

The Air Infiltration and Ventilation Rates in Two Large Commercial Buildings

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ABSTRACT

This article presents data on the air infiltration and ventilation rates in two large commercial buildings. One building is a 4-story, approximately 107,600 ft² (10,000 m²) office building located outside of Glasgow, Scotland; the other is a 26-story, approximately 1,076,000 ft² (100,000 m²) skyscraper located in downtown Newark, N.J. The data on the air infiltration and ventilation rates in these buildings were collected by a microcomputer-based automated air infiltration system, which controlled the injection of a tracer gas into the various zones of the building and monitored its decay. In addition to the data on air exchange rate produced by analysis of the tracer decay data, the microcomputer also monitored the operation of the building's HVAC systems, the interior temperature, building envelope surface pressures, the exterior temperature, and wind speed and direction.

INTRODUCTION

In the last few years, a large number of measurements have been made of air infiltration in residential buildings, and the measurement technology has advanced to such a point that such measurements can be made routinely either using automated air-infiltration monitoring equipment or using simple low-cost sampling techniques¹. Models have been developed for predicting the air infiltration rate in a residential building by measuring the tightness of the building envelope with fan pressurization methods². However, for large commercial buildings, little measured data have been collected.

It is generally assumed that the air exchange rate for large buildings is dominated by the ventilation requirements and that air leakage in such a building is only a small component of the total air exchange rate. The results of the fan pressurization tests of Tamura and Shaw support this assumption. They also have developed equations for relating the results of the fan pressurization tests to natural air infiltration in large buildings³. However, little data have been collected to verify that the air infiltration predicted by the Tamura-Shaw equations are those experienced by the building. Hunt and Treado⁴ measured air infiltration in the 11-story administration building of the National Bureau of Standards (NBS) and found that this building experienced air infiltration rates in excess of one air exchange per hour and had a large residual air infiltration rate that could not be explained by variations in the weather.

Also, little data have been gathered to verify that the ventilation rates that large buildings experience under actual usage are those intended by the designers of the building and the designers of the HVAC systems. In energy-conserving buildings, even a small air infiltration rate can have serious effects on building performance if not properly taken into in the design of the building. In the energy-conserving federal office building studied by NBS⁵,

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the poor quality of construction led to air infiltration rates that seriously degraded the performance of the building.

The parameters that influence air leakage in large buildings are not well understood. It is not certain whether the air leakage is driven by pressures induced by the operation of the mechanical system, the occupancy patterns of the building, or the natural driving forces of wind and temperature. In order to obtain a better understanding of how air exchange rates affect the energy requirements of large commercial buildings, the National Bureau of Standards, under sponsorship of the U. S. Department of Energy, undertook a study in two large commercial building on the air infiltration and ventilation rates which these buildings experience under typical usage and weather conditions.

The first building, the Collins Building, is a 4-story, approximately 107,600 ft² (10,000 m²) office building near Glasgow, Scotland. Study of this building is part of the United States' contribution to an International Energy Agency project to provide experimental data on this building's energy performance. The data are to be used to verify various computer programs for predicting energy requirements of large buildings. This effort is led by the Building Services Research Unit of the University of Glasgow. The second building is the 26-story Park Plaza Building in Newark, N.J. This Building has been designed and constructed for energy conservation. Its energy usage is being monitored by Trishman Associates for the Department of Energy. This paper will describe the instrumentation and measurement techniques used to measure the air infiltration and ventilation rates in these two buildings. It will also present data on the air exchange rates that these buildings experienced over the last two years.

The data from these two buildings tend to confirm that the air infiltration component of the buildings' ventilation rates is small; less than .2 air changes per hour for the Park Plaza building and about .3 air changes per hour for the Collins building on the whole. However, certain zones of the building may have excessively large air exchange rates. The ventilation rates in these buildings also vary with season. In the Park Plaza Building, typical ventilation rates are of the order of magnitude of .5 air changes per hour for summer operations, 1.5 air changes per hour in the spring and fall, and about .9 air changes per hour in the winter. The Collins Building in Glasgow, Scotland, typically has a ventilation rate of about 1.5 air changes per hour, fairly independent of the season. The minimum ventilation rates of these buildings are 1.1 for the Collins Building and .75 for the Park Plaza Building.

DESCRIPTION OF THE TWO LARGE BUILDINGS

The two buildings studied in this project were the Park Plaza Building in Newark, N.J., and the Collins Building in Bishopbriggs near Glasgow, Scotland. Figure 1 is a photograph of the Park Plaza Building and Fig. 2, the Colling Building. The Park Plaza Building is a 26-story, approximately 1,076,000 ft² (100,000 m²) highrise located in downtown Newark. It is served by six HVAC systems. The main HVAC system is located on the twenty-sixth floor in the upper mechanical equipment room. The system consists of five supply fans with a total capacity of approximately 425,000 cfm and four return fans with a total capacity of approximately 400,000 cfm. This system serves floors 3 through 26 through four vertical supply ducts and two return air shafts. This part of the building is referred to as the tower in this paper.

The tower occupies approximately three quarters of the building. The rest of the building receives its air circulation from five air-handling systems located in the lower mechanical equipment room in the second sublevel. These units serve: (1) the lower level offices, (2) the first and second floor lobbies, (3) the computer room, (4) the adjoining three-story Plaza Building, and (5) a bank on the first floor. Thus, the Park Plaza Building has six principal zones.

These zone are not all independent. The third floor, which is a cafeteria, opens to the second-floor lobby through an escalator. The Plaza Building connects to the third-floor of the tower and the second-floor lobby by a bridge, which is open. The building's major occupant is Public Service Electric and Gas Company of New Jersey, which occupies the Plaza Building and tower floors 2 through 22. Floors 23 through 25 are occupied by lawyers'

offices.

The Collins Building is a four-story, approximately 107,600 ft² (10,000 m²) office building located in the countryside near Glasgow. The major parts of the building are the main volume consisting of the basement, ground floor, first floor, and second floor, a computer room, the third floor, and a sports area. The sports area operates on 100 % outside air. The building is occupied by the Collins Publishing Company. The third floor is used for executive conferences, lunches, and meetings. The other floors serve as general office space.

DESCRIPTION OF THE INSTRUMENTATION

The instrumentation used to measure the air exchange rates in large buildings is a specially designed microcomputer-based automated air infiltration monitor⁵. A diagram of its major components is shown in Fig. 3. The system consists of an S-100 buss microcomputer with two 5-1/4 in. disk drives, an electron capture gas chromatograph, a CRT terminal, a ten-port sample manifold, and up to five tracer-gas injection units.

The tracer gas used in these studies was sulfur hexafluoride (SF₆). Though there are several suitable tracer gases and various types of gas monitors for measuring air infiltration rates in residences, most of these have a sensitivity in the range of a few parts per million (the most common alternative is an infrared detector using either N₂O or SF₆). For the measurement of air exchange rates in large buildings with volumes greater than 107,600 ft² (10,000 m³), this type of equipment would require prohibitive quantities of tracer gas. For the Park Plaza Building, one would need at least one A1 cylinder [99.12 lb (45 kg)] of SF₆ per day. With an electron capture gas chromatograph, sensitivities better than 1 ppb. These were not used for two reasons: their cycle time between measurements is usually greater than one minute (about 4 to 5 min.), and leaks in the solenoids of the injection units become more critical at this measurement level. The number of sample ports was selected as ten to permit monitoring of each location at least once every ten minutes with a gas chromatograph with a cycle time of one minute. The S-100 buss microcomputer consisted of a CPU card, a disk controller card, 64K of memory, a 100,000-day real-time clock, a number of 16-channel analog-to-digital converter cards (depending on the number of analog measurements to be made), and two specially designed interface cards. One card monitored the gas chromatograph and the other controlled the sample manifold, the actuator on the gas chromatograph's sample valve, and the tracer gas injection units and monitored the status of events such as the HVAC system operation and the operation of exhaust fans. The system is capable of measuring wind speed, wind direction, temperature, and pressure. A more complete description of this system is given in Ref. 5.

DATA COLLECTED IN EACH BUILDING

In the Park Plaza Building, two microcomputer-based air-infiltration units were installed because of the extreme distance between the two mechanical equipment rooms. In the tower, 3/8 -in. O.D. nylon sample tubing was run to each of the two return shafts and also to the returns on the 22nd, 20th, 16th, 11th, 7th, and 3rd floors (see Fig. 4-5). Auxiliary sample pumps were used to draw a sample from the space to the sample manifold of the air infiltration monitor. A thermistor was installed in each of the return shafts and on each floor on which a sample tube was installed. A pressure switch was installed in the supply duct to indicate to the microcomputer that the HVAC system was operating. The tracer gas was injected into each of the four supply ducts, and the injection solenoid was wired to the computer controller through the pressure switch so that the circuit was open when the supply fans were off. This prevented injection of tracer gas into the system when the fans were not operating. Later in the project, differential pressure transducers were installed on the 22nd, 16th, and 7th floors. The exterior temperature, wind speed, and wind direction were measured with sensors installed on the roof. Table 1 contains a summary of the data collected in the tower of the Plaza Building.

The air-infiltration monitor in the lower mechanical equipment room monitored the air exchange rates in the other five systems in the building. The

3/8-in. nylon sample tubing was installed in the return air ducts of each of the spaces. If more than one return existed for a space, a sample network was used. Pressure switches were installed on each of the HVAC systems, and the injection solenoids were connected to the computer through the switches. Injection tubes were placed in each supply duct, and a thermistor was installed in each return air duct. Table 2 lists the measurements made in the lower mechanical room.

A similar technique was used for the Collins Building. The only difference was that flow switches were used in place of pressure switches to indicate the status of the HVAC system and the exhaust fans. These were later replaced by relays connected across the indicator lights on the control panel for the HVAC system because turbulence in the duct system made the flow switches unreliable. Table 3 lists the data collected in the Collins Buildings.

CONTROL AND DATA ANALYSIS SOFTWARE

The advantage of a microcomputer system is that data analysis can occur while the data is being collected. However, the use of a microcomputer required the development of software for both controlling the various components of the system and analyzing the data. Software was also developed for calibrating the gas chromatograph and diagnosing the functioning of various components in the system.

Two general subroutine libraries were written for the microcomputer. The first contained the interrupt-related sub-routines that were needed for controlling the injection of tracer gas into the building, determining the status of the HVAC system, and controlling the sample manifold. These subroutines were written in assembly language; however, they were FORTRAN callable. The second library consisted of subroutines that did not depend on the interrupt features of the microcomputer. Fig. 6 shows a block diagram of the structure of the main monitoring program for gathering the air exchange rates in large buildings.

A separate program was written for each system used in this project because of the differences in the types of data collected in each building. Recently a general monitor program has been developed to handle the most common types of information desired in monitoring large buildings.

Initially the monitor program requires the input of data on the gas chromatograph calibration and the building. These data consist of the calibration constants of the electron capture detector, the number of sample points, the number of injection units used, the sample points that correspond to a zone controlled by an injection unit, the volume of the zones, the flow rate of the injection units, and labels used to identify the sample locations and the zones of the building.

These parameters are stored in a file on the program disk. On restart of the monitor program, the computer checks for the existence of the parameter file; if it exists, it continues without asking for new parameters. The program then measures the initial concentrations of tracer gas in each zone and uses these to calculate the time each injection unit must operate to bring the tracer to a predetermined level.

At ten minutes before the hour, tracer is injected into the zones of the building. The program then begins a repeating hourly sequence that consists of: (1) measuring the concentrations of each location once every ten minutes; (2) at the end of five readings for each location, calculating the air exchange rate by statistically determining the best semi-log curve that fits the data; (3) monitoring the status events and analog sensors; (4) storing the data on the data disk; (5) calculating the amount of tracer needed for the next hour; and (6) injecting tracer gas if needed. The progress of the air infiltration unit can be monitored by examining the screen of the CRT terminal. A menu is updated every minute by the computer after the tracer concentration of the sample location has been determined. This menu contains: (1) the time and date (the time is updated each second), (2) the exterior temperature, (3) the wind speed and direction, (4) the interior temperatures, (5) the differential pressure differences, (6) the values of the tracer concentrations measured up to that time, (7) the air infiltration rate of the last hour, (8) the status of the HVAC system, (9) the amount of tracer injected at the start of the hour, and (10) the number of data records on the data disk. Table 4 is

a copy of the screen produced on a printer at the completion of an hourly sequence (without the number of data records and injection times). The system can run unattended for about 18 days.

After the data disks are removed, they are analyzed in the laboratory on a similar microcomputer. This computer reproduces the screen data for filing, calculates average daily ventilation and infiltration rates, and stores this data in files.

DATA GATHERED ON THE AIR INFILTRATION AND VENTILATION RATES

Some of the data collected in the two large buildings are presented in Figs. 7 and 8 and in Tabls. 4 through 10. In these figures and tables, the air exchange rate is expressed in air changes per hour, temperatures in degree Celsius, wind speed in M/S, wind direction in degrees from North, events-on times in seconds, and tracer-gas concentrations in ppb. Table 4 shows the data collected from 9:50 a.m. to 10:50 a.m. on February 3, 1982. Figure 8 shows a five hour sequence of tracer concentrations for the morning of May 7, 1981, plotted on a semilog scale.

An examination of Tabl. 4 and Fig. 7 reveals certain points that must be remembered when gathering and analyzing data in a large interconnected building. For example, note that floors 16 and 20 do not initially start at the same concentrations as the other floors; they are consistently lower. This is due to the fact that the ratio of supply air flow to the volume of the floor is not the same for these floors as for the other floors. In the author's opinion this is due to either a balancing problem, to the VAV boxes not opening on this floor, or to a damper not opening. In the Collins Building a similar problem with the initial concentrations in the basement was finally traced to a closed fire damper.

If the tracer is not injected every hour, the second hour after injection floors 16 and 20 reach concentrations approximately equal to the other floors. Also, their air exchange rates are approximately equal to the air exchange rates indicated for the other floors. The observation of this phenomenon resulted in a change in the initial monitoring software. The software was modified so that it would use the concentration at the end of the hour and the air exchange rate during the hour to predict what the concentration level would be at the end of the next hour. If this level was above the predetermined level, no tracer was injected. A study of this data indicated that floors 7 through 22 have the same air exchange rates during the second hour as the other floors in the tower.

In general, differences in the calculated air exchange rate were more an indication of the amount of supply air the floor was receiving - floors with high apparent air exchange rates will receive more supply air, floors with low apparent air exchange rates, less supply air. In all cases, the return-air tracer decay gives a good value for the total air exchange rate of the building.

The data analysis was broken down into periods when the HVAC fans were operating and when they were off. During the period when the fans were operating, the tracer gas was well mixed and the sample drawn by the auxiliary sample pumps is representative of the floor. This allows for good determination of the air exchange rate. However, the HVAC system is also bringing in outside air for ventilation. Data in this period are more indicative of the ventilation rate than the air infiltration rate. Fig. 8 is a plot of the daily average ventilation for the tower return, 16th floor, and 22nd floor for the spring months of 1981. Note that during the earlier spring the ventilation rates are high because outside air is used for cooling the building. However, by the middle of May, these rates have decreased to about 0.5 air exchanges per hour.

Table 5 is a summary of the daily ventilation rates when the fans are operating for the months of June and July. In Tabl. 5 column "EXT." is the exterior temperature in °C; "INT.", the average interim temperature in °C; W.S., the windspeed in M/S; and D.R., the wind direction in degrees from North. In Tabl. 5, the temperature -.1 to -.50.3 is due to a shearing of the wiring to the thermistor when service technicians lowered the weather mast. Note that the ventilation rates can be lower than the minimum ventilation requirements for the fully occupied building. Extremely low or negative air exchange rates are days when a floor was not occupied or when a sample pump malfunctioned.

(Note: dates with two readings are days when the data disk was changed.)

The ventilation rates for the tower of the Park Plaza Building during the summer was approximately .5 air changes per hour during periods when the building was occupied. Tabl. 6 gives the ventilation rates for the period of occupancy for the winter months of January and February. During this period the tower is experiencing air exchange rates of approximately .9 air changes per hour. Tabl. 7 gives the air exchange rates for the lower zones of the building and the Plaza Building. Note that the lobby and the bank experience high air exchange rates. The lower level offices and the computer room have comparable air exchange rates.

In order to estimate the air leakage through the building envelope, the tracer gas data were analyzed during periods when the fan was off in the evening. Because the sample tubing was installed in the ceiling plenum in front of the return duct, it is not possible to use the concentration readings directly from this period. The method used was to determine the tracer concentration after the fans went on in the mornings. These two readings were used to determine the air leakage rate.

Usually the period between these readings was about ten to twelve hours. The results of this analysis are presented in Tabl. 8 for the Winter and Tabl. 9 for the Summer. Note that the air leakage is small in both cases, about .2 air changes per hour for the winter months and .1 air changes for the summer months.

Tabl.10 summarizes the results of the data gathered from the Collins Building for various days. Note that there is much less seasonal variation than in the Park Plaza Building data. However, weather variations in Scotland are not as extreme as they are in Newark. Leakage in the Collins Building was higher than in the Park Plaza Building, about .32 air changes per hour.

CONCLUSIONS

Air infiltration and ventilation measurements have been made over a period of a year and a half in two large commercial buildings. The air exchange rates for the Park Plaza Building during periods of occupancy varied from rates of about changes in the Spring. Certain parts of the building that opened to the exterior, such as the lobby and the bank, could experience air exchange rates of 2.0 air changes per hour and usually tended to be higher than other parts of the building.

A similar effect could be observed in the Collins Building. The Collins Building has air exchange rates of about 1.3 air changes per hour with little seasonal variation. The leakage rates of both of these buildings were low compared to the ventilation rates, less than .2 air changes per hour for the Park Plaza Building and about .3 air changes per hour for the Collins Building.

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REFERENCES

1. D.T. Harrje, R.A. Grot, and D.T. Grimsrud, "Air Infiltration Measurement Techniques", Proceedings of the Second Air Infiltration Centre Conference, Building design for Minimum Air Infiltration (Bracknell, England: Air Infiltration Centre, 1981 [AIC-PROC-81]).
2. M.H. Sherman and D.T. Grimsrud, "The Measurement of Infiltration Using Fan Pressurization and Weather Data," Proceedings of the First Air Infiltration Centre Conference, Air Infiltration Instrumentation and Measuring Techniques (Bracknell, England: Air Infiltration Centre, 1980 [AIC-PROC-80]).
3. G.T. Tamura and C.Y. Shaw, "Studies on Exterior Wall Air Tightness and

Air Infiltration of Tall Buildings," ASHRAE Transactions 82 (1976) 2:122-134.

4. C.M. Hunt and S.J. Treaso, " Air Exchange Measurements in a High-Rise Office Building," Proceedings of the ASHRAE/DOE Conference, Thermal Performance of the Exterior Envelope of Buildings (Atlanta: ASHRAE, 1981, SP-28).
5. U.S., National Bureau of Standards, Performance of the Norris Cotton Federal Building for the First Three Years of Operation, by J.E. Hill et al. [BSS 133] (Washington, D.C.: National Bureau of Standards, 1981).

TABLE 1
Summary of Data Collected in Park Plaza Tower

<u>Tracer Concentrations</u> <u>Measurement Locations</u>					<u>Interior Temperature</u> <u>Measured</u>	
1.	HVAC	return	shafts		1.	South return shaft
2.	22nd-floor	return			2.	North return shaft
3.	20th-floor	return			3.	22nd-floor space
4.	16th-floor	return			4.	20th-floor space
5.	11th-floor	return			5.	16th-floor space
6.	7th-floor	return			6.	11th-floor space
7.	3rd-floor	return			7.	7th-floor space
					8.	3rd-floor space

<u>Wall Differential Pressures Measurements</u>					<u>External Environment</u>	
Floor/Wall	East	Number per Wall				
		North	West	South		
22nd	1	1	3	1	1.	Temperature
16th	3	3	3	3	2.	Wind speed
7th	1	1	3	1	3.	wind direction

Status

1. Hvac System On/Off

TABLE 2
Data Collected in Lower Mechanical Room of Park Plaza Building

<u>Tracer Concentration Measurement</u> <u>Locations</u>		<u>Interior Temperatures</u>	
1.	1st and 2nd-floor lobby return	1.	1st and 2nd-floor lobby return
2.	Lower-level offices return	2.	Lower-level offices return
3.	Plaza Building return	3.	Plaza Building return
4.	Computer area return	4.	Computer area return
5.	Bank return	5.	Bank return

Status

1. 1st and 2nd-floor lobby HVAC system
2. Lower-level offices HVAC system
3. Plaza Building HVAC system
4. Computer area HVAC system
5. Bank HVAC system

TABLE 3
Data Collected in the Collins Building

<u>Tracer Concentration Measurement Locations</u>	<u>Interior Temperatures</u>
1. 2nd-floor return	1. 2nd-floor space
2. 1st-floor return	2. 1st-floor space
3. Ground-floor return	3. Ground-floor space
4. Basement return	4. 3rd-floor return
5. 3rd-floor return	5. Computer room return
6. Computer room return	6. Sports area space
7. Sports area	
8. Outside air	

<u>Differential Pressures</u>	<u>Status</u>
1. North wall 1st-floor	1. Main HVAC system
2. East wall 1st-floor	2. 3rd-floor HVAC system
3. West wall 1st-floor	3. Computer HVAC system
4. South wall 1st-floor	4. Sports air handler
	5. West toilet exhaust
	6. East toilet exhaust
	7. West stairway exhaust
	8. East stairway exhaust

TABLE 4
Copy of CRT Screen Menu for the Tower of the Park Plaza Building

PARK PLAZA TOWER								2/3/82
EXT. TEMP. = 5.8°C		WIND SPEED = 1.3 M/S		WIND DIRECTION = 122°				
+/-1.0				+/- .3				
INTERIOR TEMPERATURES (°C)								
N.RET.	S.RET.	22ND-FL	20TH-FL	16TH-FL	11TH-FL	7TH-FL	3RD-FL	
25.4	23.7	25.1	25.6	25.3	24.9	25.9	22.5	
+/- .7	.1	.1	.1	.1	.1	.1	.1	
EVENT ON-TIMES								
#1	#2	#3	#4	#5	#6	#7	#8	
0	0	0	0	0	0	0	0	
#9	#10	#11	#12	#13	#14	#15	#16	
0	0	3600	0	0	0	0	0	
TRACER CONCENTRATIONS								
	RETURN	22ND-FL	20TH-FL	16TH-FL	11TH-FL	7TH-FL	3RD-FL	
10: 0	52.6	68.9	41.7	48.4	70.3	56.7	48.0	
10:10	49.1	50.1	44.1	42.6	56.6	45.8	25.4	
10:20	44.3	43.8	39.9	39.9	42.5	42.1	30.0	
10:30	38.8	34.6	37.9	34.6	38.2	36.5	25.2	
10:40	33.1	29.9	36.5	29.8	31.8	29.5	18.2	
INFIL	.79	1.07	.37	.73	1.10	.88	.70	

TABLE 5
Daily Average Ventilation Rates for Plaza Tower
for Months of June and July, 1982

DATE	RETURN	PARK PLAZA TOWER DAILY AIR EXCHANGE RATES									
		22ND	20TH	16TH	11TH	7TH	3RD	EXT.	INT.	W.S.	DIR
6/ 9/82	.60	.48	-.26	.22	.26	-.76	.51	24.5	25.2	1.8	135.
6/10/82	.41	.37	.21	.34	.37	.47	.40	22.8	23.8	1.2	247.
6/11/82	.43	.49	.34	.41	.47	.18	.51	18.2	23.8	1.5	157.
6/12/82	.17	.05	-.04	.04	.08	.06	-.04	15.4	24.4	1.8	135.
6/14/82	.44	.57	.31	.35	.35	.31	.28	17.9	24.1	2.4	247.
6/15/82	.49	.52	.36	.46	.52	.50	.51	24.1	24.2	1.6	225.
6/16/82	.66	.66	.54	.62	.68	.74	.74	26.5	24.6	3.2	225.
6/17/82	.48	.50	.39	.48	.50	.50	.53	23.7	24.3	3.1	247.
6/18/82	.51	.50	.37	.42	.44	.54	.50	23.8	24.3	1.6	135.
6/19/82	.23	.30	.11	.18	.24	.39	.18	18.4	25.2	1.9	90.
6/19/82	.21	.29	.03	.11	.21	.58	.18	19.2	24.8	2.0	67.
6/21/82	.53	.47	.28	.43	.54	.51	.49	20.7	24.3	2.8	202
6/22/82	.52	.49	.37	.44	.52	.59	.55	23.6	24.5	1.7	157.
6/23/82	.42	.65	.27	.44	.65	.81	.65	20.6	24.2	3.1	247.
6/24/82	.50	.56	.07	.20	.35	.45	.31	21.9	24.2	2.5	247.
6/25/82	.58	.53	.34	.38	.59	.63	.55	23.9	24.4	1.7	225.
6/26/82	.34	.43	.21	.32	.10	.40	.29	26.4	25.6	1.4	225.
6/27/82	.29	.56	.16	.38	.35	.26	-.09	18.5	28.2	1.4	157.
6/28/82	.50	.45	.32	.42	.52	.46	.44	22.8	25.5	1.0	135.
6/29/82	.55	.52	.42	.45	.53	.54	.49	21.9	24.7	2.3	180.
6/30/82	.61	.55	.39	.46	.59	.64	.53	23.8	24.3	2.6	270.
7/ 1/82	.54	.47	.31	.33	.52	.72	.57	20.9	24.1	3.4	247.
7/ 2/82	.55	.54	.25	.40	.43	.56	.46	19.8	23.9	1.1	247.
7/ 2/82	.58	.56	.31	.34	.56	.68	.57	24.2	24.3	2.1	225.
7/ 5/82	.41	.28	.61	.59	.48	.48	.23	18.4	27.5	3.0	225.
7/ 6/82	.44	.49	.32	.34	.47	.54	.41	20.4	24.9	2.3	225.
7/ 7/82	.53	.54	.36	.46	.63	.68	.52	23.3	24.8	2.3	225.
7/ 8/82	.79	.66	.48	.59	.73	1.06	.63	28.1	24.7	2.0	247.
7/ 9/82	.66	.63	.41	.52	.67	.77	.64	28.2	24.9	1.7	247.
7/10/82	.32	.45	.24	.26	.38	.33	.29	28.5	26.2	1.4	157.
7/12/82	.67	.69	.40	.51	.68	.74	.67	25.1	25.0	1.4	135.
7/13/82	.47	.53	.30	.31	.51	.61	.43	23.6	24.8	1.5	270.
7/13/82	.79	.84	.55	.70	.78	.78	.81	30.2	24.2	1.5	225.
7/14/82	.59	.62	.43	.53	.67	.85	.66	26.4	24.4	1.7	90.
7/15/82	.64	.61	.45	.49	.59	.77	.55	-.1	24.4	1.1	157.
7/16/82	.58	.61	.52	.55	.62	.70	.62	-50.3	24.9	.9	202.
7/17/82	.32	.43	.20	.22	.28	.26	.30	-50.2	26.3	1.3	202.
7/19/82	.77	.73	.51	.61	.78	.86	.73	-50.3	24.9	1.7	225.
7/20/82	.63	.64	.34	.46	.61	.70	.61	-50.1	23.4	1.6	225.
7/21/82	.61	.54	.30	.40	.57	.70	.57	-50.3	23.8	2.8	225.
7/22/82	.66	.58	.26	.35	.52	.76	.62	-50.3	24.0	1.8	247.
7/23/82	.72	.33	.24	.45	.67	.76	.48	-50.3	25.0	2.0	270.
7/24/82	.40	.74	.27	.15	.21	.76	.33	-50.2	25.5	1.8	90.
7/26/82	.59	.41	.13	.27	.39	1.42	.38	-50.3	25.0	2.5	270.

TABLE 6
Daily Ventilation Rates for the Park Plaza Building Tower
for January and February, 1982

DATE	RETURN	PARK PLAZA TOWER DAILY AIR EXCHANGE RATES									
		22ND	20TH	16TH	11TH	7TH	3RD	EXT.	INT.	W.S.	DIR
1/14/82	.77	.82	.30	.56	.72	.74	.43	-1.2	24.5	2.3	180
1/15/82	.73	.86	.17	.49	.72	.84	.43	-1.9	24.5	4.2	135.
1/16/82	.55	1.02	.36	.27	.74	.86	.38	-2.6	24.6	1.8	45.

1/18/82	.73	.75	.06	.47	.54	.78	.50	-11.1	23.3	1.1	135.
1/19/82	.81	.84	.20	.56	.80	.88	.55	-4.1	24.4	1.2	225.
1/20/82	1.03	.91	.41	.70	1.15	1.00	.72	3.1	25.1	2.3	135.
1/21/82	.90	.84	.12	.51	.70	.79	.42	-4.4	24.3	2.5	202.
1/22/82	.73	.96	.11	.36	.62	1.03	.47	-7.8	23.3	2.2	180.
1/23/82	.43	.93	.30	.22	.52	.74	.26	2.1	23.8	3.1	292.
1/25/82	.71	.92	.13	.35	.73	.88	.65	-5.4	23.6	2.9	135.
1/26/82	.79	.85	.25	.48	.76	.91	.66	-3.1	24.2	3.3	157.
1/27/82	.82	.82	.20	.52	.90	.98	.75	-3.8	24.2	1.2	180.
1/28/82	1.17	.90	.35	.69	.90	1.23	.97	-.7	24.4	2.6	67.
1/29/82	.95	.92	.02	.46	.78	1.12	.54	1.6	23.4	1.6	90.
1/29/82	.81	.88	.14	.43	.87	.87	.85	5.0	24.3	3.1	135.
1/30/82	.73	1.66	.11	.53	.93	1.34	.72	3.6	23.5	2.4	67.
2/ 1/82	1.38	1.42	.31	.77	1.29	1.32	1.11	6.0	24.4	6.2	135.
2/ 2/82	.77	.82	.03	.45	.76	.95	.73	1.5	24.2	2.2	225.
2/ 3/82	1.02	1.06	.24	.64	1.03	.95	.66	6.4	24.7	1.7	202.
2/ 4/82	1.25	1.27	.49	.84	1.29	1.22	.93	7.2	24.7	3.7	157.
2/ 5/82	.94	1.02	.14	.57	.90	.95	.76	3.3	24.5	1.1	202.
2/ 6/82	.81	1.33	.49	.50	1.02	1.15	.81	3.3	24.1	3.4	135.
2/ 8/82	.72	.71	-.37	.36	.66	1.05	.70	.5	23.6	1.6	112.
2/ 9/82	.98	.85	.07	.44	.61	.67	.50	3.6	23.9	.5	247.
2/10/82	.97	.99	.08	.46	.75	.94	.68	-.7	23.8	3.1	135.
2/11/82	.90	.98	.21	.53	.74	.98	.69	-.6	23.6	1.6	157.
2/12/82	.68	.84	.09	.35	.76	.85	.57	2.3	23.7	1.3	180.
2/13/82	1.55	.25	-.18	.26	.68	1.22	1.13	.5	24.5	2.7	202.
2/15/82	1.26	.42	.07	.36	.30	1.05	.68	8.5	24.4	2.6	67.
2/16/82	1.04	1.06	.30	.81	1.06	1.22	1.01	11.2	24.8	2.8	135.
2/17/82	.93	.83	.13	.22	.46	.63	.65	.8	24.0	4.9	270.
2/25/82	.90	.91	.19	.28	.72	.90	.68	-3.5	23.1	4.6	157.

TABLE 7
Ventilation Rates for the Lower Zones of the Plaza Building

DATE	DAILY AIR EXCHANGE RATES					AVERAGE TEMPERATURES				
	PLAZA BLDG.	L.L. OFFICES	1ST-2ND LOBBY	COMP. ROOM	BANK	PLAZA BLDG.	L.L. OFFICES	1ST-2ND LOBBY	COMP. ROOM	BANK
9/25/81	.24	.45	1.08	.51	1.29	23.7	23.5	23.2	24.4	21.8
9/28/81	-.36	.71	1.56	.37	1.51	24.4	23.8	23.5	23.7	22.1
9/29/81	.92	.81	1.65	.58	1.57	23.0	23.3	22.5	23.4	21.6
9/30/81	-.25	.95	1.85	.58	1.87	23.4	23.4	22.6	23.6	21.6
10/ 1/81	.08	1.11	1.74	.65	1.94	23.1	23.7	22.8	23.2	21.5
10/ 2/81	-.01	.83	1.51	.61	1.79	23.5	23.8	23.5	22.8	21.7
10/ 5/81	.53	1.02	1.38	.70	1.90	23.7	23.9	23.5	23.3	21.0
10/ 6/81	.52	1.23	1.24	.85	1.99	24.6	24.2	24.7	23.7	21.5
10/ 7/81	.11	1.14	2.01	.91	2.33	23.6	23.9	23.9	24.0	21.2
10/ 8/81	.61	1.39	2.06	1.11	2.21	23.0	23.9	23.6	24.1	21.4
10/ 9/81	.54	1.23	2.03	.96	2.35	22.9	23.7	23.6	24.0	21.3
10/12/81	.64	.35	.37	.79	.70	23.4	23.5	24.0	24.3	21.1
10/13/81	.26	1.16	1.66	.91	2.18	23.3	23.9	23.7	24.3	21.0
10/14/81	1.29	1.34	2.15	1.01	2.50	21.8	23.2	22.1	22.9	20.6
1/13/82	.51	.77	1.56	.86	1.23	20.9	21.9	21.3	22.9	17.7
1/14/82	.44	.67	1.17	.83	.98	21.2	21.8	21.6	23.2	17.9
1/15/82	.43	.67	1.20	1.08	1.25	21.5	22.2	21.8	22.8	18.6
1/16/82	.49	.74	1.34	1.15	1.30	20.1	21.9	21.7	22.6	17.8
1/17/82	.47	.71	1.45	.89	1.26	17.8	21.1	20.2	21.8	17.1
1/18/82	.51	.76	1.54	1.10	1.43	19.1	21.3	20.1	22.3	17.0
1/19/82	.43	.72	1.44	1.07	1.31	21.7	22.1	21.3	23.1	17.9
1/20/82	.35	.56	.87	.78	.82	22.4	22.7	23.0	24.8	18.3
1/25/82	1.42	1.05	2.70	1.06	2.47	23.1	23.2	22.6	24.3	19.0
1/26/82	.79	1.12	2.47	1.12	2.42	22.0	22.9	21.9	23.6	18.8
1/27/82	.71	1.15	2.61	1.16	2.67	21.1	23.1	21.9	23.7	19.1
1/28/82	1.34	1.46	2.28	1.29	1.86	22.0	23.9	22.9	24.5	19.8

1/29/82	.66	.92	1.30	.44	.76	23.0	24.4	24.6	25.4	20.3
2/11/82	.95	1.18	2.67	1.35	2.05	21.5	23.0	21.6	23.9	20.1
2/12/82	1.00	1.22	2.63	1.26	1.95	21.8	22.9	22.3	24.0	19.9
2/16/82	.24	1.43	1.48	1.66	2.37	23.7	23.9	25.6	24.8	20.5
2/17/82	.87	1.52	3.40	1.50	2.61	21.8	23.1	21.9	23.5	19.7
2/18/82	.89	1.44	3.56	1.38	1.28	21.7	23.2	21.1	24.1	19.5
2/19/82	.79	1.38	3.15	1.39	.03	22.2	23.4	21.6	24.4	19.5
2/22/82	.59	1.33	2.75	1.41	.07	22.9	23.5	23.0	24.2	19.5
2/23/82	.48	1.28	2.31	1.29	1.28	23.1	23.6	23.4	24.3	19.6
6/ 9/82	.41	1.05	2.14	.99	-.15	24.2	23.7	24.5	24.6	21.0
6/10/82	.34	.82	1.19	.68	.43	23.4	23.8	24.3	23.8	21.0
6/11/82	.22	.90	.90	.61	.22	22.6	24.2	23.6	23.0	21.2
6/14/82	.02	.93	.81	.65	.19	21.4	24.0	22.6	23.3	20.8
6/15/82	.10	.62	.50	.41	.13	23.0	23.6	24.4	23.3	21.0
6/16/82	.19	.87	.83	.49	.28	24.1	24.1	25.2	23.9	21.8
6/17/82	.20	.76	.75	.54	.28	23.9	24.0	23.7	23.5	21.7
6/18/82	.09	.71	.63	.50	.17	24.0	24.2	23.9	23.5	21.8
6/21/82	.11	.18	.83	.44	.19	24.1	24.1	23.6	23.8	21.6
6/22/82	.18	.09	.79	.37	.14	23.9	23.9	23.9	23.5	21.8
6/23/82	.05	.11	.80	.43	.09	23.5	23.8	23.6	23.1	21.8
6/24/82	.11	.13	.58	.38	.05	23.4	23.5	23.6	23.0	21.7

TABLE 8
Leakage Rates for Plaza Tower in Early February, 1982

DATE	RETURN	PARK PLAZA TOWER AIR INFILTRATION RATES									
		22ND	20TH	16TH	11TH	7TH	3RD	EXT.	INT.	W.S.	DIR
2/ 9/82	.17	.19	.18	.16	.13	.14	.12	1.5	25.2	3.3	135.
2/10/82	.16	.19	.14	.14	.15	.15	.14	-4.5	24.6	2.5	135.
2/11/82	.13	.15	.10	.10	.12	.13	.10	-1.1	24.4	2.8	135.
2/12/82	.20	.21	.19	.20	.20	.19	.19	-.1	24.9	1.5	270.
2/13/82	.07	.09	0.00	.08	.08	.08	.06	.0	24.4	2.2	135.
2/15/82	.13	.17	.11	.14	.14	.17	.15	10.8	25.4	2.9	67.
2/17/82	.14	.21	.09	.18	.14	.20	.18	2.9	25.2	3.0	225.
2/18/82	.10	.05	.02	-.00	.04	.06	.01	-1.9	24.3	4.7	247.
2/25/82	.24	.22	.16	.21	.23	.29	.24	-4.3	24.0	3.3	157.

TABLE 9
Leakage Rates of Plaza Tower in First Part of June, 1982

DATE	RETURN	PARK PLAZA TOWER AIR INFILTRATION RATES									
		22ND	20TH	16TH	11TH	7TH	3RD	EXT.	INT.	W.S.	DIR
6/ 9/82	.12	.07	.05	.06	.09	.07	.03	18.7	24.8	1.9	247.
6/10/82	.02	.03	.05	.04	.03	0.00	.01	17.3	24.7	1.6	112.
6/11/82	.07	.04	-.01	.02	.04	.05	.07	14.3	25.0	1.1	157.
6/12/82	.00	.02	.01	.01	.01	.01	.02	11.1	24.4	1.7	135.
6/12/82	.01	.01	.01	.01	.02	.02	.02	11.8	23.7	2.8	90.
6/14/82	.05	.05	.05	.06	.05	.05	.06	17.9	25.7	1.3	225.
6/15/82	.04	.05	.06	.06	.06	.05	.04	21.5	26.5	3.7	202.
6/16/82	.10	.10	.07	.09	.11	.12	.10	19.7	26.5	2.1	180.
6/17/82	.07	.08	.05	.08	.09	.08	.09	22.5	26.6	.9	202.
6/18/82	.07	.05	-.02	.02	.06	.07	.08	18.6	26.5	1.0	135.

TABLE 10
Air Exchange Rates in the Collins Building for Various Dates

DATE	Main HVAC System				EXT. TEMP	INT. TEMP	W.S.
	1ST-FL	2ND-FL	3RD-FL	BASEMENT			
2/10/81	1.10	1.61	1.36	1.25	0.6	22.3	*
2/11/81	1.54	1.25	2.11	1.33	3.3	22.6	*
2/12/81	1.62	1.46	2.54	1.12	8.9	22.9	*
2/13/81	1.60	1.35	2.21	1.20	8.0	23.0	*
5/15/81	1.25	1.29	1.84	0.44	17.6	22.0	5.8
5/22/81	1.02	1.04	1.38	0.28	10.3	22.2	4.2
5/26/81	1.26	1.15	0.86	0.62	10.3	24.0	1.5
5/27/81	1.18	1.19	1.13	0.28	9.2	23.0	2.2
11/20/81	1.05	1.20	2.00	1.00	*	*	*
1/23/81	1.50	1.85	0.83	0.85	6.3	25.0	1.7

LEAKAGE

1/30/81	0.29	0.32
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DATE	COMPUTER	DATE	3RD-FL
2/10/81	1.12	2/12/81	1.31
2/11/81	1.34	2/13/81	1.32
2/12/81	1.51	5/15/81	1.32
2/13/81	1.02	5/22/81	0.87
2/14/81	1.71	5/26/81	0.83
2/15/81	1.68	5/27/81	0.91
5/15/81	1.51		
5/22/81	1.32		
5/26/81	1.01		
5/27/81	1.17		
11/20/81	1.60		
1/23/81	0.99		

SPORTS AREA

DATE	
11/20/81	3.75

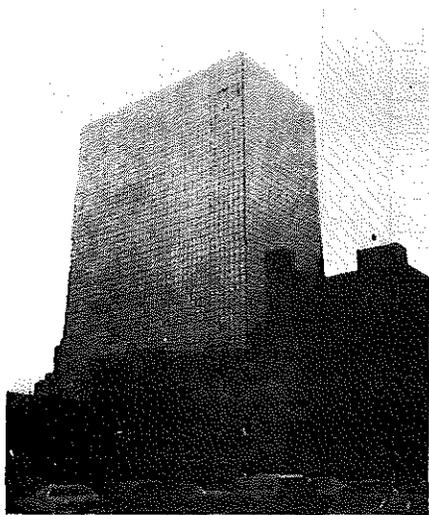


Figure 1. Park Plaza Building, Newark, NJ

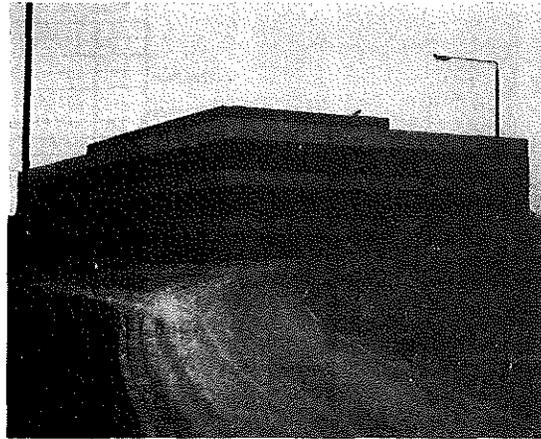


Figure 2. Collins Building, Bishopbriggs, Scotland

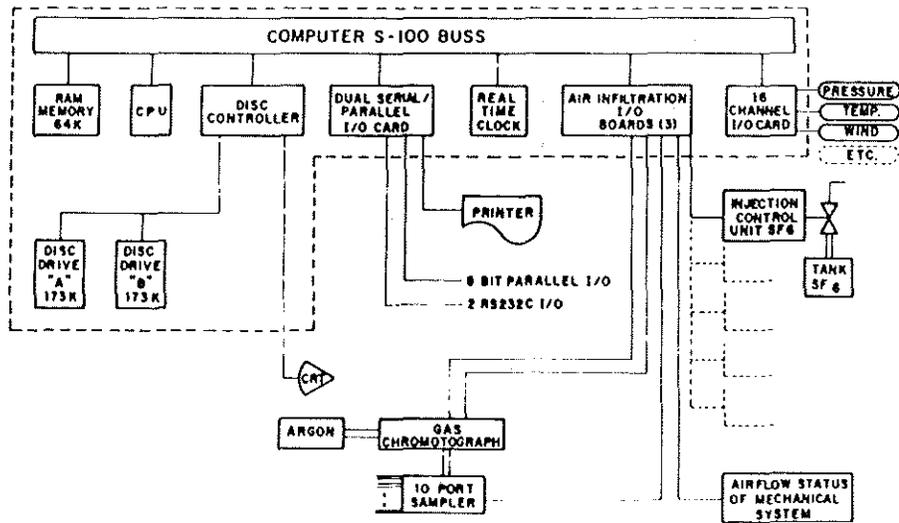


Figure 3. Schematic of major components of automated air infiltration system for a large building

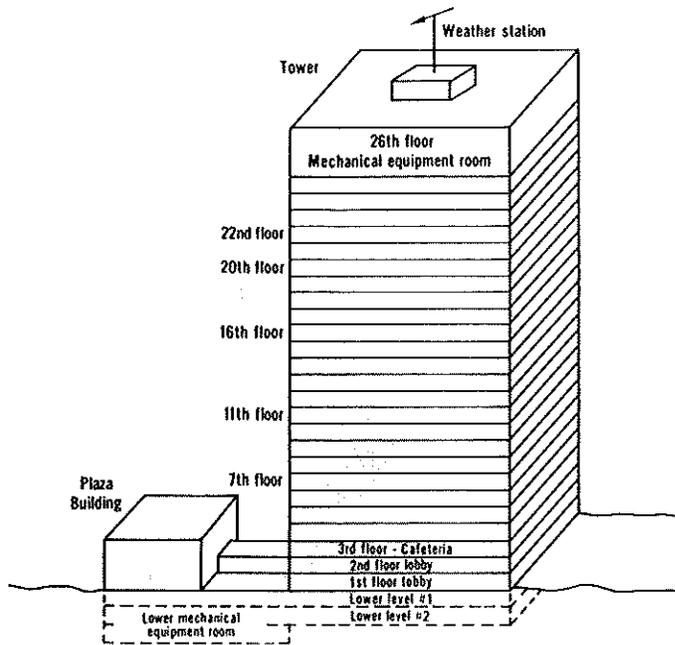


Figure 4. Schematic of Park Plaza Building, Newark, NJ

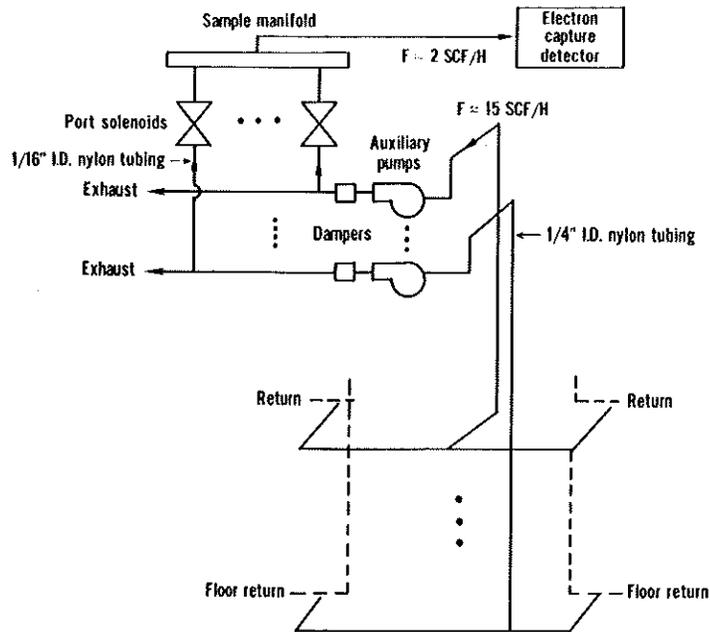


Figure 5. Schematic of sample network for Park Plaza Building Tower

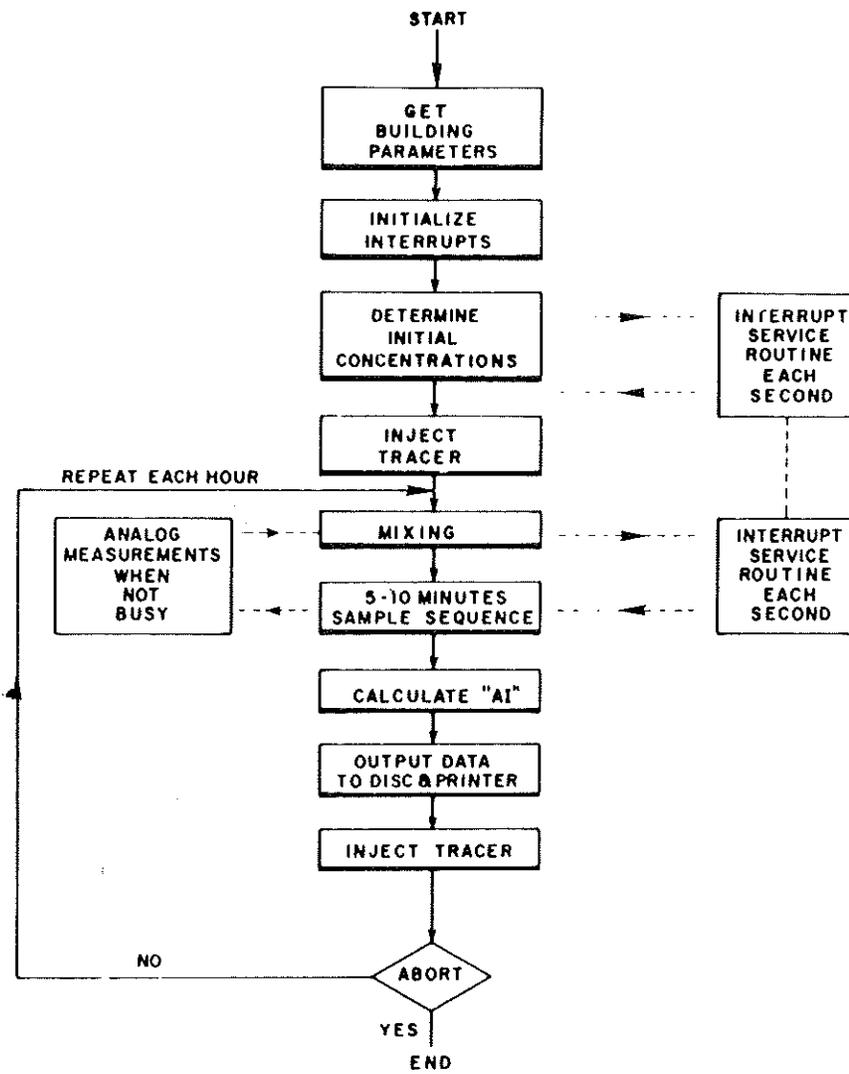


Figure 6. Simplified flow diagram for monitoring program for air infiltration in large buildings

