#6003

Ventilation for Energy Efficiency and Optimum Indoor Air Quality
13th AIVC Conference, Nice, France
15-18 September 1992

Poster 24

A Combined Pressurisation and Tracer Gas Technique for Air Flow Measurements.

L. Shao, H-G. R. Kula, S. Sharples, I.C. Ward

Building Science Unit, School of Architectural Studies, University of Sheffield, P O Box 595, The Arts Tower, Western Bank, Sheffield, S10 2UJ, United Kingdom

SYNOPSIS Building air flow is directly related to the building energy consumption and indoor air quality. As buildings become increasingly air tight, air flow through building background cracks becomes more important, and can account for up to half of the total building air infiltration. However, background leakage is not well understood, due to the lack of appropriate measurement methods. The multi-fan guarding zone or deduction technique provides a means for testing background leakage distributions, an important parameter for characterising the background leakage. However, its reliable application in buildings is limited either due to practical constraints or due to the presence of certain types of air leakage paths, namely the branched paths. In this paper an alternative method, for measuring background leakage distributions, which does not have such problems, has been examined. This method is based on the simultaneous use of the pressurisation and tracer gas technique and termed in short the combined technique. It potentially suffers from all the accuracy problems associated with the tracer gas technique, which could be made more serious by the high pressurisation flows. To counter this problem, mixing fans, among other measures, were utilised. The validity of this measure was examined and its effectiveness tested by applying the combined technique to one single and several multi-zone set-ups. Results showed that the technique is of good accuracy with relative errors consistently below 10%.

1. Introduction

The information on building air flows is of great importance to building service engineers. The air flow can occur through well defined openings and less well defined background cracks. As the buildings become increasingly air-tight to reduce energy consumption, the latter become significant, accounting for up to half of the total air infiltration. There are generally two approaches to the measurement of background crack flows. The first one is to measure the flow through individual cracks using, for example, a portable pressurisation facility of the type developed by Baker et al [1]. While this is useful for trouble-shooting and detailed fundamental studies, it is time-consuming and probably impossible for surveying the background leakage cracks in a building or a building zone. The second method is to measure bulk flows from one building zone to the other zones and the outside due to background cracks. In other words, instead of measuring each individual cracks, this method measures the integral effects of the cracks connecting one zone to each of the other zones in the building. The information thus obtained is termed building background leakage distribution which, although not as detailed as that from the first method, is an improvement over the information of overall leakage obtained using the single fan pressurisation technique. The formal definition of the background leakage distribution is the combination of the flow rates through background leakage paths from one zone to the outside and each of the other zones in the building when measured at equal pressure differences between the former and each of the latter. Obviously, each zone in the building has its own leakage distribution.

Building air flow measurements have been relying on either tracer gas techniques or pressurisation techniques. However, the former can not yield the leakage distribution information which requires a controlled pressure environment. In comparison, the pressurisation technique in the form of multi-fan guarding zone or deduction method is more capable in this area [2]. Nevertheless, as pointed out by Wouters et al [3], there are situations in which it is not practical to perform the pressurisation measurements. Moreover, it has been shown that the pressurisation techniques break down as they are applied to buildings containing branched leakage paths --- those linking three or more zones together[4]. Therefore, neither of the above techniques can be totally relied upon to provide leakage distribution information.

Since the initial work of Wouters et al [3] a technique based on the combination of the above two has emerged, referred to in the following as the combined technique. As for the multi-fan guarding zone technique, pressurisation fans were also used in the combined technique to provide the equal pressure differences mentioned above. However, different to the multi-fan technique, whereby leakage flow is measured indirectly by analysing the flow rates through the pressurisation fans, it does the measurement directly using the tracer gas method. Since the tracer gas method is not affected by the presence of branched paths [4], the combined technique can be applied to any type of building to measure leakage distributions, without having to find out first whether branched paths are present.

The combined technique, while having promising capabilities, potentially suffers from the low measurement accuracy associated with poor tracer mixing. It is well known that for the tracer gas measurement to be accurate, the tracer gas must be reasonably uniformly mixed with the air. This requires that the leakage rate be limited to low values, below 0.5ACH according to Alevantis and Hayward [5]. However, this is highly likely to be exceeded when applying the combined technique, the pressurisation element of which generates strong air flows. The objective of this work, therefore, was to improve the accuracy of the technique, principally by means of enhancing tracer mixing. It was found that using mixing fans led to satisfactory mixing and was acceptable in the combined technique. In the following, experimental work is presented in which the effectiveness of the mixing fan was tested by examining the tracer distribution uniformity (indirectly), the accuracy of the combined technique in measuring high flow rates as well as its accuracy in measuring background leakage distributions. Results showed that the combined technique is consistently accurate, with relative errors smaller than 10%.

2 Test Facility

The experiments were carried out a laboratory, where test conditions can be more easily tailored to suite the many requirements, so that the accuracy of the combined technique can be examined more accurately and under a wider range of situations. Five multi-zone set-ups and one single zone set-up were used in the study. The maximum number of zones in a set-up is five and the zones vary in size from 0.182 to 10.35m³. Summary information, including total number of zones, sizes of the zones and positions of calibrated cracks, on these set-ups can be found in Table 1.

Table 1. Summary information on the various set-ups

	Number of Zones	Zone sizes					Zone Pairs with Connecting Cracks
		1	2	3	4	5	
Set-up 1	1	1.027					
Set-up 2	2	1.027	0.530				1-2
Set-up 3	4	1.027	0.530	0.292	0.182		1-2 2-3 2-4
Set-up 4	5	1.027	0.530	0.292	0.182	0.233	1-2 2-3 2-4 2-5
Set-up 5	2	10.35	10.35				1-2
Set-up 6	3	10.35	5.47	4.88			1-2 1-3

Note that the zone numbering for one set-up bears no automatic relation to that of another. A more detailed description of one of the set-ups, No. 3, will be given in the following. As the experimental arrangements for the all the set-ups are quite similar, this description will not be repeat for the other ones.

The test facility for set-up 3 is schematically shown in Fig. 1. It consists of four zones, the pressurisation equipments and the flow rate measurement equipments.

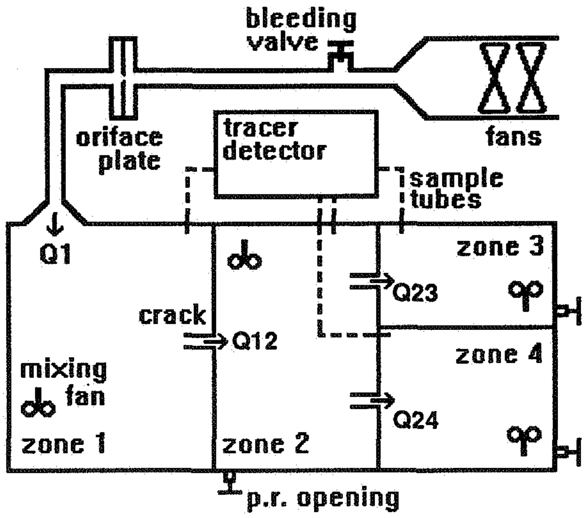

Fig. 1 Schematic of the test facility

The four zones are arranged and numbered as shown in Fig. 1. The zones are wooden structures and have internal volumes of 1.027, 0.530, 0.292 and 0.182 m^3, respectively. Wooden panel joints were air-tight sealed, using for example silicon plastic. Manufactured cracks, marked "crack" in Fig. 1, were mounted on the partitions between the zones. The fact that there is a crack connecting zone 2 and zone 4 is described in Table 1 in its last column by means of a number pair 2-4. Likewise, the position of the other two cracks in Fig. 1 or set-up 3, is indicated by the number pairs 1-2 and 2-3. The same system was used for indicating crack positions in other set-ups described in table 1. The above partitions were so designed or so well sealed that the flow between any two zones was solely through the manufactured crack between them. The cracks were pre-calibrated so that the flow rate through a crack at various pressure differences across it was known. This information were then used to judge the accuracy of the measurement data from the combined technique. Details of the calibration is presented later.

The pressurisation was provided by two axial fans linked serially and connected to zone 1. The same arrangement was made for the other set-ups, with only one slight variation for set-up 5 and 6 where the two fans were replaced with a single, more powerful centrifugal fan to cope with the larger volumes. In the experiment, the pressure in each of the four zones frequently needed to be changed or regulated, either for selecting another test condition or for maintaining the equal pressure difference required for the leakage distribution measurement. This was effected by taking one or a combination of the following three measures: adjusting the bleeding valve opening, blocking part of the fan air inlet and adjusting the pressure regulating openings (marked "p.r. opening" in Fig. 1) in the walls of the zones, the equivalent of which in a real building could be either windows or doors. Pressure tappings were installed in each of the four zones. The pressures there were measured using digital micromanometers and collected using a micro based data acquisition system.

Interzonal flows such as Q_{12}, Q_{23} and Q_{24} in Fig. 1 are usually measured using multi- rather than single tracer techniques. This is because in a multizone situation one zone can receive air flows from two or more other zones but the single tracer method can only measure the sum of these flows, unable to tell one of them from another. However, if the pressure condition is such that a zone receives air flow from only one other zone, then the single tracer method can be used to measure that interzonal flow. A close examination of Fig. 1 shows that the above condition is always the case for zone 2 and if, for example, a zero pressure difference is maintained between zone 3 and 4, then all interzonal flows in Fig. 1 or set-up 3 can be measured using a single tracer gas method. This method was used for all six set-ups, in preference to the multi-tracer version, which is less robust, less portable, more expensive and more difficult to operate. The equipment arrangement was as that described in Ref. [6]. Samples of the tracer (SF_6)/air mixture were periodically taken from the zones to be analysed using a electron capturing detector. The decay of the tracer concentrations were then analysed to provide the flow rates. In this experiment, samples were returned to where they were taken after each analysis to avoid the sample flow being counted towards the interzonal flow.

As said in the introduction the objective of this work was to improve the accuracy of the combined technique by enhancing tracer air mixing. Among the mixing enhancement measures tested, that of using mixing fans was found to be the most effective. The following discussion will be confined to the tests on this method.

Although strict sealing procedures were applied to the construction of the zones, the flow rates through the pressurisation fans --- typically 10ACH --- were still much higher than what is acceptable --- 0.5ACH [5] --- for the reasonable tracer air mixing uniformity. The high flow rate and thus the short flow residence period in a zone means that the flow does not mix well with the mixture in the zone during its stay. The resulting highly non-uniform tracer distribution in a zone contradicts the pre-condition for tracer gas method application and thus can lead to a large flow rate measurement error. To counter this problem, a mixing fan was installed in each of the four zones to improve the mixing. These fans were so positioned that the flows from them are not directed at the manufactured cracks. The use of mixing fans should normally be avoided for conventional tracer gas tests, since the fan may alter the characteristics of the original flow which is to be measured. However, the use of the fan is acceptable for measuring flows driven by given pressure differences as in this case. Calibration tests showed that the crack flow was solely determined by the pressure difference. In other words, turning on the fan did not affect the rate of the flow to be measured, but it helped to measure the flow rate more accurately.

3 Procedures and Results

The above mentioned crack flow calibration was carried out using the same facility as that show in Fig. 1, but with zone 2, 3, 4 and the tracer detecting equipment removed. The calibration procedure was as described in Ref. [1].

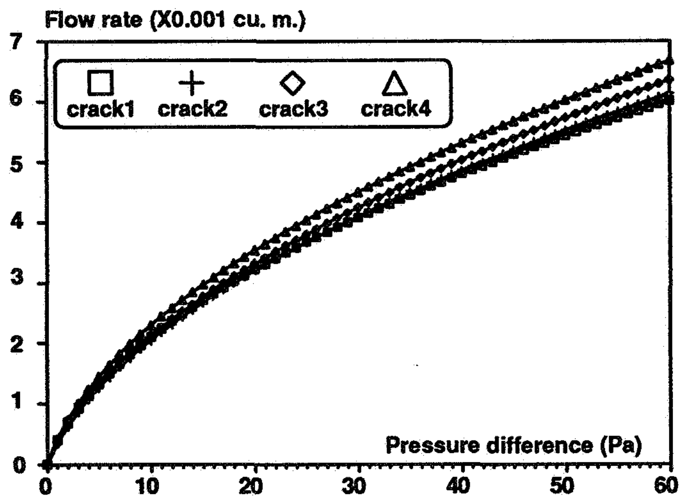

Fig. 2. The flow characteristics of four calibrated cracks

A typical set of calibration results --- the Q-ΔP relation curves for four manufactured cracks --- is shown in Fig. 2. The range of pressure difference was sufficiently wide to cover those likely to be encountered in the combined technique tests. It was found that the calibration curves conformed well to quadratic curves, with deviations about 3%.

The combined technique was first applied to the measurement of high flow rates generated by the pressurisation fans, during which its accuracy and the tracer mixing uniformity were examined. It was then tested on leakage distribution measurements. While the latter must be carried out in set-ups consisting of at least three zones and under strict pressure arrangements, the former can be performed in a single zone and with much relaxed pressure controls, thereby simplifying the procedures and facilitating the concentration of efforts on the essential problem of tracer mixing in large pressurisation flows. Set-up 1, 2, 3 and 5 were used in the above "former" tests, with No. 3 having the most number of zones. As can be seen from Fig. 1, in such a test using set-up 3, air is blown by the fans into zone 1, building up pressure in that zone. The pressure, ΔP_{12} drives air, Q_{12}, into zone 2, building up the pressure there, $\Delta P_{23}, \Delta P_{24}$, which in turn drives air, Q_{23} and Q_{24}, into zone 3 and 4, respectively. These flow rates were measured using the tracer gas method described above and compared with the calibrated flow rates through the cracks under the pressure differences $\Delta P_{23}, \Delta P_{24}$ and ΔP_{12}, respectively. The agreement in the above comparison was then used to evaluate the accuracy of the combined technique in the high flow rate measurement. In addition, the tracer mixing uniformity was evaluated by examining the agreement between the measured tracer concentration decay curve and the theoretical one, which is based on the assumption of absolute tracer concentration uniformity. This information is important as it may add confidence in the technique and the effectiveness of the mixing fan.

The procedure for applying the combined technique to the "latter" tests mentioned above --- measuring leakage distributions --- is similar to that outlined above, except that by definition the equal pressure difference condition must be maintained. For example, suppose flow rates from zone 1 to the neighbouring three zones 2, 3 and 4, Q_{12}, Q_{13} and Q_{14}, form the leakage distribution for zone 1, which is to be measured, then the corresponding pressure difference between zone 1 and 2, 3 and 4, ΔP_{12}, ΔP_{13} and ΔP_{14} must be kept equal during the test.

The mixing fan effect on tracer uniformity can be demonstrated by the following results. Refer to the set-up shown in Fig. 1. Fig. 3(a) shows the tracer concentration decay history in zone 1. The theoretical decay curve between the start and the end of the test was obtained with the assumption of perfect tracer air mixing. The good fit between the measured and the theoretical curve indicates that by installing the mixing fan, the mixing problem associated with high pressurisation flows has been solved. Fig. 3 (b) to (d) shows that the same is true for the other zones. Data for the above were then analysed to obtain the measured interzonal flow rates, using the method of Ref. [6].

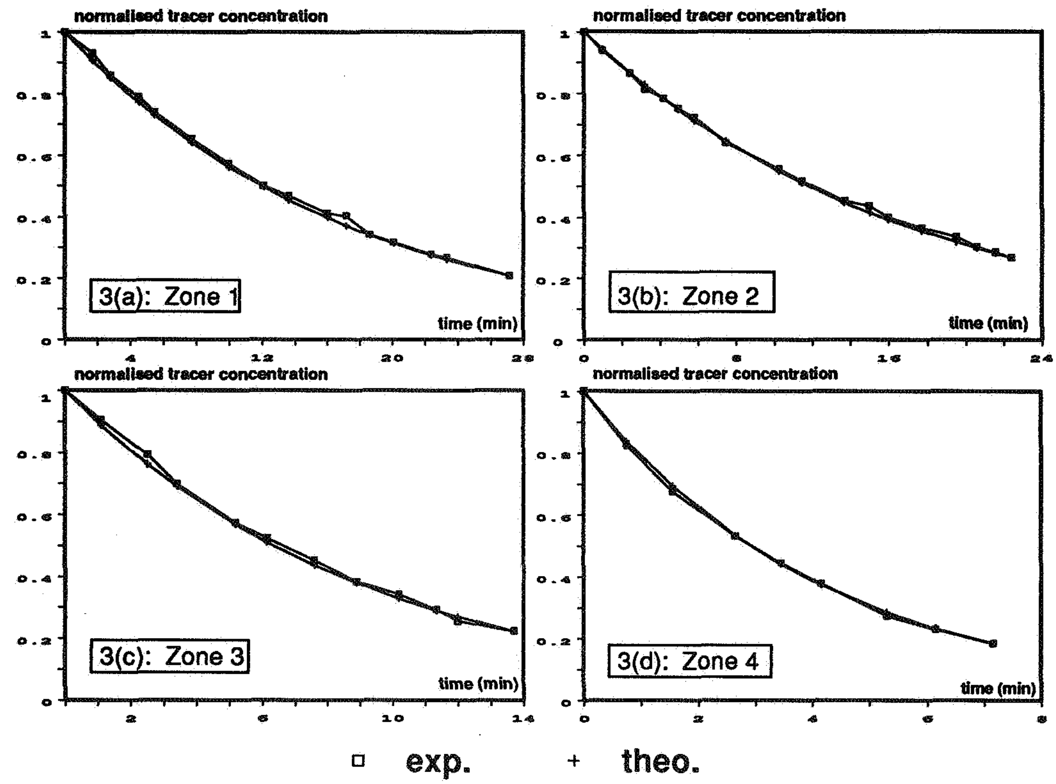

Fig. 3 (a)-(d). Tracer concentration decay in the zones of Fig.1.

The accuracy of the combined technique in dealing with large pressurisation flows was tested in set-ups 1, 2, 3 and 5. The measured inter-zonal flow rate data for each of these set-ups are listed against the corresponding calibration data, in Table 2, which also shows the corresponding relative errors. The subscripts for the flow rates were used to indicate the two zones between which the flow occurs. They correspond to those used in the last column of table 1. For example, Q_{12} of set-up 2 in Table 2 is the flow rate through the crack 1-2 of set-up 2 indicated in table 1.

Table 2 Combined technique measurements as subjected to large pressurisation flows.

	Set-up 1	Set-up 2	Set-up 3		Set-up 5
	Q_1	Q_{12}	Q_{23}	Q_{24}	Q_{12}
Combined Method (m3/h)	3.47	1.84	1.77	2.22	28.7
Calibration (m3/h)	3.78	1.91	1.61	2.42	29.5
Relative Error (%)	8.2	3.7	9.9	8.3	2.8

As can be seen from Table 2, the combined technique copes well with large flows with relative measurement errors ranging from 3.7% to 9.9% for several small sized set-ups (1, 2 and 3) and 2.8% for the larger sized set-up 5. The case of set-up 1 is slightly different to the others in that the total air change rate, instead of a crack flow rate, of the single zone was measured and compared with the rate measured using an orifice plate.

The combined technique was then applied to the leakage distribution tests, in set-ups 4 and 6. One set of results (i.e. under one pressure difference condition) for each of the two set-ups were listed, again against the corresponding calibration data, in Table 3. The subscripts were used in the same way as in Table 2. The resulting relative errors were all below 10%, showing that combined technique is of good accuracy.

Table 3. Leakage distribution results obtained using the combined technique.

	Set-up 4			Set-up 6	
	Q_{23}	Q_{24}	Q_{25}	Q_{12}	Q_{13}
Combined Method (m3/h)	2.09	2.24	1.94	35.25	33.8
Calibration (m3/h)	2.00	2.46	1.90	37.1	36.9
Relative Error (%)	4.5	8.9	2.1	5.1	9.2

4 Conclusions

Experimental work on a combined pressurisation-tracer gas technique has been carried out. The technique is based on the simultaneous use of the pressurisation and tracer gas methods. It can be used to measure background leakage distributions, which are important building air flow parameters. This technique avoids the problem of a currently available technique, the multi-fan guarding zone or deduction technique, which is ineffective in buildings containing branched leakage paths.

The accuracy of the combined technique has been significantly improved by the use of mixing fans The test results showed that the technique is now consistently accurate, with a relative error smaller than 10%

It is felt that a multi-tracer version of the technique should be developed as its application in practice could be more flexible in certain situations than utilising the single tracer method.

Acknowledgement

This study was part of an air infiltration research project funded by the UK Science and Engineering Research Council (Grant No. GR/F28397).

References

[1] Baker, P.H., Sharples, S. and Ward, I.C. "The validation and application of a portable pressurisation test facility for the measurement of the flow characteristics of background leakage areas." Proc. Int. Congress on Building Energy Management, Lausanne, 28 Sep. - 2 Oct. 1987.

[2] Furbringer, J.-M, Roecker, C. and Roulet, C.-A. "The use of a guarded zone pressurisation technique to measure airflow permeabilities of a multizone building." Proc. 9th AIVC Conf., Gent, Belgium, 1988, pp233-250.

[3] Wouters, P., l'Heureux, D. and Voordecker, P. "The determination of leakages by simultaneous use of tracer gas and pressurisation equipment." Air Infiltration Review, Vol. 8, No. 1, 1986, pp4.

[4] Shao, L., Sharples, S., Ward, Ian C. and Kula, H.-G. "An analytical study of branched connections: its implications to multizone air flow measurements." Proc. 13th AIVC Conf., Nice, France, 14 -18 Sep. 1992.

[5] Alevantis, M.S. and Hayward, S.B. "The feasibility of achieving necessary initial mixing when using tracer gas decay for ventilation measurement." Proc. 5th Int. Conf. on Indoor Air Quality and Climate, Toronto, Canada, 29 Jul. - 3 Aug. 1990, pp349-354.

[6] Shao, L. and Howarth, A.T. "Air infiltration through background cracks due to temperature difference." Building Serv. Eng. Res. Technol., Vol. 13, No. 1, pp25-30, 1992.