FRENCH POLICY FOR SHELTER-IN-PLACE: AIRTIGHTNESS MEASUREMENTS ON INDOOR ROOMS

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ABSTRACT

Accidental dispersion of toxic gas clouds may occur around industrial platforms or during hazardous materials transportation. In case of such a toxic risk, the best protection strategy is to remain inside a building and seek refuge in an airtight room identified as "shelter" until the toxic cloud has finally been swept off. This strategy called "passive shelter-in-place" also includes obstructing all external openings and turning off all mechanical ventilation systems

Following the AZF chemical accident (Toulouse, 2001, 31 deaths), a French law was adopted in 2003 that can compel public and private building owners to adopt such a shelter-in-place strategy. To prove that the shelter airtightness is sufficient and that the occupants will not be exposed to irreversible effects, the shelter's air leakage measurement is compulsory for buildings owners. Envelope leakage does not need to be measured.

This paper gives an overview and first analysis of collected airtightness measurements for these indoor shelters. More than 100 results have been collected, with information on the building use (one-family dwelling / multi-family dwelling / non residential), the required airtightness level, the volume, the floor area, the year of construction. The final goal of this database is to give a picture of the vulnerability of housing stock around industrial platforms.

The aim is to help local decision makers with information related to the cost and the extent of works to be done on buildings in order to protect people against toxic risk, e.g. to reach the expected airtightness requirement, regarding some criteria like building use, geometric characteristics of the shelter, year of construction.

These experimental data can also be used as inputs in multi-zone airflow and pollutant transfer model, when data on internal airtightness are needed to study inter-zone airflows.

KEYWORDS

Air infiltration, air leakage, shelter-in-place, vulnerability, toxic risk, land-use, indoor air transfer, airtightness measurement

INTRODUCTION

Accidental dispersion of toxic gas clouds can occur around industrial platforms or during hazardous materials transportation. In case of such a toxic risk, two strategies can be implemented to protect people: shelter-in-place or evacuation [1]. In France, like in other countries, passive shelter-in-place has been found the best protection strategy. It consists in having people remain inside a building and seek refuge in an airtight room identified as 'shelter' until the toxic cloud has finally been swept off. Following the AZF chemical accident (Toulouse, 2001, 31 deaths), a French law adopted in 2003 established a land-use tool around all SEVESO II (high level) classified establishments [2]: the technological risk

prevention plan (PPRT) [3]. Such a plan specifies protective construction works for future and existing buildings in case of toxic risk in the plant, which consist into the implementation of a shelter-in-place system against toxic risk.
On 14th August 2012, 182 PPRT have been established, 8 PPRT have not begun and 212 are under development.

DESCRIPTION OF SHELTER-IN-PLACE REQUIREMENTS ON BUILDINGS

Shelter-in-place requirements are detailed in a guide we wrote up for the French Ministry in charge of PPRT plans development [4]. It is compulsory for a shelter-in-place system to achieve the protection of people during 2 hours against irreversible effects caused by a toxic cloud.

Firstly, a shelter-in-place system includes general constraints on the whole building and on a room used as shelter. These constraints do not depend neither on the toxicity of the products, nor on the intensity of the toxic cloud.
For instance, each building has to be equipped with a system that quickly stops all voluntary airflows, which supposes an emergency circuit breaker on ventilation systems and devices to close rapidly the air inlets and outlets. The room used as shelter must respect a minimum size per occupant (1 m², 2.5 m^3). The heating system must be adjustable from the room. Toilets are compulsory in the shelter for non-residential buildings, but not for dwellings.

Secondly, the shelter's airtightness level must guarantee that the concentration in the shelter remains lower than the irreversible effects threshold (SEI) during 2 hours, for the considered toxic cloud.
During the elaboration of the PPRT, different zones are defined along with the severity of the effects (irreversible, lethal 1%, or lethal 5% effects) and types of pollutants. For each zone, a conventional toxic cloud (60 min duration) can also be defined.
Then, the maximum attenuation rate on concentrations A (Eq.1) is calculated, defined as the ratio between the threshold in the shelter and the concentration of the conventional outdoor toxic cloud. As a result, the maximum attenuation rate depends on the toxicity of the products, and on the severity of the effects caused by the toxic cloud. In case of several toxic products, the lowest attenuation rate is selected.

$$A(\%) = \frac{SEI(2h)}{C_{outdoor}(1h)} \qquad (1)$$

With this, it is possible to calculate the airtightness level of the shelter that will be able to guarantee this maximum attenuation rate. For shelter-in-place issues, we use as an indicator the air change rate at 50 Pa: n_{50} (Eq.2, [5]). Pressure codes like CONFINE can be used, under conditions described in the guide [4].

Since 2005, we have developed CONFINE ([6],[7]), a software that calculates the minimum airtightness level required for a shelter in order to maintain the internal concentration under a given limit. With CONFINE, we assume that any building can be modeled as a 3-zones building with a default envelope airtightness level: Q_{4Pa_surf}, the airtightness indicator in French Thermal regulation (Eq.3, [8]).

$$n_{50} = \frac{q_{50}}{V} \quad (2)$$

$$Q_{4Pa\_Surf} = \frac{q_4}{A_{Tbat}} \quad (3)$$

$q_{\Delta P}$: volumetric airflow through envelope leakage defaults with an induced pressure difference ΔP, between indoor and outdoor ($m^3.h^{-1}$)
V: internal volume of the tested zone (m^3)
A_{Tbat}: total envelope area of the building, excepted ground floor area, according to the French thermal regulation (m²)

SHELTER-IN-PLACE AIRTIGHTNESS REQUIREMENTS FOR DWELLINGS

Airtightness requirement on an internal room envelope

The French Ministry for Ecology wished to avoid an airtightness calculation for each dwelling, which would result in an additional cost for individual owners. In this goal, we used CONFINE software to generate abacus, using "standard dwellings", as presented hereafter. These abacuses deliver the shelter airtightness requirement (n_{50}) depending on the maximum concentration attenuation rate (Eq.1). They are includes in the guide [4] used by State departments responsible to design PPRT. As a result, PPRT-plans include, for each zone, airtightness requirements for dwellings, and not only the maximum attenuation rate, which is not directly applicable. Contrarily to non-residential buildings, there is no need to use modeling software such as CONFINE to define the shelter airtightness level of dwellings.

The "standard single-family dwelling" (Figure 1) has been considered in the abacus as a single level house, with a 98 m² ground floor and whose envelope airtightness level is estimated as the 95th percentile of the CETE airtightness database[1]: Q_{4Pa_surf} = 2 m^3/h/m² (n_{50}=7.7 h^{-1}, considering V/A_{Tbat}=1.4 m).
The "standard multi-family building" (Figure 2) has been considered as a four-stories building, with an envelope airtightness level estimated following the 95th percentile of the CETE airtightness database on multi-family dwellings[2]: Q_{4Pa_surf}, = 3 m^3/h/m² (n_{50}=6.5 h^{-1}, considering V/A_{Tbat}=2.5 m).

For both types of buildings, two configurations were studied depending on whether the shelter is down- or upwind.
Lastly, three wind velocities have been considered: 3-5-10 m/s.
As a result, we computed 12 abacuses (Figure 3), which are used by State services during technological risk prevention (PPRT) plans design.

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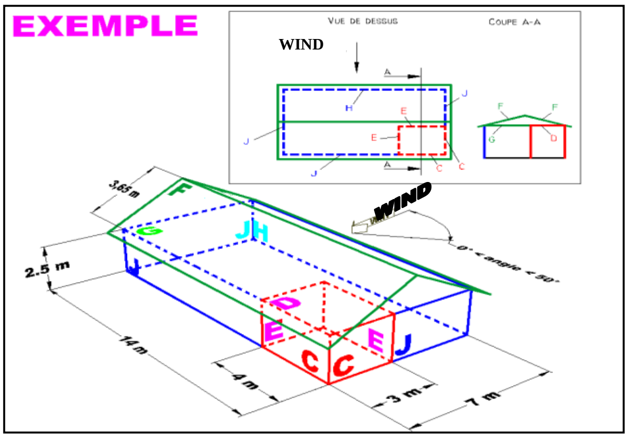
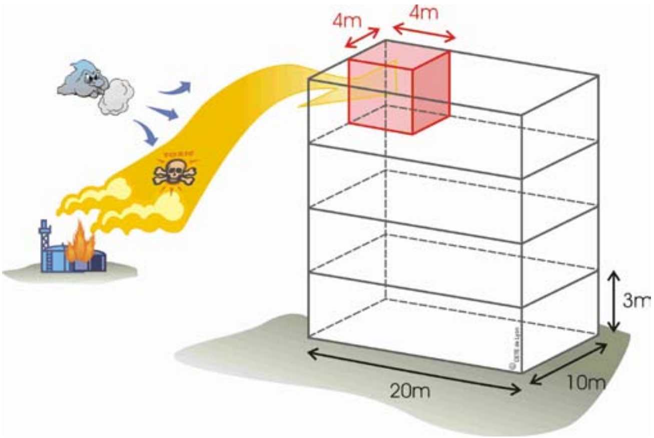
1 217 single-family dwellings in 2007
2 190 multi-family dwellings in 2007



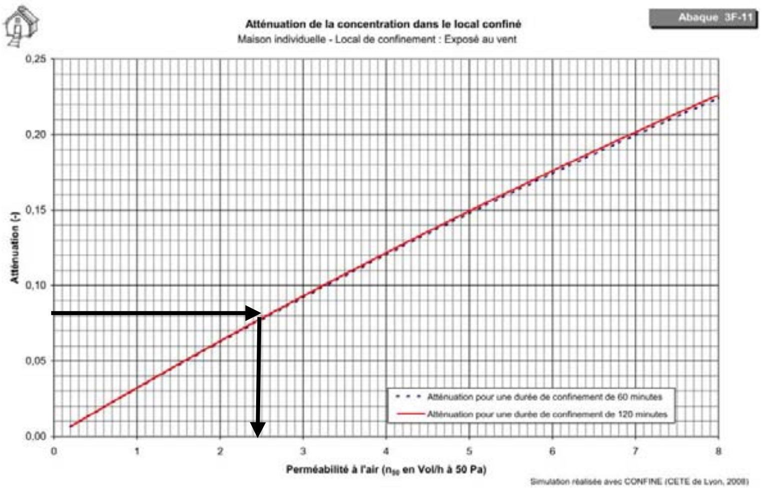
$V_{shelter}$ (m^3)	27
V_{attic} (m^3)	98
$V_{rest\ of\ the\ building}$ (m^3)	251
$H_{building}$ (m)	4.2
Slope of the roof (°)	25
$Q_{4Pa\ Surf,attic}$ ($m^3/h/m^2$)	30
$Q_{4Pa\ Surf,building}$ ($m^3/h/m^2$)	2

Figure 1 and Table 1: Characteristics of the 3-zones "standard single-family dwelling", with downwind shelter



$V_{shelter}$ (m^3)	48
V_{attic} (m^3)	0
$V_{rest\ of\ the\ building}$ (m^3)	2352
$H_{building}$ (m)	12
Slope of the roof (°)	0
$Q_{4Pa\ Surf,attic}$ ($m^3/h/m^2$)	/
$Q_{4Pa\ Surf,building}$ ($m^3/h/m^2$)	3

Figure 2 and Table 2: Characteristics of the 2-zones "standard multi-family building", with upwind shelter



A =	**8 %**
	n_{50}
Upwind shelter, v=3m/s	2.5 h^{-1}
Downwind shelter, v=3m/s	> 8 h^{-1}
Upwind shelter, v=5m/s	1.3 h^{-1}
Upwind shelter, v=10m/s	0.5 h^{-1}

Figure 3 and Table 3: Example of use of "standard single-family dwelling" abacus for shelter airtightness requirement establishing

Measurement requirements

For every building, air leakage level of the shelter must also be measured after constructive works have been implemented, including works on ventilation systems.
As it was shown in Rolfsmeier et al.'s paper [9], there can be misinterpretations of the measurement protocol and analysis, with consecutive errors in the estimations of derived quantities that are used in the calculation method. As a consequence, the French Ministry for Ecology decided that the air leakage measurers will have to be authorized to perform such measurements, and has streamlined a procedure in this goal. This procedure described in a paper [10] concerns measurements in the field of low-energy labels and of the new French thermal regulation (RT2012). On September 2012, around 400 persons have been authorized.
In the PPRT plan, buildings owners are encouraged to work with those authorized measurers. A special measurement protocol has been developed and published [11].
In order to accompany the market transformation in this field, we have conducted a free training program for authorized measurers, including information on the PPRT context and the shelter-in-place strategies, and works to be realized on buildings. On September 2012, around 80 persons have been trained. The list of the trained professionals is maintained on a website [12] and largely distributed to State organizations and local authorities.

COLLECTED DATA

Context

During the working out of each PPRT, shelter-in-place studies may be implemented by local State organizations, in order to get information on the vulnerability of the territory, and have an idea on the financial impact of the PPRT.
For selected dwellings and with their owners' agreement, a free-of-charge vulnerability diagnostic may be realized, supported by the Ministry for Ecology, including an air leakage measurement. In those cases, measurements are performed before any constructive work has been done. Thanks to these diagnostics we were able to collect data and to generate a small database.

Description of the database

In September 2012, data from 140 measurements performed between 2008 and 2012 on 95 single-family dwellings and 45 multi-family dwellings were collected.
For each dwelling, the database includes the location, the type of dwelling (single-family or multi-family), ground floor area and volume of the shelter, required and measured airtightness of the shelter. Year of construction and envelope airtightness level are sometimes given.

First analysis

Airtightness measurements on internal rooms give results from n_{50}=0.7 h^{-1} to 30.7 h^{-1}, with a median value of 6.1 h^{-1} and a mean value of 8.0 h^{-1}. A first analysis in terms of cumulative frequency shows that 95% of the tested rooms have an air leakage level under n_{50}=22 h^{-1}. Figure 4 shows that it is much higher for single-family dwellings (n_{50}=22 h^{-1}) than for multi-family dwellings (n_{50}=17 h^{-1}). For 6 cases, we were able to compare the airtightness of the shelter to the envelope airtightness of the dwelling (Table 3). For one case only, shelter envelope is tighter than dwelling envelope. Internal rooms are rarely designed to be tight because there is rarely an energy issue, even if acoustics or IAQ problems could contribute to design airtight rooms. On the field, we often observe that high air leakage is due to a leaky internal wall: for instance wood intermediate floor without concrete slab.

We observe also that year of building's construction, volume and ground floor area of the shelter have no influence on its airtightness level.

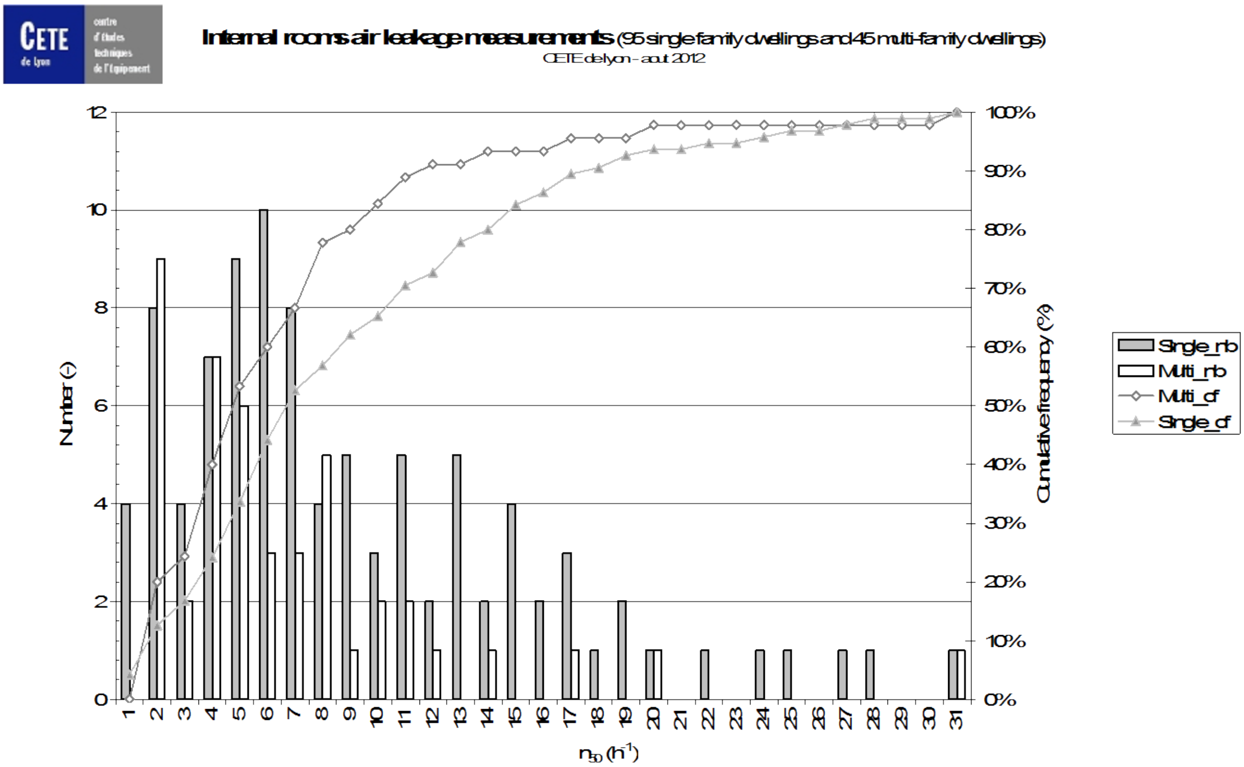


Figure 4: Internal rooms air leakage measurements on 140 dwellings. Cumulative frequencies.

Type of dwelling	n_{50} room (h^{-1})	n_{50} enveloppe (h^{-1})
Single-family	5.5	8.2
Single-family	6.9	5.0
Single-family	13.3	10.3
Single-family	15.8	8.0
Single-family	20	9.0
Multi-family	3.1	2.6

Table 4: Comparison between internal and envelope airtightness levels

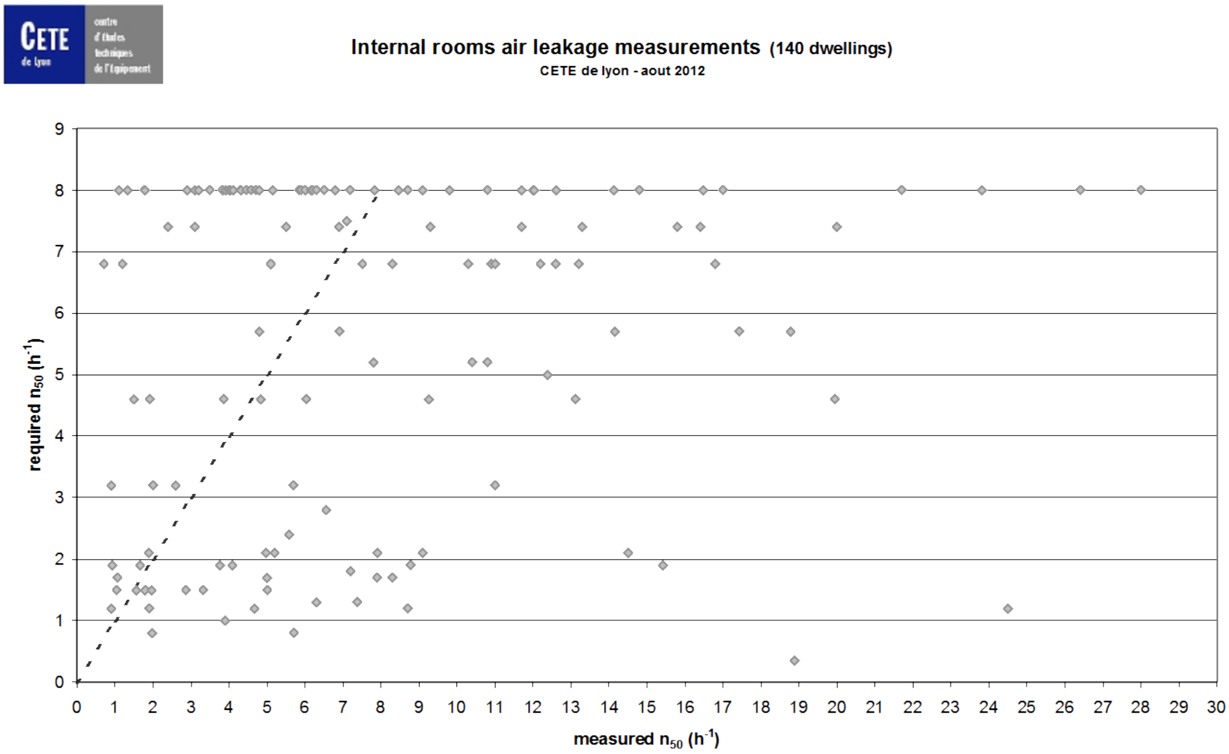


Figure 5: Internal rooms air leakage measurements on 140 dwellings. Difference between airtightness requirement and measurement

As a result, 60 % of the tested shelters have lower performance than expected (Figure 5). In those cases, private individuals have to perform constructive works in the room in order to achieve an airtightness level, which will guaranty their protection. On the other size, a significant number of shelters are tight enough (40%). In those cases, buildings owners would just have to do works to respect general constraints on the whole building and on the room used as a shelter (e.g. a system to quickly stop all voluntary airflows).

CONCLUSION

When all PPRT plans will be promulgated, we expect to have a database of about 1000 airtightness measurement of shelters. Later on, it will be more difficult to collect these data because each dwelling's owner will order its own measurement.
Analysis of this database allows us to estimate the territory vulnerability around Seveso facilities in France and overall cost consequences of this public policy.
This database is also a good opportunity to collect precise information about internal air leakage in dwellings. These experimental data can be used as inputs in multi-zone airflow and pollutant transfer model, when data on internal airtightness are needed to study inter-zone airflows.

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