# AIRTIGHTNESS FIELD MEASUREMENT STUDY OF 123 NEW FRENCH DWELLINGS WITH A SIMPLIFIED MEASURING DEVICE

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## ABSTRACT

Studies on buildings' airtightness have shown that several issues can arise from uncontrolled airflow leakages in buildings (e.g., higher energy cost, thermal comfort and health of occupants, building components and equipment preservation). The new French thermal regulation, RT2000, applicable since June 2001, has set explicitly airtightness performance levels for new buildings. Yet, buildings' airtightness performance knowledge is only possible by means of on site controls and measurements. A recent study has shown that the development of a simplified buildings' airtightness measuring devices (IMPEC), can reduce the duration and the number of people involved in the measurement controls, and therefore can significantly decrease the associated costs of controls.

In this work, we aim at developing an IMPEC in a commercial version and at performing a nation wide field measurement study in order to increase the knowledge of the construction field actors both on the airtightness performance of new French dwellings and on the availability of lower cost controls. We present the characteristics of an automated model of IMPEC, developed under the brand PERMEASCOPE®. The IMPEC's measurement protocol is based on dwellings' depressurisation by means of a portable fan connected to the air distribution systems, through the kitchen or bathrooms ventilation exhausts. The results of a field measurement study of the airtightness of 123 new French dwellings are presented and compared to the results of former studies. Finally, we discuss the control performances of IMPEC devices in terms of potentials to reduce negative impacts on energy consumption and occupant's health and comfort.

## KEYWORDS

Field measurements ; Infiltration ; Airtightness ; Building Envelope ; Dwellings; Thermal Regulation

## BACKGROUND

The negative impact of air infiltration through buildings envelope – namely, by negative consequences on occupant's health and comfort, on building systems and fabrics' pathologies and on energy consumption - has been thoroughly detailed in the literature. The French thermal regulation RT2000, applicable since June 2001, has set airtightness performance levels for new buildings. If regulatory thermal calculations account explicitly for airtightness performance levels, progress need yet to be done to develop means of controlling the effective performance of buildings. Indeed, development of reliable, simplified and low-cost airtightness measurement tools has been identified as a necessary condition to widespread on site controls and therefore buildings' airtightness performances. A former work by CETE de LYON, ALDES and EDF has led to develop a pre-commercial version of a simplified dwelling airtightness measuring device (IMPEC), Litvak et al. (2002).

## OBJECTIVES

In the continuity of former efforts on development of commercial versions of IMPEC with a view to widespread onsite measurement controls, this article presents a work of four Technical Study Center (CETE), as part of the technical and scientific network of the French ministry of Equipment, in partnership with ALDES. This work aims at answering to a double concern : to develop an IMPEC in a commercial version and to perform a nation wide field measurement study in order to increase the knowledge of the construction field actors both on the airtightness performance of new French dwellings and on the availability of lower cost controls.

## METHODOLOGY

### Airtightness indicators and air leakage assessment

The modelling of airflow patterns through cracks of the building envelope follows from the early works on hydrodynamics of pipes, that allowed to assess the airflow rates Q $_{[m^3/h]}$ through elementary holes, as a function of differential pressure between indoor and outdoor, $\Delta P_{\,[Pa]}$, see Eqn 1 :

$$\mathbf{Q = K \cdot \Delta P^n} \qquad \textbf{(1)}$$

where n $_{[\,-\,]}$ and K $_{[m^3/h/Pa^{-n}]}$ are the flow exponential and the airtightness constant.

For their specific requirements, some European countries, including France with RT2000, have decided to consider the leakage index $I_{\Delta P}$ [m³/h/m²], defined as the infiltration airflow rate at $\Delta P_0$ weighted by envelope surface areas the most susceptible to promote the infiltration of air leakages. In accordance to RT2000, we considered the specific *unheated surfaces*, defined as the *« surfaces that separate the indoor heated volume from the outdoor air and indoor unheated air, excluding the floor »*. For RT2000, leakage airflow rates are assessed by extrapolating to 4 Pa the Equation 1, determined by measurements in the pressure intervals [10-70 Pa] as recommended by the EN NF 13829 norm.

### State-of-the-art of onsite measurement techniques

To date, the most reliable manner to determine the airtightness of a building consists in measuring its infiltration airflow rate. A standardized method, using a fan depressurization technique (known as the "blower-door method") is commonly used and follows the procedure described in the norm NF EN 13829. It consists in replacing a large opening of a dwelling (usually the doorway) by a "blower-door" frame, with an incorporated extracting fan capable of depressurizing the dwelling. All commercially available airtightness measuring devices are based on this "blower-door" technique. Yet, to our knowledge, very few commercially available devices are distributed in France to measure the airtightness of buildings' envelope.

The "blower-door technique" is particularly adapted to measure the air leakages in relatively small buildings. For larger constructions and/or extremely leaky buildings, the building depressurization usually becomes impossible, due to the power limitation of the fan. For this buildings, CETE de Lyon has developed an equipment, unique in France, that measures infiltration airflow rates up to 65 000 $m^3/h$, Bringer (1997). One should know that this 5 meter long equipment is towed by a truck to operation site.

Although earlier studies have occasionally succeeded in depressurising large multi-family buildings with commercially available Blowerdoor devices, Litvak (2001), a main concern remains the capacity of assessing the airtightness of these types of buildings from individual measurements (e.g., apartment measurements), for technical and economical reasons. Yet to our knowledge, no work has determined an experimental relationship between individual and global measurements of multi family dwelling buildings. Since RT2000 mandatory performance levels refer exclusively to the whole building characteristics, such knowledge would offer valuable information in order to develop lower costs controls.

## Measurement protocol

If the "Blowerdoor" technique appears to be a very accurate method to determine the infiltration airflow rate of a building's envelope, its main drawback remains the possible occultation of air infiltrations through the large opening where the extracting fan is mounted. The IMPEC's protocol, developed in this work and extensively described elsewhere, Litvak (2002), relies on the "Blowerdoor technique", but it connects to the mechanical ventilation network as exhaust, if available, or as an alternative, to a small trap in a wooden frame.

***Figure 1. IMPEC onsite measurement protocols: connected to the mechanical ventilation network (left) or to a wooden "fake trap" (right)***

The operative IMPEC's measurement protocol follows the recommendation of EN 13829. A field measurement campaign was led nationwide with 5 Perméascope®, a commercially available model of the IMPEC, distributed by ALDES, in order to assess the infiltration airflow rates of 123 new French dwellings. Complementary measurements were performed with a Minneapolis Blowerdoor® instrument, on 4 large multi family buildings of the sample, in order to compare global and individual dwelling measurements in these buildings.

## Characteristics of the 123 nationwide dwelling sample

The main characteristics of the 123 dwellings, spread over 58 buildings and composed of 71 % of multi-family dwellings and 29% of single family dwellings, are presented in Table 1.

| Single Exhaust Ventilation | Humidity Controlled Ventilation | Exhaust and Supply ventilation |
|---|---|---|
| 42% | 58% | 0% |
| 52 | 71 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 2% | 24% | 40% | 25% | 9% | 0% |
| 2 | 30 | 49 | 31 | 11 | 0 |

**Number of main rooms of each dwelling**

| Electricity | Gas | other |
|---|---|---|
| 41% | 57% | 2% |
| 51 | 70 | 2 |

**Type of Heating Energy**

| Masonry | Concrete | Timber frame | Metal frame |
|---|---|---|---|
| 28% | 67% | 3% | 2% |
| 35 | 82 | 4 | 2 |

**Building Structure**

**Table 1 : Characteristics of buildings and dwellings**

## FIELD MEASUREMENT RESULTS AND DISCUSSION$

### Leakage pathway observations

The air leakage pathways of 123 dwellings were carefully investigated under the IMPEC's test depressurization conditions by qualitative observations. The onsite observations, from a total of 189, have been reported for each dwelling and were classified according to the occurrence of different air leakage pathway types. The most recurrent and major locations observed for air infiltration are the electrical conduits and window and door frames, see Figure 2.

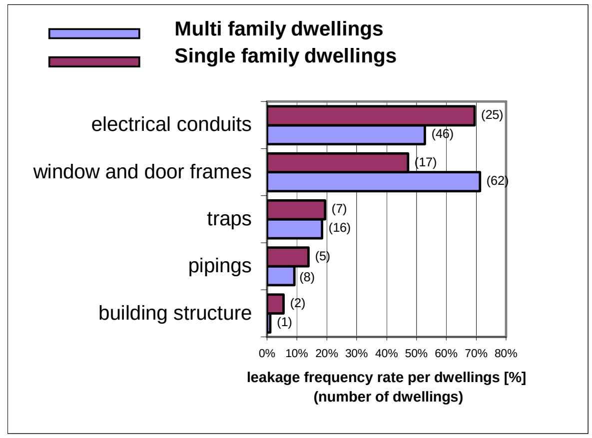


**Figure 2 : Leakage pathway rate frequency**

If these results corroborate the earlier findings on a field measurement study (performed with Minneapolis Blowerdoor® instruments) on airtightness of 71 French dwellings, Guillot (2000), a significant increase in air leakage pathways through doorway frames, as compared to this former study, shows evidence that this type of leakage can be occulted if measurements are performed with a conventional Blowerdoor technique, i.e. through a large opening such as a doorway.

### Pressure test results

Median values of the measured $I_4$ indicators show good performances as related to the mandatory performance levels of RT2000 for airtightness for single family dwellings : 46% of the dwellings are more airtight than the *reference* value of 0.8 $m^3/h/m^2$, and 72% show better results than the *default* values of 1.3 $m^3/h/m^2$. As a reminder, one should note that all the dwellings (i.e., houses and apartments) were considered as single-family dwellings. These good results concern mainly concrete and masonry constructive types, which are more airtight than metal or timber frame, that have appeared to show lower performances in earlier work, Guillot (2000).

$I_4$ : single family dwellings = 0.77 $m^3/h/m^2$ (SD = 0.42)
$I_4$ : multi family dwellings = 1.06 $m^3/h/m^2$ (SD = 0.67)

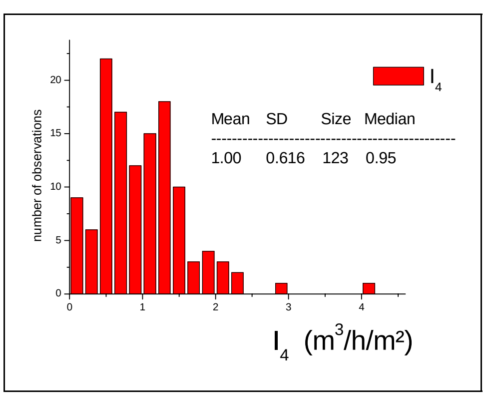


**Figure 3 : Histogram of $I_4$ values**

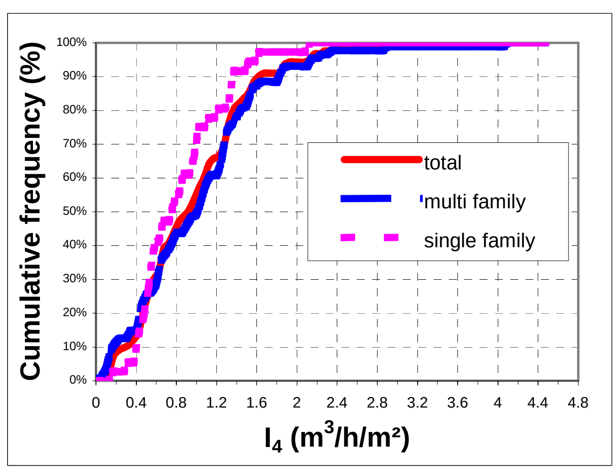


**Figure 4 : Cumulative Frequencies of $I_4$ values**

### Potential improvements by corrective actions

The relationship between n and $I_4$, was studied both on the 123 measured values on individual dwellings and on the 4 multi family dwelling buildings. The observed hyperbolic-type decrease, see Figure 5, shows that a gain on the flow exponent from n = 0.60 (that represents turbulent regime caused by larger holes in the building envelope) to n = 0.66 (which is generally the median value observed in onsite measurements) can lead to a net gain of 60 % on $I_4$ :

$$I_4(0.60) / I_4(0.66) = 1.6 .$$

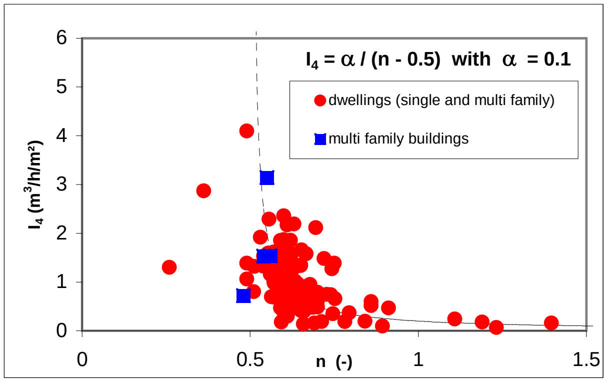


***Figure 5. Influence of the flow exponent value on the infiltration rate.*** *The dotted line represents the hyperbolic fit* $I_4 = 0.1 / (n-0.5)$

In the ligh of this result, complementary onsite depressurizing tests have been performed on 14 dwellings, after sealing with adhesive tape the major air leakage pathways observed, namely through larger holes. The types of corrections concerned mainly door frames and doorsteps, window frames, electrical rack boards and traps. Results of these 14 complementary test show that simple sealing after onsite visual inspection, can lead up to 70% of improvement on the air infiltration rate $I_4$, with an observed median value of 36%. These results show that significant improvements on the airtightness performance of buildings can be done by very simple means, e.g. by sealing with pointing or adapted joints, major defects observed through the building envelope. Such observations can easily be achieved by quality control inspections associated with onsite measurement controls.

### Relationship between individual airtightness measurements and building measurements

Individual measurements done with the IMPEC instrument (Perméascope®) among different dwellings of 4 buildings of the nationwide sample have been compared to the global building infiltration airflow rate measured with a Blowerdoor commercial instrument (Minneapolis Blowerdoor®). If no empirical relationship was assessed between these four cases, one can note that the ($I_4$ IMPEC, $I_4$ BD) measured couples show good correspondence with the RT2000 mandatory levels for single family dwelling and multi family dwelling buildings (respectively, 0.8 $m^3/h/m^2$ and 1.2 $m^3/h/m^2$), see Figure 6. This trend, that would need to be confirmed by further research, would then offer to regulatory performances an interesting correspondence with low cost means of control.

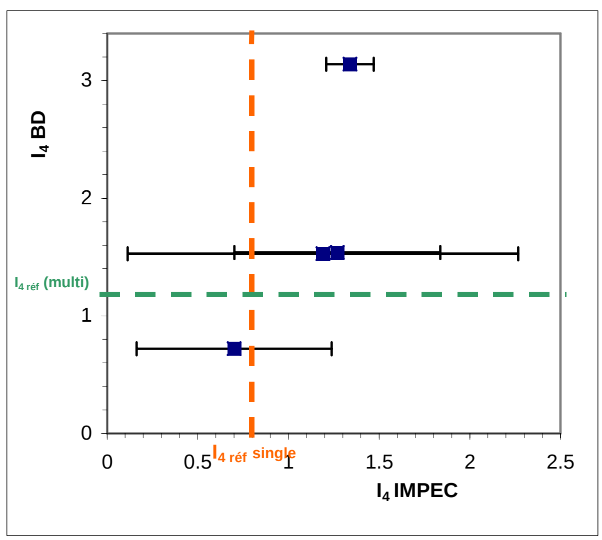


***Figure 6. Comparison between individual apartment measurements – median values – done with IMPEC ($I_4$ IMPEC) and whole building measurement done with Blowerdoor instrument ($I_4$ BD).*** *The error-bars correspond to the standard deviation of the median values of the IMPEC's measurement on the different dwellings of the building. Measurements on individual dwellings with IMPEC were done on 3, 5 (twice) and 10 dwellings.*

### Impact of airtightness on associated energy cost

Most of RT2000 thermal calculations of the 58 inspected buildings take into account a *default* value, 0.5 $m^3$/h/m² less airtight than the *reference* value of 0.8 $m^3$/h/m² for single family dwellings and 1.2 $m^3$/h/m² for multi family dwelling buildings. By accounting for this reference value, designers do not need to justify any airtightness performance. This late reason, coupled with frequent lack of knowledge on airtightness issues, makes the *reference* value to be the predominant choice for engineers in their RT2000 thermal calculations. Numerical simulations from 40 buildings of the field measurement sample (36 single family dwellings and 4 multi family dwellings) have been done through a sensitive analysis of airtightness on the RT2000 energy consumption coefficient C. Calculations have been done by modelling dwelling well known case studies and varying the airtightness airflow rate, when assessing the C coefficient with the engine of calculation developed by the CSTB, *THC 2000* (version 2.1.1). Detailed methodology has been described elsewhere, (Litvak, 2005). Results show that almost 75 % of the single family dwellings and 3 buildings out of 4 would improve the C coefficient by up to 6% for single family and 2% for multi family dwellings, if the actual (i.e. measured) airtightness value would have been chosen, instead of the default value leading to $C_{déf}$.

## CONCLUSION AND FUTURE WORK

A commercial version of IMPEC, under the name Perméascope®, has been developed and tested successfully on a 123 dwelling nationwide field measurement campaign. The results corroborate earlier findings on the major infiltration locations and on the performance of concrete and masonry constructive types, that appear to be particularly airtight as referred to the present French thermal regulation RT2000. If, air infiltration impacts on energy consumption and hygienic air renewal are shown to be significant, simple corrective actions provided after measurement tests show that potentials for improving performance can reach up to 70%. Moreover, development of onsite low-cost measurement instruments, as part of quality assurance tools, appear to be a major solution to reduce the likelihood of infiltration pathways, caused by lack of care during the construction phase. It can also help designer to optimise the airtightness performance level in their regulation thermal calculations.

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