#651 ⑤

AIC Translation No.5

"Ventilation and permeability of dwellings"

Translated from the original French:
"Ventilation et transparance à l'air des
habitations"
P. Jardinier
Cahiers Techniques du bâtiment No.27
February/March 1980

Ventilation and air permeability of dwellings

Two fundamentally different notions

The changes in construction methods necessitated by the energy crisis are not being made without difficulty, and are often accompanied by disorders (condensation, mould, consumption far greater than forecast), which must be clearly explained. We might well blame ventilation for this, but the true culprits are in fact holes, cracks, joints, the "A1's, the A2's" (1), fillisters of windows, insulating materials and their use, and in many cases also regulations and their technical texts relating to implementation. All these factors have a disturbing influence on ventilation, which is not the "culprit", but rather the "victim".

Caption: The Four Winds. Engraving by Normand junior (18th cent.). Boreas, the North Wind. National Library. Doc. Roger-Viollet.

In 1963 and 1966, two studies (2) relating to natural ventilation and the effects of wind on a building were published in the reports by the C.S.T.B.

As far as we know, no new phenomenon has been discovered which disproves what was written at that time. We shall merely change the method of presentation by defining a new concept: "the total air permeability of a dwelling", which is approximately the total area of the openings facing outwards, expressed in cm2.

We shall show that it is possible to forecast the air flows crossing dwellings, and hence also the losses during the heating period, with great accuracy.

This air flow is not ventilation, which has a precise function: to circulate, in each room in the dwelling, an air flow suitable for the requirements of the dwelling. For example, we know that 30 m3/h is required in a room, whatever its area, if it is occupied by two persons.... etc.

---

(1) Air permeability classes in joinery.

(2) "Comment assurer la ventilation des immeubles collectifs d'habitation" (How to guarantee ventilation of collective dwellings),by P. Jardinier, report 542, December 1963, "Vent, ventilation et bâtiment" (Wind, ventilation and buildings), report 720, December 1966.

The terms transversal ventilation, uncontrolled, even natural ventilation used to describe these infiltrations are misused; they only relate to ventilation by chance and accidental coincidence.

The movements of air in premises

A dwelling is a body which is exposed to the outside by the provision of air inlets, air outlets, doors, windows, joints between walls and floors, etc. The openings allow the air to pass through in one direction or the other, according to the states of pressure at various points in the dwelling. Thus at any given time we have a fully defined air circulation which can be calculated if we know:

the characteristic curve of each opening;
the shape of the building and its height;
the position of each opening in this building;
the wind speed and direction;
the outside and inside temperatures.

It is obviously a complicated procedure to make allowance for all these parameters. Moreover, we must, more often than not, resort to the solution which consists in stating: "For the rate of ventilation we shall take 1 volume/hour of the main rooms, even if in reality the rate only attains 1/2 volume or happens to exceed 2 volumes/hour".

In fact we no longer look for what is happening at any given moment, we merely wish to know what is happening in one year or at the very least during one heating season, whatever the direction in which the air is circulating. If the air circulates from one room facade to another, it has the same effect, as far as our thermal calculation is concerned, as if it sweeps through the dwelling from the main rooms to the technical rooms (kitchen etc.), even if the air cirulates from the technical rooms to the main rooms.

In the following we shall use four types of information:

1 - If we maintain a pressure difference Δp on both sides of an opening, the air flow crossing it is written as follows:

$$Q = \frac{1}{C} \cdot \sqrt{\Delta p},$$

which is the characteristic of the opening.

2 - The wind exerts a forward thrust on certain facades, and exerts suction on others. It therefore exerts pressures or drops in pressure which, fortunately for the calculation, are proportional to the square of the wind speed.

The coefficients k are dependent on the geometry of the dwelling, but for simple dwellings the coefficients indicated in figure 1 may be used.

The roof projections always have a coefficient equal to -0.31. It will be seen from table 1 that a maximum of 2 facades are under pressure and 3 subject to a drop in pressure for an angle of incidence of 45^{o}; otherwise there are always 4 subject to a drop in pressure, and only 1 under pressure, which does not mean that there are no movements between two facades subject to a drop in pressure.

Table I

Angle of incidence	Mean value n
$\frac{Q}{VT_2}$	
Error related to the mean value	

Figure 2 shows how coefficient k develops for winds acting on a facade through an angle of incidence of 0^{o} to 360^{o}.

The actual pressure p is calculated on the basis of the formula:

$p = k\ V^2$

3 - The thermal draught exerts a special action, shown diagramatically in figure 3, when the infiltration openings are distributed as indicated.

The total available pressure is written as follows:

$p = 0.044\ h\Delta T$,

where:

h is the height in metres,

ΔT is the difference in temperature between the inside and outside,

p is expressed in pascals.

The zero (0) pressure area is displaced in the same direction as all the openings.

4 - k and C, being the coefficient of pressure due to wind and the characteristic coefficient of the openings on each facade respectively, are linked to π, the internal pressure of the building, and the air flow, Q, by the following formula (fig. 4):

$$\begin{aligned} K1\ V^2 - \pi &= C1\ (Q1)^2 \\ K2\ V^2 - \pi &= C2\ (Q2)^2 \\ \pi - k3\ V^2 &= C3\ (Q3)^2 \qquad\qquad 1 \\ \pi - k4\ V^2 &= C4\ (Q4)^2 \\ Q1 + Q2 &= Q3 + Q4 \end{aligned}$$

which enables Q1, Q2, Q3 and Q4 to be calculated.

If there is another possible air passage through the roof, it is sufficient to add a supplementary equation.

C1, C2, C3, C4 and possibly C5 are not generally known; thus it is not possible to solve these equations. On the other hand, we could already make assumptions on the basis of the distribution of the leaks.

For example, we could say that the openings are distributed equally on each facade, and we would have C1 = C2 = C3 = C4 = C5.

If there are only two facades, we may write C1 = C2. What we would then require is the total value C1 + C2 + C3 + C4 + C5 or C1 + C2, which would enable us to solve the system of equations in each hypothesis. Now it just happens that these total values may easily be obtained by measurement.

Fig. 1: value of coefficient k according to the angle of incidence of the wind

Total air permeability of a building

The total air permeability of a dwelling, Tr, is defined as the air flow which crosses the dwelling, expressed in m3/h, for a pressure difference of 10 pascals between the inside and outside. It is therefore an easily measurable value.

Pressure on a facade as a function
of the angle of incidence

Fig. 2

Fig. 3: thermal draught

Fig. 4

It should be noted that the value obtained corresponds quite closely to an equivalent opening area expressed in cm2, which allows the same flow to pass through with the same pressure difference of 10 pascals.

Thus a permeability of 750 m3/h is equivalent to an area that a 750 cm2 opening would allow to pass through, distributed between various cracks and holes.

If we knew all the characteristic curves of each element, it would be sufficient to add the flows obtained for 10 pascals to find Tr. Generally speaking we do not know these, but Tr can be measured.

<u>How can Tr be measured?</u>

According to the definition, it is sufficient to replace a structural element, a window for example, by a panel on which are arranged in series a fan and a flowmeter, and to set the fan so that there is a pressure difference of 10 pascals between the inside and outside. The flow is equal to Tr.

It is possible to proceed with the measurement for greater values of Δp than 10 pascals. If we then read a flow Q, Tr is deduced from the formula:

$$Tr = Q \sqrt{\frac{10}{\Delta p}}$$

It should be noted that this procedure is not desirable when the dwelling is fitted with self-adjusting air inlets, but it is interesting in that we can determine Tr by this method with a greater degree of accuracy, particularly when there is wind.

Thus if we have a high degree of confidence in the self-adjusting air inlets, they can be plugged or filled in and the nominal flow through these air inlets then added to the value Tr':

$Tr = Tr' + nq$.

In order to analyse the origins of the permeability it is sufficient to fill in the inlets in succession. Thus we may:
measure the total permeability Tr;

then, by blocking up the air inlets, measure Tr'; (Tr - Tr' corresponds to the contributory portion of the air inlets);

finally, by blocking up the air outlets for natural ventilation, we may measure Tr'' (Tr' - Tr'' corresponding to the part played by the air outlets).

This procedure is useful for determining the causes of permeability.

The permeability measurements, room by room, are carried out using the same method, but attention must be paid to the flow between rooms through partitions which did not exist when the entire dwelling was subjected to a pressure difference.

The permeability calculations

In all the equations (1), with no wind, pressure π is equal to 10, and coefficient C is expressed in the form:

$$C1 = \frac{10}{(Q1)^2}; \quad Q1 + Q2 + \ldots = \pi.$$

Thus we may now solve the problem by making assumptions on 4 opening distributions.

Cell open on 2 sides

In practice this case is found in dwellings with single exposure, provided with natural ventilation, or in double exposure dwellings.

We shall discuss this in detail to show that the question of whether the openings are equal is not very important,

C1 and C2 being the characteristic coefficients of the openings,

k1 and k2 being the coefficients of pressure due to the wind, speed V, and

π being the internal pressure, we have:

$$k1\ V^2 - \pi = C1\ Q^2; \qquad \pi - k2\ V^2 = C2\ Q^2$$

from which we deduce:

$$Q = \left(\frac{k1 - k2}{C1 + C2}\right)^{1/2} V$$

Fig. 5 By choosing 0.32, it is seen that we cover ± 10% what occurs on openings equally distributed or in the ratio of 1 to 2, 0.33-0.66 or 0.66-0.33.

Fig. 6

Distribution of permeability on 2 facades.
Flow coefficient as a function of the angle of incidence

Fig. 7

It will be noted that the result must be increased by 10% if we have a distribution equal to the permeability. (sic ? - an equal distribution of the permeability ?).

Angle of incidence.

On the other hand, if we call α a number between 0 and 1 which expresses the proportion of the permeability of opening no. 1, we have:

$$10 = C1\ (\alpha Tr)^2 \text{ and } 10 = C2\ (1 - \alpha)\ 2\ Tr^2$$

from which we deduce:

$$Q = 0.316\ V\ Tr\ (k1 - k2)^{1/2} \left\{ \frac{(1 - \alpha)}{\sqrt{2\alpha^2 - 2\alpha + 1}} \right\}$$

Function f (α) is represented by a relatively flat curve (fig. 5).

It will be seen that: f (α) = 0.35 when the 2 openings are equal ($\alpha = 0.5$), and that f (α) = 0.29, i.e. the previous value reduced by 20 percent, when one opening is double the other, which means that by choosing 0.32 to distribute the uncertainties, at 10 percent, between the two extreme cases, flow Q would be written thus:

$$Q = 0.1\ V\ Tr\ (k1 - k2)^{1/2}$$

and would cover the configurations in figure 6.

This formula has been applied on 3 buildings as a function of the angle of incidence of the winds, thus different k coefficients (fig. 7).

In particular it will be seen that the flow varies considerably with the angle of incidence of the wind, since it may be equal to 0.9 V Tr or 0, and it might then be thought that the direction of the openings in relation to the prevailing winds would give very different results. In reality this is not as serious as it would appear on first analysis.

It will already be observed that if the winds were equiprobable, the difference between the 2 configurations - parallel facades (0.56) or perpendicular facades (0.48) - is not great.

In figure 8 the percentage path travelled by the wind at Orly (i.e. the product of the speed by the time) is plotted as a function of the orientation; it will be seen that the differences are considerable. In the calculation, a dwelling, with double exposure at an angle, selected because it exhibits a high degree of anisotropy, is subjected to this wind.

The results are given in table I.

The mean value is 0.0506, with discrepancies generally lower than 10 percent, except four values out of fifteen, which differ by ± 20 percent.
It will be observed that the value provided by equiprobable winds is 0.048.

Thus it is not incorrect to use for this case results equal to those which would have been obtained with equiprobable winds, noting that discrepancies of ± 20 percent could be found in one out of four cases, but more generally discrepancies of ± 10 percent.

Study of other cases

Openings distributed not on 2 sides, but on 3, 4 or 5 sides may be assumed, with equal distributions; the coefficient to be applied to each opening is used in table II below.

The calculations are carried out in the same way, and the results are shown in figure 9. Assuming winds equiprobable in direction and speed, the C coefficients below are found, for application in the formula:

$Q = C\ V\ Tr$

to obtain the mean annual flow rate:

Openings distributed on 5 facades: 0.06
Openings distributed on 4 facades, in double flow: 0.068

Openings distributed on 2 parallel facades: 0.062

Openings distributed on 2 perpendicular facades: 0.053

Table II

Number of openings	2	3	4	5
$^{Q}/_{Tr}\sqrt{\Delta p}$	0.16	0.105	0.08	0.063

Table III

Angle of incidence	0	22.5	45	67.5	90	112.5	135	157.5	180
$\frac{S2}{V\ T_2}$	0.059	0.066	0.07	0.054	0.06	0.054	0.051	0.052	0.059
Error in relation to mean value	0.99	1.11	1.17	1.11	1	0.90	0.85	0.86	

Fig. 8 $\%\ \frac{\text{Path travelled by the wind in one direction}}{\text{Path travelled, whatever the direction}}$ At Orly in one year

Fig. 9 Flow coefficient as a function of the angle of incidence

------ 2 facades and 1 roof : Mean value 0.058
__- __ 5 facades : Mean value 0.060

——— 4 double flow facades: Mean value 0.068

Incidence

Openings distributed on 1 facade and one roof: 0.042

By choosing 0.06 all cases are generally covered, ± 10 percent.

The more the openings are distributed (dispersed), the less important the direction of the wind. But in fact equiprobable winds do not exist. What, then, is the actual situation?

For control purposes, the annual flow coefficients for a dwelling open on 2 facades and the roof, located at Orly, were calculated on the basis of meteorological data relating to wind. The results obtained are given in table III.

The mean value $\frac{Q}{VTr}$ is 0.06, with a discrepancy of ± 15 percent.

It may therefore be concluded that a knowledge of Tr enables the mean annual flow crossing the dwelling to be forecast with a relatively low risk of error using the formula:

$Q = 0.06\ V\ Tr.$

If we know the exact position of the openings in relation to the prevailing winds, we may use correction coefficients, by reducing or increasing by ± 20 percent. We shall see that these corrections, interesting as they may be, are insignificant in relation to the Tr's found in reality.

V remains to be determined. The average speeds of the winds at Orly, Le Bourget and at St-Maur were plotted in figure 10 for the different directions. The result was 2 types of mean annual values, according to whether the winds whose speed is lower than 2 m/second are included or not. These are listed in table IV.

Table IV

	General mean value for winds	Mean value for winds with a speed greater than 2 m/s
Orly	3.71	4.48
Le Bourget	3.83	4.73
St-Maur	2.87	3.91

It will be seen that the choice of wind speed introduces an additional error factor.

The effect of thermal draught

Thermal draught is capable of developing a pressure

$\Delta p = 0.044 \, h \, \Delta T$,

where:

h is the height in metres,

ΔT is the difference in temperature, in °C, between the inside and the outside. It therefore creates sets of pressures, as shown diagrammatically in figure 11.

Since the inlets facing outwards are assumed to be distributed into 2 classes, we know that we can write:

$$Q = 0.16 \, Tr \sqrt{\delta p}$$

δp being the effective difference in pressure at each inlet, either as a mean value:

$$Q = 0.16 \, Tr \sqrt{\frac{0.044 \, h \, \Delta T}{4}} \quad \text{or:}$$

$$Q = 0.017 \, Tr \sqrt{\frac{4}{h \, \Delta T}}$$

In the case of a dwelling on a single level
($h = 3$ metres and $\Delta T = 15^{\circ}C$)
$Q = 0.11 \, Tr.$

In the case of a dwelling on 2 levels:
($h = 9$ metres and $\Delta T = 30^{\circ}C$)
$Q = 0.28 \, Tr.$

The combined effect of the wind and thermal draught

If we wish to combine the effect of the wind and thermal draught, the calculations are the same, but much longer.

Average 1: Mean value for winds 2 m/sec. Average 1 Average 2

Wind speed
in metres/second

Fig. 10 Direction.

Fig. 11

It will be observed that the flow due to thermal draught decreases when the wind increases, only to rise again. This is explained by the fact that the excess pressure due to the wind compensates for the excess thermal pressure at the top of the dwelling, whilst at the same time, but on the other side, the low pressure due to the wind compensates for the low thermal pressure at the bottom of the dwelling.

Half the air inlets or outlets are therefore ineffective, and the flow passes through a minimum, which may be as much as 70 percent in the extreme cases of the right direction. For the average wind, which interests us, it may be considered that this effect is weak, and it may be stated that the permeability flow is greatest by:

$$Q1 = 0.06\ V\ Tr$$

$$Q2 = 0.017 \sqrt{h \Delta t}$$

Observing that Q1 is greater than Q2 when the wind speed is greater than 2 m/s and $h \Delta T$ less than 50, which is the case with a dwelling on one floor, $\Delta t = 15^{o}$, mean value in winter, only:

$$Q = 0.06\ V\ Tr$$

may be used to calculate the estimated heat consumption due to permeability, selecting the average of the winds whose speed exceeds 2 m/s, i.e. for the Parisian region 4.5 m/s (in the knowledge that at St-Maur 3.90, and at Le Bourget 4.75 would have to be taken).

If the dwelling is on 2 floors, the flow must be increased by 8 percent; in fact, the flow due to thermal draught exceeds the previous flow by 4 percent if the wind speeds are lower than 2 m/s, i.e. for 20 percent of the time.

If the dwelling comprises 3 floors, the flow must be increased by 12 percent.

The speeds of the wind are plotted in figure 12 on the x-axis, and the hourly renewal, as a function of the rate of permeability, which is permeability Tr divided by the habitable volume, is indicated in the y-axis: $Tr = 0.06\ V$.

If we have no exact data on the wind, we may choose $V = 4$ m/s if we know that each m3/h which crosses a dwelling consumes an average of 25kW/h per annum; we may estimate the losses due to permeability, which are:

$$E = 6\ Tr\tau$$

It is obviously possible to improve the estimate, bearing in mind what has been said previously.

It should be noted that 1 cm2 of additional opening costs 6 kW per annum.

Some consequences

o Natural ventilation is provided on the basis of various openings strategically positioned, which will be permeability elements. A natural ventilation system is a special permeability type. To achieve an hourly renewal of 0.7 vol/hour, the permeability must be 4, sometimes 5, if the average wind is light. This is obviously not enough, for here again the distribution must be satisfactory between each room and the technical rooms (kitchen etc.).

It will be observed that the direction of circulation remains uncertain. Considerable sensitivity to winds will also be noted.

A wind of 6 m/s involves an hourly renewal of 1.5, and an absence of wind 0.5 vol/hour for the average thermal draught in winter.

As a guide, 120 m2 of equivalent opening area, i.e. 60 cm2 per facade, is required to ventilate a room with a volume of 30 m3.

If we know that a self-adjusting low pressure air inlet (used incorrectly as a natural ventilation system) only represents 22 to 23 cm2 of equivalent area, we shall have an idea of the origin of the condensations leading to mould.

o Given a permeability rate of 4, mechanical ventilation is of no interest, and the energy consumptions are greater than in natural ventilation; the installation of mechanical ventilation is only useful where there is no wind.

o Given a permeability rate of 2.5, mechanical ventilation becomes necessary, unless the average rate of renewal is 0.4 vol/hour. On the other hand, wind protection is not very good. From 3 to 4 m/s transversal ventilation is added, i.e. overconsumption.

o Given a permeability rate of 1, it is necessary to have good mechanical ventilation. The overall stability of the flows is remarkable and there is no excessive loss to the air up to winds of 8 m/s, which is very rare. However, it should be noted that the excess consumption is effective (considerable) from 5 to 6 m/s for preferential directions, if the dwelling is not provided with self-adjusting air inlets.

Thermal draught corresponding to $\Delta t = 15^{\circ}C$

Number of volumes/hour

Mechanical ventilation with $\frac{Tr}{Vh} = 4$

Thermal draught with $\frac{Tr}{Vh} = 4$

Mechanical ventilation with $\frac{Tr}{Vh} = 2.5$

Thermal draught with $\frac{Tr}{Vh} = 2.5$

Mechanical ventilation with $\frac{Tr}{Vh} = 1$

Thermal draught with $\frac{Tr}{Vh} = 1$

Fig. 12

Wind speed in metres/second, whatever the wind direction.

o Given a permeability rate of 1 in a flat or house measuring 100 m2 (i.e. 250 m3), all the openings on the outside must have an equivalent area of 250 cm2. 6 air inlets, with a total area of 150 cm2, are generally fitted. The remaining openings must be of the order of 100 cm2, which is not difficult to achieve with modern joinery. On the other hand, a cross bar not in position, allowing a clearance of 15 mm at the bottom of the door, represents 100 cm2. It will be observed that such an occurrence, which is frequent, not only costs 600 kW per annum, but also reduces the ventilation in each room by 40 percent.

o What is the effect of permeability on the double flow systems?

First of all it will be noticed that the coefficient 0.06 becomes 0.066 in this case because of the mean pressure, which is equal to the outside pressure.

A permeability rate of 1 gives rise to a transversal flow of:
0.066 x V x 250 = 66 m3/h
i.e. an energy consumption of 1,650 kWh. The flow would not be passed by simple extraction, but it should be noted that the removal of the facade inlets would produce a permeability of 0.5.

With a permeability rate of 2.5, a simple mechanical extraction system would have consumed, given a rate of 0.7 vol/hour, 175 m3/hour on average, i.e. 4,400 kWh. With a double flow system, the following would have been consumed: 2.5 x 0.066 x 250 x 4 = 4,100 kWh. The use of double flow with recovery is of no interest in this case. Well over double the ventilation would simply be obtained.

For a double flow system with heat recovery to be of any interest at all, the permeability rate must be of the order of 0.5, which is rarely the case.

o During the measurements we carried out we found permeability rates of 5 in mechanical ventilation, with quite considerable excess energy consumptions.

Conversely, we found permeability rates of 1 in natural ventilation, which is an aberration. Even when opening windows throughout the day, which increases the losses, disorders occur quickly due to the absence of air renewal.

o The important factors in permeability are:

open, not closed fire chimneys;

the passage between the outside and inside through the insulating material and the skirting board (very important)

the roller blind cases;

garage doors facing the dwelling or doors in the basement;

outside doors;

the clearance between the frame and ground beam (shelf) of woodwork;

communications with the sanitary vent around the water pipes, electric cables, etc.;

the woodwork is generally of a high standard, often type A3, i.e. it allows 1 m3/h to pass through at 10 pascals. It is equivalent to 1 cm2, whilst woodwork of type A1, previously used, allowed 10 times more to pass through (between 4.3 and 13 m3/h).

It is easy to measure the air permeability of a house or flat. The result of this measurement provides a very simple explanation of the faults, and reveals disorders which must not be attributed to ventilation but which, on the other hand, prevent it from operating satisfactorily.

If the consumption balances do not comply with the forecasts, in cases where there is condensation and if we wish to experiment with new systems such as: heat pumps, solar heating, recovery by exchanger, superinsulation, it seems to us that a permeability measurement is necessary to reveal, a priori, any distortions in the results, or to allow defects to be remedied, by taking the appropriate measures, before the measurements are carried out.

Pierre JARDINIER
Consultant Engineer.

Les Quatre Vents. Gravure par Normand fils (XVIII^e). Borée, le vent du Nord. Bibliothèque Nationale

Doc. Roger-Viollet

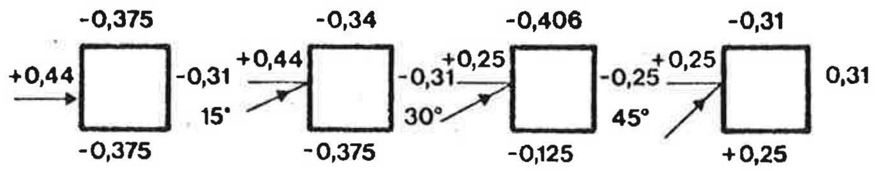


Fig. 1 : valeur du coefficient k suivant l'angle d'incidence du vent

Pression sur une façade en fonction de l'angle d'attaque

Fig. 2

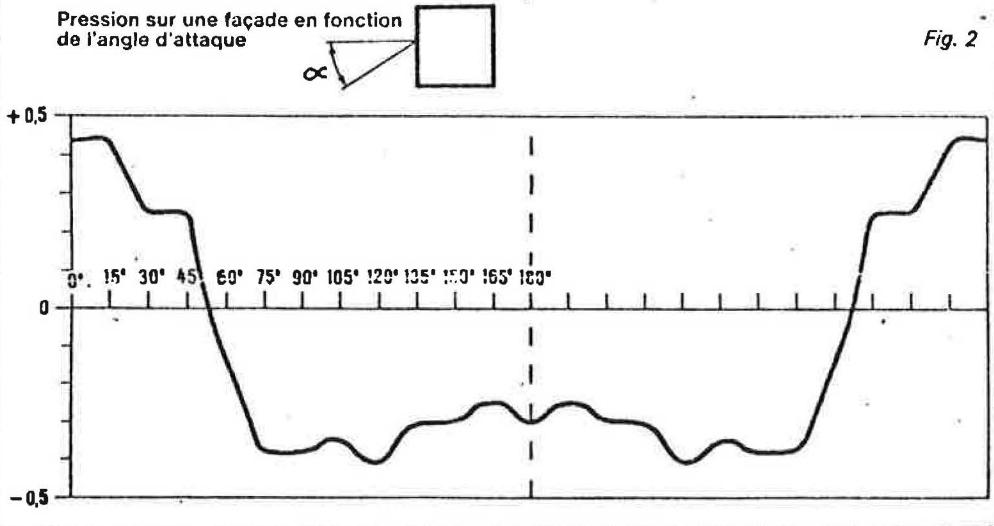


Fig. 3 : le tirage thermique

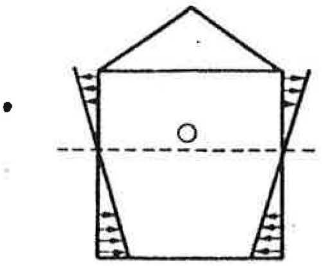


Fig. 4

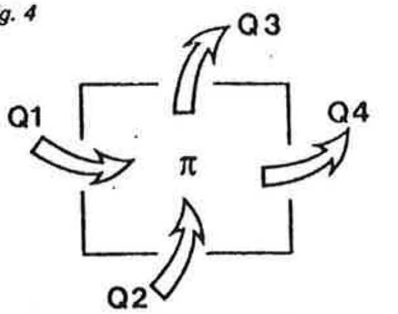


Fig. 5

En choisissant 0,32 on voit que l'on couvre à ± 10 % ce qui se passe sur des ouvertures également réparties ou dans le rapport 1 pour 2, 0,33-0,66 ou 0,66-0,33

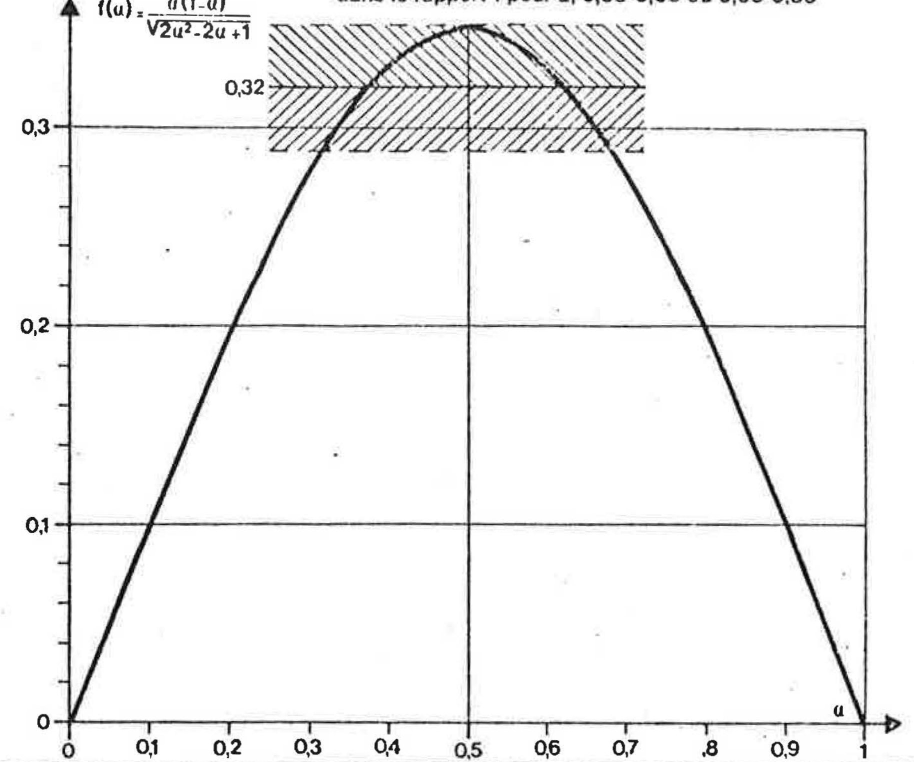
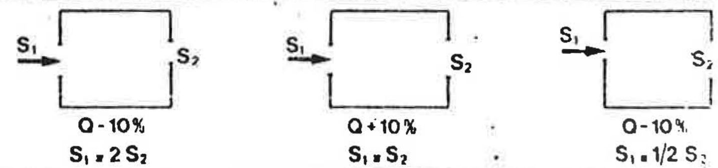
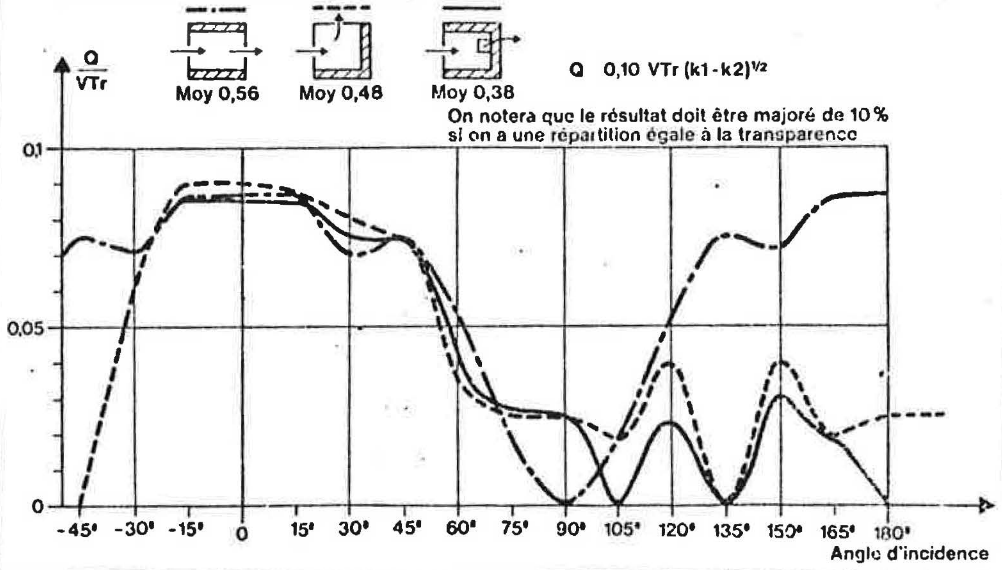


Fig. 6



Répartition de la transparence sur 2 façades
Coefficient de débit en fonction de l'angle d'incidence

Fig. 7



$Q \quad 0{,}10\ VTr\ (k1-k2)^{1/2}$

On notera que le résultat doit être majoré de 10 % si on a une répartition égale à la transparence

Fig. 8

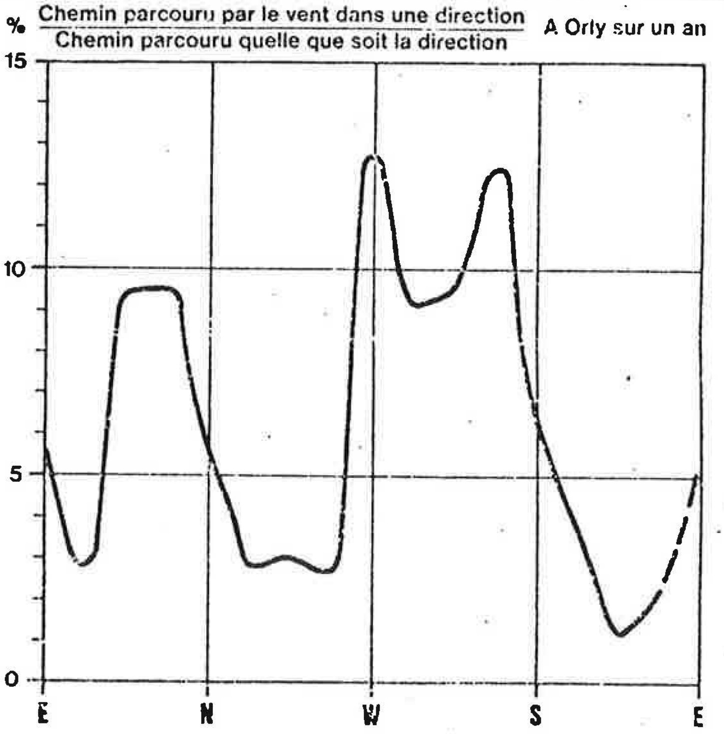
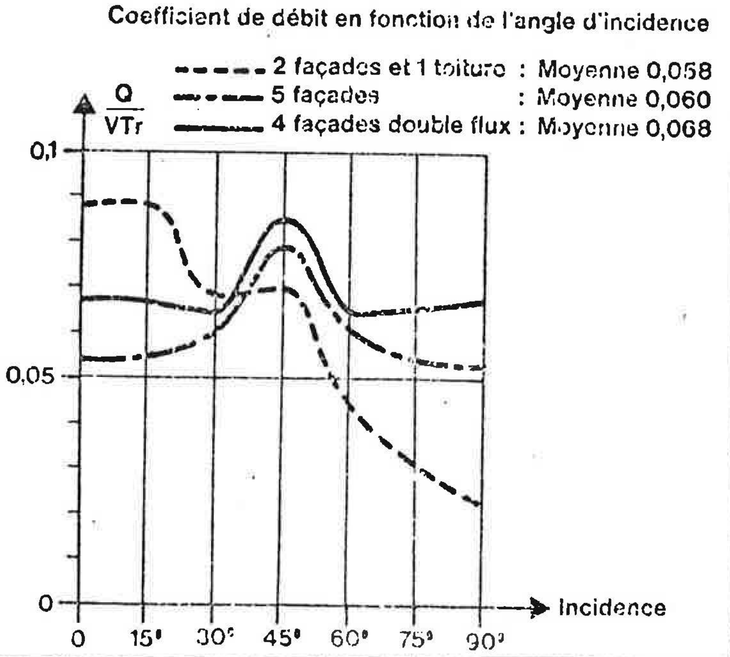


Fig. 9



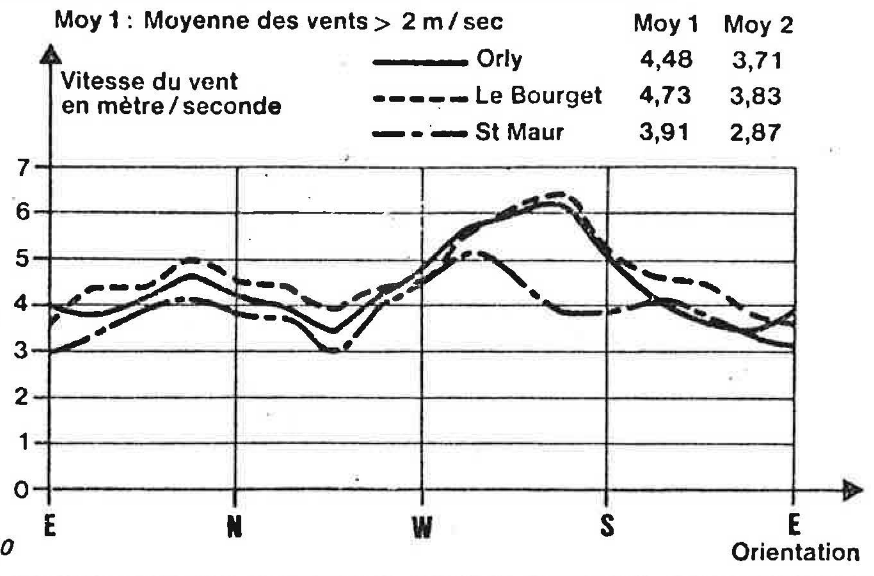


Fig. 10

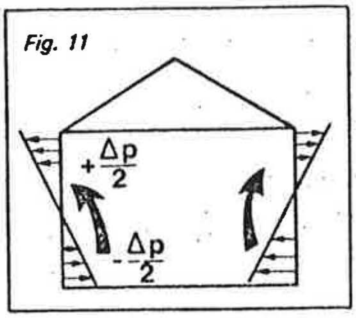


Fig. 11

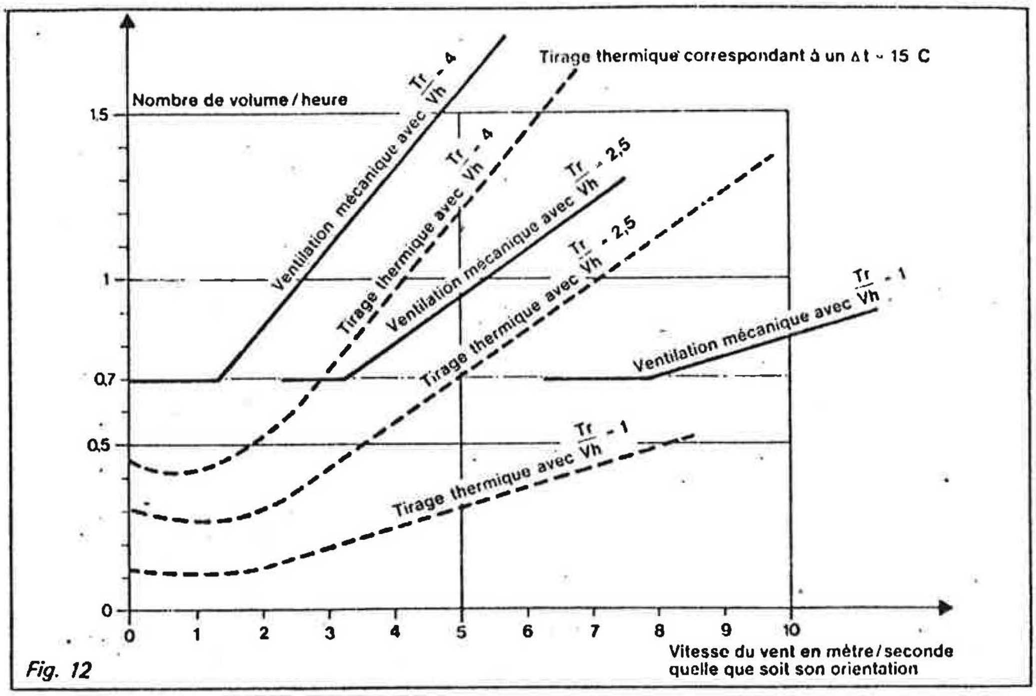


Fig. 12

Tableau I

Incidence	0	22,5	45	67,5	90	112,5	135	157,5	180	202,5	225	247,5	270	292,5	315	337,5	Moyenne n
$\frac{Q}{V T_2}$	0,040	0,041	0,05	0,056	0,06	0,051	0,051	0,053	0,05	0,049	0,054	0,05	0,054	0,051	0,045	0,046	0,0506
Erreur par rapport à la moyenne	0,79	0,80	0,99	1,10	1,19	1,20	1,12	1,05	1	0,96	1,06	0,99	1,07	1	0,89	0,91	