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Air Infiltration Measurements in Large Military Aircraft Hangars

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ABSTRACT: Air leakage measurements by the tracer dilution technique were performed in five military aircraft hangars. The hangars were located in regions of the country having diverse weather characteristics. In several of the hangars, distinct measurements were performed to assess the degree of homogeneity of the air-tracer gas mixture in these large volume structures. Air leakage rates in the range of 0.6 to slightly above 2.0 air changes per hour (ACH) were measured. Surprisingly, these values do not differ significantly from those which might be measured in single-family residences. Since, in use, aircraft hangars often have at least one sliding door open, tracer dilution measurements were performed to show the increase in air leakage to be expected with one and two (oppositely located) doors open.

KEY WORDS: sulfur hexafluoride, tracer gas, infiltration, large buildings, aircraft hangars

Few measurements in large, open buildings have been reported. Freeman et al [*1*] have performed tracer dilution measurements in buildings with internal volumes ranging from 100 to 650 m^3. Their data range from a low of 0.42 air changes per hour (ACH) to a high of 13.2 ACH. The latter number was obtained in a building with all windows open. Waters and Simons [*2*] report measurements on three open factory buildings ranging in volume from 3000 to 4000 m^3. Their data extend from a low of 0.015 ACH to a high of 4.4 ACH. These authors explicitly discuss the problems attendant to good mixing in large, open, internal-volume buildings. Grot and Persily [*3*] report infiltration rates ranging from 0.20 to 0.55 in eight U.S. office buildings with internal volumes ranging from 8800 to 174000 m^3.

Potential reductions in the energy requirements of aircraft hangars have

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been investigated. These investigations suggest that data related to air infiltration rates are insufficient to accurately evaluate many energy conservation concepts. Accordingly, joint investigation was funded by Headquarters Air Force and its Engineering Center and the Naval Facilities Engineering Command to determine the air infiltration rates associated with military hangars.

Two Air Force hangars and three Navy hangars ranging in volume from approximately 24000 to 96000 m^3 were selected for investigation. Measurements in four of the hangars were conducted during winter 1980–1981, while measurements in the fifth hangar were undertaken in summer 1981. Air leakage (infiltration) measurements were performed as per ASTM Method for Determining Air Leakage Rate by Tracer Dilution Test (E 741-80), using sulfur hexafluoride (SF_6) and a portable electron-capture gas chromatograph manufactured by S-CUBED.[3]

The objective of the investigation was to obtain data using existing measurement technology, from which guidelines could be developed for use by engineering personnel when evaluating hangar energy conservation concepts that may be influenced by air infiltration.

Sampling Technique and Data Analysis

Conventional tracer gas dilution techniques achieve initial homogenous gas mixtures by using central ventilation systems, multiple gas injections throughout a building, portable blowers, or all three. Disposable plastic syringes often are used to obtain gas samples. These samples are analyzed to establish that an initial homogeneous mixture of tracer gas and air exists inside a building, as well as to provide samples of time-dependent tracer gas concentration decay. This sampling method is satisfactory [*4–6*] for dwellings and office buildings where ceiling heights seldom exceed 3 to 4 m, where portable blowers or ventilation systems can rapidly mix the tracer gas and interior air, and where gas concentration samples can be obtained with hand-held sampling devices.

Building air infiltration rates can be calculated from data obtained using a tracer gas dilution method by measuring the logarithmic decay rate of tracer gas concentration with respect to time, according to Eq 1 [*4*].

$$V\,\dot{C}(t) + q \cdot C(t) = F(t) \qquad (1)$$

and

$$I = q/V = \left(\frac{1}{t}\right) \log_e (C_o/C) \qquad (2)$$

where we assume C_{initial} is negligible, and

[3]Citing the trade name of the product is not an endorsement by the U.S. Navy but is provided to assist in the traceability of the equipment specifications and performance.

where

V = volume,
t = time,
C = tracer gas concentration at time t,
C_o = tracer gas concentration at time 0,
q = average air leakage rate into the structure, and
I = air change rate (infiltration rate).

A problem commonly associated with the tracer gas dilution measurement method was magnified by the physical characteristics of aircraft hangars. The establishment of a homogeneous mixture of tracer gas and air inside a hangar, with subsequent acquisition of representative samples, is critical if accurate air infiltration rates are to be measured. Hangars are large-volume, high-ceiling, open-bay structures. These characteristics complicate the attainment of an initially homogeneous gas mixture and the subsequent acquisition of tracer-laden air samples. Accordingly, tracer gas samplers were developed that could inject a tracer gas at, or obtain samples from, any height up to 15 m above floor level. They consisted of a pulse pump connected to an approximately 15-m length of 0.635-cm polypropylene tubing. The output from the pump was fed into a Mylar sampling bag. Suspension for the sample lines was provided by overhead cranes, aircraft service scaffolding, overhead aircraft grounding cables, overhead personnel safety cables, or helium-filled weather balloons.

When used in the tracer gas injection mode, the sampler pumps 90 L/h through the tubing. Tracer gas is injected into the tubing on the sampler pump's discharge side. Approximately 20 s is required for the tracer gas to be transported from the pump to the array's discharge point. The pump is operated for 10 min after the tracer gas injection in order to purge the tracer gas from the tubing. Initial testing disclosed that this technique resulted in no contamination of samples due to potential SF_6 retention of the tubing.

Conversion of the array from tracer gas injection to the sampling mode is accomplished by switching the 0.635-cm tubing from the pump's discharge port to its intake port. After a 5-min purge period, the pump's output is reduced to a rate of 4 L/h. During testing, mixing is allowed to occur for roughly 30 min after tracer injection. After this, a 1-L sample bag is attached to the pump's discharge port. The maximum sampling time for a 1-L bag is 15 min. During an air infiltration test measurement period, all gas sample bags are replaced at equal time intervals.

For most of the hangar testing, five samplers were used to inject tracer gas and to obtain samples. The height of the sampling point varied from 40 to 60% of the maximum hangar height and was dependent upon the method used for array suspension. In addition, circulating fans within the hangar were turned on for the duration of the test. No tests were done with the circulating fans turned off. A 1-L sample bag was obtained from each sample point during each time interval. To expedite analysis, in some cases a 2-cm^3 sample was removed by syringe from each bag filled during a common time interval. This effectively mixed each sample and provided an averaged sample for that particular time interval. The overall hangar air infiltration rate was then inferred using the averaged samples from each time interval.

Unlike syringe samples, which are essentially instantaneous, the samplers gathered gas samples over a period of time. To utilize Eq 2 in calculating infiltration rates, the instantaneous value of time used in Eq 2 was replaced by the time at which the sample bag is half full.

For this approach to be valid, the following conditions must be met:

1. Constant sample bag fill rate.
2. Constant sample bag filling intervals.
3. Steady-state condition in the pressure distribution inside and outside.
4. Small change in concentration during sample line transit time.

Hangar Data Acquisition

Naval Air Rework Facility (NARF), Norfolk

Hangar V-147 was selected for evaluation. The hangar possesses approximate dimensions of 120 m long, 48 m wide, and 17 m high with aircraft access doors located across the entire northern and southern ends. The hangar shares its western wall with another hangar that is a mirror image of V-147. Six movable overhead cranes are located on ceiling tracks that provide service to all working areas of the hangar's floor. Closure doors are of the staggered-section variety commonly found in military aircraft hangars. Some air leakage protection is afforded by rubber-boot seals along the base of each door section.

Ambient weather conditions during the test period, 10–11 Feb. 1981, were winds gusting from 8 to 12 m/s from the northwest, with the outside air temperatures decreasing from 1.6 to 0.6°C. The weather station at Naval Air Station Norfolk was used as the source for weather data.

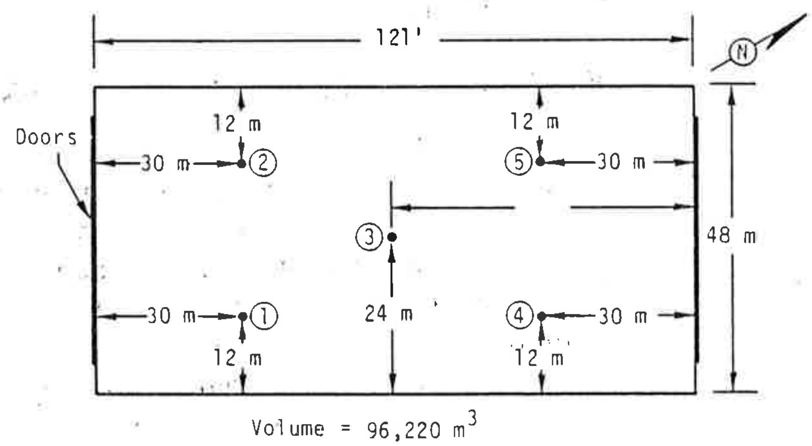
Overhead cranes were used to suspend the five samplers 11.6 m above the floor level. Ten cubic centimeters of tracer gas was injected into each sampler and another 10 cm^3 was injected at floor level in the general area of each of the five samplers. The tracer gas was mixed with the air inside the hangar by using the hangar's unit air circulating heaters.

These heaters, which were located in the ceiling near each sampler, circulated large quantities of warm air that easily could be felt at floor level. Gas samples were taken from the bags and from floor level syringes. A summary of the data obtained from Hangar V-147 is presented in Table 1. All times shown are elapsed times at a particular sample location. Samples were taken contemporaneously. Blanks in the table indicate that a sample from a particular location was not individually analyzed, generally due to time pressures

TABLE 1—*Air infiltration data for Hangar V-147, NARF Norfolk, VA.*

	SF$_6$ Concentration, ppt											
	Sample Bags[a]						Syringe Samples[b]					
Elapsed Time, min	1	2	3	4	5	Average[c]	1	2	3	4	5	Average[c]
0	820	748	757	848	739	802	857	730	793	802	767	790
15	...	...	...	...	...	580	...	...	...	...	...	...
30	...	...	...	...	...	405	...	...	...	...	...	...
45	325	263	271	317	217	279	317	249	302	310	256	287
60	...	...	...	...	...	176	...	...	...	...	...	...
ACH[d]	1.23	1.39	1.37	1.31	1.34	1.41[e]	1.32	1.44	1.29	1.27	1.46	1.35

[a]11.6 m above floor.
[b]Floor level.
[c]This is a physically averaged sample as described in section entitled, "Sampling Technique and Data Analysis."
[d]Air infiltration rate.
[e]Calculated over same interval as syringe samples.



on the experimenters. Raw concentrations are shown so as to provide a more complete description of the spatial and temporal evaluation of tracer concentration within large open structures. A comparison of the results from the floor level syringe samples (instantaneous) and the ceiling level bag samples (time-dependent) showed that both sampling methods produced similar results; the maximum variance at any one point was 9%. The difference in the air infiltration rate measured by syringe at floor level and sample bags at 11.6 m was 0.06 ACH, or slightly less than 5%.

Minot Air Force Base (AFB), North Dakota

Hangar 867, a B-52 maintenance facility, was selected for evaluation. The hangar is approximately 61 m wide by 40 m long with a maximum height at the roof peak of 15.8 m. All exterior surfaces were insulated. There are no seals installed on the hangar aircraft access doors. Cracks as wide as 3.75 cm exist between the door panels. A large hole, which allows the tail of a B-52 to protrude from the hangar, is located at the center of the hangar doors. A canvass drawstring seal is used to seal the space between the B-52's tail and the hole. Hot-air unit heaters are suspended from the ceiling at a height of 8.5 m. Canvass ducts are attached to the heaters to direct the heated air to floor level. Aircraft access doors are located only on the northern side of the hangar, with smaller vehicle access doors located on the southern side.

Weather conditions were measured by the base facility at the Minot Air Force Base (AFB). Tests were conducted on 19 Feb. 1981, during which the wind speed decreased from 8 to 5.8 m/s from the northwest. The outside air temperature increased from 4.4 to 7.8°C.

Overhead cranes were used to suspend two samplers, and movable aircraft service scaffolds were used to suspend the remaining three samplers. The sample point height was roughly 6 m above floor level.

Five cubic centimeters of tracer gas was injected into each sampler and dispersed at the 6-m level within the hangar. Another 5 cm^3 was injected at floor level in the vicinity of each sample point and at each corner of the hangar.

Strong drafts were noticeable throughout the hangar. These drafts arose from wind blowing through the numerous cracks between the hangar door panels and around the protruding B-52 tail assembly. Twenty minutes after the initial injection of SF_6 only minute traces of the gas were detectable in the floor level syringe samples and from the samplers. During this time, the wind was gusting from 10 to 12 m/s from the northwest. Apparently, the combination of the cracks and the wind was sufficient to displace most of the tracer gas from the hangar. The hangar was surveyed to determine if any temporary repairs could be made. The canvass seal between the hangar doors and the protruding B-52 tail assembly had gaps of up to 0.6 m. This seal was temporarily repaired with duct tape. No other repairs were made to the hangar.

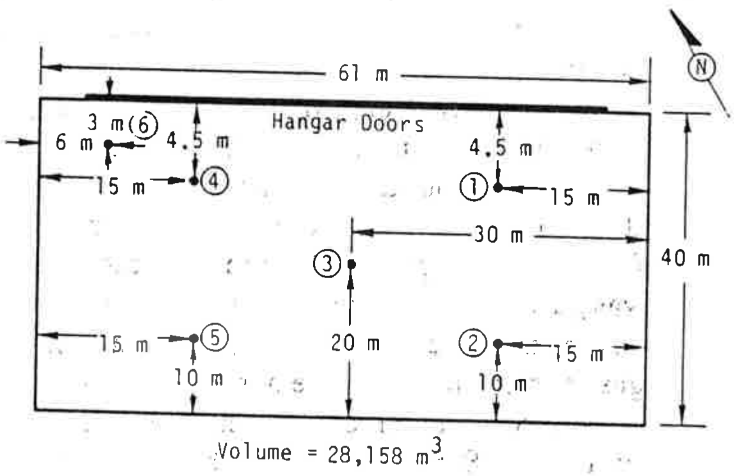
When the wind subsided to a steady 8.2 m/s, an additional 70 cm^3 of SF_6 was injected into the hangar. This time the gas was released at a constant rate at floor level across the north side of the hangar where the aircraft access doors were located. Mixing of the gas with the air inside the hangar was aided by the drafts of air blown through the cracks in the door. Within 30 min, a semihomogeneous, measurable mixture existed and data acquisition commenced.

A summary of data obtained from Hangar 867 is presented in Table 2. For these measurements, the syringe-measured air infiltration rate was 20% lower than the bag-measured rate. However, instrument problems precluded analysis of most of the syringe samples, and it is possible that those presented are in error.

TABLE 2—*Air infiltration data for Hangar 867, Minot AFB, ND.*

	SF$_6$ Concentration, ppt											
	Sample Bags[a]						Syringe Samples[b]					
Elapsed Time, min	1	2	3	4	5	Average[c]	1	2	3	4	5	Average[c]
0	...	...	...	...	74.3	54.9	...	...	...	...	64.0	49.0
10	...	...	29.4	36.6	...	30.3	...	...	28.9	31.2	...	...
30	23.7	21.9	19.4	24.5	24.5	22.8	...	...	...	...	...	25.4
40	...	...	...	17.4	...	13.4	...	...	...	16.1	...	...
50	7.0	11.0	8.8	1.4	14.5	10.3	...	...	...	...	...	...
60	...	...	...	...	...	...	...	...	...	...	...	...
ACH[d]	3.66	2.06	1.81	1.75	1.96	1.62[e]	...	...	...	1.32	...	1.31

[a]6 m above floor.
[b]Floor level.
[c]This is a physically averaged sample as described in section entitled, "Sampling Technique and Data Analysis."
[d]Air infiltration rate.
[e]Calculated over same interval as syringe samples.



Mc Clellan Air Force Base, California

Hangar 365 was selected by the Air Force for evaluation at McClellan AFB. The hangar is approximately 37 m wide by 61 m long, with a maximum height of 10.7 m. Large amounts of glass were used in the hangar doors and walls. Spring-tensioned, overhead-mounted aircraft grounding cables were located throughout the hangar. The grounding cables provided suspension for four of the samplers, and a movable aircraft service scaffold provided suspension for the fifth sampler. The height of the sample point was 4.6 m above floor level.

Ambient weather conditions during the test period, 25 Feb. 1981, were variable winds from 0 to 2 m/s from the east with an outside air temperature of approximately 7°C. The base's weather facilities were used for weather data measurements.

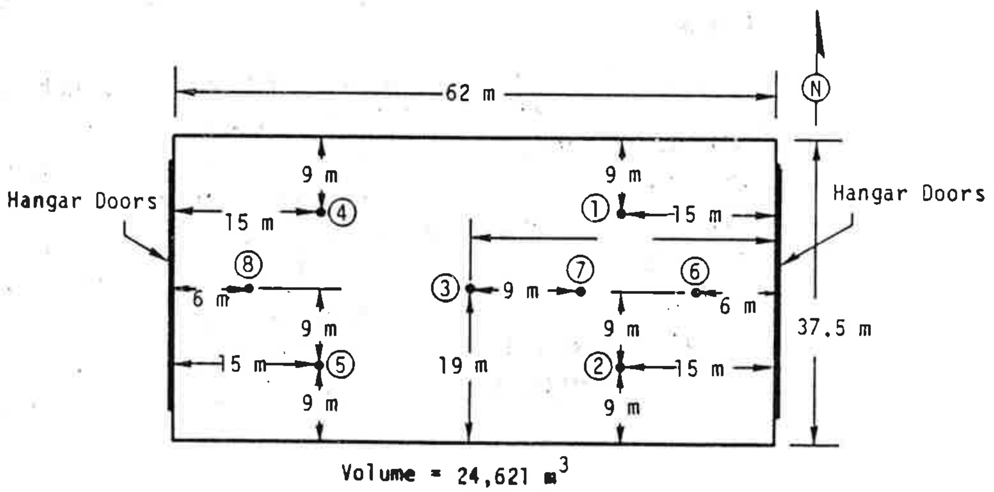
SF_6 was injected into the hangar using the samplers and floor level syringes. Mixing was attempted using ceiling-mounted unit heaters. Floor-level syringe samples were obtained at three points along the hangar's centerline (denoted 6, 7, and 8 on the plot contained in Table 3).

A summary of data obtained from Hangar 365 is presented in Table 3. The bag-measured and syringe-measured air infiltration rates differ by 3%.

TABLE 3—*Air infiltration data for Hangar 365, McClellan AFB, CA.*

Elapsed Time, min	SF_6 Concentration, ppt									
	Sample Bags[a]						Syringe Samples[b]			
	1	2	3	4	5	Average[c]	6	7	8	Average[c]
0	14.9	21.5	26.3	20.7	19.8	21.9	20.3	24.5	...	22.4
10	...	...	...	...	...	19.0	16.9	17.8	17.8	17.5
20	...	...	...	...	...	16.9	...	...	...	...
30	10.7	14.5	14.1	14.5	17.4	14.9	...	...	...	...
40	...	...	...	...	...	12.6	14.1	11.4	12.6	12.7
50	...	...	...	...	...	12.6	...	...	...	...
60	9.9	10.7	11.4	11.8	13.4	11.4	10.3	11.2	12.6	11.4
ACH[d]	0.41	0.70	0.84	0.56	0.39	0.66	0.68	0.78	0.41	0.67

[a]4.5 m above floor.
[b]Floor level.
[c]This is a physically averaged sample as described in section entitled, "Sampling Technique and Data Analysis."
[d]Air infiltration rate.



Naval Air Station (NAS), Brunswick, Maine

Hangar 250 was selected for evaluation at NAS Brunswick. The hangar measures roughly 73 m long by 43 m wide, with a maximum height of 18.3 m. The hangar door seals were in excellent condition. The hangar is used to service and wash patrol aircraft. A system of movable personnel safety cables is located throughout the hangar. These cables are attached to maintenance personnel while washing the aircraft to prevent them from slipping and falling.

Ambient weather conditions during the test period (10–11 March 1981) were mild for the area. The wind was very light, ranging from 0 to 0.5 m/s from the northwest. The outside air temperature was almost constant and varied little from 0°C. The air station's weather facilities were used for weather data measurements.

The personnel safety cables were used to support three samplers, and movable aircraft service scaffolds were used for the remaining two samplers. One hundred twenty cubic centimeters of SF_6 was injected into the hangar; 10 cm^3 was discharged at 7.6 m above the floor by each sampler, and 10 cm^3 was injected at floor level in the vicinity of each sampler. The remaining 20 cm^3 was injected at floor level at points remote from the samplers' locations. Floor-level syringe samples were taken along the hangar's centerline at a point 6.1 m from each end of the hangar and at the center of the hangar.

A summary of data obtained from Hangar 250 is presented in Table 4. The bag-measured and syringe-measured air infiltration rates differ by less than 6%.

Naval Air Rework Facility (NARF), Norfolk, Virginia

Hangar V-88 at NARF Norfolk was selected for evaluation. Measurements were performed on 22 July 1981 in the central bay of a three-bay hangar. The central bay is separated from the outlying bays by double brick walls, between which are located various shops and offices. A plan view of the central section of Building V-88 is shown in Table 5. Note, especially, the staggered nature of the hangar doors. Such doors may be expected to exhibit considerable air leakage.

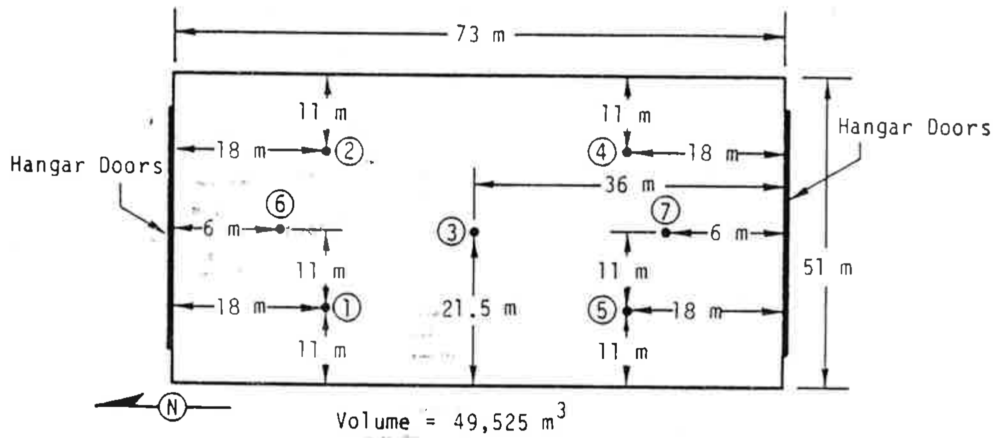
For this test, the sampler and syringe release techniques used in the previous four tests were not used. Instead, a compressed cylinder of 1% SF_6 in nitrogen was used as a source. This bottle was mounted on a portable bottle rack and wheeled around the interior of the hangar. SF_6 was released through a critical orifice valve attached to the down-stream side of the pressure regulator. In this experiment, a Nupro Type-S fine metering valve was used with a C_V of 0.00125 and a driving pressure of 200 kPa.

Prior to onset of actual SF_6 injection, it was determined that a single, complete pass around the interior of the hangar with the bottle rack could be

TABLE 4—*Air infiltration data for Hangar 250, NAS, Brunswick, ME.*

	SF₆ Concentration, ppt											
	Sample Bags[a]						Syringe Samples[b]					
Elapsed Time, min	1	2	3	4	5	Average[c]	1	2	3	4	5	Average[c]
0	...	3173	2981	2779	2580	2711	...	...	2686	...	...	...
10	...	2574	2653	2156	2379	2507	...	...	...	...	...	...
20	...	2200	...	1906	...	2022	...	...	...	...	...	...
30	...	1874	1820	1526	1510	1720	...	...	...	...	...	...
40	...	1641	...	...	...	1526	...	...	...	...	...	...
50	...	...	...	...	...	1352	...	...	...	...	...	...
60	...	1310	1246	1236	1151	1201	...	...	1092	...	...	...
ACH[d]	...	0.88	0.87	0.81	0.81	0.85	...	...	0.90	...	...	...

[a]7.6 m above floor.
[b]Floor level.
[c]This is a physically averaged sample as described in section entitled, "Sampling Technique and Data Analysis."
[d]Air infiltration rate.



accomplished in 5 min. Accordingly, actual SF_6 injection occurred for three passes around the hangar, or approximately 15 min. Initial calculations showed that an initial concentration on the order of 100 ppt could be expected.

SF_6 mixing in the hangar was effected by the use of eight overhead ceiling circulatory fans and eleven 0.6-m-diameter floor-stand fans. These fans were adjusted to provide peripheral circulation of air within the hangar.

Samples were drawn at three locations, which are marked on the figure in Table 5. Samples were drawn at 5 intervals for 1 h. Measured data are provided in Table 5. After this, one section of the downwind hangar door (in this case, the north door) was opened. Note that one section of door is roughly 3.8 m wide by 12.1 m high. Tracer concentration samples were drawn at the

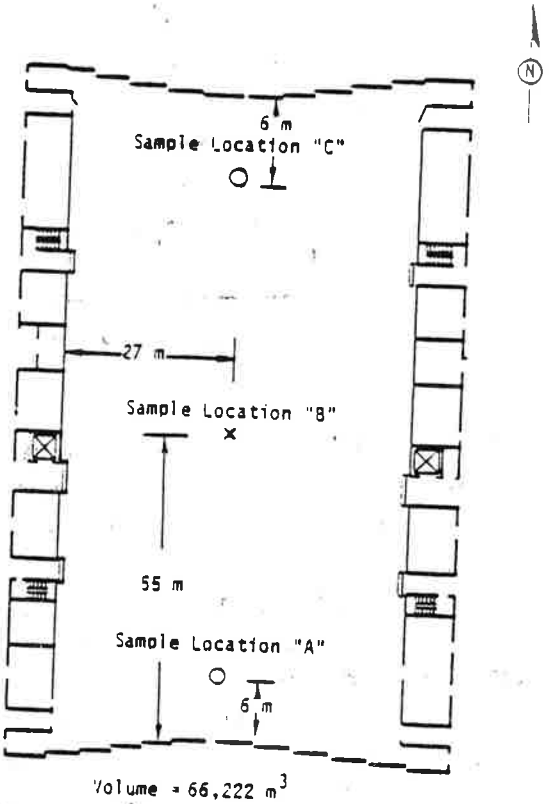
TABLE 5—*Air infiltration data for Hangar V-88, NARF Norfolk, VA.*

Elapsed Time, min	SF_6 Concentration, ppt			
	Syringe Samples[a]			
	A	B	C	Average[b]
0	969	1350	1550	1287
10	920	1350	1300	1191
20	880	1100	1150	1043
30	770	1050	1050	957
40	750	960	950	887
50	660	820	710	730
60	540	720	700	653
ACH[c]	0.55	0.65	0.81	0.68

[a]Floor level.

[b]This is a physically averaged sample as described in section entitled, "Sampling Technique and Data Analysis."

[c]Air infiltration rate.



three locations every 5 min for a period of 20 min. After this, one section of the south-facing door (which, for these tests, was the windward side) was opened, and samples were drawn every 2 min for 10 min. Thus, a measure of air leakage within the hangar for the case of the hangar bay completely closed, with one section of downwind door open, and with one section of downwind door and one section of upwind door open was obtained. Data are presented in Table 6.

Discussion

The concentration data presented in Table 1, and to a lesser extent the data presented in Tables 3 and 5, illustrate the degree of homogeneity which can be obtained within these large-volume structures. In particular, for Hangar V-147 (data contained in Table 1) the standard deviations of the various concentrations determined by sample bag and syringes range from 6 to 16% of the mean. The standard deviation of the mean air change rates at the various sample locations, however, was less than 6%. The agreement between the measured mean rate from the sample bag and the measured mean rate from the syringe samples was within 5%. Similar agreement exists for the data contained in Table 3 for Hangar 365. This agreement suggests that it is possible to obtain representative air infiltration rates in large-volume structures using the tracer dilution technique without the necessity for large numbers of sample positions at various spatial locations throughout the volume.

To further illustrate the degree of homogeneity obtained, with its attendant effect on the inferred air infiltration rates, mean values of the various concentrations measured are presented in Table 7 along with the attendant standard deviations of the measurement expressed as a percentage of the mean value. Note that, with few exceptions, the standard deviations (and, hence, the presumed homogeneity) were within roughly 15% of the mean value measured. The mean air infiltration rates determined from the bag samples and syringe samples generally are very close; however, the standard deviations of these measurements are such that differences of up to 25% could occur. Thus, the reasonable agreement between the measurements drawn from sample bags and from syringes, while gratifying, may not be as good as first appears. How-

TABLE 6—*Measured air leakage rates for door opening with average meterological conditions in Hangar V-88, NARF, Norfolk, VA.*

Condition	Air Change Rate	Wind Speed	Indoor/Outdoor Temperature Difference
Downwind door—open one section	0.75 ACH	3 m/s	2.5°C
Upwind and downwind door—open one section	6.25 ACH	3 m/s	2.5°C

ever, the data do suggest that limited measurements in large-volume structures may be representative of the actual air infiltration rate to within uncertainties given in Table 7.

Conclusions

The measurement of air infiltration rates associated with the five hangars encountered no major problems. The heating systems of the various hangars created enough turbulence to obtain relatively homogeneous tracer gas/air mixtures. Air infiltration rates calculated from bag samples suspended roughly midway between floor and ceiling were comparable with rates calculated from floor-level syringe samples. As indicated in Tables 1 through 5, tracer gas concentration decay is not the same everywhere inside a hangar. It is dependent upon location; thus, slightly different air infiltration rates can be measured at different locations within a hangar. The air change rate measured near an outer wall will reflect the effects of local air leakage before one measured in the center of a hangar.

In order to determine an air change rate which reflects the entire hangar, several readings should be obtained over a crosssection of the hangar floor and averaged together. Data obtained from the various hangars suggest that floor-level syringe samples provide a reasonably accurate measurement of hangar air infiltration, thereby eliminating the requirement for elevated samplers to measure tracer gas concentrations.

TABLE 7—*Comparison of Calculated and Prepared Averaged Concentrations and Inferred Air Infiltration Rates.*

		Sample Bag Concentration, ppt			Syringe Concentration, ppt		
Hangar	Volume, m³	Mean	Standard Deviation, % of Mean	I_{mean}, ACH	Mean	Standard Deviation, % of Mean	I_{mean}, ACH
V-147	96220	782 274	6 16	1.33	740 287	6 11	1.36
867	28158	22.8 10.5	10 27	2.25	... ...	... ...	...
365	24621	20.6 14.2 11.4	20 17 11	0.58	17.5 12.7 11.4	3 11 11	0.62
250	49525	2878 2410 1682	9 7 11	0.84	... ...	... ...	...
V-88	66222	... ...	... ...	...	1286 956 653	23 17 15	0.67

Air infiltration rates in the range of 0.62 to 2.10 were measured. These rates lie midway between the extremes reported by Waters and Simons [2] and are somewhat higher than typical values presented by Grot and Persily [3]. These values are comparable to those which have been measured in rowhousing at Norfolk [7] as well as those obtained in single-family residences [8].

Acknowledgments

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[8] Grot, R. A. and Clark, R. E., "Air Leakage Characteristics and Weatherization Techniques for Low Income Housing," in *Proceedings*, ASHRAE/DOE-ORNL Conference on the Thermal Performance of the Exterior Envelopes of Buildings, Kissimmee, Florida, 1979, ASHRAE, Atlanta, GA.

DISCUSSION

M. Sherman[1] *(written discussion)*—In your talk you mentioned that you used the same tubing and pump for sampling and injection. We find that most tubing adsorbs SF_6 and can interfer with subsequent sampling at concentrations in the range of a 100 ppt. Could you comment on the materials

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and concentration ranges you used and on how you deal with the adsorpt problem.

J. L. Ashley and P. L. Lagus (authors' closure)—One of us (P. Lagus) used a brand of polypropylene tubing denoted "Impolene" to draw tra samples up to 650 m with no tracer retention after flushing with air.

A. Birenzwige[2] *(written discussion)*—Were the mixing fans operat throughout the sampling period?

J. L. Ashley and P. L. Lagus (authors' closure)—Yes.

[2]U.S. Army, CRDC Edgewood Area, APG, MD 12010.