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Measurement of Actual Performances of Ventilation Systems in Buildings.

J. Riberon, J.G. Villenave, R. Simeon, J.R. Millet

Centre Scientifique et Technique du Batiment, 84 Avenue Jean Jaurès, BP 02, 77421 Marne La Vallee Cedex 02, France.

ABSTRACT

Airtightness deficiencies of building envelopes and weaknesses in the ventilation systems can disrupt the operation of heating and ventilation systems. This can lead to an insufficient level of air quality and higher energy consumptions. In order to assess the performances of buildings and ventilation systems, CSTB has designed and developed different experimental devices for field testing.
In a first step, an equipment was produced to measure the envelope air leakage. This apparatus is mainly used for research purposes. In order to allow low-cost controls in dwellings, two simplified methods have been developed using either the ventilation system itself or a light and compact device. To measure both air leakage and pressure loss in ventilation ducts, two devices have been produced : the first one applies to single-family dwellings with mechanical ventilation, the second one to multi-family dwellings with passive stack ventilation.

1 - INTRODUCTION

Ventilation of buildings is necessary both to insure adequate air quality and to protect the building itself against condensation and mould growth. On the other hand, ventilation flow rates must not lead to excessive energy consumptions.
To comply with these requirements the airtightness of buildings must be improved. Nevertheless, it is recognised that the improvements in the airtightness can lead to a reduction in the air quality unless the ventilation problem is dealt with. Therein, examination and testing of ventilation systems must be required to ensure that they operate effectively.
A great deal of effort has been devoted to the determination of the relevant parameters of ventilation which should be measured and several measurement techniques for air infiltration and ventilation have been examined by the International Energy Agency [1-3].
In order to assess the performances of buildings and ventilation systems, CSTB has defined measurement methods and designed and developed different experimental apparatus. These apparatus which are used for the building envelope or ventilation duct airtightness measurements have been tested on different types of dwellings.

2 - MEASUREMENT OF BUILDING AIRTIGHTNESS

Attention must be paid to control of the building envelope airtightness. Indeed, air leakage through the building envelope is detrimental to the performance of the building equipped with a ventilation system. Air leakage wastes energy and can disturb the operation of the ventilation system leading to an insufficient air quality. In addition, it can cause draught and noise problems.
This is why research work has been carried out in order to improve the knowledge in the field of air infiltration [4-6]. In many countries, air leakage measurement methods have been developed [7-9] ; and in some countries a specific level of airtightness is required and the new dwellings are checked according to the standardized measurement method [10].
In France, a guide describes how to measure the overall air leakage of a dwelling by using the fan depressurization method [11]. This test method is suitable for research work or field study. In order to extend its field of application to building inspection two simplified methods have been developed.

2.1 - Traditional method

The test procedure involves replacing an external door with a panel door and using a fan to depressurize the dwelling. The air flow rate is measured for different values of the pressure difference between the inside and the outside of the building. This technique was selected because the dwellings usually have a

negative pressure owing to the mechanical exhaust systems with which they are equipped.
The test equipment, so-called "fausse-porte CSTB", was developed in the late seventies. It is composed of a panel door to apply tightly into the grooves of the existing door frame, a fan, a long measuring pipe where the pressure difference over an orifice plate is translated to air flow, a micromanometer (see figure 1). The panel door can be adjusted in height and width to fit a wide variety of existing door sizes. A set of orifice plates makes it possible to accurately measure a wide range of air flow rate.

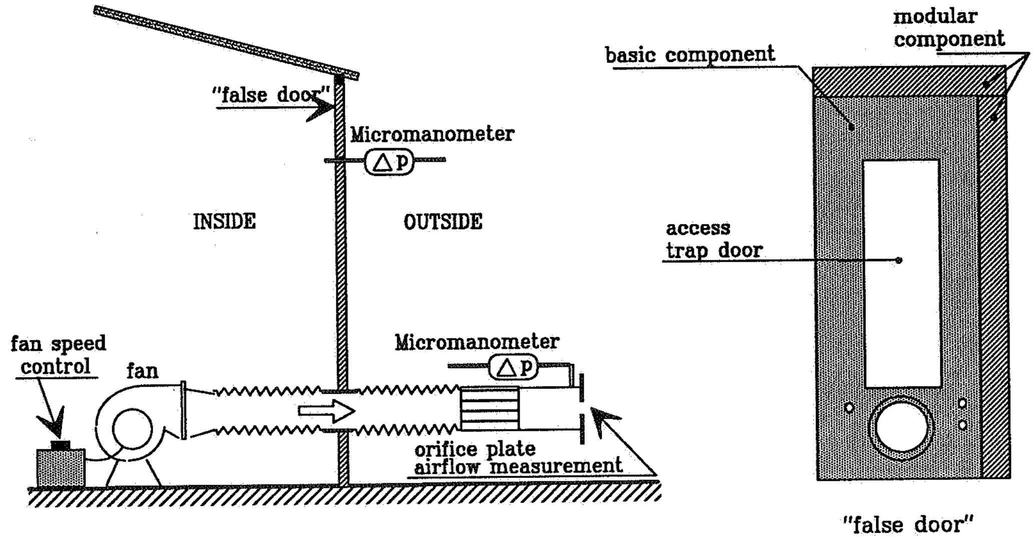

Figure 1 : sketck of dwelling airtightness test equipment "fausse-porte CSTB"

Once the test equipment is set up, all vent are sealed off, then the leakage flow rate is measured for at least ten values of pressure difference in the range 10 - 60 Pa. The measurement data are analysed using the power law fit :

$$Q = k\,\Delta P^{n}$$

where Q is the air flow rate (m^3/h)
k is the air flow coefficient (m^3/h at 1 Pa)
ΔP is the pressure difference across the building envelope (Pa)
n is the flow exponent ($0.5 \leq n \leq 1$)

Values of k et n describe the air leakage characteristics of the tested dwelling.

The guidance about preparing the building and setting up the equipment, the instrumentation required, and the procedure for carrying out the test is laid down in the guide [11] and ensures the accuracy of results.
Numerous measurements were performed according to this method (see section 2.3) and led to get a better understanding of the airtightness deficiencies related to the type of construction. However, this method is mainly intended for research purpose because it needs sophisticated equipment and highly specialised technicians ; that is why it was necessary to develop simplified methods in order to make dwelling check easier.

2.2 - Simplified methods

Two simplified methods for inexpensive checking of dwellings airtightness have been developed [12-13]. The first method involves using existing fan in the block of flats for depressurization. Investigations conducted in Scandinavian countries [1-14] have shown that is a good and sufficient method to show if the dwelling envelope is airtight enough or too leaky. The second method uses a compact and light specific apparatus to depressurize the dwelling.

2.2.1 - Using existing fan

This method is quite suitable for the air leakage measuring of multi-family dwellings having a mechanical exhaust ventilation. The test procedure is quick and easy (see figure 2). The air flow rate across the dwelling envelope is measured by means a flowmeter applied to one exhaust vent (e.g. kitchen vent), all the other ventilation openings are sealed off. The pressure difference across the envelope is measured by means a micromanometer and a capillary tube introduced through one air inlet. Here, a particular attention must be paid to seal up the air inlet opening.

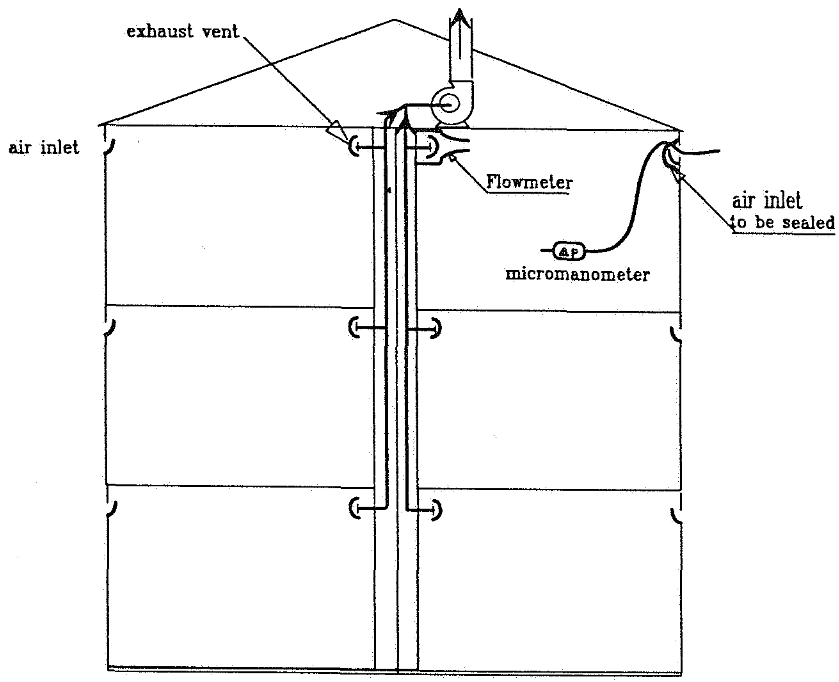

Figure 2 : sketch of airtightness test using the fan of the building

Unsealing several exhaust vents makes it possible to obtain several flow rate and pressure difference measurement points. The method for expressing the measurement result(s) assumes that the exponent flow n is conventionally equal to 2/3 ; the final result is the air change rate at 10 Pa i.e. air flowrate at 10 Pa divided by the volume of the dwelling.

This method was tested in a flat located in a six-storeys building. I was possible to create a pressure difference of about 40 Pa. This method was compared with the traditional method i.e. fan-depressurization method involving a panel door. Both measurement results are in close agreement ; difference in air leakage level between simplified and traditional methods is of 11 % which is reasonable since the accuracy is not the same according to the methods.

When the dwelling is tight enough it is possible, according with this method, to depressurize it up to about 30 Pa and thus to assess the airtightness level of the dwelling. When the dwelling is too leaky or large ventilation system is insufficient to create an available pressure difference and it is required another simplified method. Such a method is described below.

2.2.2 - Using a compact specific equipment

When the dwelling is not equipped with a mechanical ventilation or when the ventilation system does not enable to create a sufficient pressure difference (e.g. mechanical exhaust ventilation of single-family dwellings) a specific measurement equipment must be used to perform the airtightness test.

The basic principle of this method is the fan-depressurization. The test procedure is the following : All vents are sealed off. The measurement equipment is connected to an extract duct (e.g. kitchen extract duct), then it creates and measures the air flow rate. Pressure difference across the building envelope is measured by means a micromanometer like in section 2.2.1.

The airtightness measurement equipment is composed of a small fan linked with a flowmeter and a supple jointing duct 2.7 m long with a terminal device to be applied to the exhaust vent (see figure 3). The equipment is light (10 kg) and easy to handle. The flow calibration and flow-pressure curves of this equipment have been derived from laboratory tests.

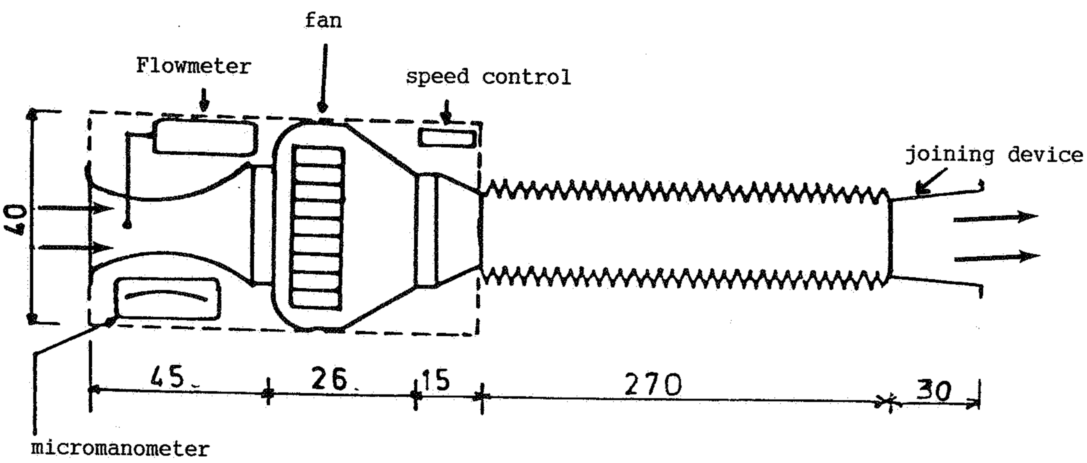

Figure 3 : compact equipement for airtightness measurement

In order to test this equipment for ability, airtightness measurement were carried out on a house by using both simplified equipment and "fausse porte". The results showed the air leakage flow rate measured by the simplified equipment is higher than the flow rate measured by the "fausse-porte". The main explanation for this is that leak of the external door of house is not taken into account with the "fausse-porte" method. After this correction, both methods yielded the same result within approximately 10 %.

2.3 - Results

Numerous compaigns of airtightness measurement were carried out on dwellings by using the "fausse-porte CSTB". Synthesis of measurement results is given in the table 1 relevant to the type of construction.

	type of construction				
	heavy frame				light frame
	exterior insulation		interior insulation		
	house	flat	house	flat	house
average	0.26	0.12	0.36	0.17	0.39
standard deviation	0.07	0.10	0.12	0.14	0.18
number of dwellings	9	39	93	23	16

Table 1 : Air change rate of dwellings (ach at 1 Pa)

The tests have made it possible to identify the most frequently encountered leakage paths.
The airtightness deficiencies are particularly important on walls with interior insulation (plasterboard plus insulation complexes). A route by which air enters is also door and window frames, electrical ducts, gaps around water pipes, attic access trap doors, ...
In France, manufactured windows and doors are built in compliance with standards ; theses components are classified in groups according to the air leakage performance. The measurement results have shown that the actual performances are in agreement with the required level. These building components have good airtightness ; on the other hand, the airtightness between the window frame and the wall is generally poor.

3 - AIR LEAKAGE AND PRESSURE LOSS MEASUREMENT IN SUPPLE DUCTS

Measurements were performed on about twenty newly-built single family dwellings having a mechanical exhaust ventilation system, in order to get a better understanding of the actual functioning of the ventilation [15].

3.1 - Method

The test procedure involves using an appropriate apparatus enabling to accurately measure air leakage as well as pressure loss in the supple extract ducts. The apparatus is composed of a portable case housing a centrifugal variable speed fan. The upstream side of this case is connected to a flattened cone-shaped adapter taking the duct to be tested and the downstream side to an air flow measuring pipe which is 1 m in length and 156 mm in diameter and equipped with an orifice plate. The use of the adequate orifice plate among a set of five (from 19 to 76 mm) ensures an accurate measuring of the air flow. The case has a tapping for measuring pressure downstream in the duct.
The test procedure for pressure loss measurement is the following : the apparatus is installed in the attic of the house, close to the extract unit of the ventilation system (see figure 4). The duct to be tested is taken off the extract unit then connected to the adapter of the apparatus ; the related exhaust vent being taken out. The pressure below the duct is measured For a given air flow rate. Usually, three or four measurement points can be obtained thanks to the variable speed fan. for air leakage measurement, the same procedure is used except that the exhaust vent is sealed off and that a smaller orifice plate is necessary.

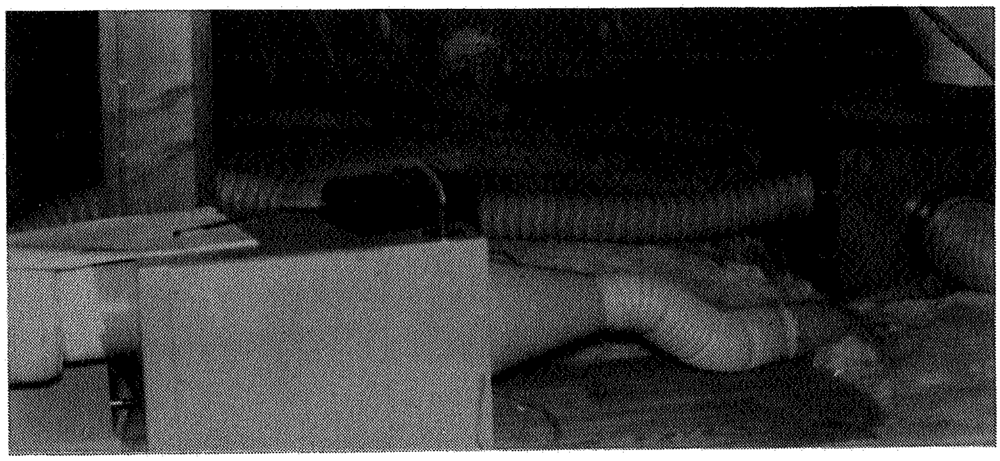

Figure 4 : equipment for measuring air leake and pressure loss in supple extract ducts

3.2 - Results

Figure 5 depicts the distribution of pressure losses measured in the supple ducts. The pressure loss coefficient Λ was derived from the measurement results and the dimensional characteristics of the duct. In 55 % of cases, ducts have an actual Λ value comparable to the theoretical value measured in laboratory (about 0.5), that means installation work is properly achieved. The higher values of Λ may be due to failing in installation work such as sharp bends, insufficient stretch in the supple duct, numerous windings in the ductwork. In a few cases, the pressure loss is very high (Λ value is over 1.8), that indicates the supple air duct is trampled down.

Figure 6 depicts the distribution of air leakage rate in the ducts defined as the ratio of the air leakage flow to the exhaust air flow calculated at the same pressure difference. The results have shown the sample might be divided into three groups :

. Airtight duct (64 % of the sample)
the range of the leakage flow rate is 0.7 - 3 m^3/h at 100 Pa. The leakage rate is contained between 2 % and 12 %.

. Little leaky duct (24 % of the sample)
the range of the leakage flow rate is 3 - 10 m^3/h at 100 Pa. The average value of the leakage rate is approximately 30 %. Leak is usually caused by a bad connection to the extract unit.

. Very leaky duct (12 % of the sample)
the leakage flow rate is from 30 up to 190 m^3/h at 100 Pa. It is so considerable that the exhaust air flow is exceedingly low, indeed non-existent. Miscellaneous reasons cause this poor result, particularly : joining deficiencies with the exhaust vent or with the extract unit, damage in supple duct caused by poor design or installation.

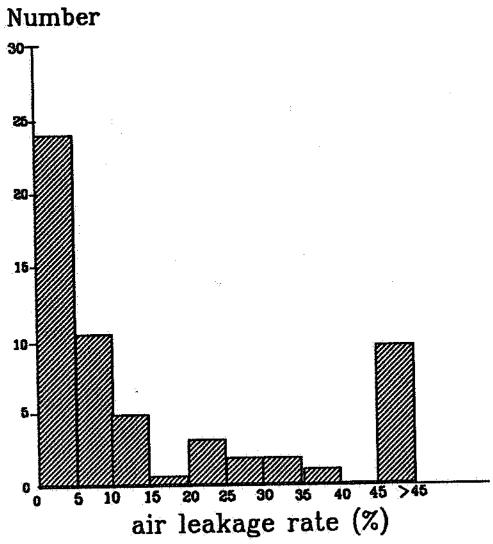

Figure 5 : distribution of air leakage rate in ducts (total number of ducts = 59)

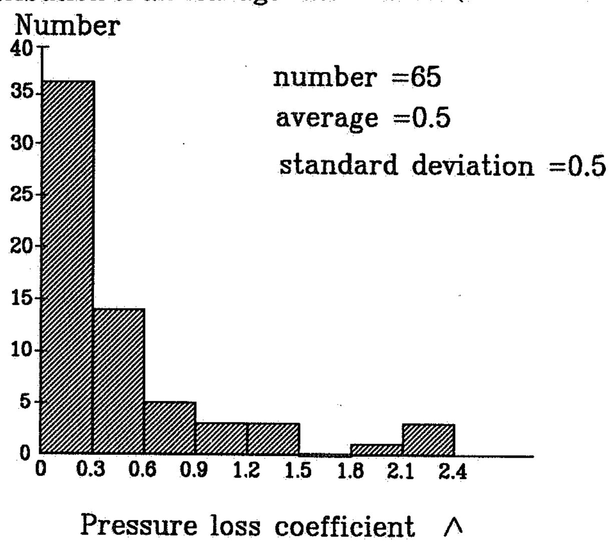

Figure 6 : distribution of pressure loss in ducts for 19 dwellings

4 - MEASUREMENT OF SHUNT DUCT AIRTIGHTNESS

Numerous buildings built in the sixties and before have to be renovated ; in that times, ventilation by building envelope leakages compensate for stack effect ventilation insufficiency.
Façade renovation (thermal and acoustic insulation) reduces the cross ventilation ; the new ventilation system have to make use, if possible, of the existing ventilation and exhaust smoke ducts ; for this use the ducts airtightness has to be measured [16]. In this section a measurement method of shunt ducts airtightness is described and tested on existing buildings.

4.1 Method

After sealing air outlets with bladders or sticky tape, a variable speed fan is connected at the top of the duct and makes it possible to depressurize the shunt duct. The negative pressure in the duct related to the atmospheric pressure is measured with an micromanometer, the air flow rate with a measuring pipe equipped with an orifice plate (see figure 7).

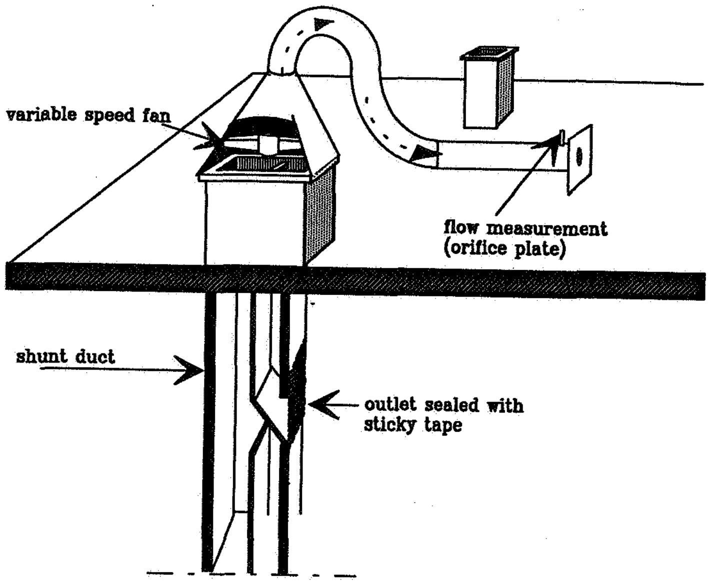

Figure 7 : sketch of shunt duct airtightness test

The equation describing the air leakage in shunt ducts is given in section 2.1. Values of flow exponent n describe the air leakage characteristic of the duct :

$n \sim 0.5$ holes or thick cracks
$n \sim 0,66$ little cracks
$n \sim 1$ duct porosity

The equivalent leakage area (ELA) is a measure of the total area of all cracks in the duct. The ELA value in cm^2 is approximately equal to the air flow rate (in m^3/h) for a pressure difference of 10 Pa.
Several pressure taps are within the duct and measuring the negative pressure all duct long can indicate the location of leakages.

4.2 - Results

Two measurements results given in tables 2 et 3 show how this method makes it possible to assess actual performance of the shunt ducts.
Table 2 shows the change in pressure into a shunt duct 17 m long when air flow rate varies. Pressure difference is measured at the top storey. The values of the flow coefficient K and the flow exponent n are derived from the fit for the air flow equation :

$K = 2.2\ m^3/h$ at 1 Pa
$n = 0.98$

air flow rate (m^3/h)	18	105	270	390
pressure difference (Pa)	7	50	130	190

Table 2 : Airtightness measurements on a shunt duct for six storeys
lenght : 17 m cross-sectional area : 0.2 m x 0.2 m

These values indicate there is no important leaks, like hole, but only duct porosity. The equivalent leakage area is 21 cm^2.
Table 3 shows the change in pressure into a eight-storeys duct according to the storey height for an extract flow rate of 1230 m^3/h. At the sixth floor the pressure difference rises suddenly that indicates an important crack in the shunt duct.

floor	1	2	3	4	5	6	7	8
pressure difference (Pa)	16	22	25	28	30	43	84	115

Table 3 : Airtightness measurement along a eight-storeys duct

5 - CONCLUSION

Tools well suited for on-site measurements have been developed and used to assess the actual performance of ventilation systems in regard to indoor air quality and energy efficiency.
Airtightness measurement carried out on nearly two hundred dwellings using the fan depressurization technique demonstrated the air leakage of envelope was important. The average air change rate at a pressure difference of 1 Pa is about 0.15 ach for a flat and 0.35 ach for a single-family dwelling. The air leakage depends on the type of construction and the quality of workmanship.
The method used is very time consuming ; consequently new simpler methods have been developed. To depressurize the dwelling these simplified techniques utilize either the mechanical ventilation of the building or a light equipment. Comparison tests have shown the simplified and traditional methods yielded the same result within 10 %.
A test equipment was produced to quantify the air leakage and pressure drop in the supple ducts of the mechanical ventilation system. measurement carried out on twenty newly-built single-family dwellings revealed that in most cases leakage was insignificant and pressure loss not to high.
Another technique has been developed for the assessment of the airtightness of shunt duct in tests were usefully performed according to this technique in order to know the actual conditions of the shunt ducts before planning retrofit for existing buildings.

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