VENTILATION STRATEGIES AND MEASUREMENT TECHNIQUES

6th AIC Conference, September 16-19 1985, Netherlands

PAPER 9

CONTINUOUS AIR RENEWAL MEASUREMENTS IN DIFFERENT INHABITED BUILDINGS

J.-L. Scartezzini, C.-A. Roulet, O. Jolliet

Solar Energy Research Group
Ecole Polytechnique Federale
Lausanne, Switzerland

ABSTRACT

A Compact Equipment for Survey of Air Renewal (CESAR) was developed at the Ecole Polytechnique Federale de Lausanne in Switzerland. Controlled by a microcomputer, this apparatus uses tracer gas methods (decay, continuous flow or constant concentration). Up to ten different locations in inhabited rooms can be monitored simultaneously over extended periods of time, using mainly the "constant concentration" technique.

Several air renewal surveys were carried out on different inhabited buildings. During 1983/1984 and 1984/1985 heating seasons the following three main objects were investigated:

- an inhabited passive solar office building (LESO building)
- a three storey one family Swiss dwelling
- a low energy test greenhouse at the European Nuclear Research Center (CERN).

Following significant results were obtained:

- Air renewal measurements surveys were carried out in different inhabited dwellings over several weeks.
- Determination of actual outdoor-to-room and building-to-rooms flowrates were obtained in multi-chamber house configuration.
- Influence of inhabitants on the various air flowrates were determined.

Results of these surveys as well as a short descritpion of the developed apparatus are reported in this communication.

RESUME

Un dispositif compact de mesure du taux de renouvellement d'air (CESAR) a été développé à l'Ecole Polytechnique Fédérale de Lausanne. Contrôlé par une calculatrice de table, cet appareil utilise les méthodes à gaz traceur (décrément logaritmique, flux constant ou concentration constante). Jusqu'à dix endroits différents peuvent être mesurés simultanément et pendant de longues périodes dans des chambres habitées, en utilisant principalement la technique à concentration constante.

Plusieurs campagnes de mesure ont été effectuées sur différents bâtiments habités. Pendant les hivers 1983/84 et 1984/85 les objets suivants ont été mesurés:

- le Laboratoire d'Energie Solaire de l'EPFL, bâtiment solaire passif expérimental,
- une villa familiale de trois étages,
- une serre horticole expérimentale au CERN.

Les résultats suivants ont été obtenus:

- L'infiltration a été mesurée pendant plusieures semaines dans des bâtiments habités.
- Les infiltrations provenant de l'extérieur et du reste du bâtiment ont été déterminées.
- L'influence des habitants sur le taux de renouvellement d'air a été mise en évidence.

Cet article présente brièvement le dispositif de mesure et les résultats de ces campagnes.

INTRODUCTION

Improvement in the thermal performances of low energy buildings is concerned with precise air renewal measurements. In particular, great efforts are now dedicated to quantification of the occupants' influence on air change conditions. To attain this objective, measurement techniques must have the following characteristics:

- Allow continuous measurement over extended periods of time (several days or weeks) under varying air change conditions.
- Avoid presenting any health risks to living beings when exposed to prolonged measurement constraints.

The Compact Equipment for Survey of Air Renewal (CESAR) was developed at the Ecole Polytechnique Federale de Lausanne in Switzerland (1, 2). By use of an appropriate tracer gas technique with a non toxic gas at a very low constant concentration (100 ppm N_2O), the two criteria mentionned above can be attained.

Several air renewal surveys were carried out on the following three inhabited buildings (3,4) during 1983/1984 and 1984/1985 heating seasons:

- an inhabited passive solar office building (LESO building)
- a three storey one family Swiss dwelling (Roulet house at Apples)
- a low energy test greenhouse at the European Nuclear Research Center (CERN)

Results of these surveys as well as a short description of the developped apparatus are reported in this communication.

Figure 1: View of the Compact Equipment for Survey of Air Renewal (CESAR)

DESCRIPTION OF THE APPARATUS

CESAR is a compact and mobile installation for "in situ" measurements (Figure 1). This apparatus was designed for simultaneous analysis of up to ten inhabited rooms over extended periods of time. Three operating modes with different tracer gas techniques can be used: the "decay" and "continuous flow" methods and above all the "constant concentration" method (5,6). This last approach shows serious advantages when compared to the others; measurement of infiltration can be carried out even in inhabited buildings with varying air change rates.

Figure 2 shows a bloc-diagram of the developed apparatus. The overall equipment is integrated on a mobile rack shown in Figure 1.

Four main components constitute the overall apparatus:
- a monitoring microcomputer
- an infrared N_2O and H_2O spectroanalyser
- a ten channel gas sampling unit
- a ten channel programmable gas injection unit

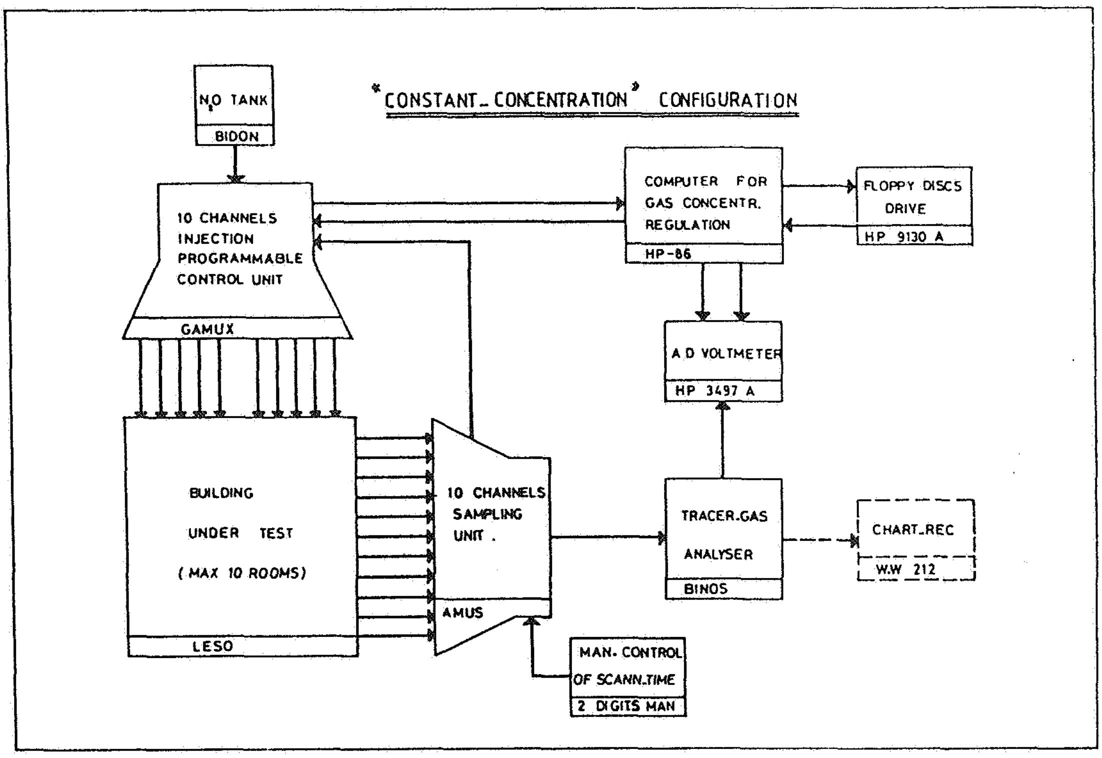
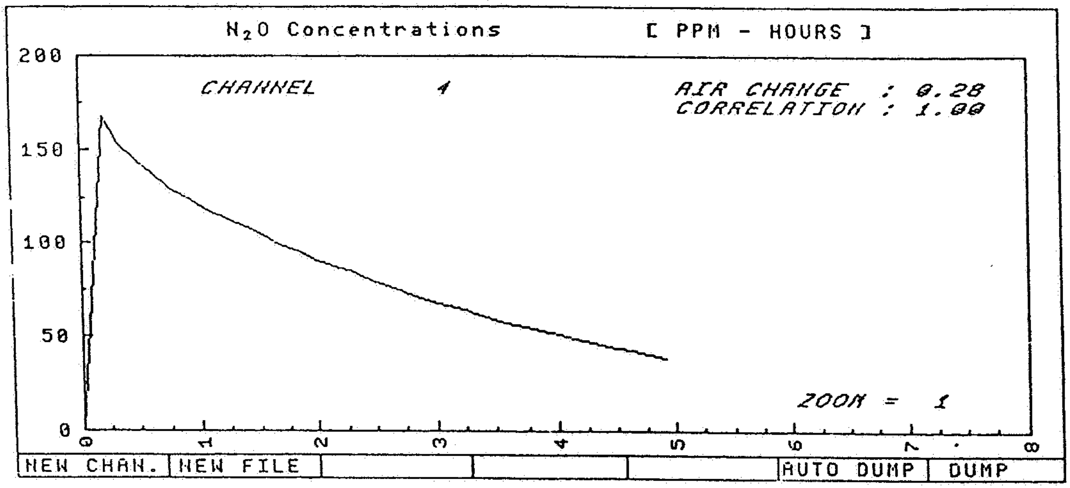


Figure 2: Bloc - diagram of CESAR

The following describes the main operations performed by these components:

a) Monitoring micro-computer

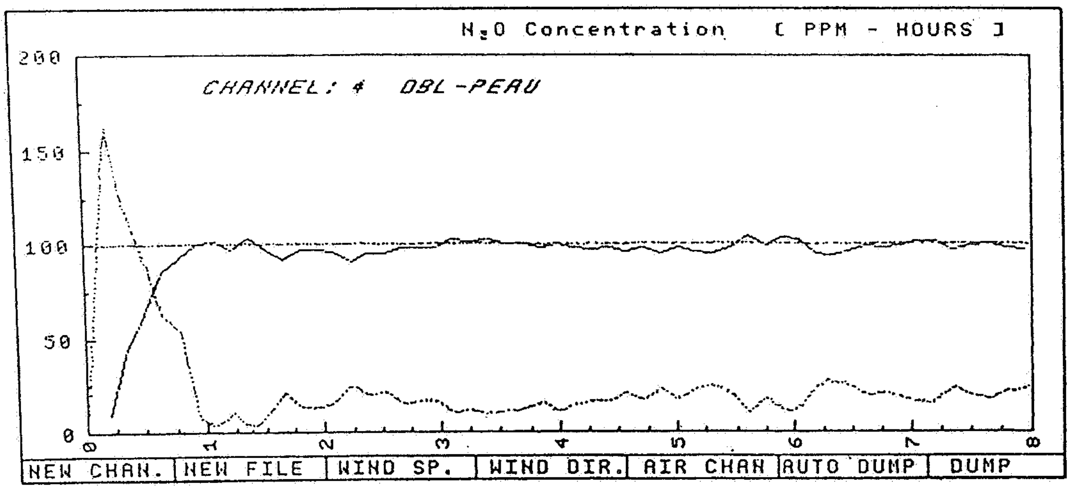
Acquired data is recorded on a magnetic support (floppy disc). Analysis of monitored data is done automatically by the computer at the end of the survey. Air infiltration rates and air flow rates as well as statistical parameters are displayed after each analysis. Figure 3 shows an example of a "decay" analysis delivered after treatment of the monitored data.



(MONITORING PERIOD OF 8 HOURS - FEBRUARY 1984)
VERTICAL AXES : CONCENTRATION (PPM). HORIZONTAL AXES : TIME (HOURS)

Figure 3 : Decay analysis delivered by the computer after processing the monitored data.

Figure 4 illustrates a "constant concentration" analysis done on an inhabited 86 m^3 room. The target level is maintained with a 4 to 8 % accuracy even for periods of several days. "Constant concentration" operation is controlled by the microcomputer, through the use of a proportional - integral - differential (PID) control. Air change rates obtained in a first "decay" experiment as well as room volumes were used as input parameters for the gas concentration control. The typical desired concentration level of 100 ppm N_2O can be achieved for rooms of up to 200 m^3.



ANALYSIS OF A "SOLAR UNIT" OF LESO BUILDING USING "CONSTANT CONCENTRATION" METHOD

(MONITORING PERIOD OF 8 HOURS WITH OCCUPANTS - MAY 1984)
VERTICAL AXES : N_2O CONCENTRATION (PPM) (N_2O FLUX NOT SCALED). HORIZONTAL AXES : TIME (HOURS).

Figure 4: "Constant concentration" analysis made on an inhabited 86 m^3 room.
Solid line: concentration level. Dotted line : tracer gas flow.

b) <u>Infrared nitrogen protoxyde and water vapour spectroanalyser</u>

The nitrogen protoxyde (N_2O) concentration level is measured by means of a Leybold-Heraeus "BINOS" IR beam analyser. Since IR absorption bands slightly ovelap, water vapour disturbs the N_2O measurement. Measurement of the H_2O content is made simultaneously for automatic correction by the microcomputer. A high precision N_2O/N_2 gas mixture is used for periodical calibration.

c) <u>Ten channel gas sampling unit</u>

A Leybold-Heraeus "AMUS" unit performs the sampling of small amounts of air in up to ten different rooms. The scanning interval can be chosen between 10 and 1000 second. The typical scaning interval between two rooms is 50 seconds.

d) <u>Ten channel injection programmable unit</u>

This device was developed at our laboratory. Its purpose is to inject, under microcomputer control, known quantities of tracer gas in up to ten different rooms. Injection flowrate is stabilized by use of a high accuracy double stage pressure valve or a constant pressure dumper tank. Gas exhaust pressure is 200 kPa (2 Bar). Small fans provide dispersion of the tracer gas in the investigated rooms. The overall injection device was calibrated by use of a high precision (2 % accuracy) volumetric flowmeter.

<u>LESO AIR RENEWAL EXPERIMENTAL SURVEY</u>

The first infiltration survey was made on the LESO building during the 1983/84 heating season. Eight south rooms of the building, distributed over thgree floors and having various passive solar systems were investigated. Figure 5 shows the cross section of the building.

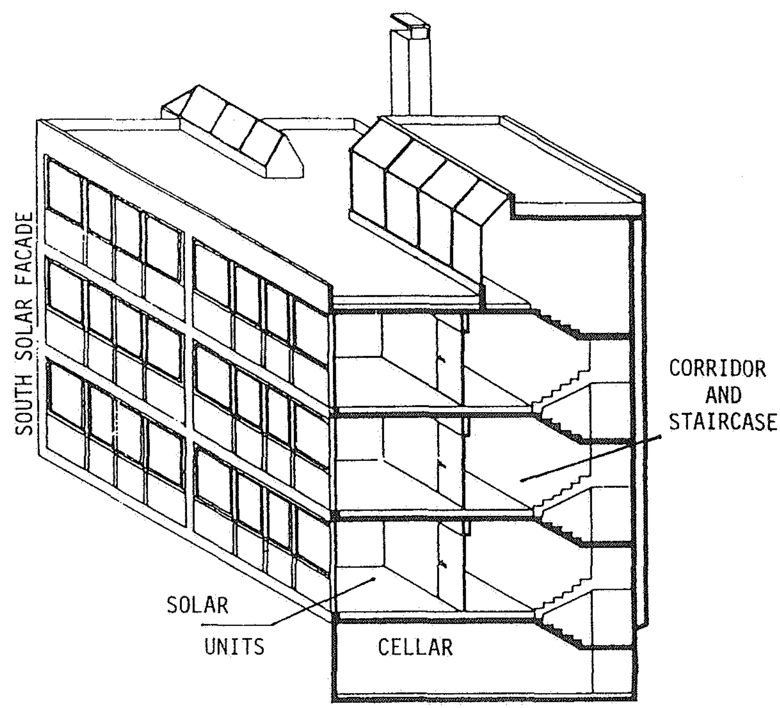


Figure 5: Representation of the passive solar office building (LESO building)

During this first experimental survey, the main effort was devoted to determining the outdoor-to-room and building-to-room (from the staircase) air flowrates. Precise evaluation of the south rooms' energy balances motivated this approach.

Fist, mean "decay" air change rates were determined for the 8 rooms. Figure 6 shows the measured values obtained over the February 1st to 29th period. Minimal and maximal values over the same period are also reported in the same Figure. Designation of the various passive solar systems, set up on the south facade of each room, are reported from bottom to top of the vertical axis in the same order as they were distributed in the building.

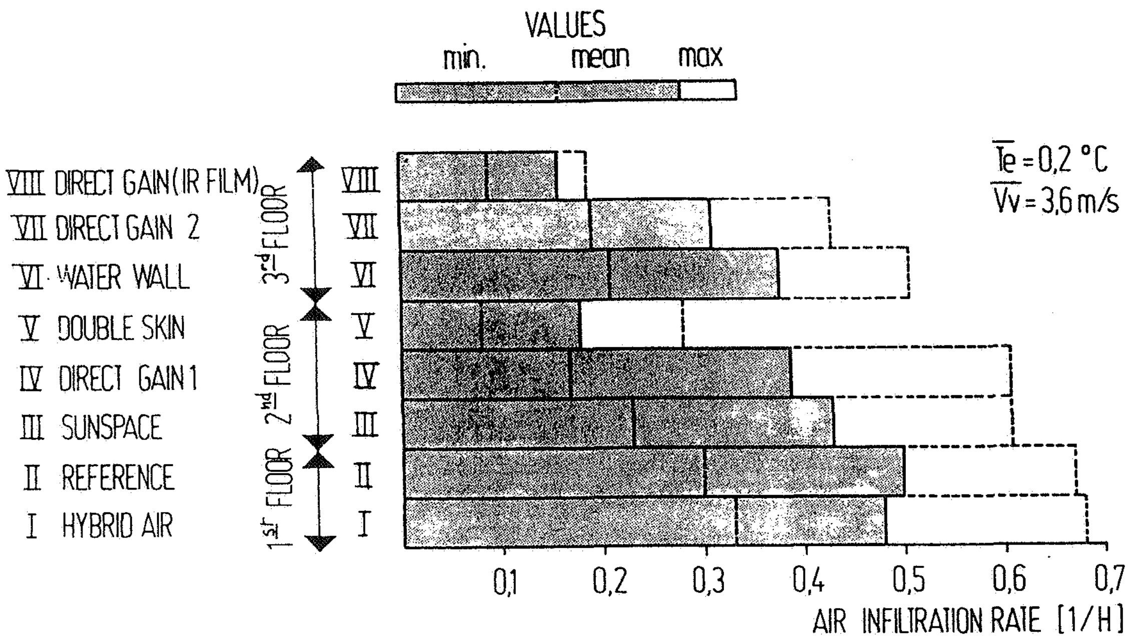


Figure 6: Minimal, average and maximal air change rates measured with the "decay" method from February 1st to 29th, 1984 on the LESO building.

Significant differences in air change rates have been found for the 8 investigated facades. New technology passive solar facades using double skin (V) or double infrared reflecting foils windows (VIII) have been shown to produce a drastic reduction in air infiltration, demanding a new air quality control strategy.

Total infiltration flowrates were also measured for each investigated room using the "constant concentration" technique, the tracer gas being injected only into the rooms.

Outdoor-to-room infiltration flowrates were determined for each south room by imposing the same desired N_2O concentration level over the entire building.

The mean building-to-room infiltration flowrates were obtained by substracting the mean outdoor-to-room air infiltration flowrates from the mean total infiltration flowrates.

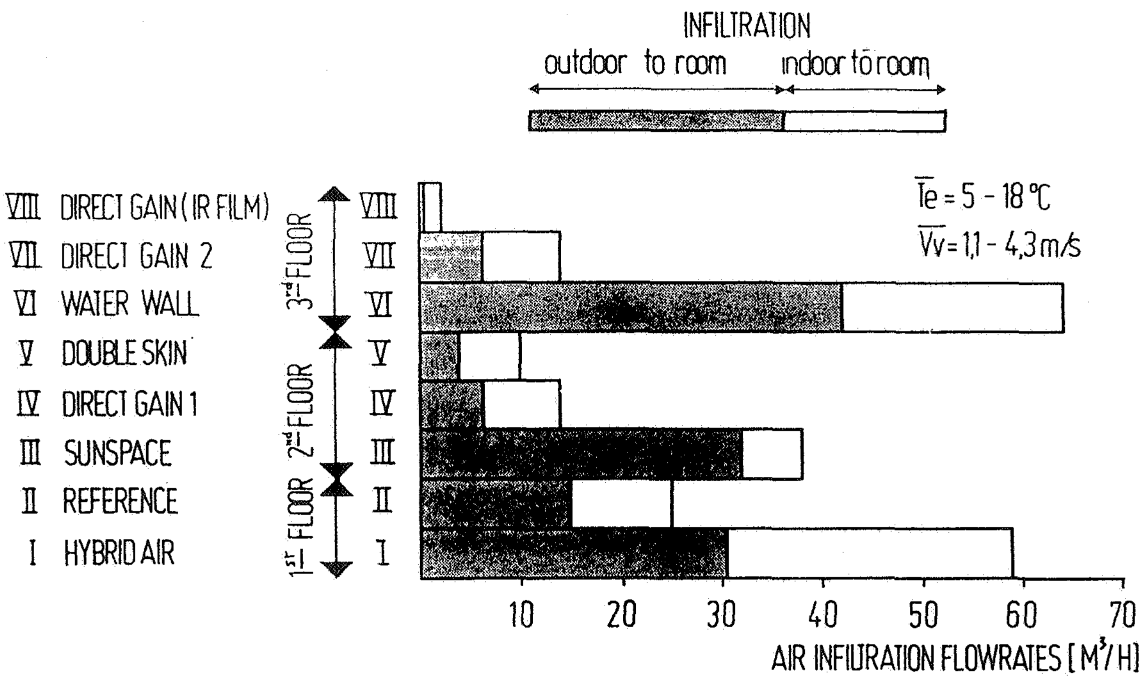


Figure 7 : Outdoor-to-room and building-to-room air infiltration flowrates experienced at the LESO on the March to end of May 1984 period.

Figure 7 shows outdoor-to-room air infiltration flowrates in grey, ranging from 1 to 40 m^3/h. Significantly low outdoor-to-room air infiltration flowrates were measured for the new technology facades. Building-to-room air flowrates of about 5 m^3/h were measured in unoccupied rooms having only one door connecting to the rest of the building.

A second air infiltration survey has been made on the LESO building during the 1984/85 heating season. The same south rooms, some of them having a new passive solar facade, were again investigated. The main effort this time was devoted to quantification of the occupants' influence. For this purpose, total air infiltration flowrates were measured for the 8 different south rooms over occupied and unoccupied periods. The "constant concentration" technique was used for this purpose. Total air infiltration flowrates were divided by the room's physical volume to obtain total air infiltration rates.

Figure 8 shows the measured air change rates obtained for the 8 different south rooms. Two different measuring periods (November 1984 and January 1985) are represented. Increase of air change rates due to colder meteorological conditions can be seen by comparing the results of the two months. The influence of occupants on the air infiltration rate is responsible for the air change rate increase measured for occupied rooms. Since windows were shut at all times, these increases were due only to door openings by the users. Mean values obtained for the overall 1984/85 heating season sho an 18 to 100 % higher value in air infiltration rates for inhabited rooms as compared to empty rooms.

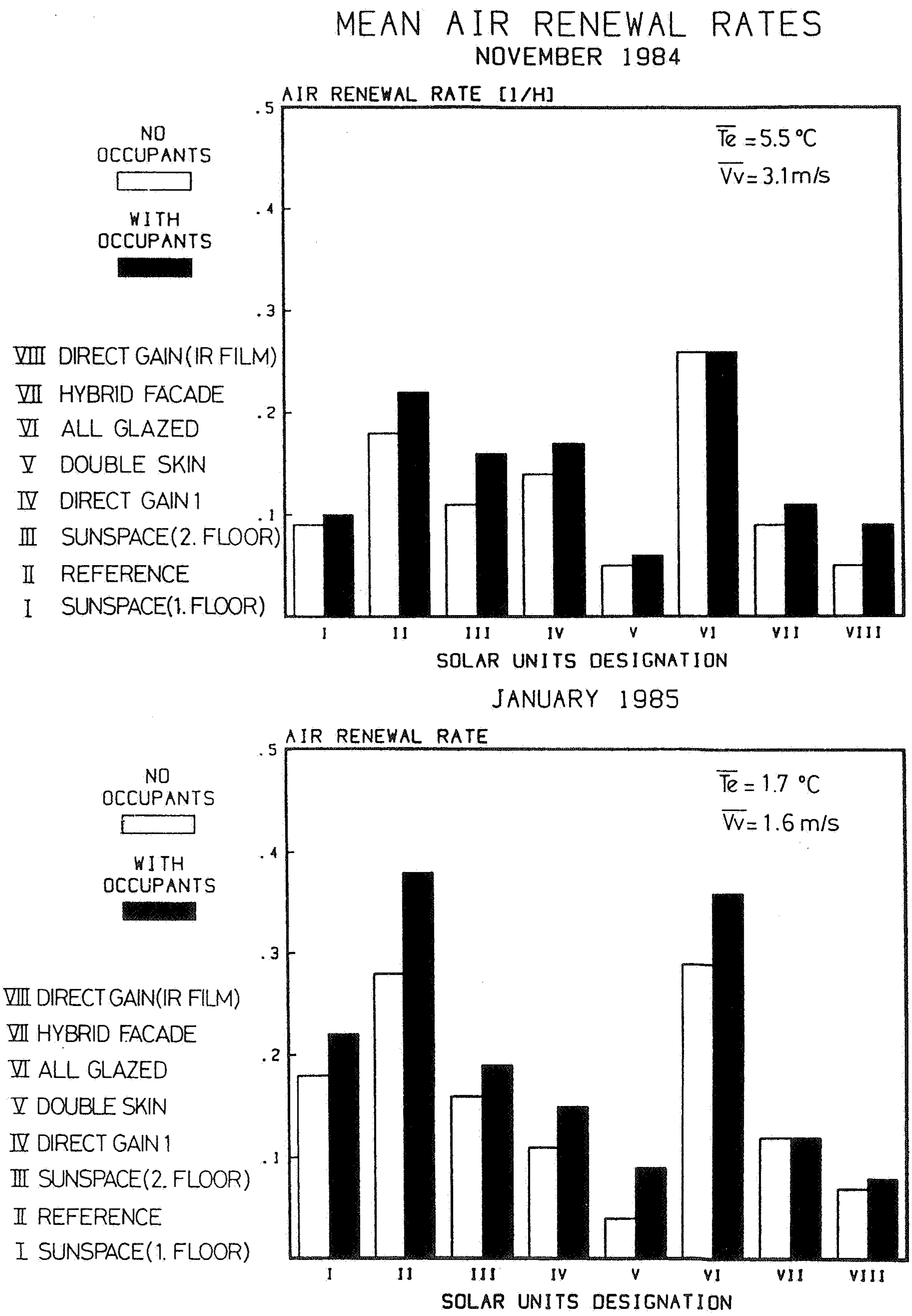


Figure 8 : Mean air change rates for two months with different outdoor temperature (January colder than November).
Black bars: with occupants   White bars: without occupants.

AIR CHANGE SURVEY IN A ONE FAMILY HOME AT APPLES

Purpose of the survey and description of the building

A 12 day survey was made on a high one family home located in Apples, Switzerland; the main purpose being to test CESAR in the field. This home is built on 6 half levels (Figure 9). It has a heated volume of 530 cubic meter and 10 heated rooms which are interconnected with respect to air change. Air flows occur between the 10 rooms since they all open to the staircase.

The building has masonry walls with an external 4 cm fiberglass insulation, double glazed windows with weatherstripped wood frames and a frame wood roof including 14 cm fiberglass insulation. The toilets have ducts for natural ventilation and a fan is used in the kitchen when cooking. For the other rooms, natural ventilation occurrs through leaks and open windows.

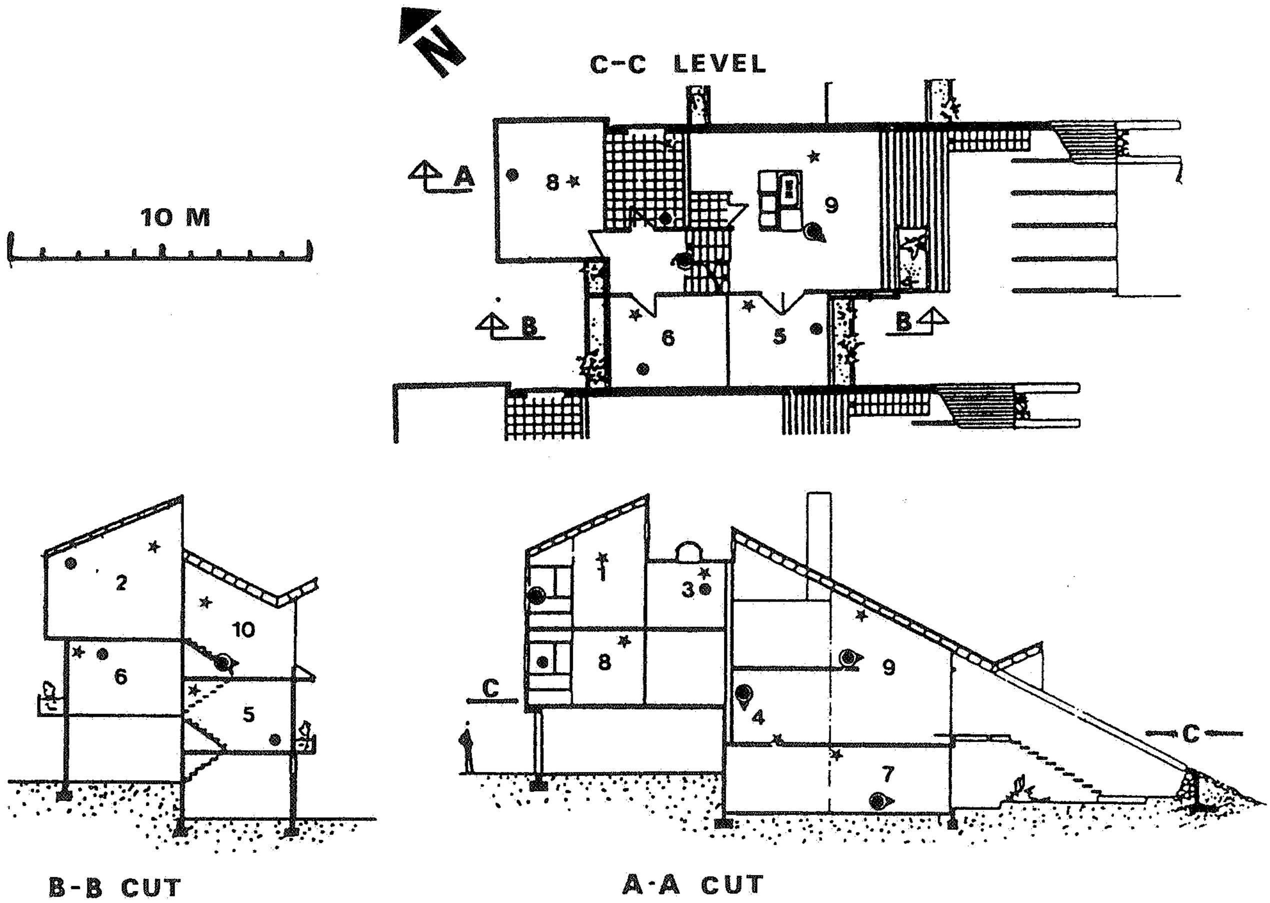


Figure 9 : Sketch of the middle level Apples family home and vertical cuts showing the inter-connected half levels.

1 Yve's bedroom	2 Parent's bedroom
3 Bathroom	4 Entrance and stairs
5 "Fumoir"	6 Knitting room
7 Friend's room	8 Kitchen
9 Living room	10 Guy's bedroom

● Tracer injection point ✱ Tracer sampling point

◀◉ Tracer injection point with fan. Arrow shows direction of the flow.

The building is occupied by 2 to 4 adults and their habits did not change during the survey. The structure of the building (high spaces, interconnected rooms) as well as the inhabitant behaviour (opening doors and windows) bring to this experiment some difficulties which are interesting for testing the apparatus and the monitoring software.

Measurements

The 10 measuring channels of CESAR were used for the heated rooms. Five other non-heated rooms such as the cellars were not measured. The air change between the heated space and the outdoor or unheated space was monitored.

Measurements were made using the "constant concentration" method between October 24th and November 7th, 1984. The data were recorded in 8 hour files on a floppy disk. During this period, the wind velocity was very low, between 0 and 3 m/s.

Because the large air change rate variations that occur in inhabited dwellings, it is quite difficult to maintain a constant tracer gas concentration level. Even with the sophisticated control system of the CESAR apparatus, small variations cannot be avoided. The measurements were then interpreted with the following equation (5), giving the volume Q of indoor air lost between the time t_1 and t_2:

$$Q = \int_{t_1}^{t_2} \frac{\dot{q}(t)}{C(t)}\, dt - V \left[\ln C(t_2) - \ln C(t_1)\right]$$

Where $\dot{q}$ is the tracer gas flow rate, C(t) the tracer woncentration level and V the measured volume. The integral is evaluated on the discrete measurement points by the trapeze method. One such equation was applied to each room, as if these rooms were independant and the total air lost quantity for the entire dwelling is obtained by summation. From this quantity, the mean air flow and air change rates can be easily evaluated. This interpretation method neglects the effects of the air changes between the rooms. In fact, these effects are negligible since the concentrations are nearly the same in every room.

Results

Figure 10 shows the mean air change rate for the entire dwelling averaged over 8 hours intervals. It is obvious that the behaviour of inhabitants can lead to very strong variations of the air change.

Separate sums of the air flowrates can be made for two different configurations: one when all the windows are closed, and another when only one or two windows, located in the bedrooms on the upper level are open (inhabitants sleep there with open windows).

The total mean air change rate, for the entire heated space during the whole survey is 0.5 /h.
This air change rate decreases to 0.37 /h for the time periods when all the windows are closed and increases to 0.56 /h if one or two bedroom windows are open. It is obviously larger when more windows are open.

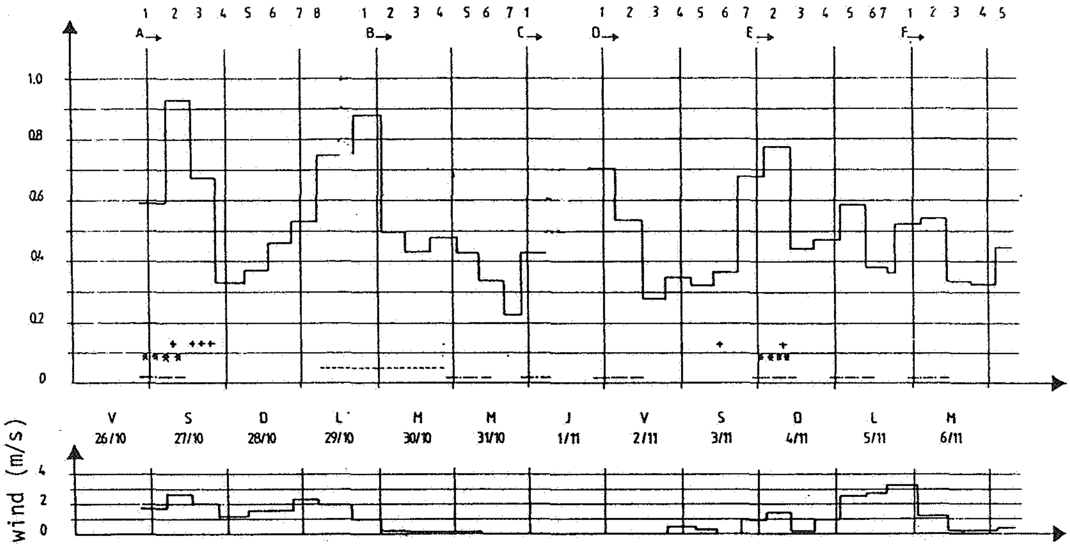


Figure 10 : Mean air change rate (ach) for the whole Apples dwelling obtained by the constant concentration method, averaged over every 8 hours interval. At the bottom, the wind speed is represented.

++++ : Large ventilation of the dwelling by opening kitchen and livingroom windows for 15 min.

**** : Window open in Yve's room.

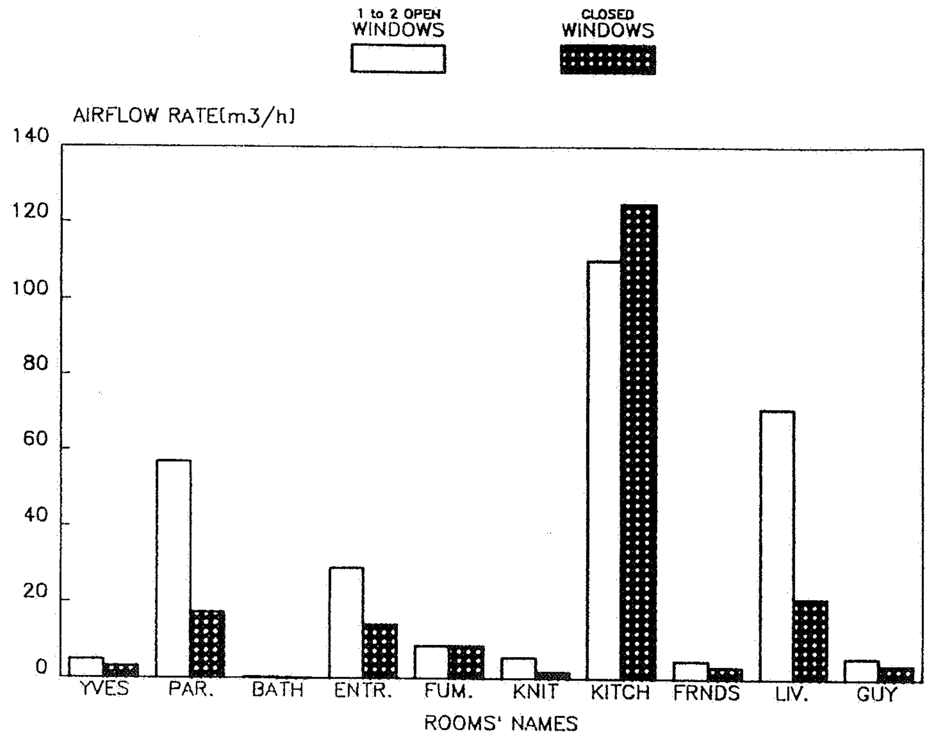
---- : Sky-window in the bathroom opened

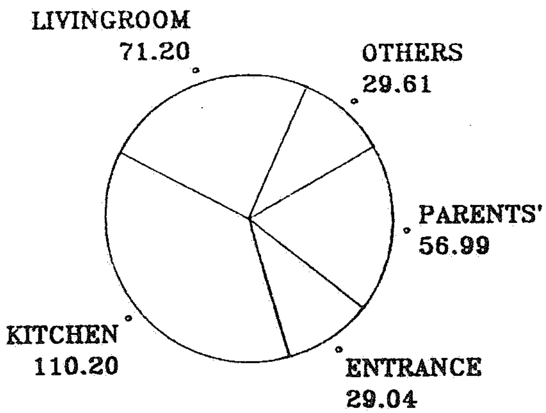
-.-.-: Parents' bedroom window open during the night.

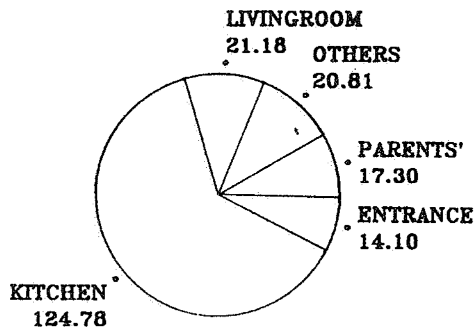
Figure 11 shows the air infiltration flowrates for each room. The main infiltration occurs in the kitchen and the livingroom, which are on the lower levels and have large sliding glass doors. It is obvious that the fresh air is coming into the house mainly in these rooms. For example, the infiltration in the parents' room with open windows looks very low, since large quantities of indoor air, already containing the target concentration level of tracer gas, comes from the livingroom by way of the staircase and an untight door.

This total rising air flow is more obvious when looking at peculiar records, as in Figure 12. When closing the parents' bedroom window, effects can be seen in five other rooms located either at the same level as in the bathroom,(channel 3), at the lower level as in the kitchen (channel 7) and in between as in the staircase (4), the livingroom (9) and knitting rooms (6).

More developments on the tracer gas concentration control system will be made, taking into account the exchanges between rooms, to avoid the overshoots as those which can be seen on channels 2 and 7 in Figure 12.







1 TO 2 OPEN WINDOWS
TOTAL 297 m3/h

CLOSED WINDOWS
TOTAL 198 m3/h

Figure 11 : Comparison of the total air flows of each room. The windows which are open some time are in the bedrooms, on the upper level.

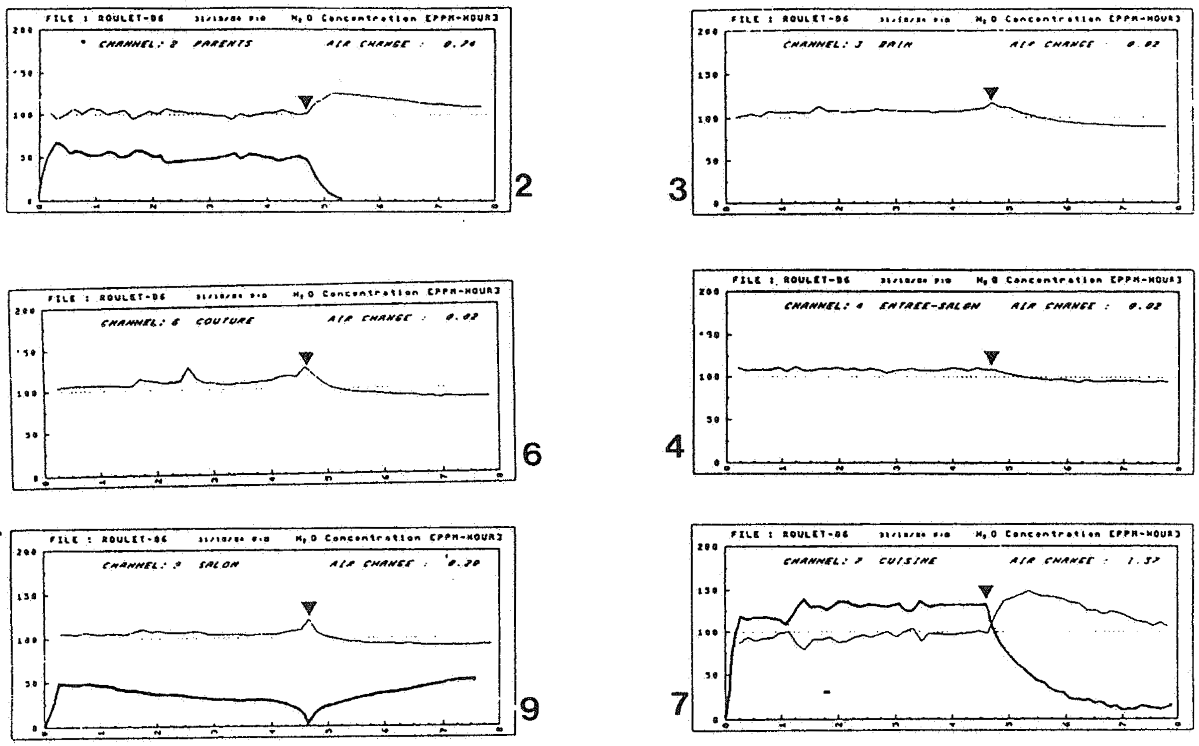


Figure 12 : Record of the tracer gas concentration (thin line) and of the tracer gas flow (thick line) in 6 rooms. This record shows the effect of closing the parents' room window (channel 2) on the air change in other rooms (arrows) and hence the strong inter-connections through the untight interior doors and the staircase.

AIR INFILTRATION SURVEY IN A LOW ENERGY TEST GREENHOUSE IN GENEVA

Purpose of the survey

In 1982, a research project was begun at CERN in Geneva to examine different methods of maximizing the solar energy contributions and minimizing heating costs in a greenhouse, using various heating systems and thermal screens.

The CESAR was used to study the fluctuations of air infiltration and particularly to quantify the influence of the following factors on the air change rate:

- the roof windows openings
- the use of thermal screens during the night
- the wind and the indoor/outdoor temperature difference.

It also provides an opportunity to test the CESAR on a large building (2670 m^3).

Description of the building and experimental setup

The greenhouse has an area of 668 m^2 and a total volume of 2670 m^3 (Figure 13). It is divided into five thermal zones separated by plastic films, each zone being equipped with a different low temperature heating system.

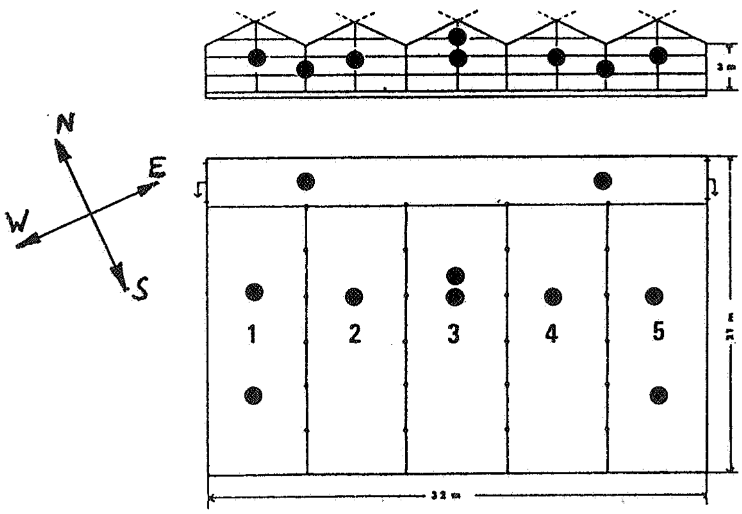


Figure 13: Top view of the CERN greenhouse with the 5 independant thermal zones. The dots show the tracer gas sampling points.

Two horizontal thermal screens were installed in the upper part of the greenhouse to reduce the night heat losses. The greenhouse has a single glazed roof and double glazed sides with aluminium frames. The airtightness of the greenhouse is improved by using rubber seals on the frame (Figure 14). During overheating periods (indoor air temperature over 24 ^{o}C) the control system opens the roof windows in order to create a natural ventilation. For more details see (6).

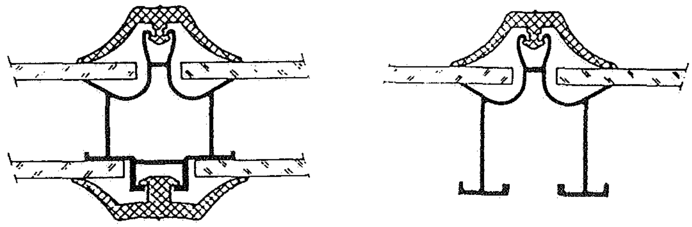


Figure 14: Detailed view of the frames and the rubber seals for the single and double glazing.

Measurements were made using constant concentration method from November 28th to December 14th, 1984 and from February 6th to 21st, 1985. The ten measuring channels of CESAR were installed and used for the entire greenhouse as shown in Figure 13. In addition, an automatic data acquisition unit allowed for detailed analysis of the climate and operating conditions of the greenhouse.

The method of analysis was similar to that used on the Apples survey but was directly performed using the total air infiltration flowrate and the mean concentration level for the entire greenhouse.

Results

Figure 15 shows the strong influence of opening the roof windows during overheating periods: even for a small opening of 5 cm, the air change rate increases from 0.2 - 0.28 /h (window closed) up to 0.6 - 1.5 /h.

During these periods, the tracer gas concentration level decreases down to 80 ppm because of the response time of the control. The effect of this on the results however is negligible considering the analysis method used.

One can also observe in Figure 15 that the thermal screens slightly reduce the air infiltration into the greenhouse by about 15 % (ach = 0.28 /h without screens, 0.22 /h with screens). This is confirmed in Figure 16 where, for similar wind velocity and temperature differences, air change is also slightly lower with screens than without.

Figure 16 shows the combined influence of the wind velocity (v) and the indoor to outdoor temperature difference. Note that during the measurement periods, the wind velocity was low ($v < 3$m/s)

A multiple linear regression was performed on the data recorded with the screens, in order to determine the air change rate as a function of v and the temperature difference. The regression coefficients and their 90% confidence intervals are as follows:

$$ach = a + b\,v + c\,(\theta_i - \theta_e)$$

$$a = 0.104 \pm 0.04 \quad h^{-1}$$

$$b = 0.045 \pm 0.008 \quad s\,m^{-1}\,h^{-1}$$

$$c = 0.011 \pm 0.003 \quad K\,h^{-1}$$

Finally, one can note that, because of the frame rubber seals, this greenhouse is very tight. Its air change rate ranges from 0.15 to 0.4 /h as compared to approximately 1/h for a standard greenhouse.

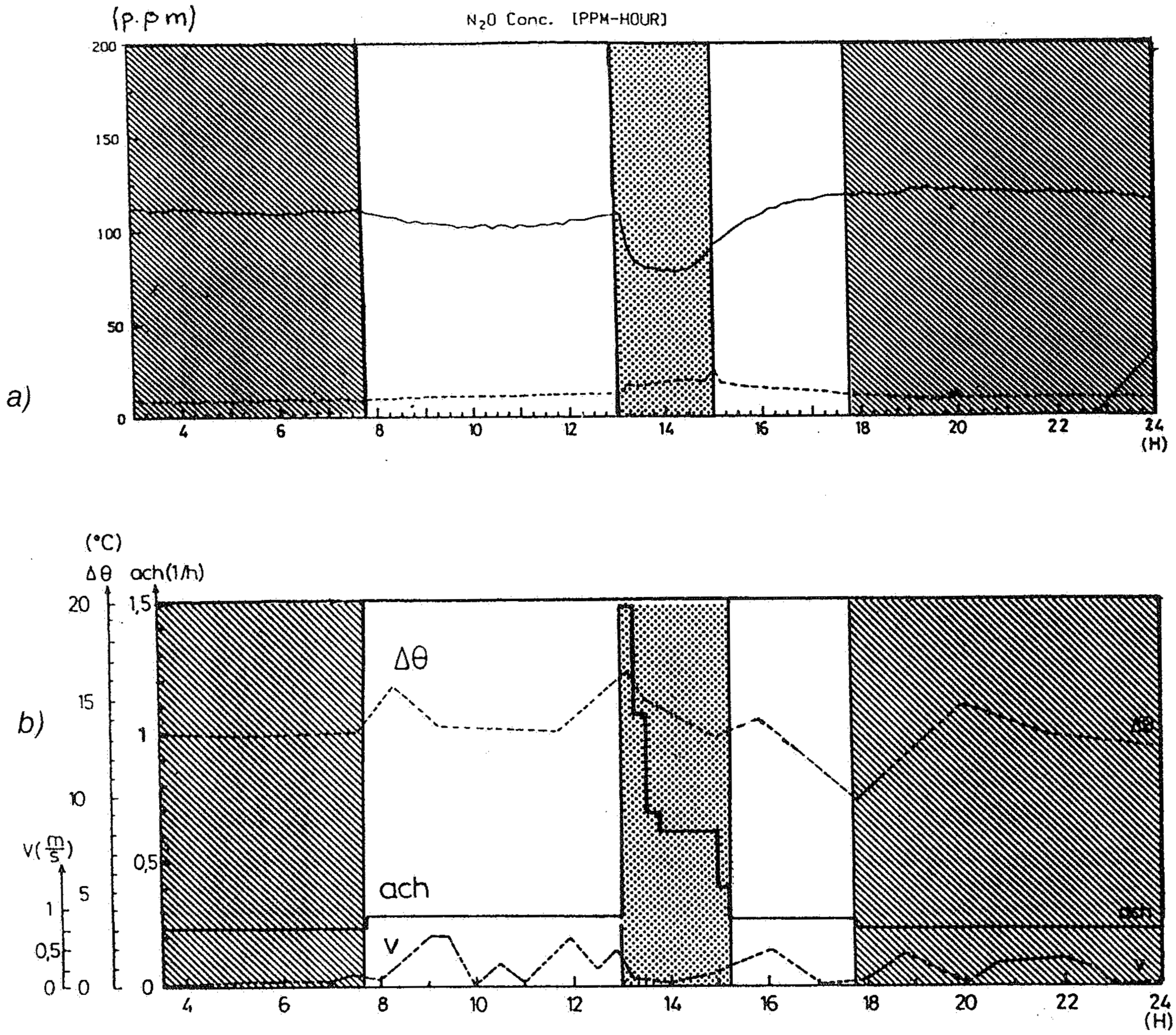
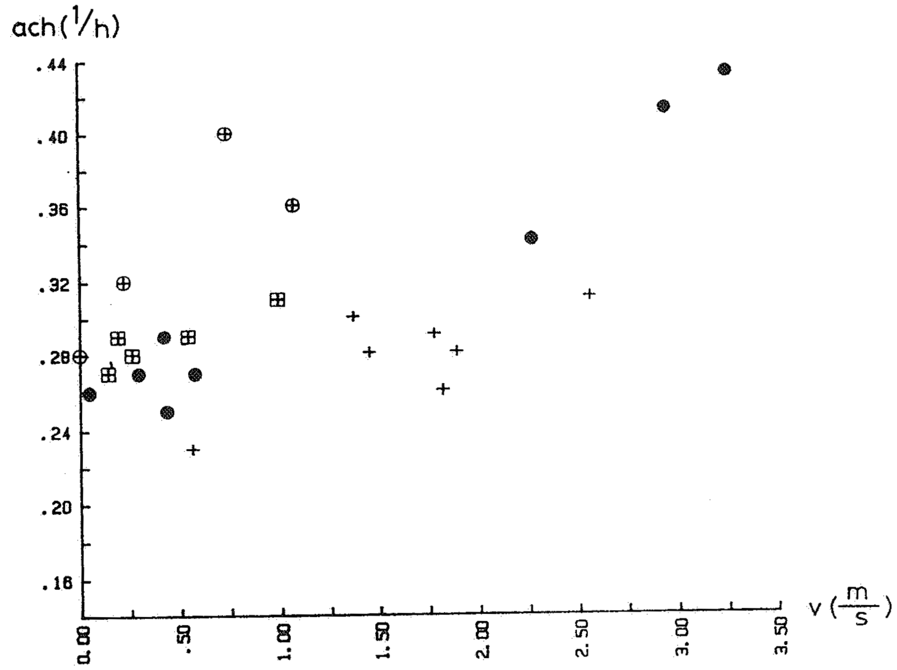


Figure 15: Measurements on the greenhouse during 24 hours:
 a) Evolution of the tracer gas concentration (solid line) and the tracer gas flowrate (dotted line) for the entire greenhouse.
 b) Evolution of the air change rate (ach), the indoor/outdoor temperature difference an the wind velocity (v)

Dotted zone : windows open. Hatched zone : thermal screen closed a)



b)

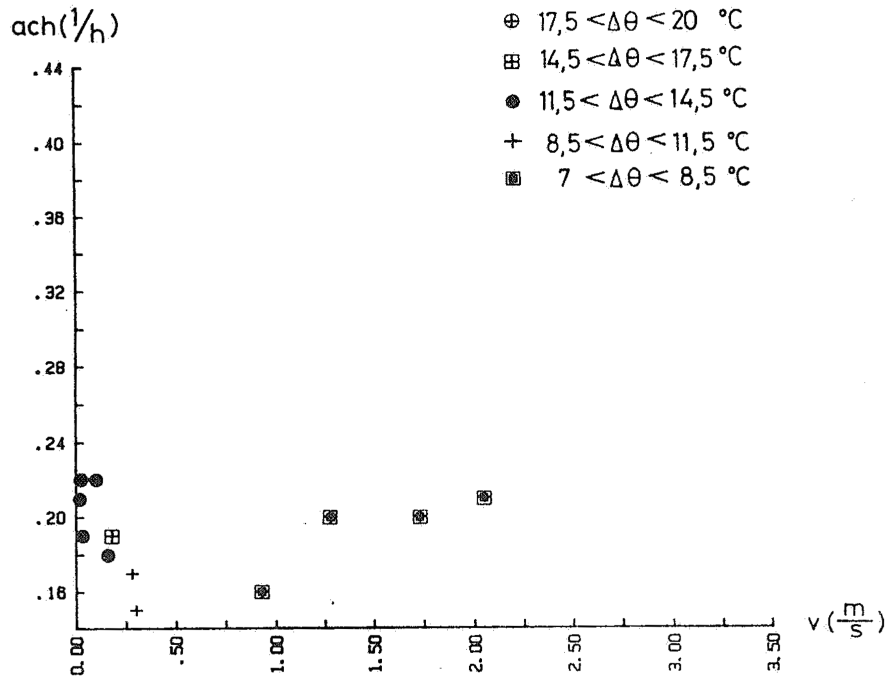


Figure 16: Air change rate as a function of wind velocity for different indoor/outdoor temperature differences. Mean values over 4 to 8 hours time periods where windows are closed.

a) without screens b) with screen

AKNOWLEDGEMENTS

The National Energy Research Fund (National Energie Forschungs Fonds NEFF) and the Federal Bureau for Economics and Growth Policies (Bundesamt für Konjunkturfragen BFK) have sponsored this work.

The authors wish to thank Dominique Quévit, Christian Roecker, Pierre Loesch and Philippe Stauffer for their contribution to the development of the CESAR and for their help during the measurements as well as Mrs Patrice Schaepe for the correction of the manuscript.

REFERENCES

1 - C. Roulet, J.-L. Scartezzini : CESAR: Compact Equipment for Survey of Air Renewal.
Communication to ISO TC 163 ad hoc group "On site measurements" meeting, Washington DC, April 4-6, 1984

2 - J.-L. Scartezzini : CESAR: Dispositif compact de mesures multi-chambres du renouvellement d'air par gaz traceur.
GRES-EPFL internal report, Lausanne, Switzerland, 1985

3 - J.-L. Scartezzini, C. Roecker, D. Quévit: Continuous air renewal measurements in an occupied solar office building.
CLIMA 2000 proc. Copenhagen, Aug. 23.-28., 1985

4 - C. Roulet, J.-L. Scartezzini: Mesure du taux de renouvellement d'air dans la villa Roulet, Apples.
GRES-EPFL 84-01-10 internal report, Lausanne, 1984

5 - Perera: Review of techniques for measuring ventilation rates in multi-celled buildings.
Proc. of E.C. contractors meeting on natural ventilation, Bruxelles, 1982

6 - M. Bourgeois & al. : Serre pilote du CERN.
Internal reports CERN/DIR/EN/85-1 (1985)