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ABSTRACT

The Brookhaven air infiltration measurement system (BNL/AIMS) uses a family of four passive perfluorocarbon tracer (PFT) sources and miniature passive adsorbent samplers to inexpensively but very effectively tag individual zones within multizone buildings with uniquely discernible tracer vapors. The concentrations measured with the passive samplers allow the air infiltration and exfiltration rates from each zone to be computed as well as the air exchange rates between zones. Two naturally ventilated buildings, a 2-zone (3056 m^3) jailhouse and a 4-zone (1028 m^3) apartment building were tested; the former showed a 2.5 to 1 ratio in the fresh air rates into the zones. Two mechanically ventilated buildings, each of 3-zones, were also tested. The 3-story (each floor was a zone) library (5840 m^3) was shown to have 10 times more fresh air entering the first floor than the second (1.33 h^{-1} compared to 0.15 h^{-1}). The 16-story office building (142,500 m^3) had 4 times as much fresh air in one zone compared to a side-by-side identical zone (1.07 h^{-1} versus 0.25 h^{-1}). The performance of BNL/AIMS in certifying HVAC systems is demonstrated.

Numerous researchers have proposed models and methods for using tracer gases in the solution of those models for determining the air infiltration rate into a home or building considered as a single, well-mixed chamber or zone [1-3]. Recently, however, it has been recognized that many larger, more complex buildings, especially those with multiple-zoned HVAC systems, and even one- and two-story homes with basements realistically can only best be represented by models which recognize the building as multiple-connected zones, each of which is well mixed [4-8].

Although multiple tracers have been used with some success in modeling multizone building flows, their application has generally been awkward and expensive [6,7]. However, with the development of the miniature passive perfluorocarbon tracer (PFT) source and sampler system [1,9], the implementation of multizone measurements has now become practical.

This paper provides a brief description of the passive tracer technique and demonstrates its application in determining air infiltration and exchange rates in multizoned naturally and mechanically ventilated buildings. The method can be used for performance certification of heating, ventilating, and air conditioning (HVAC) systems.

Description of AIMS

Coined the Brookhaven air infiltration measurement system (BNL/AIMS), the technique uses small (about half the length of a cigarette) aluminum shells filled with a PFT liquid and closed with a silicone rubber plug to provide a calibrated source of the PFT vapors which permeate through the rubber plug at a rate which is dependent only on the temperature of the device [9]. When deployed uniformly throughout a naturally ventilated building or within the source plenum of mechanically ventilated buildings at a density of one source per 500 to 5000 ft^2 of occupancy space, a steady-state tracer concentration of typically between 0.5 to 50 pL/L is established. Passive PFT samplers called capillary adsorption tube samplers (CATS), each about the size of a cigarette (a 2.5-in. long glass tube filled with an adsorbent and closed with a rubber cap on each end), collect and measure the PFT concentrations when deployed throughout the building at about the same density as the sources. Sampling by passive Fickian diffusion, they are subsequently returned to the laboratory for thermal desorption and analysis on an electron capture gas chromatograph system [9].

For a building considered as a single, well-mixed zone or chamber, the average tracer concentration (e.g., pL/L or nL/m^3) is approximately equal to the sum of the emission rate of all sources (e.g., nL/h) divided by the average air infiltration rate (e.g., m^3/h). Knowing the source rate and measuring the PFT concentration then provides a means to calculate the air infiltration rate. Extending this technique to a multichamber or multizone concept, in which a different type of PFT source is deployed in each zone of the building, allows the calculation of not only the fresh air infiltration rate into each zone but also the individual exfiltration rates and the rates of air exchange between zones as well [9]. Currently there are four uniquely discernible PFT source vapors and thus buildings with up to 4 zones can be accommodated. Since both the PFT source and passive sampler are small, mailable, inexpensive, and reusable, the BNL/AIMS is a very cost-effective means for determining these whole building multizone flow rates.

Use of AIMS in Naturally Ventilated Multizone Buildings

The County Jailhouse. Concern was expressed on the part of inmates that their cell building was not receiving adequate fresh air. The building was 40 ft wide by 100 ft long by 30 ft high and divided vertically along its length by a double wall as shown in Fig. 1. Nine PDCH* sources were used in zone 1 and 6 PMCH sources in zone 2, spread uniformly between the 2 floors in each half of the building. Similarly 6 passive samplers (CATS) were deployed throughout zone 1 and 4 in zone 2. The 2-day measurement period was from March 19-21, 1983, with the sources having been deployed the night before.

Referring to Table 1, the samplers in zone 1 were located as follows: CATS nos. 363 and 342, grade level; 402 and 280, 8 ft above grade, 227 and 305, 19 ft above grade and for zone 2: 361 on grade, 417 at 8 ft above grade, and 455 and 393 at 19 ft above grade. With the exception of two high PDCH levels, one of which was located within 2 ft of a PDCH source, the tracer concentrations were quite uniform with height, indicating very little stratification.

The results of the analyses in Table 1 are shown pictorially in Fig. 1. The whole building fresh air infiltration rate was 0.67 ACH (air changes per hour or h^{-1}), gotten by dividing the sum of the zone 1 and 2 air infiltration rates, 563 and 1488 m^3/h, respectively, by the sum of the zone volumes, 1528 m^3 each. Since the fresh air infiltration rates into each zone were 0.37 and 0.97 ACH, about a ratio of 2.6 to 1, it is conceivable that the occupants in the first zone may have been more uncomfortable than those in the other half of the building. However, there was moderate air exchange between the zones despite the double dividing wall such that the exfiltration rate ratio was only 1.5 to 1.

The Quadraplex Housing Unit. Located in Yuma, Arizona, this earth-sheltered passive solar-gain building consists of 4 individual apartment units, each approximately 900 ft^2 in size, arranged in a rectangular fashion as shown in Fig. 2. Being monitored by Rockwell International under the Solar in Federal Buildings Program (SFBP), each unit was considered a separate zone and was therefore tagged with one type each of the four available PFTs. The AIMS technique was deployed from February 3 to March 7, 1984.

Listed in Table 2 are the emission rates of the dual sources used in each of the 4 units and the concentrations found for each of the 4 tracers on each CATS passive sampler. First it is noted that the concentration of the tracer deployed in a unit, e.g., PDCH in Unit 1, was always higher in the master bedroom than the rest of the unit. Apparently with only 1 window, no doors, and a source deployed in that room, there is a bias in the concentration distribution compared to the other rooms, which generally had uniform concentrations.

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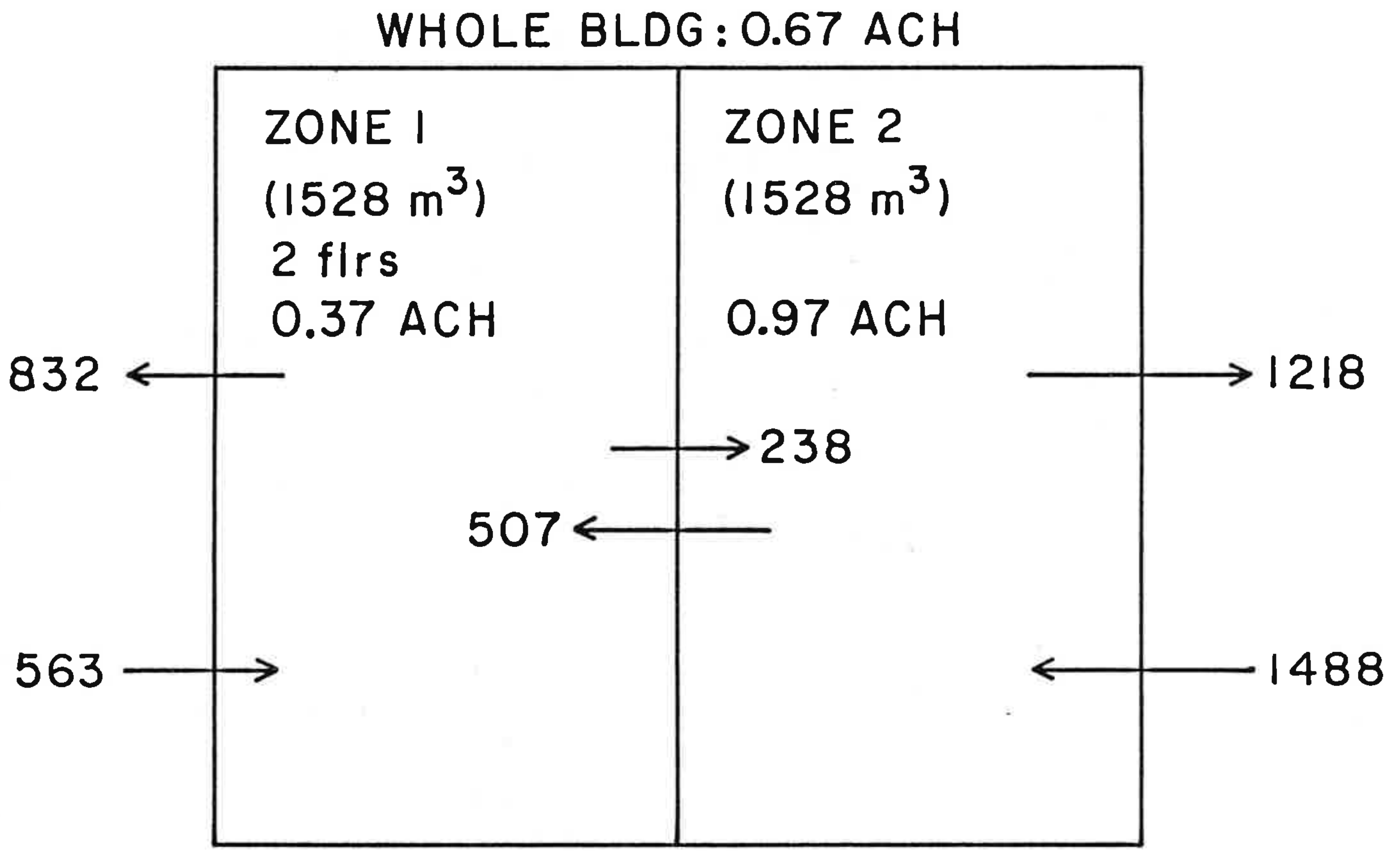
*Tracer codes:
PDCB - perfluorodimethylcyclobutane
PMCP - perfluoromethylcyclopentane
PMCH - perfluoromethylcyclohexane
PDCH - perfluorodimethylcyclohexane



2 STORY-2 ZONE JAILHOUSE
(all flow rates in m^3/h)

FIGURE 1

TABLE 1

BNL-AIMS

ACCOUNT: PIERCE   HOUSE: P2IS #CHAMBERS:2   DATE ANAL: 3/83

CHAMBER	VOL (M↑3)	SOURCE RATE (nL/hr)	AVG.CONC.TRACER (pL/L) 3	2		RATES(M↑3/HR) EXFILT.	INFILT.
1	1528.20	10015	10.0	3.7	0.0	832	563
2	1528.20	12439	1.4	7.7	0.0	1218	1488

CHAMBER-CHAMBER	RATE(M↑3/hr.)	CATS#	CONC. (pL/L) PDCB	PMCH	PDCH
1-2	237.8	363		4.034	9.874
2-1	506.9	342		3.544	8.867
		402		3.500	12.738
		280		3.461	7.706
		227		3.714	7.637
		305		3.679	13.278
		361		7.143	1.492
		417		7.382	1.357
		455		8.866	1.406
		393		7.465	1.267

TRACER CODES
1=PDCB
2=PMCH
3=PDCH

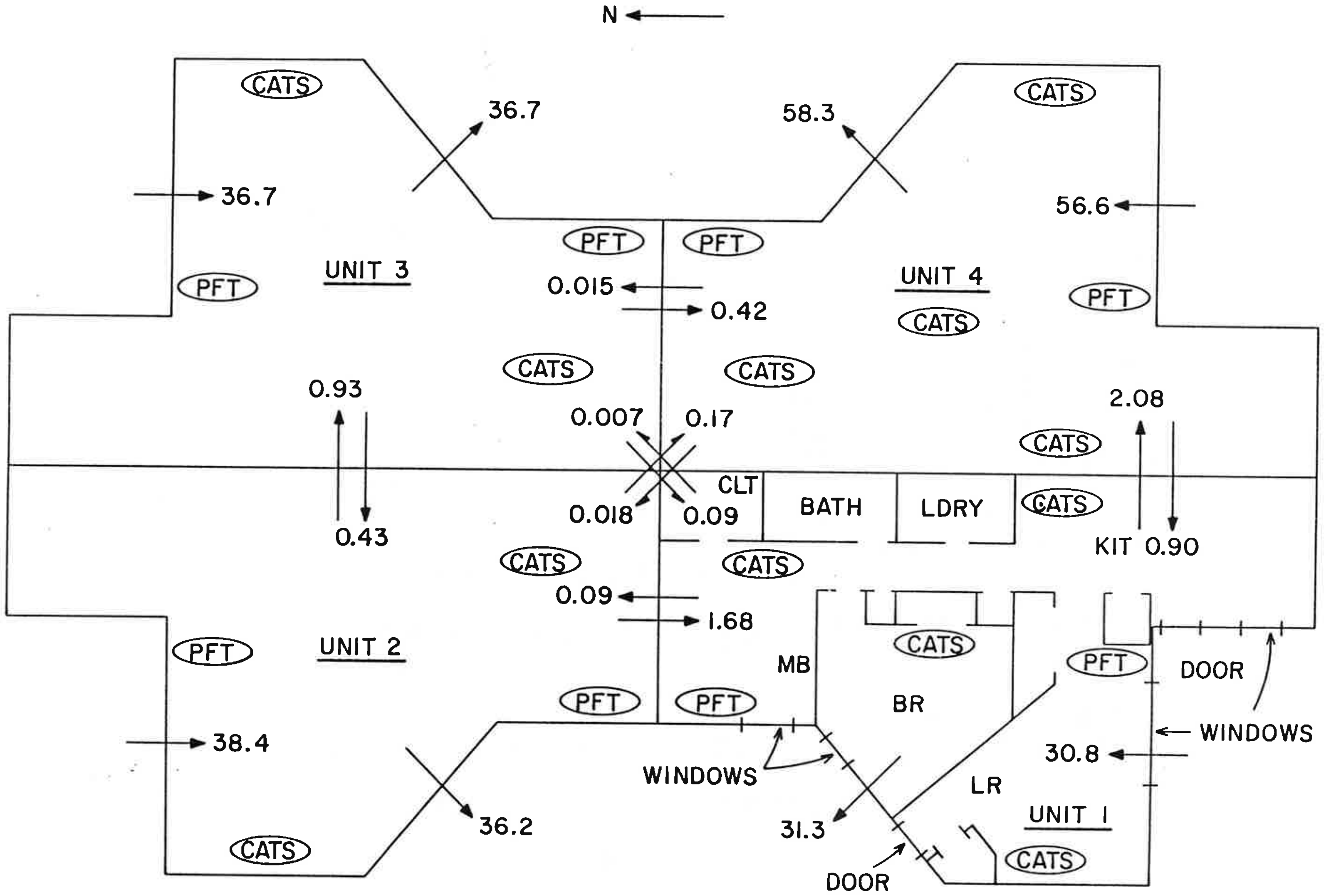


FIGURE 2 MESO Environmental Quadraplex Housing Units in Yuma, Arizona

Table 2

PFT CONCENTRATIONS IN 4-ZONE QUADRAPLEX HOUSING UNITS
(CATS Samplers Deployed for 33 Days)

			PFT Concentrations, pL/L			
Unit	CATS No.	Location	PDCH (U1)[b] (2143 nL/h)	PDCB (U2) (4656 nL/h)	PMCP (U3) (4838 nL/h)	PMCH (U4) (3096 nL/h)
1	1672	Liv. Rm.	74.9	6.56	0.47	1.61
1	1649	Kitchen	69.5	6.65	0.25*	1.57
1	1666	Mas. Bdrm.	115.0*	7.83	0.52	1.79
1	1657	Sm. Bdrm.	64.1	6.49	0.53	1.46
	avg.		80.9 ± 20.1	6.88 ± 0.55	0.44 ± 0.11	1.61 ± 0.12
	avg.[a]		(69.4 ± 4.4)		(0.51 ± 0.03)	
2	1651	Mas. Bdrm.	0.177	135.3	1.56	0.0315
2	1635	Liv. Rm.	0.158	116.7	1.56	0.0309
	avg.		0.168 ± 0.010	126.0 ± 9.3	1.56	0.0312 ± 0.003
3	1643	Mas. Bdrm.	---	3.40	142.9	0.0242
3	1227	Liv. Rm.	0.018	3.07	124.6	0.0235
	avg.		0.018 ± 0.004	3.23 ± 0.17	133.8 ± 9.2	0.0239 ± 0.0004
4	1650	Liv. Rm.	2.58	0.63	0.99	57.3
4	1415	Kitchen	2.55	0.61	0.94	46.6
4	1452	Mas. Bdrm.	2.61	0.74	1.51*	81.7*
4	1319	Sm. Bdrm.	2.63	0.66	1.13	62.3
	avg.		2.59 ± 0.03	0.66 ± 0.05	1.14 ± 0.23	62.0 ± 12.7
	avg.[a]				(1.02 ± 0.08)	(55.4 ± 6.6)

[a]Average also computed excluding value with asterisk.

[b]Values in parentheses are the unit location tagged with that tracer and the average emission rate for the 2 sources deployed.

It was also found, of course, that the concentration of a particular tracer was always highest in the unit in which it was deployed. For Units 1 and 3, the concentration of the unit tracer was next-to-the-highest in the adjacent unit with the largest common wall and lowest in the diagonally adjacent unit. Units 2 and 4 had just a slight variation to that general observation.

A material balance solution gave the internal flow rates shown in Figure 2 and tabulated in Table 3. Compared to the infiltration and exfiltration rates, which ranged from 30 to almost 60 m^3/h, the air exchange rates were quite low, ranging from 0.007 to 2.1 m^3/h with a median value of 0.17 to 0.42 m^3/h. Based on our observations of floor-to-floor air exchange rates in multistory houses and buildings, these rates are quite low--about 2 orders of magnitude. Thus, the units are essentially isolated from each other.

In terms of air changes per hour, the values ranged from 0.12 to 0.22 h^{-1}, not unreasonably low for energy efficient structures, as we have seen average values in typical housing from 0.4 to 0.5 and in tight houses from 0.2 to 0.25 h^{-1}.

The exfiltration and infiltration rates were nearly identical in Units 1, 2, and 3, averaging about 35 m^3/h; unit 4 was about 60% higher. One possible reason may be the prevailing wind direction. It is noted that the infiltration into Unit 2 was greater than the exfiltration rate (cf. Fig. 2). There was a net flow from Unit 2 to Units 3, 4, and 1. Also there was a net flow from Unit 3 to 4 and Unit 1 to 4 and the exfiltration rate was greatest from Unit 4 as well as having the largest exfiltration to infiltration rate ratio. Thus it would appear that Unit 4 was being subjected to a stack effect or slightly reduced barometric pressure resulting in net internal flow from the northwest to the southeast.

Use of AIMS in Mechanically Ventilated Multizone Buildings

The Bonneville Power Administration (BPA) is supporting a study of infiltration determination in multistory buildings in the Oregon area under the experimental direction of David T. Grimsrud at Lawrence Berkeley Laboratory (LBL). At their invitation, Brookhaven directed a portion of its DOE support to demonstrate the potential capability of the BNL/AIMS multizone approach while LBL was simultaneously determining whole building air infiltration by their SF_6 tracer decay technique. Two buildings were tested in March 1984, a 3-story library with a net volume of 206,000 ft^3 (5840 m^3) and a 16-story office building with a volume fo 5,032,000 ft^3 (142,500 m^3).

The Lake Oswego Library. This 2-story building with a partial basement is shown pictorially in Fig. 3 and the BNL/AIMS detailed results are given in Table 4, which tabulates for each zone, its volume, the type and rate of the PFT sources, the average of each tracer concentration, and the computed exfiltration and infiltration rates. Below is shown the computed zone-to-zone flow rates, the concentrations of each tracer measured by each CATS tabulated according to zone location, and the computed whole building air changes per hour.

Because the HVAC system was somewhat complex in its distribution for this building, 4 PFT sources of a given type were distributed uniformly on the 3

Table 3

CALCULATED AIR EXCHANGE AND INFILTRATION RATES
IN THE QUADRAPLEX HOUSING UNITS
(2/3/84 to 3/7/84)

	AIR EXCHANGE AND INFILTRATION RATES, m^3/h			
	Unit 1	Unit 2	Unit 3	Unit 4
to Unit 1	----	1.68	0.090	0.90
to Unit 2	0.089	----	0.43	0.018
to Unit 3	0.007	0.93	----	0.015
to Unit 4	2.08	0.169	0.42	----
R_E	31.3	36.2	36.7	58.3
R_I	30.8	38.4	36.7	56.6
ACH_I, h^{-1}	0.120	0.150	0.143	0.220

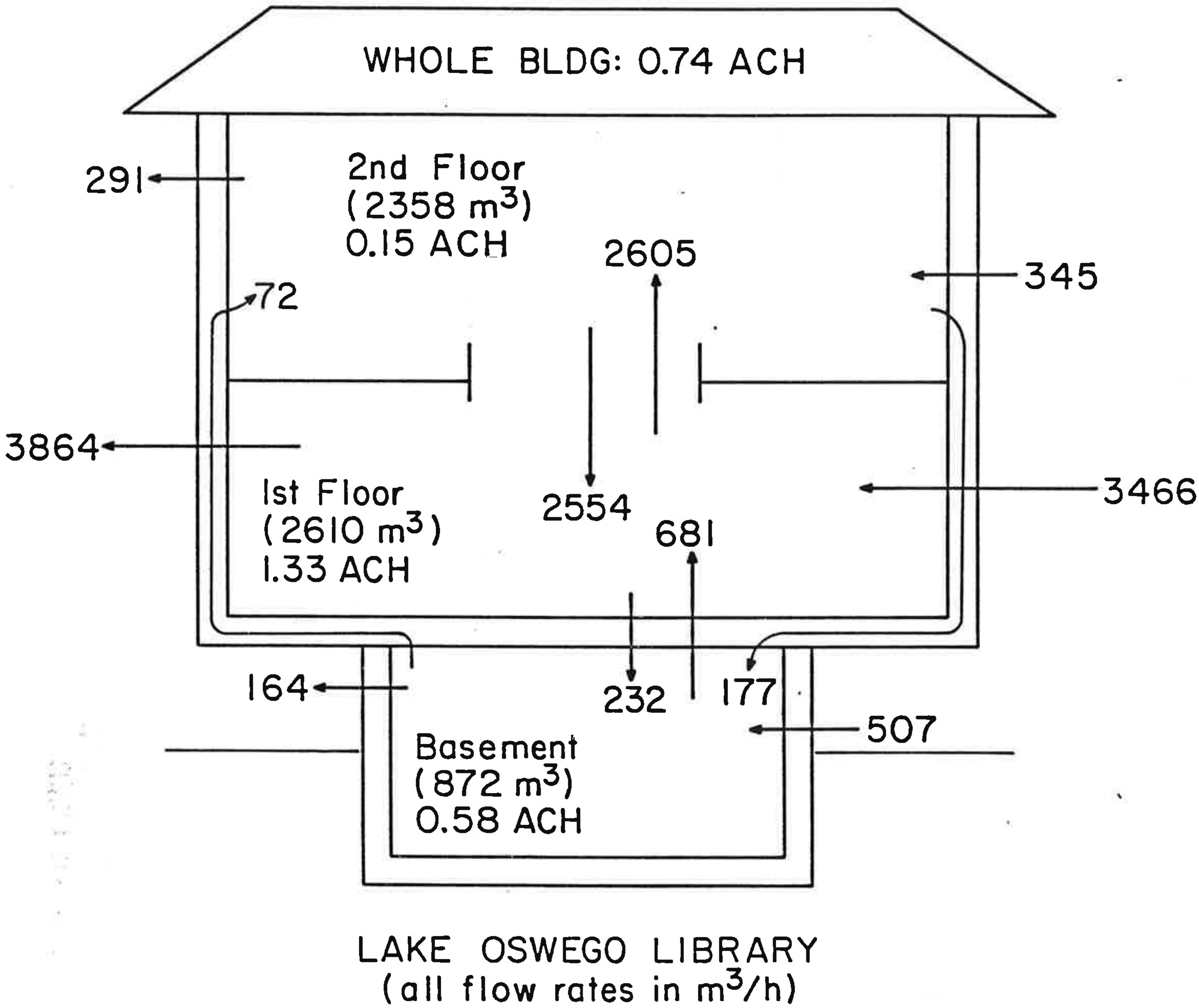

WHOLE BLDG: 0.74 ACH
2nd Floor
(2358 m3)
0.15 ACH
291
72
2605
345
3864
Ist Floor
(2610 m3)
1.33 ACH
2554
681
3466
164
232
177
507
Basement
(872 m3)
0.58 ACH
LAKE OSWEGO LIBRARY
(all flow rates in m3/h)

FIGURE 3

TABLE 4

BNL-AIMS

ACCOUNT: LBL-LIBRARY HOUSE:LB04 #ZONES:3 FILE: 89
DATES SAMPLED: 030184-030294 DATE ANAL: 5/16/84

ZONE	VOL (M^3)	SOURCE TYPE	SOURCE RATE (nL/hr)	AVG.TRACER CONC. (pL/L) PDCB	PMCH	PDCH	EXFILT. RATE (M^3/hr)	EXFILT. ACH (1/hr)	INFILT. RATE (M^3/hr)	INFILT. ACH (1/hr)
1	2358.0	PDCB	8420	4.4	1.7	0.8	290.7	0.12	345.4	0.15
2	2610.0	PMCH	8012	1.8	1.9	0.8	3864.2	1.48	3466.3	1.33
3	872.0	PDCH	4006	1.3	0.8	4.7	163.5	0.19	506.7	0.58

INFILTRATION RATE (WHOLE HOUSE)= 0.74 /hr

ZONE-ZONE	RATE(M^3/hr.)	*	ZONE	CATS#	CONC.(pL/L) PDCB	PMCH	PDCH
1-2	2554.2	*	1	1037	3.450	1.605	0.453
2-1	2605.1	*	1	1546	4.379	1.723	0.902
1-3	177.1	*	1	1641	5.008	1.653	0.812
3-1	71.5	*	1	1664	4.621	1.694	0.963
2-3	231.8	*	2	24	1.422	1.830	0.895
3-2	680.6	*	2	1048	1.952	2.170	0.754
			2	1453	1.955	1.828	0.721
			2	1442	1.854	1.827	0.743
			3	1000	1.204	0.759	4.306
			3	1569	1.344	0.840	5.008
			3	1523	1.349	0.823	4.857

ZONE 1 IS 2ND FLR
ZONE 2 IS 1ST FLR
ZONE 3 IS BSMNT

floors. Similarly, 4 passive samplers (CATS) were located on each of the 2nd and 1st floors, with only 3 in the basement.

With the exception of a low PDCH concentration found in the first CATS, the tracer concentrations in each zone were quite uniform.

The flow rates computed in Table 4 are shown in Fig. 3. The large central open area between the 1st and 2nd floors apparently encouraged a moderate exchange rate between those zones of about equal magnitude up and down. However, the fresh air infiltration rate into the second floor (345 m^3/h or 0.15 h^{-1}) was an order of magnitude less than that into the first floor (3466 m^3/h or 1.33 h^{-1}), similar to observations in other smaller 2-story homes [4,9].

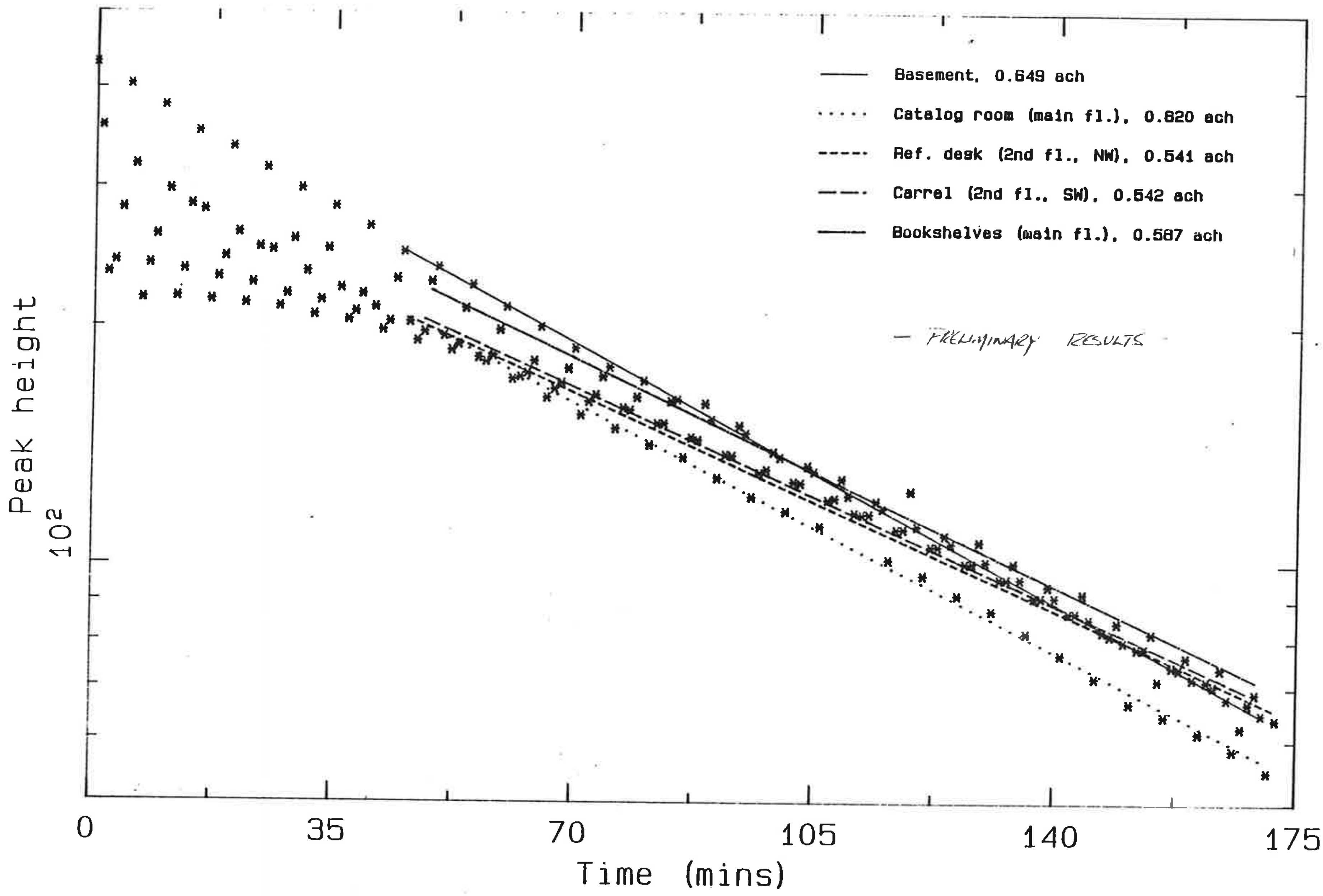
During the BNL/AIMS 32-h monitoring period, LBL performed 5 SF_6 decay experiments (one SF_6 injection with sampling at 5 locations). As shown by the results in Fig. 4 and tabulated in Table 5, the whole building air changes per hour as measured by the 5 tracer decay tests is close to the true value determined with BNL/AIMS. But as demonstrated by D'Ottavio and Dietz [10], a tracer decay method cannot readily be used to compute the individual zone infiltration rates nor will it give the precisely accurate whole building rate.

The Portland Building. This 16-story building in downtown Portland has 3 HVAC systems, one each handling the northwest and southeast corners of the 4-15th floors (zones 1 and 2, respectively) and 1 for the entire ground to 3rd floors. For the most part, the office space within each floor is completely open and, therefore, the rates of mixing between zones 1 and 2 would be expected to be high.

Because each HVAC system had a separate, single supply air plenum (a very large accessible room) which subsequently distributed air "uniformly" to all levels within their respective zones, it was convenient to deploy the PFT sources as a group of each type in a nylon stocking fastened near each zone's fan intake. Thus, 56 PMCH sources were used in zone 1, 41 PDCB sources in zone 2, and 36 PDCH sources in zone 3, deployed at 2100 hours on 2/29/84.

On the morning of March 1, 1984, 16 pairs of CATS were deployed on the 5th, 7th, 11th and 15th floors in each of zones 1 and 2, and 12 pairs within zone 3 plus 2 uncapped CATS as controls. One of each pair was removed and capped later in the afternoon after about 7 hours exposure and the second, the next early afternoon after about 28 hours exposure. The HVAC system were maintained in an operating mode for the duration of the test with the exception of a 4-hr period at night when LBL was injecting and mixing SF_6 with no fresh air infiltration.

The results of the BNL/AIMS tests are given in Tables 6 and 7 for the 7- and 28-hour periods, respectively, and shwn pictorially in Figures 5 and 6. Again the concentrations of tracer in each zone were quite uniform; a few outliers, usually for physical reasons, were deleted from the averages as indicated. The variability, however, does indicate that additional dilution on each floor is occurring, probably by natural ventilation, since the variability among multiple samplers at one location is within $\pm$ 2% [9]. The last 2 CATS in Table 6, controls, had essentially zero concentrations.



LAKE OSWEGO LIBRARY 03/02/84

FIGURE 4

Table 5

COMPARISON OF BNL/AIMS WITH SF_6 DECAY

Building	Date	Meas. Period, h	Method	Air Infiltration Rate, h^{-1} [a] Zone 1	Zone 2	Zone 3	Whole Bldg
Lake Oswego	3/2/84	2	SF_6 Decay	---	---	0.65	---
Library	"	"	"	---	0.62	---	---
(3 stories)	"	"	"	0.54	---	---	---
"	"	"	"	0.54	---	---	---
"	"	"	"	---	0.57	---	---
"	Avg.	"	"	0.54	0.59	0.65	0.58
	3/1-2/84	32	BNL/AIMS	0.15	1.33	0.58	0.74
Portland	3/1/84	2	SF_6 Decay	---	---	0.79	---
Building	"	"	"	---	---	0.82	---
(16 stories)	"	"	"	---	0.84	---	---
"	"	"	"	0.79	---	---	---
"	"	"	"	1.06	---	---	---
"	"	"	"	---	0.83	---	---
	Avg.	"	"	0.92	0.83	0.81	0.85
"	3/1/84	7	BNL/AIMS	1.07	0.25	1.08	0.80
	3/1-2/84	28	"	1.07	0.49	0.50	0.69

[a] For the library, zone 1 is the 2nd floor, zone 2 the 1st floor, and zone 3 the basement.

For the Portland Building, zone 1 is the northwest portion of the 4-15 floors, zone 2 the southeast portion of floors 4-15, and zone 3 the entire ground to third floors.

TABLE 6 (7-H TEST)

BNL-AIMS

ACCOUNT: PORTLAND HOUSE:POR1 #ZONES:3 FILE: 6
DATES SAMPLED: 030184-030184 DATE ANAL: 3/20/84

ZONE	VOL (M^3)	SOURCE TYPE	SOURCE RATE (nL/hr)	AVG. TRACER CONC. (pL/L) PMCH	PDCB	PDCH	EXFILT. RATE (M^3/hr)	EXFILT. ACH (1/hr)	INFILT. RATE (M^3/hr)	INFILT. ACH (1/hr)
1	47709.0	PMCH	83040	1.1	0.7	0.1	51142.0	1.07	50930.3	1.07
2	47709.0	PDCB	74361	0.9	1.7	0.1	13999.5	0.29	11919.2	0.25
3	47079.0	PDCH	29415	0.2	0.2	0.5	48750.7	1.04	51050.6	1.08

INFILTRATION RATE (WHOLE HOUSE)= 0.80 /hr

ZONE-ZONE	RATE(M^3/hr.)	*	ZONE	CATS#	CONC.(pL/L) PDCB	PMCH	PDCH
1-2	53578.9	*	1	1003	1.289	0.849	0.161
2-1	45676.7	*	1	1062	0.768	1.135	0.000
1-3	8995.7	*	1	1260	0.477	1.336	0.112
3-1	17109.5	*	1	264	0.574	1.233	0.209
2-3	5514.7	*	1	648	1.109	0.934	0.045
3-2	-307.2	*	1	1391	0.589	1.158	0.000
			1	458	0.515	1.041	0.088
			1	1662	0.645	1.180	0.112
			1	1522	0.997	1.179	0.117
			1	1568	0.483	1.250	0.026
			1	1038	0.502	1.145	0.111
			1	1660	0.760	0.900	0.126
			1	1226	1.170	0.931	0.116
			1	1477	0.729	1.673	0.115
			1	1636	0.477	1.192	0.225

TABLE 6 (cont'd)

~~1~~	~~506~~	~~0.326~~	~~0.634~~	~~0.392~~
2	1644	0.935	1.230	0.152
2	513	1.584	1.143	0.077
2	1067	1.916	0.533	0.153
2	981	1.130	0.868	0.000
2	754	1.824	0.670	0.096
2	1053	1.838	0.686	0.104
2	1673	1.926	1.071	0.062
~~2~~	~~504~~	~~1.600~~	~~1.248~~	~~0.151~~
2	1016	1.830	1.235	0.081
2	1656	1.965	1.186	0.070
2	25	2.035	1.149	0.115
~~2~~	~~1063~~	~~1.029~~	~~1.369~~	~~0.060~~
2	1068	1.785	0.768	0.087
2	1196	1.990	0.565	0.060
2	1500	1.953	1.088	0.028
~~2~~	~~1615~~	~~1.444~~	~~1.088~~	~~0.083~~
3	1018	0.228	0.239	0.770
3	1025	0.124	0.192	0.256
3	1054	0.103	0.164	0.160
3	1045	0.619	0.341	0.408
~~3~~	~~832~~	~~1.672~~	~~0.561~~	~~0.000~~
3	28	0.155	0.193	0.267
3	736	0.306	0.270	0.207
3	1049	0.263	0.346	0.202
3	1001	0.211	0.200	0.662
3	1675	0.213	0.215	0.580
3	920	0.222	0.194	0.779
3	1076	0.289	0.238	0.877
	1006	0.000	0.000	0.000
	1591	0.000	0.000	0.025

ZONE 1 IS 4-15 NW
ZONE 2 IS 4-15 SE
ZONE 3 IS G-3 ALL

TABLE 7 (28-H TEST)

BNL-AIMS

ACCOUNT: PORTLAND   HOUSE:POR2   #ZONES:3   FILE: 7
DATES SAMPLED: 030184-030284   DATE ANAL: 3/19/84

ZONE	VOL (M^3)	SOURCE TYPE	SOURCE RATE (nL/hr)	AVG. TRACER CONC. (pL/L) PMCH	PDCB	PDCH	EXFILT. RATE (M^3/hr)	EXFILT. ACH (1/hr)	INFILT. RATE (M^3/hr)	INFILT. ACH (1/hr)
1	47709.0	PMCH	86855	1.1	0.7	0.1	62370.9	1.31	51111.2	1.07
2	47709.0	PDCB	76519	0.7	1.5	0.2	17412.2	0.36	23365.0	0.49
3	47079.0	PDCH	30666	0.2	0.4	1.0	18246.4	0.39	23553.4	0.50

INFILTRATION RATE (WHOLE HOUSE)= 0.69 /hr

ZONE-ZONE	RATE(M^3/hr.)	*	ZONE	CATS#	CONC. (pL/L) PDCB	PMCH	PDCH
1-2	39586.8	*	1	996	1.290	0.741	0.238
2-1	46725.9	*	1	490	0.763	1.039	0.110
1-3	2206.1	*	1	14	0.482	1.280	0.109
3-1	6326.7	*	1	772	0.530	1.004	0.239
2-3	6974.0	*	1	958	1.074	0.935	0.125
3-2	8160.3	*	1	34	0.596	1.253	0.141
			1	1059	0.517	1.305	0.135
			1	756	0.598	1.246	0.125
			1	787	0.869	1.072	0.087
			1	1020	0.474	1.308	0.131
			1	623	0.438	1.325	0.095
			1	1070	0.612	1.277	0.130
			1	1041	0.968	1.047	0.135
			1	1499	0.676	1.130	0.184
			1	1654	0.589	1.195	0.233

TABLE 7 (cont'd)

~~1~~	~~1547~~	~~0.297~~	~~0.541~~	~~0.476~~
2	1280	0.942	0.991	0.138
2	1017	1.709	0.960	0.430
2	763	1.606	0.518	0.199
2	280	1.085	0.850	0.207
2	529	1.629	0.555	0.193
2	1668	1.649	0.525	0.172
2	798	1.713	0.496	0.175
2	992	1.522	0.615	0.067
2	939	1.177	0.849	0.208
2	140	1.414	0.628	0.210
2	780	1.696	0.526	0.244
~~2~~	~~1199~~	~~1.009~~	~~0.944~~	~~0.190~~
2	1592	1.476	0.657	0.204
2	76	1.702	0.562	0.106
2	1044	1.778	0.533	0.198
~~2~~	~~1642~~	~~1.276~~	~~0.764~~	~~0.170~~
3	1029	0.692	0.568	1.265
3	1039	0.179	0.087	0.494
3	972	0.179	0.111	0.613
3	1072	0.736	0.249	0.892
~~3~~	~~1051~~	~~1.938~~	~~0.499~~	~~0.164~~
3	1413	0.197	0.129	0.747
3	795	0.376	0.218	0.871
3	843	0.344	0.286	0.802
3	1250	0.326	0.178	1.339
3	1050	0.319	0.169	1.316
3	11	0.321	0.176	1.307
3	1009	0.380	0.228	1.228

ZONE 1 IS 4-15 NW
ZONE 2 IS 4-15 SE
ZONE 3 IS G-3 ALL

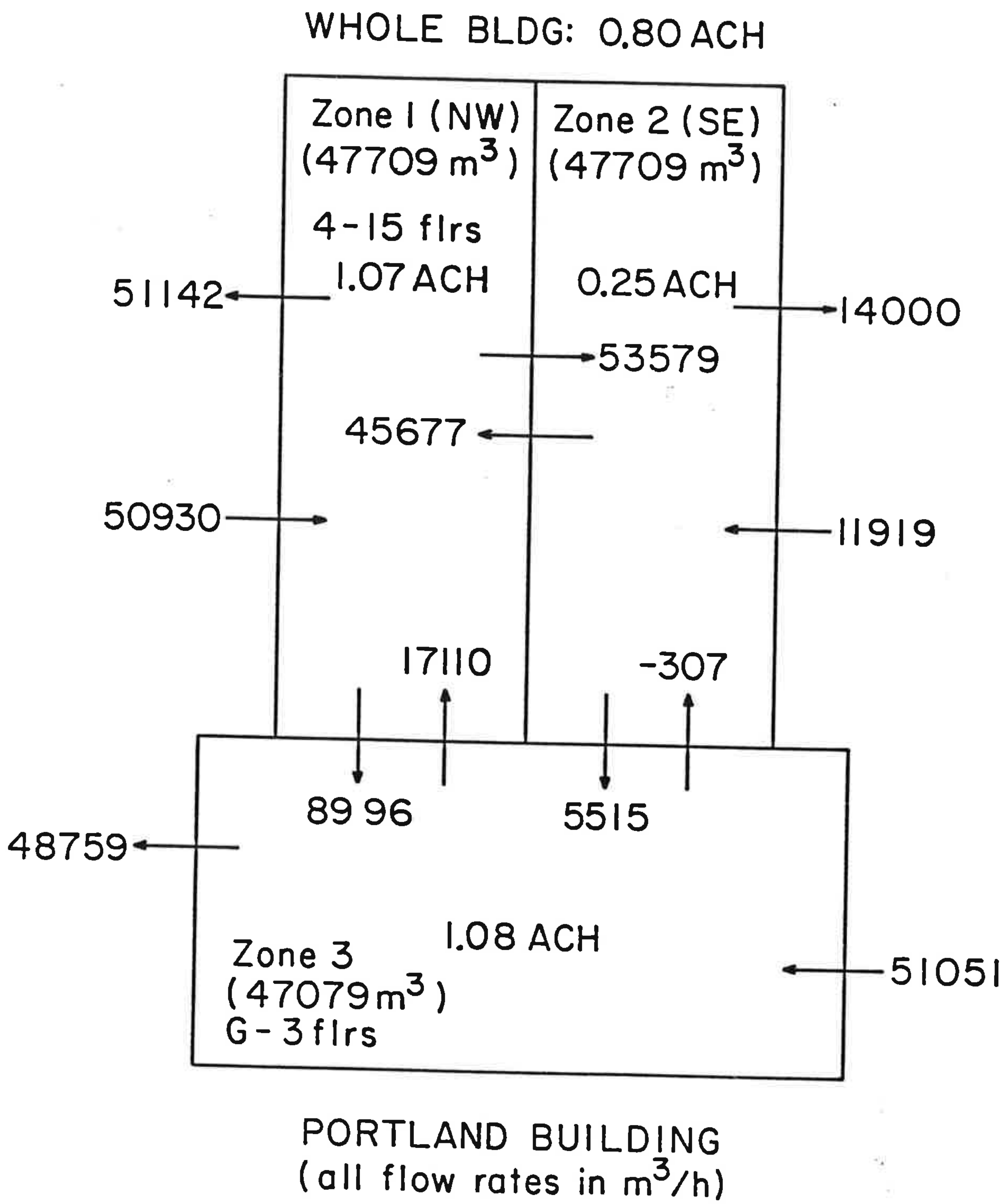


FIGURE 5 (7-H TEST)

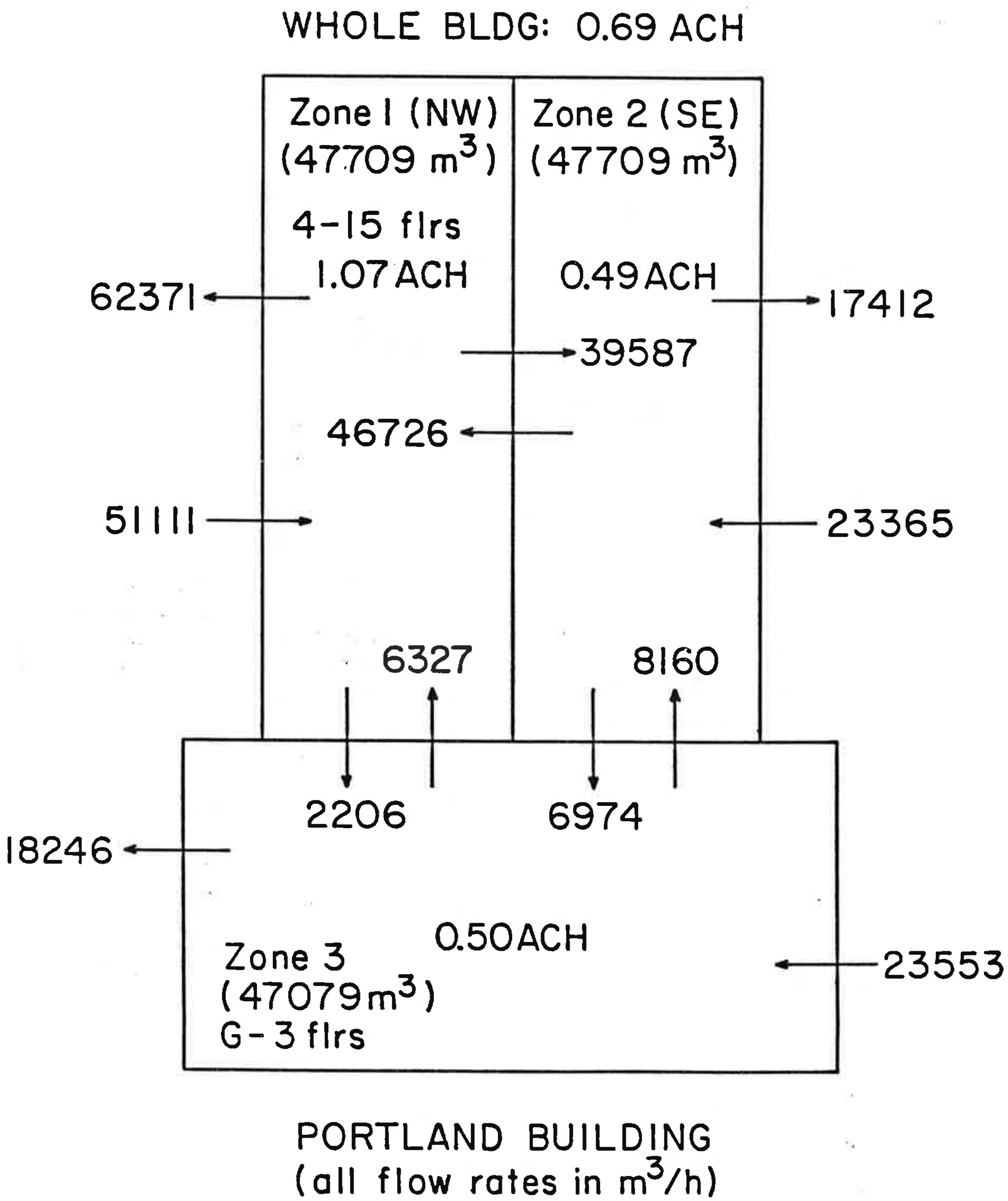


FIGURE 6 (28-H TEST)

The two figures show that there was a 4-fold ratio in the fresh air infiltration rates between zones 1 and 2, with the former at 1.07 h^{-1} and the latter, 0.25 h^{-1}, during the 7-hr period. This ratio was a factor of 2 during the entire 28-hr period, not as bad because of the off-time during SF_6 injection. Since the occupants were complaining about a lack of fresh air during the 7-hr period, the 0.25 h^{-1} rate may be too low. In any event, a system that the HVAC engineer considered to be in balance was shown by the BNL/AIMS to be significantly out of balance.

During the night of the 28-hr test, 6 SF_6 decay tests were run as shown by the results in Fig. 7 and tabulated in Table 5. Here again, the average SF_6 decay result is close to the true whole building rate determined by BNL/AIMS. Note also the inability of the SF_6 decay to detect the HVAC imbalance.

Implications of BNL/AIMS

For energy conservation and indoor air quality assessment studies, the BNL/AIMS is a powerful technique for determining air infiltration, exfiltration, and mixing between zones in multizone building situations. The technique conveniently and accurately gives the infiltration rates into each zone, during actual occupancy conditions, and with no disruption to the occupants nor the normal ventilation situation. With this method, HVAC manufacturers, installers, and operators can certify the performance of their systems. Proper assessment of a whole building ventilation character can be determined. Studies should be initiated to intercompare this technique with the capabilities of other approaches, primarily for a validation of the performance of the other methods.

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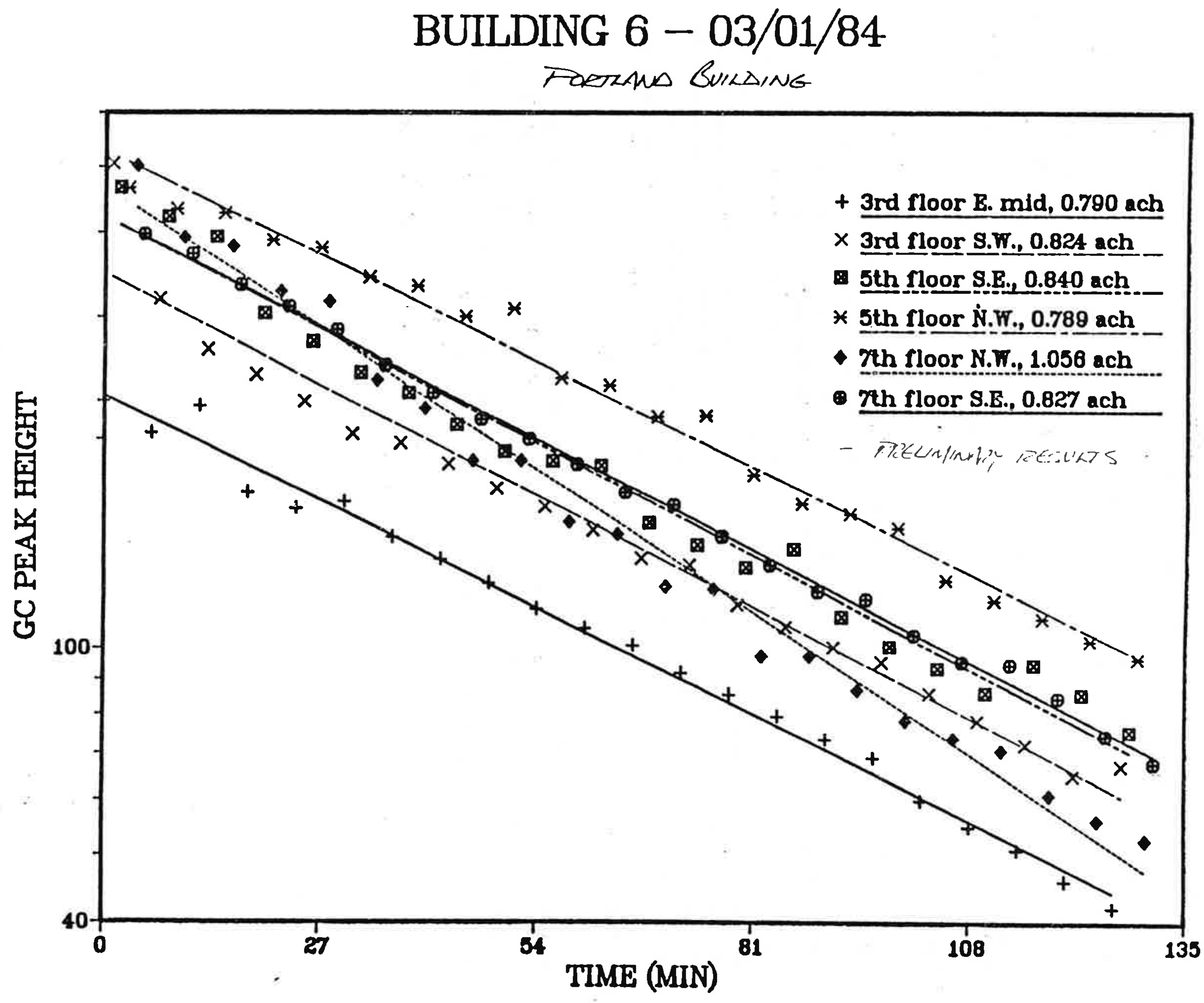
BUILDING 6 – 03/01/84
PORTLAND BUILDING
3rd floor E. mid, 0.790 ach
3rd floor S.W., 0.824 ach
5th floor S.E., 0.840 ach
5th floor N.W., 0.789 ach
7th floor N.W., 1.056 ach
7th floor S.E., 0.827 ach
– PRELIMINARY RESULTS
GC PEAK HEIGHT
100
40
0
27
54
81
108
135
TIME (MIN)

FIGURE 7

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