VENTILATION SYSTEM PERFORMANCE

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Paper 9

AN AUTOMATED APPARATUS FOR AIR INFILTRATION MEASUREMENTS WITH TRACER GASES
(Researbh activity at Politecnico di Torino)

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Synopsis

This paper describes the activity on Air Infiltration and Ventilation of the research group of "Dipartimento di Energetica" in Politecnico of Turin. The group formed in 1988 and only at the beginning of 1990 it began to work on multizone flow analysis.
The aim of the group is to set up an apparatus for air infiltration measurement comparable to those of other countries; up to now only measurements using decay technique were made in laboratory in a scale-model which represents a two-zone system.

1 Introduction

Brief on the previous activity of the research group in the field of AIV

Research in this field started in 1982 during studies on building energy balance in a test room. Particular attention was devoted to the study of heat losses due to mass flow-rates of the air entering and exiting the room. Both pressurisation tests and tracer gas measurements were performed. The gas used was methane; the sampling was carried out by bags whose content was afterward analyzed in laboratory. The results are exposed in [1].

Research went on in the following two years due to a request of measurements of the air changes in the internal volume of a car. In a first step, a test room was built in laboratory to calibrate an apparatus for the measurements of the N_2O concentration by an infrared gas analyzer. At the same time calibration was also made by the pressurisation technique. The calibrated apparatus was used to measure the air flow rate through the internal volume of a car subjected to a high speed external wind; the measurements were performed in a wind tunnel using only the pressurisation technique. The high values (ten or more) of air change rates made it impossible to use the tracer gas method. The results are reported in [2, 3].

Many other measurements have been made in rooms and dwellings by the decay method for some months, with the aim of evaluating the infiltration energy loss in a more complex study of energy balance in buildings.

In 1985 the research group broke up and the activity in this field was suspended. In 1988 some people of the previous group started again to study the air infiltration problem, but many parts of the laboratory needed rebuilding and some instruments had to be replaced with new ones.

This paper refers to this latter activity, which is essentially devoted to building an experimental apparatus that allows us to reach the same level as the one of the other countries [4, 5, 6, 7, 8, 9] in AIVC and, at the same time, to applying the experience developed in the theoretical studies of inverse problems (applied to heat conduction) to air infiltration studies.

Actual activity

Presently, both Italian universities and some public and private laboratories are showing a growing interest in the knowledge of experimental techniques for the measurement of the air exchanged between different zones of buildings. The main reasons for such concern are the introduction of a more severe standards in fire protection, the major attention to air quality problems and the high number of fatal accidents in houses due to bad ventilation of rooms containing combustion equipments.

Consequently, universities and research centres are more and more involved in field measurements and in improving the knowledge in this research area by companies and consultants.

In order to answer to these requests we are trying to develop our activity in two main directions.

The aims of the first one are essentially:

a. That researchers and technicians of our laboratory working in this field can develop an adequate degree of knowledge of the theoretical problems and of apparatus in the market.

b. Designing, constructing and calibrating a laboratory apparatus that can be used as a reference device for portable instrumentation. The characteristics of this apparatus must include flexibility (constant concentration, decay and constant flow-rate methods), high quality of devices and high automatization.

c. Designing, constructing and calibrating a portable apparatus, for field measurements.

The second goal is essentially theoretical. We have some experience in the field of inverse problems applied to the measurement of thermophysical properties, solved with numerical and probabilistic methods. As the measurement of the concentration versus time of one or more tracer gases in one or more interconnected rooms is essentially an inverse problem, we are studying the application of this theory to the experimental techniques in AIV studies. Other researchers are working successfully in this field (for example see [10]).

Only some of these aims have been presently attained (first half 1990):

1. A laboratory test room, which will be described later on, has been equipped with measurement and control devices. Up to now only single room measurements have been carried out and the data analysis algorithms have been tested [11].

2. An apparatus for measurement in more zones interconnected is being built.

2 Apparatus description

This apparatus was designed for on-site measurements and for laboratory test. It consists of two main sub-sets of components:

- Sub-Set A (SSA): a compact and mobile multi-tracer gas system developed for multizone analysis and for on-site measurements;
- Sub-Set B (SSB): it just includes the components used in laboratory experiments in order to test the calculation technique based on the "Ill - posed problems" theory [12, 13]. Since the conservation equations of the mass of tracer and the mass of air are written for a zero-dimensional model, we have decided to use small boxes, easy to build, to model different zones.

Figure 1 displays schematically SSA. The system consists of:

- two infrared-photometer for the measurements of the nitrogen protoxyde (N_2O) and sulphur hexafluoride (SF_6), Leybold-Heraeus model Binos 1.1 and Binos 3 with the following characteristics:

- *Measurement accuracy*:	≤ 2% at full-scale
- *Number of channels*:	1
- *Zero drift per week*:	< 2% at full-scale
- *Typical temperature effect per K*:	≤ 0.1% at full-scale
- *Influences of gas or ambient pressure*:	0.1% of measured value per 1 mbar pressure difference
- *T_{90} time*:	1.8 s ...... 10 s

- *measuring gas flow*: approx. 1 l/min (0,1....2,5 l/min)

- PC computer, laptop model based on Intel 80C286 12 MHz processor; the computer controls the valves position and acquires data (tracer concentration, indoor and outdoor temperature);
- an IBM - compatible multifunction analog and digital I/O board (16 single-ended analog input channels 12 bits resolution, 2 analog output channels 12 bits resolution, 8 digital inputs and 8 digital outputs);

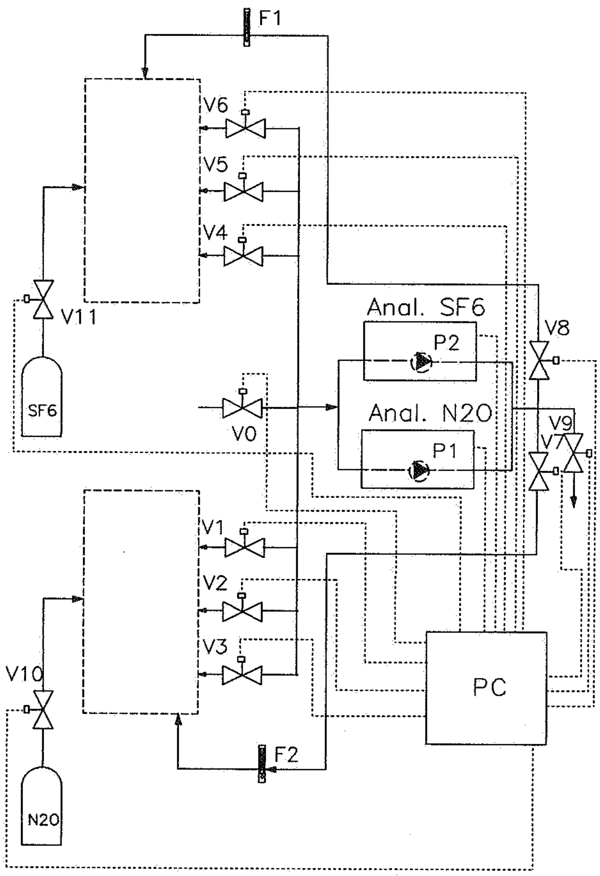

Figure 1 - SSA sub-system

- an IBM - compatible digital I/O board (24 channels of digital I/O, three 8-bit groups independently selectable for I/O, connected to a solid-state relay sub-systems);
- an HP-3497A data acquisition control unit able to replace the two IBM - compatible boards;

- twelve solenoid valves (V0 - V11) to perform the sampling of air and the gas injection; the valves requires 24 V electrical supply.

The sub-system SSB is schematically represented in figure 2; it consists of:

- two small boxes made of wood: the volumes of the first (ZONE 1) and the second (ZONE 2) are respectively 0.0525 m^3 (0.35 x 0.50 x 0.30 m) and 0.1242 m^3 (0.467 x 0.566 x 0.470 m); they are a small scale representation of two different zones connected by a pipe between the points 14 and 15 of figure 2; each zone has three sampling points (points 1 - 2 - 3 for ZONE 1 and 4 - 5 - 6 for ZONE 2) and is connected to the external environment by a pipe equipped with a flow-meter (see points 13 and 14 in figure 2); the injection of the tracer gas and the air supply are accomplished in zone 1 only (points 10 and 12);
- two mixing fans, one for each zone;
- three flow-meters and three pumps to control the air change and verify the mass balance in each zone;
- one electric resistance to vary the air temperature;

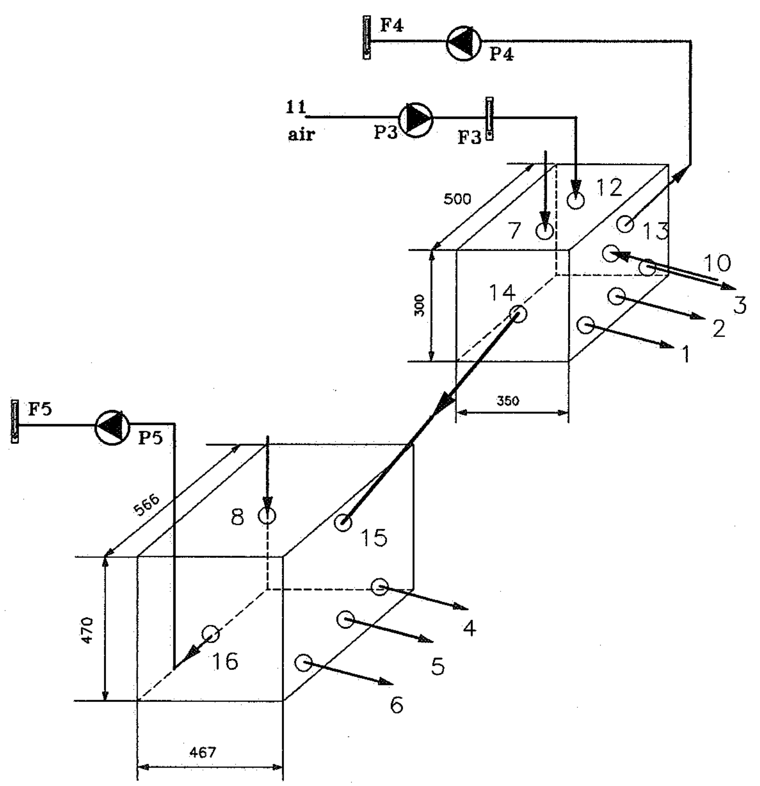

Figure 2 - SSB sub-system

- two platinum resistance thermometers to measure the air temperature in each zone, so that it can be taken into account in the mass balance equations as pointed out by Roulet [14].

The two sub-systems are presently used to perform laboratory tests whose main purposes are improving our experience on tracer gas measurement and obtaining the wide set of experimental results necessary to check the numerical technique chosen to calculate the air flows.

As shown in fig. 3, the complete apparatus is a multizone and single tracer gas system. The zones are represented by the two boxes, which are very tight as indicated by the pressurization test results (see Table I).

Table I - Results of the pressurization tests

Q	ΔP[Pa]		
[l/h]	ZONE 1	ZONE 2	ZONE 1+2
20	460	300	320
30	850	430	600
40	1230	560	920
50	> 1500	690	1100

In the tests without pumps P4 and P5 and with an air flow-rate due to the pump F3 equal to 116 l/h, the pressure drop across the flow-meters F4 and F5 is approximately 200 Pa; hence, the internal pressure in the two zones is very high and Table I shows that the air exfiltration is not negligible; on the other hand all air flows had to be known in our test in order to be able to compare calculated and measured flows. For this reason the two pumps P4 and P5 have been introduced in the system; the difference between the cases with pumps and without pumps are shown in Table II.

Both the constant tracer flow-rate technique and the constant concentration technique requires the control of the tracer gas flow-rate injected. In our apparatus the volumes of the boxes are so small that suitable valves are not only very expensive but also difficult to find on the market. Moreover, this type of valves could be used only in laboratory tests due to their small operating ranges, which make them unsuitable to field applications. Therefore, keeping in mind our goals, only decay techniques has been developed up to now; an example of measurements results is shown in figure 4.

Table II - Pressure differences between inside zones and outside during measurement		
Q	ΔP[Pa]	
[l/h]	Without pumps P4 and P5	With pumps P4 and P5
100	270	15
125	310	9
150	350	7
175	390	~0

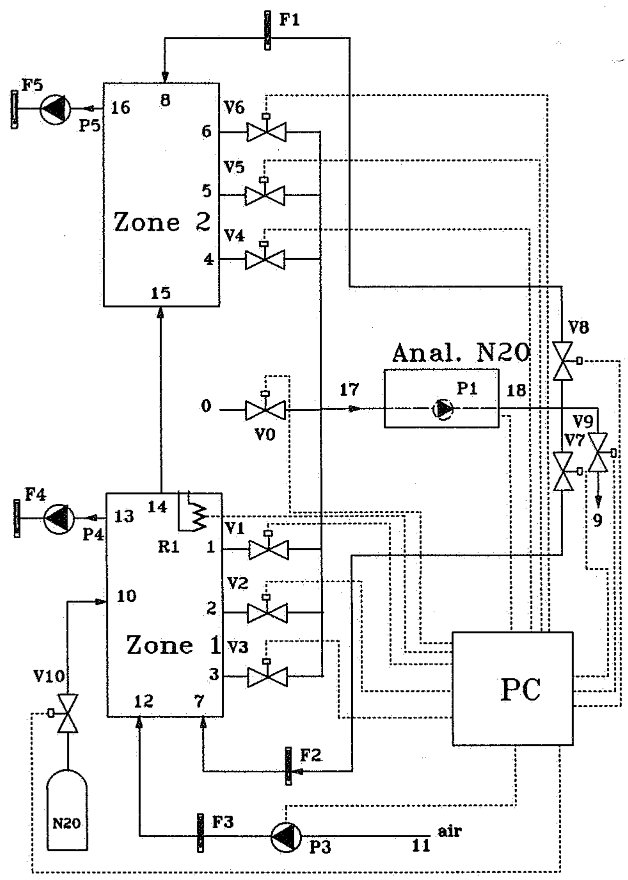

Figure 3 - The complete laboratory apparatus

A computer program interactive with the operator runs on the PC and executes all the different operations required to carry out the measurements; the main steps are (see fig. 3):

a - injection of the tracer gas to reach the defined initial concentration level; closure of all valves;

b - opening of valves V0 to V9 to wash the pipe between the points 0 and 9 with external air (required time: about 29 seconds);

c - closure of valve V0 and opening of the valves for sampling from the defined zone (V1, V2 and V3 or V4, V5 and V6); this step is necessary to avoid that an amount of tracer gas and air mixture of the previous sampling period circulates once more in the zone (required time: about 10 seconds);

d - closure of valve V0 and opening of the valve that circulates again the sampling mixture and wait for stationary condition on the analyzer to be reached (required time: about 19 second);

e - save the measured tracer gas concentration on the hard disk or floppy disk, write and plot this new concentration value on PC monitor;

f - repetition of steps b - e for each zone.

The program includes also utilities to set the zero and full scale points of the analyzer; the on-line calculation of the air change and of the initial tracer concentration are also displayed.

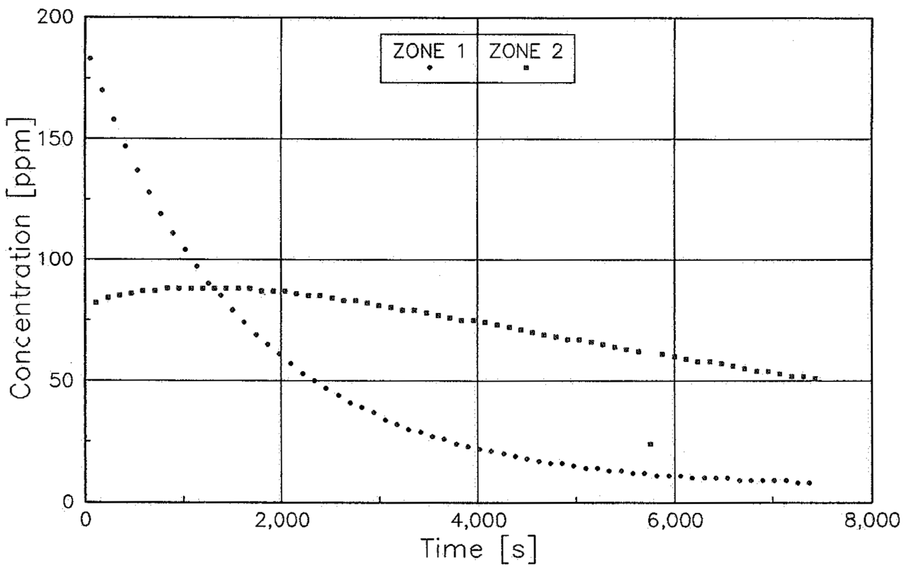

Figure 4 - Example of measurement results

3 Data analysis

A model is the mathematical physical reality representation; it establishes analytical correlations between the physical quantities that properly describe the phenomenon. As to AIV problems, for example, the model consist of the mass conservation equation. The quantities used in the model's equations can be distinguished in measurable quantities (y) and parameters (v). Then the model's equations can be written in the general form:

$$y = f(v) \qquad (1)$$

The measurable quantities in our problems are tracer gases concentrations, source flow-rates, temperatures and pressures, while the parameters are volumes of each zone and air flow-rates [10].

Therefore, the estimation of the parameters v made by the measured concentrations c is a typical "inverse problem" which has been widely treated in literature; we chose the calculation strategy exposed in [12, 13, 15] and using statistical considerations [10] it's possible to define the scalar S, which is a quadratic function of the parameters, as follows:

$$S = e^{T} W e + S^{*} \qquad (2)$$

S^{*} is a regularization term and e is the error defined by:

$$e = c - y = e(v) \qquad (3)$$

The values v which minimize S are an extimation of the model parameter.

We have applied this approach successfully to single-room measurements; the measured data were analyzed after the end of the experiments (whole domain technique); now we are trying to apply this approach to multizone measurements using either whole domain or sequential (on-line) technique.

4 Conclusions

All the aims haven't been presently attained, but we are motivated to continue by our brief experience; as also pointed out by other authors [14, 10], the outcomes of the research work made up till now show that great attention must be paid to:

- the influence of the temperature difference between zones and also to temperature changes during measurements;

- the data covariance matrix, mainly when high speed acquisition system is used.

Therefore next year our efforts will be devote to improving the data analysis technique.

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