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Paper 11

EXTENDED TESTING OF A MULTIFAMILY BUILDING USING CONSTANT CONCENTRATION AND PFT METHODS

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SYNOPSIS

More than two months of detailed test data have been gathered using modified constant concentration tracer gas techniques for a six-story, 60 apartment, multifamily building. Weather, and interior conditions in the building were part of the data set. Because of occupant effects, large changes in air exchange rates were observed, often over short time periods. The test apartment allowed us to evaluate the influences of weather alone with the added feature to employ controlled window openings. Detailed air exchange information in the test apartment, those apartments above and below, and those on either side are presented. These same zones were also measured independently by perfluorocarbon tracer methods. Comparisons are made between the information obtained by the two methods and it is pointed out how the methods complement each other.

1.0 INTRODUCTION

As air infiltration measurements are applied to more complex buildings, there are important choices to be made with regard to the detail of the measurements and the cost of the procedures. Two quite different air exchange measurement methods are the constant concentration tracer gas (CCTG) system[1-3] and approaches using perfluorocarbon tracers[4-6] in special ways. This paper describes testing these two air exchange measurement systems in a six-story, 60 apartment, multifamily building which is located in Asbury Park, New Jersey.

The test building is shown in cross section in Figure 1, and was chosen for these test series because of the previously obtained detailed information on energy use through several years of monitoring, and the ability to obtain a research apartment in the building. The energy monitoring was aided by the use of powerline carrier and microcomputer technology, with the data acquisition system monitored directly via telephone modem from our laboratory 60 km away[7]. The same telephone communications approach was used for the monitoring of the CCTG equipment.

Naturally, there is a great difference in the detail of the information obtained using the CCTG and PFT approaches. The paper will illustrate these differences and capabilities of the two approaches pointing out how they can complement each other.

2.0 EMPLOYING THE CCTG SYSTEM:

Because of the physical size of the CCTG equipment and the fact that to maintain the equipment it is necessary to provide both tracer gas and carrier gas bottles on a weekly basis, a dedicated research apartment was absolutely necessary to carry out the studies. Besides housing the tracer gas equipment this also allowed one to control window openings thereby covering those closed window conditions seldom found in the occupied apartments[8].

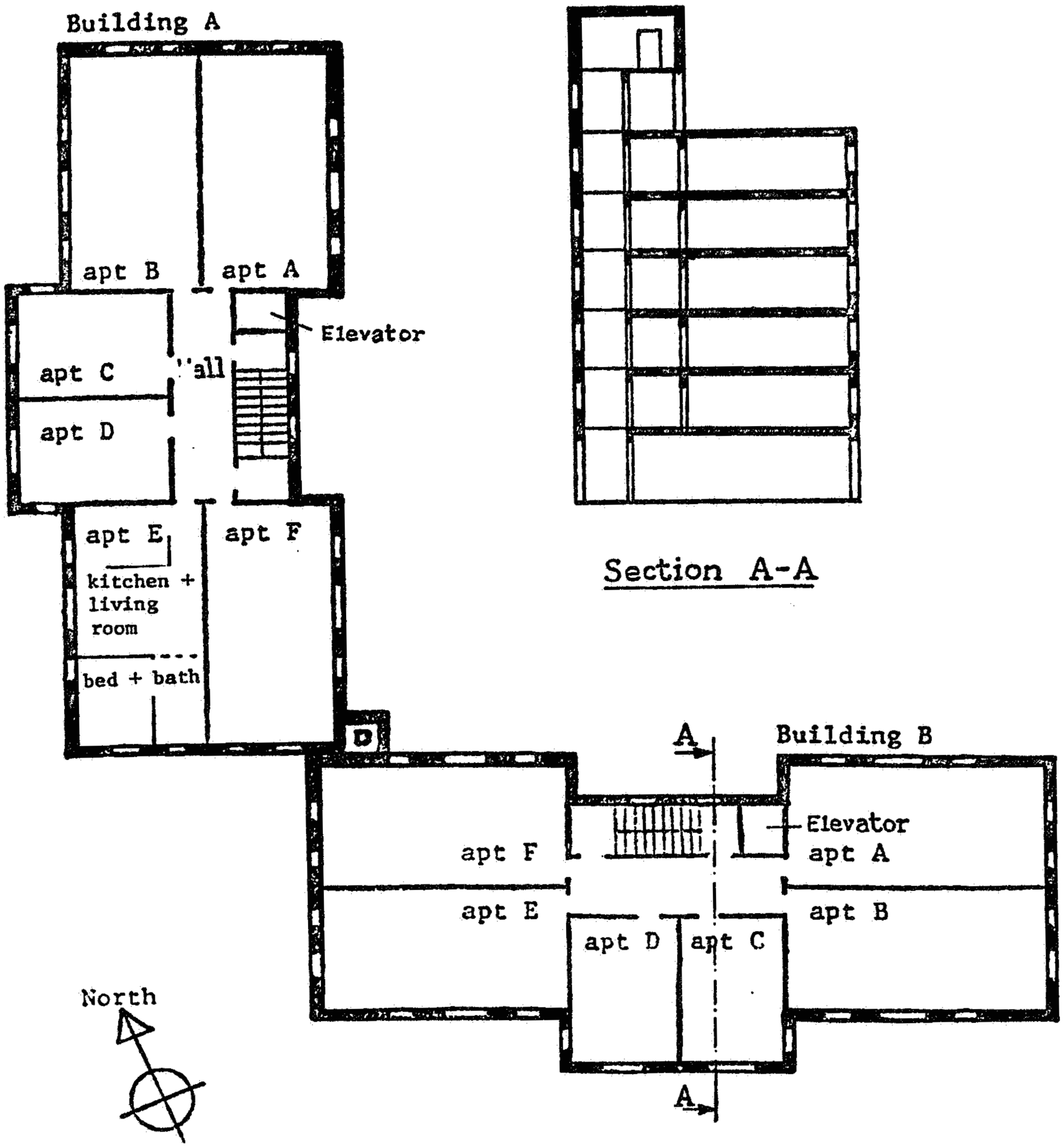


Figure 1 - Lumley Homes multifamily apartment building showing A and B wings and apartment arrangements.

Differences between occupied and unoccupied apartments are easily seen in Figure 2. Here the test apartment exhibits very low infiltration rates averaging approximately 0.17 air changes per hour. A typical occupied apartment during that time period covers a wide range of air exchange rates (up to 15 ACH) and averages 1.5 ACH, an order of magnitude higher than the closed window testing (Previous blower door testing placed the apartments in the 3.0 ACH at 50 pascals range, which would have predicted closed window air exchange rates of about 0.15 for single family residential testing). Figure 2 points out that with window openings the building is operating far from optimal based upon ventilation rate, which should be in the 0.35-0.5 ACH range.

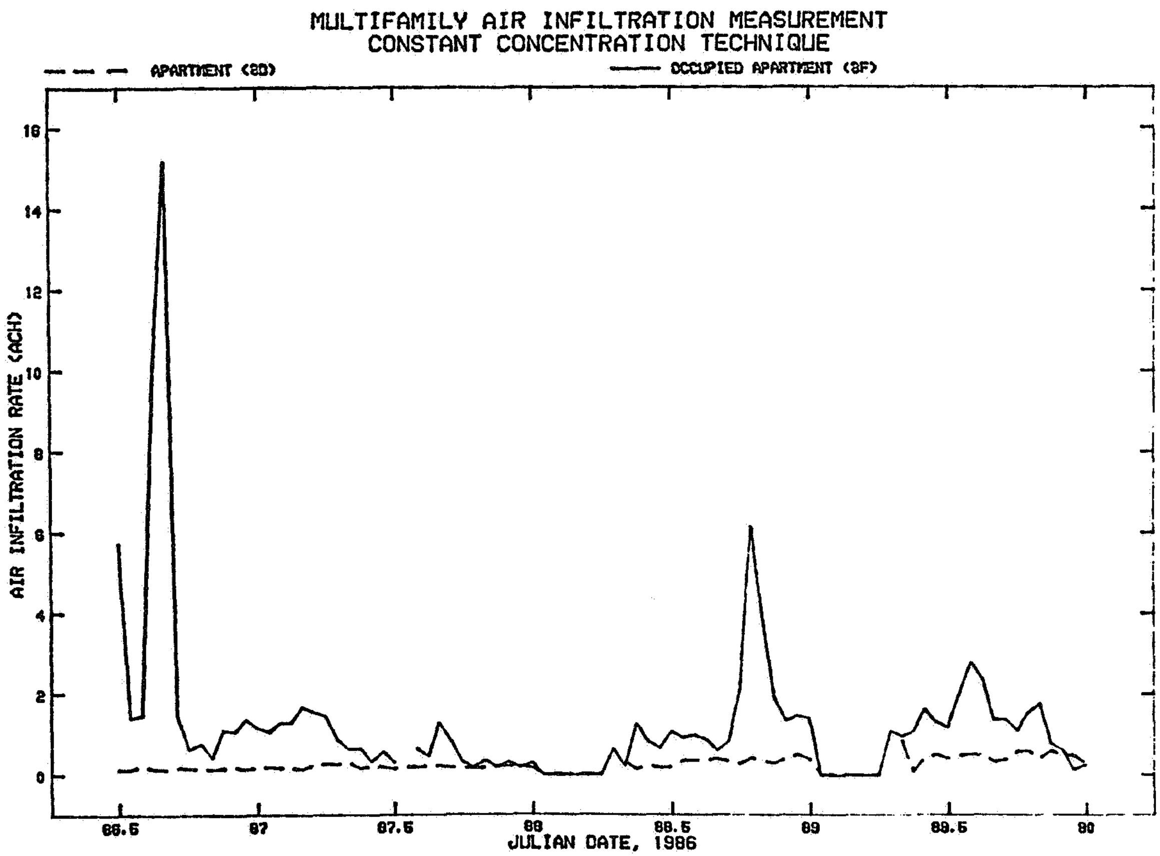


Figure 2 - Constant concentration tracer gas technique used to evaluate the air exchange in an occupied and a closed window apartment in Lumley.

Figure 3 makes use of box plots to illustrate closed and occupant controlled window opening conditions for several apartments in each category. It is very clear from the figure that occupied and closed window conditions for these weather conditions are distinctly different from an air exchange standpoint. There is considerable variability in the three occupant controlled apartments as the box plots point out.

Referring to Figure 1, the relative locations of the apartments can be seen, where A3E refers to building A, floor 3 and apartment E. The apartments on floors 2 and 4 are immediately below and above the test apartment A3E, with A3D and A3F the adjacent apartments. These choices were made so as to allow the necessary plastic tubing (for tracer gas injection and sampling) to extend easily to those apartments from the dedicated test apartment. Actual tube placement made use of steam pipe riser openings and careful routing through door frame mouldings.

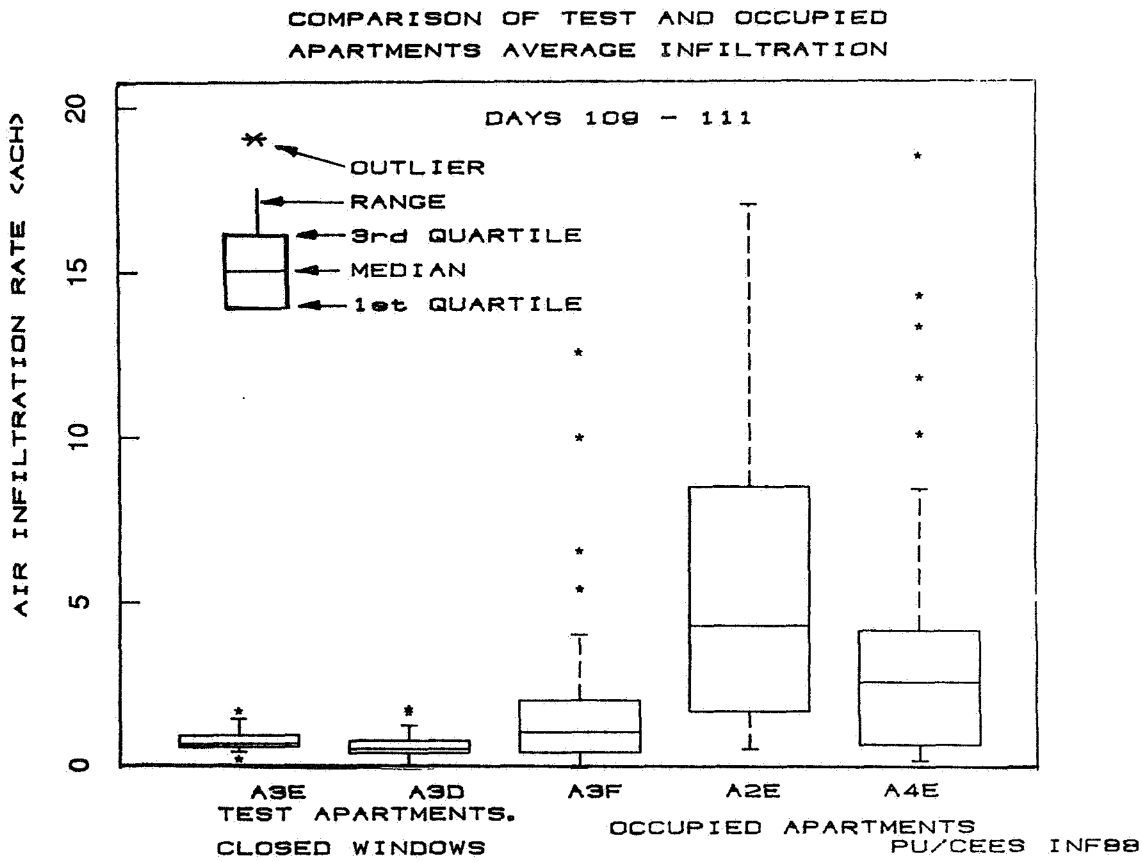
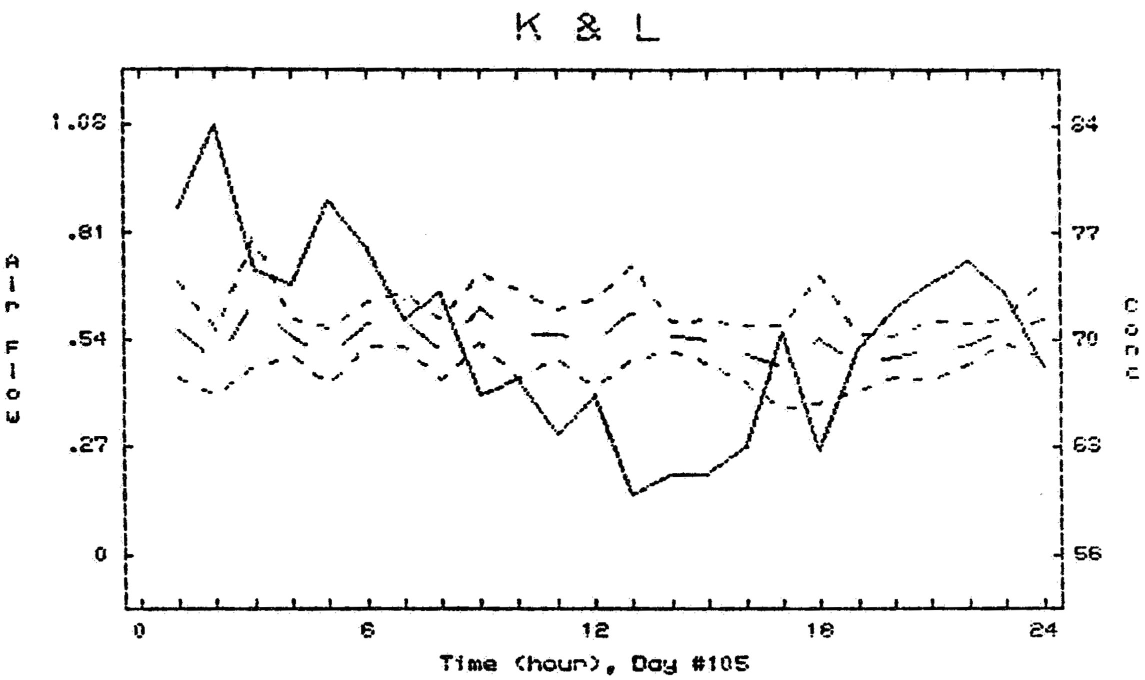


Figure 3 - Box plots showing the range of variation in air exchange between occupied and unoccupied apartments.

Typical CCTG data from the test apartment and the surrounding apartments are shown for Julian date 105 in Figures 4-7. In each of the figures one can observe the achievement of target concentration of the SF6 tracer gas at 70 ppb. Even though there is no mechanical mixing taking place in apartments A3D, A3F, A2E and A4E target concentrations generally tend to stay within a band of the target concentration with a standard deviation in the 15-25 ppb range. Within the test apartment deviations in the target SF6 concentrations are considerably less (standard deviation of 3 ppb) with air mixing aided by small fans.

Figure 4 illustrates the variation in air infiltration pattern for the two zones of the test apartment with the bedroom zone exhibiting air exchange rates approximately twice those of the kitchen living room.

Looking at apartments A3D and A3F, Figure 5 it is easily seen that interzone flow experiments were also run in the early morning hours until 6:00 a.m. This technique using discontinued injection was described in Reference 9. The plot of tracer gas concentration points out the rapid recovery following such testing and the increased tracer gas flow to the hall zone during the test in order to compensate for the reduced concentrations from A3D and A3F and



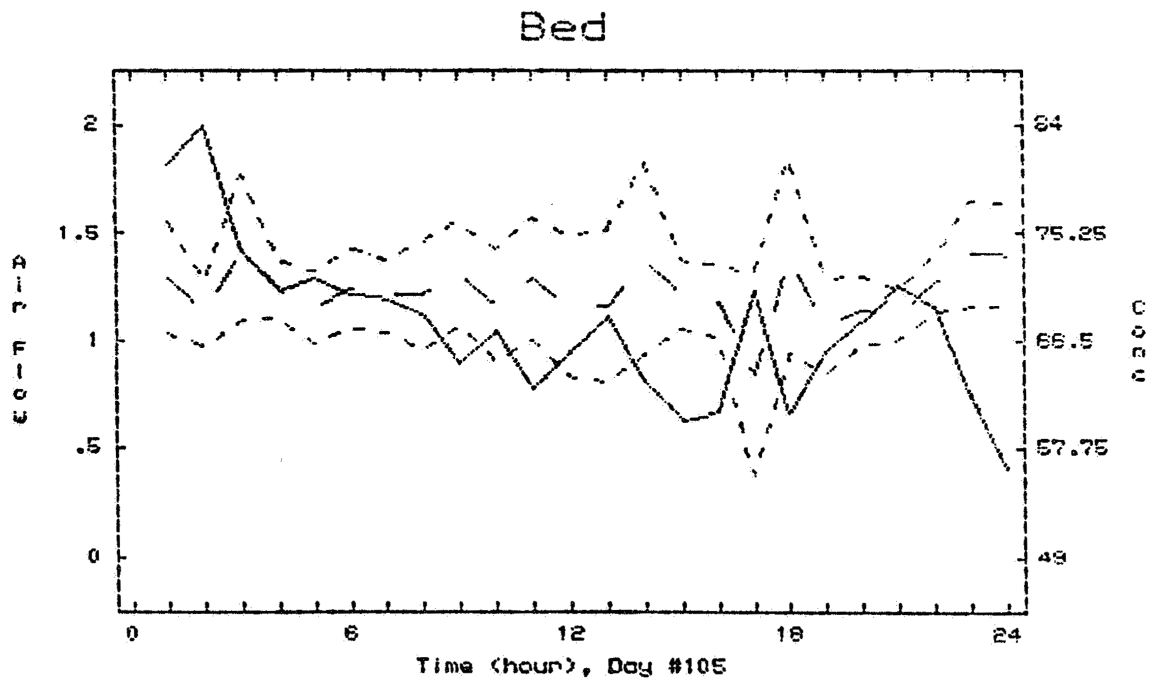
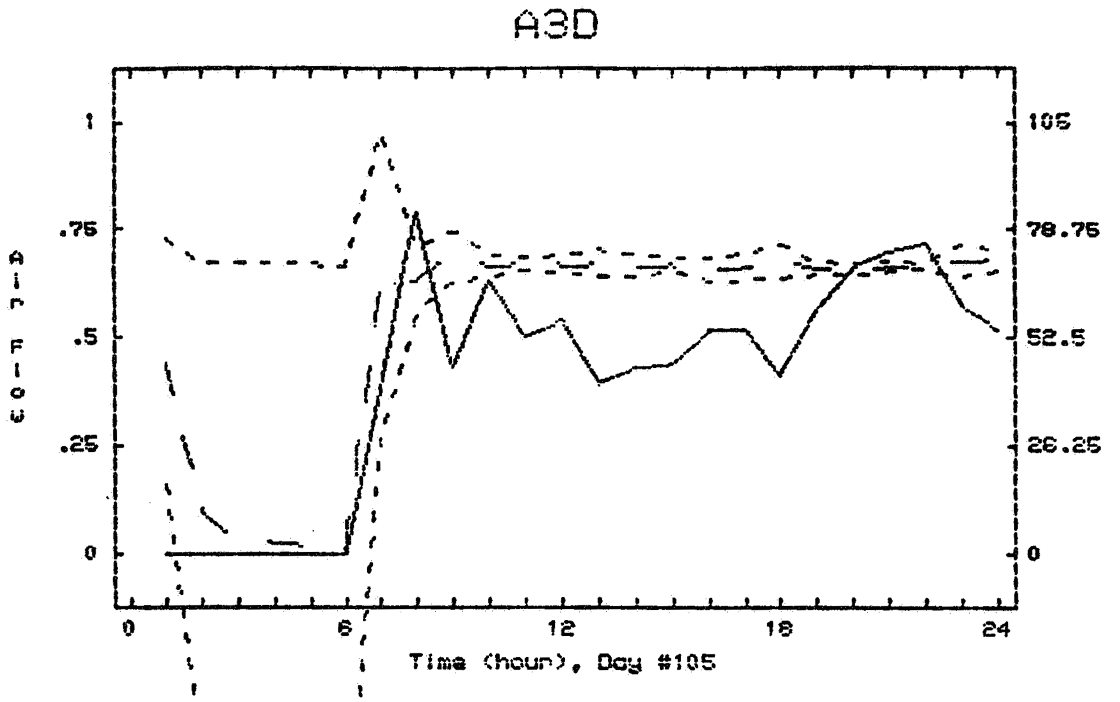


Figure 4 - Time history of air exchange in the kitchen/living room and bedroom zones in the test apartment.



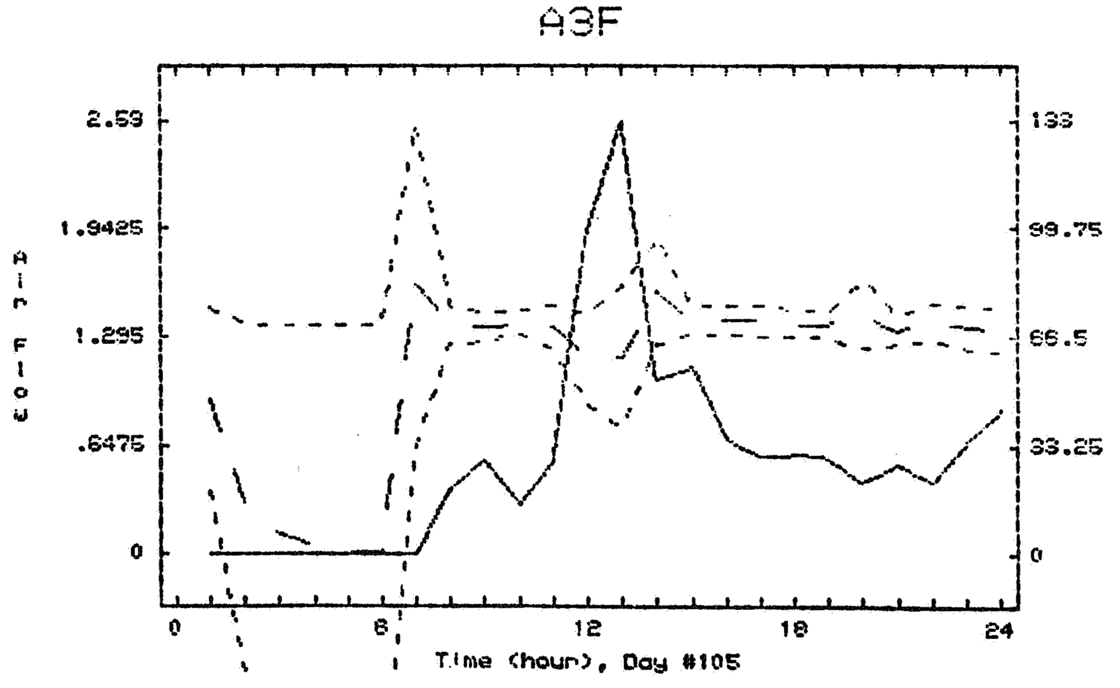
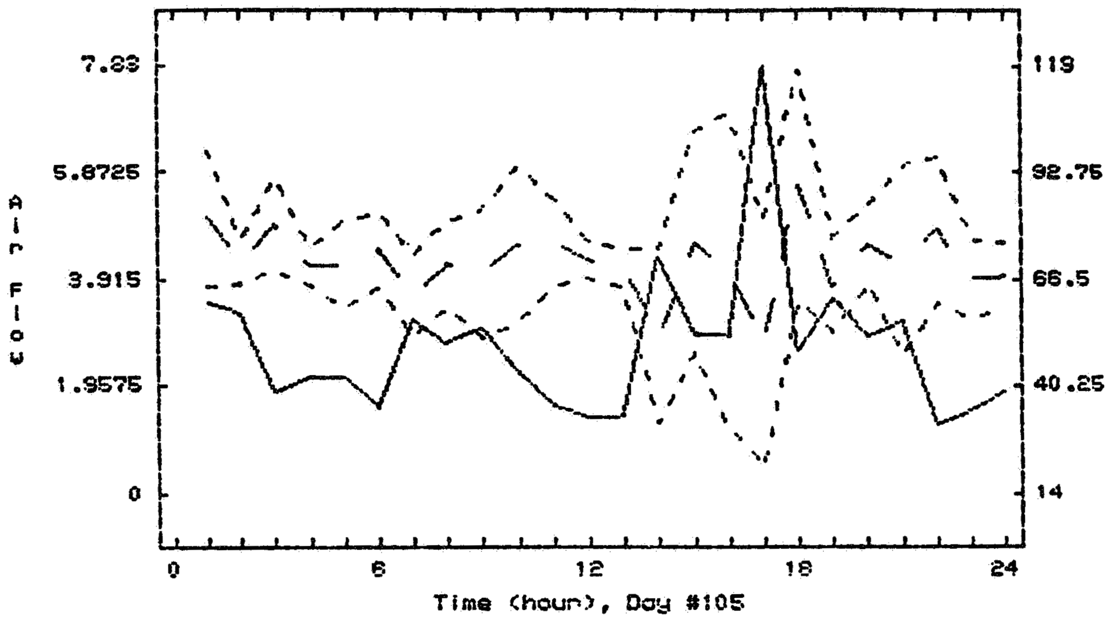


Figure 5 - Time history of air exchange in the occupied apartments adjacent to the test apartment.

A2E



A4E

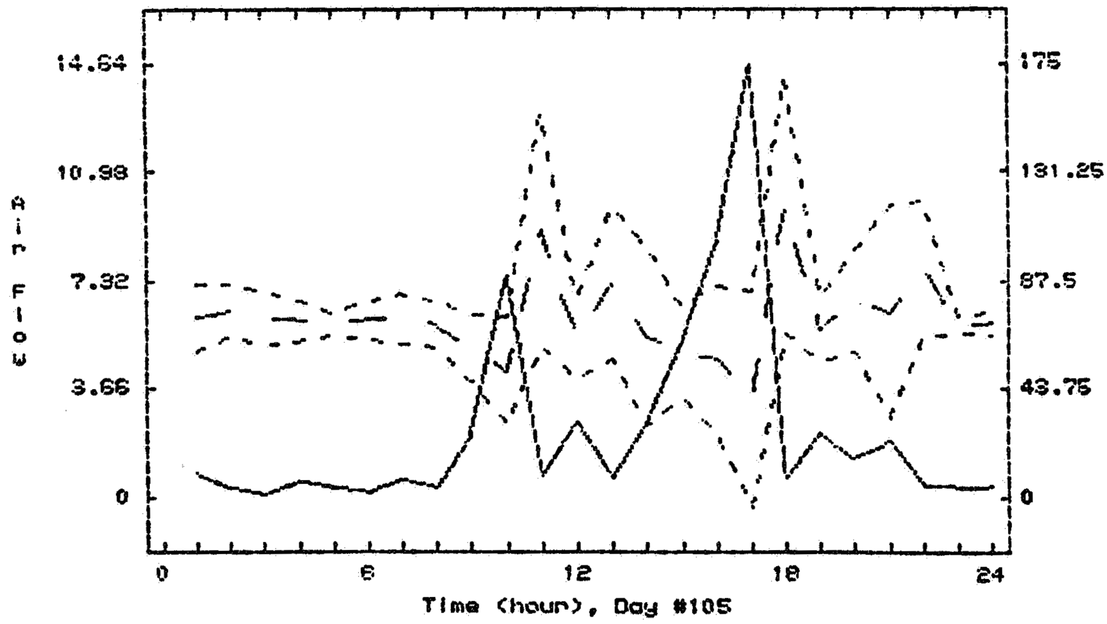


Figure 6 - Time history of air exchange in the occupied apartments above and below the test apartment.

therefore evidence of flow into the hall. Because of such testing the period beyond 8:00 a.m. should be used as representative of the air infiltration values.

Again, as pointed out in Reference 7, occupant effects are evident in the window opening habits and resultant changes in air exchange rate. For example in Figure 6, A2E exhibits a sharp air exchange peak at 17:00, A4E has peaks at 10:00 and 17:00, while in Figure 5 A3F has a peak at 13:00, and A3D is relatively constant. In the test apartment variations and the levels of air infiltration are much reduced with trends exhibited, rather than peak values which suddenly more than triple the air exchange rate.

The data for the hall on floor 3 are illustrated in Figure 7. Hall values are important as representing a communications link to all apartments, and when stairway doors are open, the hall values may prove representative of the entire building. (Stairwell doors should be closed to prevent spread of fire, but were often left open for ventilation purposes.)

From the summaries of these individual daily air exchange data (67 days of data were collected) we obtain the information for the behavior of the building over longer periods. These comparisons may then be made with the information available from passive measurement techniques, such as the perfluorocarbon tracer method, which stresses air exchange measurements over longer periods. Such comparisons are made in section 4.0.

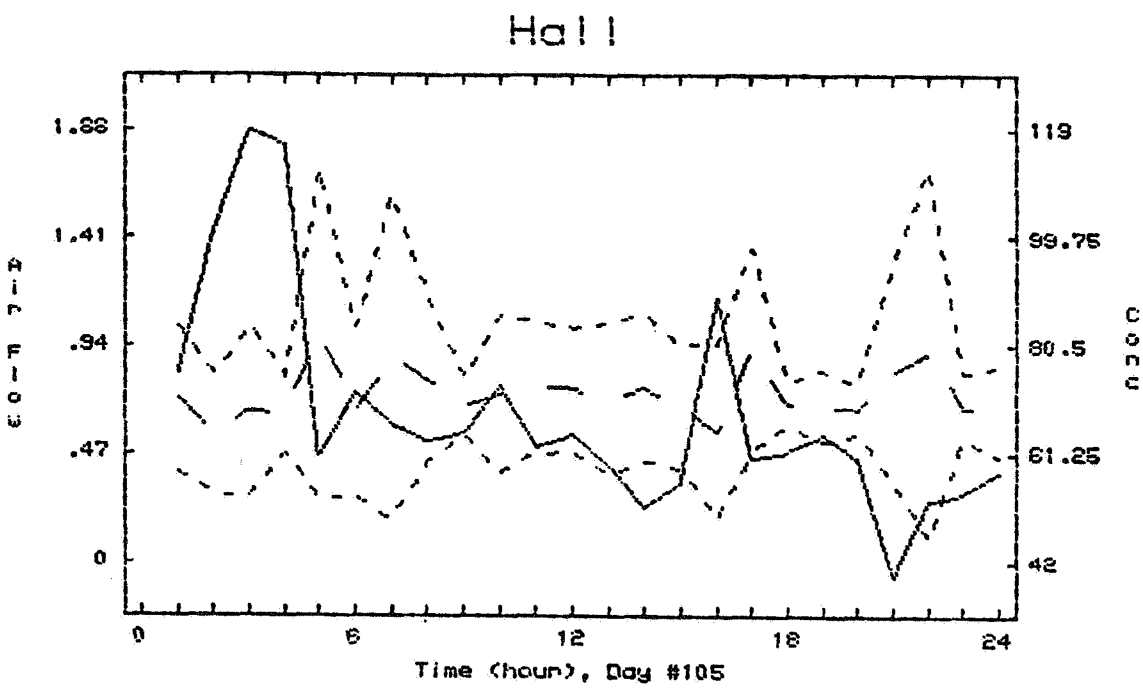


Figure 7 - Time history of air exchange in the hall outside the test apartment.

3.0 USE OF THE PERFLUOROCARBON TRACERS IN THE BUILDING

The perfluorocarbon tracer techniques as currently employed can use six or even seven distinct PFT sources[10]. In the study described here we were limited to three PFT sources because of the way in which our PFT analysis equipment was set up (we have since moved up to four tracers).

The approach used in the multifamily building airflow modeling is described in Figure 8. As the figure points out, the way in which the apartment interacts with the hall and/or adjacent apartments directly effects how many tracer gases are required.

In order to maximize the benefit of the limited number of tracer gases available for these tests, logical source placement was necessary. Three hallways were used but just two floors were done in detail. The actual placement of PFT sources and samplers is shown in Figure 9. In total the number of apartments was 12, measured for periods ranging from one to two weeks. In the simplest test, as described in Table 1, two apartments and the hall on Floor 3 were chosen. Air infiltration and zone interchange takes place and is quantified by the analysis of the CATS (capillary desorption tube sampler). The hall is found to significantly interact with the apartments, i.e., predominantly outward flow through the apartments. Checking the reverse airflow

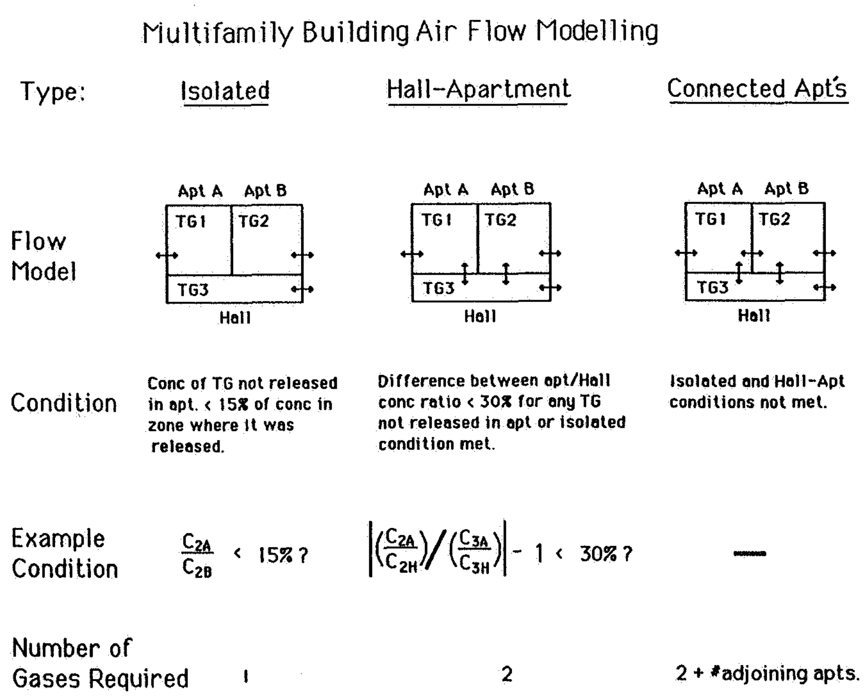


Figure 8 - Airflow considerations used to determine the number of tracer gases required for modeling the multifamily building.

PFT Source and Sampler Placement

Building A

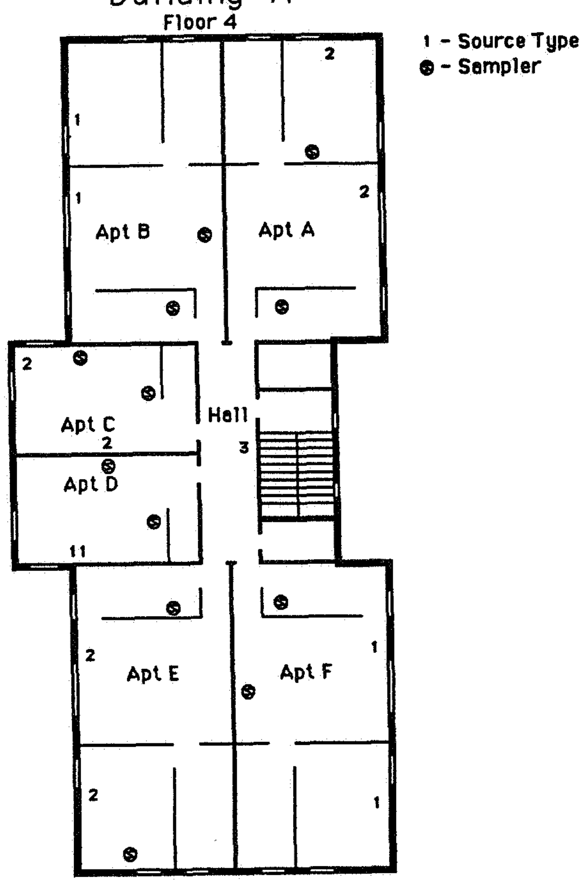


Figure 9 - PFT source and sampler placement in the A wing of Lumley Homes.

case, apartment to hall, flows are very small indicating this is not the preferred path. Looking at hallways above and below Floor 3 we see the flow is upward as anticipated from the stack effect.

In Table 2, additional apartments are added to the test. Tracer 1 is again located in the hall and tracers 2 and 3 are used in alternate apartments surrounding the hall, i.e., tracer 2 is in Apartments B, D, and E and tracer 3 is in Apartments 3C and 3D (see Figure 9). Again, as in Table 1, flows may be traced but now we see significant flow from Apartment 3D to the hall when compared to the other apartments. Flow from the hall to the apartments is greatest for Apartment 3D and 3E and it is also showing a higher than average outward airflow component. Windows were opened in these apartments to a height of one-inch. In this test period there is a significant inward flow component for both tracer 2 and tracer 3 apartments. Looking at vertical flow, again flow is upward with no Floor 3 tracer detected on Floor 2.

Table 3 points out the reduction in outward flow with the windows closed and is the first test where some Floor 3 tracer reaches Floor 2 - i.e., a weaker stack flow is exhibited.

TABLE 1

Test Results For
Period 1: (3-13-87, 16:00 to 3-27-87, 13:35)

Zone Name	Concentration [pL/L]			Source Rate	Source Type	Source/ Conc.
	PMCP(1)	PMCH(2)	PDCH(3)	(nL/h)	(1-3)	(m^3/h)
hall 3	41.33	1.47	5.52	15780	1	381.8
3D	18.45	87.73	2.09	1938	2	22.1
3E	13.11	2.25	68.49	2810	3	41.0
hall 2	0.00	0.00	0.00			
hall 4	6.09	0.63	1.17			

TABLE 2

Test Results For
Period 2: (3-27-87, 13:35 to 4-3-87, 10:40)

Zone Name	Concentration [pL/L]			Source Rate	Source Type	Source/ Conc.
	PMCP(1)	PMCH(2)	PDCH(3)	(nL/h)	(1-3)	(m^3/h)
hall 3	54.69	20.82	13.54	16132	1	295.0
3B	1.16	28.99	0.71	4532	2	156.3
3C	4.88	2.22	28.12	2066	3	73.5
3D	19.18	101.02	5.08	1938	2	19.2
3E	8.43	6.59	70.92	2797	3	39.4
3F	4.36	90.35	3.42	5943	2	65.8
hall 2	0.00	0.00	0.00			
hall 4	4.13	1.57	1.28			

TABLE 3

Test Results For
Period 3: (4-3-1987, 10:40 to 4-16-87, 14:40)

Zone Name	Concentration [pL/L]			Source Rate	Source Type	Source/ Conc.
	PMCP(1)	PMCH(2)	PDCH(3)	(nL/h)	(1-3)	(m^3/h)
hall 3	56.77	17.34	8.86	16132	1	284.1
3B	2.06	47.56	0.31	5197	2	109.2
3C	5.77	1.45	30.28	2112	3	69.8
3D	5.83	25.32	0.81	1981	2	78.2
3E	2.14	1.30	13.48	2615	3	194.0
3F	1.99	62.86	0.98	5560	2	88.4
hall 2	0.15	0.03	0.02			
hall 4	4.74	1.61	0.94			

Tables 4 and 5 introduce tracers in apartments on two floors. Hall four uses tracer 3 and the apartment tests make use of tracers 1 and 2; where tracer 2 has been indexed one apartment location from that used on Floor 3. The patterns are similar except that Apartment 4D has essentially the same concentration as the hall on Floor four. All indications are that the door was open during both test periods, but even with the door open, flow to the hall from that apartment was insufficient to achieve complete coupling and thus raise the hall to the apartment concentrations of tracer 1.

Looking at the third floor apartment air infiltration data, of Table 6, occupied units exhibit average air infiltration rates of 0.81 - 0.96 air exchanges based on the total airflow per hour, and these values are fairly constant across the test periods. The air infiltration values cover a range from 0.51 to 1.29.

TABLE 4

Test Results For
Period 4: (4-16-87, 14:40 to 4-24-87, 12:40)

Zone Name	Concentration [pL/L]			Source Rate (nL/h)	Source Type (1-3)	Source/ Conc. (m^3/h)
	PMCP(1)	PMCH(2)	PDCH(3)			
hall 3	55.69	14.46	8.33	16490	1	296.1
3B	6.25	49.87	0.72	5813	2	116.6
3C	16.30	3.22	36.41	2207	3	60.6
3D	21.94	34.33	2.63	2017	2	60.3
3E	3.48	2.24	22.39	2848	3	127.2
3F	1.03	60.35	0.52	5560	2	92.1
hall 2	0.25	0.05	0.00			
hall 4	8.78	8.53	15.44	7072	3	458.0
4A	1.11	77.06	0.58	3387	2	44.0
4B	9.99	2.35	3.05	5278	1	528.4
4C	5.32	118.73	5.65	4051	2	34.1
4D	32.34	5.27	17.07	6596	1	204.0
4E	1.99	40.20	2.85	3790	2	94.3
4F	27.75	1.92	5.00	5906	1	212.8

TABLE 5

Test Results For
Period 5: (4-24-87, 12:40 to 5-6-87, 13:20)

Zone Name	Concentration [pL/L]			Source Rate (nL/h)	Source Type (1-3)	Source/ Conc. (m^3/h)
	PMCP(1)	PMCH(2)	PDCH(3)			
hall 3	49.30	16.79	10.77	16132	1	327.2
3A	2.89	1.02	16.13	1890	3	117.2
3B	2.58	34.36	1.03	5081	2	147.9
3C	6.69	2.15	44.68	2112	3	47.3
3D	4.79	28.38	1.37	1895	2	66.8
3E	1.61	1.50	16.51	2615	3	158.4
3F	2.31	66.01	1.02	6212	2	94.1
hall 2	0.33	0.20	0.33			
hall 4	12.84	8.51	23.71	7072	3	298.3
4B	10.84	2.60	4.20	3544	1	326.8
4C	4.28	165.44	7.97	5906	2	35.7
4D	39.02	5.59	22.05	4141	1	106.1
4E	1.68	29.65	2.99	6039	2	203.7
4F	25.71	2.39	6.66	3875	1	150.7

Tables 6-10 summarize the airflow computation for the same five test periods. Total flows to each zone are calculated together with the breakdown of hall-apartment flow versus air infiltration, air infiltration is then expressed in air exchanges per hour, and infiltration related to the total flow. The last columns relate to whether flow is from the hall or adjacent apartment.

Reviewing the information obtained from the PFT testing to evaluate the ratio of airflow from hall to apartments versus flow to the hall, the indication is that approximately 10% reaches the apartment via this route versus flow paths associated directly with the outside air. Both Floor 3 and Floor 4 can be evaluated in this way.

Table 11 summarizes the air infiltration values during four periods noting windspeed and outdoor temperature for each period.

TABLE 6

Air Flow Rate Computation For
Period 1: (3-13-87, 16:00 to 3-27-87, 13:35)

Zone Name	Total Flow (m3/h)	Hall-apt (m3/h)	Infil (m3/h)	Infil (ACH)	Infil/ Total	Zone conc/Hall conc Hall TG	Adj Apt TG
3D	22.3	9.9	12.3	0.21	0.55	0.45	0.38
3E	42.1	13.4	28.8	0.24	0.68	0.32	1.53
Total	64.4	23.3	41.1	0.23			

TABLE 7

Air Flow Rate Computation For
Period 2: (3-27-87, 13:55 to 4-3-87, 10:40)

Zone Name	Total Flow (m3/h)	Hall-apt (m3/h)	Infil (m3/h)	Infil (ACH)	Infil/ Total	Zone conc/Hall conc Hall TG	Adj Apt TG
3B	158.8	3.4	155.4	1.29	0.98	0.02	0.05
3C	76.8	6.9	69.9	1.17	0.91	0.09	0.11
3D	20.7	7.3	13.4	0.22	0.65	0.35	0.36
3E	40.6	6.3	34.4	0.29	0.85	0.15	0.32
3F	67.0	5.3	61.7	0.51	0.92	0.08	0.25
Total	363.9	29.1	334.9	0.70			

Ratio of the sum of hall to apartment
air flow to the total flow into hall : 0.10

TABLE 8

Air Flow Rate Computation For
Period 3: (4-3-1987, 10:40 to 4-16-87, 14:40)

Zone Name	Total Flow (m3/h)	Hall-apt (m3/h)	Infil (m3/h)	Infil (ACH)	Infil/ Total	Zone conc/Hall conc Hall TG	Adj Apt TG
3B	110.7	4.0	106.7	0.89	0.96	0.04	0.04
3C	71.9	7.3	64.6	1.08	0.90	0.10	0.08
3D	84.2	8.6	75.5	1.26	0.90	0.10	0.09
3E	199.0	7.5	191.5	1.60	0.96	0.04	0.08
3F	89.3	3.1	86.2	0.72	0.96	0.04	0.11
Total	555.0	30.6	524.5	1.09			

Ratio of the sum of hall to apartment
air flow to the total flow into hall : 0.11

TABLE 9

Air Flow Rate Computation For
Period 4: (4-16-87, 14:40 to 4-24-87, 12:40)

Zone Name	Total Flow (m3/h)	Hall-apt (m3/h)	Infil (m3/h)	Infil (ACH)	Infil/ Total	Zone conc/Hall conc Hall TG	Adj Apt TG
3B	120.5	13.5	107.0	0.89	0.89	0.11	0.09
3C	65.0	19.0	45.9	0.77	0.71	0.29	0.22
3D	72.3	28.5	43.8	0.73	0.61	0.39	0.32
3E	130.2	8.1	122.1	1.02	0.94	0.06	0.16
3F	92.5	1.7	90.8	0.76	0.98	0.02	0.06
Total	480.5	70.8	409.7	0.85			
4A	44.1	1.7	42.5	0.35	0.96	0.04	0.13
4B	639.4	126.3	513.1	4.28	0.80	0.20	0.28
4C*	35.0	12.8	22.2	0.37	0.63	0.37	0.61
4D*	291.4	322.2	-30.7	-0.51	-0.11	1.11	0.62
4E	98.1	18.1	80.0	0.67	0.82	0.18	0.23
4F	237.1	76.8	160.3	1.34	0.68	0.32	0.23
Total	1053.7	235.7	818.1	1.52			

Ratio of the sum of hall to apartment floor 3 - 0.24
air flow to the total flow into hall : floor 4 - 0.51

TABLE 10

Air Flow Rate Computation For
Period 5: (4-24-87, 12:40 to 4-5-87, 13:20)

Zone Name	Total Flow (m3/h)	Hall-apt (m3/h)	Infil (m3/h)	Infil (ACH)	Infil/ Total	Zone conc/Hall conc Hall TG	Adj Apt TG
3A	122.0	7.2	114.8	0.96	0.94	0.06	0.06
3B	151.8	7.9	143.8	1.20	0.95	0.05	0.10
3C	48.9	6.6	42.2	0.70	0.86	0.14	0.13
3D	70.9	6.9	64.0	1.07	0.90	0.10	0.13
3E	161.8	5.3	156.6	1.30	0.97	0.03	0.09
3F	95.2	4.5	90.8	0.76	0.95	0.05	0.09
Total	650.5	38.4	612.1	1.02			
4B	413.6	73.3	340.3	2.84	0.82	0.18	0.31
4C	36.3	12.2	24.1	0.40	0.66	0.34	0.33
4D*	152.9	142.2	10.7	0.18	0.7	0.93	0.66
4E	211.3	26.7	184.7	1.54	0.87	0.13	0.13
4F	175.3	49.3	126.1	1.05	0.72	0.28	0.28
Total	836.5	161.5	675.2	1.61			

Ratio of the sum of hall to apartment floor 3 - 0.12
air flow to the total flow into hall : floor 4 - 0.54

*Note - apartment 4D not included in total

TABLE 11

Variation of Air Infiltration in Three
Third-Floor Occupied Apartments

Period	Infiltration(ACH) 3B	3C	3F	Average	Outdoor Temperature(C)	Wind Speed(m/s)	Time Span(days)
2	1.29	1.17	0.51	0.96	8.4	5.6	6.8
3	0.89	1.08	0.72	0.86	9.4	4.4	12.9
4	0.89	0.77	0.81	0.81	10.2	5.2	7.9
5	1.20	0.70	0.76	0.92	9.1	5.5	12.0

TABLE 12

Ratio of Concentration in Hall Four to that in Hall Three

Period	PMCP	PMCH	PDCH	Average
1	15	-	-	15
2	8	8	9	8
3	8	9	11	9

- The air flowing from the third floor to the fourth floor hallway came from the third floor hallway and not directly from the apartments.

- Eight to 15 percent of the air entering the fourth floor hallway came from the third floor hallway.

Table 12 looks at the origin of air reaching hall four and points out that it is hall-to-hall flow upward in the building.

4.0 COMPARISONS OF AIR EXCHANGE MEASUREMENTS

Based upon the measurement periods used to collect the air exchange information using the PFT method, we can now return to the CCTG data and calculate air exchange values. Table 13 summarizes this information for the CCTG method.

TABLE 13

CCTG Lumley Air Exchange Values
Corresponding to the 5 PFT Periods
(negative values excluded throughout)

		Air Exchange MIN	MAX	AVG
Period 1				
PFT Day 72/16:00 - 86/13:35	Hall 3	0.0	95.2	7.20
CCTG 72/16:00 - 86/13:00	3D	0.0	6.90	0.32
(78.084-79.709 and 82.918-83.751 missing)	3E	0.0	67.6	1.01
Period 2				
PFT Day 86/13:35 - 93/10:40	Hall 3	0.0	44.9	3.67
CCTG 86/14:00 - 93/10:00	3D	0.0	0.83	0.27
	3E	0.0	0.36	0.17
	3F	0.0	19.4	1.54
Period 3				
PFT Day 93/10:40 - 106/14:40	Hall 3	0.0	24.7	0.88
CCTG 93/11:00 - 106/13:00	3D	0.0	7.96	0.71
	3E	0.0	12.17	0.84
	3F	0.0	27.6	1.13
Period 4				
PFT Day 106/10:40 - 114/12:40	Hall 3	0.0	18.6	1.76
CCTG 106/11:00 - 114/11:00	3D	0.0	32.1	0.93
	3E	0.0	19.3	0.96
	3F	0.0	66.5	1.66
	4E	0.0	39.3	2.44
Period 5				
PFT Day 114/12:40 - 126/13:20	Hall 3	0.0	14.3	1.38
CCTG 114/12:00 - 126/12:00	3D	0.0	4.98	1.23
	3E	0.0	5.48	1.40
	3F	0.0	81.3	1.71
	4E	0.0	12.3	1.45

Table 14 summarizes the comparisons of readings for the apartments and building zones common to the two measurement methods for the same time periods. Altogether 16 conditions are compared. One might first conclude that the PFT air exchange measurements tend to be lower than the CCTG measurements, especially for the highest

TABLE 14

Comparison of CCTG and PFT Measurements for the Same Apartments and Time Periods

		APARTMENTS 3D	3E	3F	4E
Period 1	PFT	0.21	0.24		
	CCTG	0.32	1.01		
% Diff PFT to CCTG		34% less	76% less		
Period 2	PFT	0.22	0.29	0.51	
	CCTG	0.27	0.17	1.54	
		19% less	71% more	67% less	
Period 3	PFT	1.26	1.60	0.72	
	CCTG	0.71	0.84	1.13	
		77% more	90% more	36% less	
Period 4	PFT	0.73	1.02	0.76	0.67
	CCTG	0.93	0.96	1.66	2.44
		22% less	6% more	54% less	73% less
Period 5	PFT	1.07	1.30	0.76	1.54
	CCTG	1.23	1.40	1.71	1.45
		13% less	7% less	56% less	6% more

CCTG air exchange rates (1.54, 1.66 and 2.44). However, the fourth highest CCTG value of 1.45 is exceeded by a 1.54 PFT reading, and the highest PFT reading of 1.60 only registered 0.84 on the CCTG equipment. One reason for the differences between the two measurement methods may be the mixing factor. With window openings mixing tends to be more erratic and often incomplete (e.g., the increased variability of the target concentration shown in Figures 5, 6, and 7). There is no doubt that air exchange rates change rapidly, one only has to look at the occupied apartment 4E shown in Figure 2.

5.0 CONCLUSIONS

The use of both CCTG and PFT methods reveal the necessary air exchange information for a complex, multifamily building. Measurements point out the nature of the interaction between zones and show that for this building air exchange occurs between the hall and respective apartments rather than between the apartments themselves. Stack effect is evident with only isolated instances of measured downward flow. Extremes of air exchange rates are evident and are illustrated in the detailed hourly data, where the low levels directly relate to indoor air quality and high levels indicate energy waste. The average air exchange data reveals the true energy impact of air infiltration. As more apartments are measured one begins to see patterns of air exchange and changing stack flow influences on individual floors. Adjustment of window openings is also shown to immediately influence the air exchange rate. One would have hoped for better agreement between the CCTG and PFT measurements on the same apartments, however, the differences point out how important complete mixing is to measurement procedures, and to obtaining accurate air exchange information.

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Discussion

Paper 11

J. Van Der Maas (Ecole Polytechnique Federale de Lausanne, Switzerland) Is it true, as suggested in the Figure comparing PFT and CCTG data, that in the case of incomplete mixing the effects of PFT and CCTG are opposite and that therefore these are complementary methods giving the potential to discard "incomplete mixing" data points?

D. Harrje (Princeton University) If all PFT samplers and sources were identically placed to the CCTG sampling and injection tubes, we would anticipate that mixing effects would be the same. However restrictions as to where the CCTG tubing could be run in the occupied apartments and the fact that multiple sources of the PFT gases were required to supply sufficient tracer, made the layout of source and sampling points different for PFT and CCTG. Hence mixing effects can be different between systems and between apartments.

M. Bassett (Building Research Association of New Zealand) Can you briefly outline your PFT system and give some indication of set-up and operational costs?

D. Harrje (Princeton University) The version of the PFT system we use at Princeton is modelled after the Brookhaven Laboratory's airborne unit - the unit used to measure power plant seeded PFT in the study of acid rain. The table-top version used in our laboratory costs approximately $20,000 for the gas chromatographic equipment and $12,000 for the special rack to hold samplers, the heating controls for energising the rack and the microcomputer to operate the entire system. The system has used three or four tracer gases with 8 minutes per analysis required for each tracer sampler (CATS).