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Large Indoor Air Test Chamber Characterization

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Abstract

The U.S. Environmental Protection Agency's Indoor Environment Management Branch (IEMB) has designed and installed a state-of-the-art large indoor air quality test chamber in their Research Triangle Park facility. The room-sized (30 m^3) stainless steel test chamber and sophisticated analytical instrumentation will permit characterization of emissions from products and processes that cannot readily be studied using small chambers. Initial experiments have been conducted to evaluate the performance of the chamber, and to evaluate comparability to two other chambers recently built in Canada and Australia. Tests have been conducted that were designed to evaluate critical factors that may influence experiments. These tests evaluated 1) chamber system air leakage rate; 2) the ability of the chamber control system to maintain a wide variety of temperature and relative humidity set points; 3) air speed within the chamber at different flow conditions; and 4) mixing of pollutants at different flow and temperature conditions. Results of these tests show the capabilities of the large chamber system, demonstrate its limitations, and point to opportunities for improving its operation.

Introduction

EPA has been conducting experiments to characterize and understand the behavior of sources of indoor air pollution. Most experiments to date have been conducted in small (53 liter) chambers, in a test house, or with a Field and Laboratory Emission Cell (FLEC). Using this equipment, IEMB has developed a model to estimate the exposures of residential occupants to chemicals from sources and mass-transfer based models describing vapor-phase-controlled (evaporative) emissions from several sources. These models have been verified at the whole-house scale using the test house. Figure 1 shows IEMB's research facilities.

These experimental facilities have provided a good beginning, but they cannot be used to characterize all sources of interest. In order to expand its capability, IEMB has constructed a large (30 m^3) test chamber [1] (see Figure 2). This chamber may operate with any combination of the three following flow modes:

- Mode 1 -- Fresh air flow. Fresh air is cleaned to remove particles and organic compounds, then flows through the chamber and is exhausted outside;
- Mode 2 -- Air from the chamber return is recirculated back into the chamber supply; and
- Mode 3 -- Air from the chamber return is mixed with the cleaned fresh air (if any), sent to the conditioning system for adjustment of temperature and humidity, then recirculated back into the chamber supply.

The chamber is controlled for temperature, relative humidity, flow rate (of all three modes), and pressure using a PID (proportional integral derivative) control system. Flow and pressure are controlled using a system of computer-actuated flow valves and variable-speed blowers. Temperature and relative humidity are controlled by a steam heating coil, a cooling coil, and a steam humidifier contained in a conditioning box in the fresh air and mode 3 (conditioned recirculation) loops, after the mode 3 and fresh air are mixed.

This chamber will allow investigations not possible with other equipment:

- Testing of large sources, such as office equipment, that won't fit in small chambers;
- Very tightly controlled source tests at loading and air exchange conditions similar to those found in a residence;
- Scaleup testing under highly controlled conditions of models developed using small chamber test data;
- Testing of sources where a reduction in wall adsorption of chemicals is important;
- Measurement of emissions during human activities, such as painting or cleaning; and
- Evaluation of source management and control strategies.

Similar-sized chambers have been constructed by others, including the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the National Research Council (NRC) Canada[1]. Large chambers are commonly used by composite wood manufacturers to measure emissions from products used in manufactured housing, in order to meet a regulatory standard set by the U.S. Department of Housing and Urban Development (HUD)[2]. Several commercial testing firms use large chambers of various designs to do product emission testing.

It is critical to understand the characteristics of a large chamber system before conducting experiments in it. This permits researchers to better control experimental conditions, and to differentiate between the behavior of the source being measured and the chamber itself. Chamber characterization also provides a baseline of performance that can be compared between different chambers and used to develop standardized test methods that different laboratories can use to test sources and get reproducible, comparable results. The characterization described in this paper includes tests for leak tightness; temperature, humidity, pressure, and flow control; air speed; and mixing.

The work described in this paper was done primarily to help IEMB understand and improve the functioning of its large chamber system, but it also forms the scoping work for a proposed interlaboratory comparison study[1]. This interlaboratory comparison will be similar to interlaboratory comparisons conducted earlier in small test chambers[3,4].

EXPERIMENTAL METHODS

Leak Test

Chamber system leakage must be checked after construction and after any subsequent maintenance activity that involves disassembling any part of the system (e.g., the conditioning box) to ensure the integrity of the system. A leaky system could cause error in experiments by leaking pollutants emitted from the source to the laboratory space surrounding the chamber or by allowing the infiltration of contaminants from the laboratory space into the chamber, depending on the pressure at the leak point (positive or negative with respect to the laboratory), and the partial pressures of individual compounds.

Leakage was measured by injecting sulfur hexafluoride (SF_6) into the chamber while operating the chamber in a static mode (that is, no fresh air flow, just recirculation), and plotting the logarithm of the SF_6 concentration vs. time. The air exchange rate is calculated as the absolute value of the slope of this line. This air exchange rate was compared to the air exchange rate attributable to the total sampling air flow rate to determine whether there was significant leakage.

Set Point Tests

Set point tests were conducted during commissioning of the chamber in order to understand the behavior of the chamber PID control systems. The variables examined were chamber temperature (T), chamber relative humidity (RH), differential pressure between the chamber and the laboratory space (P), and air flow rates in the supply, return, conditioned recirculation loop (mode 3), unconditioned recirculation loop (mode 2), and exhaust (mode 1). Set point tests were run to determine whether the chamber met design specifications set for these variables (Table 1), and whether it could run in a stable manner at those conditions for a 48 hour period. The PID process control system parameters were adjusted until the chamber conditions came within the specifications. One set of PID parameters was sought that could adequately control the chamber systems across their entire range of set points.

The procedure used for the set point tests was:

1) Start the chamber with set points at the designated temperature, RH, and flow. Conditions were selected to reflect the most common modes of operation as well as the extremes;
2) Allow the system to come to steady operating conditions (usually overnight);
3) Measure all variables for the next 48 hours;
4) Compute maximum and minimum for each variable; and
5) Compare these to the specifications and adjust PID parameters, if needed.

Chamber Air Speed Tests

Air speed is an important variable to control and/or monitor in source characterization experiments, because it can influence the emission rate of some sources. Preliminary measurements of air speed were made approximately 1 cm above the surface of a 4 X 4 ft (1.2 X 1.2 m) wood floor (placed in the chamber for a wood stain test), to determine whether air speeds were comparable to those previously measured in our test house. A 4 X 4 line grid was marked on the floor, and measurements were made over each intersection. Two types of measurements were made:

1) The air speed was measured over one point on the grid overnight to gain an understanding of the stability of the air speed over time, and
2) Measurements were made over each grid intersection to determine the variation and range of air speeds over the floor's surface.

A Bruel & Kjaar hot-wire anemometer with an omnidirectional probe was used for these measurements.

Mixing Tests

Tests were conducted to determine how quickly and how well a nonreactive gas introduced into the chamber's inlet (supply) flow becomes mixed with the chamber air. A three-step approach was used:

1) Stabilize chamber conditions for air exchange rate, temperature, and relative humidity;
2) Dose the inlet stream with a known amount of tracer gas (SF_6); and
3) Monitor the concentration of the tracer gas at the outlet of the chamber until the tracer gas concentration falls below the analytical detection limit.

From these data, maximum concentration, time to reach maximum concentration, and decay rate of the tracer gas were determined. The amount of time that elapsed between the end of the SF_6 injection and the maximum chamber concentration represents the approximate mixing time of the chamber.

If the chamber behaves as a well-mixed continuous-stirred tank reactor, the rise and fall of tracer gas concentration can be predicted from the following equations:

Dosing period:
$$C_t = \frac{K_1\,(1 - e^{-K_2 t})}{K_2 V} \tag{1}$$

where: C_t = SF_6 concentration at time (μg/m^3)
K_1 = injection rate of the tracer gas (μg/h)
K_2 = air exchange rate (h^{-1})
t = time (h)
V = chamber volume (m^3); and

Purging period:
$$C_t = C_0 e^{-K_2 t} \tag{2}$$

where: C_0 = SF_6 concentration before purging starts (μg/m^3)

The results were also evaluated by examining the difference between the air exchange rate as measured by the orifice meter in the chamber's exhaust duct and that calculated from the SF_6 decay. The air exchange rate was calculated as the slope of the logarithm of the SF_6 concentration vs. time.

RESULTS

Leak Test

Results of several leak tests are shown in Table 2. The leak rate varied from 0.0014 to 0.0025 air changes per hour (ACH), which was very close to the total sampling flow rate in these experiments (0.0018 ACH).

Set Point Tests

The large chamber control system met all set point specifications for relative humidity and air flow (see Table 3); however, the temperature did not quite stay within ±0.5°C for the highest and lowest temperature settings. At the 15°C set point, the temperature exceeded the specified ±0.5°C range by +0.1 and -0.3°C. At the 35°C, 45% RH set point, the temperature went out of specification by -0.4°C. At the 35°C, 70% RH set point, condensation occurred in the ducts, making humidity control difficult. Figure 3 provides an example of graphs showing the chamber's behavior at 15°C, 30% RH, 0.48 ACH fresh air, and 4.8 ACH conditioned recirculation, a test that did not quite meet the chamber temperature specification.

Chamber Air Speed Measurements

The results of overnight air speed measurements are shown in Figure 4. They demonstrate stability over time. The measurements taken at the grid intersections across the surface of the floor show some variation (Figure 5), but are all reasonably close to measurements previously made in our test house. Mean air speeds in the large chamber ranged from 5 to 21 cm/s, with a median speed of 19 cm/s, and a mean value of 15.8 cm/s. For comparison, in the test house living room, the mean air speed measured 1.5 cm over a board placed on the floor was 10.1 cm/s (Table 4). Mean air speeds measured near a wall ranged from 1.4 to 56 cm/s with a median of 7 cm/s, and a mean value of 14.3 cm/s. These "near wall" air speeds were taken in conjunction with latex paint testing, so they represent air speeds near the source surface. Figure 6 shows a histogram of air speed measurements made 1 cm from the walls of the test house, and Figure 7 shows a histogram of the air speeds 1 cm from the oak floor placed in the large test chamber.

Measurements of air speed near the chamber walls have not yet been completed. The chamber design and construction are such that high velocities would be expected along the chamber walls. The diffusers currently installed in the chamber are flat, solid steel plates which force the air to flow along the wall surface, which is made of polished stainless steel. If the chamber is used for measurement of source or sink behavior of a wall surface, the chamber supply diffusers will be reconfigured, and the velocity measured and adjusted as necessary to achieve realistic flow conditions.

Mixing Tests

Air exchange rates calculated from the SF_6 tracer gas data are consistent with those calculated from the chamber's orifice plate readings, within experimental error (see Table 5). The uncertainty in the air exchange measurements includes the error in the orifice meter readings, the error in the measurement of the internal chamber volume, and the analytical uncertainty in SF_6 measurement. Table 6 shows the results for a series of individual tracer gas releases during one test.

The theoretical mixing curves shown in Figure 8 demonstrate that the theoretical curve, based on a perfectly mixed chamber, fits the experimental data very nicely.

CONCLUSIONS

The large indoor air quality test chamber is capable of simulating a wide range of indoor conditions. Temperature and relative humidity can be controlled within about ±0.5°C, and 5% RH at normal operating conditions of 23°C and 50% RH . Slight deviations from these ranges occur at the extremes of temperature (15 and 35°C), and condensation on duct walls may be a problem during high humidity operation, particularly at high temperatures. Experience has shown that tight control of the temperature of the laboratory space around the chamber is vital to maintenance of constant chamber temperature when the chamber is operated near room temperature. Measurements of the speed of air movement 1 cm above the surface of a wood floor placed in the chamber are in approximately the same range as measurements taken in the test house. Tracer gas tests have shown that the chamber is well mixed when operated at normal conditions and leak-free.

REFERENCES

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2.Department of Housing and Urban Development (HUD), Federal Register **1984** 24 CFR 3280.308.

3. Colombo, A., DeBortoli, M., and Tichenor, B.A., "International Comparison Experiment on the Determination of VOCs Emitted from Indoor Materials Using Small Test Chambers," Indoor Air '93, Proceedings, Vol.2, pp 573-578. Helsinki, Finland, 1993.

4. Matthews, T.G., Wilson, D.L., Thompson, A.J., et al., JAPCA **1987** 37, 1320-1326.

Table 1 Design ranges and flow conditions.

Parameter	Specification
Temperature	15-35°C ± 0.5°C
Relative Humidity	20-70% ± 5%
Total Air Flow	0.26 - 26 ACH[a]
Leakage Rate	<1.7 m^3/hr
Positive Pressure	0 - 100 Pa

[a]Air changes per hour

Table 2 Results of leak tests.

Flow Regime	Mean leak rate (ACH)	Standard deviation (ACH)	Number of tests
5 ACH unconditioned recirculation	0.0021	0.00075	3
5 ACH conditioned recirculation	0.0023	0.00049	4
Sampling flow only	0.0020	NA	1

Table 3 Set point test conditions.

Test	T (°C)	RH (%)	Fresh air (ACH)	Conditioned recirculation (ACH)	Comments
1	22.8	45	0.5	0	Met all set point conditions.
2	22.8	30	0.5	0	Met all set point conditions.
3	22.8	70	0.5	0	Met all set point conditions.
4	23.2	70	5.0	0	Met all set point conditions.
5	23	30	5.0	0	Met all set point conditions.
6	23	45	5.0	0	Met all set point conditions.
7	15.2	31	5.0	0	Met set point conditions for 12 h, then system shut down.
8	15.2	30	0.5	4.5	Temperature fluctuation beyond specifications (14.2 to 15.6 °C).
9	35.6	45	5.0	0	Temperature slightly out of tolerance (34.1 to 35.2 °C).
10	35.2	70	0.5	4.5	Reached 35 °C but could not maintain it for 48 h.

Table 4 Air speeds measured over a board on the floor of the test house.

Room	Air handler blower	Ceiling fan	Air speed (cm/s)
Living Room	on	no fan	9.9
Living Room	on	no fan	10.5
Living Room	off	no fan	11.8
Living Room	off	no fan	11.3
Living Room	off	no fan	6.9
Den	on	high	62.5
Den	on	low	11.2
Den	on	high	47.8
Den	on	low	8.4
Den	on	off	6.8

Table 5 Mixing test conditions.

Parameter	Test 1	Test 2
Temperature (°C)	15.2	23
Relative Humidity (%)	30	50
Fresh Air Flow (ACH)	0.5	0.5
Unconditioned Recirculation (ACH)	0	0
Conditioned Recirculation (ACH)	4.5	0
Mixing Fan?	no	yes
Difference[a] (%)	4.6	5.3

[a]The Difference is computed as the difference between the SF_6 value and the orifice plate value, divided by the orifice plate value.

Table 6 Air exchange rate from a series of tracer gas releases.

Release	Air exchange orifice plate (ACH)	Air exchange SF_6 (ACH)	Difference[a] (%)
1	0.475	0.499	5.1
2	0.475	0.506	6.5
3	0.475	0.493	3.8
4	0.475	0.493	3.8
5	0.475	0.494	4.0
Mean	0.475	0.497	4.6

[a] The Difference is computed as the difference between the SF_6 value and the orifice plate value, divided by the orifice plate value.

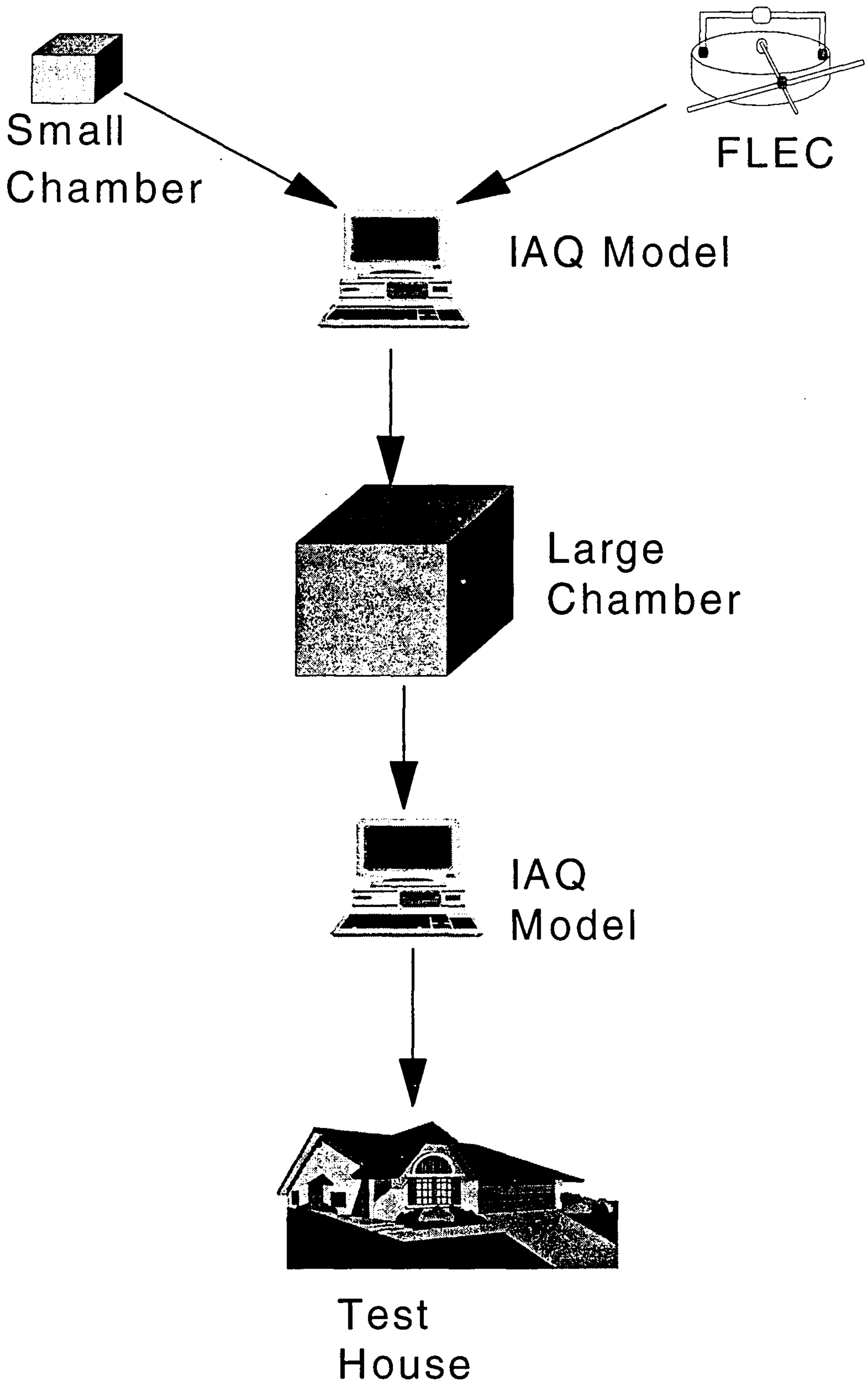

Figure 1 Indoor air quality testing facilities and approach.

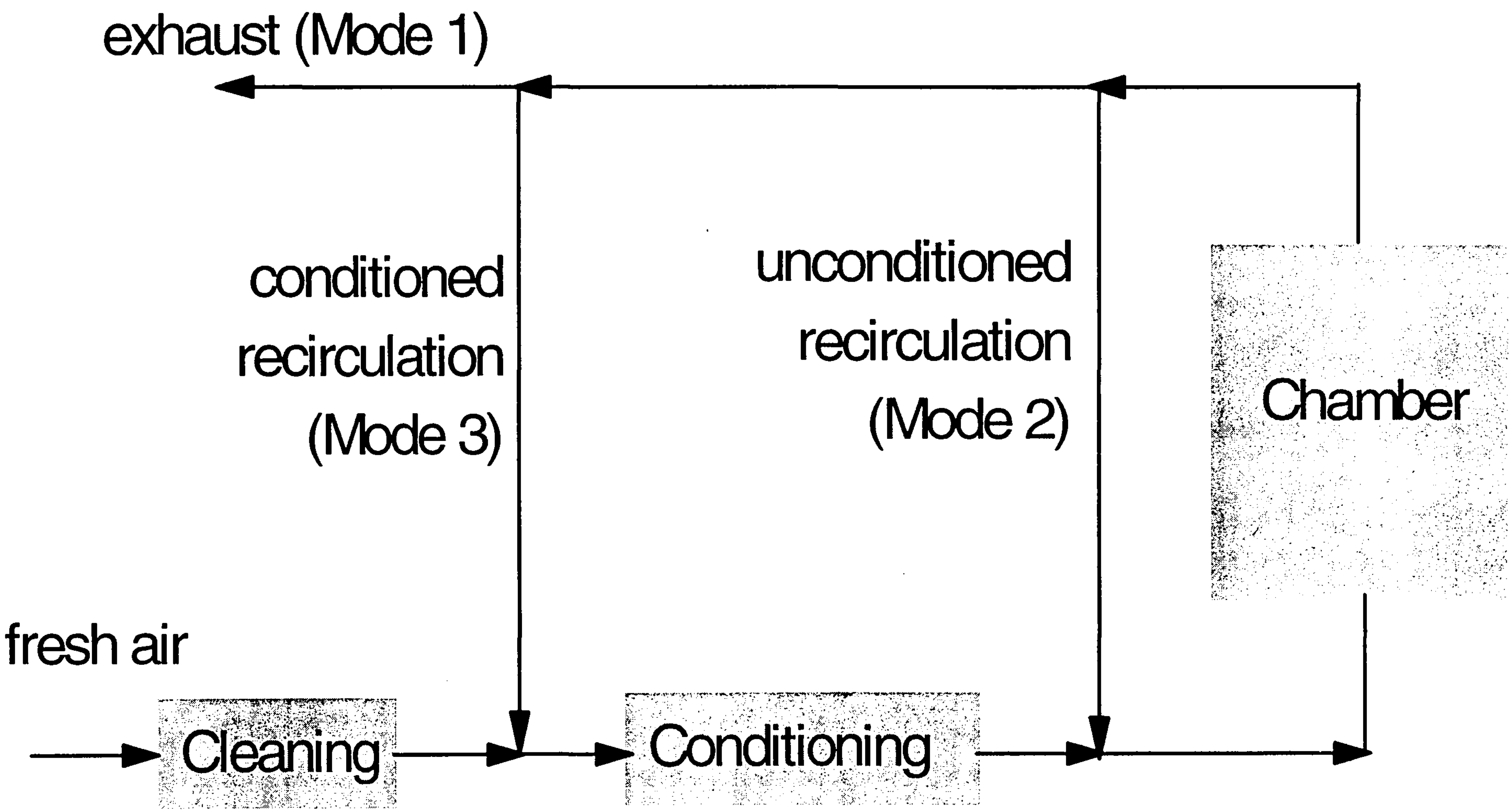

Figure 2 Large chamber flow diagram.

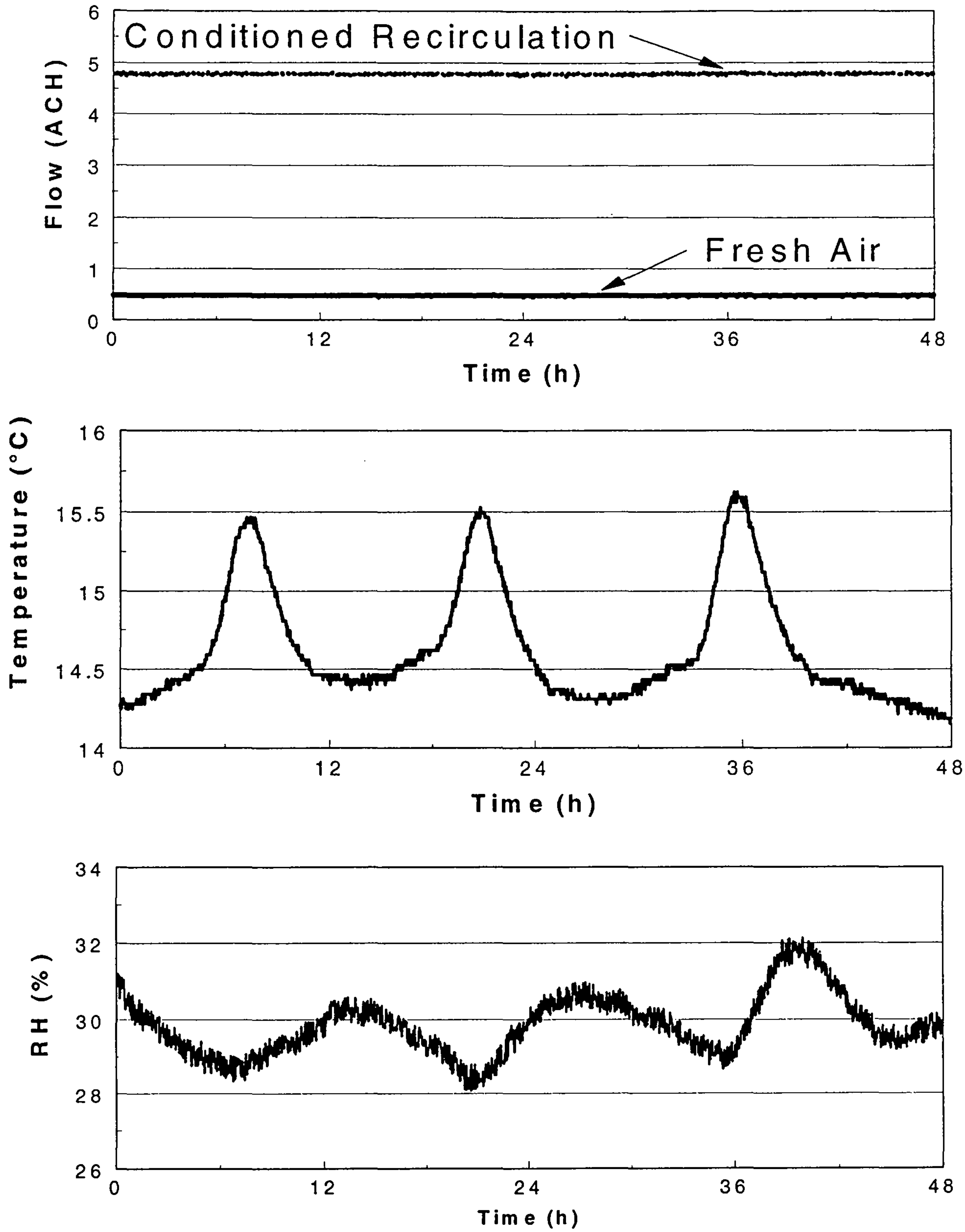

Figure 3 Large chamber control at 15°C and 30% RH.

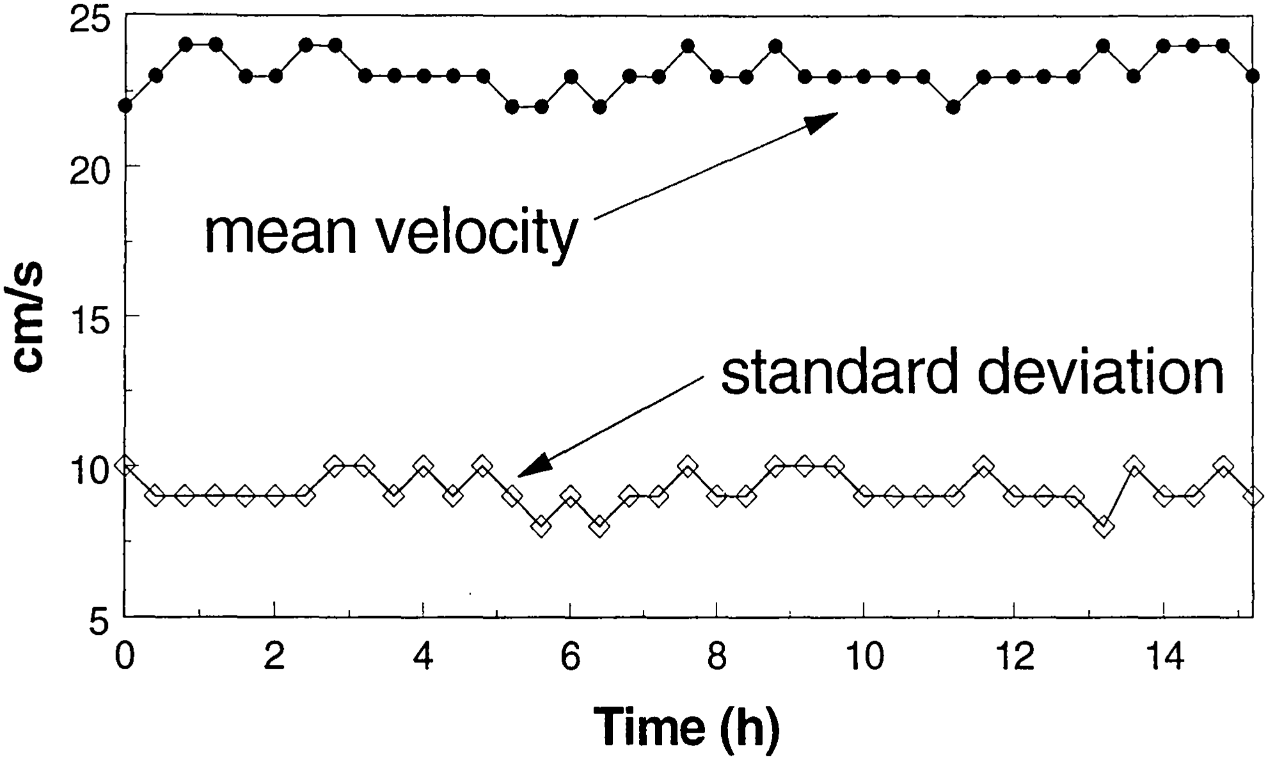

Figure 4 Air speed stability over one point on a wood floor.

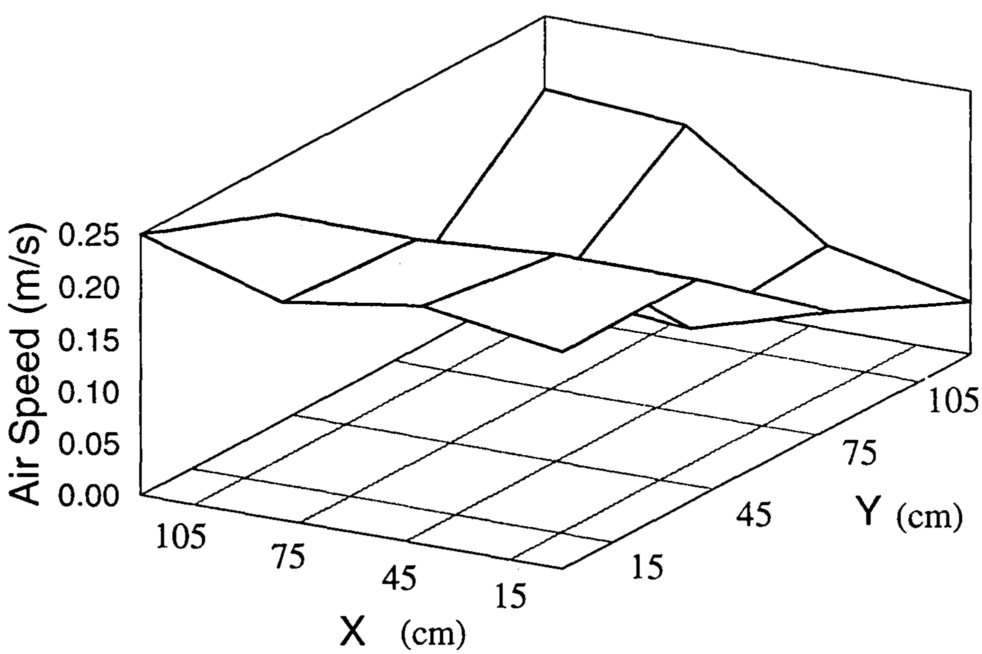

Figure 5 Air speed 1 cm above wood floor placed in center of large chamber floor.

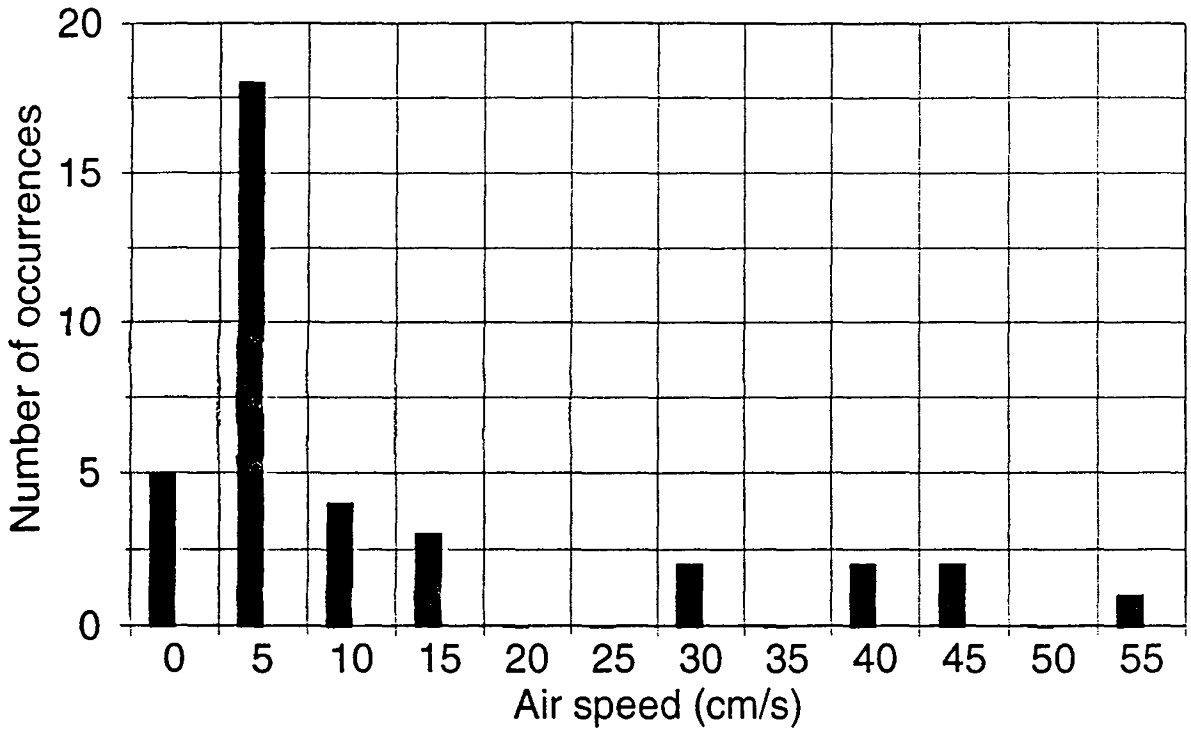

Figure 6 Histogram of air speeds measured 1 cm from test house walls.

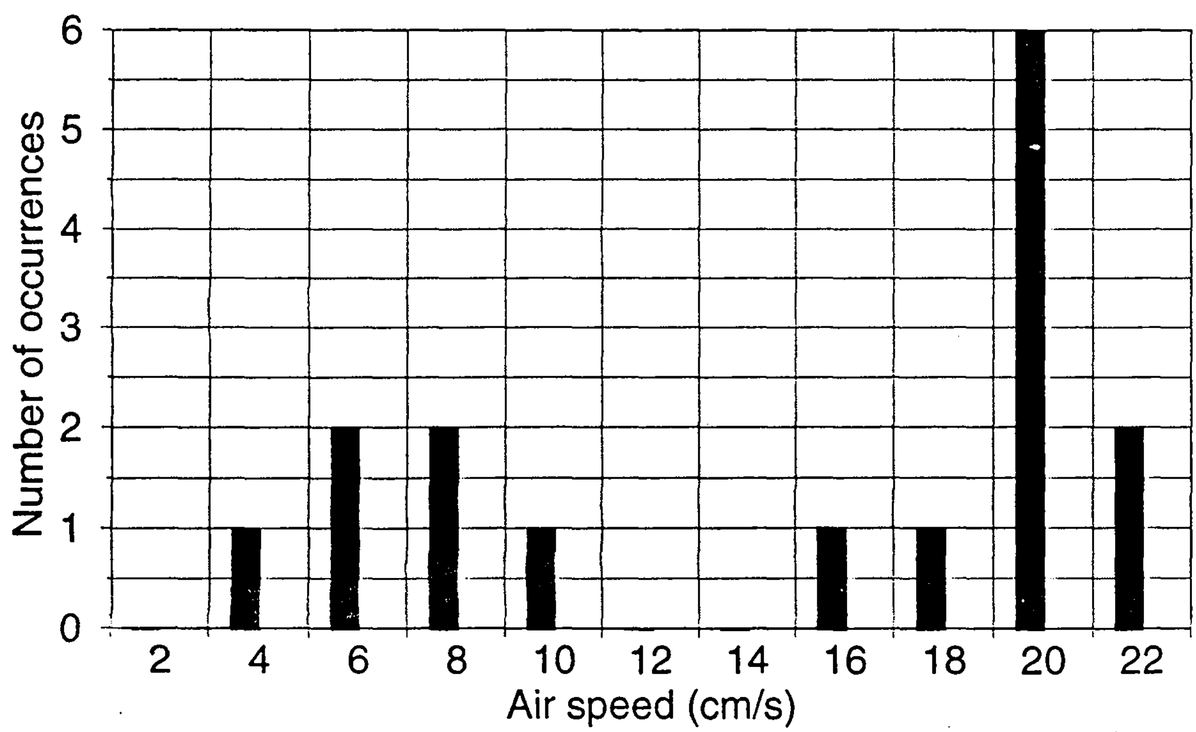

Figure 7 Histogram of air speeds measured 1 cm over wood floor in large chamber.

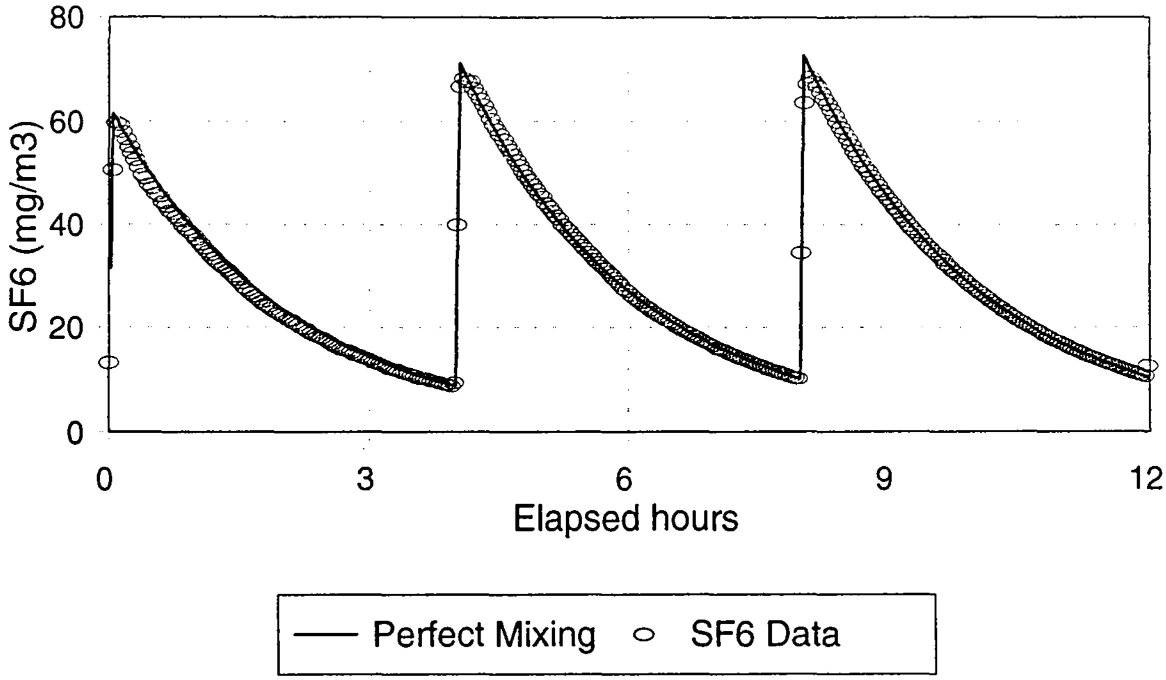

Figure 8 Results of mixing test.

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17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution Test Chambers	Pollution Control Stationary Sources Indoor Air Quality (IAQ)	13B 14B

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