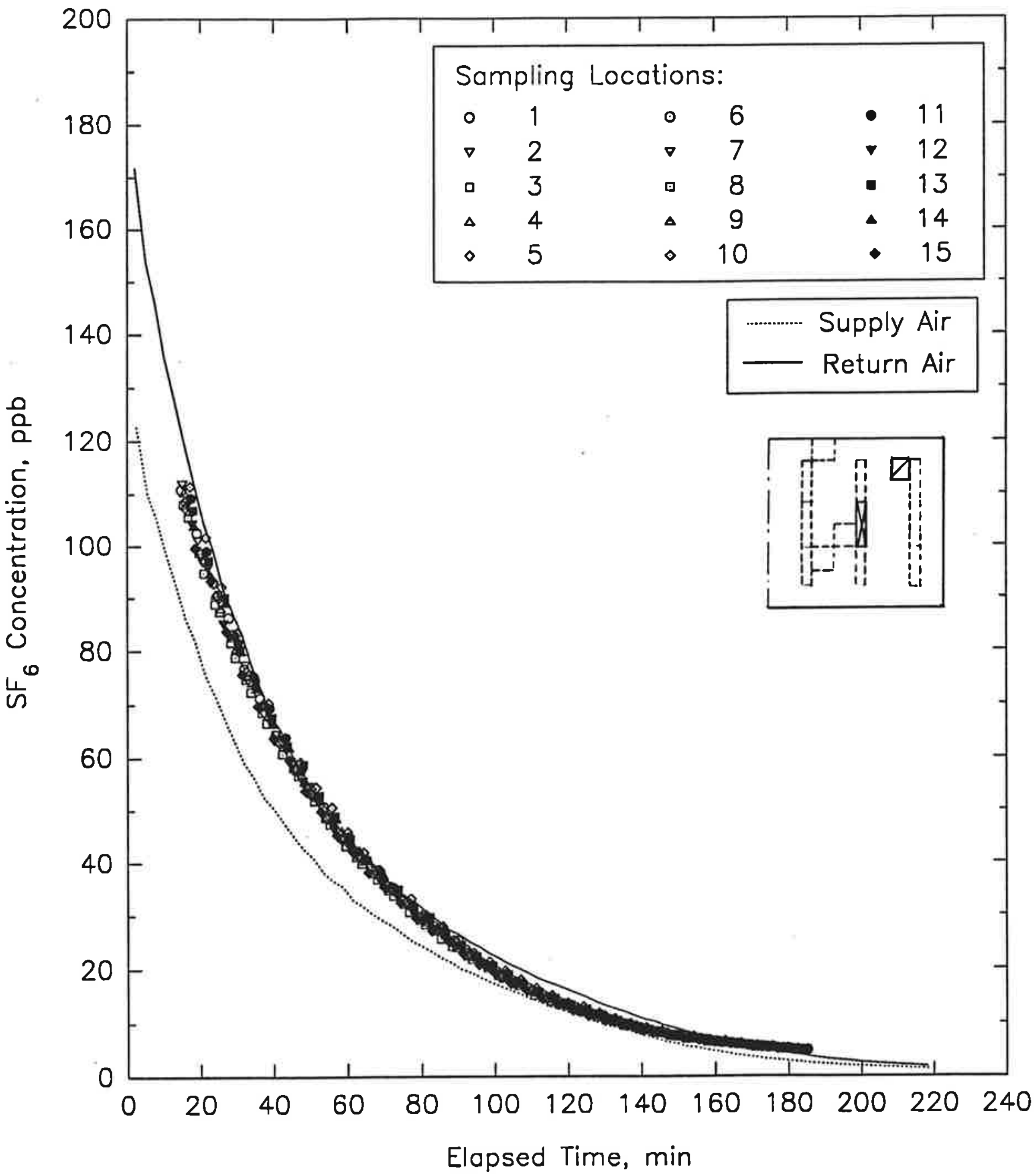


Figure 5 Air distribution patterns for Case 03 (gap height at base of workstation, 152 mm)

r2

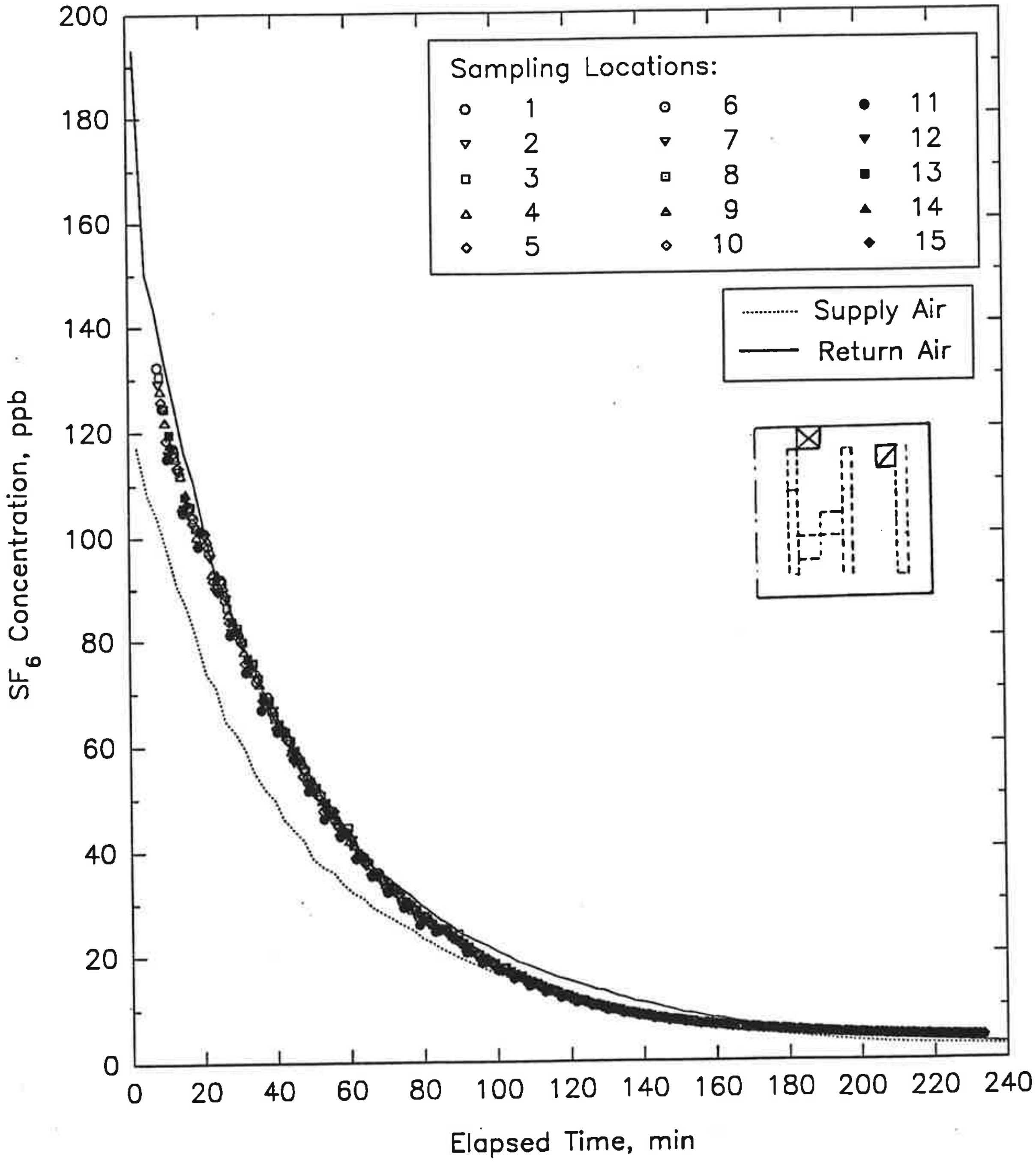


Figure 6 Air distribution patterns for Case005 (gap height at base of workstation, 152 mm)

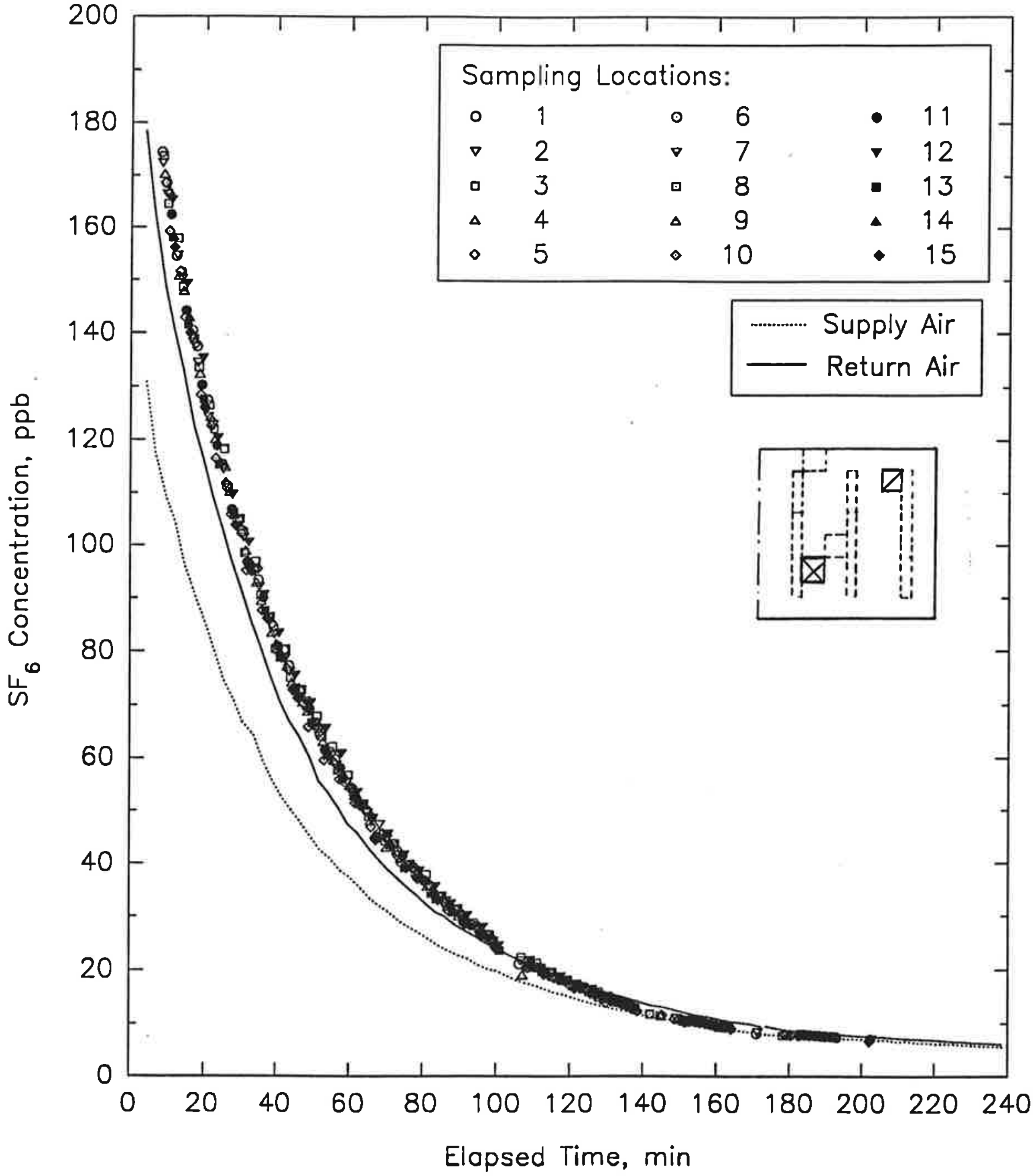
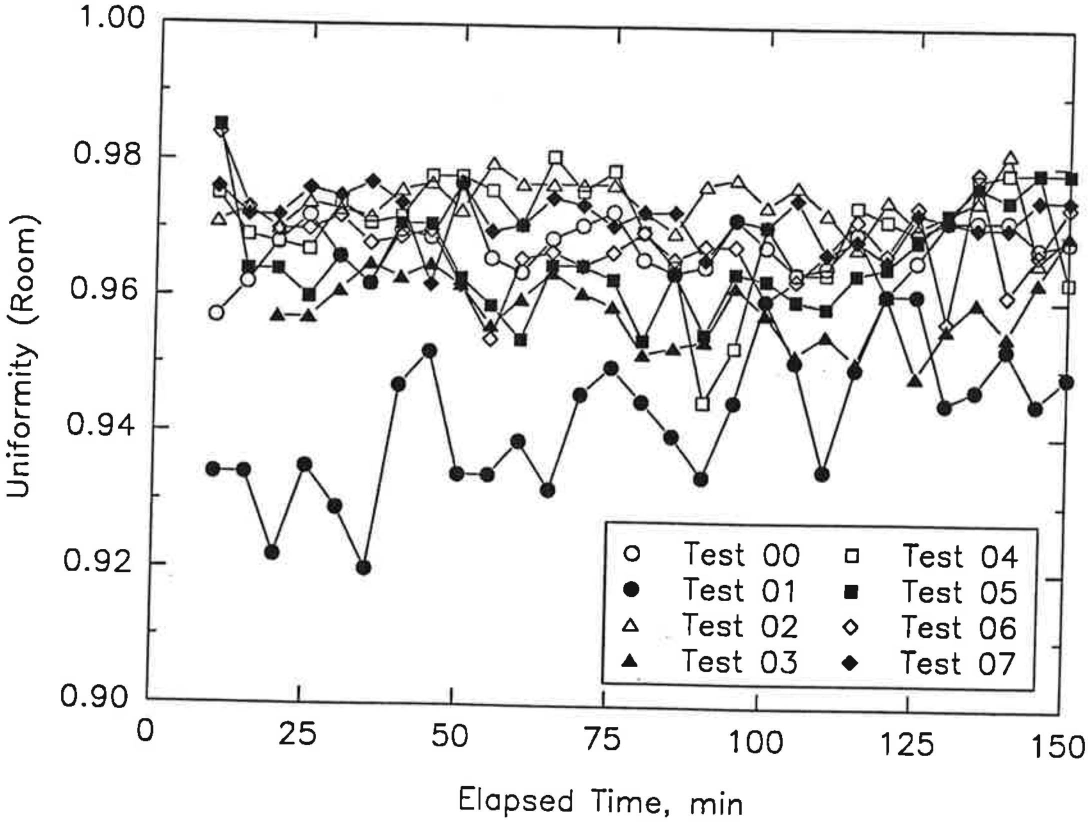


Figure 7 Air distribution patterns for Case 06 (gap height at base of workstation, 152 mm)



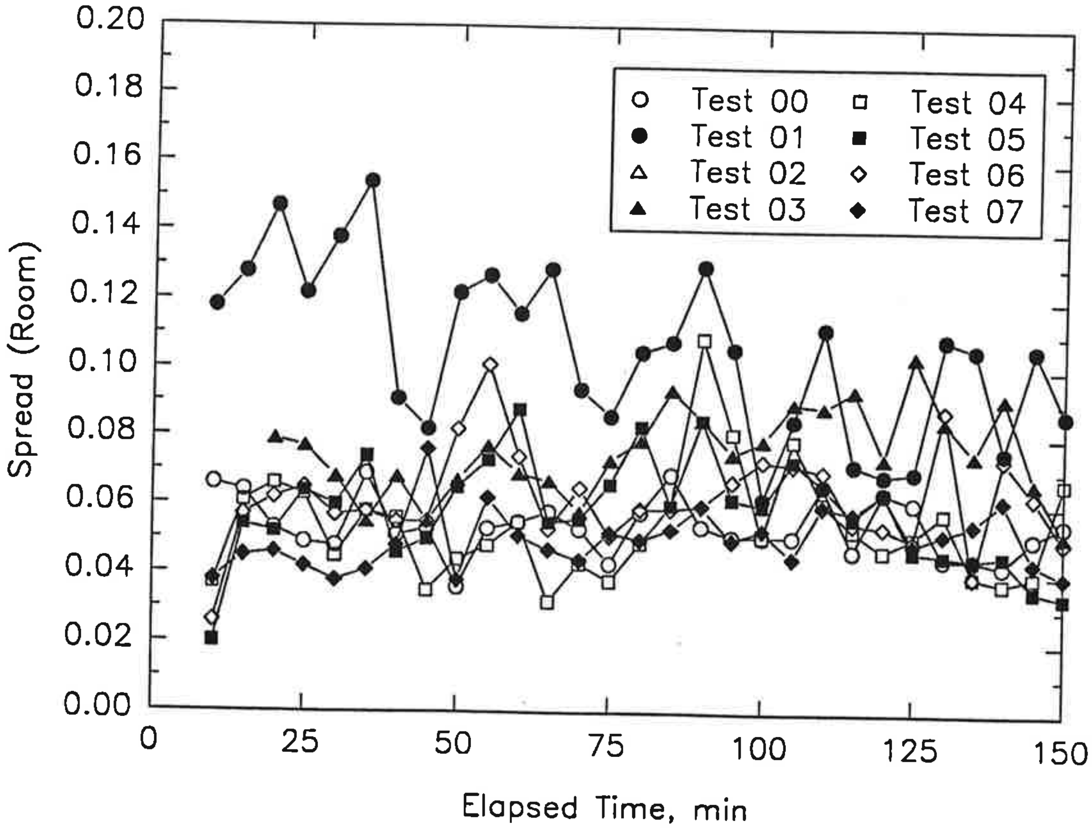


Figure 8 Uniformity and relative spread for Cases 00 through 07

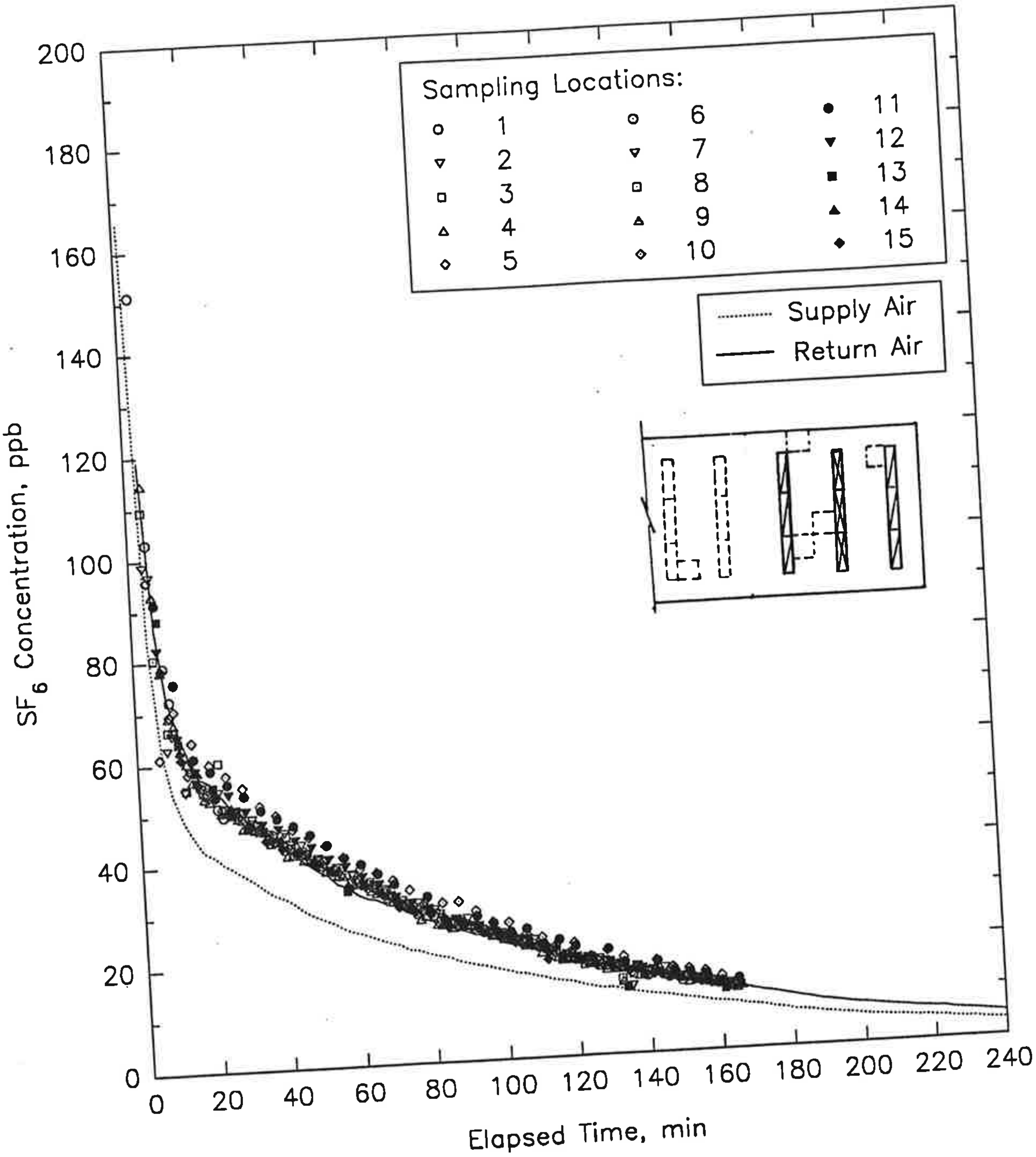


Figure 9 Air distribution patterns for Case 12 with one test room wall removed

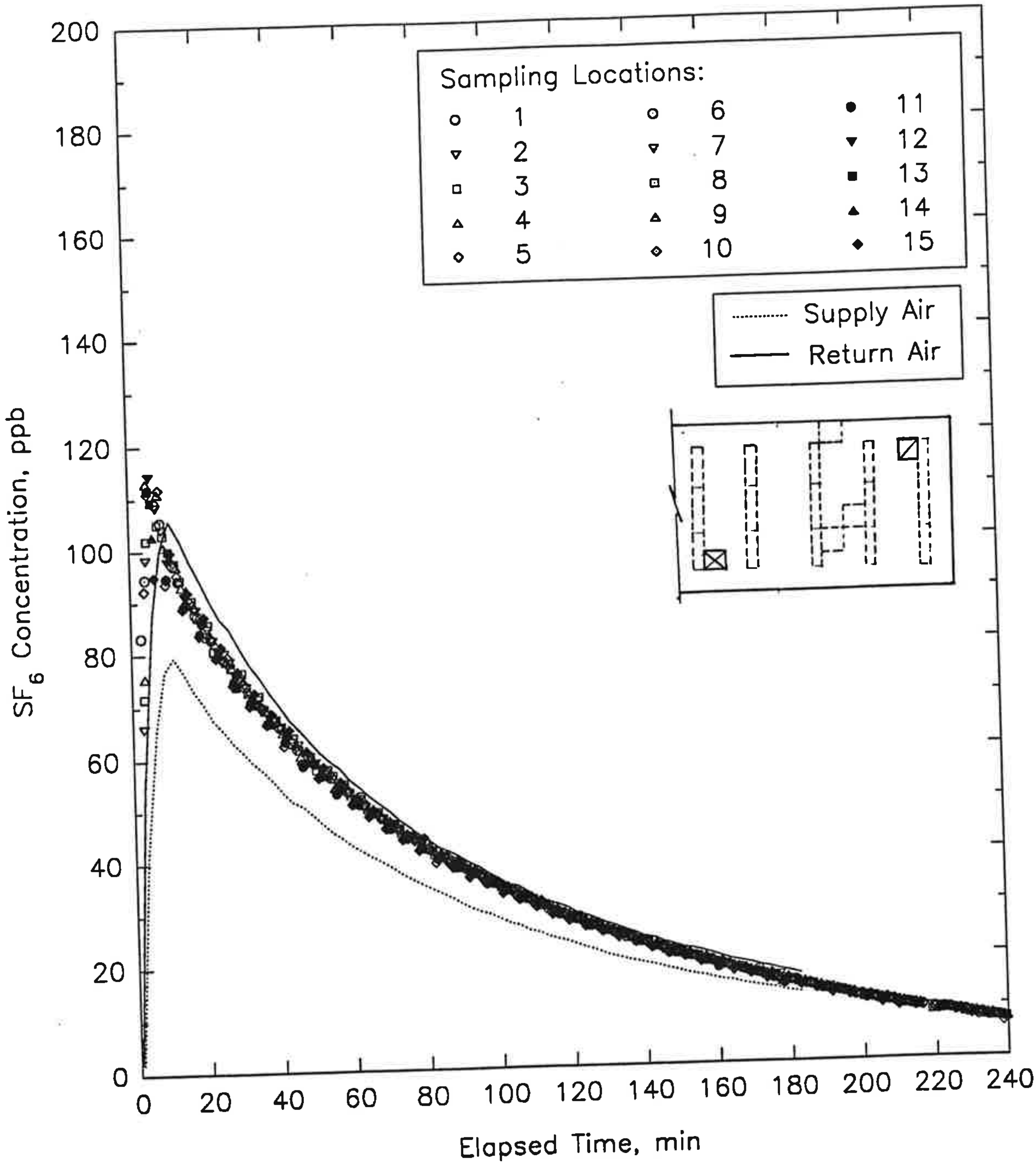


Figure 10 Air distribution patterns for Case 13 with one test room wall removed

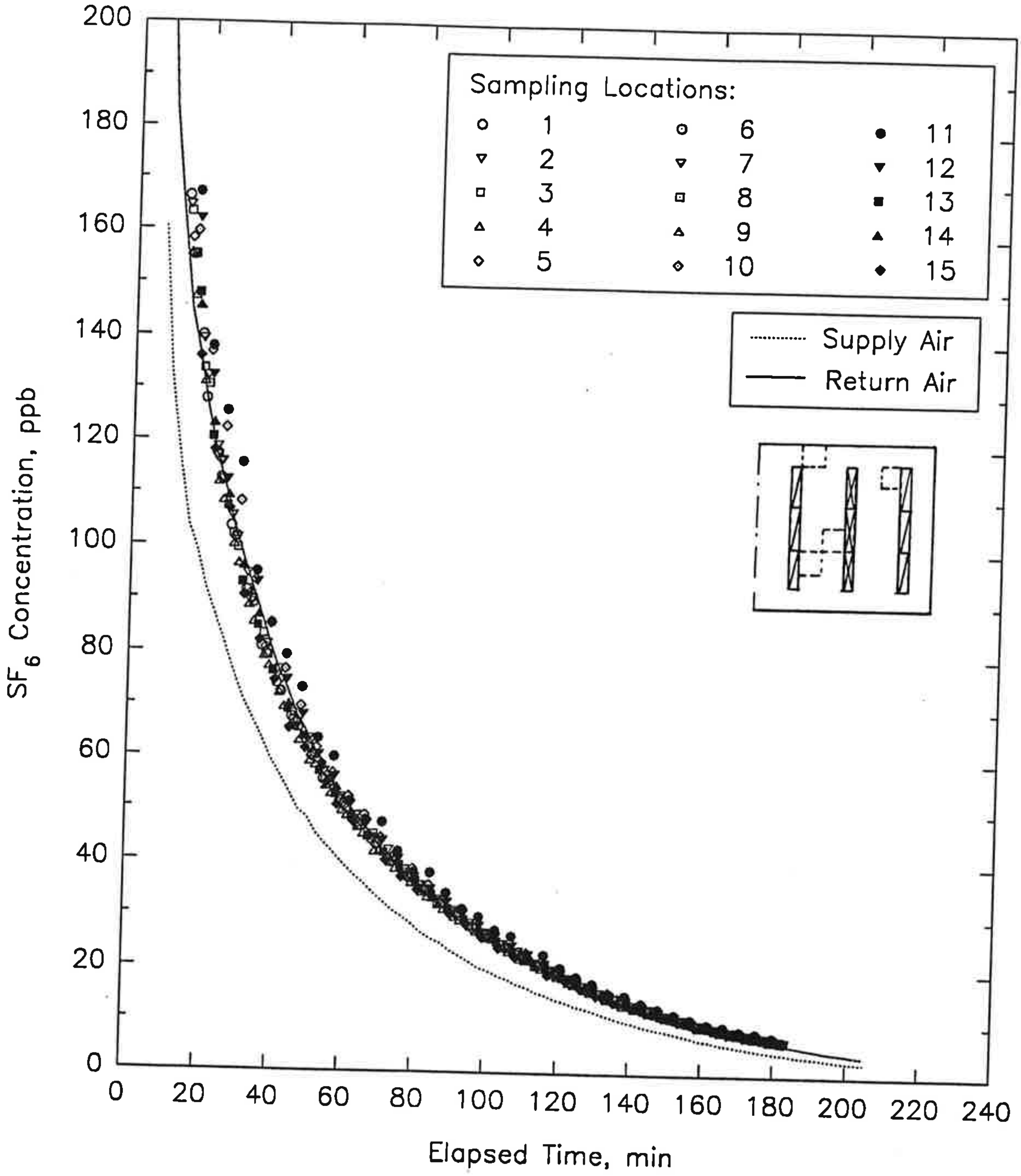


Figure 11 Air distribution patterns for Case 01 (gap height at base of workstation, 0 mm)

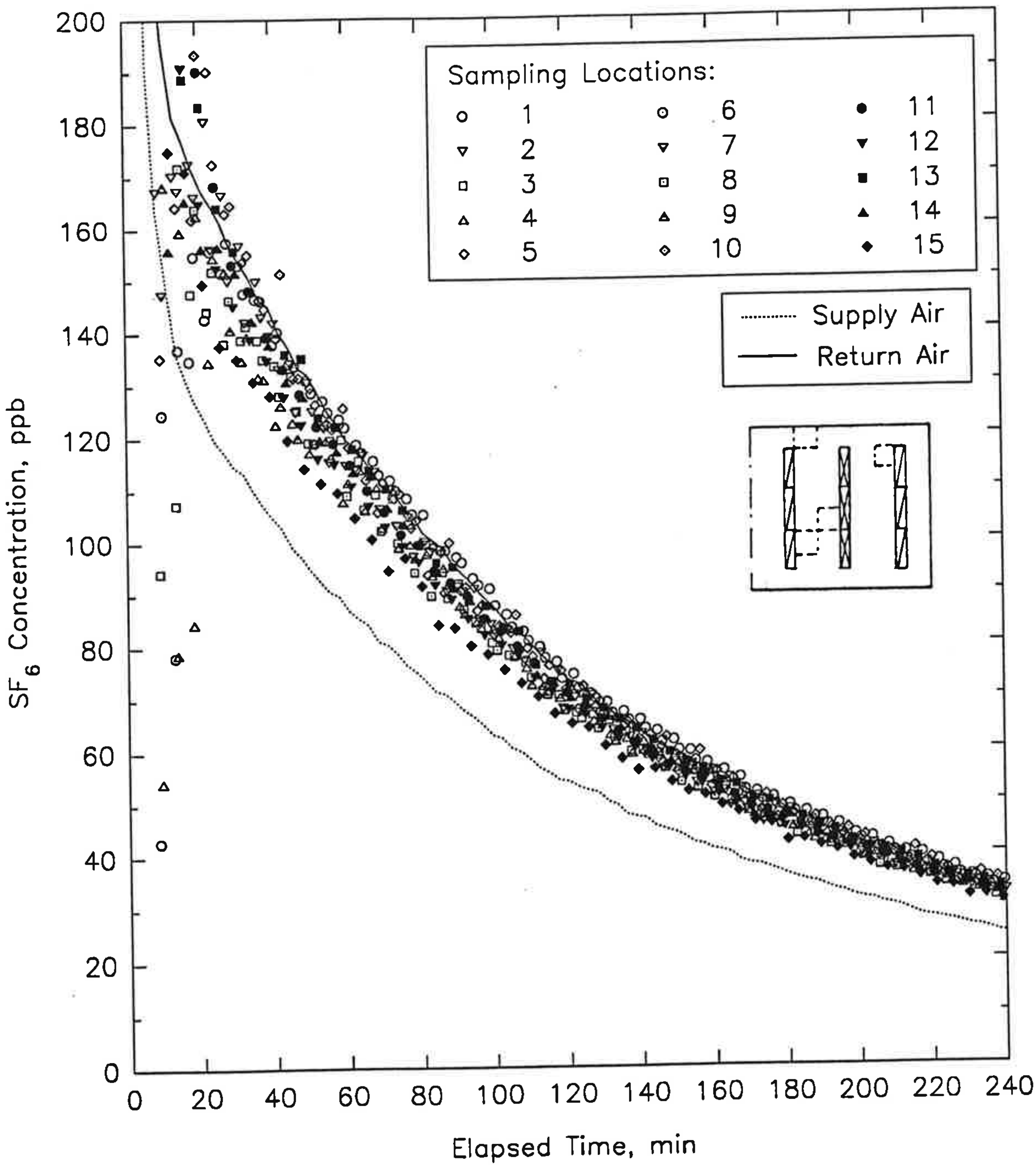


Figure 12 Air distribution patterns for Case 01 (supply airflow rate, 25 L/s)