DETERMINATION OF THE VENTILATION RATE IN A SERIES OF SOCIAL HOUSES.

ir. P. NUSGENS (University of Liège)
ir. P. Caluwaerts (C.S.T.C.)

Chapter I - Introduction.

- Within the framework of the research on the real energy use for the heating of houses, performed in situ on 10 houses in Seneffe, the determination of the air infiltration in the rooms of these houses was necessary. For the calculation of the thermal balance and energy use it is indeed indispensable to acquire a precise knowledge of the rate and effect of the natural ventilation.

- In view of the different methods for the measurement of this natural ventilation and the knowledge acquired in other research units, it was decided to proceed at a comparison between two measuring methods :

  a) the method based on the infra-red absorption.

  The Thermodynamics Institute of the University of Liège has been performing tests with an apparatus of this type, within the framework of the research "Controled Mechanical Ventilation - IRSIA - 2260 IC 13/7".

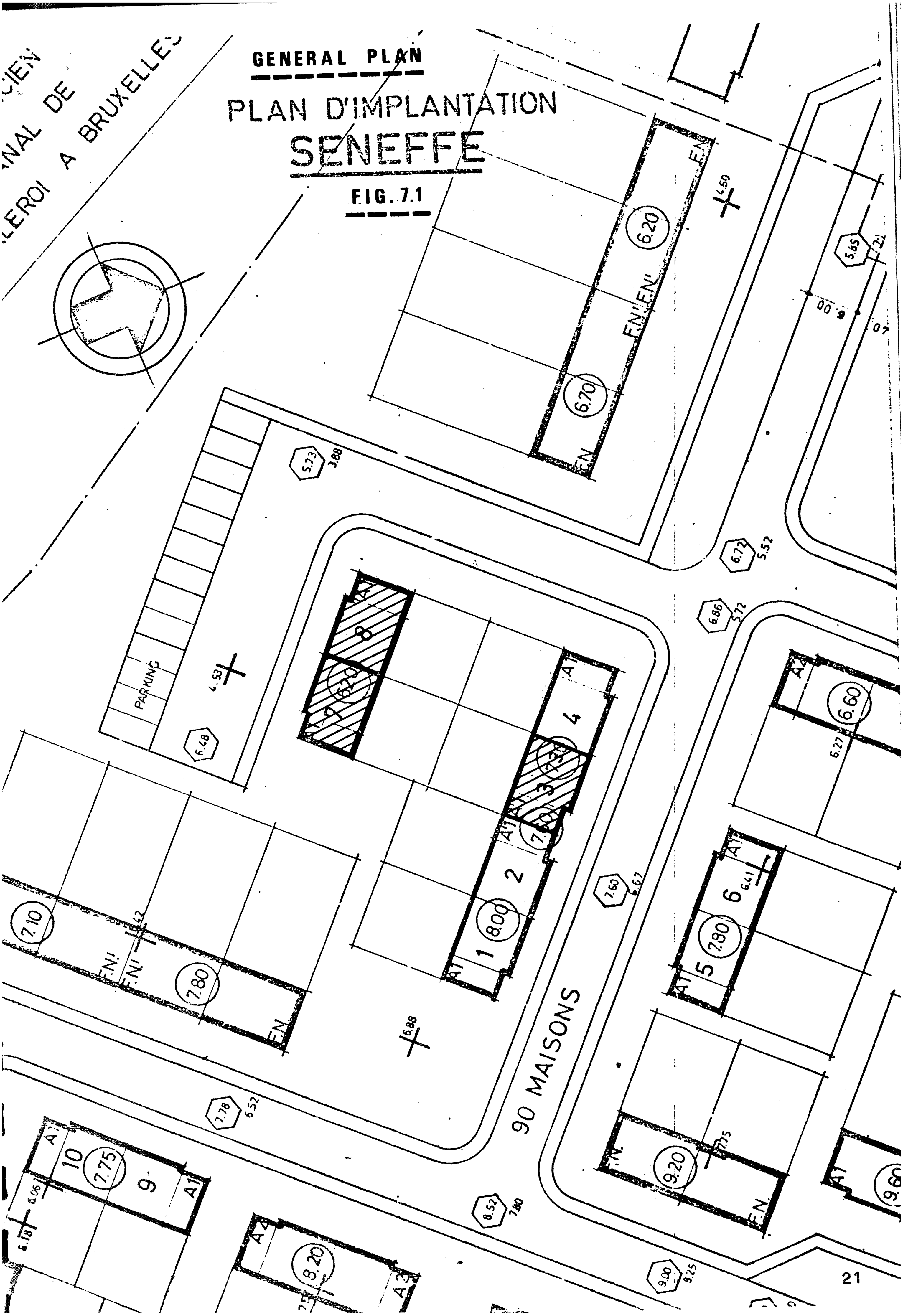
  The method used was based on the infra-red absorption of CO_2. Within the framework of this "Seneffe"-research and after modification of the analyser in view of effecting measurements with the tracer gas N_2O, the University of Liège proceeded during the month of August 1976 at infiltration measurements in the house nr. 8 (see fig. 7.1). Chapter 3 of the present part of the report gives the description and the results.

  b) the method based on the para-magnetic properties of certain gases such as oxygen.

  During a short period, the CSTC has been able to perform some reference tests with an apparatus of this kind, which it had on loan (tests on house nr. 3, see fig. 7.1). After these positive experiences, the CSTC has been able to perform ventilation tests in Seneffe during the summer of 1976 (test on house nr. 7).

  All these tests are described in chapter 2 of this report.

Chapter 4 gives a description of the comparison between the two test methods, and tries to explain the complexity of the natural ventilation of a whole house


GENERAL PLAN
PLAN D'IMPLANTATION
SENEFFE
FIG. 7.1
A BRUXELLES
PARKING
90 MAISONS

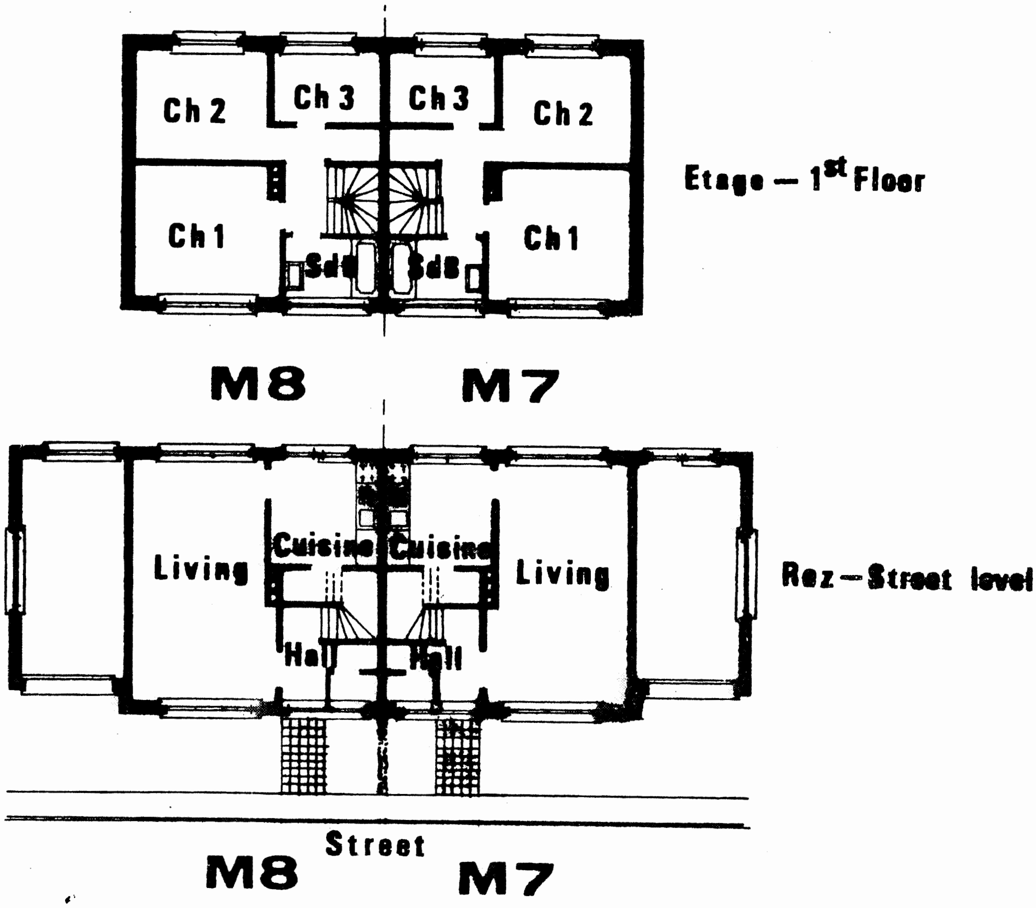


Fig 7.2

ch 1 (chambre) = room 1
ch 2 = room 2
ch 3 = room 3
living = living-room
cuisine = kitchen
SdB = bathroom

Chapter II - Tests performed by the CSTC.

II.1. Principle of the measuring method.

The measuring is based on the para-magnetic qualities of oxygen. In the room to be tested an important amount of nitrogen is rapidly injected in order to reduce the oxygen rate in the air of the room from 21% to about 17%.

Afterwards the increase of the oxygen from 17% to 21% through the adding of fresh air is measured. From this measurement the air renewal rate of the room is deduced.

II.2. Apparatus.

The tests were performed with an apparatus measuring at each moment the oxygen rate in the room, based on its para-magnetic characteristics.

One disposed also of a special circulator connected with the apparatus in order to constantly renew the gas volume measured and of mixing ventilators disposed in the room to obtain a homogenous mixture mixed room air - incoming fresh air.

The measurements of the oxygen rate were continuously registered on a single channel graphic recorder.

II.3. Measurements.

The tests were performed during the summer of 76, in the houses nr. 3 and 7 (see fig. 7.1). For these two houses, and in particular for house nr. 7, most of the rooms were tested several times on different days in order to obtain results with different climatological situations.

From each of the tests (31 in total) the curve of the oxygen decrease has been retransformed in a semi-logarithmic curve.

Some examples of these curves are represented in fig. 7.3 to 7.6. Apart from the number of the test, the figures indicate the house in which the test was performed (e.g. M3 for house nr. 3), and the test room (e.g. ch1 for room nr. 1). As for the numbering of the rooms see fig. 7.2.

The figures of the tests represent on the abscissa the duration of the test in minutes and on the ordinate the difference in % with 100 % of the normal oxygen rate in the air (21% O_2) e.g. the ordinate 10 corresponds with 90% of 21% of O_2.

This rather indirect method has been chosen because of the fact that it allowed the analysis and directly putting on curves of the graphically read data. Mathematically it is possible to prove that if the tracer gas decrease curve (used in most of the methods), thus in our case nitrogen, is a straight line in a semi-logarithmic graph, the oxygen increase curve (which we measure) is, in this same type of graph, also a straight line. A fortiori, one can prove that the curve type used by us (difference in % with regard to 21%) must also yield a straight line in the semi-logarithmic system.

The straight lines drawn in the figures 7.3 to 7.6 have been determined by the method of the smallest squares, for the test time zone without incertitude (incertitude due to the graphic reading, at the end of the test, or at the start of the oxygen re-increase at the start of the test. The drawings indicate clearly the validity zone of the straight line (e.g. in fig. 7.4 the straight line is valid from t=0 to t=118).

If it is possible for most of the tests to retransform the experimental curve measured in one single straight line in the semi-logarithmic system, for some tests on the other hand, the inclination of the straight line changes during the tests, one arrives at different interpretations. For each of these cases, the different possibilities are represented in the drawing (e.g. fig. 7.3 and 7.5).

II.4. Air renewal rate (vol/h).

When the basis of the measuring system is a decrease of a tracer gas in time, the formula used for the calculation of the air renewal rate is the following :

$$n = \frac{1}{t - t_o} \ln \left(\frac{c_o - c_n}{c_t - c_n}\right) \qquad (1)$$

with n : air renewal rate (vol/h)

t_o : initial measuring instant considered

c_o : tracer gas volume concentration in the gaseous ambiance of the room studied

c_n : tracer gas volume concentration in the normal exterior atmospheric air

t : time considered for the test

c_t : tracer gas volume concentration in the gaseous ambiance of the room studied at the moment t.

Mathematically one can prove that this formula takes the following form for the case of our curve :

$$n = \frac{1}{t - t_o} \ln \left\{\frac{100 - x_o}{100 - x_t}\right\} \qquad (2)$$

for $100 - x_t = (100 - x_o)e^{-n\Delta t}$ (3)

with $\Delta t = t - t_o$ is the temporal variable

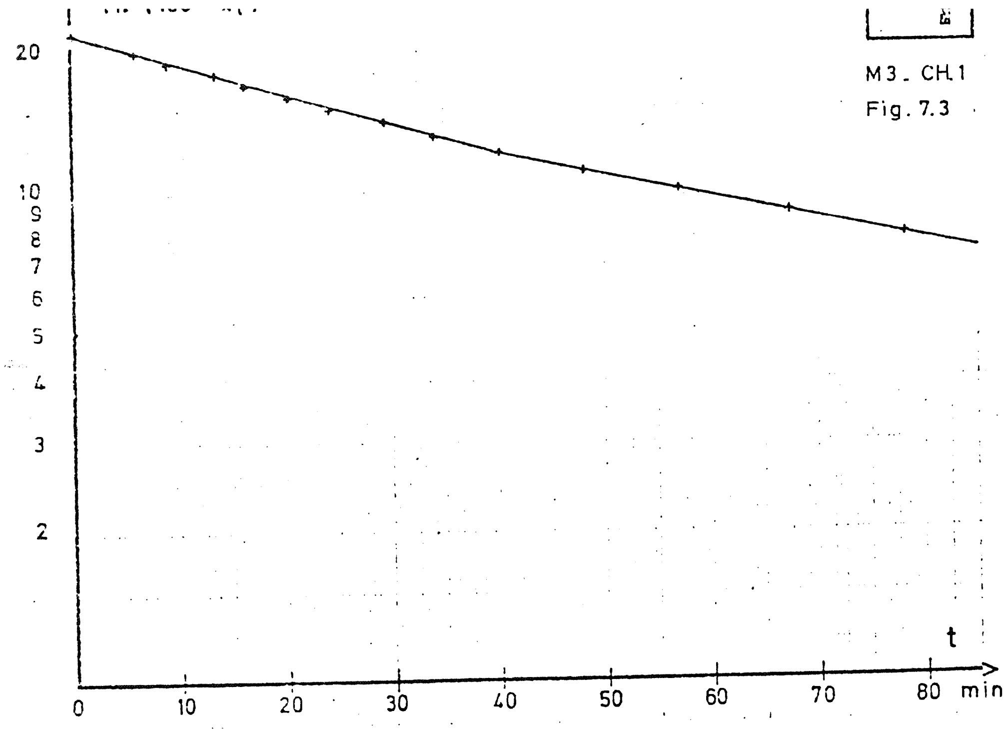
t and t_o : same significance as above

$(100 - x_o)$: start ordinate of the graph considered, corresponding with an oxygen concentration of $(100 - x_o)$% of 21%

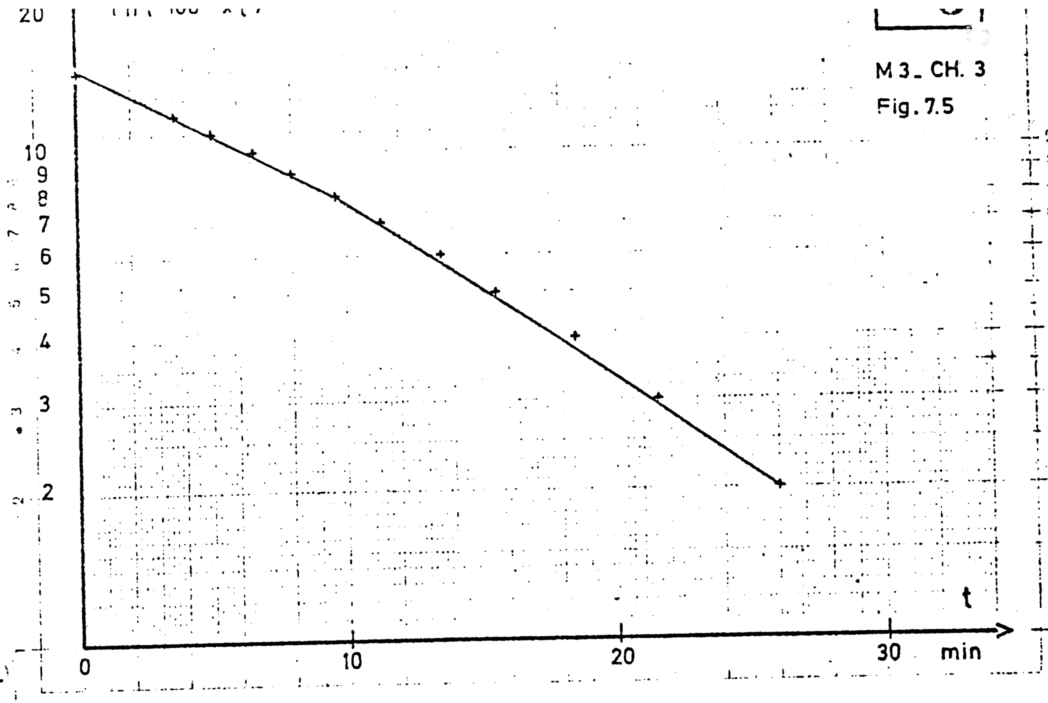
$(100 - x_t)$: ordinate at the moment t, corresponding with an oxygen concentration of $(100 - x_t)$% of 21%.

In the case in which it is possible, for a same test, to find several straight lines, these different renewal rates have been calculated.

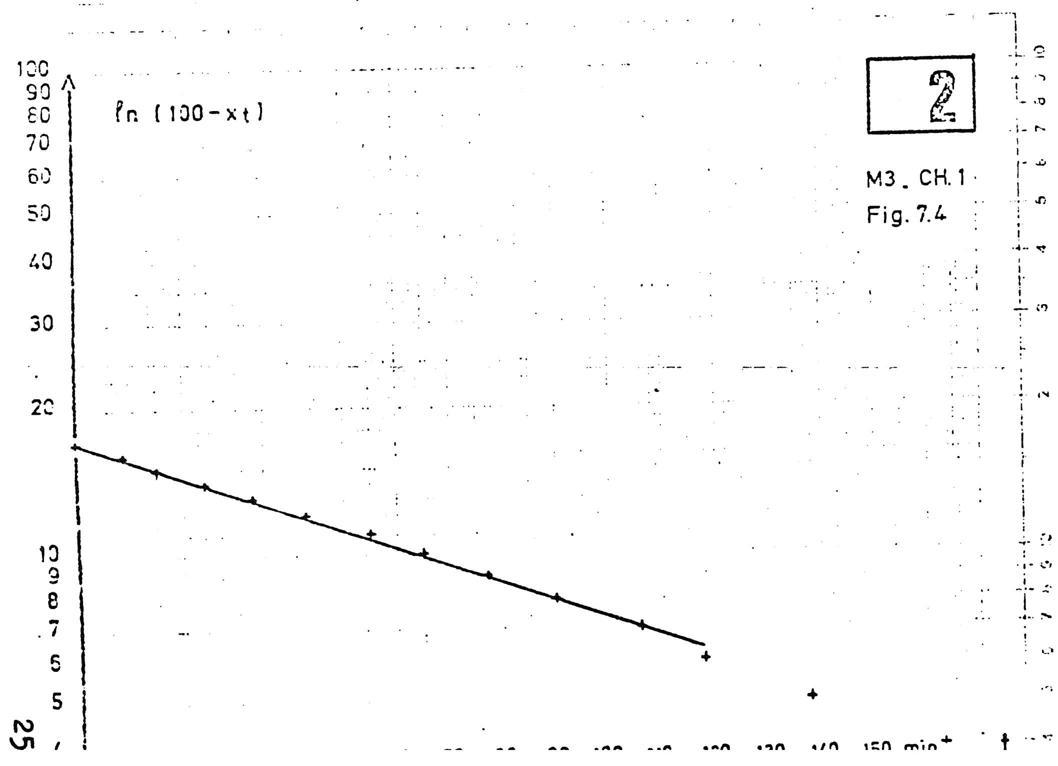
For each test, the results of these calculations are given in table 1



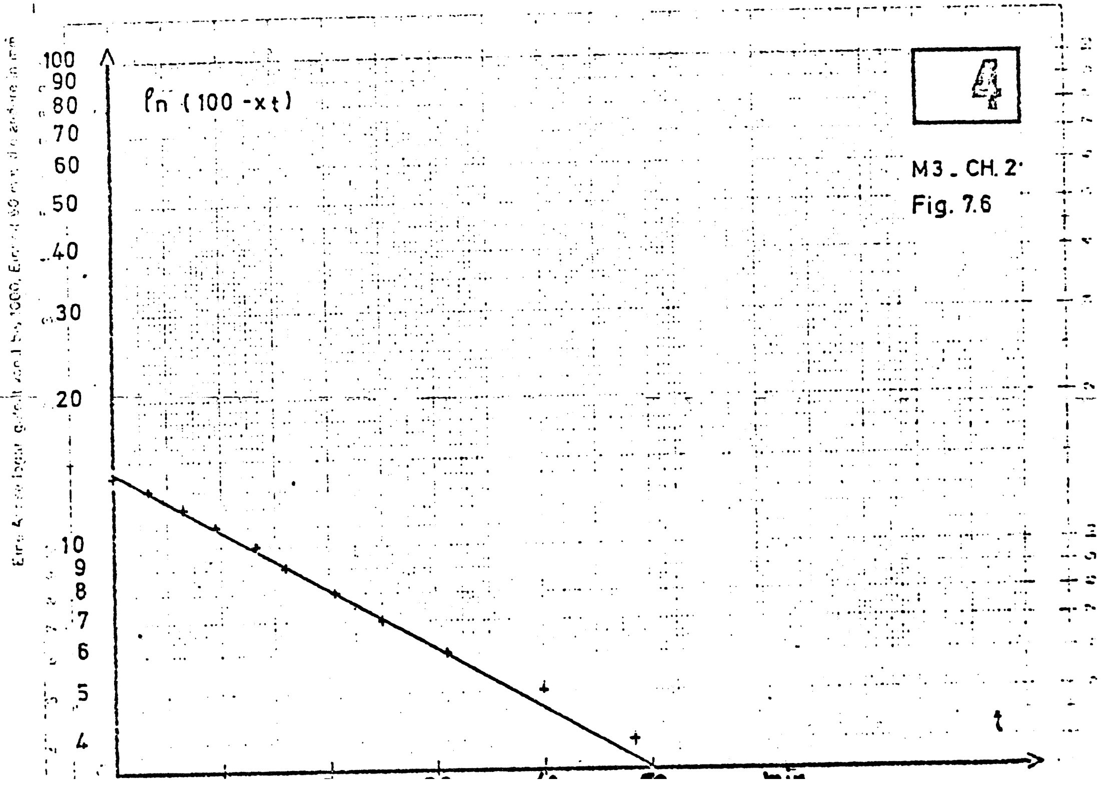
M3 _ CH.1
Fig. 7.3



M3 _ CH. 3
Fig. 7.5

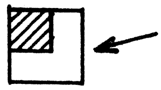
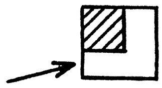
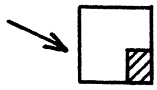
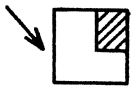
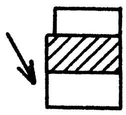
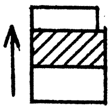
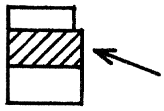
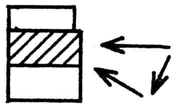
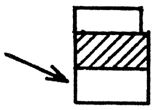
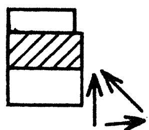
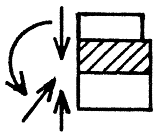


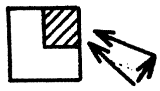
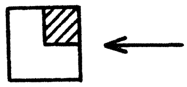
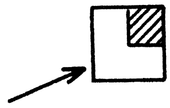
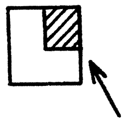
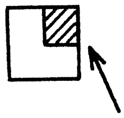
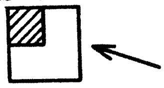
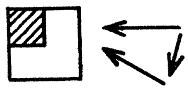
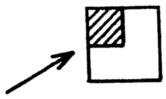
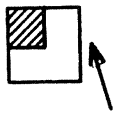
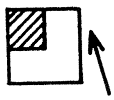
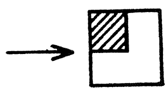
M3 _ CH.1
Fig. 7.4

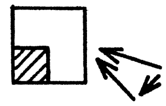
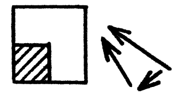
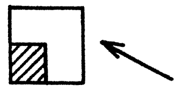
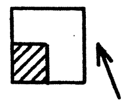
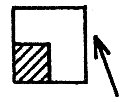
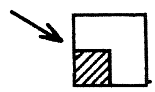
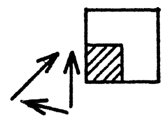
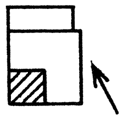
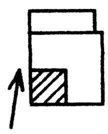


M3 _ CH. 2
Fig. 7.6

SYNTHETIC TABLE OF THE RESULTS - TABLE NR 1

test nr	house + room	wind Houdeng direction+velocity	renewal rate	r^2	relation wind orientation-room
1	M3 ch 1	2,90 m/sec SSW	{0,918 (0'-40') {0,632 (40'-80')	0,999 0,999	
2	M3 ch 1	1,99 m/sec NNE	0,498 (0'-106')	0,999	
3	M3 ch 3	5,05 m/sec E-ENE	{0,391 (0'-10') {0,526 (10'-26')	0,998 0,998	
4	M3 ch 2	3,85 m/sec E	1,645 (0'-32')	0,999	
5	M3 living	5,95 m/sec ESE	0,319 (0'-452')	0,999	
6	M7 living	2,20 m/sec NW	0,421 (0'-107,5')	0,999	
7	M7 living	3,86 m/sec WSW	0,762 (10'-108')	0,995	
8	M7 living	2,65 m/sec SW-W-NNW	0,532 (0'-115')	0,999	
9	M7 living	3,85 m/sec ENE	0,719 (0'-120')	0,999	
10	M7 living	2,21 m/sec NW-W	0,486 (0'-100')	0,994	
11	M7 living	1,83 m/sec SE-NNW-NW	0,364 (0'-110')	0,989	

12	M7 ch 1	7,18 m/sec W-WSW	1,152 (0'-59')	0,998	
13	M7 ch 1	2,42 m/sec SW	0,309 (0'-107,5')	0,999	
14	M7 ch 1	4,49 m/sec N	0,616 (0'-120')	0,999	
15	M7 ch 1	3,29 m/sec WNW	0,603 (0'-140')	0,999	
16	M7 ch 1	4,86 m/sec WNW 4,03 m/sec 4,03 m/sec (?)	0,886 (0'-80') 0,579 (80'-130') 0,870 (140'-160')	0,995 0,996 0,999	
17	M7 ch 2	4,86 m/sec WSW	1,810 (0'-56')	1,000	
18	M7 ch 2	1,25 m/sec SW-WSW	1,031 (0'-34')	0,999	
19	M7 ch 2	3,31 m/sec N	0,634 (0'-90')	0,998	
20	M7 ch 2	2,73 m/sec WNW	0,914 (0'-113')	1,000	
21	M7 ch 2	6,39 m/sec WNW 6,39 m/sec	0,478 (0'-40') 0,690 (40'-80')	0,998 0,998	
22	M7 ch 2	1,95 m/sec NE	0,429 (0'-100')	0,983	

23	M7	ch 3	5,55 m/sec	WSW-W	3,756 (0'-32,5')	0,999	
24	M7	ch 3	1,1 à 1,5 m/sec	WNW-WSW	2,294 (0'-47')	0,997	
25	M7	ch 3	2,10 m/sec	WSW	1,634 (0'-29')	0,996	
26	M7	ch 3	4,05 m/sec	WNW	{2,190 (0'-47') {2,290 (16,5'-47')	0,999 0,999	
27	M7	ch 3	3,02 m/sec	WNW	2,060 (0'-50')	0,998	
28	M7	ch 3	4,70 à 5,95 m/sec	ENE	{3,310 (0'-7,5') {2,300 (7,5'-28') {2,860 (28'-47')	0,997 0,997 0,998	
29	M7	ch 3	2,08 m/sec	NW-NNW	0,862 (10'-100') (air tightening of the room prior to the test)	0,988	
30	M7	cuisine	3,71 m/sec	WNW	1,200 (0'-53,5')	1,000	
31	M7	cuisine	2,08 m/sec	NNW	1,107 (0'-48')	0,995	

II.5. Meteorological data.

The meteorological data required for the analysis of the infiltrations come, for the wind velocity and direction, from the nearest meteorological station, in the case of Seneffe, from Houdeng at ± 10 km flight distance.

These tables indicate by groups of 2 hours, the mean value of the wind direction and velocity.

It is to be noted that this direction and velocity are measured at an altitude of 10 m above the ground.

The data derived from these tables of importance for the tests are given in the synthetic table nr. 1 on pages 7, 8, 9.

However, two problems should be mentioned which are inherent to this type of rather far away measurements :

1) the reproductability of the climate of Houdeng at 10 m above ground level with the micro-climate around the houses in Seneffe;

2) the duration of a test being of the order of 2 hours or even less, a mean wind direction and velocity from 2 hours allows only an approximative analysis and cannot provide an answer to for instance phenomena resulting from meteorological situations changing during the tests.

II.6. Synthesis of the test results.

Table 1 of the present part indicates the results of the different tests performed on the houses 3 and 7 in Seneffe.

It indicates :
- in the 1rst column, the test number
- in the 2nd column, the house and room examined
- in the 3rd column, the wind velocity and direction resulting from the data of the meteorological station of Houdeng
- in the 4th column, the calculated renewal rate(s) calculated for the test concerned and the duration of the test considered for the calculation of this rate
- in the 5th column, the coefficient of the determination of the straight line serving as a basis for the renewal rate calculation
- in the 6th column, the wind direction in relation with the position of the room in the house.

It is interesting to note the very good correlation between the measuring points and the measuring straight line (r^2), which proves that the test method is certainly valid for a study of the air infiltration in a room. The formula announced by the theory thus is perfectly approved by the experimental measurements.

Fig. 7.7 represents this synthesis of the results for house nr. 7 in a different form. It in effect gives the air renewal rate of the different rooms in function of the wind velocity measured in Houdeng at the moment of the test.

The points of this figure which are connected represent the different renewal rates which can be deducted, for a same test, from the experimental curve.

On the graph also the mean value of the measuring points are represented for each room. The values are :

$\overline{\text{living}}$: 0,547

$\overline{\text{room 1}}$: 0,716

$\overline{\text{room 2}}$: 0,855

$\overline{\text{room 3}}$: 2,52 (without the value of the test with tightening)

$\overline{\text{kitchen}}$: 1,15

II.7. Influence of the wind velocity.

The air infiltration of a room is a function of the wind velocity and wind direction. It thus is logical to find in a graph of the type "n - speed" a cloud of dots for each room examined and groups of dots for each direction and each room.
After the analysis of the results, this cloud is only seen for room 2, for certain directions.
For the other rooms, the measurement points seem to regroup around a single straight line. This phenomenon can be explained for cases such as the living-room, debouching with identical openings on two opposed walls and thus practically independent from the wind direction.

For each of the rooms, the straight line has been calculated by the method of the smallest squares and its characteristics are given in table 2
{ for $y = ax^b$ or $\ln y = \ln a + b \ln x$ with y - renewal rate $\overline{n}$
x - wind velocity }

TABLE NR 2

	a	b	r^2
Living	0,214	0,923	0,970
Chambre 1	0,133	0,140	0,817
Chambre 3			
-without test 24	1,053	0,596	0,605
-with test 24	1,864	0,230	0,308
Chambre 2			
-N-NE	0,262	0,738	2 measurements
-SW-WSW	0,940	0,414	2 measurements
Cuisine	1,000	0,139	2 measurements

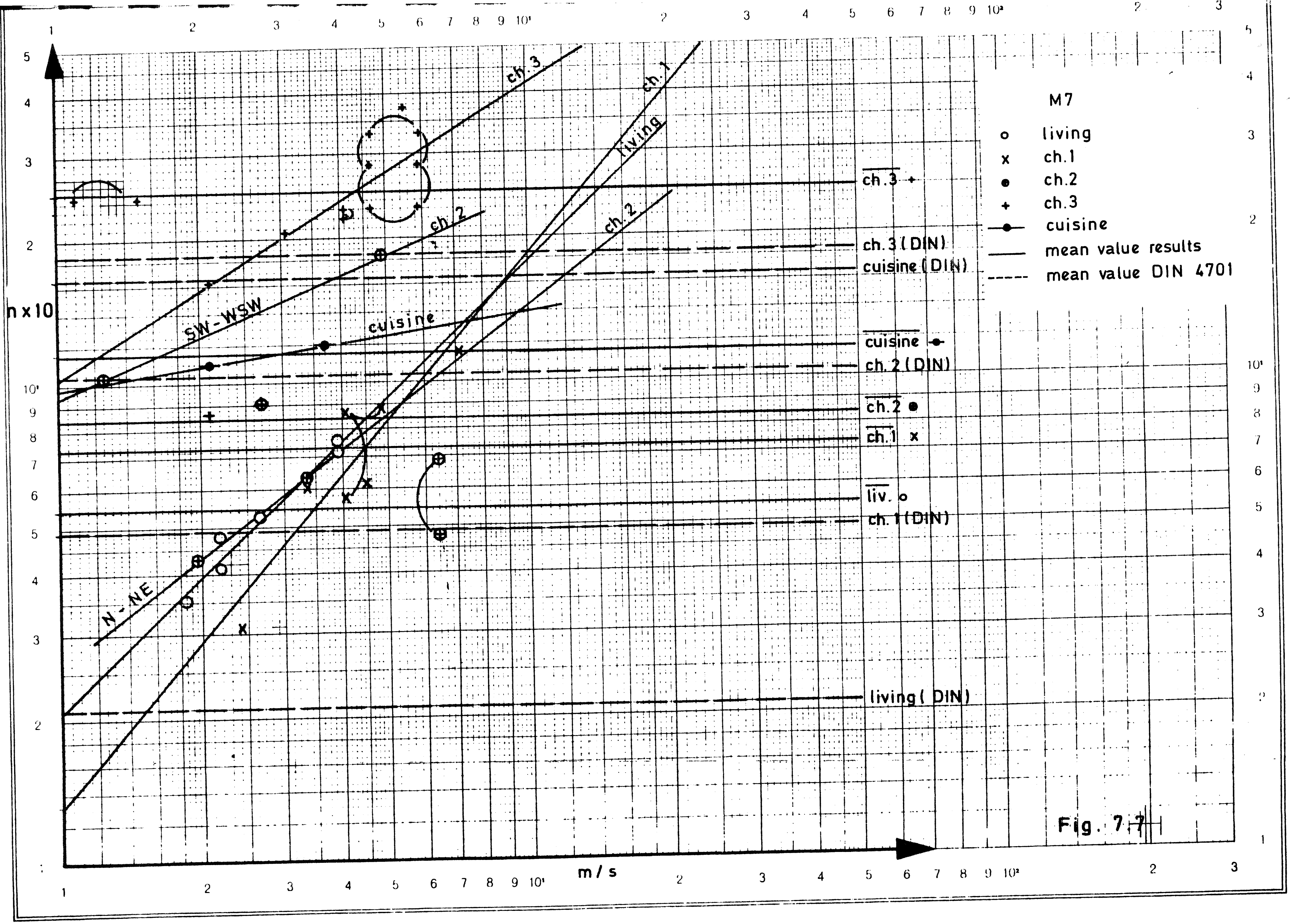

M7
living
ch.1
ch.2
ch.3
cuisine
mean value results
mean value DIN 4701
n x10
m/s
ch.3
ch.1
living
ch.2
SW-WSW
cuisine
N-NE
ch.3 +
ch.3 (DIN)
cuisine (DIN)
cuisine
ch.2 (DIN)
ch.2
ch.1 x
liv. o
ch.1 (DIN)
living (DIN)

Fig. 7.7

For room 2 and lacking more data, 2 straight lines have been drawn in fig. 7.7 :

- one for the 2 tests with N and NE wind (room under wind)
- one for the 2 tests with SW and WSW (room out of wind)

The two tests with WNW wind cannot be connected with any system.

It is probable that more precise meteorological data (e.g. very variable wind) could have helped explain these phenomena.

For the kitchen only 2 measurements are available, and 1 straight line have been drawn.

II.8. Infiltration and qualities of the frames.

For a building under the influence of a wind with a velocity v, the rate going trough this building is exressed by :

$$q = C.v^{4/3} = n.V$$

with n : renewal rate calculable by this method

V : volume of the building.

A function of the same type can also be found for one single room :

$$q_{room} = C_1 \;.\; v^{4/3} = n_1 \;.\; V_1$$

With C_1 : constant for the room in function of its characteristics

n_1 : renewal rate of the room

V_1 : volume of the room

or in a logarithmic diagram $\ln n_1 = \ln \frac{C_1}{V_1} + 4/3 \ln V.$

This relation also gives a straight line of the type $\ln y = \ln a + b \ln x$ as the one sought in the preceeding diagram.

The values of the factors "b" are to be compared with the value 4/3 :

0,923 for the living-room
1,140 for room 1
0,596 for room 3

However it must be precised that the formula $\ln n_1 = \ln \frac{C_1}{V_1} + 4/3 \ln V$ is valid for wind perpendicular on the exterior wall of the room and that the straight lines of fig. 7.7 on the other hand are mean straigth lines derived from tests with different wind directions.

II.9. Method of the DIN 4701 for the estimation of the ventilation losses.

In the German standard DIN 4701 (edition 1959) which is generally used, the ventilation losses of a room are expressed by the following formula :

$$q = \Sigma\ (al)_v\ R\ H\ M_c\ \Delta t$$

with q : rate in kcal/h

a : hourly air rate per meter joint for 1 kg/m^2 pressure difference between the two faces of the joint (corresponding with a wind with a velocity of 4 m/sec)

l : length of the opening parts of exterior windows and doors submitted to the action of the wind

R : a characteristic quantity of the room in function of the relation between the surfaces of the windows and the surfaces of the interior doors

H : a characteristic quantity of the building (exposition)

M_c : a majoration factor for the angle windows

Δt : difference between interior and exterior temperature.

This value q equals also : $n \times V \times \Delta t \times c_p$

with n : renewal rate

V : volume of the room

Δt : same temperature difference

c_p : volumetric warmth of the air (= 0,31 kcal/°C m^3).

It is thus possible to derive from the preceeding formulas an air renewal rate n_{DIN}. These values are indicated, for each room, on figure 7.7.

Table 3 indicates these values as well as the data, thus allowing the calculation.

The comparison between the air renewal rates calculated according to DIN and the mean values obtained from the tests, shows a rather good correspondence for the room with one single exterior door or window.
For the living-room on the other hand (2 openings in the 2 opposed walls) these values differ sensibly.

Instead of considering the mean values of the measuring points, it is also possible to start fromthe straight line passing through the measuring points and defined in § II.7 and to define the intersection point with the value calculated from DIN 4701, which in theory should be 4 m/s.

TABLE NR 3

room		a	l	Σ(al) v	$\frac{SF}{SP}$	R	H	Σ(al)$_v$ x H.R	nV	V	n
living	2 opening frames	3	4,6	13,8	4,07	0,7	0,41	3,96	12,77	61	0,21
cuisine	1 frame +1 door	3	3,8+6,0	29,4	0,81	0,9	0,41	10,85	35,00	21	1,67
hall	1 door	3	6,6	19,8	0,38	0,9	0,41	7,31	23,58	27	0,87
W.C.	1 frame	3	2,7	8,1	0,26	0,9	0,41	2,99	9,65	3,3	2,92
ch 1	1 frame	3	4,7	14,1	0,77	0,9	0,41	5,20	16,77	34	0,49
ch 2	1 frame	3	7,8	23,4	1,53	0,9	0,41	8,63	27,84	27	1,03
ch 3	1 frame	3	7,8	23,4	1,53	0,9	0,41	8,63	27,84	15	1,86
S de B	2 frames	3	5,6	16,8	0,58	0,9	0,41	6,20	20,00	10	2,00

Remarks : 1) the value of a = 3 corresponds with the generally admitted value for single wooden frames

2) the value of H = 0,41 is the value corresponding with a region of normal winds and non protected terrace houses

3) M_c = 1 for all cases (no angle window).

This comparison shows the following values :

for the living-room : $\pm$ 1 m/s
room 1 : $\pm$ 3,2 m/s

room 3 : 3,8 m/s

This proves again a good correspondance between the DIN calculations and the measurements, except for the living-room.

Starting from the wind velocity of 4 m/s and n-values derived for this velocity either from the calculated straight lines, or from the mean values for each room, it is possible, with the preceeding formulas, to recalculate the a-value of the frame of a room. Table 4 gives these a-values, calculated from these data and with the formula

$$\left\{ a = \frac{n.V.0,31}{RH.1} \right\}$$

TABLE NR 4

room	n for 4 m/s following the straight line	a	n for 4 m/s mean value	a
living	0,770	11,03	0,547	7,84
ch 1	0,640	3,89	0,716	4,35
ch 3	2,400	3,88	2,52	4,07

This table seems to indicate that for the rooms 1 and 3 the quality of the frame seems rather identical.

II.10. Global air renewal rate of the house.

Starting from the results obtained for each room idependtly, it is possible to determine approximatively the global air renewal rate of the whole house. This can be done by supposing, for a particular meteorological condition, that the complete air volume, coming in through the openings of the rooms giving out on a front wall, is redistributed in the dwelling, either in the rooms giving out on the opposite wall, or directly outside through the openings in this front wall (in the case of rooms having openings in the two opposite walls).

The global air renewal rate of the house is then obtained with the formula :

$$n_{global} = \frac{\Sigma\, n_i\, V_i}{V_{total}}$$

with n_i : air renewal rate of the room giving out on a given wall

V_i : volume of this room

V_{total} : total volume of the house.

In the case of the tests in Seneffe this calculation was made with the rooms giving out on the backwall of the house and for climatological situations similar to those obtained during the tests of the ULg, in order to be able to compare the two results, i.e. for a wind with a N direction, speed of 2 m/s.

Based on fig. 7.7 one can deduct the values given in table 5.

TABLE NR 5

	n	V(m³)	ΣnV	
living	0,40	61	24,40	
cuisine	1,08	21	22,68	
ch 2	0,44	27	11,88	
ch 3	1,55	15	23,25	
			82,21	V_{tot} = 198,30

The calculation of the global rate results in (for a wind of 2 m/s)

$$n_{global} = 0{,}41 \text{ Vol/h.}$$

II.11. Conclusions.

From the tests with this method the following conclusions can be drawn :

- The measuring method in itself is very valid for a unique room, in as far as sufficient number of tests is performed in order to cover the wind directions and each direction with very different velocities. If possible, days with a variable wind or a too weak wind should be avoided.

- The measurements must be performed with a very good knowledge of the local micro-climate and in particular of the wind direction and velocity at the height of the room measured. The frequency of the mean values of the wind velocities and directions of the meteorological stations (2 h) is insufficient. It should therefore be useful to measure at the same time the pressures reigning outside the building on the walls and in the different rooms.

Analysis.

Lacking more tests, allowing a more rigorous analysis, it seems equitable to signal the following facts :

- In a diagram of the type "ln n - ln vit" the experimental data for a room seem to regroup around one or more straight lines. More tests probably would have allowed a better and more precize analysis. The inclination of these straight lines seems to join the theory of the power 4/3 of the wind velocity.

- The DIN 4701 calculation method for the ventilation rate of the rooms seems to indicate a good quantity order for the rooms having one single opening to the outside. It does not at all correspond for the case of rooms with openings in two opposed walls (e.g. living in our case).

Values.

- The quality of the frames of Seneffe seems slightly inferior to generally admitted values (e.g. for the rooms a = $\pm$ 4).

- The tests show the large dispersion between the different rooms : extreme values of n = 0,3 and n = 3,8, on a factor 10.

Chapter III - Global tightness tests.

III.1. Introduction.

Considering the purge of an initially contaminated room, the decrease of the contaminant concentration varies in time following a law depending on the air renewal rate and on the contaminant concentration of this new air. In the particular case where this concentration is zero, the concentration in the room obeys an exponential law :

$$C = Co\ e^{-nt}$$

The good regressions found in the CSTC-tests, room by room, confirm this law.
On the other hand, when the air renewal is equally contaminated, the law is more complicated and the concentration in the room examined depends on the history of the contamination.

In practice, in a dwelling, certain rooms are ventilated by the exterior air, others by the air coming from neighbouring rooms.

From the energetical point of view, only the outside air rate has any interest. This is why it was decided to perform tests with contamination of the entire house.

III.2. Measurement of the air renewal.

Measurement method.

The measurement is performed by contamination with a tracer gas (N_2O) and analysis of the contaminant concentration decrease in the course of time.

Gas is injected during some ten minutes in the staircase which is strongly mixed by a ventilator; all interior doors are open and in each room ventilators assure the distribution of the contaminant.

When the injection is terminated, the interior doors are closed, after having regulated the ventilators on their minimum speed. In fact, the measurements are made in an "isothermic" regime, and it is necessary to mechanically create an air mixing similar to the one brought on by a heating source. Tests at the University of Liège have shown that this source always realized a perfect mixing in the room (*).

Measuring equipment.

The measuring equipment comprises : a gas analyser with selective absorption in the infra-red, an automatic channel selector allowing the sequential measurement of all the rooms (one measurement in 30 seconds, a same room measured every 6 minutes), a digital voltmeter and a printing device.

The measuring principle is the following :
the measuring cell is devided in two identical parts containing N_2O. The two parts receive an infra-red radiation which previously has respectively gone through a reference cell without N_2O and an analysis cell through which the gas to be analysed has gone. The gas to be analysed absorbes a part of the radiation proportional to the N_2O rate and there results a different heating in the two measuring cells. The temperature difference results in a pressure difference between the two cells which, converted in electrical quantity, delivers the measuring signal.

The measuring field is from 0 to 1 % of N_2O, the signal at the bottom of the scale is 20 mV and the response time is about 30 seconds. The gas rate traveling in the analysis cell is 2 l/min.

In order to eliminate dead time due to the emptying of the conduits relying the measuring points to the measuring apparatus, in all points a continuous outtake (1 l/min) is effected with a pump in all points. At the moment of the measurement, the valve corresponding with the point considered rocks and the air to be analysed, aspirated by the measuring pump, circulates in the analyser. By this procedure, the response time is essentially reigned by the time constant of the analyser, the conduit length between the analyser and the electrovalves being reduced to the minimum.

III 3. Test results

The tests were performed during the first week of August 1976, in house M7.

Six global contamination tests were performed.
The measuring results are given in the semi-logarithmic diagrams fig 7.8 tot fig. 7.17.

On the abscissa one finds the time in minutes and on the ordinate the contaminant concentration in the rooms considered.

During the test campaign the climate type has remained relatively stable; the wind, measured at the top of the house, had a speed of the order of 2m/s and an orientation close to North.

One finds an example of a diagram indicated the mean velocity and orientation calculated with 5 minutes intervals (fig. 7.18 and 7.19).

(*) IC-IB-research Aeraulic circuits - IRSIA-convention nr 2260.

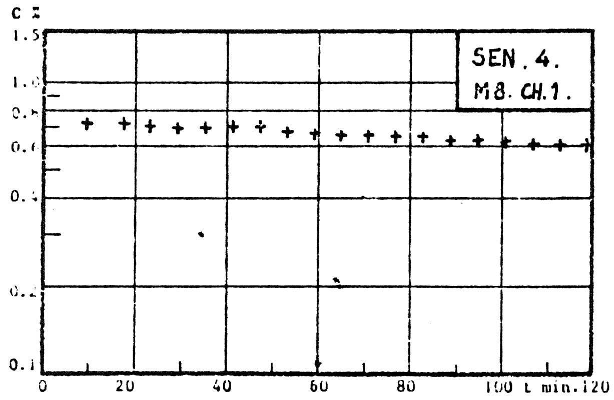


Fig. 7.8

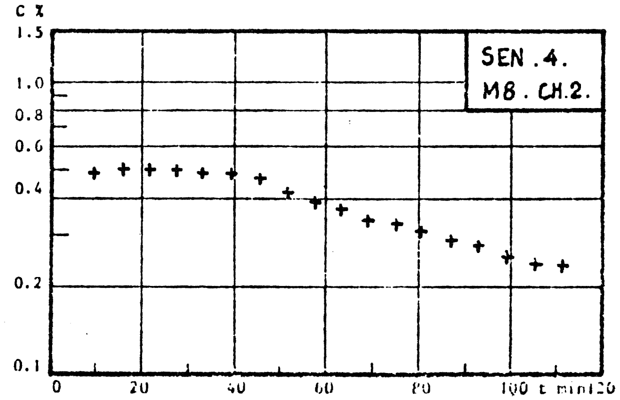


Fig. 7.9

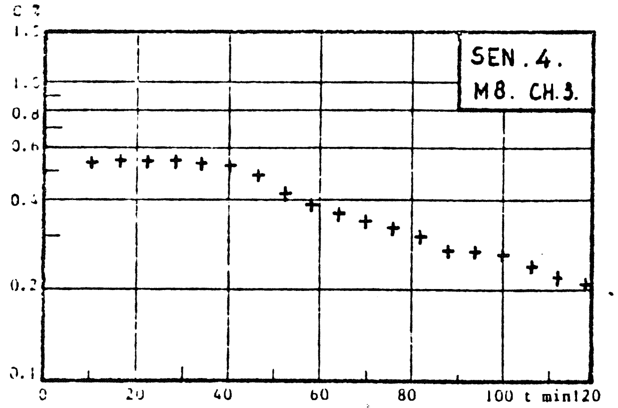


Fig. 7.10

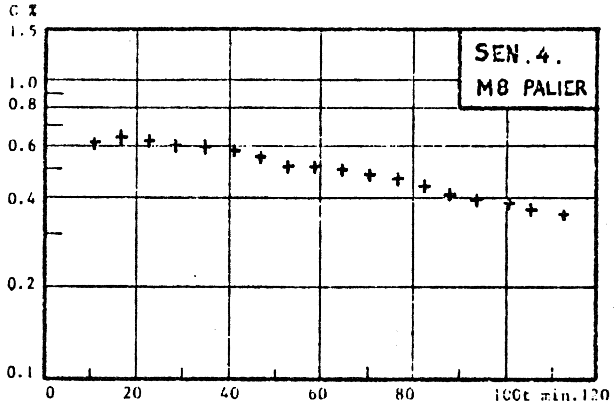


Fig. 7.11

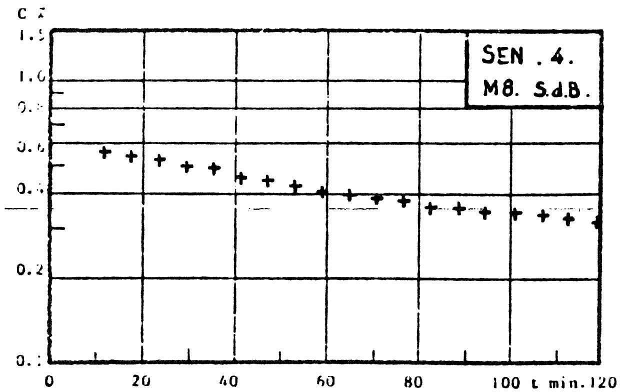


Fig. 7.12

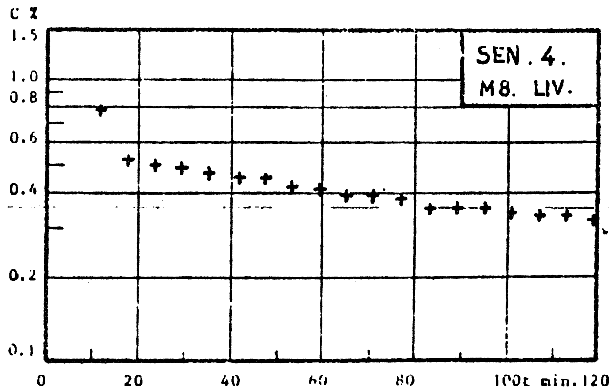


Fig. 7.13

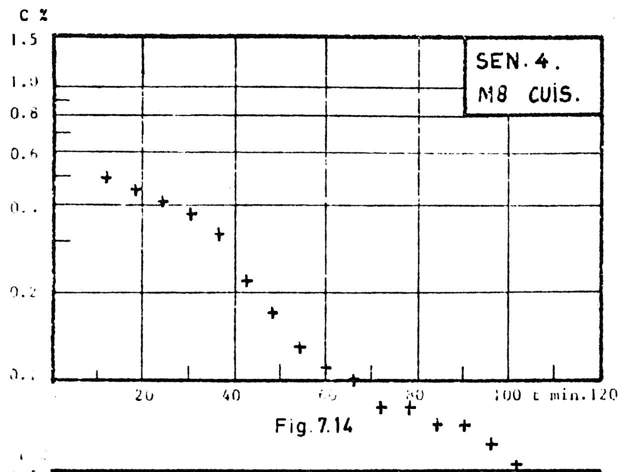


Fig. 7.14

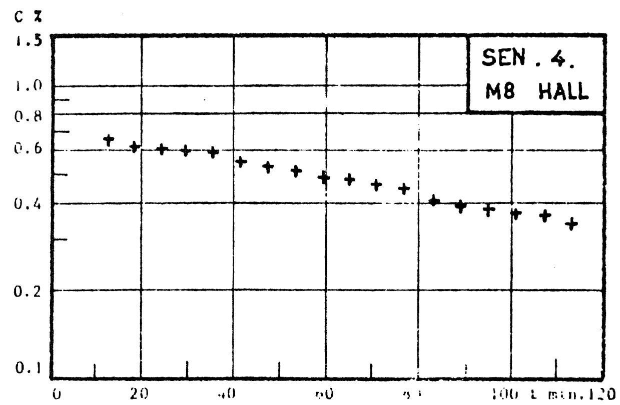


Fig. 7.15

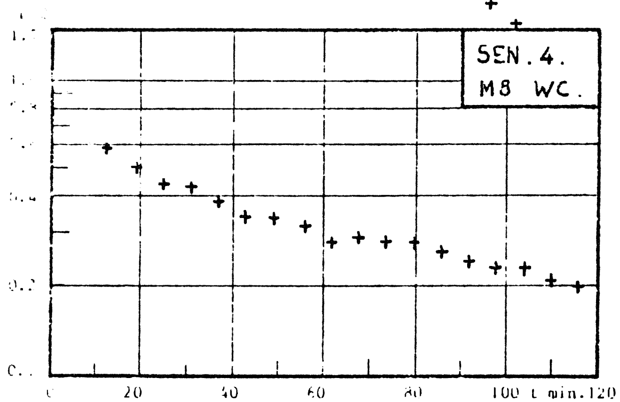


Fig. 7.16

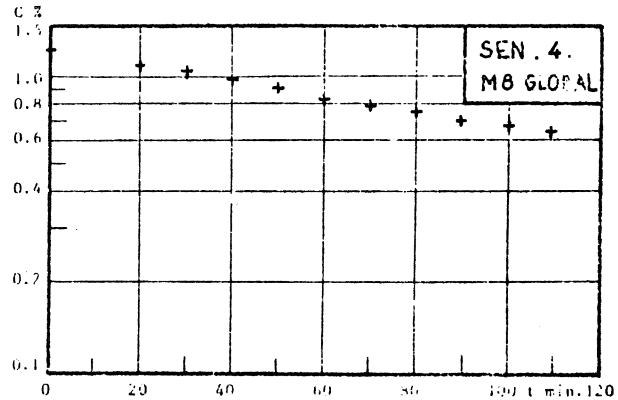


Fig. 7.17

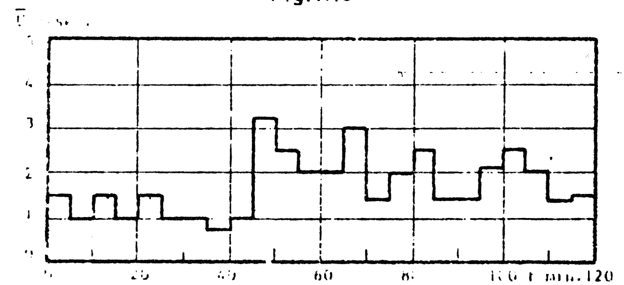


Fig. 7.18

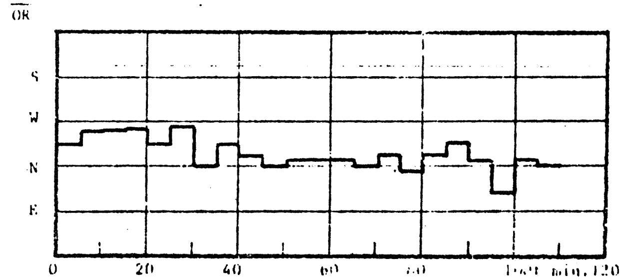


Fig. 7.19.

TABLE NR 6 - Air renewal rate in vol/h.

Test \ Room		SW Chambre 1	NE Chambre 2	NE Chambre 3	Pallier	SW S.de bain	SW - NE Living	NE Cuisine	SW Hall	SW W.C.
SEN 1	n	0,12	0,52	0,61			0,72	0,81	0,57	
	r	.9870	.9959	.9984			.9987	.9990	.9982	
SEN 2	n	0,22	0,57	0,77	0,70	(0,33)	0,90	1,04	0,79	1,59
	r	.9910	.9896	.9922	.9968	.8857	.9950	.9909	.9968	.9979
SEN 3	n	0,14	0,51	0,59	0,42	0,32	0,55	1,5	0,56	1,19
	r	.9852	.9921	.9924	.9943	.9954	.9974	.9916	.9912	.9974
SEN 4	n	0,10	0,50	0,59	0,36	0,31	0,31	1,98	0,39	0,56
	r	.9958	.9747	.9842	.9883	.9904	.9871	.9858	.9948	.9760
SEN 5	n	0,28	0,14	0,26	0,25	0,28	0,28	0,66	0,50	0,48
	r	.9943	.9689	0,9484	0,9614	.9917	.9917	.9609	.9929	.9923
SEN 6	n	0,10	0,49	0,74	0,43	0,40	0,60	1,70	0,46	0,54
	r	.9604	.9836	.9923	.9941	.9923	.9961	.9880	.9931	.9585
Mean-value	n σ	0,16 ± 0,07	0,46 ± 0,16	0,60 ± 0,18	0,43 ± 0,17	0,33 ± 0,04	0,56 ± 0,24	1,28 ± 0,53	0,55 ± 0,14	0,87 ± 0,49

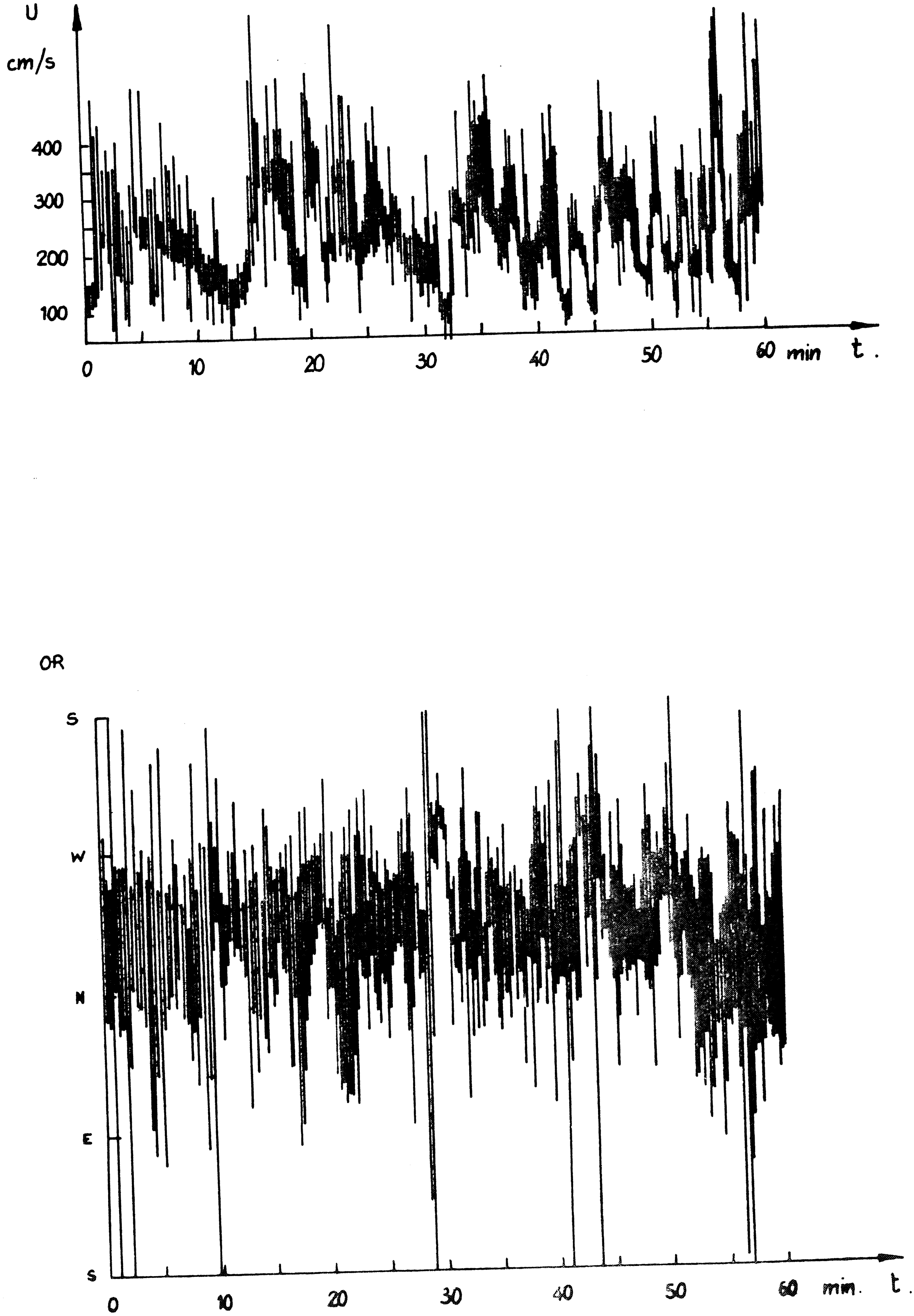

U
cm/s
400
300
200
100
0
10
20
30
40
50
60 min
t .
OR
S
W
N
E
S
0
10
20
30
40
50
60
min.
t .

Fig. 7.20

The mean values are obtained from essentially fluctuating quantities (fig. 7.20.) measured on the roof of the house.

The air renewal rate of each room can be calculated supposing the system of the first order (e^{-nt}), i.e. as if the purge were exclusively made in relation with the exterior fresh air.
Table 6 gives the results obtained and the corresponding correlation coefficients.

Starting from these concentrations Ci (t) measured in each room with a volume V_i one can determine a fictive global concentration C_T calculated from 10 in 10 minutes

$$C_T = \frac{\Sigma \, (Ci \, (t) \times V_i)}{\Sigma \, V_i}$$

which comes down to deviding by the total volume of the house the total quantity of the contaminant present at the time t.

The decrease of this concentration gives a <u>global renewal</u> n_T given in table 7 and in the diagram : fig. 7.17 .

<u>TABLE NR 7</u> - <u>Global air renewal in vol/h.</u>

	SEN 1	SEN 2	SEN 3	SEN 4	SEN 5	SEN 6	
n_T	0,51	0,68	0,46	0,36	0,32	0,50	vol/h
r	.9990	.9969	.9985	.9960	.9814	.9901	

III.4. Analysis of the results.

Renewal in each room.

It should be rembered that the rates obtained are not representative for the exterior air volume entering in the room (because of internal exchanges), but of the quality of the ventilation in the room considered.
The small values obtained for the correlation coefficients spring either from climatic variations, or from internal exchanges.

It is not possible to dissociate the two phenomena because of wind orientation fluctuations.

The exceptional air renewal rates of room 1 (0,16) and of the kitchen (1,28) should be noted compared with the rates of the other rooms which are of the order of 0,5.

For room 1 there is no evident reason to explain this bad ventilation. Tests performed by the CSTC in other houses have not shown a similar discordance for room 1.
One therefore must suppose either that the tightness characteristics of the frames can vary widely in a same serie, or that the placing of the frames is of the utmost importance.

As for the kitchen, the high ventilation rate can be explained by the presence of an outside door and a cellar door.

Global renewal.

It is not possible to correlate the global renewal with the mean wind velocity. This is no doubt due to the fact that the climatic conditions were very variable, in amplitude and in orientation during a same test. During the test campaign characterized by a weak wind velocity of the order of 2 m/s, the house tested presented an air renewal rate of the order of (0,47 $\pm$ 0,13) vol/h.

One ascertains that the law of the global fictive concentration very well verifies the exponential law, which confirms the validity of the experimental method used.

Chapter IV - General conclusions.

IV.1. Discussion of the results.

From the results obtained from two measuring campaigns in Seneffe, the following conclusions can be drawn :

- The global air renewal rate of the houses in Seneffe seems to be of the order of 0,5 V/h for a wind velocity of the order of 2 m/s. The tests do not allow extrapolations for other velocities, because of the great uniformity of the weather type in Seneffe during the test campaign of the U.Lg.

- On the level of the rooms properly speaking, the results show a very large dispersion of the results for the two campaigns. The values obtained are nevertheless only partially comparable, because the tests have been performed on two different houses (M7 - CSTC, M8 - U.Lg) and because the methodology does not allow an easy liaison between the two types of tests (see § 2 of the present chapter).

- Nevertheless the method difference alone does not by itself explain the differences existing between the renewal rates obtained for the same rooms in the two houses studied, which means that the air renewal rate of a room is a non transposable result, even in the case of series of houses, however supposed identical. The reason probably is the placing of the frame and interior doors.

IV.2. Discussion of the methods.

The two measuring methods used are rather similar.
The practical application in situ does not provoke major problems, neithe from the point of view of the application, nor from the point of view of the analysis.
Nevertheless the field of application of the two methods seems very distinct, in view of the before-mentioned tests.

In fact, when one analyses the infiltrations of a house, one is faced wit the following problems :

Under the influence of a wind with a certain direction and velocity, or thus a pressure difference between opposed walls, one supposes a certain rate entering the house through a wall and identical to the rate leaving principally through the opposed wall.

With this same principle it is unfortunately not possible to determine precisely the air renewal rate of one single room, the decontamination of which can be influenced by the decontamination of other rooms discharging in this room studied and this depending on the pressures creating inside the building and thus on the pressure losses of the interior doors.

To resolve the problem on room level, one must dispose of a method using a room per room contamination, as the one used by the CSTC and which gives for a given wind velocity and direction, an air renewal rate per room.

If the CSTC-method thus is essentially valid on room level, it provides a good estimation of the tightness of the frames of the room considered. In this case it would especially be applicable for testing in situ of the quality of the latter and equally very useful for dimensioning the heating capacity to be installed for each room. On the condition of having sufficient points per room for each wind direction and different velocities per direction, it must be easily possible to determine the maximum obtained for 4 m/s.

On the contrary it is very difficult to extrapolate the results (for isolated rooms) for the entire dwelling, because of the complexity of the exchanges among rooms of a same level and maybe even among levels. The U.Lg-method gives in this case very good results, which, when they are also obtained for different wind orientations and velocities, should provide a useful notion for the calculation of the ventilation losses of the entire dwelling.

IV.3. Development.

Within the framework of this research and its results, it is possible to define some precise points requiring to be elucidated.

1) Micro-climate.

From the point of view of the micro-climate, the reproductiveness of measurements made at 10 m above the ground in relation with the wind which really touches the wall and the pressures and depressures created by this phenomenon, is the first problem to be studied in order to arrive at an exact determination of the precise measures to be taken on the level of the house during tests of this kind.

2) Modelisation.

Knowing the results of the two methods for a same house, it must be possible to make its liaison, on the level of the results (in as far as the same wind directions and velocities are found) by way of an analogous model. This equally requires a better knowledge of the internal exchanges and thus especially of the characteristics of the interior doors.

3) Real occupation.

All tests were performed with all the interior and exterior doors normally closed. It is evident that this is not the case for a real occupation of the house and that the air renewal will be affected by this. The test results should be considered as minima.