MEASUREMENT OF AIR FLOW RATES AND VENTILATION EFFICIENCY IN AIR HANDLING UNITS

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ABSTRACT

Air handling units do not always function as planned: airflow rates are often larger than required, the recirculation rate is not at its set-point value and parasitic shortcuts sometimes decrease dramatically the ventilation efficiency. A dedicated diagnosis, based on the tracer gas dilution technique can easily detect such dysfunction, and help to cure the defects.

Within the framework of the Joule-Thermie AIRLESS project, a measurement protocol, which includes the planning of measurement and the interpretation algorithms, was developed on the basis of years of practice in such measurements and implemented in a user-friendly computer program. The protocol was applied to several air handling units in various buildings. This contribution presents the method applied, the principles used in the test protocol, and some measurement results.

INTRODUCTION

It was found that air handling units seldom function as planned: airflow rates are not those required, recirculation rate is not at its set-point value and parasitic shortcuts sometimes dramatically decrease the ventilation efficiency [1][2].

Diagnosis tools would therefore be useful to detect dysfunction, preferably before or when commissioning the air handling unit. Velocity measurements using Pitot tubes are often used for that purpose. Such techniques, however, can be applied only in long straight ducts, seldom found in technical rooms. In addition, only main airflow rates are measured that way, while many other airflow paths may be found in an air handling unit, as shown in Figure 1.

The tracer gas dilution method is used since several years for diagnosis of air handling units [3][4]. It has the advantage of being applicable on any unit and to allow the detection and quantification of unexpected air flows, such as leaks or shortcuts. Practical application of this technique is however not straightforward, since each air handling unit has its own set-up and characteristics, and several precautions should be taken to avoid measurement or interpretation errors. Therefore, a measurement protocol, which includes the planning of measurement and the interpretation algorithms, was developed on the basis of years of practice in such measurements and implemented in a user-friendly computer program.

METHOD

Measurement technique

The technique is described in more detail elsewhere [3], [5]. Tracer gases are injected, most often at a constant flow rate, at carefully chosen locations in the air handling unit. Experience has shown that most practical and efficient injection locations are as indicated in Figure 1.

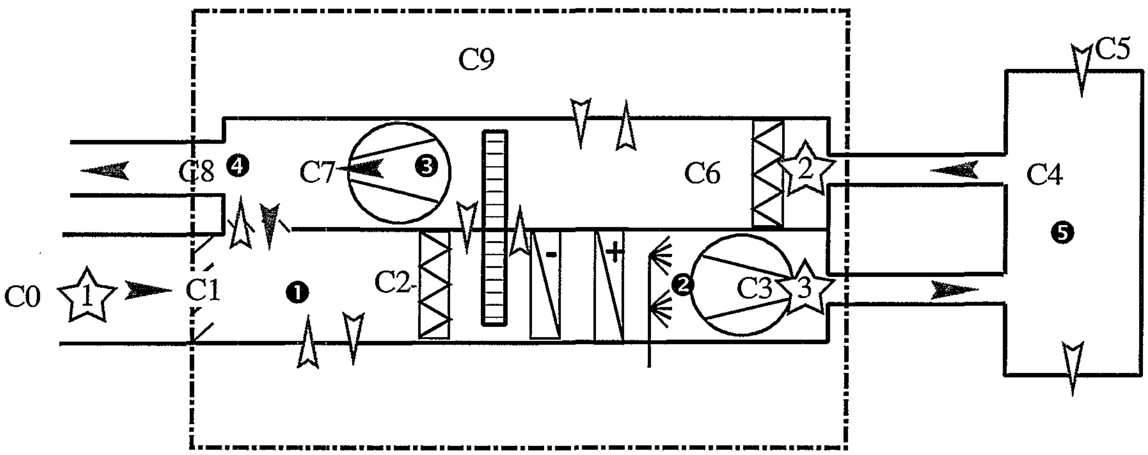

Figure 1: Schematics of an air handling unit showing main and secondary airflow paths (arrows), the locations of nodes (circled numbers), tracer gas injection (stars),and sampling points for concentration measurements (Ci).

Tracer gas concentrations are measured at various locations, in order to obtain enough equations from conservation of airflow and tracer gas flows to determine all required airflow rates. The practical procedure is as follows:

1. Analysis of the air handling unit, in order to define the list of airflow rates to assess and the non existent air flows. If some of the airflow rates, in particular the leakage and shortcut air flows, are known to be zero, the measurement can be greatly simplified.
2. Determine the number of tracer gases, the tracer injection points, and the air sampling locations. If less than three tracer gases are used, some of the airflow rates shown in Figure 1 will not be determined.
3. Inject the tracer gases and measure their concentration in air samples until reaching steady state. Check the tracer gas mixing by moving some sampling locations.
4. Interpret the measurements.

Interpretation

Conservation of air and tracer gas mass flows at each node shown in Figure 1 provides a system of linear equations, assuming steady state and perfect mixing of tracer gas at sampling locations [5]:

$$\vec{I} = \boldsymbol{C} \cdot \vec{Q} \qquad 1$$

where*:*

$\boldsymbol{C}$ is a matrix, containing the tracer gas concentrations measured at the various locations

$\vec{I}$ is a vector containing the tracer gas injection rates;

$\vec{Q}$ is a vector of the airflow rates to be determined.

Depending on the number of tracer gases injected and on the number of and sampling locations, this system may contain more equations than unknowns. This opens several possibilities:

1. The over-determined system can be solved using least square analysis. This is not the best way, since it may result in negative airflow rates. Bayesian techniques imposing positive values will improve this solving method [3].

2. Combining some of the equations of system (1) reduces the need to measure some concentrations and allows the order of the system to be reduced.

3. A sub-set of *N* equations (*N* being the number of airflow rates to be determined) can be selected to give the best accuracy. This can be done by calculating the condition number of all possible sets of *N* equations extracted from the full system, and taking the set with the smallest condition number [6].

Noting the injection starting time of tracer gas 1 and recording the tracer concentration in the exhaust duct versus time allows the assessment of the mean age of air and the air change efficiency in the ventilated space [3], [7].

RESULTS

Several air handling units were measured with this technique, and some results are given below to illustrate the usefulness of this technique.

Example of measurement

Figure 2 shows the evolution of concentrations of tracer gas (sulphur hexafluoride) injected at constant flow rate in the outdoor air duct from 10:27 to 11:45. Much information can be readily obtained from this figure.

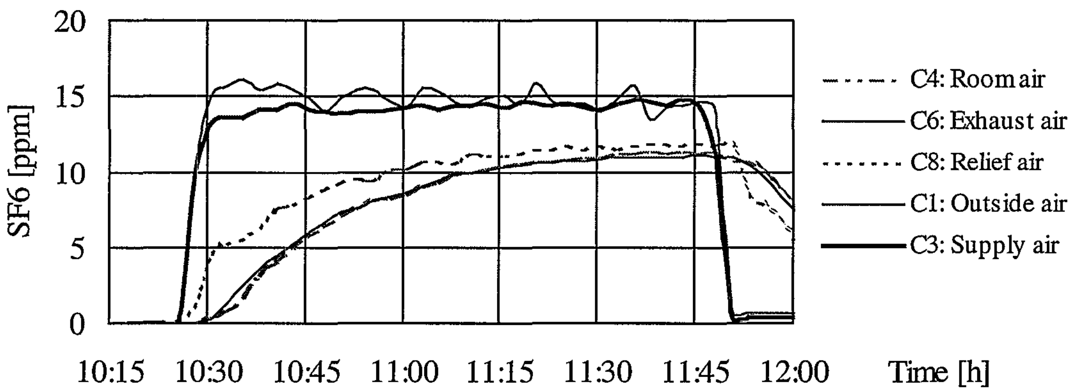

Figure 2: Evolution of concentrations of tracer gas injected at constant flow rate in the outdoor air duct.

Concentration in outside air and supply air quickly reach the steady state, the small fluctuations resulting from imperfect mixing. Since outdoor concentration of that tracer is negligible, the ratio of the tracer gas injection rate to the concentration directly gives the outdoor airflow rate (in this case, 9400 m³/h). The slow growing exhaust air concentration, identical to room air concentration, allows the determination of the room mean age of air (17 minutes), and reaches at steady state a value significantly lower than in the supply air. This indicates that extra outdoor air is added to room air, either by infiltration or by another air handling unit (this building has four units). The fast growing concentration in relief air, as well as a concentration slightly higher than in exhaust duct indicates a shortcut between outdoor air and relief air. Another tracer injected in the exhaust duct allowed the determination of all main airflow rates and the detection of bi-directional leakage through the rotating heat exchanger. Note that only this unit, out of four identical ones, has shown this dysfunction: rotating heat exchanger do not leak when properly installed.

Result of several campaigns

Nineteen air handling units located in thirteen buildings were measured during several measurement campaigns [1,8]. Design and measured recirculation rate are compared in Figure 3. These are seldom equal. Note that in six units out of twelve planned without recirculation have shown significant, but unexpected recirculation. These leaks strongly reduce the indoor air quality by mixing return air to supply air.

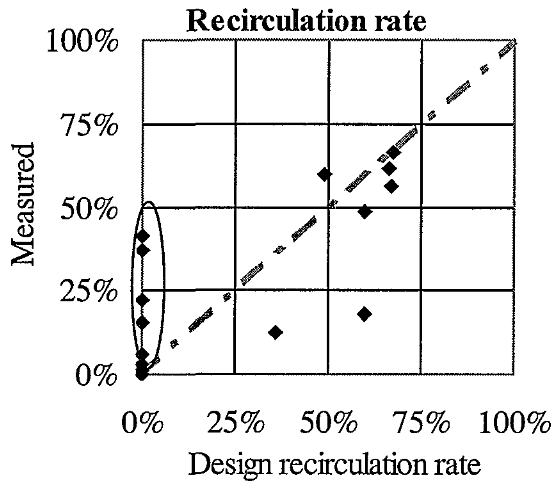

Figure 3: Comparison of design and measured recirculation rate in 19 air handling units.

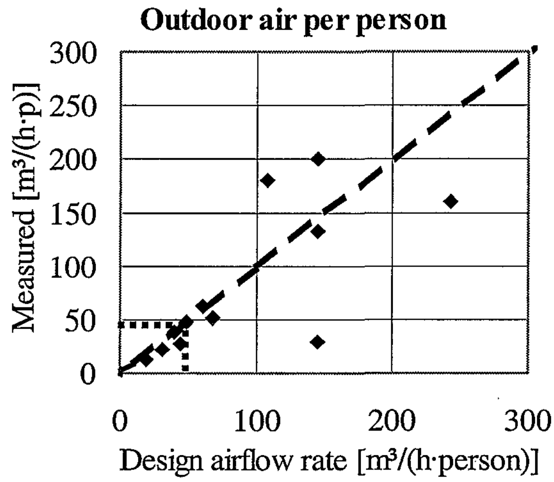

Figure 4: Design and measured outdoor airflow rate per person in 12 buildings.

The comparison of design and measured outdoor airflow rate per person in 12 buildings is shown in Figure 4. It can first be seen that in several buildings the airflow rate per person is larger than 50 m³/h, and overpasses 200 m³/h.

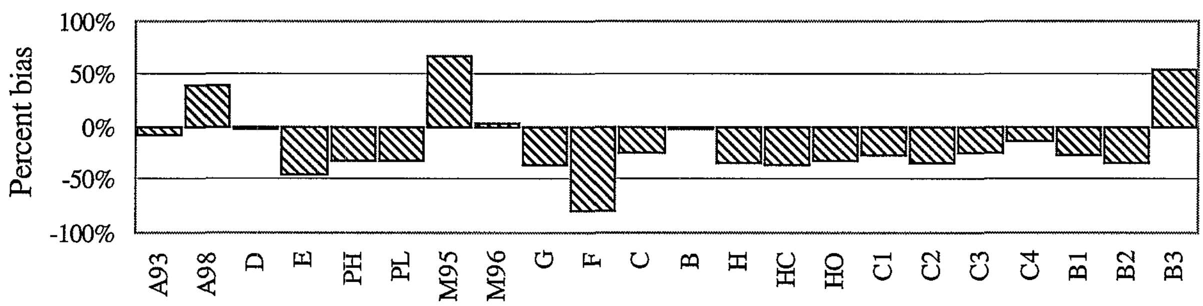

Figure 5: Relative difference between measured and design outdoor airflow rate in 19 air handling units. Note that A and M units were measured twice, before and after improvement, and that P was measured at low (PL) and high speed (PH).

Measured airflow rates differ from design ones in many buildings. The relative difference between measured and design outdoor airflow rate in 19 air handling units is shown in Figure 5. These range from - 76% to + 54%. Only four units are within the ± 10% range.

IN principle, supply and exhaust airflow rates are either balanced, or put the building under a slight overpressure. When the envelope is not airtight, and when the balance between supply and exhaust air is too large, air leaks through the envelope. This has not much influence on indoor air quality, but may strongly decrease the efficiency of the heat recovery. In some buildings, as much as 70 %of the pulsed air is lost that way.

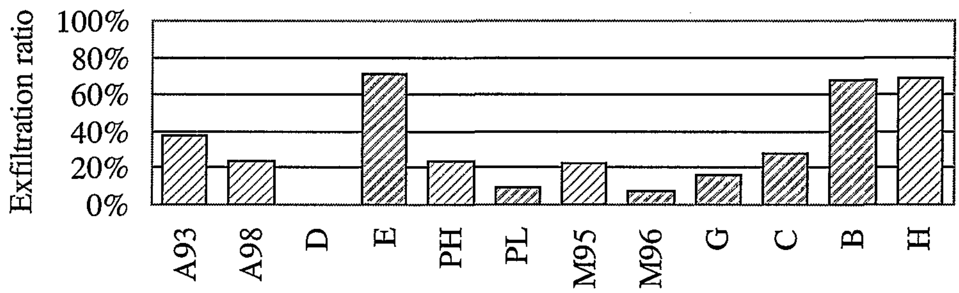

Figure 6: Exfiltration ratio, that is part of the supply air leaking through the building envelope, in 9 buildings. For A and M buildings, exfiltration ratio is shown before and after ventilation system improvement.

Improvement of ventilation efficiency

Another example of application are measurements performed in the ventilation unit of a conference room equipped with displacement ventilation. First measurements have shown unexpected leakage flow rates, an air change efficiency around 40%, showing a rather poor distribution of the air in the room, and a too large ventilation rate (unit M95 in Figure 5). On this basis, advice on how to improve the system was given and followed. New measurements were performed after the improvements, which effects on air change efficiency are clearly shown on Table 1. The poor air change efficiency measured in original room was greatly improved, thus providing the required age of air with much lower airflow rate [8].

Table 1: Age of air at exhaust and air change efficiency [8]

	Initial values		After improvement		
	Empty	Occupied	Empty	Occupied	Unit
Mean age of air in conference room	380	480	420	350	s
Nominal time constant	240	380	620	580	s
Air change rate	15	9.5	5.8	6.2	/h
Air change efficiency	30	40	74	81	%

DISCUSSION

Measurements on a series of air handling units clearly show that commissioning of these units should be greatly improved, in order to ensure that design airflow rates are achieved, and that no parasitic airflow such as leaks or shortcuts occur. It should be emphasised that the building and air handling unit presenting the best results, very close to design values (building D), was particularly carefully commissioned.

Tracer gas dilution technique, when properly applied, allows an easy assessment of main airflow rates, the detection and quantification of leakage and shortcuts, and also the determination of the mean age of air and the air change efficiency in the ventilated space.

There are however many types of air handling units, and each new measurement poses new problems. It is hence impossible to write a detailed measurement protocol valid for all types. Therefore, a computer program to help in planning and interpreting such experiments was developed. It helps with the proper choice of the tracer gas injection and air sampling locations, and computes the injection rate in a way adapted to the type of air handling unit and to the users' requirements. Furthermore, it includes the measurement of the global ventilation efficiency in the space controlled by the air-handling unit and an energy efficiency assessment.

The diagnosis technique should be extended to ducts, which often leak [9], thus decreasing the supply airflow rate and sometimes creating shortcuts from supply to exhaust air.

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