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AIR INFILTRATION CONTROL METHOD : SEALING THE JOINTS

MARIO GROSSO
GABRIELLA PERETTI
DANIELA GONELLA
LUCIANO VICARI

Abstract

The specific aim of the research program reported in this article was to test and evaluate the air-infitration control methods employed in buildings.

One technique has been thourougly considered:sylicone sealant on opening joints of external windows applied in situ;it allowed an increase of reflections on the methods for evaluating the building envelope air-permeability,in addition to the evaluation of the energetic effects and the economic advantage of the method.

The majority of existing buildings in Italy consists of dwellings not built according to energy savings standards;energy saving tools for retrofitting existing buildingshave thus,a great potential from an overall strategical point of view.

Tests were done both in laboratory on window samples and in the field on a test building. It allowed us to check the effect of the method either on single window air-permeability rate and on the energy loss due to air-infiltrations/exfiltrations through the building envelope. We regard our results as the first of an experimental series,that will have to deal with the open problem of air-infiltration control and its significance as far as energy conservation is concerned.

Air-infiltrations through the windows

Air-infiltrations through windows are air flows induced by pressure difference between indoor and outdoor.

Pressure difference depends on two main sources:

- wind action;
- thermal force.

Indoor air pressure is caused by :

- wind stop pressure;
- wind direction;
- opening and fix joints resistance;
- joints position;
- environmental building context surrounding the dwelling.

External air comes in from the windward side of the building and the suction on the leeward side makes easy the phenomenon.

The effect of temperature on the thermal force,expecially during the winter and on tall buildings is due to the density difference among air-layers at differents temperatures.

When the indoor temperature(ti) is greater than the outdoor one(te) the external air is sucked in again,while at the higher floors it is pushed out.

Therefore,air-infiltrations depend on window and building characteristics.

The most remarkable of them are:

- windows sizes;
- opening systems;
- accessories characteristics;
- joints geometric characteristics;
- glass system;
- window height from the ground;
- window placing in comparison with the building shape.

Evaluation of the air-infiltrations through a building envelope

The air-capacity due to infiltrations Q,in a building is expressible with the rate:

$$Q = A\,C\,(\Delta P)^n \qquad (1)$$

where:

A is the area or the perimeter of the opening joints of the window;

C is the"flow coefficient".It is a proportionality coefficient that introduces the influence of the airtightness of the window,or the considered element in the relation;in tab.1 you can see the values of "C" in according with the different classes of windows (UNI standards). From (1):

$$C = \frac{Q}{A(\Delta P)^n} \qquad n=0.65 \qquad (2)$$

or for unit sizes:

$$C = \frac{Q}{(\Delta P)^n} \qquad (2a)$$

The air permeability value changes with ΔP variations,(exponential function) and C can be considered the air-permeability value every Pa^n of ΔP

It is expressed as $m^3/hmPa^n$ or m^3/hm^2Pa^n

n is an index that depends on differents flow models;his value changes between 0.5 and 0.65.For windows,generally the value:0.65 is used according to UEAtc and UNI standards.

ΔP is the pressure difference due to the combined effect of wind and thermal force.

CLASS	C_l $(m^3/hm\ Pa^{0.65})$	C_s $(m^3/hm^2 Pa^{0.65})$
NC	0.60	2.50
	0.60	2.50
A1		
	0.30	1
A2		
	0.10	0.35
A3	0.10	0.35

Tab.1

Wind action

When the wind meets with an obstacle,its velocity is modified around it;it is slacked by the meeting surfaces,and so it produces a suction. At the same time it is deviated and accelerated along the side walls and by the roof,where a suction zone is produced.

The pressure difference due to the wind action is:

$$Pv = \frac{1}{2} v^2 \, Cp \, \rho$$

where:

ρ is air density (1.2 Kg/m^2);

v is the local wind speed and it is equal to:

$$v = v_m \, (d_m / h_m)^{\beta m} (h_e / d_e)^{\beta e}$$

where:

$\underline{v}$ is the meterorological wind speed (m/sec.)The data about wind velocities are contained in the I.S.T.A.T.year-book of meteorological statistics.In it there are the concerning wind speeds data that come from the observations of 130 stations located in open country at the height of 10 mt. from the ground. The data refer to 8 directions.The unit of measure is the knot.

From the statistic and meteorological data can be obtained an average value of wind speed,independent by the direction,with the relation:

$$Vm = \frac{F\ V}{Ftot.}$$

where:

V is the average value of wind speed;

FV is the summation of the frequency product,in every octant by the relatives average speeds;

F tot. is the total of the frequencies.

Having to refer to the whole heating season,the thus found average value of V has to be "flattened" to consider the calm periods.

The value to utilize is :

$$V\ stag. = \frac{VF}{F+C}$$

where:

F is the total of frequencies;

C is the total of "calms"

Italy has been divided in three parts that correspond to wind zones of the UNI standard UNI 10012/67:

- 1st part: wind zone 1
- 2nd part: wind zone 2 and 3
- 3rd part: wind zone 4

In the following table you can see the average values of wind speeds according to the above mentioned zones:

ZONE 1: V=0.6 m/sec.

ZONE 2-3:V=4.1 m/sec.

ZONE 4: V=7.2 m/sec.

d is the boundary layer thickness;it fixes the area in which the wind speed value,in parallel to the contact surface direction, is less than 99% of the free stream speed (i.e.:without any slowing due to obstacles);

β is the characteristic exponent of the boundary layer.

In tab.2 you can see the different values of **d** and β according to three geographic situations

	d	$1/\beta$
open country	280	7
suburb	400	3.5
center of the city	520	2.5

tab.2

Table 2.

$h/w<1/2$	$1<l/w<3/2$	Cp	$A = -1.2\partial/90 + 0.7$
			$B = -0.3\partial/90 - 0.2$
			$C = 1.2\partial/90 - 0.5$
			$D = 0.3\partial/90 - 0.5$
	$3/2<l/w<4$	Cp	$A = -1.2\partial/90 + 0.7$
			$B = -0.25\partial/90 - 0.25$
			$C = 1.3\partial/90 - 0.6$
			$D = 0.5\partial/90 - 0.6$
$1/2<h/w<3/2$	$1<l/w<3/2$	Cp	$A = -1.3\partial/90 + 0.7$
			$B = -0.35\partial/90 - 0.25$
			$C = 1.3\partial/90 - 0.6$
			$D = 0.35\partial/90 - 0.6$
	$3/2<l/w<4$	Cp	$A = -1.2\partial/90 + 0.7$
			$B = -0.2\partial/90 - 0.3$
			$C = 1.4\partial/90 - 0.7$
			$D = 0.6\partial/90 - 0.7$
$3/2<h/w<6$	$1<l/w<3/2$	Cp	$A = -1.6\partial/90 + 0.8$
			$B = -0.55\partial/90 - 0.25$
			$C = 1.6\partial/90 - 0.8$
			$D = 0.55\partial/90 - 0.8$
	$3/2<l/w<4$	Cp	$A = -1.2\partial/90 + 0.7$
			$B = -0.4\partial/90 - 0.4$
			$C = 1.5\partial/90 - 0.7$
			$D = 0.6\partial/90 - 0.7$

d_m; m concern the meteorological station;

d_e; e concern the place where the building is;

h_e is the height of the considered ambient;

h_m is the height of the place where the anemometer is set;

Cp is the pressure coefficient.It depends on the height and the form of the building and on the wind direction.We can find the average values of Cp from the following graphs.Every graph refers to different rates between length and width and between the heigth and width of the building.(see fig.1 and 2)

The air-infiltrations,due to the wind action are,substituting (3) in (1):

$$Qv = A\ C\ (\frac{1}{2}\ v^2\ Cp\ \rho)^n$$

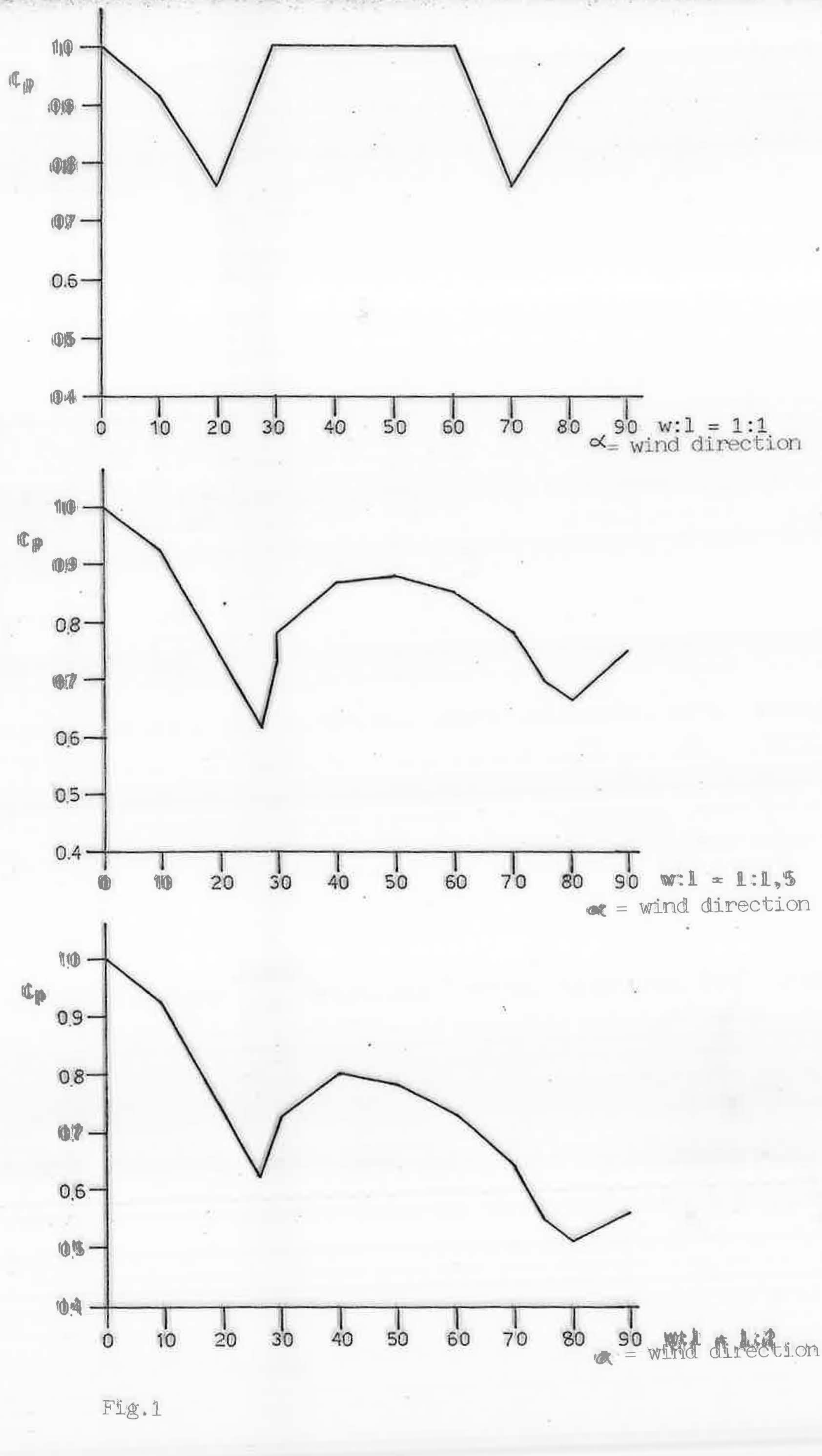

Cp
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0 10 20 30 40 50 60 70 80 90
w:l = 1:1
α = wind direction
w:l = 1:1,5
α = wind direction
α = wind direction

Fig.1

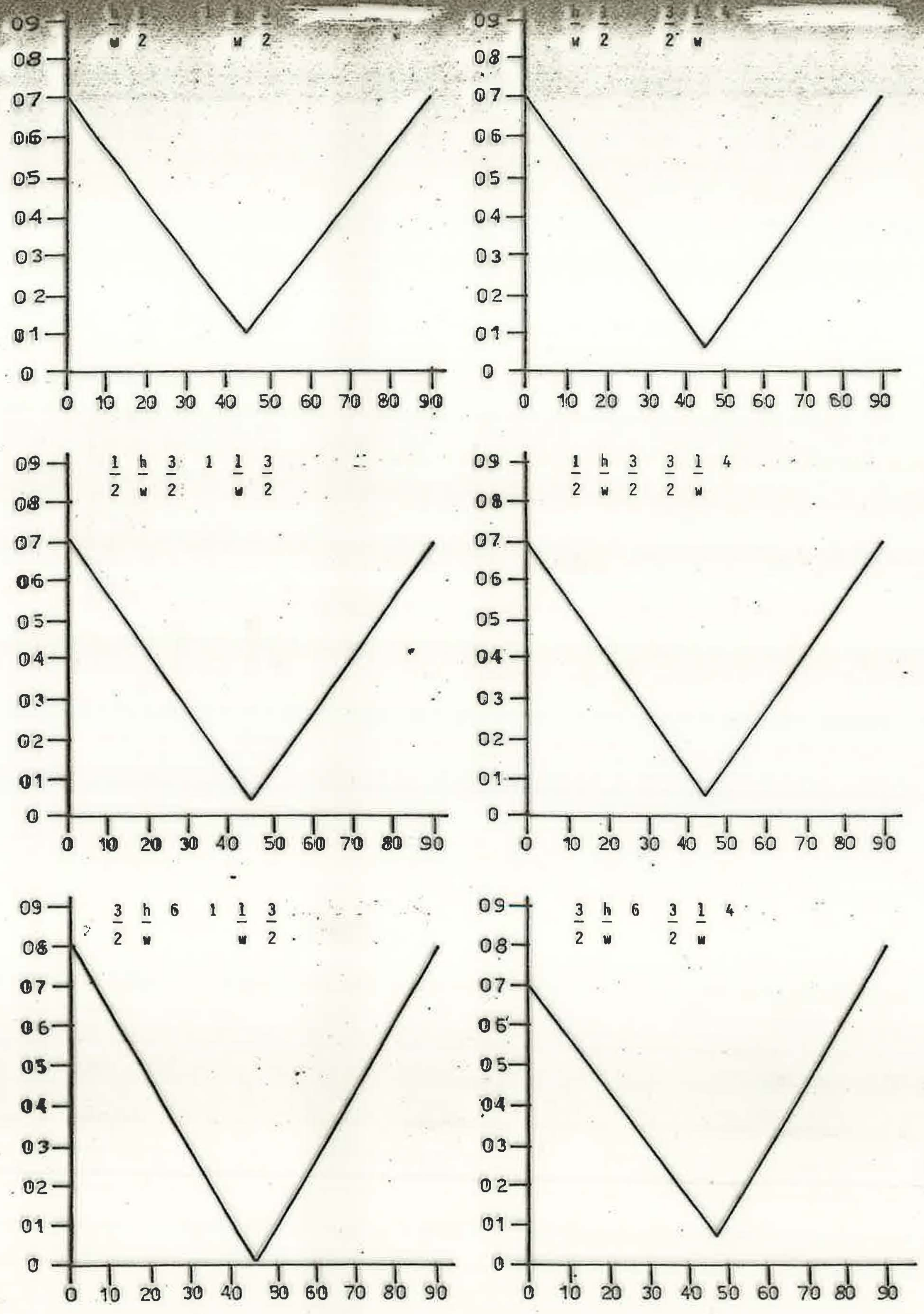


Fig 2

THERMAL FORCE

It is the temperature gradients between the indoor and outdoor air.

When the indoor temperature is greater than the outdoor one,the thermal force,at the different air-density,produces an internal suction in the lowest floors and an internal pressure in the highest ones.

There is,therefore an horizontal plain(called neutral point) on which, without other phenomenon,internal pressure is equal to external one.

The pressure difference between indoor and outdoor due to thermal force is given by:

$$\Delta Pc = 0.0342 \; py \left(\frac{1}{273+te} - \frac{1}{273 + ti}\right) \qquad (6)$$

where:

p is the atmospheric pressure that varies with the heigth;

y is the heigth of the neutral point of the building;

ti is the indoor temperature

te is the external temperature,we assume the average of the external temperature at the nearest meteorological station to the place where the building is,during the heating season.

The air-infiltrations due to the thermal force are given by:

$$Qc = A \; C \quad 0.0342 \; p \; y \left(\frac{1}{273 + te} - \frac{1}{273 + ti}\right)^{n} \qquad (7)$$

The combined effect of wind action and thermal force

The total infiltration rate is not the simple sum of the two flow rates (wind action and thermal force).

The reason for this can be seen by considering the air entering and leaving the building. Air entering the building on the windward side due to natural ventilation will be at the same temperature as the external air;it will then have to change its temperature to that of the internal room air temperature and it will then leave the building on the leeward side at this room temperature.

It's only the air entering the building on the windward side which has to be changed in temperature;Shaw e Tamura proposed the following expression:(3)

$$Qvc = Qmax \left[1 + 0.24 \left(\frac{Qmin}{Qmax}\right)\right]^{0.33} \qquad (m^3/h)$$

where:

Qmax and **Qmin** are the maximum and the minimum of the values of Qv and Qc.

TEST METHODS AND RELATIVE INSTRUMENTATION

The laboratory experimental tests follow the UNI EN 42 standard.

ACOUSTIC METHOD

It consists of the comparison between the sound-insulating power and the air-permeability characteristics of a window with acoustic insulation reliefs and with the relationships between the two phenomenona(4).As regards the air-permeability,the capacity value at the pressure of 100 Pa (Qs 100) is assumed as global parameter.

In fig.4 you can see the sound-insulating power loss Δ Rw and attenuation Δ Ra as function of the air-capacity (Qs 100) logarithm and the classification limits fixed by the UNI windows standards. In tab 4 the individual experimental values for differents windows types and for differents test conditions from the best sealing point are reported.(i.e.:of the greatest acoustic efficiency to 1)

FIXED LABORATORY

It is a laboratory where some tests are done on the windows and it has a fundamental equipment consisting of:

1) a tight-room with an opening on which the window to be tested is fixed by its support frame;
2) an apparatus that allows the creation of a controlled pressure difference between the window's faces;
3) an apparatus that allows the acquisition of a speed and controlled variation of pressure difference within fixed limits;
4) a gauge to measure the in-out tight room air-flow;
5) a gauge for the pressure difference between the two faces of the window.

The window to be tested has to be contained in a support frame. It has to be rigid to tolerate the test-pressure,without deformations. The window has to be fixed perpendicularly,without torsions and flexions;it has to be all clean and dry;the thickness and the kind of the glasses have to be in conformity with the standards.

The windows have to be subjected to gradually increasing positive pressure.

Experimental evaluation of the air-infiltration through the windows

The evaluation of air-permeability of external windows refers to UNI 7979 standard: "Classification based on air-permeability,water proofing and wind resistance".

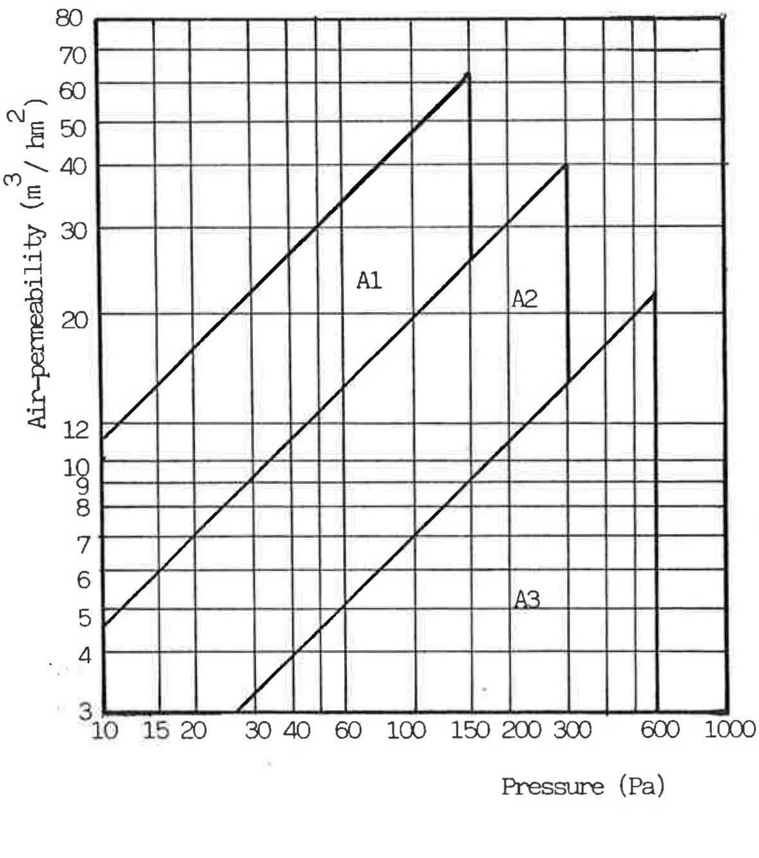
According to this rule,the components subjected to the UNI EN 42 test are classified as follows:

CLASS A1: When the value of the air-permeability is in the space A1 of the graph.

CLASS A2: When the value of air-permeability is in the space A2 of the graph.

CLASS A3: When the value of air-permeability is in the space A3 of the graph.

When the value of air-permeability doesn't fall into any class of the graph,the window is not classifiable.



METHODS TO LIMIT AIR-INFILTRATION THROUGH THE WINDOWS

There are two ways to operate in order to minimize the air-infiltrations through the windows:

- ready-made complementary packings;
- cast in situ packings.

The choice of the method has to be valued on the grounds of the window characteristics(typology,age and location) and it always needs the comparison between cost and benefit.

The first packings can be made of plastic and are cast with fasteners and screws,or more simply,they can be made of sponge and are self-adhesive. The self-adhesive sealants solve quite well the air-permeability problem as soon as they are placed,but they change their characteristics through time;the plastic packings wear better than self-adhesive ones.

Considering the known limits of this kind of sealan ts,the experimentation individualized specifically the second packings.

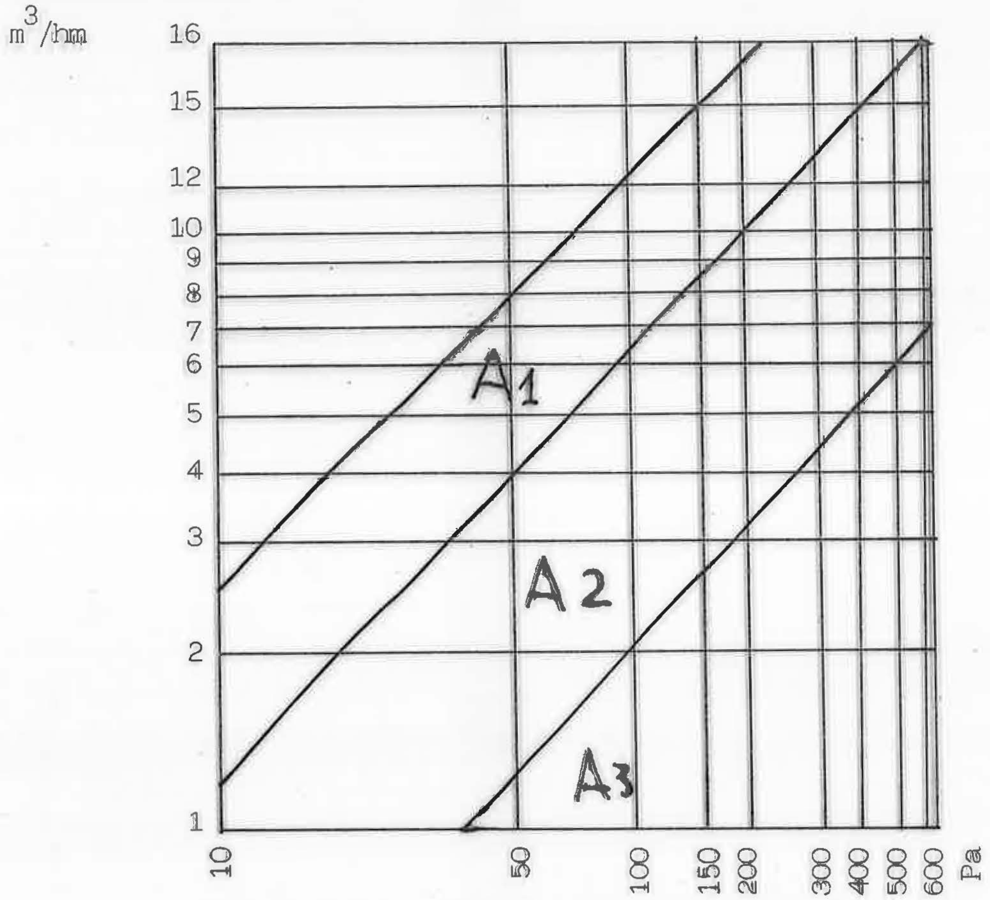
They are cast in situ in order to obtain the levelling of geometric unevenness existing in the frame and to compensate for every other defect. Therefore it's necessary to use a mouldable material that models itself to the joint shape and that doesn't change with time; silicone answers well to these needs.

Precisely an application technique that consists of the silicone rubber use has been tested.

It consists of moulding a packing to the window rabbet with the installation of silicone rubber;this material is very mouldable and is particularly indicated for windows that show defects and faults in the section between fixed and moving frames(generally these windows aren't classifiable or they belong to class A1 of the UNI classification:see tab.1)

It's possible,with the installation of silicone rubber,to reduce the winter heat loads,thus diminuishing considerably the window infiltration entity.(fig.3)

Fig.3 Air-permeability classification according to UNI standard 7979



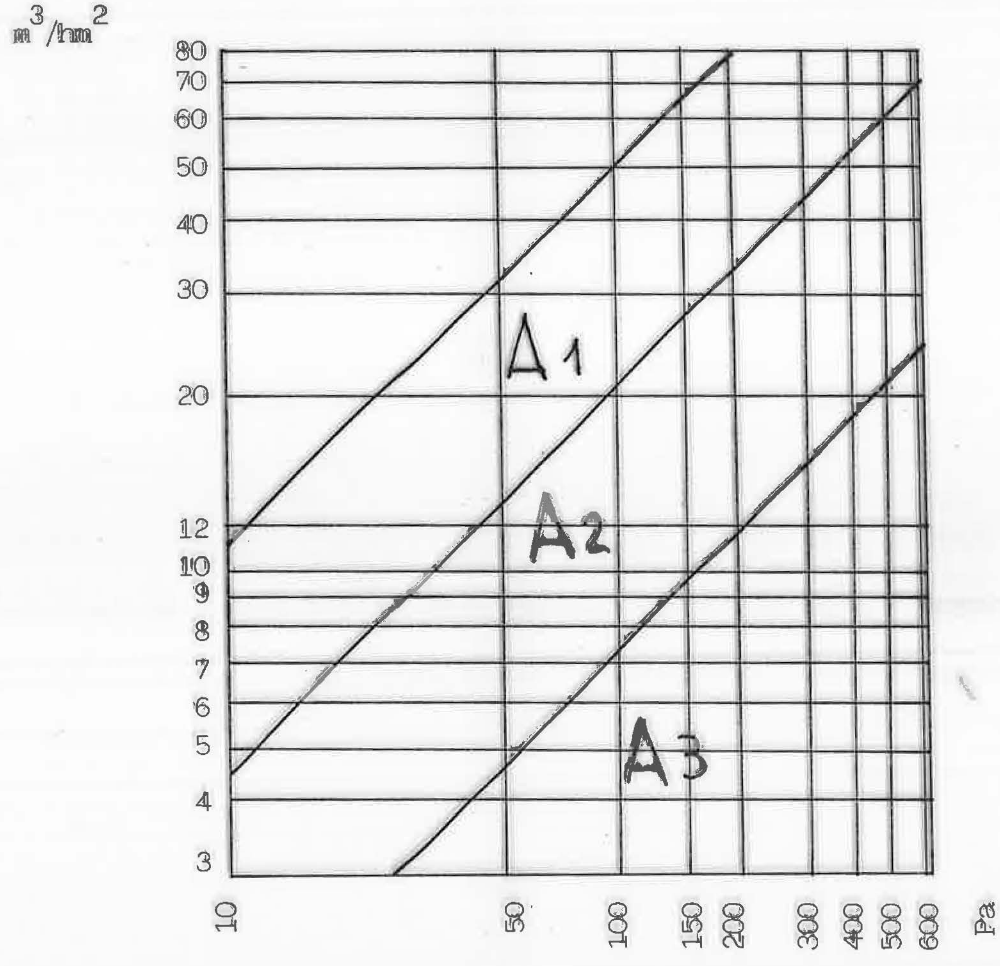


ILLUSTRATION OF THE METHOD

OPERATION SERIES:

1) Preliminary operations. These operations change according to the window characteristics.

2) Preparation of rabbets Take the grease off the rabbets between fixed and moving frame with methylated spirit or trichloroethylene

3) Priming-coat preparation Smear the frame of the windows with "primaire" and let exsiccate about 1 hour

4) Unsticking product application Apply one of the following unsticking products on the moving frame:

- a wax-talcum solution
- paraffin-oil
- polyethilene film
- adhesive tape

Choose the kind of unsticking product according to the frame material and shape.

The unsticking product has to be applied abundantly on the whole rabbet's area that is in contact with the relative window sahs when the window is closed.

5) Rubber preparation and application You can use translucid silicone rubber.The cattridge containing silicone has to be inserted in the gun after having inserted the flow regulation lug.

Cut the lug for the silicone exit according to the greatness of the interstices among the rabbets.Apply the rubber on fixed frame going from top to bottom and from left to right,inclining the gun at 45° on the horizontal plane and on the window plane; the sealant has to stick perfectly to the orthogonal surfaces of the rabbets.It is necessary to exert a regular and continual pressure on the gun,if the surfaces are particularly worn,or they show a great slack between the rabbets it would be opportune to spread another sealant coat till the interstices are completely closed.

6) Closure of the window Close the window well without forcing it;all the elements that contribute to the closure operation have to be completely performed.The window has to remain closed at least 24 hours.

7) Final operations Open the window using force.Remove the eventual sealant excesses,which have oozed out of the rabbets surfaces and you can leave or not the unsticking product on the frame.

This method is surely more laborious than the installation of ready-made packing;neverthless the greater complexity and the greater cost of the operation is compensated by the superior packing efficacy.

The silicone rubber has been applied on differents ages and building typology window-standards and on a whole building windows(in all about 4000 ml of joint).

To verify the window air-permeability variation,therefore in the following energetic consumptions between before and after the installation of the packing,differents experimental tests have been executed:

- direct test on windows-standard in laboratory;
- acoustic method test in a room of the building;
- coefficient of building global heating dispersion variation control, through the evaluation of the time constant with the "load-unload"of the (heating)system.

The first test furnished very different results because all the tested windows are not classificable in conformity with UNI standards: Cs range changes from 0.60 to 3 $m^3/hm^2Pa^{0.65}$.

The acoustic test, limited to only one room,showed that Rw,between the valutation index relative to valued sound-insulating power and the index relative to 2 experimental curves (before and after the sealant installation),passed from 8.5 to 4.5 dB.(fig.6)

Speaking of air-permeability it means a variation (100Pa)from 70 m^3/hm^2 to $18m^3/hm^2$ (i.e.: $Cs=2.6m^3/hm^2Pa^{0.65}$)

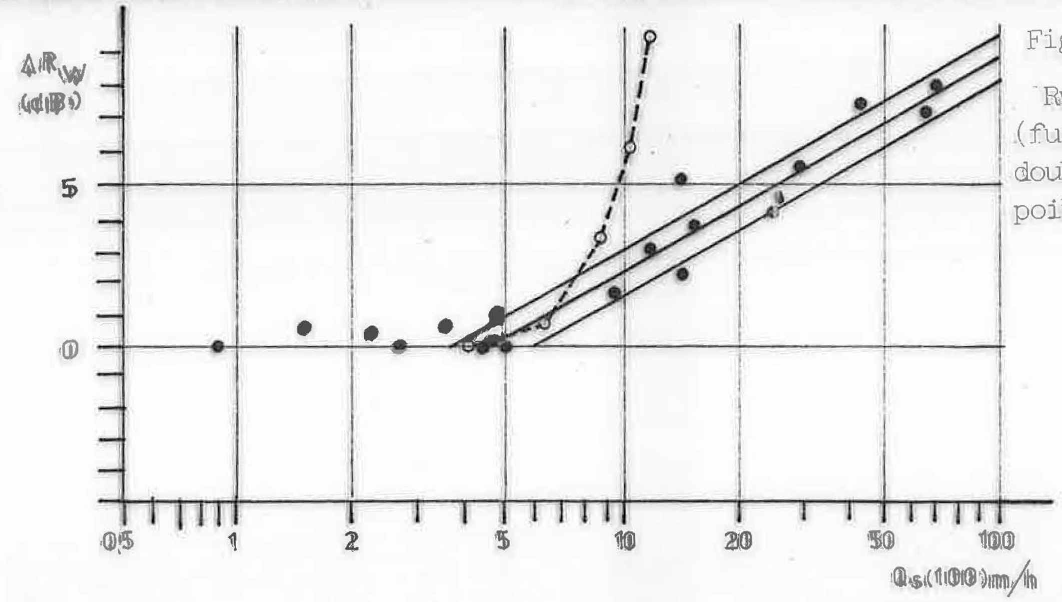


Fig.4
Rw for simple glass (full points)and for double glass (empty points)

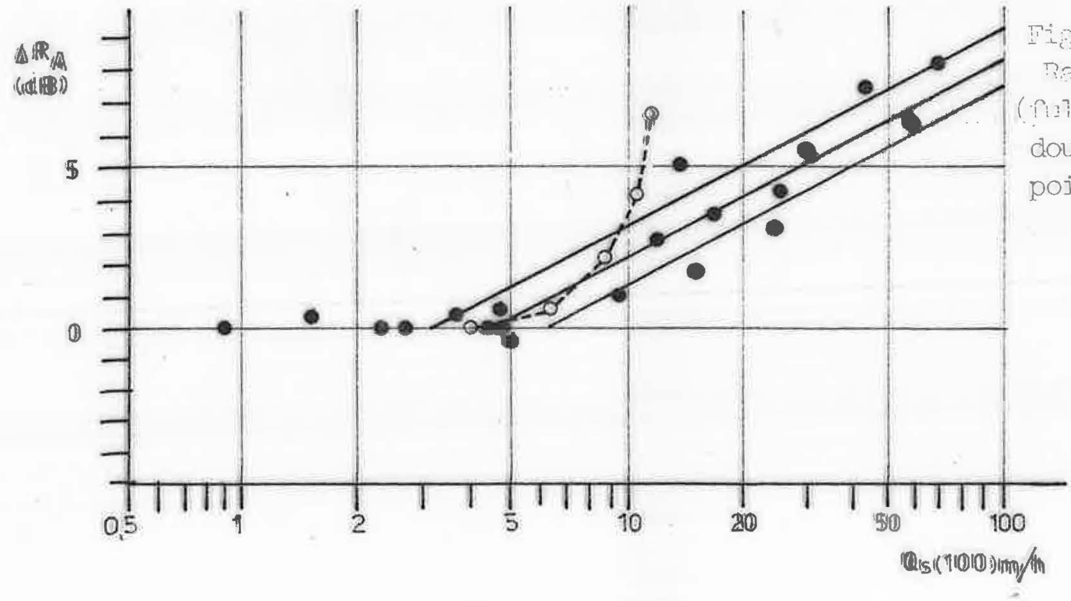


Fig.5
Ra for simple glass (full points) and for double glass(empty points)

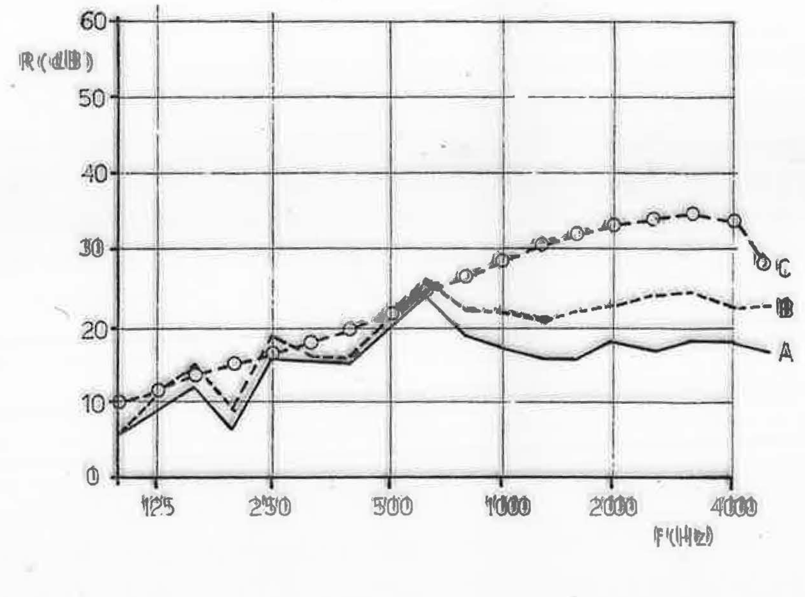


Fig.6
Soundinsulating power of a window before and after the installation of silicone packing (A- B)and of a tight glass (C)

The made tests,with the years of experience in experimental activity, induce us to say that the supposed unclassificable or A1 windows, because of the installation of the packing,go in a included between the high zone of A2 and the low zone of A1 band (fig.7);it is because the silicone acts till a certain level,surmountable only changing the joint geometry.

The third test-specific for the building heating loss-has obtained the reduction of K value from 25000 to 18900 Kcal/h°C corresponding to an energetic saving of 20% on the used fuel for an "average" heating season. (5)

The comparison between the experimental test results and the teoric method of the air-permeability calculation permitted us to convalid the hypotesis on the reduction of Δ C and to bring some arrangements to the calculation,in order to find a general method without experimental data (6).

The total air-capacity to heat in the season is given by:

$$Qvc\ h\ g$$

where:

h is the number of the hours in a day (24);

g is the number of the heating days.

The necessary energy rate is:

$$Evc = c\ Qvc\ h\ g\ \ t \qquad (10)$$

where:

c is the air specific heat (0.32Wh/m^3°C or 0.28 Kcal/m^3°C)
It is possible write the (10) also sobstituting ($g\Delta t$) by D:

$$Evc = c\ Qvc\ h\ D$$

The evaluation of the effects of the installation of the sealant on the heat loss considering that it intervenes only on the window's value of C can be given by the following operations:

- evaluate the windows'air-permeability after the sealing, supposing the new value of C (according with the new class of windows);
- calculate the Δ Qvc between before and after the sealing as follows:

$$\Delta Qvc = Qvc - Q'vc$$

- add 20% due to effects indirectly connected to installation of the sealant and directly connected to the general bond of the window. (Δ'Qvc)
- calculate the saved energy after the sealing:

$$Era = c\ Q''vc\ h\ D \qquad \text{(Wh or Kcal)}$$

$$\text{fuel gain} = \frac{Era}{Pci\ \eta} = l/\text{year}$$

where:

η is the combustion efficiency;

Pci is the heating power of the fuel;

l is the quantity of fuel (liter or Kg).

EVALUATION OF THE INCIDENCE OF THE EXTERNAL WINDOWS AIR-PERMEABILITY AND OF THE INSTALLATION OF THE SILICONE RUBBER ON THE SEASONAL ENERGY CONSUMPTION.

The evaluation of the incidence of air-infiltrations through the external windows joints,on the heat load in a building,is rather complex,on account of the changeable elements brought in the phenomena dynamics by the considered time unit:

- daily and monthly variations of wind speed and direction;
- temperature difference between indoor and outdoor.

The phenomena should have to be precisely divided,attributing to the different infiltration and exfiltration "ducts",adeguate to the specific situations shares(geometric shapes of the building, internal thermal force dynamics,rooms shape,number and localization of the opening,use model,external and internal radiations,heating system shapes and technologies,etc.....).

It is possible to suggest a very simplified hypothesis,on the ground of which it is assumed the internal air volume constancy and the continuous equality of the coming and the going out air-flow, in order to verify quantitatively,the energy load due to air-infiltrations and exfiltrations and in order to attribute it to the external envelopement elements;hence it is assumed that the air-flow has to be attributed to 50%of the area or of the opening joints perimeter responsible for the phenomenon.

The determination of the air-permeability of the external windows of a building during all the heating season,will be valued referring to half the windows area and considering average value of Δ P.

By the seasonal average values of Δ Pv and Δ Pc it is possible to find the seasonal average values of air-capacity Qvc(m^3/h)due to air-infiltration,applying the (8)

In the considered building the gain has been:

$$Era = 1.4 \times 10^{8} \text{ Kcal}$$

that is 20% of loss energy during an heating season.

NOTES

(1) These experiences are made in the External Closure tests Laboratory of the ex I.T.A.C.,now Sciences ant techniques for settlements Processes Dept. of Politecnico of Turin where the authors are working.

(2) Take as separation time between "old" and "new"-by the energetic point of view-the 1976 ~~when~~ year in which (the 373 law has been done.It introduce for the first time the duty to insulate the external building envelope,and to control the external window air-permeability.

(3) Shaw and Tamura:"The calculation of air infiltration rates caused by wind and stack action for tall buildings"-ASHRAE TRANS.n.2459/1977

(4) The method has been elaborated in the P.F.E.-C.N.R.research:" "External windows energetic Improvement"by the Galileo Ferraris Institute in Turin.

(5) The calculation procedure is described in: F.Bloisi,M.Grosso, M.Matarazzo,F.Passero,L.Vicari,"An experiment in monitoring the effects of crack elimination" to be pubblished shortly.

(6) The difference between the Δ C found in the tests and the Δ C that would have to be introduced in the calculation to obtain a close to the experimental one result have brought us to consider that not all the permeability reduction is due to the packing incidence.

Hence it is ipotizable that the 20% of the air-permeability difference is due to that window maintenance interventions that are always with the installation of the packing.

Fig.7 Air-permeability values after the installation of sealant