PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

10th AIVC Conference, Dipoli, Finland
25-28 September, 1989

Poster 2

# A COMPARISON BETWEEN THE STEP-UP, STEP-DOWN AND PULSE INJECTION TECHNIQUES FOR THE MEASUREMENTS OF THE MEAN AGE OF AIR

R. Niemela[1], A. Saamanen[2] and H. Koskela[1]

[1] Institute of Occupational Health
Laajaniityntie 1, SF-01620 Vantaa, Finland

[2] Current address: Technical Research Centre of Finland, Safety Engineering Laboratory, P.O.Box 656
SF-33101 Tampere, Finland

## 1. SYNOPSIS

A comparison of three injection manners, step-up, step-down and pulse, for determination of the mean age of air was made by using nitrous oxide and sulphur hexafluoride as tracer gases. The concentrations of nitrous oxide and sulphur hexafluoride were simultaneously measured with a dual-channel IR-analyzer. Tests were carried out in a test chamber with air change rates of 3 $h^{-1}$ and 5 $h^{-1}$. The tracer gases were injected under three conditions: into the inlet air and directly into the room with and without extra mixing fans. The results suggest that the pulse procedure is as reliable as the two other methods used.

## 2. INTRODUCTION

Various tracer gas measurement strategies have been developed to explore airflow behaviour and the performance of ventilation systems (1,2,3,4). Tracer gas techniques have been applied in different spaces ranging from a small single room to multicelled structures. Depending on the information desired, a tracer gas is released into the inlet air or within the room. The most common measurement strategies are: decay method, step-up technique (constant injection) and constant concentration technique. These techniques have been used for determining ventilation rates, interzonal airflows and air leakage characteristics especially in residential, commercial and public buildings. Typically, in these buildings pollutant sources are passive and uniformly distributed. Contaminant emission rates are rather constant resulting in relatively low concentrations. Therefore, the air quality in these buildings may be expressed in terms of recommended airflow rates and specified ventilation configurations.

In industrial work rooms, where airflow rates usually are notably higher than in public buildings, air contaminants are emitted from numerous sources ranging from a single point source to wide sources with complex geometry. Cross-contamination from several sources occurs frequently. Industrial process emissions are often intermittent, consisting of phases of strong release rates, resulting in high concentration peaks. The occurrence of concentration peaks may be critical from the standpoint of health effects. Both average and peak exposure should be controlled with ventilation processes and other preventive measures. In these conditions we are not only interested in patterns of fresh airflows but also the dispersion routes of contaminants, and the spatial and temporal variation of contaminants in the zone of occupancy.

The tracer gas technique can be used to chart the behaviour of contaminated air. In order to obtain quantitative information on the spread of pollutants, the injection process of tracer gas should simulate as accurately as possible the actual contaminant release. The information taken from step-up, and pulse experiments may be most useful as far as industrial process emissions are concerned. If the system is linear, these two injection modes should theoretically yield the same information of the flow phenomena. The step-up and step-down injection modes are widely used in non-industrial and industrial buildings, whereas the pulse injection technique has been used to a lesser extent (5,6,7,8,9). Recently, Axley and Persily have emphasized the usefulness of the tracer pulse method (10).

The purpose of this paper is to compare three tracer techniques, step-up, step-down and pulse method, for determination of the mean exit age of air or contaminants simulated with two tracer gases. Nitrous oxide and sulphur hexafluoride served as tracers. The concentrations of the tracer gases were simultaneously measured with a dual-channel, rapid-response IR-analyzer. The tests were performed in a test chamber at air change rates of about 3 $h^{-1}$ and 5 $h^{-1}$ which usually occur in industry.

## 3. METHODS

In order to compare the injection methods for exploring airflows of general ventilation, 50 series of tests were carried out. The experiments were performed in an exposure test chamber (2.0 m wide, 2.5 m long and 2.0 m high). The inlet air induced by the exhaust fan was introduced into the chamber through the rectangular register near the ceiling on one of the shorter walls. Air was exhausted from the opposite wall through outlets positioned near the ceiling. The inlet air was drawn from the surrounding laboratory room at a flow rate of 0.008 $m^3/s$ or 0.013 $m^3/s$ corresponding to approximately 3 and 5 air changes per hour. The exhaust air was dumped outdoors. The flow rate of the inlet air was measured with a thermoanemometer (Alnor Compuflow

GGA-65P). The flow rate of the exhaust air could not be measured accurately due to flow disturbances in the outlet terminals.

Two extra fans were used in some tests to accelerate mixing of the chamber air. The tracer gas source consisting of simple plastic tubing (i.d. 5 mm) was positioned in the test chamber at a height of 1.2 m at a distance of 1.0 m from the wall with the inlet air terminal. During the tests, where tracer gases were injected into the inlet air, the injection tubing was placed in the center of the inlet air duct opening. The release rates of the tracer gases were controlled with pressure-reducing valves, conventional float rotameters and dry gas meters. Tracer gases, nitrous oxide ($N_2O$, density 1.83 $kg/m^3$) and sulphur hexafluoride ($SF_6$, density 6.41 $kg/m^3$), were supplied simultaneously into the inlet air or into the test chamber using the step-up, step-down and pulse injection procedures.

In the step-up method tracer gases were injected at a constant flow rate ranging from 40 ml/min to 175 ml/min depending on the ventilation rate of the test chamber and the tracer gas used. The injection time was about five times the time constant of the test chamber. The step-down experiment began when the injection of tracer gases was stopped. In the pulse method the tracers were fed at constant flow rates during 120 s or 240 s resulting pulse volumes of 0.4 l and 0.7 l.

Concentrations of tracer gases were simultaneously measured in the exhaust air by the dual channel infra-red gas analyser (Binos 4b, Leybold Heraeus). The response time of the analyzer was less than 10 s. The output of the Binos analyzer was connected to a microcomputer (Hewlett Packard 9000 Model 310) via an AD-converter (HP 3421A). The sample interval was set to 10 s. The baseline drifts of the infra-red gas analysers were checked before and after the experiment. The eventual correction was done before calculating the mean exit ages. The mean exit ages were calculated by computer programs described by Niemelä et al. (11).

Air velocity at the tracer gas injection site was monitored during the tracer gas tests. The air velocity was detected by an omnidirectional hot wire probe (TSI 1620, Thermo-Systems Inc.) at a sampling frequency of 1 Hz. Based on these instantaneous velocity readings the arithmetic mean and the standard deviation of the sampling period of 3 minutes were calculated and stored by the microcomputer.

## 4. RESULTS

Typical concentration responses for the three techniques used are shown in figures 1-2. It can be seen that notable concentration fluctuations occurred when the tracer gases were injected within the room. The mean exit ages measured with different procedures are given in the Appendix. Figure 3 gives a summary of these results in nondimensional form. The age values have been scaled by the nominal time constant based on the inlet airflow rate, $\tau_S$=V/Qs, (V= the room volume, Qs= the flow rate of the air supplied).

When the tracer gases were injected into the inlet air, all procedures adopted gave the same value for the mean exit age within 6 % for $SF_6$ and within 11 % for $N_2O$. The results also show that the mean exit age of the inlet air was about 15 % less than the time constant based on the inlet airflow rate. The difference indicates air infiltration through the structure of the chamber. This was not surprising, because underpressure between the chamber and the surroundings existed.

When tracer gas was injected into the chamber with the mixing fans on, the mean value of the $SF_6$ step-up data was 7 % higher than that of the decay data, and the corresponding figure for $N_2O$ was 13 %. Compared to the $SF_6$ pulse data, the step-up data yielded 5 % higher ages during the tests where tracer gases were injected into the chamber without extra mixing. The corresponding difference between the $N_2O$ step-up and pulse procedures amounted to 20 %.

The step-up technique with $N_2O$ yielded the worst repeatability, 8-12 % (expressed as a relative standard deviation). The repeatability of the pulse experiments ranged from 3 to 7 % and that of the step-down procedure was 5 % or less.

Figure 4 gives the typical air velocities and corresponding standard deviations based on the averaging time of 3 minutes monitored during the tests with and without mixing. A summary of the mean velocities, standard deviations and turbulence intensities is depicted in figure 5.

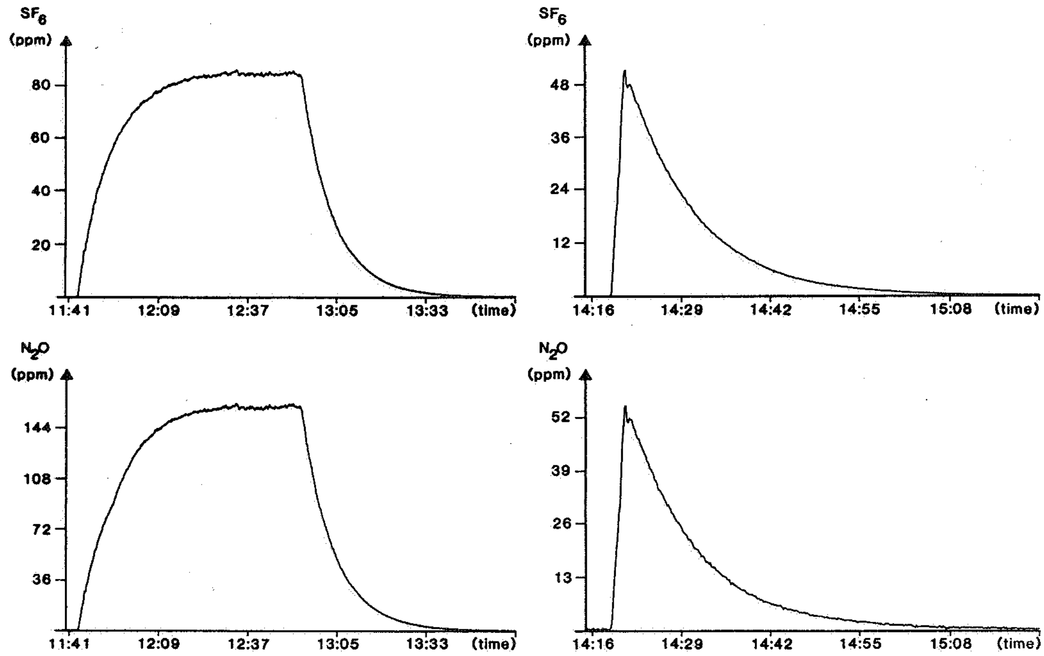



Fig 1: Typical concentration curves from tests with the injection of tracer gases into the inlet air.

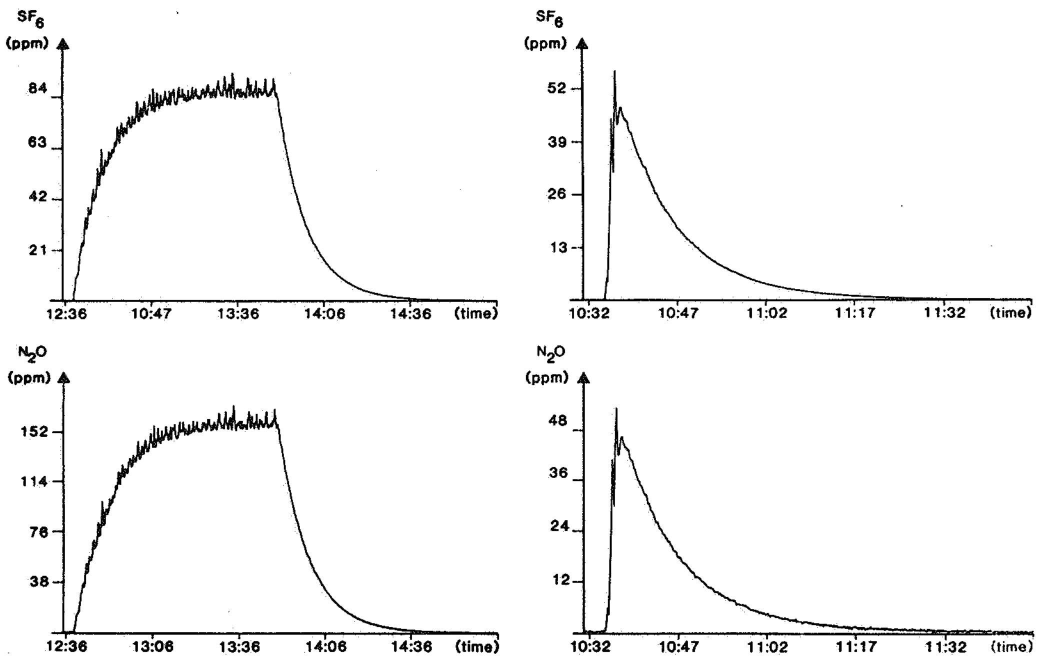



Fig 2: Typical concentration curves from tests with the injection of tracer gases in the chamber.

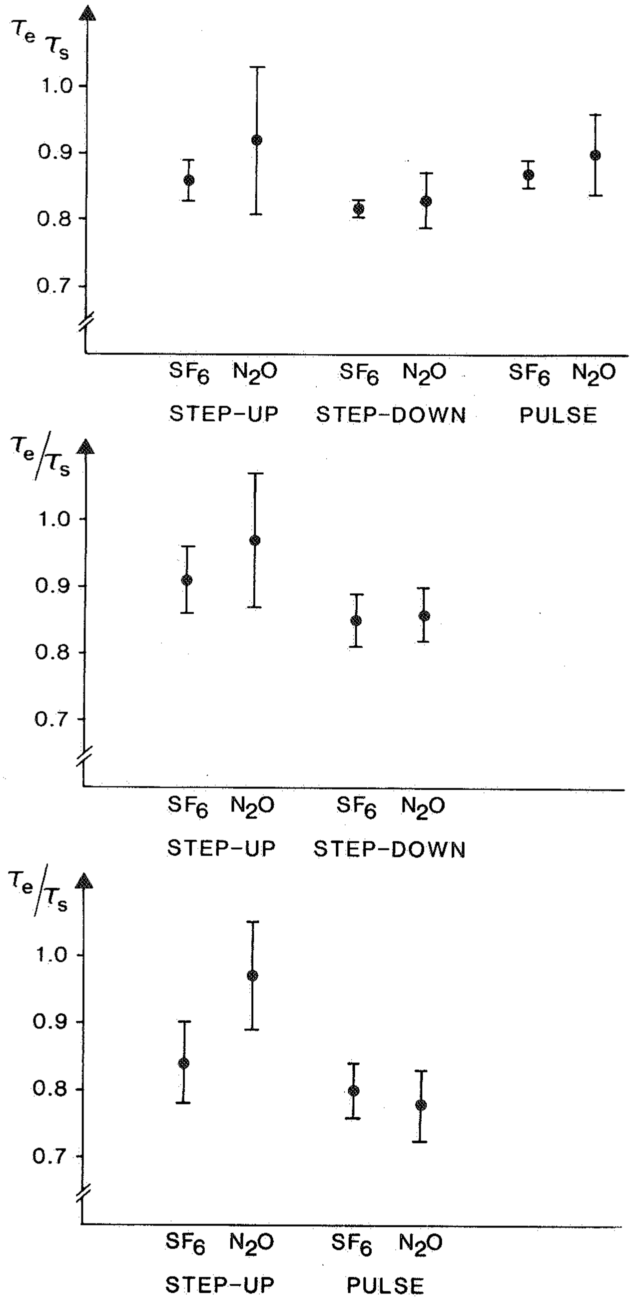
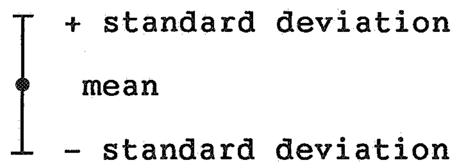



Fig 3: A summary of the test results.
Top: Injection into the inlet air.
Center: Injection in the chamber, mixing fans on.
Bottom: Injection in the chamber, mixing fans off



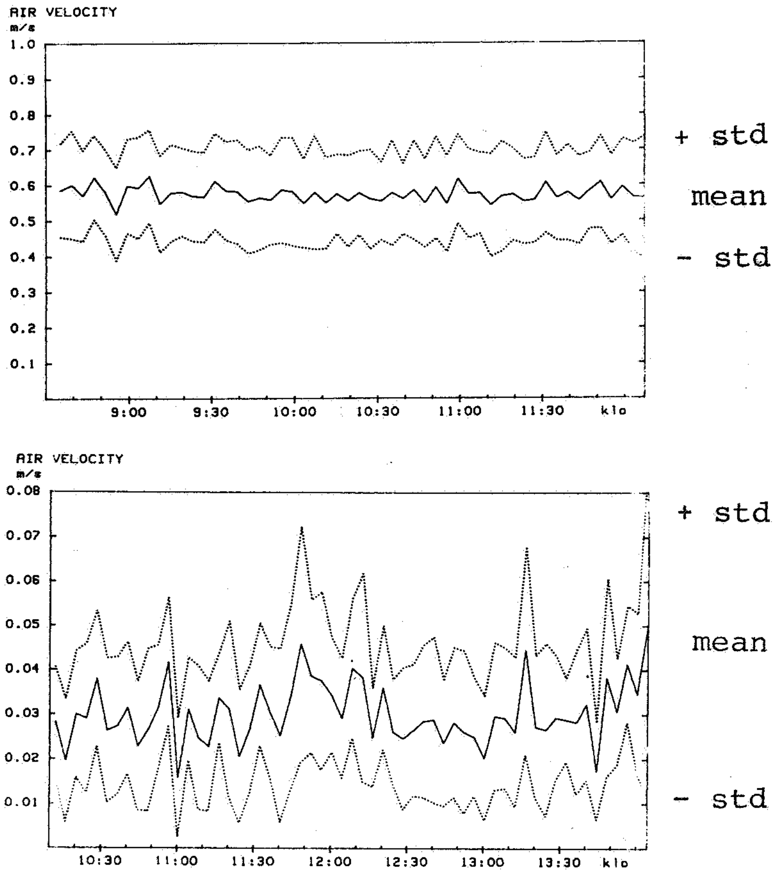



Fig 4: Air velocities recorded at the injection point with extra mixing (top) and without extra mixing (bottom).

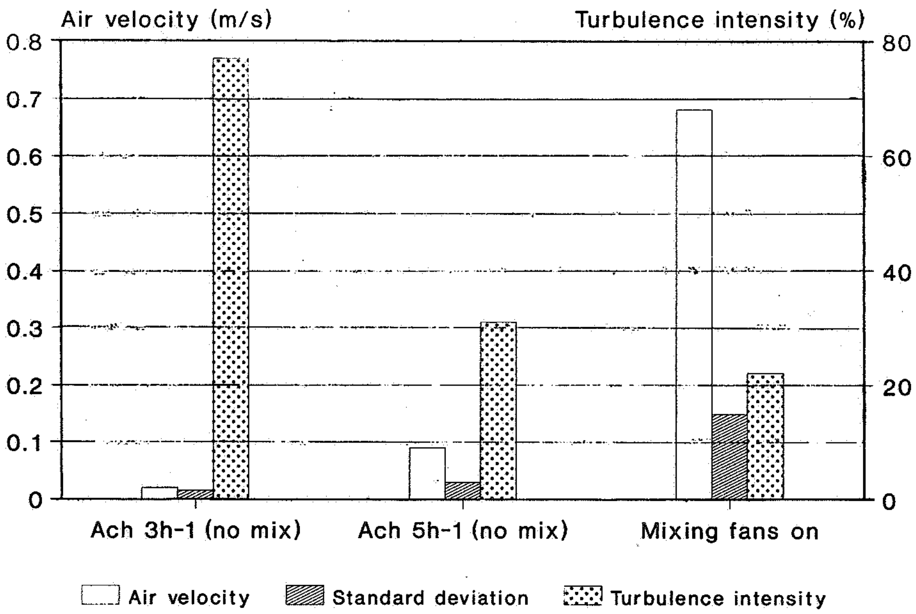



Fig 5: A summary of air velocities measured (ACH = air change rate).

## 5. DISCUSSION

The $N_2O$ step-up procedure gave slightly higher age values than the corresponding $SF_6$ procedure. Also the relative standard deviation of the $N_2O$ step-up data was greater than that obtained by other test procedures. This bias was likely due to the instability in the releasing flow rate of nitrous oxide. There was a current trend for the $N_2O$ flow rate to decrease. Apart from these $N_2O$ step-up tests no significant difference between the $SF_6$ and $N_2O$ data was observed.

The results indicate that the pulse procedure can give as reliable results as the two other methods used. The relative standard deviations obtained in this study agree with the results of Sandberg (5). On the other hand, he reported a larger scatter with the decay method in the tests carried out in a more complicated multicell test house (12).

If a tracer gas is injected into a room to simulate a contaminant source, the pulse and step-up technique should give the same information. Notable concentration fluctuations may occur with step-up injection, especially when the injection point is located in the zone of low and unstable air movements (see figures 2 and 4). Due to fluctuations of the tracer gas concentration it may be difficult to establish the steady state. Therefore, relatively long measuring times are necessary. On the other hand, maintaining stability of the tracer flow rate can be a problem under long-term injections.

The advantage of the pulse method is that the measuring time is relatively short. In addition, as regards industrial short-term emissions, it may be feasible to inject the tracer gas with a time dependence similar to that of the actual contaminant. The disadvantage of the pulse technique is that it is necessary to inject a large amount of tracer gas very rapidly, and this may disturb the flow patterns under investigation. A rapid response gas analyzer is also needed for detecting quickly changing concentrations.

## 6. APPENDIX

The mean exit age, µe, and the nominal time constant based on the inlet airflow rate.

| Test no. | Mean exit age (min) SF6 | $N_2O$ | SF6 | $N_2O$ | V/Qs (min) | Location of tracer gas source |
|---|---|---|---|---|---|---|
| | Step-up | | Step-down | | | |
| 1. | 9.8 | 9.6 | 9.8 | 9.9 | 12.0 | in inlet air |
| 2. | 10.8 | 12.8 | 10.1 | 10.3 | 12.3 | " |
| 3. | 10.6 | 11.8 | 10.1 | 10.0 | 12.1 | " |
| 4. | 11.0 | NM | 10.2 | 10.5 | 12.6 | " |
| 5. | 10.3 | 10.7 | 10.0 | 10.2 | 12.3 | " |
| | Pulse | | | | | |
| 6. | 10.6 | 10.6 | | | 11.8 | " |
| 7. | 10.8 | 12.6 | | | 12.6 | " |
| 8. | 10.7 | 11.1 | | | 12.3 | " |
| 9. | 10.9 | 10.8 | | | 12.8 | " |
| 10. | 11.0 | 11.0 | | | 12.9 | " |
| | Step-up | | Step-down | | | |
| 11. | 12.0 | 13.0 | 11.1 | 11.3 | 13.0 | within chamber, mixing |
| 12 | 13.3 | 15.0 | 11.8 | 12.5 | 13.3 | " |
| 13. | 11.5 | 10.9 | 11.5 | 11.3 | 12.5 | " |
| 14. | 11.3 | 13.0 | 11.3 | 11.3 | 12.8 | " |
| 15. | 11.5 | 12.2 | 11.3 | 11.5 | 13.3 | " |
| 16. | 19.4 | 21.4 | 17.6 | 17.1 | 20.7 | " |
| 17. | 16.7 | 17.1 | 16.7 | 16.7 | 20.0 | " |
| 18. | 19.4 | 21.4 | 16.6 | 16.6 | 20.0 | " |
| 19. | 18.6 | NM | 18.2 | 17.6 | 21.4 | " |
| 20. | 18.6 | 18.6 | 17.1 | 17.6 | 22.2 | " |

NM = not measured

APPENDIX CONT'D

| Test no. | Mean exit age (min) SF6 | $N_2O$ | SF6 | $N_2O$ | V/Qs (min) | Location of tracer gas source |
|---|---|---|---|---|---|---|
| | Step-up | | | | | |
| 21. | 19.5 | 21.2 | | | 21.6 | within chamber, no mixing |
| 22. | 16.4 | 24.0 | | | 20.5 | " |
| 23. | 18.2 | 19.5 | | | 20.3 | " |
| 24. | 17.8 | 16.9 | | | 20.1 | " |
| 25. | 18.9 | 20.2 | | | 20.5 | " |
| 26. | 20.8 | 22.9 | | | 22.2 | " |
| 27. | 18.3 | 22.8 | | | 22.2 | " |
| 28. | 19.0 | 23.1 | | | 22.3 | " |
| 29. | 16.6 | 17.9 | | | 19.3 | " |
| 30. | 19.9 | 23.3 | | | 24.0 | " |
| 31. | 9.4 | 11.2 | | | 12.5 | " |
| 32. | 10.4 | 12.0 | | | 12.5 | " |
| 33. | 10.2 | 12.2 | | | 13.0 | " |
| 34. | 10.2 | 11.1 | | | 12.8 | " |
| 35. | 10.5 | 14.7 | | | 14.7 | " |
| | Pulse | | | | | |
| 36. | 15.8 | 15.4 | | | 20.7 | " |
| 37. | 16.7 | 15.8 | | | 20.7 | " |
| 38. | 18.2 | 17.1 | | | 21.4 | " |
| 39. | 16.2 | 15.8 | | | 20.7 | " |
| 40. | 16.7 | 16.2 | | | 20.5 | " |
| 41. | 17.1 | 17.1 | | | 23.1 | " |
| 42. | 17.5 | 18.1 | | | 22.5 | " |
| 43. | 14.2 | 13.8 | | | 18.8 | " |
| 44. | 14.8 | 14.5 | | | 20.3 | " |
| 45. | 13.7 | 14.2 | | | 17.9 | " |
| 46. | 10.7 | 11.3 | | | 12.7 | " |
| 47. | 10.8 | 10.5 | | | 12.8 | " |
| 48. | 11.4 | 10.9 | | | 12.9 | " |
| 49. | 10.3 | 10.4 | | | 13.1 | " |
| 50. | 10.4 | 10.3 | | | 13.1 | " |

7. ACKNOWLEDGEMENTS

Financial support from the Finnish Work Environment Fund is highly acknowledged.

8. REFERENCES

1. Charlesworth P.S. Air exchange rate and airtigthness measurement techniques- An application quide. Air Infiltration and Ventilation Centre 1988.

2. Lagus P. and Persily A.K., A rewiew of tracer-gas techniques for measuring airflows in buildings. Preprint. ASHRAE Trans. 91 HI-85-22 No 1, (1985).

3. Perera M. D. A. E. S. Use of tracer gas techniques in the measurement of natural ventilation in buildings. Ventilation -88. 2nd International symposium on ventilation for contaminant control. 20-23 Septemper 1988, Imperial College, London.

4. Grimsrud D.T., Sherman M.H., Janssen J.E. Jr., Pearman A.N. and Harrje D.T. An intercomparison of tracer gases used for air infiltration measurements. ASHRAE Trans. 86, Part 1, 1980 pp258-267.

5. Sandberg M. and Sjöberg M., The use of moments for assessing air quality in ventilated rooms. Bldg Envir. 18, 1983, pp181-197.

6. Dickson D. J. Ventilation efficiency measurements in occupied mechanically ventilated buildings. Proceedings of the 6 th AIVC Conference. 1985.

7. Breum N.O. The air exhange efficiency of a lecture hall. Ventilation -88. 2nd International symposium on ventilation for contaminant control. 20-23 Septemper 1988, Imperial College, London.

8. Vavasseur C., Muller JP., Aubertin G., Lefevre A. Application of tracer gas methods to the measurements of ventilation parameters in nuclear power plants and various industrial sectors. Ventilation -85. (Ed. Hd Goodfellow). Elsevier Science Publishers. Amsterdam (1986), pp785-796.

9. Niemelä R. A tracer pulse method for the assessment of air flow patterns in a particleboard mill. Scand J Work Environ health 12, 1986, pp504-511.

10. Axley J. and Persily A. Intergral mass balances and pulse injection tracer techniques. 9th AIVC Conference Gent, Belgium. 12-15 Sept, 1988.

11. Niemelä R., Toppila E., Tossavainen A. A multiple tracer gas technique for the measurement of airflow patterns in large industrial premises. Bldg Envir. 22, 1987, pp61-66.

12. Sandberg M. and Blomgvist A. A quantitative estimate of the accurrary of tracer gas methods for the determination of the ventilation flow rate in buildings. Bldg Envir. 20, 1985, pp139-150.