Tracer gas measurement of airflow rates in rooms with several air-handling units

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ABSTRACT

Methods to measure airflow rates using tracer gas in single air handling units are well known. However, in some buildings, in particular in Singapore, rooms are often ventilated with two or more units. An adapted methodology that should be used to measure not only the airflow rates provided by each unit, but also to determine the inter-units airflow rates and the global ventilation efficiency is presented.

INDEX TERMS

Air distribution; Commissioning; Diagnostics; Measurement technique; Tracer gas; Ventilation rate

INTRODUCTION

Methods to measure airflow rates using tracer gas are used since several decades (ASTM, 1988; Presser and Becker, 1988; Roulet and Vandaele, 1991). They are, among other uses, applied for measuring outdoor airflow rates or all the airflow rates occurring in single air handling units (Roulet *et al.*, 1994). In some buildings, however, in particular in Singapore, rooms are often ventilated with two or more units. An adapted methodology that could be used to measure not only the airflow rates provided by each unit, but also to determine the inter-units airflow rates and the global ventilation efficiency is presented, together with an example of measurement.

MODELLING THE AIRFLOW PATTERN

It is common in Singapore to find office spaces ventilated as shown in Figure 1. The full network corresponding to such a design is illustrated in Figure 2. The following symbols are applied in the figures:

o	outdoor air	i	infiltration air
s	supply air	e	exfiltration air
r	return air	BA	from unit B to unit A
x	extract air	AB	from unit A to unit B

The concentration of tracer gas should be measured in the room (node 2′) to separately determine all illustrated airflow rates. This is not practical and may not be possible in many cases, since the building management may not allow drawing sampling tubes in the office rooms.

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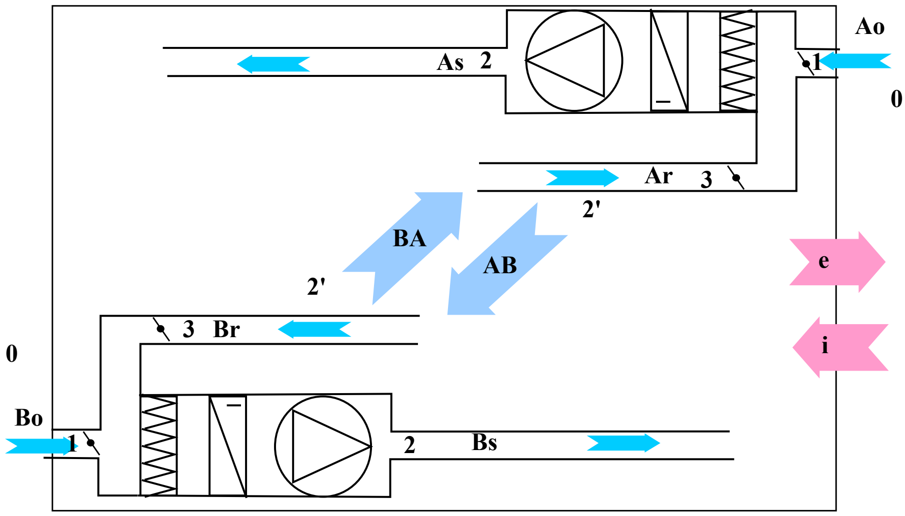

Figure 1 A room with two supply units (A and B) with recirculation. Airflows are indicated by letters and network notes by numbers (see text).

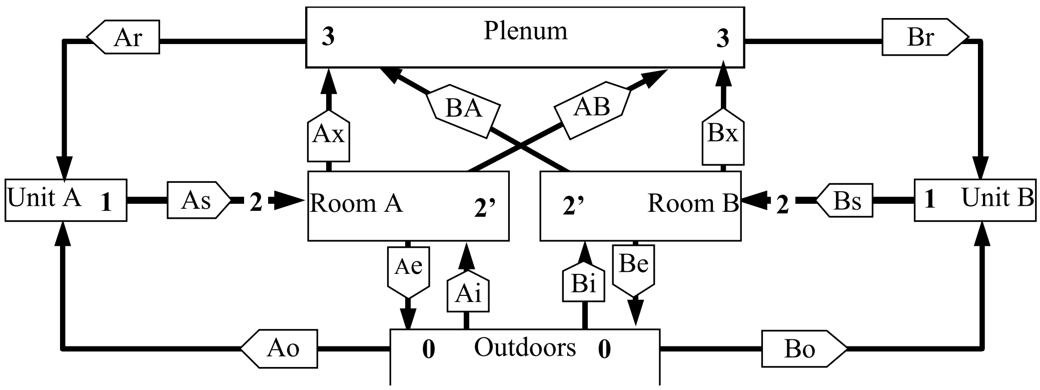

Figure 2 Complete equivalent network corresponding to Figure 1.

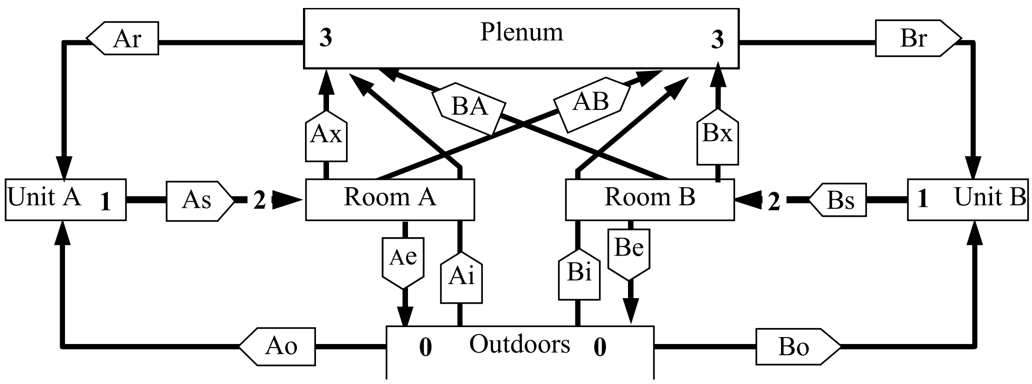

Figure 3 Proposed simplified network to determine airflow rates of Figure 1.

In order to allow determining the inter-units airflow rates without sampling air in the room, the airflow pattern is modelled according to Figure 3. Nodes 2 are in the supply ducts. This supply air is assumed to go partly into both return ducts and to outside by exfiltration. Infiltration is assumed to dilute room air and ends into recirculation duct. This compromise does not allow the exact determination of infiltration in each separate room, and biases slightly the inter-unit flow rates. It provides, however, an estimate of these airflow rates, good enough in most cases, without having to sample air in the rooms. It takes account of the fact that a wall often separates rooms.

Tracer gas 1 is injected into outdoor air duct, and tracer 2 into supply (either upwind the fan or in supply duct), once in unit A, once in unit B. There are hence either four tracer gases, or up to four successive experiments.

Sampling points

o outdoor air
i inlet duct, downwind the injection port of tracer 1,
1 after the supply fan, upwind the injection point of tracer 2,
2 supply duct, downwind enough to the injection port of tracer 2 to get good mixing,
3 return duct.

All sampling points are taken in both units, *A* and *B*. For example, C_{iA1a} denotes the concentration of tracer 1—injected in unit A—in the inlet duct of unit *A*.

Main Airflow Rates

Outdoor air and supply flow rates are obtained directly from concentrations of the tracer injected in inlet, respectively, supply ducts and measurement of concentration upwind and downwind the injection locations:

$$Q_{Ao} = \frac{I_{1A}}{C_{iA1a} - C_{oA1a}} \quad \text{and} \quad Q_{Bo} = \frac{I_{1B}}{C_{iB1b} - C_{oB1b}} \tag{1}$$

$$Q_{As} = \frac{I_{2A}}{C_{1A2a} - C_{2A2a}} \quad \text{and} \quad Q_{Bs} = \frac{I_{2B}}{C_{1B2b} - C_{2B2b}} \tag{2}$$

Conservation of airflow rates in both units provide the return airflow rates:

$$Q_{Ar} = Q_{As} - Q_{Ao} \quad \text{and} \quad Q_{Br} = Q_{Bs} - Q_{Bo} \tag{3}$$

Then, all main airflow rates can be assessed independently in each unit, applying the method described in Roulet and Vandaele (1991), Roulet *et al.* (2000) and in the other papers of the same authors in this conference. If measurements are performed in one unit only, the outdoor air brought by the other unit(s) is included in (or aliased with) the infiltration flow rate.

Inter-Units and Leakage Airflow Rates

Applying air- and tracer mass conservation at node 3 provides two systems of three equations allowing getting infiltration, extract and inter-units airflow rates for both units. Using a matrix notation, these are:

For unit A

$$\begin{bmatrix} 1 & 1 & 1 \\ C_{oa} - C_{3Aa} & C_{2Aa} - C_{3Aa} & C_{2Ba} - C_{3Aa} \\ C_{ob} - C_{3Ab} & C_{2Ab} - C_{3Ab} & C_{2Bb} - C_{3Ab} \end{bmatrix} \begin{pmatrix} Q_{Ai} \\ Q_{Ax} \\ Q_{BA} \end{pmatrix} = \begin{pmatrix} Q_{Ar} \\ 0 \\ 0 \end{pmatrix} \tag{4}$$

Or

$$(\boldsymbol{C}_A)\vec{\boldsymbol{Q}}_A = \vec{\boldsymbol{Q}}_{A\,r} \tag{5}$$

Similarly, for unit B, we get, by permuting subscripts *A* and *B*:

$$(\boldsymbol{C}_B)\vec{\boldsymbol{Q}}_B = \vec{\boldsymbol{Q}}_{B\,r} \tag{6}$$

In these equations, tracer *a*, respectively, *b*, could be either the one injected in outdoor air inlet duct or into the supply air duct. Since the return airflow rates are known, these two systems can easily be solved:

$$\vec{\boldsymbol{Q}}_A = (\boldsymbol{C}_A)^{-1}\vec{\boldsymbol{Q}}_{A\,r} \qquad \text{and} \qquad \vec{\boldsymbol{Q}}_B = (\boldsymbol{C}_B)^{-1}\vec{\boldsymbol{Q}}_{B\,r} \tag{7}$$

Exfiltration airflow rates are finally obtained by conservation of air at nodes 2A and 2B:

$$Q_{Ae} = Q_{As} - Q_{Ax} - Q_{AB} \qquad \text{and} \qquad Q_{Be} = Q_{Bs} - Q_{Bx} - Q_{BA} \tag{8}$$

Balance of whole rooms could be used for a check:

$$Q_{Ae} + Q_{Be} = Q_{Ao} + Q_{Bo} + Q_{Ai} + Q_{Bi} \tag{9}$$

No Infiltration

If, from pressure differential measurements, it can be reasonably assumed that there is no infiltration, or if infiltration is negligible, the systems of Eqns (4) and (6) can be greatly simplified. For unit A, for example:

$$\begin{aligned} &Q_{Ax} + Q_{AB} = Q_{As} \\ &Q_{Ax} + Q_{BA} = Q_{Ar} \\ &(C_{2Aa} - C_{3Aa})Q_{Ax} + (C_{2Ba} - C_{3Aa})Q_{BA} = 0 \\ &(C_{2Ab} - C_{3Ab})Q_{Ax} + (C_{2Bb} - C_{3Ab})Q_{BA} = 0 \end{aligned} \tag{10}$$

from which we can easily calculate the part of the return airflow rate that comes from unit B:

$$\frac{Q_{BA}}{Q_{Ar}} = \frac{C_{2Aa} - C_{3Aa}}{C_{2Aa} - C_{2Ba}} = \frac{C_{2Ab} - C_{3Ab}}{C_{2Ab} - C_{2Bb}} \tag{11}$$

For unit B, we get similarly:

$$\frac{Q_{AB}}{Q_{Br}} = \frac{C_{2Ba} - C_{3Ba}}{C_{2Ba} - C_{2Aa}} = \frac{C_{2Bb} - C_{3Bb}}{C_{2Bb} - C_{2Ab}} \tag{12}$$

Finally, the parts of the return airflow rate that comes from the same units are:

$$\frac{Q_{Ax}}{Q_{Ar}} = 1 - \frac{Q_{BA}}{Q_{Ar}} \qquad \textit{and} \qquad \frac{Q_{Bx}}{Q_{Br}} = 1 - \frac{Q_{AB}}{Q_{Br}} \tag{13}$$

Perfect Mixing

When complete mixing occurs in the rooms and/or plenum, the concentrations of all tracers do not differ significantly in both return ducts.

In this trivial case, both rooms and plenum can be combined in one single node, as shown in Figure 4. Only outdoor, supply and return airflow rates can be measured, since uncertainty on concentration differences of Eqns (11) and (12) is too large. It can only be deduced that inter-room airflow rates are both much larger than supply or return airflow rates.

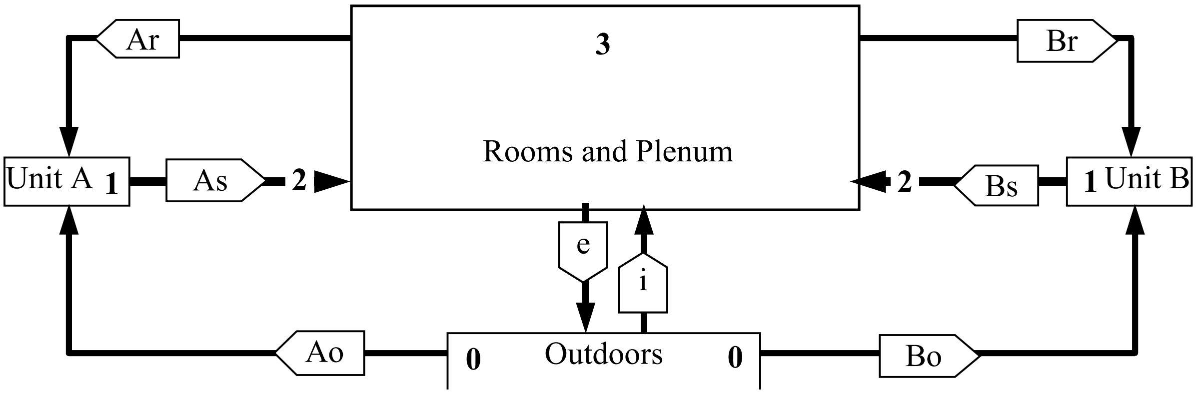

Figure 4 Simplest network corresponding to Figure 1 when perfect mixing occurs in the ventilated rooms.

EXAMPLE OF MEASUREMENT

Two measurements were performed in building HW in an office space ventilated by two units. The space layout is illustrated in Figure 5. HW is a new modern commercial office building with a very airtight design to reduce infiltration of unconditioned air. The office space can be divided into two big 'rooms' separated by a high wooden cabinet. The arrows represent the position of the supply and return ducts for the two units.

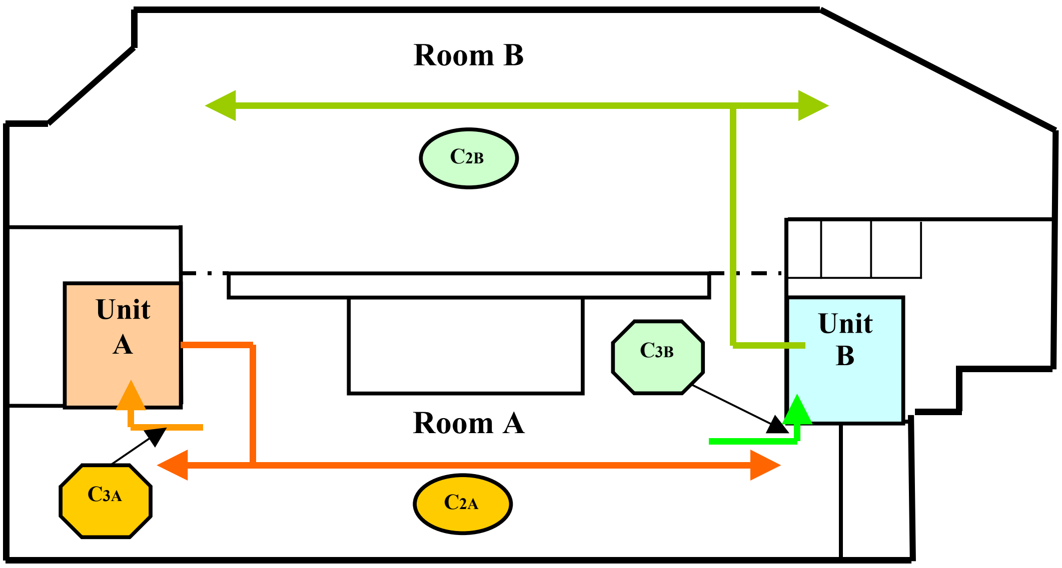

Figure 5 Layout of the measured space, showing the two air conditioning units.

The two measurements were performed with different sets of filters, but with the same fan speed, powered by a frequency controller locked at 50 Hz. In experiment 2, both units were equipped with electrostatic filters, rated at 12 Pa pressure drop @ 1000 cfm (1700 m^3/h). In experiment 1, unit B was equipped with a media filter rated at 31 Pa pressure drop, unit A still having its electrostatic filter. This significantly changed the airflow pattern in the rooms. In the first experiment, full mixing occurs, while a strong inter-room airflow from A to B dominates in the second experiment. The results of the airflow rates measurements using the above model are shown in Table 1. Only significant digits are provided. Therefore, a small airflow rate not significantly different from zero is shown as zero.

The results show that the supply and outdoor air from both units are not balanced. The main airflow rate in unit B is almost the double of that in unit A. The inter-rooms airflow rates are very large in both cases. In the second experiment, the airflow rate from room A to room B is much larger than the flow rate from the reverse direction. On the contrary, extract air from room A into unit A is large and the corresponding flow rate is not significant in room B.

Table 1 Results from measurements: airflow rates in m^3/h.

		Experiment 1				Experiment 2			
		Unit A		Unit B		Unit A		Unit B	
Outdoor air	*o*	600	±100	900	±200	900	±200	900	±200
Supply	*s*	14 100	±900	27 000	±3000	17 000	±2000	33 000	±5000
Return	*r*	13 000	±1'000	26 000	±3000	16 000	±2000	32 000	±5000
Recirculation ratio	*r*	96	±1%	96	±1%	95	±1%	97	±1%
From other room		Very large				100	±900	33 000	±5000
Extract same room	*x*	Not applicable, full mixing				16 000	±2000	0	±7000

CONCLUSIONS

It is shown that the tracer gas method used fro assessing airflow rates in air handling units can easily be extended to two—or even more—units, provided that tracer gas experiments are performed in all units. Such measurements could be useful to explain the transfer of pollutants from one location to another in the space, or to check the balance of the airflow rates provided by several units ventilating the same space.

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REFERENCES

ASTM (1988). ASTM E 741-83: Standard test method for determination of air leakage rate by tracer dilution. *Annual Book of Standards*. Philadelphia, PA: ASTM.

Presser, K.H. and Becker, R. (1988). Mit Lachgas dem Luftstrom auf der Spur Luftstrommessung in Raumlufttechnischen Anlagen mit Hilfe der Spurgasmethode. *Heizung Luftung Haustechnik* **39** (1), 7–14.

Roulet, C.-A. and Vandaele, L. (1991). Airflow patterns within buildings—measurement techniques. Bracknell. Order the AIVC CD at inive@bbri.be.

Roulet, C.-A., Deschamps, L. *et al.* (2000). DAHU: diagnosis of air handling units. In: Awbi, H.B. (ed.), *Air Distribution in Rooms—Ventilation for Health and Sustainable Development*, Vol. 2, pp. 861–866. Reading, UK: Elsevier.

Roulet, C.-A., Foradini, F. *et al.* (1994). Use of tracer gas for diagnostic of ventilation systems. *Healthy Buildings '94*, Budapest.