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FIELD MEASUREMENT RESULTS OF THE AIRTIGHTNESS OF 64 FRENCH DWELLINGS

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ABSTRACT

This work presents a field measurement study, investigating the airtightness of 64 French dwellings less than ten year old. Buildings have been classified according to the type of construction (masonry or timber frame) and of occupancy mode (multi- or single- family). Using a fan-depressurization technique, we assessed the air leakage rate of each dwelling, based on a theoretical flow model that relates the infiltration airflow rate to the differential pressure . Meanwhile quantifying air leakage rates, we also observed the locations of air leakage paths using a smoke detection method and infrared thermography. In order to compare the results obtained among the sample of dwellings, we assessed the ratio of the air leakage rates divided by intrinsic characteristics of each construction, namely the *unheated surfaces* and the *heated volume*. We compared the performance of the French dwellings measured in this study, as a function of the different building types. The results of this work show that construction characteristics can play a significant role on buildings' airtightness, as well as on the interpretation itself of the performance.

KEYWORDS

Airtightness, Field measurements, Dwellings, Infiltration, Ventilation, Buildings, Air leakages

BACKGROUND

The airtightness of buildings is becoming a growing concern in the building construction field, since it appears to be a relevant issue in terms of energy efficiency and indoor air quality. Field measurement studies and theoretical works have shown that several types of problems can arise from uncontrolled leakages in buildings (e.g., higher energy costs, thermal comfort and health of occupants, building components and equipment preservation, control of indoor air quality). Although these impacts have been recognized as of key importance, work is still needed to better characterize the airtightness of buildings and the parameters affecting it. Recent studies have shown that airtightness can strongly depend on local construction practices, as well as on factors such as the building type and height or the year and age of construction.

Yet, the mechanisms of air infiltration within buildings need to be better understood. Such knowledge is essential to assist in the development of analytical tools for predicting airchange rates that account for uncontrolled ventilation. Nowadays, the most acurate method to assess the airtightness of a construction consists in measuring it. For that, field measurement campaigns need to be led in order to know the actual situation in the concerned countries.

Objectives

The objective of this study is to quantify the actual performance of French dwellings in terms of the enveloppe airtightness, with a view to propose relevant recommendations for the New French Thermal Regulation (NRT), intended to be applicable current year 2001. In this work, we aim at establishing a classification among buildings based on different construction types. For that, we analyzed 64 measurement of the airtightness of less than 10 year-old French dwellings, performed by the CETE de Lyon during the 90s.

THEORY

The modelling of airflow patterns through cracks of the building enveloppe follows from the theory of Fluid Mechanics adapted to single elementary orifices. The early works on hydronamics of pipes allowed to characterize the governing parameters of airflow patterns from the intrinsic properties of the systems and led to the assessment of the airflow rates through elementary holes, given by Eqn. 1. It is demonstrated that the flow coefficient n in Eqn. 1 varies in the range [0.5-1.0] (a laminar airflow pattern corresponds to n = 1.0, whereas a turbulent airflow pattern corresponds to n = 0.5), Sherman (1980).

$$\mathbf{Q = K \cdot \Delta P^n} \tag{1}$$

where	Q	$[m^3/h]$	is the air leakage flowrate
	ΔP	[Pa]	is the differential pressure between indoor and outdoor
	n	[-]	is the flow exponential
	K	$[m^3/h/Pa^{-n}]$	is the airtightness constant

The modelling of airflow patterns through elementary orifices was adapted from Eqn. 1 to the cracks and holes of the building enveloppe as a whole, under conditions that consider : 1) the air as the fluid of the flow, 2) pressure differentials in the range [0 : ±100 Pa] and 3) orifice diameters larger than their respective length. Hence, for an entire building, the airtightness governing equation assessing the total infiltration airflow rate is given by Eqn. 2.

$$\mathbf{Q_{building} = \Sigma_i \left(K_i \cdot \Delta P^{\,n_i}\right)} \tag{2}$$

In general, the infiltration airflow rate of a building is assessed following the classic form of Eqn. 1 (the parameters K and n representing the airtightness and flow coefficient of the *whole* building). The Eqn. 1, relative to a whole building, enables to qualify the airtightness of the walls : namely, if $0.7 \le n \le 1.0$, the construction can be considered as having no major infiltration pathways (the value of K allowing to quantify the airtightness of the construction). On the contrary, the presence of one or more large openings within the walls is characterized by $0.5 \le n \le 0.6$. As a matter of fact, the value of n = 2/3 is commonly accepted in the literature as representative of the average flow coefficient observed accross buildings' enveloppes.
To compare building infiltration performances among themselves, one needs to assess the ratio of the (measured or theoretical) infiltration air flowrate assessed at a refence pressure ΔP_0 weighted by an intrinsic dimension of the construction. Several dimensions are used in the literature : the enveloppe

surface, the heated volume, the unheated walls surface, etc... The infiltration airchange rate $\tau_{\Delta P}$ [h^{-1}] is a commonly used indicator to compare the airtightness of buildings. It is equal to the ratio of the air leakage flowrate at ΔP, divided by the heated volume of the building. Besides, some European countries have decided to consider the leakage index $I_{\Delta P}$ [$m^3/h/m^2$], defined as the infiltration airflow rate at ΔP_0 weighted by specific surfaces of the enveloppe, more susceptible to promote the infiltration of air leakages. For our study, we considered the specific *unheated surfaces*, as the *« surfaces that separate the indoor heated volume from the outdoor air and indoor unheated air »*.
Yet, the most accurate manner to determine the airtightness of a building consists in measuring its infiltration airflow rate. A standardized method, using a fan-depressurization technique (called as well, as the « bloower-door » method), is commonly used by many countries and follows the procedure described in an international norm, ISO 9972 (1996). The *« blower-door »* technique is particularly adapted to measure the air leakages in small buildings. For larger constructions and/or extremely leaky buildings, the depressurization usually becomes impossible, due to the power limitation of the fan. For this reason, tests involving multi family buildings were performed only on single dwellings. Furthermore, one should note that experimental results are obtained under calm weather conditions (namely, for wind speeds < 2 m/s). For that conditions, the dwellings' outdoor surfaces are not exposed to any (de)pressurization force except the force supplied from indoors by the fan. Yet, normal weather conditions include outdoor positive or negative pressures (induced by the wind on outdoor surfaces). This leads us to suggest that τ_{10} is more adapted to quantify the performances of the building under the stationary depressurization test conditions, whereas I_4 is the best index of the building airtightness under normal weather conditions. It is possible to link τ_{10} and I_4 , if one knows the flow coefficient n and the ratio V/S of the building. The relationship between these two indicators leads to Eqn. 3.

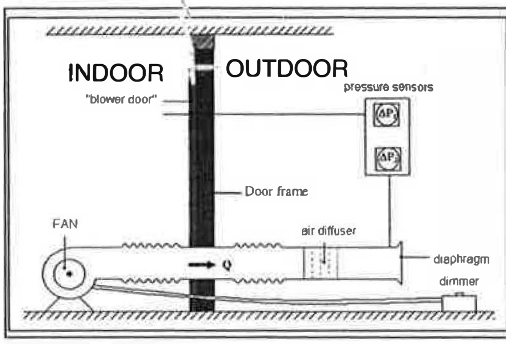
$$I_4 = 0.4^n \times \frac{V}{S} \times \tau_{10} \qquad (3)$$

METHOD

Experimental protocol and Data collection

The airtightness of 64 French dwellings have been measured from 1990 to 2000, using the same fan-depressurization equipment (the « blower-door » technique) and following the protocol described in the international norm ISO 9972. The buildings were chosen to be less than 10 year old. They were classified according to the type of construction (masonry or timber frame) and of occupancy mode (multi- or single- family).
Before each depressurization test, the openings provided to the dwelling for natural or mechanical ventilation were intentionally sealed with duct tape. A first depressurization of the dwelling enabled to inspect visually, either by smoke detection method or by infrared thermography, the potentials for air infiltration accross the enveloppe. For each test, the speed of the fan was increased by stationary steps of 10 Pa in order to depressurize progressively the dwelling, until a maximum generally close to 70 Pa. The experimental protocol is exhaustively described elsewhere, Litvak (2000).
During the depressurization test, the pressure difference ΔP_1 (between indoor and outdoor) and ΔP_2 (at the diaphragm) were recorded at each stationary step. The airflow rate through the fan (i.e., the infiltration airflow rate) was determined by Eqn. 4. Finally, the parameters (n, K) were determined by linear regresion (with $r^2 > 0.99$) of the collected data $\{\Delta P_1, Q\}$. The Eqn. 1 was then solved to assess the infiltration airflow rate at 10 Pa and 4 Pa, and the corresponding τ_{10} and I_4.

$$Q = k \times \sqrt{\Delta P_2} \qquad (4)$$



The equipment is mainly composed of 4 elements :

- the variable speed fan, that depressurizes the building
- the « blower door », a fake-door which has a flexible structure that allows to adapt it to the door-frame of the dwelling, and through which the fan extracts the air from the building
- the pressure sensor, that measures the pressure difference
- a flowmeter system, that determines the airflow rate through the fan that depressurizes the building

Figure 1 Description of the experimental protocol

RESULTS

Qualitative observations

The air leakage pathways of 30 dwellings among the sample were carefully investigated under the test depressurization conditions, by using visual smoke detection techniques or infrared thermography. The observations have been reported for each building and were classified according to the occurrence of different air leakage pathway types, Guillot & Litvak (2000). The most recurrent locations observed for infiltration are the electrical outlets (in 80% of the dwellings), the bonding between window frames and walls (77%), the indoor chests of shutters (63%) and the bonding between floors and walls (47%). Although the sample is not statistically representative, these main types of air leakage pathways are shown to be particularly sensitive to air infiltration in general. No significant link was found between the construction types and occupancy mode and the infiltration location types reported here.

Comparison of theoretical modelling and measurement results

The results collected for this field measurement campaign are in good agreement with the data published in the literature concerning the theoretical flow modeling of building airtightness. Namely, the median flow exponential found here is equal to 0.65 ($\pm$ 0.08 standard deviation), see Figure 2, while the commonly average value found in the literature is 2/3. The airtightness constants K and n of Eqn. 1, do not seem to have a significant correlation, when data are grouped all together, see Figure 3.

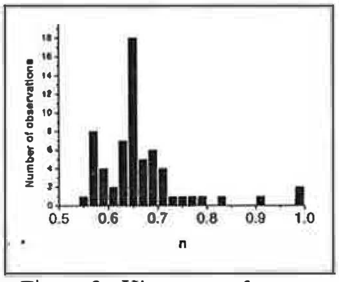


Figure 2 : Histogram of n.

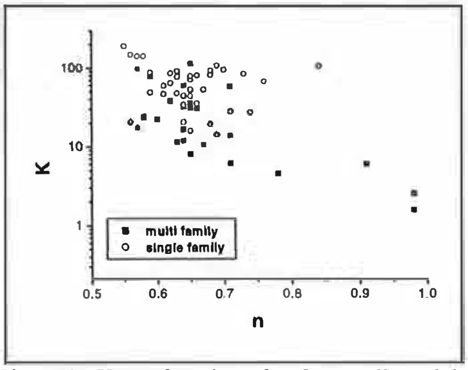


Figure 3 : K as a function of n, from collected data

However, when one considers separetely multi- and single-dwellings, two trends are observed. On the one side, multi-family dwellings appear to show an exponential decay of K with increasing n in the range [0.55 ; 1.0]. For these buildings, laminar flows (n > 0.7) are caused by micro-cracks and reveal excellent airtightness performances for these dwellings (K < 10 $m^3/h/Pa^n$). On the other side, n is found in the range [0.55 ; 0.7] for 90% of the single family dwellings. These values suggest the presence of large orifices in the enveloppe of the concerned buildings, causing large turbulent infiltration airflows.

Airtightness performance of dwellings

The airtightness performance indicators τ_{10} and I_4 should appear to be linearly correlated, in accordance with Eqn. 3. If single family dwelling regressions show good agreement between measurement results and Eqn. 3 solved with the median constants n and V/S of the collected data, multi family dwellings do not have a similar trend, due to the dispersion of the V/S ratios data collected for muti family dwellings, see Figure 4. Indeed, the V/S ratios for the multi family sample vary in the range [1 ; 5], while for the single family sample, this range is much narrower [0.8 ; 2], see Figure 5. This observation leads us to suggest that a more relevant type of classification of buildings would be the V/S ratio, that better describes the variability of constructions surface exposure to outdoors among multi family dwellings. Besides, in order to quantify the performance of buildings, we analyzed the τ_{10} distributions of each type of buildings (i.e., multi/single family and masonry/timber frame). Figure 6 and Table 1 show a significant difference of performance according to this classication. Namely, multi family dwellings and masonry constructions appear to be approximatively twice as much airtight as their complementary type do.

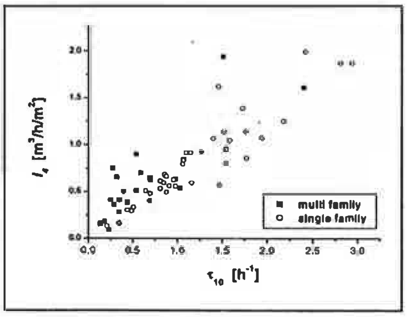


Figure 4 : Correlation between τ_{10} and I_4

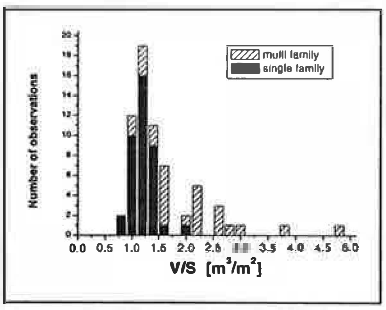


Figure 5 : Histogram of ratio V/S

MULTI FAMILY DWELLINGS		SINGLE FAMILY DWELLINGS	
V/S	median = 1.80	**V/S**	median = 1.16
linear regressions		**linear regression**	
from Eqn. 3 :	$I_4 = 1.0 \times \tau_{10}$	from Eqn. 3 :	$I_4 = 0.63 \times \tau_{10}$
linear fit :	y = 0.70 x, $r^2 = 0.75$	linear fit :	y = 0.68 x, $r^2 = 0.52$
Air Leakage change rate	τ_{10}	**Air Leakage change rate**	τ_{10}
median	0.49 h^{-1}	median	1.07 h^{-1}
Average (± 1 SD)	0.74 (± 0.76) h^{-1}	Average (± 1 SD)	1.23 (± 0.64) h^{-1}
MASONRY DWELLINGS		**TIMBER FRAME DWELLINGS**	
Air Leakage change rate	τ_{10}	**Air Leakage change rate**	τ_{10}
median	0.7 h^{-1}	median	1.36 h^{-1}
Average (± 1 SD)	0.84 (± 0.64) h^{-1}	Average (± 1 SD)	1.51 (± 0.76) h^{-1}

Table 1 : Collected data results for the 64 dwelling sample (SD stands for standard deviation).

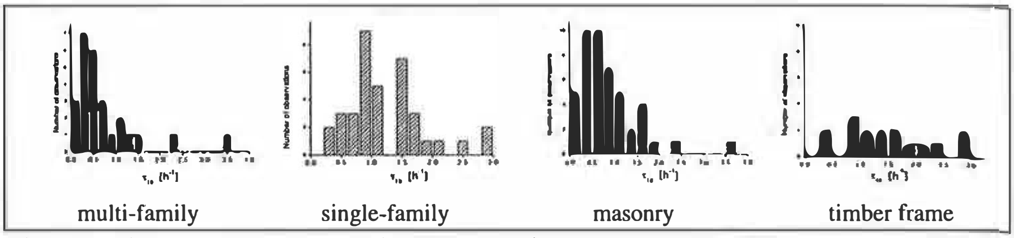


Figure 6 : Histograms of τ_{10} as a function of construction type and occupancy mode

Comparison between performances of dwellings and a reference level

We compared the actual performances of the dwellings of our sample to the reference level of the requirement stated by the Swedish Thermal Regulation, BBR (1999). The definition of the specific envelope area as accounted by the Swedish regulations is the *« aggregate area (m²) of surfaces, in contact with the heated indoor air, of enclosing elements of structure »*. The term "enclosing elements of structure" refers to elements which separate the heated parts of dwellings from the external air, the ground or partly heated or unheated spaces. One should note that the Swedish requirement is more severe than the reference indicator I_4 we used for this study, since the enveloppe surface according to BBR is usually larger than the area of the *unheated* surfaces (because it also accounts for surfaces above grounds, soils and platforms). Using an extrapolation to 4 Pa (i.e., 0.54 $m^3/h/m^2$ with n = 2/3) of the value of BBR (0.8 $l/s/m^2$ at ΔP = 50 Pa), we showed that 52% of the multi family dwellings and 27% of the single family dwellings respect the Swedish requirement, taken as a reference level here.

CONCLUSION

We report the field measurement results of the airtightness of 64 French dwellings. Qualitative and quantitative results show that the type of construction and of occupancy mode play a significant part on the airtightness performance of the buildings. The comparison of the airtightness levels of the sample with Swedish regulations shows that the good performances of Scandinavian dwellings are easily reachable for masonry and concrete buildings and for multi family dwellings. Timber frame French dwellings appear to be very sensitive to infiltration. Forthcoming studies should help us to study if the ratio V/S is a relevant parameter for differenciating airtightness performances of buildings.

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