(12)

#550

AIC Translation No 12

"Natural ventilation of single family houses"

Translated from the original French
"Ventilation naturelle des maisons individuelles"
CSTC Revue, March 1980, No.1, p4-16

1.

P. Nusgens (1)
M. Guillaume (2)

NATURAL VENTILATION OF INDIVIDUAL HOUSES

To reduce energy requirements for the heating of buildings we have considerably improved thermal insulation of the 'skin' of new buildings.

Consequently ventilation, which is required for the survival of all human beings within a building, is contributing to energy consumptions to an ever increasing degree.

It is therefore essential to know in detail, and to be able to predetermine clearly, the ventilation phenomena.

For this purpose a summary is given in this text of the most important results of three series of measurements in individual dwellings, for the most part those of the "social" type.

These three measurement series illustrate the different stages passed through in arriving at an understanding of the phenomenon.

However, a great deal of work remains to be done, more especially with regard to the correlation between the measurements of the airtightness of the different elements of a dwelling, and the measurements,carried out with a tracer gas, of air renewal rates.

1. GENERAL

1.1 Introduction

Human beings cannot live inside a building without a minimum supply of fresh air within it.

However, in view of the energy crisis which has been with us since 1973, thermal insulation of the outer skin of buildings is becoming increasingly common, and whilst energy requirements for heating these buildings are constantly falling, it is noticeable that those required for ventilation are rising steadily.

Thus it will soon be considered necessary to have a more detailed knowledge of the phenomenon of "building ventilation" in order to reduce the requirements or at least to predetermine them more accurately.

It is with this in mind that we have launched ourselves into several series of in situ measurements, the three reported on here clearly illustrating the course we have followed in attempting to understand the phenomena observed.

1.2. Laws of variation of tracer gas content in premises after injection.

1.21 Symbols

The principal symbols used in this study are given here:

q : quantity of tracer gas injected into a dwelling (m3)

r_i (r_1, r_2): rate of air renewal in premises i

t: time (h)

---

(1) Civil engineer, chief assistant at the Faculty of Applied Sciences, University of Liège.

(2) Civil engineer, laboratory manager, Research and Development Department, C.S.T.C.

v_i (v_1, v_2) : quantity of air entering premises i

V_i (V_1, V_2) : volume of premises i (m3).

X_i (X_1, X_2) : concentration of tracer gas per unit of volume in premises i (% by volume).

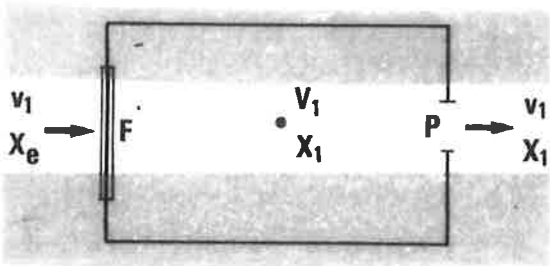
$X_{i,o}$ $(X_{1,0}, X_{2,0})$: initial concentration (% by volume).

X_e: concentration of tracer gas in the outside air (% by volume).

1.22 Case of a single dwelling

Figure 1 shows diagrammatically the case of a single dwelling comprising one outside window.

Fig. 1.
F : window
P : door



Theoretical laws

The internal equilibrium at any time is expressed by the relation:

$$V_1 dX_1 = v_1 X_e dt - v_1 X_1 dt$$

or $$X_1' (t) = \frac{v_1}{V_1} (X_e - X_1 (t)). \quad (1)$$

We shall call $\frac{v_1}{V_1} = r_1$ the rate of air renewal.

Relation (1), put in the form:

$$X_1' (t) = r_1 (X_e - X_1(t)) \quad (2)$$

is a linear non-homogeneous differential equation whose solution is:

$$\boxed{X_1 (t) = X_e + (X_{1,0} - X_e) e^{-r_1 t}} \quad (3)$$

where $X_{1,0}$ is the value of X_1 at time 0.

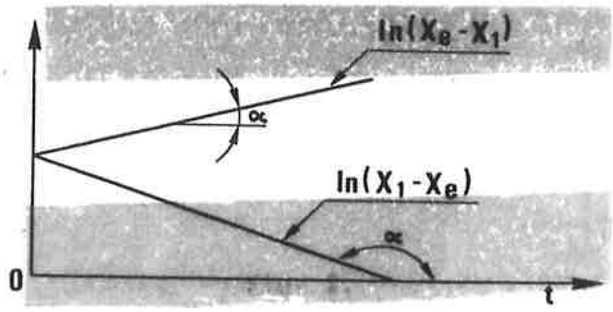
Relation (3) may also be put in the form:

$$l_n (X_1 (t) - X_e) = l_n(X_{1,0} - X_e) - r_1 t$$
$$\text{if } X_{1,0} > X_e. \quad (4)$$

or in the form:

$$l_n (X_e - X_1(t)) = l_n(X_e - X_{1,0}) - r_1 t$$
$$\text{if } X_{1,0} < X_e. \quad (4a).$$

Fig. 2.



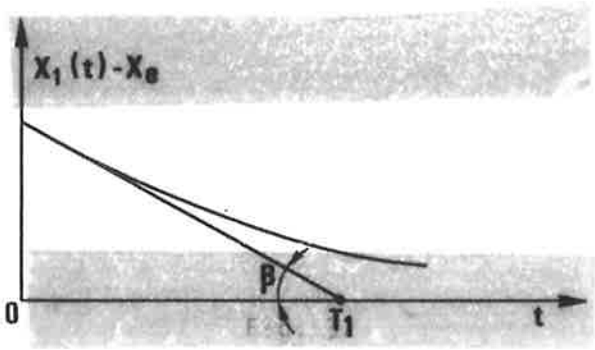
Relations (4) and (4a) plotted on a semi-logarithmic graph (fig. 2) give straight lines.

The gradient of these straight lines is $tg\alpha = - r_1$, which will be the simple means of determining the rate of air renewal r_1.

Note

We may also obtain r_1 graphically, but less precisely, by means of relation (3), which is plotted on the graph in figure 3.

Fig. 3.



At time T_1, the tangent to the curve will be expressed by the equation:

$$X_{1,0} - X_e = T_1 tg\beta \qquad (5).$$

According to relation (2), $tg\beta$ will be equal to

$$- r_1 (X_e - X_{1,0}).$$

Therefore relation (5) gives:

$$(X_{1,0} - X_e) = - r_1 T_1 (X_e - X_{1,0}) \qquad (6)$$

or, after simplifications:

$$-r_1 = \frac{1}{T_1} \qquad (7)$$

This method will be less accurate than the previous method because of the inaccuracy of the plotting of the initial tangent; however, it may be used as a quick method for determining r_1 during tests.

1.23 Case of several dwellings

1.23.1. Theoretical laws for two dwellings

The simplified case of two dwellings may be represented diagrammatically according to figure 4.

We shall use the same reasoning as in paragraph 1.22 above.

For dwelling 1, the internal equilibrium gives:

$$X_1 = X_e - (X_e - X_{1,0})\, e^{-r_1 t} \qquad (8)$$

For dwelling 2, the internal equilibrium gives:

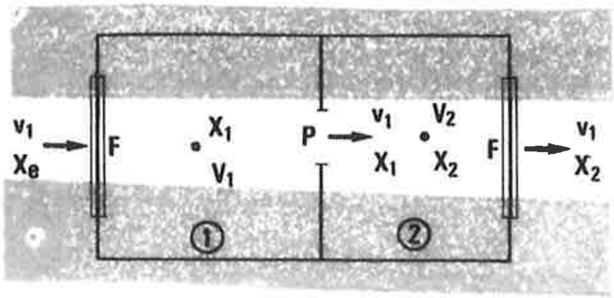


Fig. 4.
F : windows
P : door
1 and 2: dwellings

$$X_2' = \frac{v_1}{V_2} \; Xe - \frac{v_1}{V_2} (X_e - X_{1,0}) \; e^{-r_1 t} - \frac{v_1}{V_2} \; X_2. \qquad (9)$$

By substituting:

$$X_{2,0} = \frac{V_1}{V_1 - V_2} \; (X_e - X_{1,0})$$

$$\text{and } r_2 = \frac{v_1}{V_2},$$

we obtain, after solving equation (9):

$$X_2 = e^{-r2t} r_2 X_e t + X_{2,0} e^{(-2\ r2\ +\ r1)\ t}. \qquad (10)$$

Relation (10) enables us to find the value of the initial tangent (at t = 0), which is :

$$\left(\frac{dX_2}{dt}\right)_{t\,=\,0} = r_2 X_e + (-2\ r_2 + r_1)\ X_{2,0}, \qquad (11)$$

a relation in which all the factors are known except r_2.

We may therefore obtain the value for r_2 graphically by means of relation (11).

1.23.2 General case

The previous case, although simplified, produces complex results, which become even more complex when we consider the general cases of several dwellings.

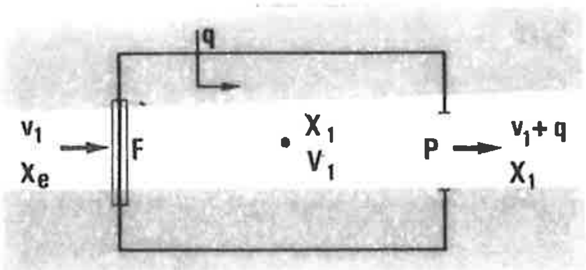


Fig. 5.
F : window
P : door

Here we shall merely consider the following experimental method.

The total quantity of tracer gas (for the entire dwelling) at any time t will be expressed by the relation :

$$\sum_i X_i(t)\, V_i = X(t) \sum_i V_i \qquad (12)$$

or

$$X(t) = \frac{\sum_i X_i(t)\, V_i}{\sum_i V_i} \qquad (13)$$

It may therefore be considered that the whole dwelling is a single premises in which the tracer gas content is $X_1(t)$, which is at all times expressed by relation (13).

Thus a semi-logarithmic graph similar to that shown in figure 2 will give a straight line whose gradient will characterise the overall rate of air renewal sought.

1.24 Other law of variation of the gas content during the injection

We shall only consider the case of a continuous injection of q constant of a tracer gas into a dwelling for a sufficient length of time.

1.24.1. General case

The descriptive diagram of the test is shown in figure 5. The internal equilibrium at any time may be expressed by the relation:

$$V_1 d X_1 = q\, dt + v_1 X_e\, dt - (v_1 + q) X_1\, dt \qquad (14)$$

or

$$X_1' = \frac{q}{V_1} + r_1 X_e - (r_1 + \frac{q}{V_1}) X_1, \qquad (15)$$

which is a differential equation whose solution is:

$$X_1 = (X_{1,0} - \frac{q}{V_1} - r_1 X_e)\, e^{-(r_1 + \frac{q}{V_1})t} + (\frac{q}{V_1} + r_1 X_e). \qquad (16)$$

1.24.2 Special case

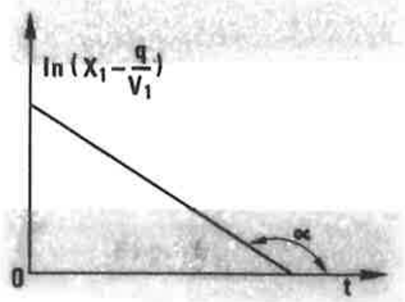
The general equation (16) will give the following where the tracer gas content of the outside air is negligible:

$$X_1 = \frac{q}{V_1} + (X_{1,0} - \frac{q}{V_1})\, e^{-(r_1 + \frac{q}{V_1})t}. \qquad (17)$$

Relation (17) may also be put in the form:

$$l_n (X_1 - \frac{q}{V_1}) = l_n (X_{1,0} - \frac{q}{V_1}) - (r_1 + \frac{q}{V_1})\, t. \qquad (18).$$

Fig. 6.



This law is plotted on the graph in figure 6.

We observe that the gradient of this straight line is equal to:

$$tg\alpha = -\left(r_1 + \frac{q}{V_1}\right), \qquad (19),$$

a relation in which $\frac{q}{V_1}$ is known; this constitutes a simple method of determining r_1.

1.25 Law of reduction of the tracer gas content

This law is that obtained with most of the tracer gases used, for example SF_6, N_2O_5, N_2O, CO_2 and O_2.

Later on in this paper we shall discuss test results obtained with CO_2, N_2O and O_2.

The injection of the tracer gas enables an initial content $X_{1,0}$, in relation (4) above, to be reached in the dwelling, because in this case the initial content $X_{1,0}$ is higher than the content X_8 of the outside air.

A measurement of the reduction in the content of this gas in the dwelling will enable a graph similar to that in figure to be drawn, and the rate of air renewal sought finally to be obtained.

If the tracer gas used is not present in the outside air (this is the case, for example, with SF_6), relation (3) explained above is simplied and becomes:

$$X_1(t) = X_{1,0}e^{-r_i t}. \qquad (20)$$

In this case, it is always the gradient of the straight line in the semi-logarithmic graph in figure 2 that will give the rate of air renewal sought.

1.26 Law of increase in the tracer gas content

This is the law obtained when the tracer gas used is oxygen (O_2).

In this case, a large injection of nitrogen (N_2) will reduce the O_2 content in the air inside the dwelling to a value $X_{1,0}$, used in relation (4a), because in this case, $X_{1,0}$ is lower than content X_e of the outside air. A measurement of the increase in O_2 content in the dwelling will enable a graph similar to that in figure 2 to be drawn, and the rate of air renewal sought finally to be obtained.

1.3 Measurement principle

1.31. Instrumentation

1.31.1 Tracer gas: N_2O or CO_2

In this case, the measuring device is a gas analyser with selective absorption in infrared light.

The measurement principle is as follows: the measuring cell is divided into two identical enclosures containing CO_2 or N_2O.

These two enclosures receive infrared radiation which has previously passed through a control cell containing no tracer gas, and an analysis cell through which the gas to be analysed passes; the gas to be analysed absorbs some of the radiation in proportion to the tracer gas content, and this results in a different rate of heating in the two measuring enclosures. The difference in temperature thus created leads to a difference in pressure between the two enclosures which, when converted to an electric value, supplies the measuring signal.

1.31.2 Tracer gas: O_2

In this case, the measuring instrument is a gas analyser based on the paramagnetic properties of oxygen and on the dependence of these properties on temperature. In fact, the paramagnetism of the oxygen reduces as its temperature increases.

In a measuring cell, the gas to be analysed is subjected to a large magnetic field created by a permanent magnet, between whose poles a filament heats the gas with which it is put in contact.

Since the magnetic field has a tendency to attract the cold gas, and repel the hot gas, what is in effect a magnetic wind is created in the measuring cell, and the speed of this wind depends on the oxygen content of the gas analysed.

The heating filament is made from a material whose strength varies considerably according to temperature; the magnetic wind will have the effect of cooling the filament and varying its resistance.

This filament is inserted in a Wheatstone bridge whose imbalance will serve to measure the speed of the magnetic wind and therefore the oxygen content of the gas to be analysed.

1.32 Tracer gas injection principle

In a dwelling, certain rooms are ventilated by the outside air, and others by the air deriving from neighbouring rooms.

From the energy point of view, only the total flow of outside air is of any interest, which is why it was decided, for the tests reported on here, to carry out tests with contamination of the whole dwelling.

The gas (tracer in the case of CO_2 or N_2O, nitrogen in the case of oxygen), is injected for about ten minutes, whilst all the air in the dwelling is thoroughly mixed by means of fans; during this injection, all the inside doors are open, and in each room the fans distribute the contaminant.

Once the injection is complete, the fans are set to their minimum speeds to simulate mechanically, if the dwelling is not heated during the tests, mixing of the air similar to that which would have been produced by a heat source. When the tests are carried out in a heated dwelling, the heating system is sufficient to obtain a perfect mixture of the contaminant and the ambient air.

2. MEASUREMENT OF THE VENTILATION OF INDIVIDUAL DWELLINGS - FIRST SERIES OR MEASUREMENTS

2.1 Description of the measurement series

As part of an investigation into the actual fuel consumption required to heat dwellings, a series of natural ventilation measurements was carried out (1). The 3 houses tested form part of a development of social dwellings of traditional construction (fig. 7). (It should be noted that only the front and rear facades are provided with openings). Two houses (M3 and M7) were tested by the contamination method, room by room. House M8 was studied by the global contamination method.

2.2 Analysis of the measurement series, room by room.

During this series of measurements, house M8 was studied in detail to obtain results in different climatological situations (26 tests). Some control tests (one per room) were carried out in house M3, and in table 1 are summarised the results obtained in the two houses for fairly similar, but certainly not identical, climatic conditions. This may explain the slight differences that can be observed in most of the rooms except the living room and room 3.

1) See bibliography no. 3.

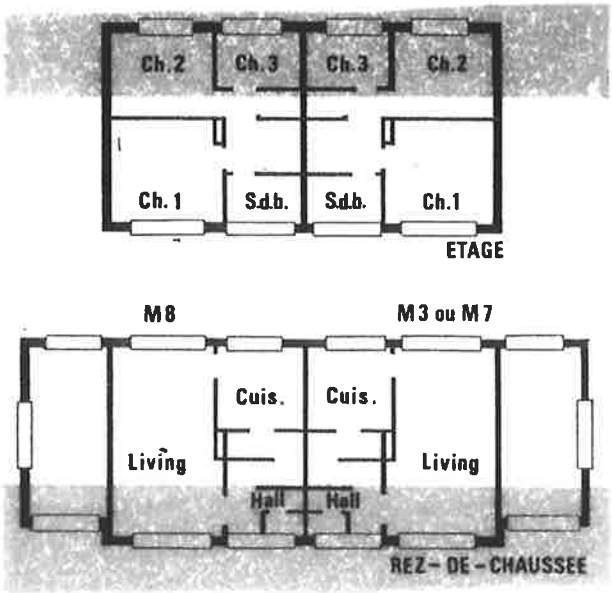


Fig. 7.

Key

Ch. = room.
S.d.b. = bathroom.
ETAGE = 1st FLOOR
Cuis. = kitchen
REZ-DE-CHAUSSEE - ground floor.

Living = living room

Hall = hall

In fact, for the living room, with fairly similar wind directions, the following is observed:

- for house 3, a renewal rate of 0.3 vol./h, with a wind speed of approximately 6 m/s
- for house 7, a renewal rate of 0.8 vol./h, with a wind speed of approximately 4 m/s.

The situation is even more serious for room 3, because under very similar climatic conditions, house 7 shows a renewal rate of 3.8 vols/h, i.e. almost ten times that of house 3.

The systematic measurements taken in the different rooms in house 7 do not generally enable a relationship to be established between the rate of renewal and wind speed.

This is due to the difficulty in obtaining a sufficient range of measurements for both speed and direction.

It was only possible to obtain a valid relationship for the living room (fig.8), which has openings (doors and windows) on two opposite walls, and which is therefore less sensitive to the direction of the wind.

For this house, a law is obtained:

$$n_{(vol./h)} = 0.11 + 0.16\ V,$$

V being the speed of the wind measured at a meteorological site (10 m in height) at the nearest station (approximately 10 km).

On the other hand, the different tests carried out enable the renewal rates to be estimated for a meteorological wind speed of 4 m/s.

They are recorded in table 2 and are compared with the rates calculated according to standard DIN 4701 (1).

(1) DIN 4701. Heating systems. Rules for calculating the heat requirement of buildings. Berlin, DIN 1959.

Table 1

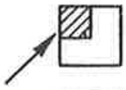
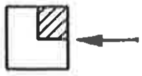
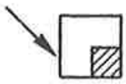
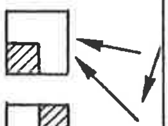
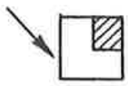
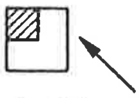
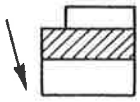
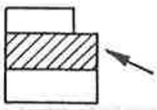
Test No.	Place	Wind (m/s)	Rate (vol./h)	Direction
2	M3. CH1	2,0	0,5	
13	M7. CH1	2,4	0,3	
3	M3. CH3	5,0	0,4	
23	M7. CH3	5,6	3,8	
4	M3. CH2	3,9	1,7	
17	M7. CH2	4,9	1,8	
5	M3. Liv.	6,0	0,3	
7	M7. Liv.	3,9	0,8	

Table 2

Place	n to DIN 4701 (vol.h)	n estimated (vol.h)
Living room	0.2	0.7
Kitchen	1.7	1.1
Room 1	0.5	0.7
Room 2	1.0	0.9-1.9
Room 3	1.9	2.2

With the exception of the living room, satisfactory agreement is observed between the calculated values and those deduced from in situ tests, but it must not be forgotten that for similar locations in different houses renewals have been measured which range from the single unit to ten times that.

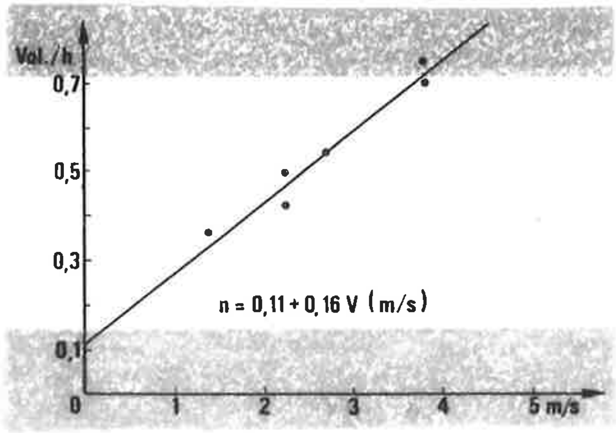


Fig. 8.

X-axis, wind speed
Y-axis, air renewal

2.3 Analysis of the "general contamination" series of measurements

This series of measurements had to be carried out in a third house (M8).

Since the gas concentration was measured in the different rooms, it is possible to determine the rates of renewal for each room. These are not representative of the volume of outside air entering the room (due to internal exchanges), but rather of the quality of the ventilation of the room considered.

The results are contained in table 3. Note should be taken of the exceptional air renewal rates recorded in room 1 (0.16) and the kitchen (1.28) compared with those in the other rooms, which are of the order of 0.5.

For room 1, there is no obvious reason to explain this low ventilation; tests carried out in other houses did not show any such discrepancy for room 1.

Table 3 - Air renewal rate (vol./h).

Place / Test	Room 1 SW	Room 2 NE	Room 3 NE	Living room SW-NE	Kitchen NE
1	0.12	0.52	0.61	0.72	0.81
2	0.22	0.57	0.77	0.90	1.04
3	0.14	0.51	0.59	0.55	1.50
4	0.10	0.50	0.59	0.31	1.98
5	0.28	0.14	0.26	0.28	0.66
6	0.10	0.49	0.74	0.60	1.70
average	0.16	0.46	0.60	0.56	1.28

It may therefore be assumed either that the tightness properties of the frames may vary considerably in the same series, or that the arrangement of these frames is of vital importance, or finally that tightness defects other than those in the frames play an important part.

As far as the kitchen is concerned, the high ventilation (air renewal) rate may be explained by the presence of an outer door and a door to the cellar.

Table 4 contains the overall renewal values measured in the different tests. It is not possible to find any correlation between the overall renewal and the average speed of the wind measured 5 m above the roof.

This is doubtless due to the fact that the climatic conditions were highly variable, both in amplitude and direction, during the same test. During the series of tests characterised by a low wind speed, of the order of 2 m/s, the dwelling tested showed a renewal rate of the order of (0.47 $\pm$ 0.13) vol./h.

2.4. Conclusions

The tests carried out room by room indicated considerable differences in the air renewal rates of similar rooms located in houses of identical structure and architecture.

On the other hand, the general contamination tests show that where the method in standard DIN 4701 gives satisfactory predeterminations in relation to the measurements, in the same dwelling, some rooms may be ventilated very differently from others.

However, since the same discrepancies were not observed in all the dwellings, we may assume that the airtightness properties of the frames and their position or arrangement, and even the overall airtightness in the dwelling, are the cause of the discrepancies.

Finally, it appears that the variations in amplitudes and frequencies, for the same average wind speed, as well as different directions observed during the tests, are responsible fot the lack of correlation between the overall renewal rate and the average meteorological wind speed.

3. MEASUREMENT OF VENTILATION IN AN INDIVIDUAL HOUSE - SECOND MEASUREMENT SERIES

3.1 Description of the measurement series

A single house was tested by the general contamination method. This was a single family house situated in an isolated situation. It comprises only one living level, whose volume is 325 m3 (fig. 9). It is normally heated by an air-air heating pump, and therefore has a network of air circulation recycling ducts.

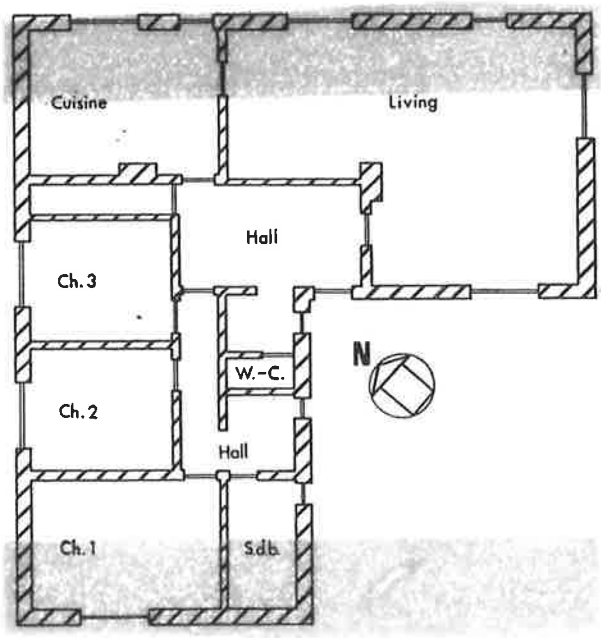


Fig. 9.

In addition to the renewal rate measurements, we carried out surface pressure measurements at the centre of the six outside walls (fig. 9). The reference pressure was the pressure prevailing in one of the rooms in the dwelling (kitchen).

A meteorological mast was erected close to the house, on the side receiving the prevailing winds . It comprised 7 thermistors, two for temperature measurements and five for the speed measurements (1 m between).

Table 4 - Overall air renewal n_T

Test	1	2	3	4	5	6
n_T(vol./h)	0.51	0.68	0.46	0.36	0.32.	0.50
$\overline{V}$(m/s)		2.5	1.9	1.7	1.0	1.6
$\overline{OR}$		N-NW	N	N-NW	N	N

Table 5 - Air renewal rates measured in the house (vol./h.) - Tests in natural ventilation.

Room in house \ Test	M_1 (1)	M_2 (2)	M_3	M_4	M_7	M_9
Bath room	1.16	0.69	0.05	0.19	0.24	0.20
Room 1	1.31	0.60	0.07	0	0.06	0.03
Room 2	1.34	0.59	0.09	0	0.03	0.02
Room 3	-	0.50	0.12	0	0.02	0.03
Hall	1.16	0.62	0.10	0.24	0.24	0.24
Kitchen	1.16	0.43	0.02	0.25	0.24	0.23
Living room (1st station)	1.15	0.70	0.01	0.15	0.26	0.23
Living room (2nd station)	1.10	0.70	0.01	0.14	0.25	0.23
Average (weighted by volumes)	1.20	0.61	0.05	0.14	0.19	0.17
Average meteorological wind (m/s) Direction	4.0 N-NW	7.3 W-SW	3.5 W-NW	2.3 W-SW	4.4 W-NW	4.8 W

(1) Uncovered air circulation vents
(2) Uncovered air circulation vents and fan operating.

3.2. Air renewal rates

Six air renewal tests were carried out. The results are given in table 5. The tests for M1 and M2 are of special interest, and were carried out with the air circulation vents uncovered, the circulation fan being off and on respectively. The importance of these vents can be seen in relation to the other tests. The airtightness defect is probably located at the pump which is installed in the cellar.(basement), directly communicating with the garage, whose door was not very airtight. Switching on the fan lessens the tightness defect because in this case the draught of air is thrust back on itself(as far as pressures are concerned), and uncontrolled ingresses are reduced.

In the other cases, the natural ingresses (infiltrations) are effectively minimized as far as practically possible. These infiltrations obviously increase with the speed of the meteorological wind, but the limited number and interpretations of the results do not enable any significant laws to be established. The infiltrations, and particularly their distribution throughout the building, are also very sensitive to wind direction.

3.3. Dynamic pressures and outside microclimate

The pressure measurements inside the different rooms indicated no significant imbalance, notably because of the gaps left at the bottom of the doors. Inner losses of head may be considered practically negligible.

As a result, the reference pressure measured in the kitchen is valid for the entire dwelling.

Figure 10 shows a survey example of the surface pressures on the facades. The size of the rapid fluctuations will be observed, with the impossibility, almost, of interpreting the graph of the instantaneous pressure throughout the test. It would therefore be necessary to resort to more

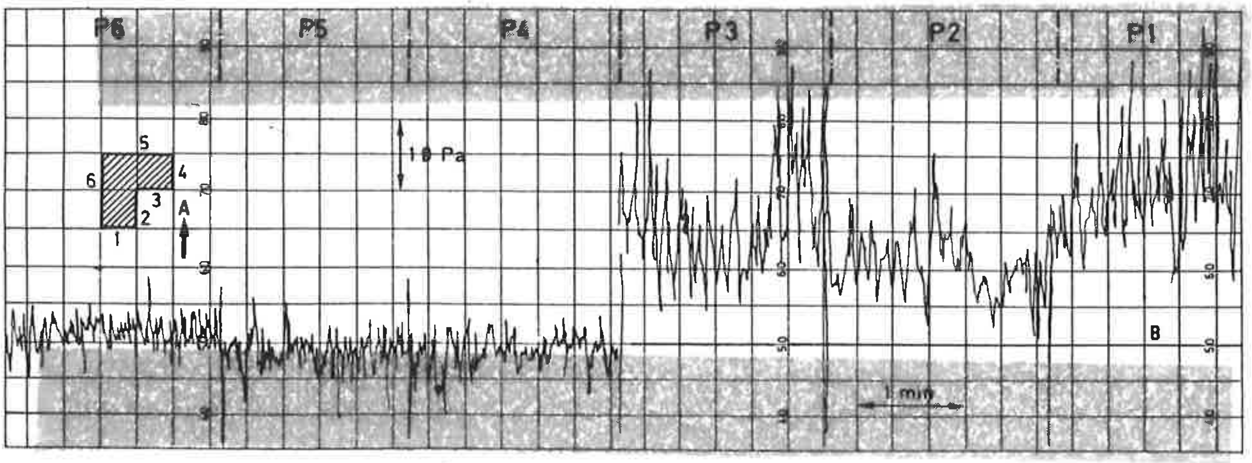


Fig. 10 - Recording of surface pressures on the facades.
A: meteorological wind 8m/s. B : zero.

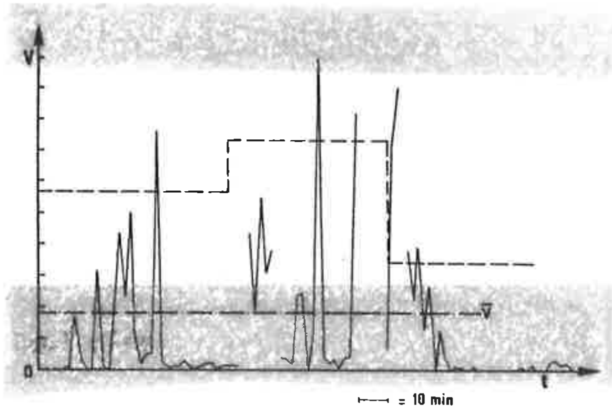


Fig. 11. Recording of the meteorological wind.
$\bar{V}$: average speed.

elaborate measurements such as the mean and effective values. In fact, it seems illusory to search for a static interpretation of the phenomenon; the oscillations doubtless lead to infiltrations which are clearly greater than those that would correspond to the average measurements in stationary flow. On the other hand, the inspections carried out on the microclimate show that the definition of the meterological wind is inadequate. Figure 11 shows the behaviour of the wind near to the house at a height of 5 m. The average wind is not even maintained close to the dwelling (table 6), and in addition major time variations are superimposed on it.

4. MEASUREMENT OF THE VENTILATION AND AIRTIGHTNESS OF THREE SOCIAL DWELLINGS (1).

4.1. Introduction

1) See bibliography no. 1.
(2) NBN B 62-001. Hygrometry of buildings. Thermal insulation. Winter conditions. Brussels, IBN, 1974.

During a series of measurements carried out in three identical social dwellings, the following was studied:

- the airtightness of the external woodwork (doors, windows and French windows).
- conformity of the air permeability of this external woodwork with the existing Belgian standards.
- the contribution made by the permeability of this woodwork to the air renewal rates measured by means of a tracer gas.

The marking out and numbering (which will serve as a reference in the remainder of this paper) of the three houses studied are shown in figure 12. Here not only the rates of ventilation due to the air infiltrations were measured, but also those obtained using a controlled mechanical system which had been provided in the hope of seeing the effect of the random infiltrations reduced, particularly the double flow system, with excess inflow in relation to extraction.

Table 6 - Wind speed profiles

Altitude (m)	Average speed and standard deviation (m/s)	
1	0.2 ± 0.5	0.4 ± 0.5
2	-	0.4 ± 1.2
3	1.2 ± 1.6	0.6 ± 0.6
4	2.0 ± 2.8	2.4 ± 2.6
5	1.8 ± 2.5	3.8 ± 5.2
Meteo. wind m/s	5.9 S-SW	10.3 NW

The Belgian standard which establishes the air permeability (airtightness) of outside windows is the standard NBN B 62-001 (2), drawn up to define the degree of comfort and reduce the energy consumption of a building in winter conditions. In order to comply with this standard, the airtightness of the outside woodwork must adhere to the following law, which is defined according to the site on which the three houses studied are marked out:

protected site $Q_{100} \leq 6$ m3/h.m.

This means that, when subjected to a differential pressure of 100 Pa, a window frame will only be infiltrated by an hourly quantity of outside air of 6 m3 per unit of length of the joints of the window or door leaves.

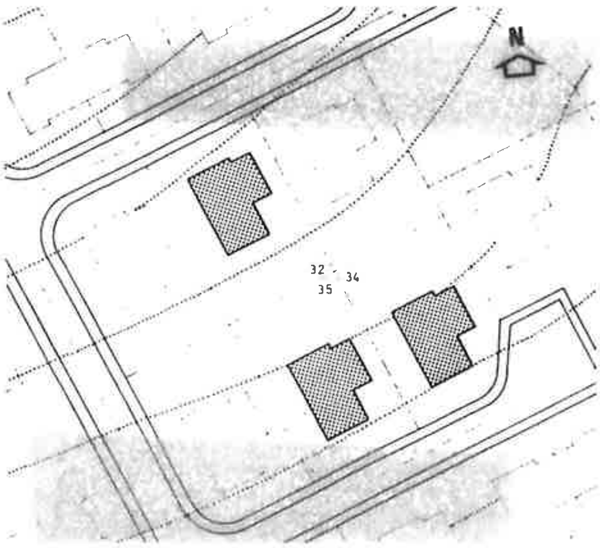


Fig. 12.

The aim of the author of the standard was to achieve an air renewal of 1.5 vol./h in dwellings equipped with this type of carpentry, for an average wind whose speed is 5 m/s.

4.2. Test methods

4.21 Measurements of the microclimate

These measurements consist in determine for the outside climate the temperature, relative humidity, speed and direction of the wind :

- the temperature is measured by means of copper-constantan thermocouples placed under a shelter and with a hair hygrometer, which also enables the relative humidity to be recorded
- a cup anemometer for measuring the wind speed, together with a potentiometric wind direction transmitter, are both placed under a mast 10 metres high.

4.22 Measurement of the airtightness of the facade elements

This measurement was carried out by means of an airtight box fixed to the outer face of the walls. The tests were conducted in such a way that the inside of the box was subjected to low or excess pressure.

4.23. Pressure due to the action of the wind on the facades

The pressure at various points on each element of the facade was measured by means of pressure sensors connected to electronic differential pressure recorders.

These measurements enabled the coefficient C, given by the relation:

$$\Delta p = C\rho \frac{v^2}{2}$$ to be determined,

where Δp is the differential pressure measured (in Pa).

ρ is the mass per unit of volume of the outside air (in kg/m3).

v is the wind speed (in m/s).

Table 7 - Airtightness measured in situ and standardised (m3/h).

No. of elements		1	2	3	4	5	6	7
To standard NBN B 62-001		20	60	40	36	20	40	40
In situ measure-ments	house 32	35	125	64	1470	18	47	70
	house 34	15	97	54	286	31	32	95
	house 35	22	140	50	298	22	92	47

4.3 Results obtained

4.31 Airtightness of outside woodwork

The numbering of the different outside woodwork elements is shown in figure 13.

For each of these elements, table 7 enables their airtightness (permeability)measured to be compared with the standardised airtightness.

Up to a differential pressure of 100 Pa, the airtightness (permeability) measured at low pressure was not much different from that obtained in excess pressure. It is observed that in most cases, the permeability measured is far greater than the permeability permitted in the standard. The conclusion drawn from this is therefore that the three houses studied are provided with frames and doors whose airtightness is poor in relation to the standard.

4.32 Pressure due to the action of wind on the facades

Only winds blowing from the SOUTH-WEST or EAST will be considered here.

The tests enabled the coefficients of dynamic pressure C to be calculated at right angles with the various outside windows; these coefficients C are shown in table 8.

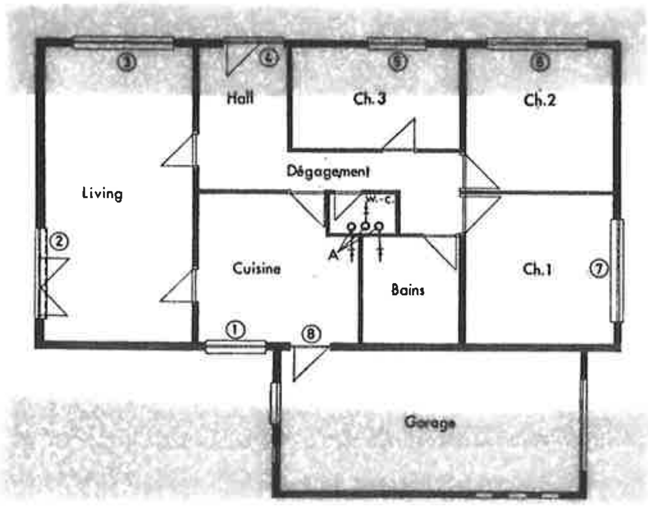


Fig. 13.

1-8: facade elements
A: "natural" vents.

Key
Ch. = room
Living = living room
Cuisine = kitchen
Bains = Bathroom
Degagement = corridor

Using the results given in tables 7 and 8, the quantities of air entering and leaving through the outside windows may be calculated, leading to the results given in table 9.

The imbalances observed between the quantities of air entering and air escaping (incoming and outgoing air) may be explained:

- by the overall airtightness of the houses, creating a situation where a quantity of air entering via the facade, for example, may escape back through the roof and vice versa.
- by gusts of wind which cause a quantity of air entering through a window frame or a door of a room may also escape back through the same frame or through the same door without affecting the air renewal rates of the other rooms.

4.33 Overall air renewal rate

During the tests we endeavoured to maintain the inside temperatures at the following values:

- $22^{o}C$ in the living rooms
- $18^{o}C$ in the kitchens and bedrooms
- $24^{o}C$ in the bathrooms
- $16^{o}C$ in the entrance halls and WC's.

Our results, plotted on a graph (fig. 14), show a net difference in the overall ventilation of houses 32 and 35, for a wind blowing from the SOUTH-WEST direction.

Table 8

Element no.	Coefficient of dynamic pressure C	
	SOUTH-WEST	EAST
1	-0.13	+0.05
2	-0.09	-0.36
3	+0.35	-0.29
5	+0.14	-0.29
6	0	-0.29
7	-0.36	-0.29

Table 9 - Quantities of incoming and outgoing air

House no.	SOUTH-WEST - 5 m/s		EAST - 2 m/s	
	incoming air (vol.h)	outgoing air (vol./h)	incoming air (vol./h)	outgoing air (vol./h)
32	0.04	0.2	not measured	not measured
34	0.19	0.09	negligible	0.1
35	0.24	0.07	negligible	0.1

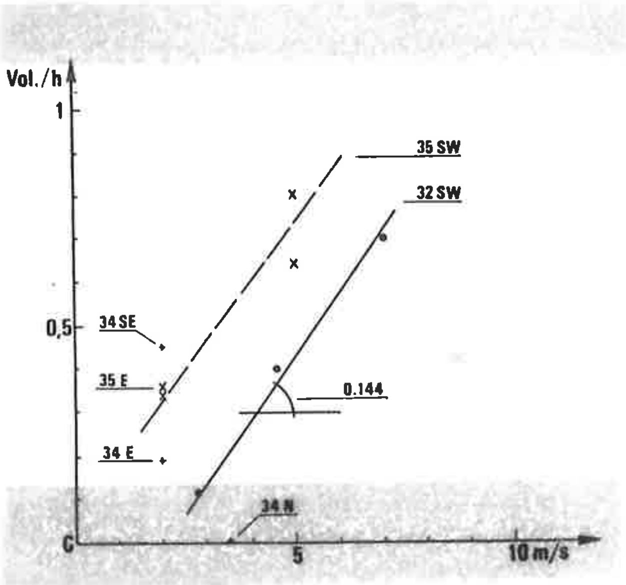


Fig. 14.
X-axis, wind speed
Y-axis, air renewal.

Unfortunately, house 34 could only be measured for a wind blowing from the EAST-SOUTH-EAST direction. However, this house appears to be sensitive to wind direction, and in any case much more sensitive to this factor than house 35.

4.34 Importance of the permeability of window frames in the overall ventilation of houses

We compared in table 10 the quantities of outside air entering through the windows with those entering generally into each house.

We observed that the quantity of air coming in through the outside windows may vary between 0% (case of an EAST wind of 2m/s, and houses 34 and 35) to 32.9% (case of a SOUTH-WEST wind of 5 m/s and house 35) of the total quantity of air entering each house. If we only consider the most common case in Belgium, that of a wind blowing from the SOUTH-WEST at a speed of 5 m/s, we observe that the contribution made by the permeability of windows and their positioning in the overall ventilation of each house varies from 8.9% (house 32) to 32.9% (house 35).

Table 10 - Quantities of incoming air

House no.	SOUTH-WEST - 5 m/s		EAST - 2 m/s	
	air coming in through the windows (vol./h)	air entering generally (vol.h)	air coming in through the windows (vol.h).	air entering generally (vol./h)
32	0.04	0.45	not measured	not measured
34	0.19	-	negligible	0.2
35	0.24	0.73	negligible	0.35

4.4 Results obtained by means of a controlled - dual flow (VMC-DF) mechanical ventilation installation

This installation was given the task of extracting spent air produced in the service areas (kitchen, bathroom, WC) and of sucking in fresh outside air into the other areas (living room, hall, bedroom).

The quantities of fresh air sucked in correspond roughly to a rate of air renewal of 1 vol./h, and are 20% higher than the quantities of spent air extracted. It may be considered that under these conditions the inside of the dwelling is subjected to slight excess pressure.

Figure 15 contains the most important results obtained in house 35. It will be seen that the quantities of air sucked in by the VMC - DF are superimposed on the quantities of air entering under the influence of the thermal draught and wind gusts on the outer skin of the building.

4.5. Conclusions

4.51 The airtightness of frames and doors (outside) is unsatisfactory if the values laid down in the standard are taken as references.

Despite this, however, it will be seen that for average winds of 5 m/s, the rates of air renewal obtained are between the two extreme values of 0.45 and 0.7 vol./h; we are far from achieving the value of 1.5 vol./h considered necessary by the author of the standard. We see here a certain discrepancy between the tolerated air permeabilities and the required performances.

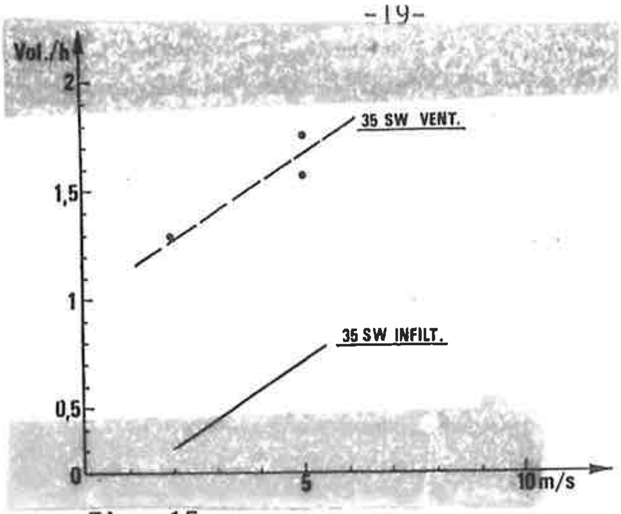


Fig. 15.
X-axis, wind speed
Y-axis, air renewal.

4.52 Even for identical houses constructed in series on the same site, the airtightness properties of the outside woodwork elements and their position may be totally different from one house to another. It is clear from this observation that valid hypotheses can never be made on the ventilation of a building on the basis of standardised values, nor on the basis of tests carried out on another building, even if this is identical to the first.

Under these conditions, the problem of estimating the ventilation of a dwelling and the energy consumption associated with the ventilation remains to be solved.

4.53 Our tests appear to show that the air permeability (tightness) of outside woodwork elements and their position are only responsible for a very low proportion of the overall infiltrations of the dwelling. We would remind readers in this connection that the maximum percentage attained in our tests was 32.9%. It is time, we think, to make all trade organisations, and not only carpenters, understand that the quality of their work has a considerable effect on the ventilation of a dwelling and hence on the energy requirements of that dwelling.

4.54 The attempt to install a controlled mechanical ventilation system - dual flow - in the dwellings studied did not produce the expected results, in the sense that the infiltrations were in no way reduced by subjecting the dwelling to excess pressure, and in that these infiltrations, for some winds, are of the same order of magnitude as the quantities of air sucked in by VMC-DF.

Thus this ventilation will not be efficiently controlled and will not generate energy savings until the airtightness of the entire dwelling (and not only the outside woodwork elements) improves considerably.

Bibliography

1. ...
Circuits d'air. Economie d'énergie dans les équipements de ventilation (Air circuits. Energy saving in ventilation equipment), 2nd part. Brussels, Research Report IC-IB, January 1979.

2. Nusgens P. and Caluwaerts P.
Determination of the ventilation rate in a series of social houses. Ventilation and infiltration in dwellings. CIB proceeding 52.

3. Uyttenbroeck, J. and Heikhaus, H.
Measures de la consommation d'énergie dans dix maison neuves non habitées (Measurements of the energy consumption in ten new unoccupied houses), Brussels, C.S.T.C. Review no. 1, March 1978.