VENTILATION TECHNOLOGY - RESEARCH AND APPLICATION

8th AIVC Conference, Überlingen, Federal Republic of Germany
21 - 24 September 1987

PAPER 2

MEASUREMENTS OF INFILTRATION AND AIR MOVEMENT IN FIVE LARGE SINGLE-CELL BUILDINGS

G. V. LAWRANCE and J. R. WATERS

Department of Civil Engineering and Building
Coventry Polytechnic
Priory Street
Coventry CV1 5FB
U. K.

SYNOPSIS

A six channel, computer controlled, tracer gas detection system for the measurement of infiltration rates and air movement in large single-cell industrial buildings has been designed, constructed and calibrated. This has been used for over 50 sets of tracer decay measurements in five single-cell buildings ranging in size from 4000 to 31000 m³. The buildings included a sports hall, a vehicle maintenance depot, two factory workshops and an aircraft hanger. Infiltration rates and interzonal flows were derived from the tracer decay curves using methods based on multizone theory. The analysis method includes a specially developed, constrained least squares technique which gives both infiltration rate and internal flow rates.

The equipment and method of analysis are briefly described, and results for each data set presented. A comparison of infiltration rates, derived from interzonal flows and from averaged tracer decay data is also given. In addition examples are given of comparisons between measured decay curves and theoretical decay curves reconstructed from the measured flow rates. Finally inconsistencies in the data and the model are discussed, together with suggestions for improvements to the experimental technique and the method of analysis.

1. INTRODUCTION AND OBJECTIVES

Although modern industrial buildings are often equipped with sophisticated mechanical ventilation systems, many new ones and most existing ones still rely on a combination of natural ventilation, infiltration and localised extract fans for control of indoor temperature and air quality. As with any other type of building, the potential for energy saving by reducing infiltration must be balanced against the need to maintain air quality, and this balance should be evaluated if any building improvement actions are to be judged. Knowledge of infiltration rates and internal contaminant concentrations is of considerable value in determining the need for such action and its subsequent effectiveness. The significant characteristic of industrial buildings is that they consist of a small number of large spaces, or cells, within each of which there are likely to be strong spatial variations in the effective infiltration rate and in the distribution of contaminated air. Therefore it is necessary that a measurement system should be capable of yielding information not only on whole building infiltration rates but also on the internal air movement patterns which give rise to the spatial variations. Furthermore, the distribution of contaminant concentrations within industrial buildings is due as much to the industrial activity as to the design of the building. Any realistic assessment must therefore be based on measurements of the building in use.

The objective of the study was to develop equipment and a methodology which would enable measurements to be made on industrial buildings which would give values of whole building infiltration rates, and in addition information on air movement patterns within the building. As it was the intention to conduct measurements on buildings in use, acceptability to the building's occupants was an important consideration. A subsidiary objective, therefore, was that the technique should cause minimum disturbance to activities within the building, and that it should be possible to conduct measurements and produce the results within a short time span, say, less than a day. Clearly the complete determination of internal air movement patterns requires very detailed measurements, and this is incompatible with the aim of minimising disturbance to the occupant. The approach therefore has been to adopt procedures which are acceptable to building occupiers, and to determine the extent to which air infiltration rates and air movement patterns can be obtained from a practical number of measurements.

2. THE MEASUREMENT SYSTEM

A detailed description of the tracer gas measurement system has been given by Waters et.al.[1] The need to measure internal air movements imposes a limitation on the choice of tracer gas method. Methods which require some additional imposed stirring throughout the monitoring period will upset the internal air movements which are to be measured. Therefore the tracer decay method is to be preferred to the constant concentration or constant injection methods. Also it is necessary to use tracer gases which are unlikely to be present in industrial atmospheres, and which, because of the large volumes of such buildings, are detectable at low concentrations. Although there are advantages in using multiple tracer systems, especially where internal flows are to be measured, it was considered simpler to choose a single tracer, and to optimise the detection system for that tracer. Sulphur hexafluoride was chosen and has been found to be entirely satisfactory. The measurement system is therefore a tracer gas monitoring device, in which detection is achieved by six independent custom built gas chromatograph units. The use of six independent units permits rapid sampling from at least six sample points, and the use of pulse modulated electron capture detectors within the chromatographs provides both high sensitivity and good linearity over a wide range of tracer concentrations.
A comprehensive evaluation of the detector behaviour was carried out, from which it was possible to optimise the chromatograph parameters with respect to sulphur hexafluoride. Because the system uses six separate detector units, calibration is of particular importance. Therefore a special calibration rig was built, based on the accurate dilution of a sulphur hexafluoride/ air mixture. A standard mixture is used at intervals during actual measurements to give a check on the relative performance of the six units.

The whole system, complete with calibration gases, data acquisition unit, and control computer, is mounted in a small covered trailer, which in most cases may be parked within the building under investigation.

3. MEASUREMENT METHODOLOGY

The theoretical basis of the methodology that has been adopted is that the large volume of air enclosed by a single-cell building can be notionally subdivided, or discretised, by imaginary boundaries into a large number of small volumes, or zones. Although the boundaries between the zones are hypothetical, in practice many single-cell buildings contain partitions screens or furniture which give physical reality to some of the boundaries. If each zone is small enough the distribution of contaminants, including the tracer gas, within the zone will be sufficiently uniform for the air in the zone to be considered well mixed. The system is then identical to the usual multizone model[2] of air flow within a building, and the interzone flow rates will be a measure of the magnitude and direction of the air movement within the complete volume. A detailed theoretical analysis of single gas tracer decay in a multizone model has been carried out by Waters and Simons[3]. This showed that the best seeding strategy is to seed a single zone, and that this should be the zone associated with the smallest component of the dominant eigenvector in the solution of the multizone equations. This is also the zone which, as the transients die out and the process approaches a steady decay, exhibits the lowest value of the tracer concentration. It can therefore be identified by a preliminary measurement. If this is not convenient, it can also be identified as the zone receiving the largest inflow of fresh air, and is therefore likely to be the most exposed zone on the windward side of the building. Fortunately, it is almost as satisfactory to seed any single zone, provided that in the subsequent measurements it is possible to detect tracer gas in all zones in the system. Nevertheless the analysis also revealed two possible difficulties. One occurs with particular flow patterns, which give rise to repeated eigenvalues in the multizone solution. The other occurs when there are certain kinds of symmetry in the interzonal flows, which, when a particular zone is seeded, leads to decay curves in which the concentration in one zone is a constant ratio of the concentration in another zone. The latter leads to linear dependency in the solution for the inter-zone flows, which because of experimental scatter in the data, manifests itself as ill-conditioning. Seeding strategy had to take account of these possible difficulties. The actual measurement procedure is conventional. The trailer is parked either within the building, or immediately outside, so that it is only necessary to run tubing from the trailer to the sample points. The position of the sample points is chosen according to building geometry and the extent of internal obstructions. In open buildings with few obstructions, the building is divided into imaginary zones of approximately equal volume, with a sample point at the centre of each zone. Where internal obstruction are significant, sample points are placed to represent the spaces that obstructions delineate. However, in occupied buildings, it is often necessary to displace the sample point from the desired position to avoid interference with building activities. The sampling heads themselves consist of a small cylindrical manifold from which radiate nine 1 cm lengths of copper tubing, in the manner of the spokes of a wheel. At each sample point, therefore, air is collected from nine equally spaced points around the circumference of a 2 m circle. This provides some spatial integration of the sample collection within each zone. Pure sulphur hexafluoride is injected into a single zone on the windward side of the building, with stirring during the injection process, and the tracer decay is followed for between one and two hours.

4. MEASUREMENT PROGRAMME

A total of 58 sets of measurements have been obtained, distributed approximately equally between the following five buildings:

1. Abbey School Sports Hall, Kenilworth, Volume 4220 m^3
2. Courtaulds Engineering Workshop, Coventry, Volume 14370 m^3
3. Courtaulds Pattern Making Shop, Coventry, Volume 6420 m^3
4. Hangar 5, Coventry Airport, Volume 31300 m^3
5. British Gas Maintenance Depot, Birmingham, Volume 31020 m^3

Except for the Sports Hall, all the buildings were in use during the measurements; in Hangar 5 all measurements were taken with the aircraft doors closed. In all cases, six sampling points were used, which were positioned to represent equal volumes, except where internal obstructions were significant, in which case they were positioned to represent the spaces that the obstructions created.

All the buildings were naturally ventilated, but Courtaulds Pattern Making Shop and British Gas Maintenance Depot had fume extract systems at strategic positions. Also, the British Gas building had an experimental mechanical ventilation and heat recovery system which was switched off for all but three of the measurements.

5. ANALYSIS OF RESULTS

Results for each measurement set were processed in two ways:

1. Readings for all six sample points were averaged to give a single overall average tracer concentration for the whole building. The decay of the average concentration was used to obtain the fresh air infiltration rate of the whole building.

2. Using multizone theory, a constrained least squares technique was used to determine the complete set of interzone flow rates. The fresh air infiltration rate of the whole building was found by summing the flows between individual zones and the outside.

For both methods of analysis, the data set for each run was split into sections, and each section analysed separately. These sections were:

1. the first third of the data in the time series

2. the second third

3. the last third

4. the first two thirds

5. the last two thirds

6. the whole data set.

Thus for each method of analysis there were six sets of results for each run.

The justification for the first method of analysis follows from the standard solution to the multizone problem. If $\underline{c}(t)$ is the vector representing the tracer concentration in the $\overline{n}$ zones of a building, then

$$\underline{c}(t) = \sum_{k=1}^{n} a_k \underline{x}_k e^{\lambda_k t}$$

where λ_k and $\underline{x}_k$ are the eigenvalues and their associated eigenvectors of the solution, and the a_k are the constants associated with the initial condition (i.e. the seeding strategy). The average concentration $\bar{c}(t)$ of the n zones is, if the zones are of equal size, given by

$$\bar{c}(t) = \frac{1}{n}\left[a_1(x_{11} + x_{12} + ..)e^{\lambda_1 t} + a_2(x_{21} + x_{22} + ..)e^{\lambda_2 t} + ..\right]$$

$$= \frac{1}{n} \sum_{k=1}^{n} A_k e^{\lambda_k t}$$

where $A_k = a_k(x_{k1} + x_{k2} + ..)$.

The decay of the average concentration is therefore governed by the same set of eigenvalues. Now Waters and Simons[3] have demonstrated that as the internal flow rates increase, the dominant eigenvalue decreases, and approaches the value that would apply if the whole building were a single fully mixed zone. At the same time the other eigenvalues also get smaller, approaching in the limit $-\infty$. The implications of this for the decay of the average concentration, $\bar{c}(t)$, are shown in figure 1, in which the natural logarithm of $\bar{c}(t)$ is plotted against time. Now the gradient of the decay curve for the fully mixed case gives the whole building infiltration rate.

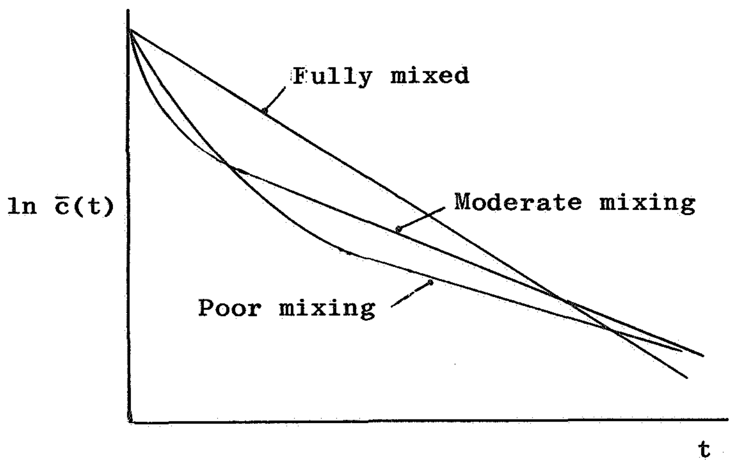


Figure 1. The effect of mixing on the decay of $\bar{c}(t)$

It can be seen therefore that in all other cases the gradient from the early part of the decay will over-estimate the whole building ventilation rate, whereas the gradient from the later stages where the dominant eigenvalue is in control will under-estimate it. These two values must give the limits within which the whole building infiltration lies, and the average gradient of the whole data set will lie close to the true value.

The solution for the individual flows is found by direct substitution of measured tracer concentrations and concentration gradients in the fundamental equations. However, the problem is first reduced by determining, from building geometry and from examination of the decay curves, which of the interzonal flows, F_{ij} are zero. Secondly, constraints are applied. Obviously we must have all $F_{ij} \geqslant 0$, but in addition examination of the decay curves in the seeded zone and zones adjacent to it, at times close to the start of the process, provides the possibility of including further constraints. If i is the seeded zone, and j a zone with a flow connection to i, then it may be shown (ref.3) that at time $t = 0$,

$$\sum_{j=0}^{n} F_{ji} = \sum_{j=0}^{n} F_{ij} = -V_i \frac{\dot{c}_i(0)}{c_i(0)}$$

and $$F_{ij} \leqslant V_j \frac{\dot{c}_j(0)}{c_i(0)}$$

where v_i is the volume of zone i. Using the method described by Lawson and Hanson[4], these constraints are applied to the least squares solution.

6. PRESENTATION AND DISCUSSION OF RESULTS

Tables 1 to 5 inclusive give the results for the whole building infiltration rate, calculated by both methods of analysis. For each run, the first row, marked AC, gives values computed from the average concentration, and the second row, marked IF, gives values computed from the interzonal flows. The last column gives the best value of the infiltration rate, which is assumed to be that given by the whole data set, and the range, which is the difference between the best value and the extreme values expressed as a percentage. Each table also includes a plan diagram of the building, with the interzonal flows computed from one of the runs superimposed.

For each run, the infiltration rates obtained from the average concentration vary according to the data subset from which they have been calculated in the expected manner. With very few exceptions, the highest value comes from the first third of data and lowest from the final third. The range is often much greater on the positive side than the negative side. This again is to be expected, because the early decay rate is primarily a function of the flow rates out of the seeded zone, which may be very large. It is likely, therefore, that a large value on the positive side over-estimates the probable error in the best value.

If the data set were free from experimental error, and if the assumptions of multizone theory were valid in these buildings, the infiltration rates computed from interzone flows would be the same whichever data subset was used in the analysis. Neither condition is true, and the results often show marked variability. Comparing the infiltration rates from the interzone flows with the 'best value' from the average concentration suggests that where agreement is good, variability is low, and vice versa. For example, taking as a measure of the variability of the six IF values in any run the ratio of the standard deviation to the mean, the following three runs illustrate the trend:

Building 1	Best Value	IF Value	SD/mean
Run 13	4.15 ach	1.09 ach	0.61

Building 3	Best Value	IF Value	SD/mean
Run 36	2.69 ach	3.05 ach	0.43

Building 3	Best Value	IF Value	SD/mean
Run 39	2.57 ach	2.48 ach	0.30

One possible explanation for the variability is that the length of the data sets was determined arbitarily by the time available for each run. Waters and Simons[3] demonstrated that for single zone seeding the decay process is close to uniformity at a time of two time constants from the start, where the time constant is defined as the reciprocal of the dominant eigenvalue. The inclusion of data beyond this time may be weighting the least squares solution towards linear dependency. Some of the results were recalculated with the data set restricted to two time constants, where the time constant was assumed to be given with sufficient accuracy by the reciprocal of the 'best value' infiltration rate. In table 6 run 13

TABLE 6

EFFECT OF RESTRICTING DATA SET TO TWO TIME CONSTANTS

	Infiltration rate, ach, from interzonal flows						
	Data Subset						SD/means
	1	2	3	4	5	6	
Run 13							
Full data	0.72	0.83	0.48	0.63	2.13	1.09	0.61
2t	1.48	0.19	0.69	3.98	0.03	0.84	1.21
Run 36							
Full data	5.71	4.10	1.88	3.35	1.97	3.05	0.43
2t	3.09	3.24	4.05	3.72	1.39	1.58	0.39

the variability and agreement with the 'best value' are worse, and for run 36 there is no improvement. The individual interzonal flows also show considerable variation between the solutions from different data subsets, and again there is a tendency for the variability to be less where agreement for the infiltration rates is good. The extreme sensitivity of the interzonal flows to the manner in which the data is selected and processed has also been noted by Afonso et.al[5] who also used a single tracer gas. Nevertheless, they were able to get reasonable agreement with independently measured values of the interzonal flows, but it is of interest to note that they were using only 2 zones in an experimental set-up which was designed to match the assumptions of the multizone model.

As a further indicator of the quality of the interzonal flow results, theoretical decay curves were computed from the flows, and compared with the original measured curves. This is a severe test, and where the flow results are in doubt because the whole building infiltration rates are inconsistent, the reconstituted curves bear little resemblance to the measured originals. However, where there is some measure of consistency in the infiltration rates, the two sets of curves can show at least a reasonable similarity. Figs 2-4 show as an example run 36. This run also illustrates one of the major reasons for the difficulties in obtaining good matching. It can be seen from the measured curve that there is a time lag effect, shown by tracer concentration peaks in standing above the general trend of the decay. This is not possible on the basis of the normal multizone model.

7. CONCLUSIONS

The results for infiltration rate computed from the average concentration appear to be sufficiently consistent to be considered reliable, and show that it is comparatively easy to obtain reasonable values for buildings in the size range considered without recourse to elaborate technique or analysis. The values for the infiltration rates were in most cases surprisingly high, but all these buildings were very leaky, with large badly fitting doors, which in some cases were left open during normal working.

The results for interzone flows were always plausible, but this was due to the imposition of constraints on the solution technique. In most cases, lack of consistency and poor agreement with the infiltration rates obtained from the averaged data, suggest that at the present stage of development the interzone results are too unreliable to be useful. The most probable explanations for the poor results are:

1. The size of the hypothetical zones was too large to give adequate discretisation of the internal volume of these buildings. The choice of six channels for the measurement system was dictated partly by experience from a preceding pilot study and partly by available resources. Thus, in these buildings, each zone was large enough for there to be spatial variations within it.

2. The 2 metre diameter sampling head used in each zone was small in relation to the size of each zone, and therefore may not have given a reasonable measure of the average tracer concentration in that zone.

3. Because artificial mixing of the air in these buildings has been deliberately avoided, the normal multizone model is not strictly applicable, even with discretisation into small zones.

Each of these problems can be overcome to some degree. The first two could be ameliorated by increasing the number of zones, either by adding extra channels to the equipment, or by multiplexing the existing channels. At the same time, the sampling arrangement could be altered to give a more representative value of the concentration in each zone. Unfortunately, both of these possible courses of action would increase the disturbance caused to the building occupier.

The third problem has been approached by reconsidering the air flow model of the building. Instead of considering the air volume as an assembly of perfectly mixed zones, it is more realistic to consider it as a combination of pockets of good mixing (or zones) linked by air streams in which the air flow is predominantly in one direction. These latter approximate to ducts. An alternative model is therefore, an assembly of perfectly mixed zones linked by ducts in which the flow is unidirectional. The solution of this alternative model is much more difficult. Nevertheless a solution has been obtained for the case of two zones linked by two ducts (reference 6). The most significant feature of the solution is that the decay curves can exhibit the time delays and oscillatory behaviour which has often been observed in our measured decay curves. It would be very interesting to solve a model of six zones connected by unidirectional flow ducts, but this has not yet been achieved.

8. REFERENCES

1. J.R. Waters, G.V. Lawrance and N. Jones, A tracer gas decay systems for monitoring air infiltration and air movement in large single-cell buildings. Symposium on Design and Protocol for Monitoring Indoor Air Quality, ASTM, Cincinnati, April 1987 .

2. F.W. Sinden, Multi-chamber theory of air infiltration. Building and Environment, 13, 21-28, 1978 .

3. J.R. Waters and M.W. Simons, The evaluation of Contaminant Concentrations and air flows in a multizone model of a building. Building and Environment.

4. C.L. Lawson and R.J. Hanson, Solving least squares problems. Prentice-Hall, Englewood Cliffs, N.J., 1974 .

5. C.F.A. Afonso, E.A.B. Maldonado and E. Skaret, A Single tracer-gas method to characterize multi-room air exchanges. Energy and Buildings, 9, 273-280, 1986.

6. J.R. Waters, The effect of time lags in a two zone air movement model. BSER & T

Table 1

BUILDING 1 : ABBEY SCHOOL SPORTS HALL

Run No	Wind Vel m/s	Analysis Method	Whole Building Infiltration Rate (ach) Data Subset 1	2	3	4	5	6	Best Value & Range %
12	5.1	AC	4.95	4.04	3.59	4.24	3.73	3.83	3.83 +29 -6
		IF	5.70	6.71	80.8	2.08	28.4	14.1	
13	5.7	AC	5.56	4.25	3.83	4.60	3.97	4.15	4.15 +34 -8
		IF	0.72	0.83	0.48	0.63	2.13	1.09	
14	6.9	AC	5.39	4.78	4.35	4.91	4.49	4.56	4.56 +18 -5
		IF	1.89	10.3	0.86	2.45	3.42	1.68	
16	5.1	AC	3.64	3.69	3.53	3.68	3.58	3.58	3.58 +3 -1
		IF	1.60	4.99	293	0.33	4.27	4.57	
17	3.1	AC	4.23	4.41	3.99	4.37	4.12	4.13	4.13 +7 -3
		IF	3.69	0.77	1.17	1.14	2.46	1.93	
18	5.1	AC	3.60	3.13	3.28	3.24	3.23	3.26	3.26 +10 -14
		IF	0.98	1.27	2.85	1.86	0.45	2.31	
19	6.2	AC	4.66	3.32	2.95	3.61	3.07	3.20	3.20 +46 -8
		IF	4.06	3.50	14.8	2.77	9.07	2.25	

Interzone Flows ms^{-1} , Run 13 Data Subset 6

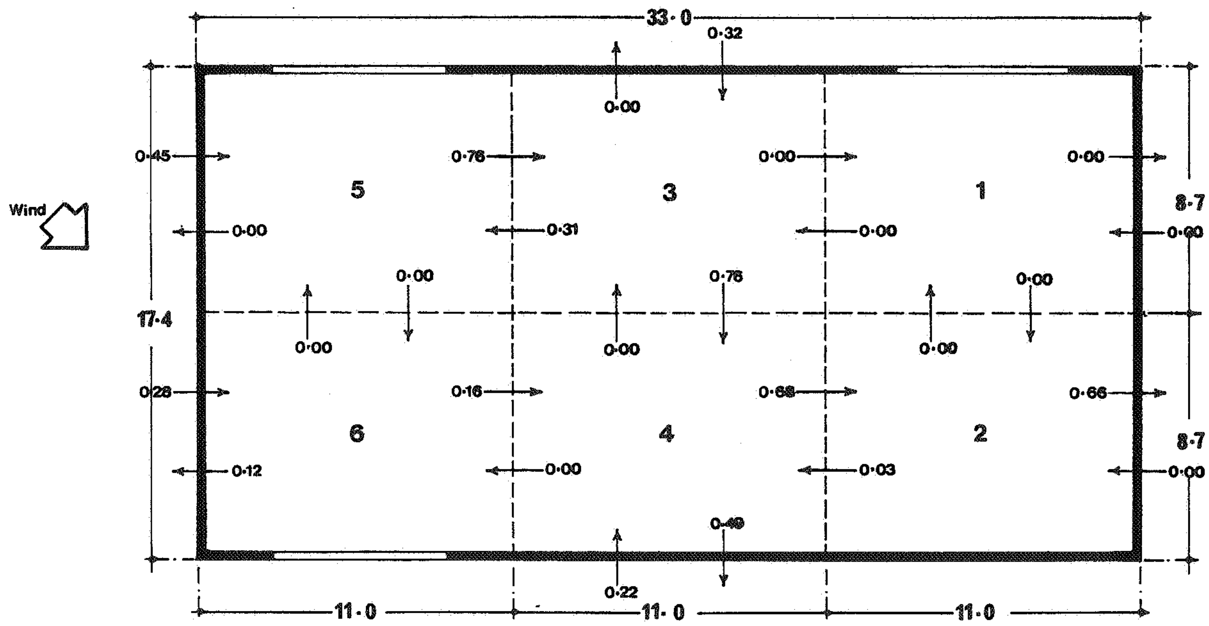


Table 2

BUILDING 2 : COVENTRY AIRPORT HANGER 5

Run No	Wind Vel m/s	Analysis Method	Whole Building Infiltration Rate (ach) Data Subset 1	2	3	4	5	6	Best Value & Range %
21	6.2	AC	9.27	6.33	4.97	6.81	5.36	5.57	5.57 +66 -11
		IF	9.86	3.11	6.02	7.91	2.94	7.10	
22	7.2	AC	5.69	5.84	5.70	5.81	5.74	5.74	5.74 +2 -1
		IF	5.35	2.17	395	3.16	4.04	6.53	
23	6.7	AC	5.64	5.02	4.69	5.13	4.79	4.84	4.84 +17 -3
		IF	3.72	1.26	106	4.66	7.34	3.62	
24	6.7	AC	5.24	4.20	3.34	4.42	3.61	3.73	3.73 +40 -10
		IF	7.14	3.24	54.1	3.11	10.8	11.7	
26	5.1	AC	4.17	3.34	2.58	3.52	2.81	2.92	2.92 +43 -12
		IF	4.23	4.85	30.2	2.48	57.2	3.91	
27	3.6	AC	5.84	4.66	3.94	4.89	4.16	4.27	4.27 +37 -8
		IF	9.48	10.1	16.8	6.08	5.21	10.6	
28	5.1	AC	5.24	4.16	3.58	4.33	3.74	3.84	3.84 +36 -7
		IF	1.95	1.58	2.60	2.47	5.62	3.14	
30	3.6	AC	6.98	3.72	3.00	4.41	3.22	3.51	3.51 +99 -15
		IF	3.82	2.11	0.47	1.48	2.37	1.19	

Interzone Flows ms^{-1} , Run 28 Data Subset 6

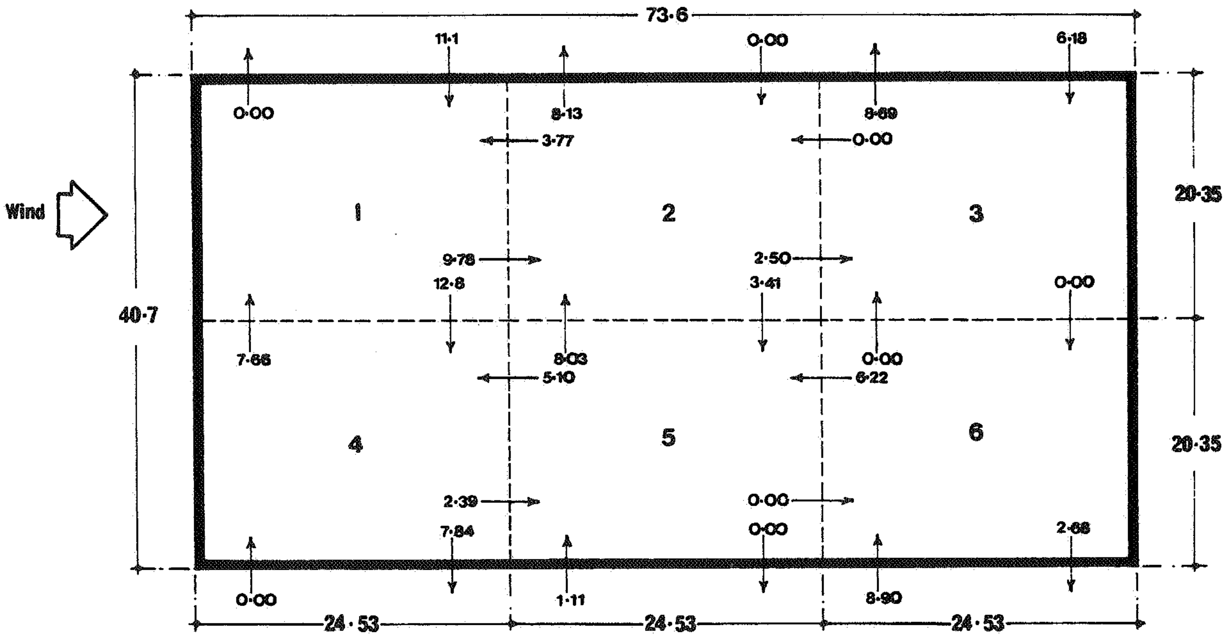


Table 3

BUILDING 3 : COURTAULDS FITTING SHOP

Run No	Wind Vel m/s	Analysis Method	Whole Building Infiltration Rate (ach)						
			Data Subset						Best Value &
			1	2	3	4	5	6	Range %
31	6.7	AC	5.05	3.10	2.31	3.47	2.55	2.71	2.71 +8.6 -15
		IF	4.83	8.66	18.9	13.2	11.4	6.49	
32	4.1	AC	4.24	2.72	2.15	3.00	2.32	2.44	2.44 +74 -5
		IF	3.89	2.58	1.01	2.97	3.33	1.67	
34	2.6	AC	4.36	2.85	2.19	3.21	2.40	2.58	2.58 +69 -15
		IF	1.43	0.88	1.78	2.65	0.75	2.60	
35	1.5	AC	4.27	2.64	2.04	2.95	2.22	2.36	2.36 +81 -14
		IF	2.10	2.11	2.01	4.94	3.95	2.52	
36	1.5	AC	4.75	3.02	2.34	3.34	2.54	2.69	2.69 +77 -13
		IF	5.71	4.10	1.88	3.35	1.97	3.05	
38	4.1	AC	3.72	2.48	1.91	2.70	2.08	2.18	2.18 +71 -5
		IF	3.61	0.20	1.40	3.68	1.31	3.83	
39	3.1	AC	4.53	2.88	2.22	3.21	2.42	2.57	2.57 +76 -14
		IF	2.16	2.47	1.88	1.51	0.99	2.48	

Interzone Flows ms^{-1} , Run 34 Data Subset 6

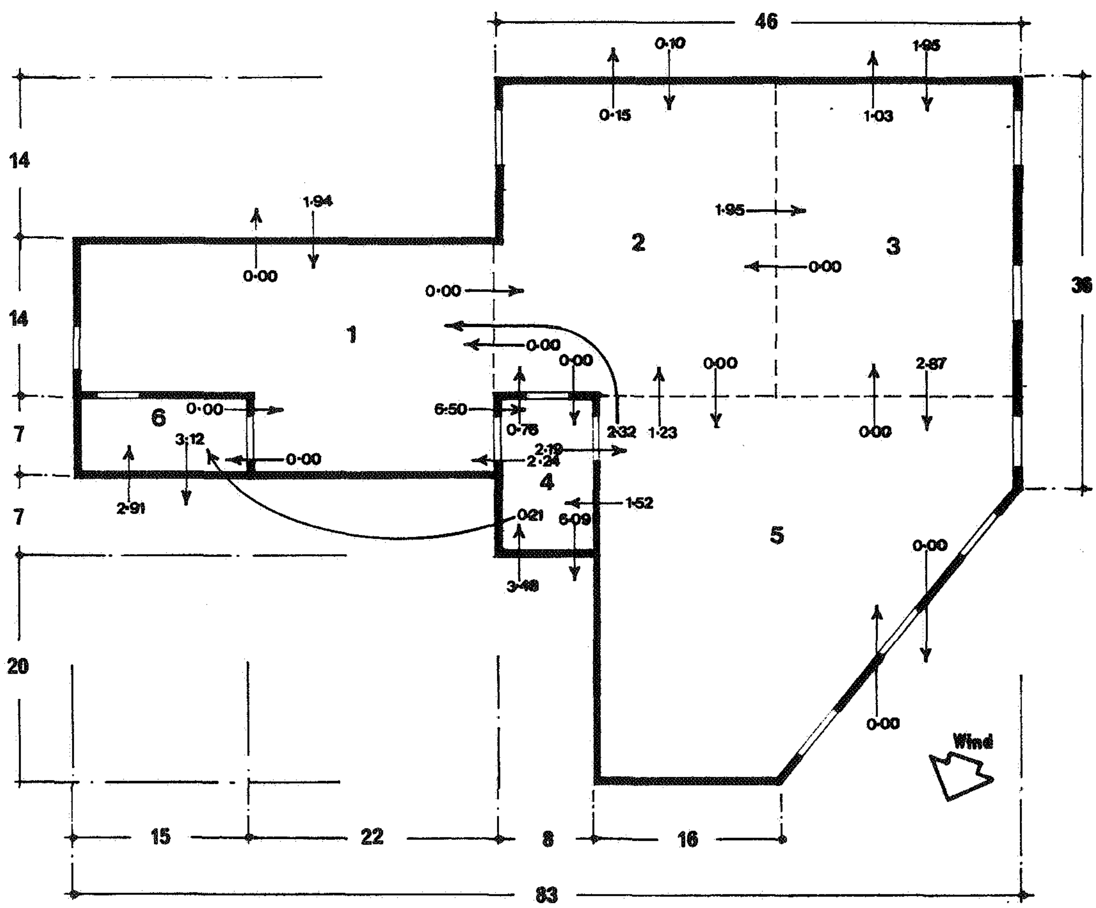


Table 4

BUILDING 4 : COURTAULDS PATTERN SHOP

Run No	Wind Vel m/s	Analysis Method	Whole Building Infiltration Rate (ach)						
			Data Subset						Best Value & Range %
			1	2	3	4	5	6	
41	6.2	AC	2.54	1.91	1.63	2.01	1.71	1.75	1.75 +45 -7
		IF	5.70	1.05	1.33	2.93	0.96	1.64	
42	7.2	AC	2.38	1.75	2.10	1.84	2.00	2.01	2.01 +18 -13
		IF	2.50	1.74	4.75	1.06	1.34	3.44	
43	1.5	AC	2.09	1.69	1.35	1.76	1.45	1.48	1.48 +41 -9
		IF	1.04	2.90	2.99	2.71	3.05	0.80	
45	5.7	AC	1.93	1.47	1.61	1.55	1.57	1.59	1.59 +21 -8
		IF	2.04	3.81	1.52	2.05	2.27	3.18	
46	5.7	AC	2.37	1.90	1.70	1.99	1.76	1.80	1.80 +32 -6
		IF	0.91	1.16	3.22	0.93	1.45	1.36	
47	10	AC	2.84	2.23	2.08	2.35	2.13	2.17	2.17 +31 -4
		IF	0.72	1.53	2.29	2.94	2.01	1.30	
48	6.2	AC	3.61	2.70	3.11	2.91	2.98	3.03	3.03 +19 -11
		IF	7.83	1.41	6.36	1.89	4.44	3.38	
49	8.2	AC	2.65	2.09	1.95	2.19	1.99	2.03	2.03 +31 -4
		IF	3.10	1.26	1.43	1.29	3.47	0.88	
50	9.3	AC	2.94	2.72	2.69	2.76	2.70	2.72	2.72 +8 -1
		IF	0.49	1.42	3.34	1.01	0.68	0.29	

Interzone Flows ms^{-1} , Run 49 Data Subset 6

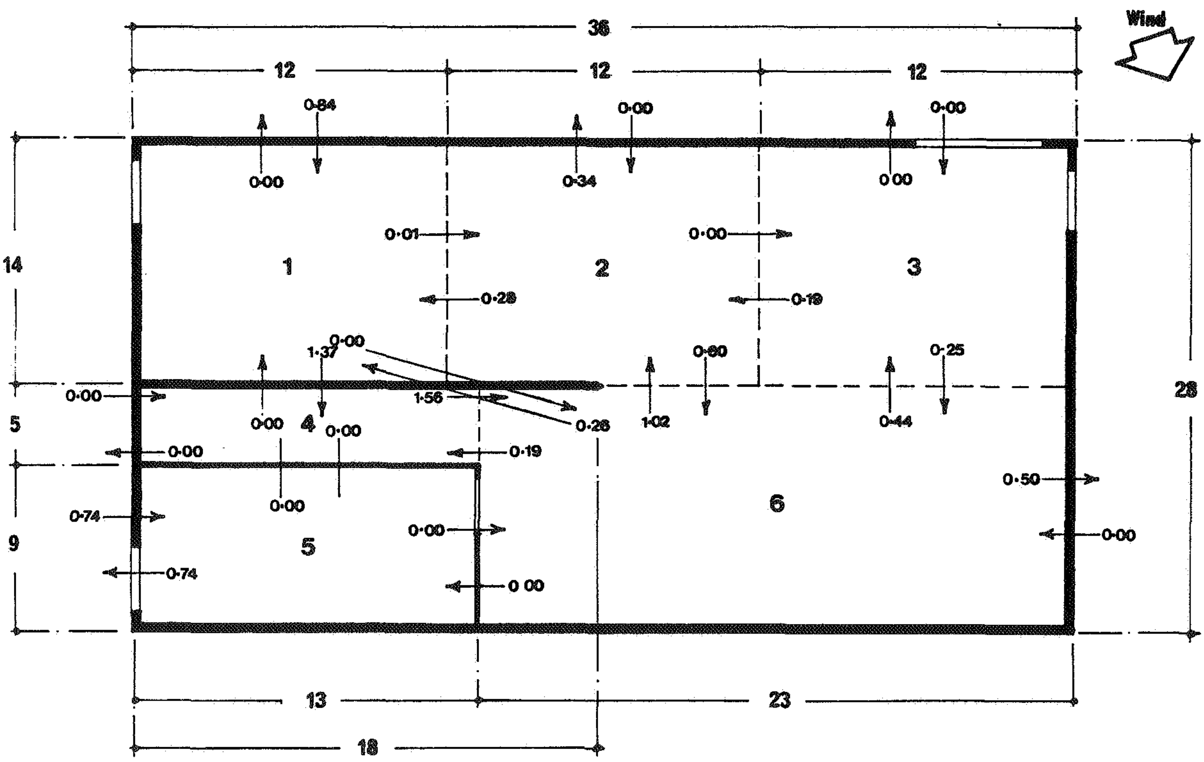
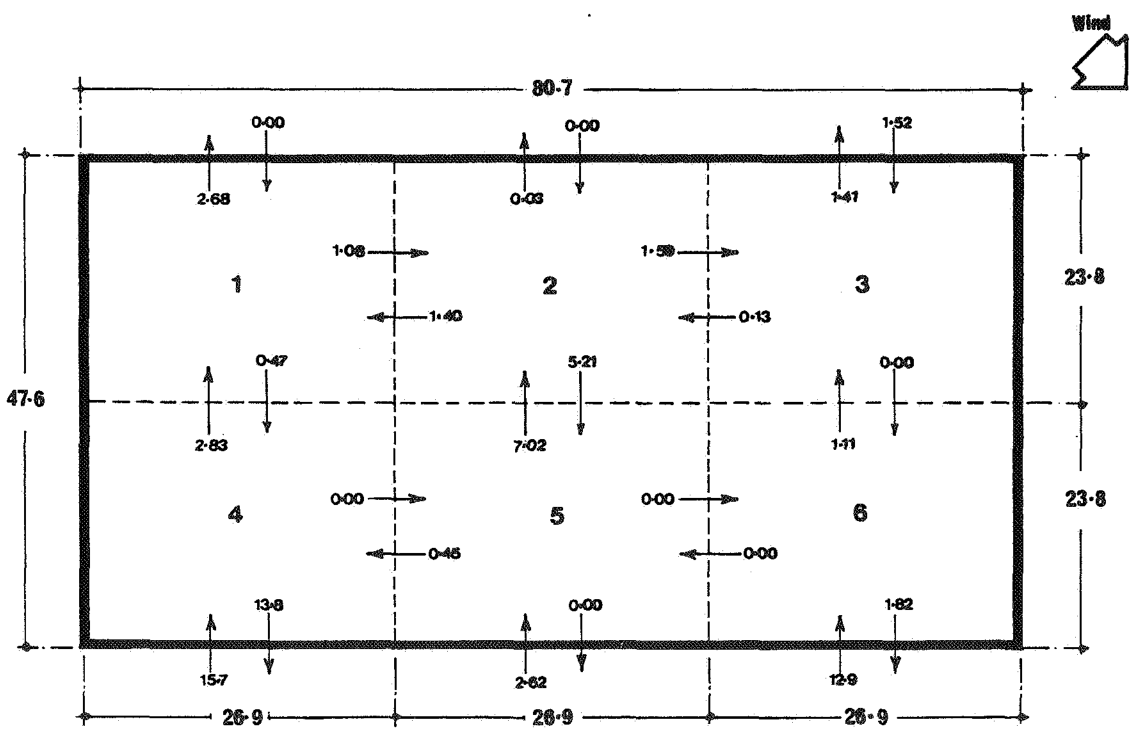


Table 5

BUILDING 5 : BRITISH GAS MAINTAINANCE DEPOT

Run No	Wind Vel m/s	Analysis Method	Whole Building Infiltration Rate (ach) Data Subset 1	2	3	4	5	6	Best Value & Range %
63	5.1	AC	3.54	2.54	2.83	2.77	2.74	2.81	2.81 +26 -10
		IF	3.65	4.05	6.08	2.01	4.65	2.20	
65	3.6	AC	3.14	2.47	2.46	2.60	2.46	2.51	2.51 +25 -2
		IF	0.53	1.00	2.12	2.26	1.66	0.91	
66	2.6	AC	6.42	4.29	3.65	4.79	3.86	4.09	4.09 +57 -11
		IF	1.75	1.38	0.81	0.46	1.78	0.80	
67	2.6	AC	4.29	3.26	2.96	3.50	3.06	3.17	3.17 +35 -7
		IF	1.40	4.04	4.33	2.98	4.94	3.76	
68	3.6	AC	9.29	6.07	4.91	6.82	5.28	5.63	5.63 +65 -13
		IF	6.55	2.89	5.14	2.33	4.94	4.36	
69	4.6	AC	2.97	2.59	2.83	2.46	2.76	2.69	2.69 +10 -9
		IF	0.88	1.97	1.28	0.61	2.31	1.17	
71	2.6	AC	4.47	3.85	3.36	4.00	3.52	3.61	3.61 +24 -7
		IF	0.54	2.16	3.71	0.99	2.15	0.75	
73	2.6	AC	2.92	2.52	2.56	2.61	2.55	2.58	2.58 +13 -2
		IF	0.96	2.85	1.14	0.54	1.05	1.21	
74	2.1	AC	3.44	2.73	2.81	2.94	2.78	2.87	2.87 +20 -5
		IF	6.05	3.06	4.33	3.42	5.75	4.19	

Interzone Flows ms^{-1} , Run 67 Data Subset 6



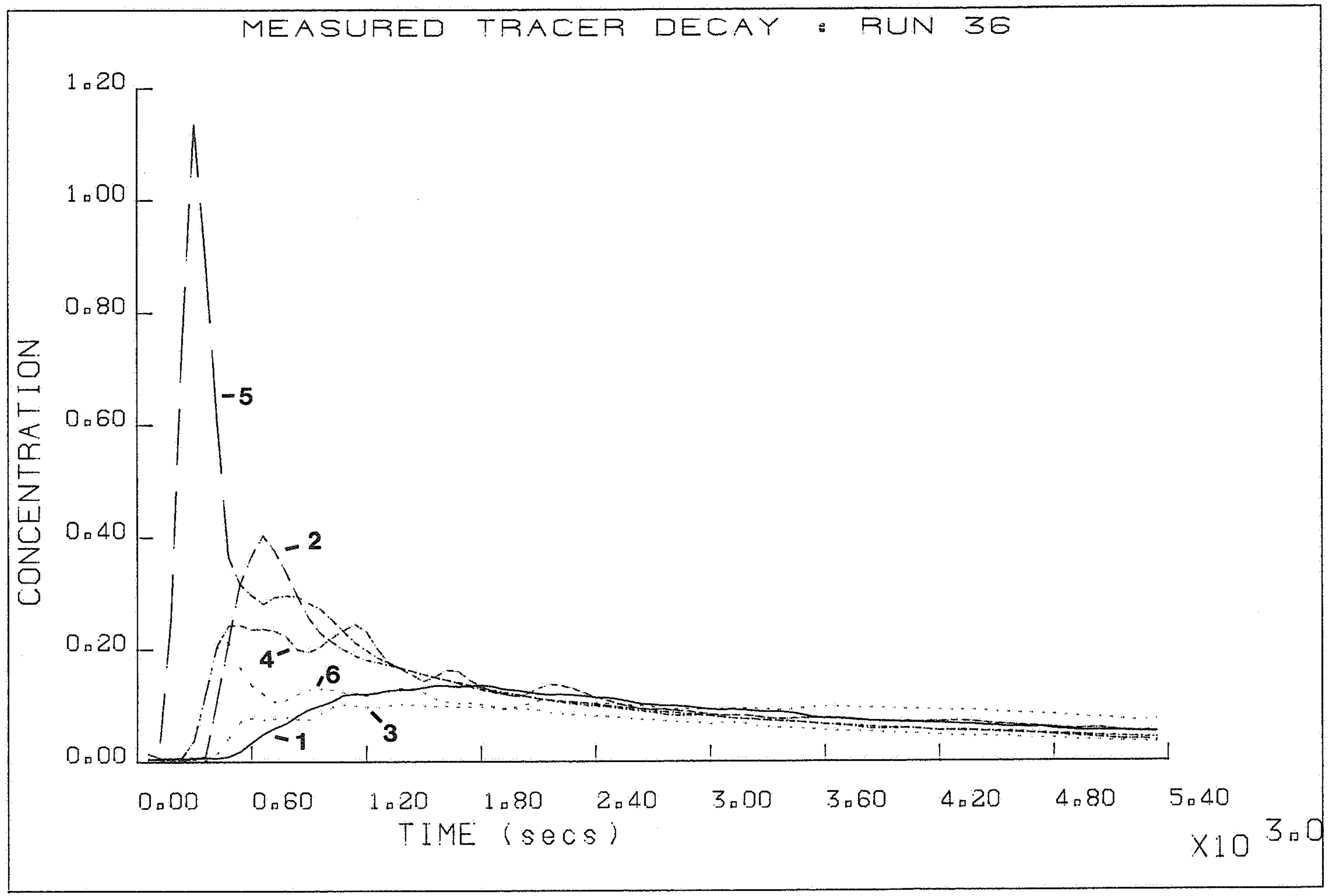


Figure 2. Measured tracer decay in Building 3, run 36

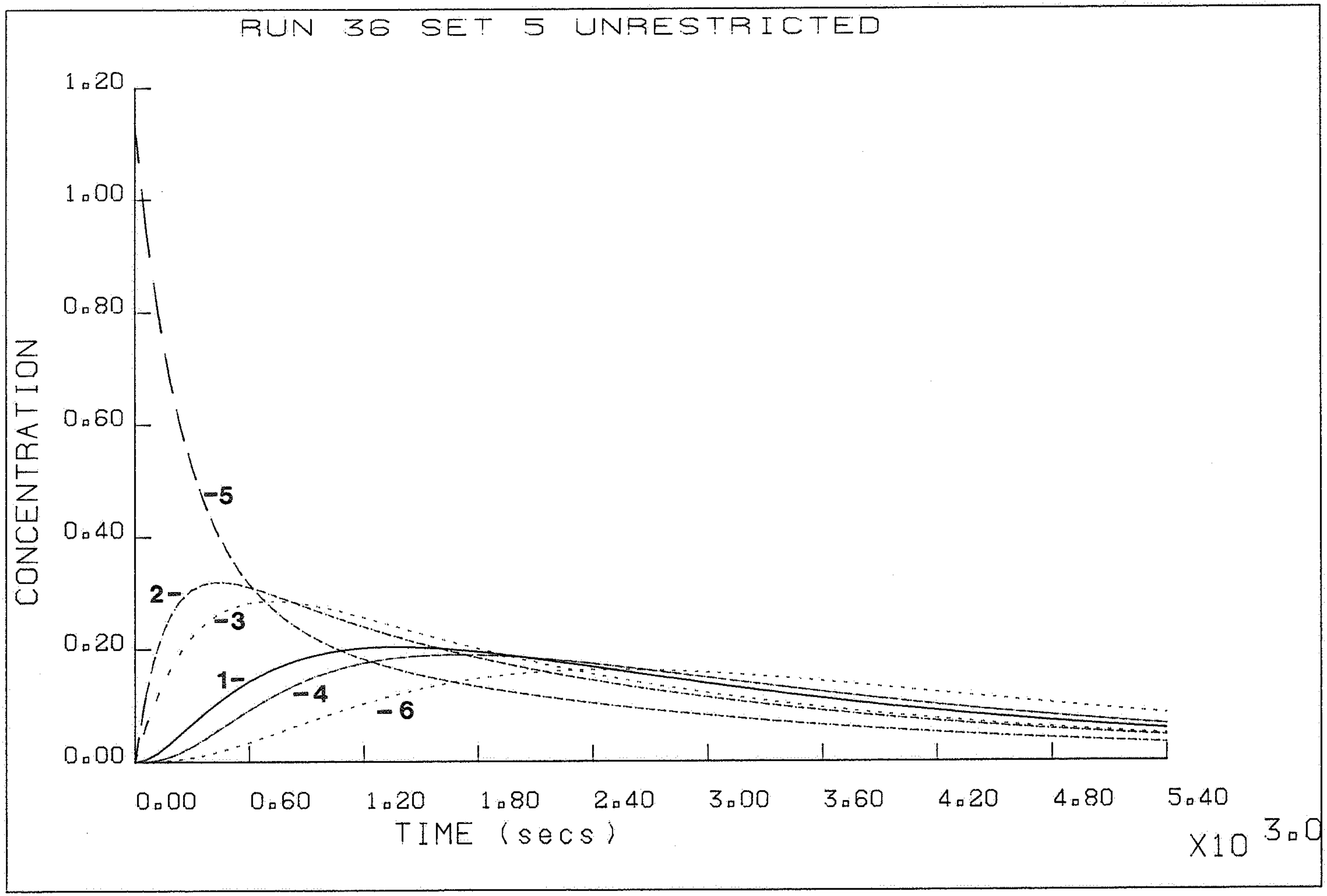


Figure 3. Computed tracer decay in Building 3, run 36
Interzonal flows obtained from data subset 5 of full data

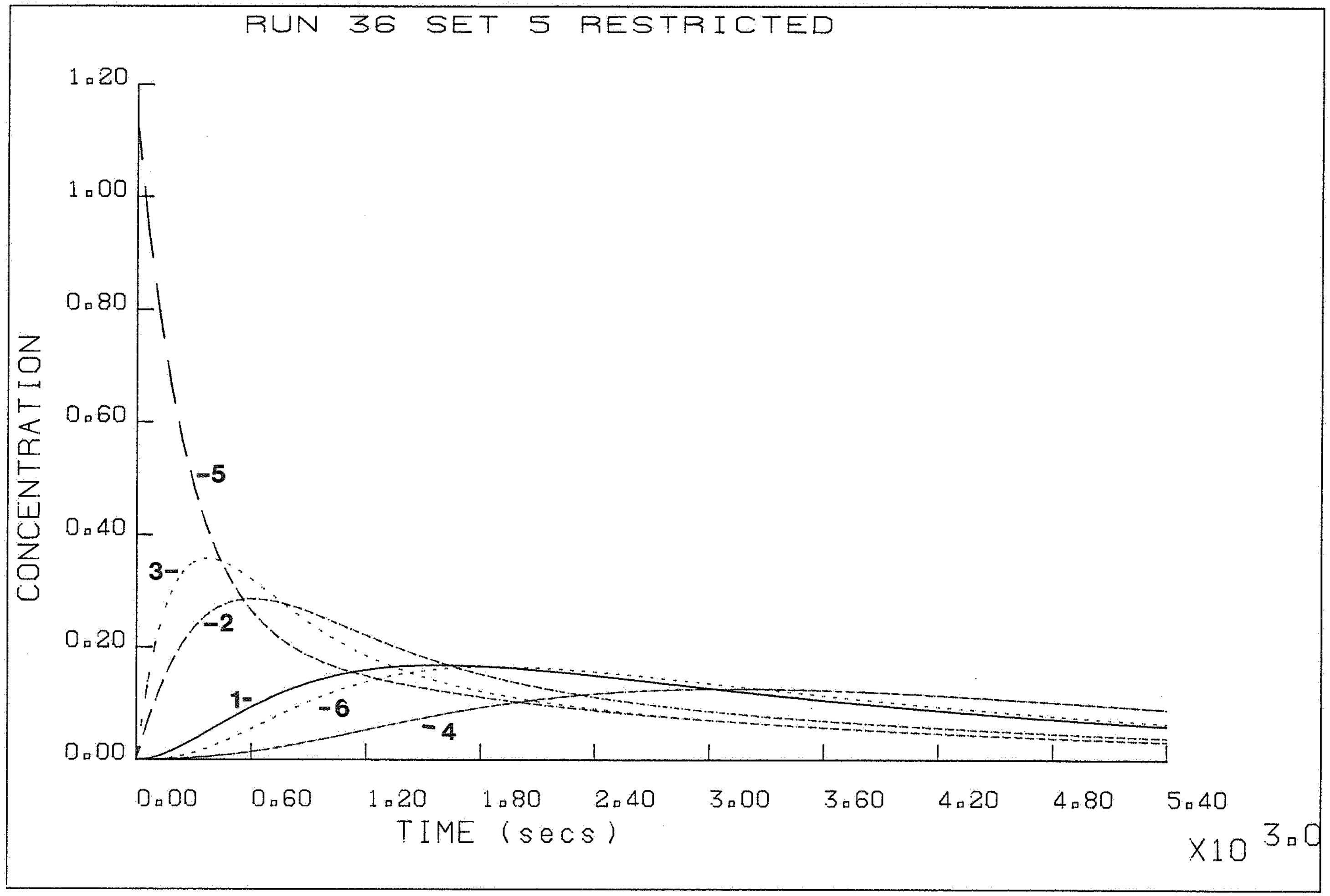


Figure 4. Computed tracer decay in Building 3, run 36
Interzonal flows obtained from data subset 5 of
data restricted to 2 time constants