PAPER 5

AUTOMATIC MEASUREMENTS OF AIR CHANGE RATES (DECAY METHOD) IN A SMALL RESIDENTIAL BUILDING WITHOUT ANY FORCED-AIR-HEATING SYSTEM

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Abstract

In this paper we describe an automatic measurement system for air infiltration and relevant influence factors, which is applicable to measurements in single rooms or in a group of connected rooms. This system works on the decay rate method and is controlled by a purpose-designed controller. The test data are evaluated by computer, but off-line. Recommendations in connection with different details of this system will be valid for tests in similar, relatively tight rooms.

In the last section, test data of long-term air infiltration measurements, correlations of this data with wind- and temperature-difference-data and finally a comparison with pressurization-test-data are given.

1. Introduction, Conditions for the Measurement System

After a period of different short-term-tests in Swiss buildings, there was a need to develop an automated air-infiltration measurement system which would allow long-term measurements without intensive manual control. A relatively tight budget imposed a tendency to cheap but well-adapted solutions for the different parts of the system.

A real lack of another Central-European institute with some experience in this field, forced us to evaluate many details in connection with the system by various small experiments.

The system should be able to do measurements in single rooms or in groups of some connected rooms (6 in maximum).

In connection with the test programme, some ambitious plans to simulate the buildings in comparison with intensive flow and pressure measurements could finally not be treated, but we were able to install a large number of sensors to measure necessary influence factors for the infiltration.

The planned infiltration measurement-system is adapted to typical Central-European buildings, which generally have the following characteristics:

- larger buildings are usually of solid-wall construction .
- single family houses are built as solid-wall or light-weight construction.
- windows, especially in new buildings, are relatively tight.
- additional ventilation systems are installed in internal toilets and sometimes in kitchens; otherwise they are ventilated by window-opening.
- open fireplaces in houses or apartments are uncommon.
- water-heating systems are very common (radiators, under-floor heating occur less frequently).

2. Concept of Measurement-System

The first two choices in connection with the system had to be the principle measurement-procedure and the type of tracer-gas to be used. At the planning stage we considered that we were not able to introduce a reasonable constant-concentration-control, so we decided to choose the decay method.

The choice of the tracer-gas type was influenced by our good experience with N_2O which we had gained in earlier years (see Ref 2). Usual test-concentrations for the available American type of analyser (Infra-red type, "Miran") are in the range of 10 to 20 ppm. Rather than employing systems with a very refined injection system (see Ref 12), or using on-line computer evaluation of data, we developed a relatively simple system with a purpose-designed controller for the injection and logging systems. A refined computer program for the evaluation of data avoids a lot of time-consuming work.

The system is presented in Figure 1 with its main parts:

controller, supply-system, analyser with scanner, data logging system for recording both gas concentration values and a large number of influence factors.

Figure 2 shows the instruments on a photograph, the analyser in the centre on the table, the controller at its left side, the scanner below the table.

Measurement procedure:

The procedure is not extraordinary but the method of choosing the different sequences may be of interest:

- The controller stops the analysis below a level of about 15% of the start-concentration.
- Adjusted volumes of test gas are injected in the different rooms and mixed by fans for about 10-15 minutes.
- Afterwards, the scanning and analysing procedure starts again in sequences of 5-10 minutes per sample.
- An analogue printer gives a visual display of the concentrations in different rooms; also the resulting concentration of each sequence is stored on a tape.

Evaluation of the data:

In connection with the design of this evaluation program, we spent some time devising a certain variety of evaluation procedures, making a comparison of the corresponding results. This program is able to calculate the following infiltration rates:

- of every sample location during the whole run or during a desired period.
- of a mean infiltration rate, taking into account all samples for a desired period.
- of a mean value including a weighting procedure, if the samples are selected from rooms with a certain variety of sizes.

The timing of evaluation and measurement procedure is chosen in such a way that all relevant data are printed a short period before the automated change to the next sample position.

Figure 3 shows an analogue print of a test run (notice the unusual direction of the time axis !). It is clearly visible that, although there is relatively good mixing at the beginning, there is quite a spread of concentrations in the different rooms of this house during the test period of some hours. Except for some special tests, which did not give a significant difference, we do not run the fans during normal tests, but evaluate the overall infiltration rate by weighting the values of the different rooms.

It may be of interest that manual evaluations and these automated evaluations of the data differ by a very small percentage, which is, in any case, in the range of other errors. Maximum deviations for single values of a test-run show 6%; mean deviations for a whole run are smaller than 2%.

During tests in the same house over a period of some months, the system worked quite well in nearly all conditions. If wind direction and wind velocity changed very much, the initial mixing was not good enough without some manual assistance.

3. Detail-evaluations in connection with the instrumentation set

This section seems to be reasonable in the context of a seminar on measurement technique; we hope to deliver some hints to other institutes starting similar experiments in the near future, especially in Central Europe. It will conclude with some general recommendations.

(a) Test gas characteristics

We did not find any indications of adsorption or absorption characteristics of usual building surface materials for our favoured test gas, N_2O. Therefore, we executed a certain number of long-term exposure tests of materials in closed-test-loop (for details, see Ref 2, p43). Test specimen included woodboard, gypsum-board, wallpaper, carpet, paint and plastic surfaces of different kinds. There is no evidence of adsorption/absorption for test-gas concentrations in the same range, as they are used in our experiments. Similar experiments are conducted with extremely long plastic tubes, which we used for sampling purposes.

Although we observed very small losses of gas per hour, they seemed to be generally due to fittings and valves (about 1%). These experiments nevertheless indicated the danger of leakages, especially for tubes with high concentrations of tracer-gas coming out of the pressure reservoir.

(b) Checking of the analyser

The manufacturer of the analyser recommends a test procedure in a closed circuit with a defined amount of test gas. Besides the procedure, which needs a lot of care, we developed another relatively simple laboratory procedure:

We were able to vary the infiltration rate in a 3 m^3 test box in a range of 1 to 10 a.c. per hour and to measure the air flow accurately ($\pm$ 1%). By measuring these infiltration rates a second time using the analyser, we obtained a good test of its function (Figure 4). This checking procedure avoided any problems of temperature drift, which has to be considered when measuring in very small circuits.

(c) Injection system

Figure 5 illustrates an injection tube end. Each contains a slit, which is adjusted according to the volume of the room and closes itself very tightly as soon as the overpressure disappears. For the test gas we used only one magnetic valve with an adjustable opening-duration with a controlled small overpressure; all tubes to the injection ends had the same length.

Although this system is very much less refined than systems used by other institutes, it works reasonably under "normal" wind situations, as we mentioned before.

Recommendations

(i) Applicability of the system to different purposes:

Without contradicting the various discussions about advantages of a measurement system with constant level (see, e.g. Ref 3, Ref 7, et al), which seem to have been proven recently,

our system delivered, for a limited budget:

- accurate results for single rooms
- results with reasonable accuracy, e.g. repeatability, for groups of connected rooms with little internal resistances (usual in Swiss homes and apartments)
- indications of mean ventilation rates in buildings/flats with singular openings (may be one or two windows); refined measurements on these effects would need, e.g. a multiple-gas-system to detect internal flows.

(ii) The infra-red analyser as we use it does not need much recalibration (which seems to cause problems for other instruments), but it does need a "warming-up" time of more than one hour.

(iii) Painstaking attention to all possibilities of leakage is seen to be very important, especially for tubes with high tracer-gas concentrations, maybe under pressure. Such leaks may occur after a longer period of tight running of the system, e.g. by ageing of tubes. As a consequence of some problems in this connection, we avoided placing injection tubes or gas reservoirs within the test rooms as much as possible and also paid attention to an eventual mixture of tracer leakage gas and inlet air of any room.

(iv) Evaluation system:

It is recommended to install a simple analogue registration device for the test-gas concentration in addition to any refined evaluation system. The displays provide the best way of supervising the performance of the system.

4. Test Results on Long Term Tests in a Single Swiss One-Family-House

Although test results have only secondary interest in this seminar, some results from our tests last winter would well fit into the data collections of other authors, where Central-European results are scarce.

A vertical section (Figure 6) shows the principle design of this building, which is nearly square. The surroundings of the building are relatively free; only its north facade is protected in the lower half by a slope at the back of the house. Prevailing winds are from the west-side/southwest-side, which have, as usual, some large windows. The building is a wooden, lightweight construction but protected on its outside by an overall styrofoam-insulation. The wooden windows have rubber gaskets (round form) and may be protected either by shutters or by roller blinds.

The following table gives a selection of main test results, which will be commented upon afterwards.

Results:

Variable	Conditions	Numbers
Leakage of elements	- windows (measured on site) - window (example, in lab.) - balcony doors - entrance door	0.02 - 0.05 $m^3/m\ h\ Pa^{2/3}$ 0.03 - " 0.03 - 0.1 " 0.5 - "
Leakage of buildings	- whole building, measured under overpressure and underpressure (similar results) - whole building at 50 Pa calculated from all known window gaps and leakages	$\sim 1.5\ h^{-1}$ at 50 Pa $\sim 0.3\ h^{-1}$

Variable	Conditions	Numbers
Mean infiltration rates	chimney always completely sealed; test period - winter 1979/1980	
	- minimum value ($v \simeq 0.5 - 1$ m/s)	$0.15\ h^{-1}$
	- maximum value ($v \simeq 10 - 11$ m/s)	$0.66\ h^{-1}$
	- typical day in cold winter period ($v \simeq 1 - 3$ m/s, $\Delta t = 20K$)	$0.25 - 0.3\ h^{-1}$
Mean infiltration rate with singular openings	- night condition, typical winter day; building closed except two windows in sleeping rooms slightly open, shutter closed	$0.6\ h^{-1}$
	- typical winter day; one window on first and second floor, in same facade, slightly open	$0.8\ h^{-1}$

Additional to the above table, Figure 7 describes the correlation between wind-speed, temperature, difference and infiltration rate in the closed test building. This correlation follows one of the more simple attempts to relate to the physical background of the flows, which is given in Ref 4:

$$- \text{Inf} = A + B\ .\Delta t + C.\ \text{Vel}^2$$

The corresponding coefficients are indicated in the figure.

Comments:

The overall tightness of this building is excellent. The results of pressurization tests show that air leakage is far less than that set by Swedish Standards as it is in the same range as tight buildings reported by Dumont (Ref 12). Other Swiss buildings with solid, heavy construction will show similar, probably lower, leakage rates.

Natural infiltration rates in usual winter periods are less than recommended values. The last results show well that user influence will probably double or triple the values measured in the closed building, at least in warmer and low-wind situations.

Although this experimental house (with same construction as series buildings of the manufacturer) was built with special attention, about 80% of infiltration happens through "unknown" gaps. Maybe another 20% of the air flows through gaps just around windows and doors. This fact shows how poorly the usual simple calculation rules, based on window gap lengths and leakage, work. Nevertheless, these rules are introduced in thousands of Central-European building laws. We hope that our Air Infiltration Centre will be able to provide refined new methods on such data sets.

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Figures

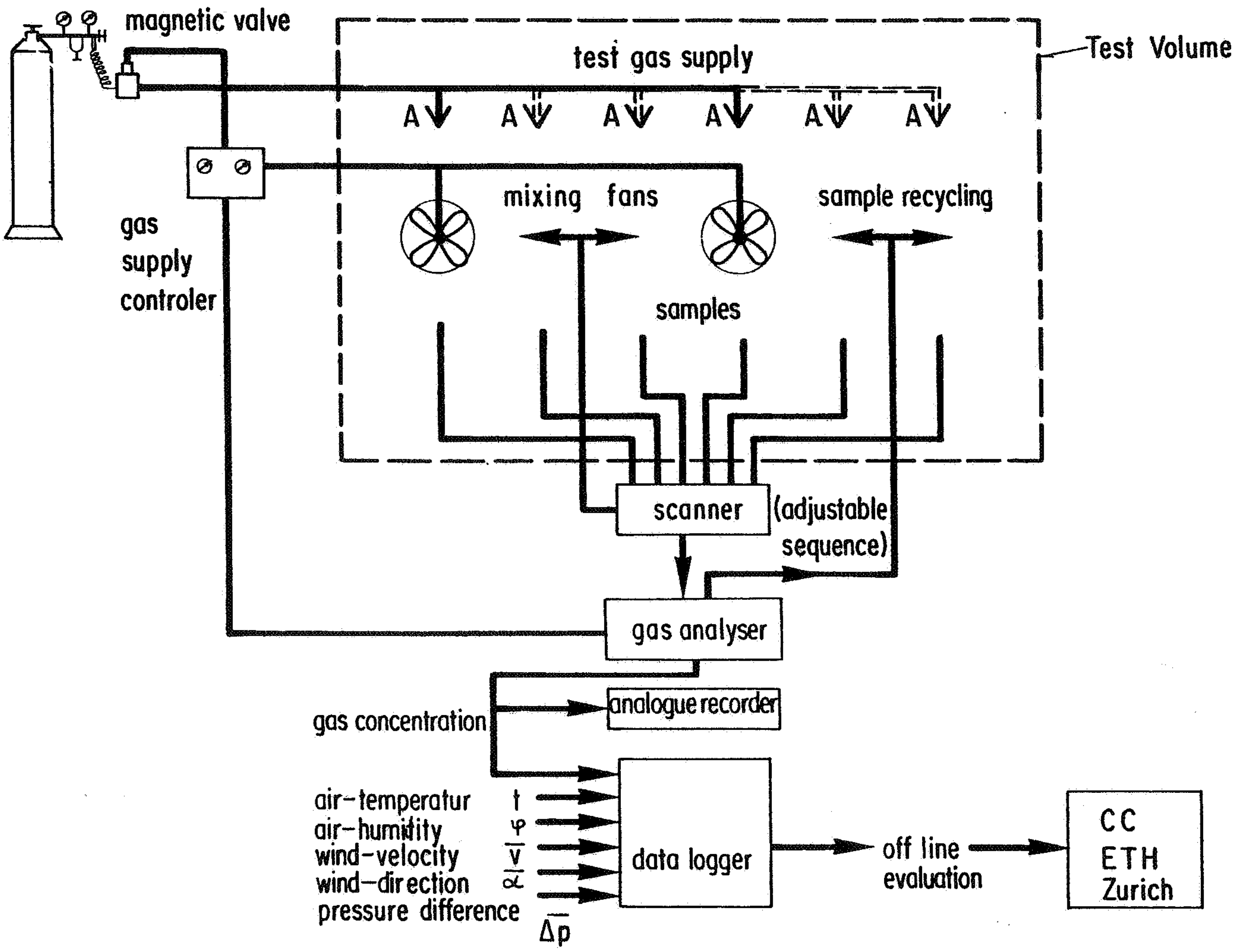

Fig. 1:System for automated decay-rate-tracer-gas-measurements

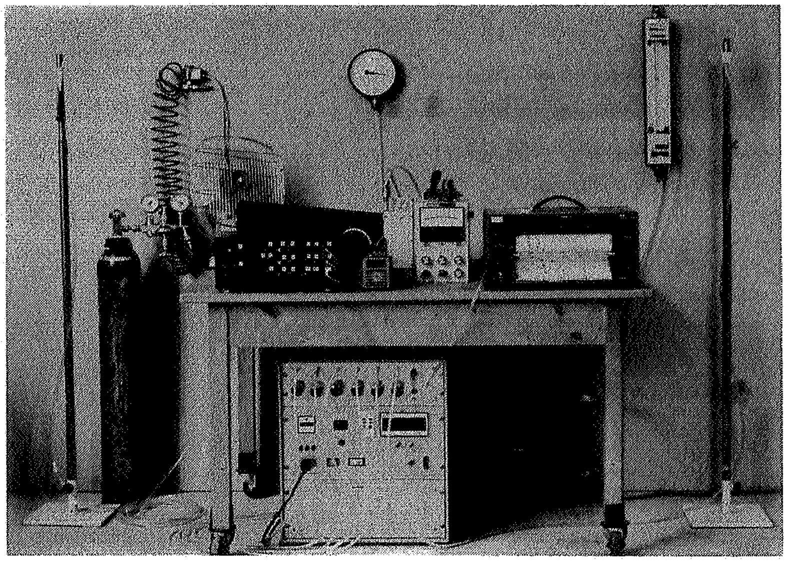

Fig.2 : Instruments for automated infiltration measurements

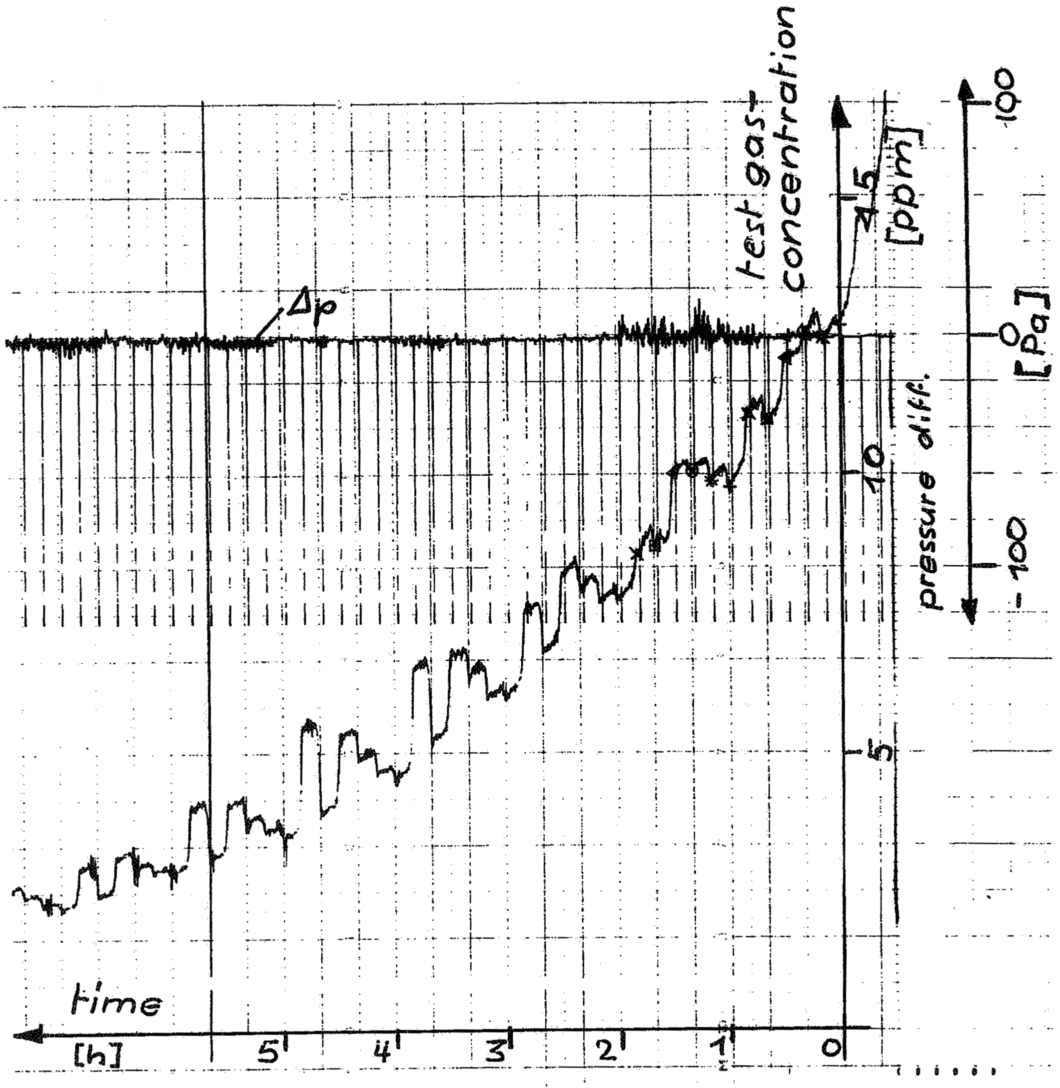

Fig.3 : Analogue print of tracer-gas concentration (6 different, automatically changed samples) and of the pressure difference over the main, wind opposed facade

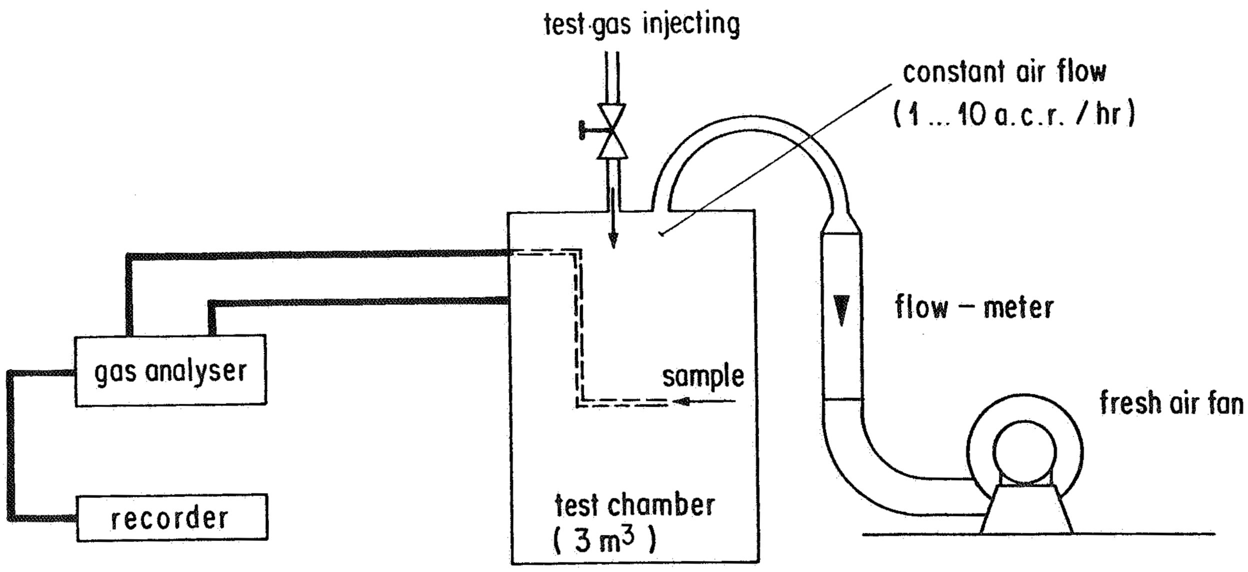

Fig. 4 : Checking equipment for gas analyser

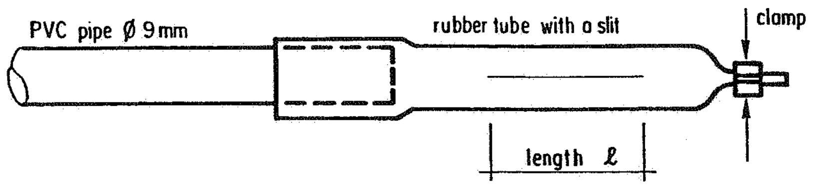

Fig. 5 : Injection tube with variable slit length, in order to adjust the injection flow to the volume of the correspon-ding room (detail A in Fig. 1)

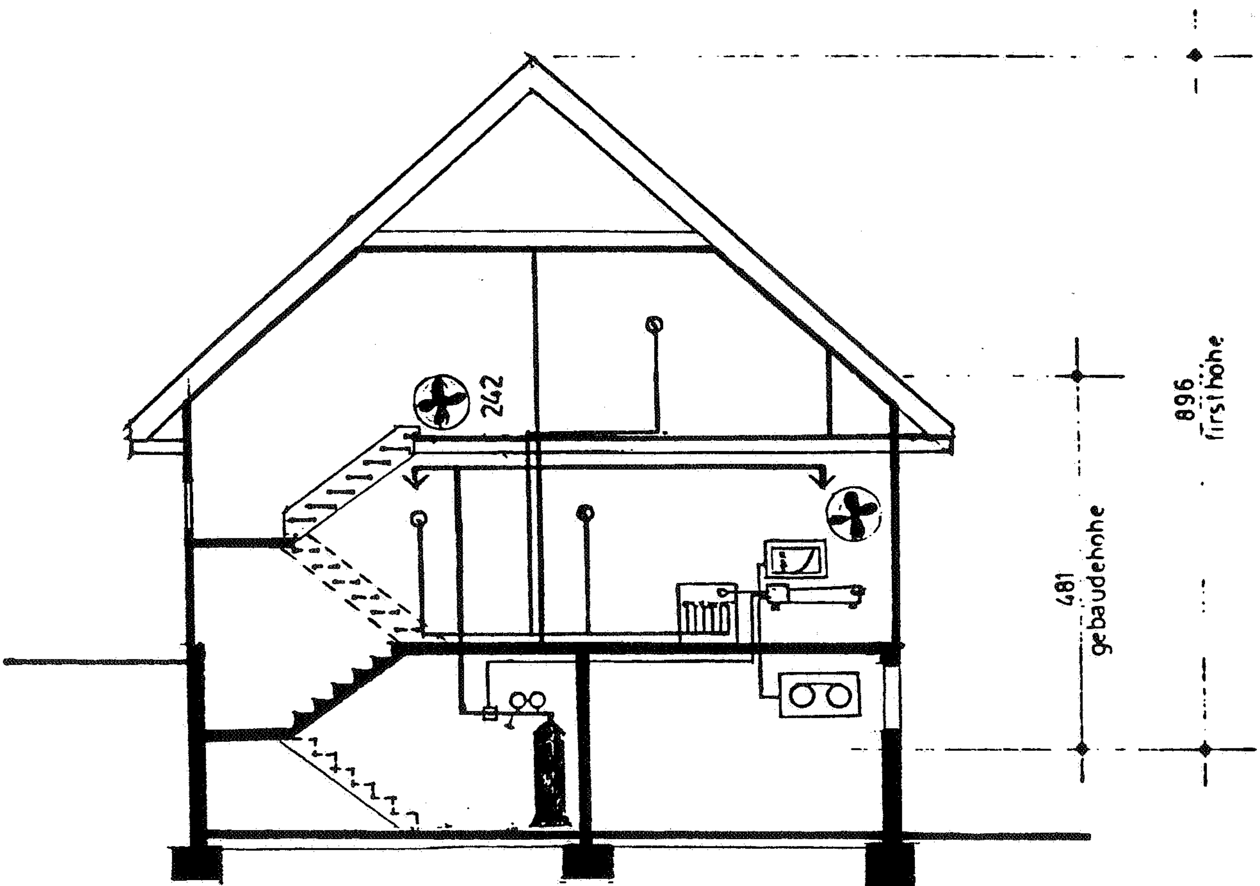

Fig. 6 Schem atic vertical section through the test-building, inclu-ding the main parts of the infiltration-instrumentation

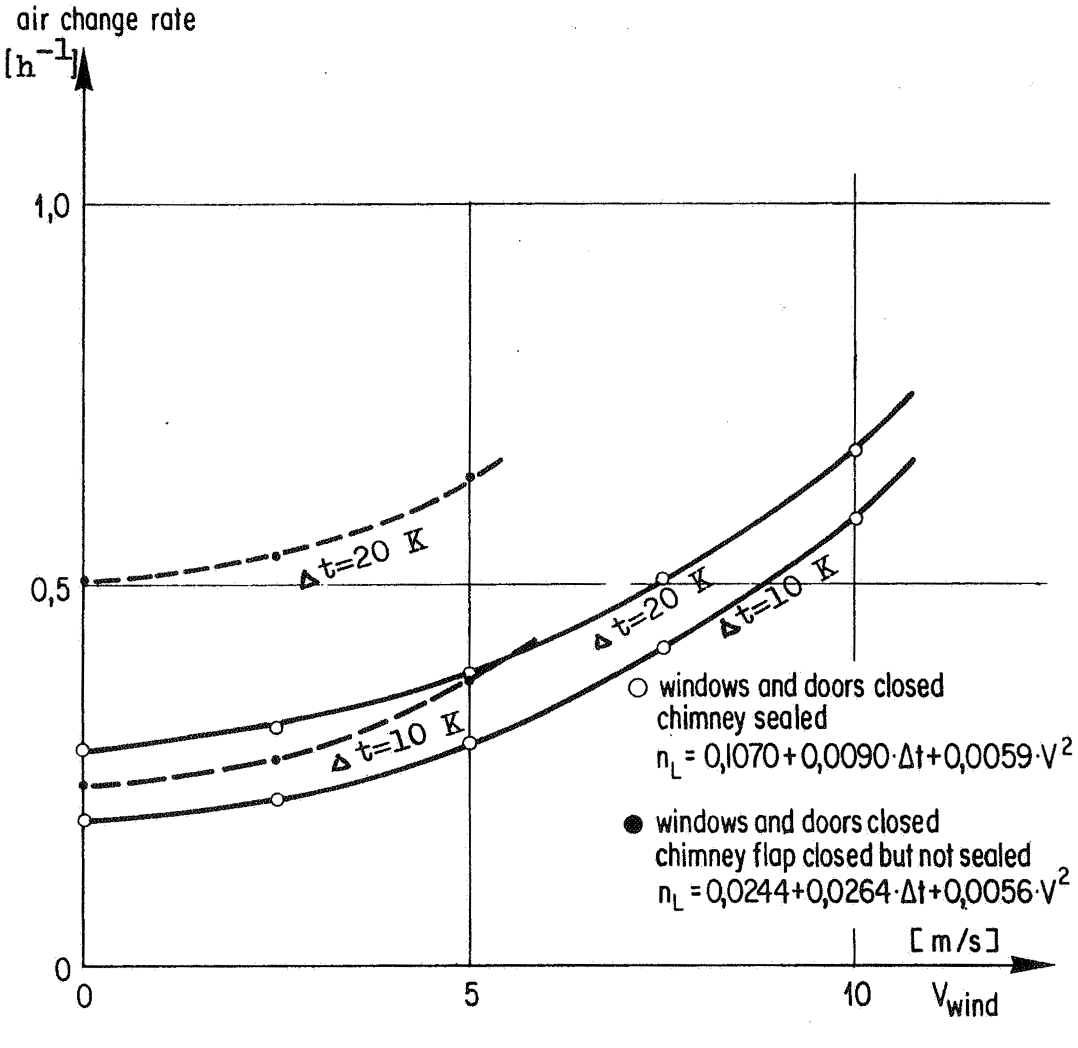

Fig. 7 Correlation of air-infiltration with wind-speed and temperature difference for the type of the test-building;

0 without an open fire-place

● with a fire place in the dining-room, with a closed, but not sealed flap