Designing a model-scale experiment to evaluate the impact of steady wind on building air leakage measurements

Adeline Bailly Mélois*[1,2], Anh Dung Tran[1,2], Mohamed El Mankibi[2], François Rémi Carrié[3], Bassam Moujalled[1] and Gaëlle Guyot[1]

1 CEREMA BPE Project Team
46 rue Saint Théobald – BP128
38081 L'Isle d'Abeau Cedex, France
**Corresponding author: adeline.melois@cerema.fr*

2 ENTPE LTDS
3 rue Maurice Audin
69518 Vaulx-en-Velin, France

3 ICEE
93 rue Molière
69003 Lyon, France

KEYWORDS

Building airtightness, Measurement, Wind tunnel, model, Wind impact

NOMENCLATURE

A	Area of opening (m^2)
L	Length (m)
p	Pressure relative to external pressure (Pa)
q	Volumetric airflow rate ($m^3\ s^{-1}$)
U	Wind speed at the building level ($m\ s^{-1}$)
V	Internal building volume (m^3)
ρ	Air density ($kg\ m^{-3}$)

1 INTRODUCTION

Since the 1970s, many authors have discussed the impact of poor airtightness on building energy use, indoor air quality, building damage, or noise transmission [1–7]. Nowadays, because poor airtightness affects significantly the energy performance of buildings, and even more significantly with low-energy targets, many countries include requirements for building airtightness in their national regulations or energy-efficiency programs [8]. Building pressurization tests are increasingly used for compliance checks to energy performance requirements and may result in severe penalties [9]. Therefore, the uncertainty of the measurement results has become a key concern in several countries over the past few years. More specifically, several studies [10–14] have shown the significant uncertainties induced by the wind. Nevertheless, further investigations are needed to understand how the wind impacts pressurization tests and to characterize the error induced by the wind on the test results.

2 OBJECTIVES

The goal of our work is to increase the reliability of building air leakage measurements results regarding steady wind impact. Starting from model-scale experiments in controlled laboratory conditions, we propose to improve uncertainty estimates and tests protocols. In this presentation, we focus on:

- Similarity criteria for model-scale experiments;
- Experimental design and wind tunnel design.

3 METHODOLOGY

3.1 Similarity conditions

Our approach is to design a model to be able to conduct controlled experiments in laboratory conditions. Similarly to Carrié and Leprince [11,12], we assume that the building can be represented by a single zone model that consists of only two types of wall regarding pressure behaviour: the windward walls and the leeward walls. Thus, we assume that all leakages can be represented by only two leakages: one on the windward side and a second one on the leeward side.

One specific challenge in model-scale experiments is to achieve similarity conditions. To this end, we write the fundamental equations governing the pressurisation tests in non-dimensional form. There are 6 key equations that can be grouped as follows:

- pressure difference at the leaks Δp_i (2 equations);
- airflow through the leaks q_i (2 equations);
- mass balance of the system (1 equation);
- energy conservation of the system (1 equation).

We study a specific configuration with two identical leaks (same size and same height) in isothermal initial conditions and consider a steady wind. Then, for each dimensional variable X of these equations, we introduce a reference size X_{ref} according to the method described by N. Le Roux [15]. We also obtained the 4 dimensionless numbers (Π_1 to Π_4) described in Equation 1 to Equation 4.

$$\Pi_1 = \frac{\rho_{ref}.{U_{ref}}^2}{p_{ref}}$$ Equation 1

$$\Pi_2 = \frac{p_{ref}.{A_{ref}}^2}{\rho_{ref}.{q_{ref}}^2}$$ Equation 2

$$\Pi_3 = \frac{\sqrt{A_{ref}}}{L_{ref}}$$ Equation 3

$$\Pi_4 = \frac{V_{ref}.U_{ref}}{L_{ref}.q_{ref}}$$ Equation 4

To meet similarity conditions, the values of the dimensionless numbers Π_1 to Π_4 have to be identical both at reduced and real scales. It leads to the following relationships between scales:

$$\bar{U} = \bar{p} \qquad \bar{p}.\bar{A}^2 = \bar{q}^2$$

$$\bar{A}^{0,5} = \bar{L} \qquad \bar{V}.\bar{U} = \bar{L}.\bar{q}$$

with for each variable, $\bar{X} = \frac{X_{ref\ model}}{X_{ref\ real}}$.

Considering a generic real 2-story house (total floor area = 120 m², internal volume = 320m³, loss surface area excluding the basement floor = 224 m²) as our real building, and a scale ratio for the length of $\bar{L} = 1/25$, we obtain the scale ratios given in Table 1, and a geometric model described in
Figure 1.

Table 1: Scale ratios

$\bar{L}$	1/25
$\bar{A}$	1/625
$\bar{V}$	1/15,652
$\bar{U}$	1
$\bar{p}$	1
$\bar{q}$	1/625

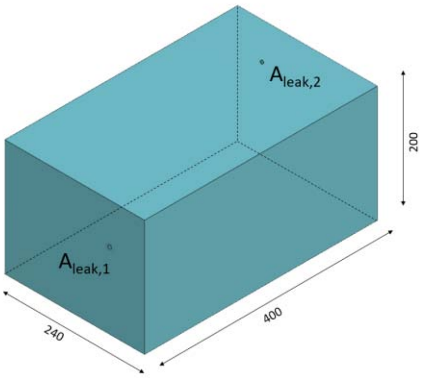


Figure 1: Model dimensions [mm]

3.2 Experimental design

During the air leakage measurements performed on our model placed in the wind tunnel, the following parameters are fixed:

- Initial inside and outside temperatures. The stack effect is not taken into account here to be able to estimate the wind error only.
- Total leakage area. Carrié and Leprince [11] have shown that it does not influence the error on the leakage coefficient in steady conditions.

On the other hand, we can adjust the following parameters from one test to another, which are expected to have a significant impact:

- Wind speed (from 0 to 12 $m.s^{-1}$) (steady wind during a test);
- Leakage areas distribution ($\frac{windward\ leakage\ area}{leeward\ leakage\ area}$ from 0.1 to 9);
- External pressure tap location (6 different locations).

3.3 Wind tunnel design

Figure 2 shows the key components of our wind tunnel, inspired from Stefano et al. [16] and Hernandez et al. [17].

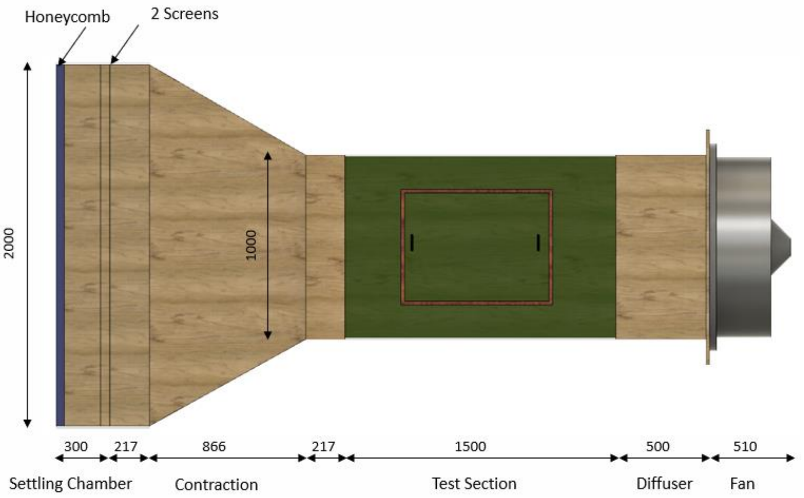
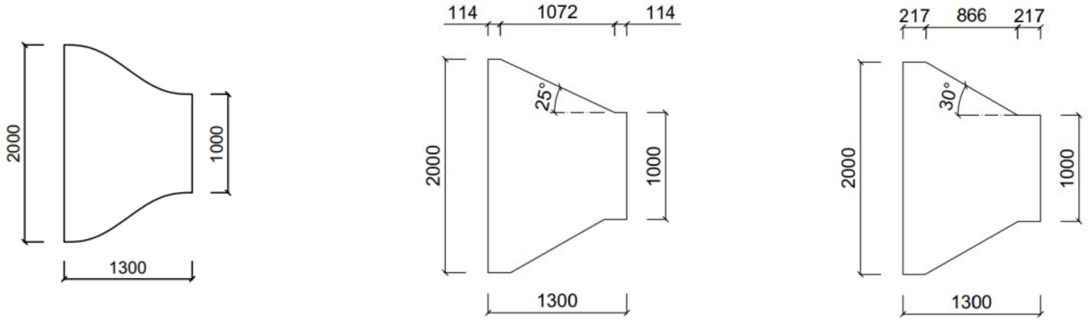


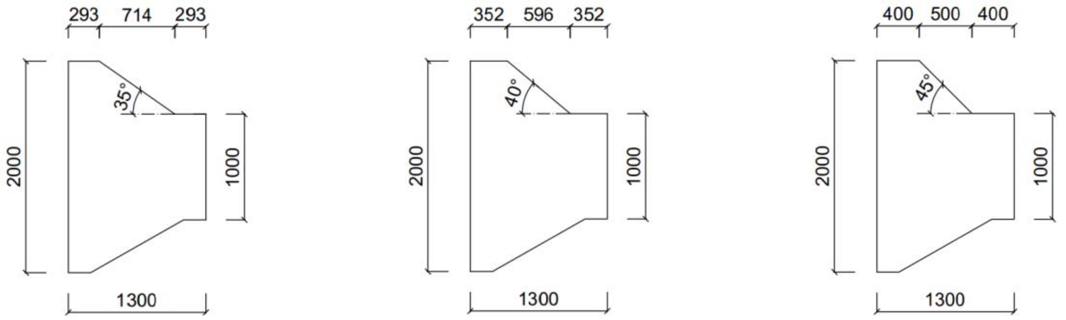
Figure 2: Final dimension of wind tunnel [in mm]

Note that:

- The Settling Chamber is equipped with a honeycomb and a series of screens.
- The Contraction accelerates the flow into the test section. The ideal form for a contraction is generated using the Bell-Mehta fifth order polynomials [18] (Figure 3 (a)). In order to reduce the difficulty of fabrication, we tested simplified forms with a CFD software. These CFD simulations compare wind behaviours with various angles of the contraction, from 25° up to 45° (Figure 3 (b) to (f)). Figure 4 shows the dispersion of velocity field in the flow direction in 8 points of the test section depending on the form of the contraction. We choose the 30° simplified contraction which offers an acceptable compromise between a small deviation in the velocity field in the flow direction (less than 3% discrepancy from the Bell-Mehta form) and no difficulty of fabrication in our case.



(a) Bell-Mehta form (b) 25° simplified form (c) 30° simplified form



(d) 35° simplified form (e) 40° simplified form (f) 45° simplified form

Figure 3: Different forms tested for the contraction

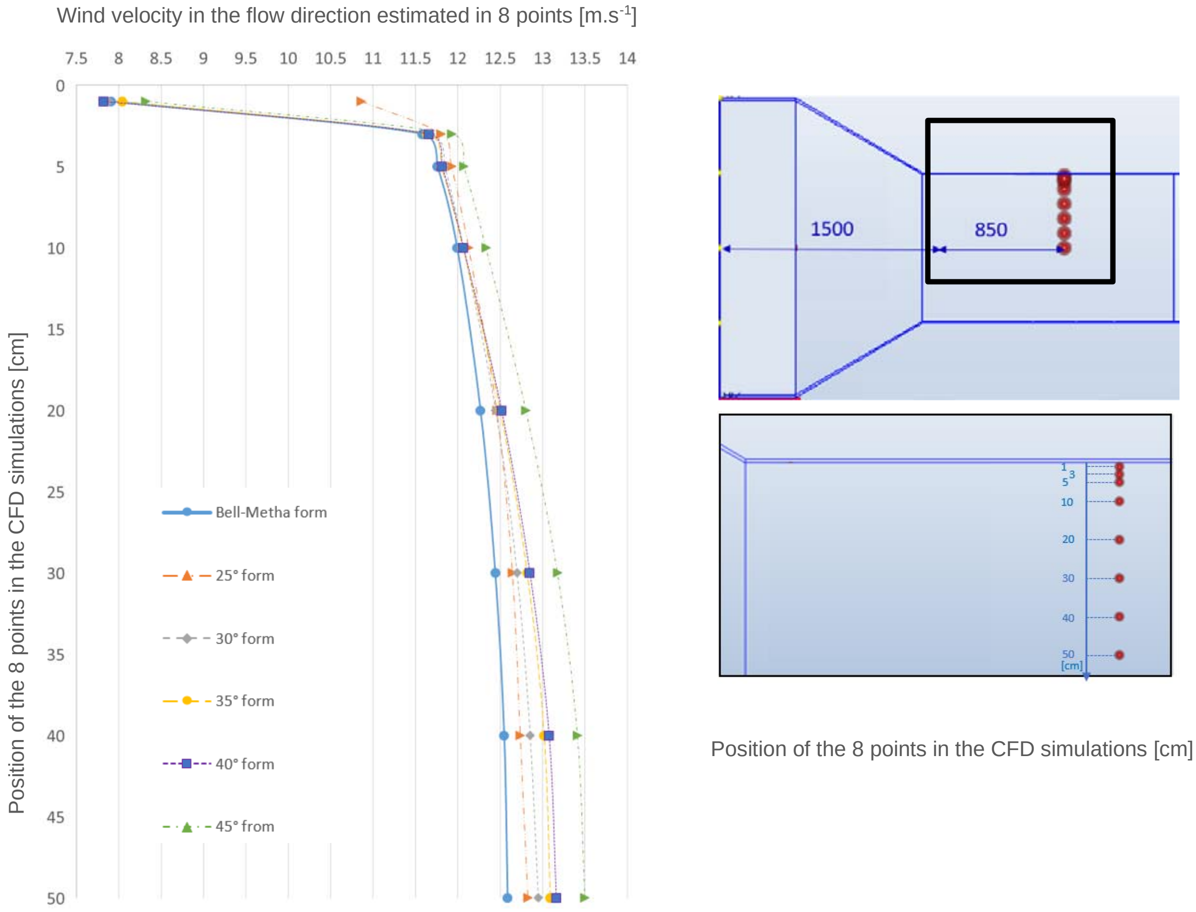


Figure 4: Wind velocity field inside wind tunnel for different forms of contraction

- The dimensions of the Test Section are 1x1x1.5 m^3. The frontal area of the model represents 4.8% of the test section cross-sectional area, which is under the 5% limit recommended by the ASCE as indicated by Choi and Kwon (1998)[19] (no blockage correction is needed).

4 EXPECTED RESULTS

The main expected results of this work are:

1) The evaluation of the measurement uncertainty due to a steady wind;
2) Propositions of improvement in the ISO 9972 protocol to reduce the uncertainty.

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