In situ measurement of window air tightness : stakes, feasibility, and first results

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ABSTRACT

In order to limit ventilation losses in low-energy buildings, balance ventilation systems with high-efficiency heat recovery units are often used. However, the effectiveness of the heat recovery system may be severely affected by envelope leakage as the system can be short-circuited by uncontrolled airflows. Therefore, limiting envelope leakage becomes a critical issue in such low-energy buildings.
However, in a typical French house, air leakage through and around windows represents 15 to 70% of the total leakage airflow through the building envelope. Besides, field measurement campaigns presented in this paper have shown that although the air tightness of a window may be excellent as it leaves the factory, the quality of its installation can greatly affect its performance. In fact, poor installation can increase the leakage rate by a factor of 3, and we have estimated the subsequent heat load increase to be in the region of 40% in some cases in houses built according to the French EP regulation (RT 2000).
To address this installation issue, in the framework of a PREBAT project including a manufacturer of windows, an ergonomist, and an industry consultant besides our institute, we have developed and tested in real conditions an apparatus to measure the air tightness of windows on site. The system can measure leakage through windows whose height and width lie between 0,7 and 2,2 m, and 0,7 and 1,10 m respectively. Our perspective is to have this system used either in a certification process of contractors now discussed in France or in a self-quality control approach.

1. WINDOWS : COMPONENTS WHOSE PERFORMANCE DEPENDS LARGELY ON INSTALLATION

High-performance windows are more and more needed in response to the increasingly demanding requirements for heat and noise insulation, solar gains and protections, as well as water and air tightness.
These characteristics are mostly controlled and certified at the end of the industrial process. However, despite the fact that intrinsic characteristics can be guaranteed ex-works, real performance can be greatly affected on site. Kappes Grange & collaborators (2005) have shown that the major problems are due to inadequate use of sealing materials, poor carcass workmanship (geometry, surface aspect and quality), poor working conditions leading sometimes to inadequate postures for sealing, productivity goals sometimes incompatible with quality). They have also shown that many difficulties found on a building site can be overcome with existing technologies.

2. ENERGETIC STAKES

2.1 From joinery to envelope air tightness

In France, window air tightness is certified at the end of industrial process according to the NF EN 12207 which specifies 5 categories : best window air tightness class corresponds to class A4, while the poorest air tightness corresponds to class A0 (table 1).
This standard is mostly adapted to quality control of windows at the end of the industrial process : the leakage allowed concerns only the air flowing through the window itself (e.g. between the frame and the doors). In such a industrial quality control procedure, a sample of the manufactured products is tested. It will guarantee the air tightness of the window itself provided that is it properly installed and sealed on the carcass work.
Consequently, all installation defects, in particular those between carcass work and window frame, will decrease the certified performance. In a previous study (Kappes Grange & collaborators (2005), CETE de Lyon has already noted that A3-certified windows could in turn comply with class A2, A1 or even A0 when installed on site.

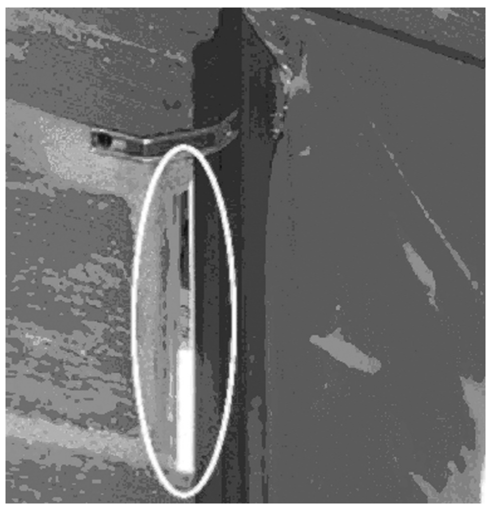

Figure 1 : Example of inadequate carcass work : opening size is too large given window size.

Figure 2 : Example of delicate posture while putting silicone sealant.

Table 1: Air tightness classification of windows according to NF EN 12207

Window class	Maximum air tightness ($m^3/h/m^2$ at 100 Pa)
A4	3
A3	9
A2	27
A1	50
A0	> 50

Downgrading the window class increases the envelope air leakage. This can be expressed with the following equation :

$$I_{4\ corrected} = I_{4\ initial} + \alpha.\Delta I_{4\ joinery} \quad (1)$$

where:

$I_{4\ corrected}$ is the observed envelope air tightness normalized by the cold wall area ($m^3/h/m^2$ at 4 Pa)

$I_{4\ initial}$ is the expected envelope air tightness ($m^3/h/m^2$ at 4 Pa)

$\Delta I_{4\ window}$ is difference between observed and expected window air tightness ($m^3/h/m^2$ at 4 Pa)

A is the ratio of window-to-cold-wall surface area (%).

Equation (1) can be applied to different types of buildings assuming a mean window-to-cold-wall ratio (according to POUGET Consultant energy performance of buildings observatory), and various envelope air tightness. This approach enables us to quantify the impact of the window class on the overall envelope leakage (Table 1, table 2).

Table 2 : Impact of window class on envelope air tightness – individual house with 12% of glazed wall.

Window class	A4	A3	A2	A1	A0
Envelope air tightness I4 (m3/h/m2 at 4 Pa)	0,75	0,8	0,96	1,15	1,35
I4 / I4 réf (%)	-6%	0%	20%	44%	69%

Table 3 : : Impact of window class on envelope air tightness – office building with 32% of glazed wall.

Window class	A4	A3	A2	A1	A0
Envelope air tightness (m3/h/m2 at 4 Pa)	1,06	1,2	1,87	2,73	3,6
I4 / I4 réf (%)	-12%	0%	56%	128%	200%

This preliminary study demonstrates that window installation defaults can lead to a significant increase of air leakage. Assuming a window class downgrading from class A3 to A1, the impact is in the region of 40% for an individual house and 130% for an office building.

2.2 Impact on heating load

The impact of poor window installation on energy use can be approached through a sensitivity study on the heating needs expressed in kWh/year for a typical individual houses and an office building as a function of air leakage. The other parameters that were investigated in this paper are the insulation level (U-value), and the ventilation system type (extract-only system versus supply-extract system with heat recovery).

To conduct these sensitivity analyses, we have used the RT 2000 model (TH-C motor) developed for the French EP regulation. It is based on EN 13465 [2] for the computation of the ventilation and infiltration flow rates in the building, and on the ISO 13790 [3] for the computation of the heating needs. The model described in EN 13465 is based on a mono zone pressure approach to compute the pressure inside the building given the characteristics of the ventilation system, the airflow laws of openings in the building envelope, as well as the temperature and wind conditions.

Table 4 and table 5 indicate the variations of heating needs obtained with this model for an individual house with gas heating, and an office building with fan-coil units.

Table 4 : Sensitivity of heating needs to window air tightness class for an individual house with gas heating system

Window class	A4	A3	A2	A1	A0
Building characteristics	Change in heating needs				
French EP regulation level (U-value = Uref)	-0,5%	0%	2%	2,5%	4,5%
Reinforced insulation (Uref -30%)	-0,5%	0%	2%	4%	7%
Reinforced insulation (Uref-30%) and ventilation with heat recovery system (90%)	-1%	0%	5%	8%	14%

Table 5 : Sensitivity of heating needs to window air tightness class for an office building with fan-coil heating system

Window class	A4	A3	A2	A1	A0
Building characteristics	Change in heating needs				
French EP regulation level	-1%	0%	7%	15%	25%
ventilation with heat recovery system (70%)	-1%	0%	8%	18%	29%
Reinforced insulation (Uref-30%) and ventilation with heat recovery system (70%)	-2%	0%	13%	29%	47%

Therefore, a window installation failure which would result in downgrading the window air tightness class from A3 to A0 would increase the total heating needs around +4,5% for an individual house that complies with the RT 2000 regulation. This variation could reach about +14% for an individual house with greater energy performance (corresponding to French 2010 EP regulation), and up to + 47% for an office building.

2.3 Financial approach and pay-back

In turn, the increase in heating needs due to downgrading the window air tightness class can be converted into Euros. Assuming an energy cost of 0,15 €/kWh, poor window installation can increase the annual energy bill of about 100 € for an individual house, and 1000 € for a medium-size office building (1000 m^2).

In parallel, the additional cost necessary for a careful installation of windows has been estimated within our project (Fournier et al., 2007). The basic assumption is that a careful installation is equivalent in terms of cost to fitting an extra seal around the window frame. With this assumption, without taking into account the cost induced by building pathologies, the savings made on the heating needs in one year are in many cases are greater than the additional cost for a careful installation. This suggests that the payback is less than one year in these cases.

3. IN SITU MEASUREMENT OF WINDOW AIR TIGHTNESS

3.1 Objectives

It appears necessary to safeguard the installation of windows, especially as the increasing demands on the overall performance of buildings lead to an increasing share of the infiltration losses. Being able to measure the airtightness of windows on site appears to be an interesting strategy to implement to improve the situation and avoid energy waste due to poor window installation This procedure could be included in a certification procedure of contractors. The cost for this certification, including on site measurement, could be compensated on one hand by the reduction of insurance costs, on the other hand by the energy savings.

Beyond a certification process, in situ window airtightness measurement can be used for other applications such as : awareness raising of building practitioners to installation issues, performance-based commissioning, or damage expertise.

3.2 Existing methods and tools

Standards such as NF EN 1026 or ASTM E 783-02 are interesting for our work, but their goal is to characterize the leakage between the frame and the door(s), which excludes leakage between carcass work and frame.

Two types of measurement methods have been developed and used in the past to characterize the latter leakage:
- pressurizing the window with a fan connected to an airtight enclosure surrounding the window and sealed on the building walls (direct method);
- subtracting the leakage found by pressurizing part of the building to that found by pressurizing the same zone with the window sealed (subtraction method).

The subtraction method with a blowerdoor is difficult to use in practice due to the uncertainty on the final result. Regarding the direct method, we have not found in our literature search specific tools to conduct such measurement. In addition, the prototype device developed at CETE de Lyon a few years ago needed extra work to minimize the installation time (estimated to half a day), to be able to test window of various sizes, and finally to deal with leakage-to-inside infiltration with the internal building insulation. Figure 3 shows the prototype developed in 2005.

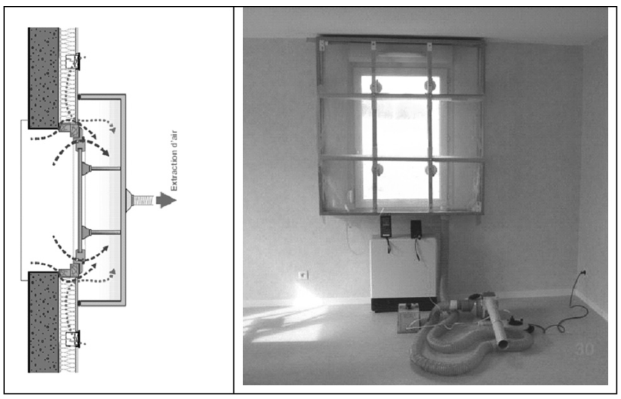

Figure 3 : Prototype device developed in 2005 to directly measure window air tightness on site.

As far as we know, we can conclude that there exists methods and tools to characterize window airtightness but these do not match the needs quoted above, e.g. for a certification procedure.

3.3 Development of a specific tool

CETE de Lyon has developed a prototype in the framework of a PREBAT project including a manufacturer of windows, an ergonomist, and an industry consultant. The underlying principle remains that of the direct method and relies on the pressurization of an enclosure with an adjustable frame similar to that of blowerdoors (Figs 4-5). This frame includes a fan to pressurize the enclosure from outside, which allows the operator to make a qualitative diagnostic from the inside, e.g. with a smoke generator or an infra-red camera. To install the prototype, the operator needs a minimum depth of 120 mm. The operator puts a rubber mastic around the frame to seal the enclosure. Concerning the quantitative diagnostic, a vane anemometer enables us to measure the airflow rate with an uncertainty lower than 5% on the readings in the range between 10 m^3/h and 150 m^3/h. The pressure difference across the enclosure is measured with a auto-zeroing pressure sensor with an accuracy of ± 1Pa. The absolute pressure and temperature is measured with two separate sensors in order to correct the volumetric airflow rate. The data from these four sensors are connected to a data acquisition system with a belt passing through the window without creating leaks. A dedicated software enables us to analyze the data.

At the end of the measurement procedure, the software produces a report showing the performance of the window installed classified according to NF EN 12207.

3.4 Preliminary field measurement results

We have performed a preliminary field measurement campaign in 2005 with the prototype shown in figure 3. This campaign has already demonstrated the large discrepancies between stated and actual window air tightness due to installation issues. The leakage airflow rate measured on 10 windows is typically two to three times greater than the expected leakage airflow rate (Fig. 7) given the certification.

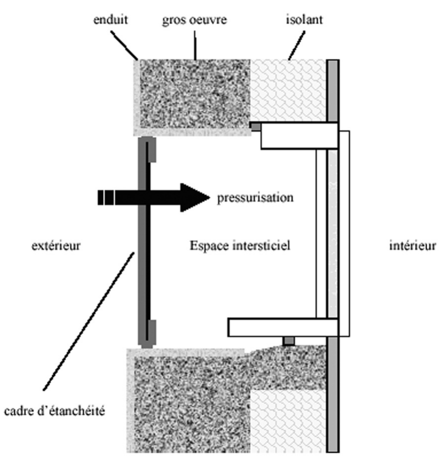

Figure 4 : Measurement principle.

Figure 5 : Prototype installed on site photographed from the inside of the building.

Figure 6 : Prototype installed on site photographed from the inside of the building.

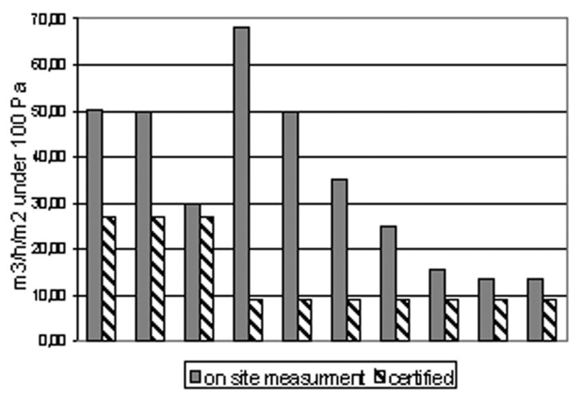

Figure 7 : Air flow rate at 100 Pa in ($m^3/h/m^2$) measured on site (solid bar) and certified ex-works (stripes). Results of preliminary field measurement campaign.

4. CONCLUSION

Air tightness becomes a key element in today's context of increasing demands regarding the energy performance of buildings. In particular, windows need to be carefully installed, not so much because of intrinsic leakage, but rather because of leakage that occurs at the wall-window interface.

Our preliminary measurement campaign has shown that the airflow rate can be doubled or tripled compared to its expected intrinsic leakage due to poor installation. Therefore, to improve the situation, it is important to be able to control the air tightness on site, e.g. in the framework of a contractor's certification procedure. The prototype we developed appears appropriate to achieve this goal. However, there remains three important steps for this tool to ease a necessary market transformation : first, the need for this kind of certification or procedure has to integrated by owners and contractors ; a certification body has to offer this service ; third, the device has to be commercially-available at a reasonable price.

Our latest version of the prototype, which is at a pre-industrial stage, will be tested on a field measurement campaign on 30 windows to verify the reliability of the protocol and device. This campaign will also allow us to give a range of the person-hours and cost related to this measurement.

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