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AIR FLOW THROUGH BUILDING SLITS AND COMPONENTS

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Abstract

Pressure models require a good knowledge of the pressure distribution around the building and a precise description of air paths. The hydrodynamic behavior of these connections is usually reduced to an empirical power law $Q = K\Delta P^n$ with n equal to 0.5 for a turbulent flow and 1.0 for a laminar one. We present three levels of approach to improve our knowledge of the flow behavior of building components. First, we propose a new light experimental tool to determine the on site flow behavior of building elements. Second, we present the flow behavior of innovative air inlets developed in France and from on-site feedback, we suggest design improvments. Finally, we expose an extensive set of experiments on calibrated slits in the 0-100 Pa range and compare our results with other experiments. We point out that the fixed power law is not well suited in the low ΔP (0-20) Pa range which is the range of interest for building ventilation.

LIST OF SYMBOLS

Ca	discharge coefficient
Dh	hydraulic diameter
e	height
K	permeability
l	width
L	depth
n	exponent of the power law
Q	flow rate
Re	Reynolds number
S	section
V	air velocity
ΔP	pressure difference
λ	friction loss
ρ	density
ν	cinematic viscosity
ξ	minor friction loss

1 INTRODUCTION

The knowledge of the flow behavior of building components is important from many points of view :

- the results of pressure model simulation is conditioned by the relevance of the coefficients (K,n) given in input data [1].
- the efficiency of the ventilation system could be dangered by a poor component. Experiences has demonstrated that a high leakage area in a kitchen with a mechanical exhaust system induces a short-circuiting within this room [2].
- the energy losses through leakages may significantly increase the energy bill.
- the leakage comparaison between two building elements is based on their flow equation.
- the quality of the building construction can be evaluated from these data.
- the improvement of ventilation components and the development of innovative ones should integrate the hydrodynamic behavior in the design approach.

Unfortunately, the flow behavior through building elements is not well apprehended and documented. In most of the numerical pressure models, the flow equation for the parasitic openings is supposed to be a fixed power law $Q = K \Delta P^n$ where K is the component permeability and n is an exponent depending on the flow type. n is equal to 0.5 for a turbulent flow like through large openings, or 1 for a laminar flow like through thin cracks. Otherwise, n can vary between these limits and is usually set to a fixed value issued from practice or building regulation, because of a lack of more precise information. However, parametric studies have demonstrated the sensibility of the ventilation analysis with the parameters (K,n). We propose three levels of approach to improve our knowledge on the hydrodynamic behavior of building components. They correspond to a hierarchy in the understanding of the leakage physics : on-site components, innovative products, calibrated slits.

2 MEASUREMENT OF THE BUILDING COMPONENT AIRTIGHTNESS

DC pressurization techniques has been used for many years for the evaluation of the on site building envelope leakage [3]. This method has been refined and extended to identify the behavior of a specific component in various directions : reductive sealing of the element with a plastic foil and tape in two consecutive DC pressurisation tests allows the deduction of the flow behavior of the component. Baker and Valotaire (1987), Furbringer (1988) use a secondary fan to isolate hydrodynamically the component or the zone. Phaff (1987) develops a pressure compensating flow meter to place in an interior door to measure the relative contribution of the room façade. However, these tests are lengthly, require heavy equipements and are not really appropriate during the contruction phase. However, for important building complexs, we note that if a component (window, shutter,...) is not well set, fixed or installed, the probability of the others to be as poorly set is high. Therefore, we wanted to develop a prototype in order to evaluate the quality of construction from an airtighness issue at the construction phase and as well to identify the flow characterics of any building component. To answer these two objectives, the equipment had to be light and robust and the experimental procedure rapid and illustrative.

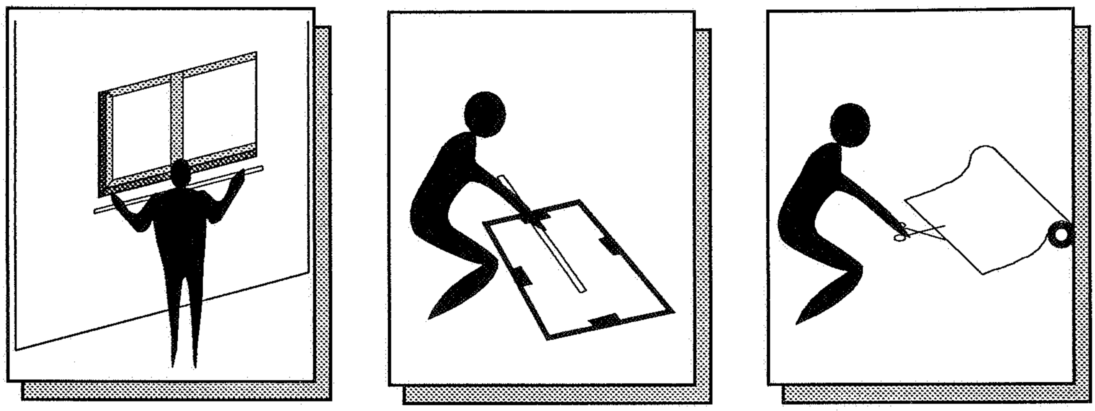
The prototype (protected by patent) is composed of three main elements :

- a light ajustable frame, (0.8mx1.1m to 1.6mx2.3m). Its weight never exceeds 20 kg.
- A measurement equipement including a flow meter, a flow controller, a pressure device
- a smoke generator

The various stage of positioning the frame are illustrated in figure 1. Before starting the recording phase, we do some pressure overshootings in order to simulate the position of our element after various wind loadings. We record the measures (Q, ΔP) in an ascending then descending ΔP and finally for a few random ΔP. The curve (Q, ΔP) is instantaneously drawn.

In the design process, we looked at various perturbations and found the following conclusions [4] :

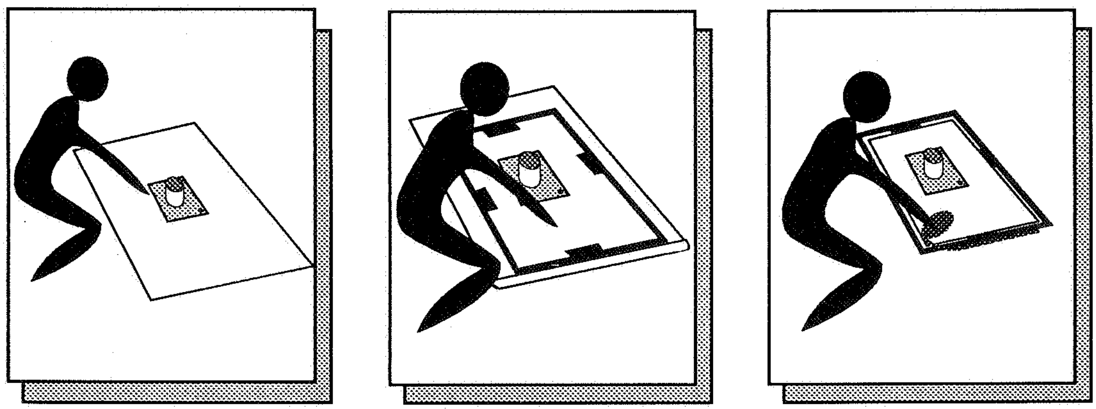
- the test should be conducted in an opened space (ie the interior door is opened)
- the position of the base (ie the injection or extraction point), do not influence the result



1 Measurement of the element size

2 Rough adjustment of the frame to the element size

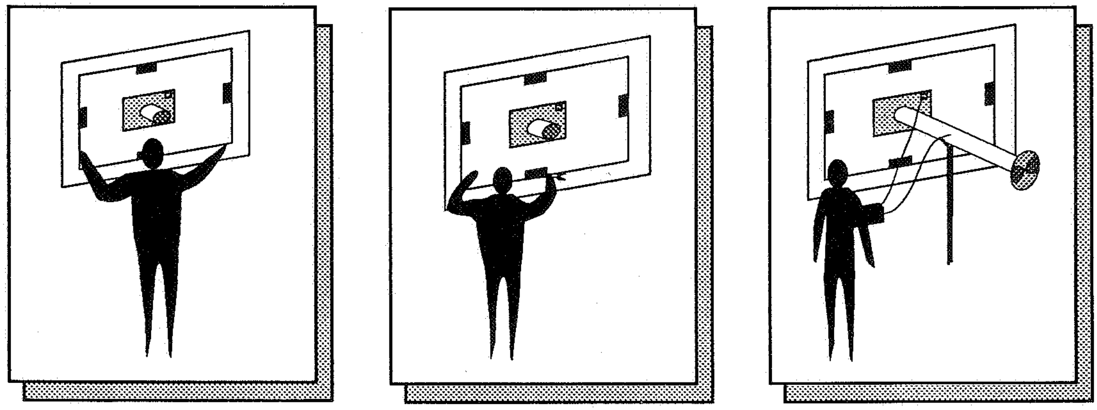
3 Cutting up of plastic foil



4 Fixing of the base on the plastic sheet

5 Placing of the frame on the plastic sheet and folding loosely the edges

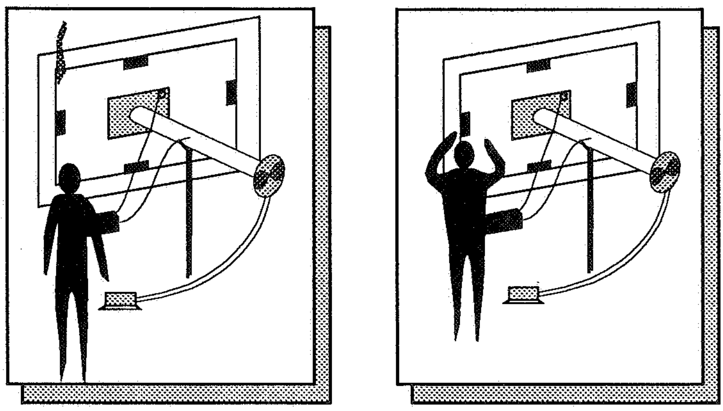
6 Sticking a 5 centimeter wide rubber joint around the frame



7 Lifting and placing of the frame

8 Adjustment of the frame

9 Connecting the fan and the measurement device



10 Injection of smoke

11 Sealing of potential leakage under high pressure conditions

Figure 1 : The various stage of positioning the frame

- the frame should be placed as far as possible of the tested element. However, the zone between the frame and the element is at an homogeneous pressure even with a few centimeters gap.

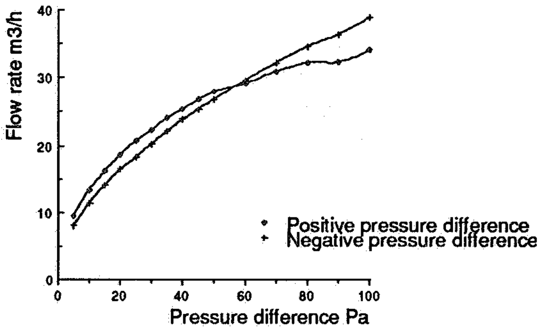
The overall test requires one hour and a single technician if the frame is placed in the interior side and two technicians otherwise.

From the curve characteristics, we control if the initial performance of the element are preserved. With the release of smoke, we identify the location of the poor mounting. This visualization allows the building workers to correct their installation procedure in the early stage of the project. This equipment appears to be an attractive tool for building quality. After the preliminary succesful tests, we are presently refining the prototype for ease of use by unqualified technicians. This equipment allows us to characterize on-site components and to better apprehend the leakages in the buiding stock but is not appropriate in the design phase of building components.The next two approaches are devoted to answer this issue.

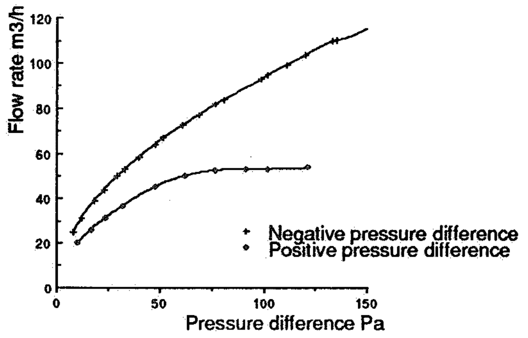
3 IDENTIFICATION OF THE FLOW BEHAVIOR OF INNOVATIVE COMPONENTS

The French market of ventilation has been active and successful in developing new devices to control the flow rate through inlets or outlets according to the humidity, the temperature, the pressure difference and so on. Unfortunatey, the flow behavior of these innovative products is not really available in the range of interest for the pressure differences -20 to 100 Pascals. The characterics of these components can not be simulated by a power law. Let us present some results.

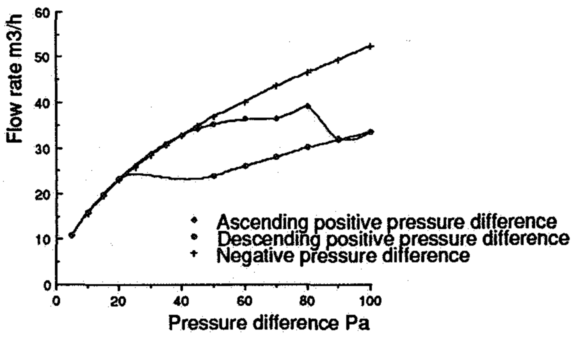
The flow rate is not limited to a maximum value when the pressure difference increased. The regulating device is not efficient and draft problems may occur with this product. This product acts as a hole in the façade.



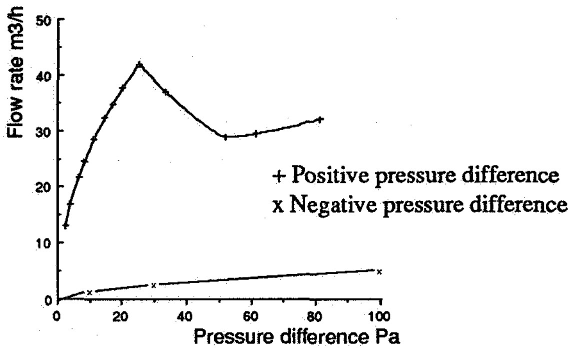
When the pressure increase on the building façade, the flow rate is limited to a maximum value of 50 m^3/h. When the pressure difference is opposite (ie the facade is on the leeward side of the building), the inlet acts as a hole and some air exist through an inlet !



This inlet which limits the flow rate presents a large hysteresis and evaluating the flow rate with a fluctuating wind is tricky because of the dependance of the flow rate and the previous stage of the controlling device. This hysteresis can be simply explained by the sudden blockage of the regulating blade on the inlet frame. Above a high pressure limit (100Pa), the controller blade reaches its maximum deformation and can no longer reduce the inlet area.



This inlet was manufactured for a maximum flow rate of 30 m³/h but in fact we notice this overshoot around 30 Pascals. Under 30 Pascals, this product acts as a hole and the regulating device plays its role only above this limit. Backward flow is restricted to 5 m³/h by a special device.



Air inlets represents the major source of fresh air and conditions the efficiency of the ventilation system. The improvement of their performance has resulted in a complex flow behavior which can not be apprehended by a power law.

Limitation the flow rate under high pressure differences is essential if we want to avoid draft problems and excess of incoming air. Because of the conditions of the certification, we notice that no care has been taken to avoid the air to exist when the pressure difference is opposite. This configuration is frequent, especially with the limited extraction rate we encounter in the new French houses. Moreover, in the presence of high wind, infiltrations in existing buildings are high and satisfy the requirement of fresh air. The air transiting through the inlet is not necessary. Therefore, we could imagine to shut down the air inlet above a ΔP limit. Unfortunately, the French regulations do not allow this opportunity. Knowing that a building will never be perfectly tigth, Figure 2 represents the ideal behavior of an air inlet. The limits are given as examples.

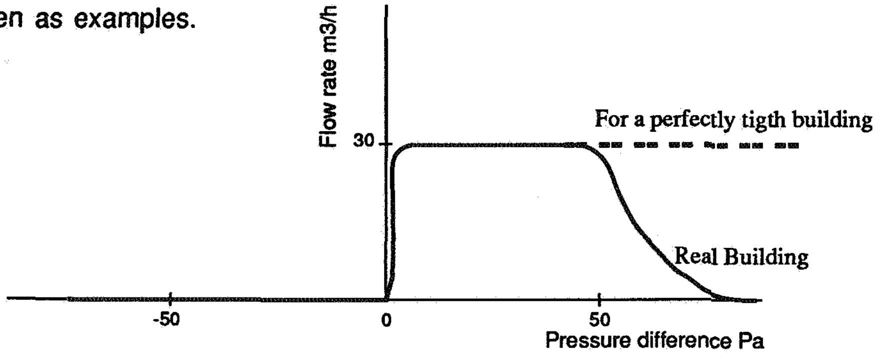


Figure 2 : Ideal behavior of an air inlet

4 AIR FLOW THROUGH BUILDING SLITS

4.1 Introduction

In the first approach, we supposed that the flow behavior follows the empirical power law. This assumption is valid above a 20 Pa pressure difference [5] and appropriate for on-site experiments where the control at low pression is tricky. However, building elements encounter more often pressure differences under this limit. Therefore, we develop an experimental laboratory equipement to test calibrated slots and evaluate the most appropriate law to suit the data. Figure 3 illustrates the test facility.

4.2 Fluid mechanics approach

The equilibium between the body, inertia, viscosity and pressure forces on a moving fluid in a duct is represented by the Navier-Stockes equations,which can not be solved analytically except in very simple configurations. So in fluid mechanics, the pressure difference between two points in a duct is supposed to be correlated with the fluid average velocity :

$$\Delta P = \frac{\lambda \rho L V^2}{2\,Dh}$$

The friction loss coefficient has to be evaluated according to multiple parameters of the flow configuration including the Reynolds number. For a building crack of height e and of width l, the pressure difference between the two sides is less than 100 Pa, the aspect ratio is low and the flow can be considered between parallel plates. So

$$\lambda = \frac{96}{Re}$$

Some particular accidents such as entrance, exit... increase the flow resistance :

$$\Delta P = \frac{\xi \rho V^2}{2} + \frac{96 \rho L V^2}{2\,Re\;Dh}$$

Using $Re = \frac{VDh}{\nu}$ and Q = VS, we get the two following equations :

$$\Delta P = AQ + BQ^2 \qquad (1)$$

with $A = \frac{K_1 L \nu \rho}{2\,S\,Dh^2}$

$$B = \frac{K_1\,\rho}{S^2}$$

or $Q = Ca\;S\left(\frac{2\,\Delta P}{\rho}\right)^{0.5}$ (2)

with $\frac{1}{Ca^2} = K_1 \frac{L}{Re\,Dh} + K_2$

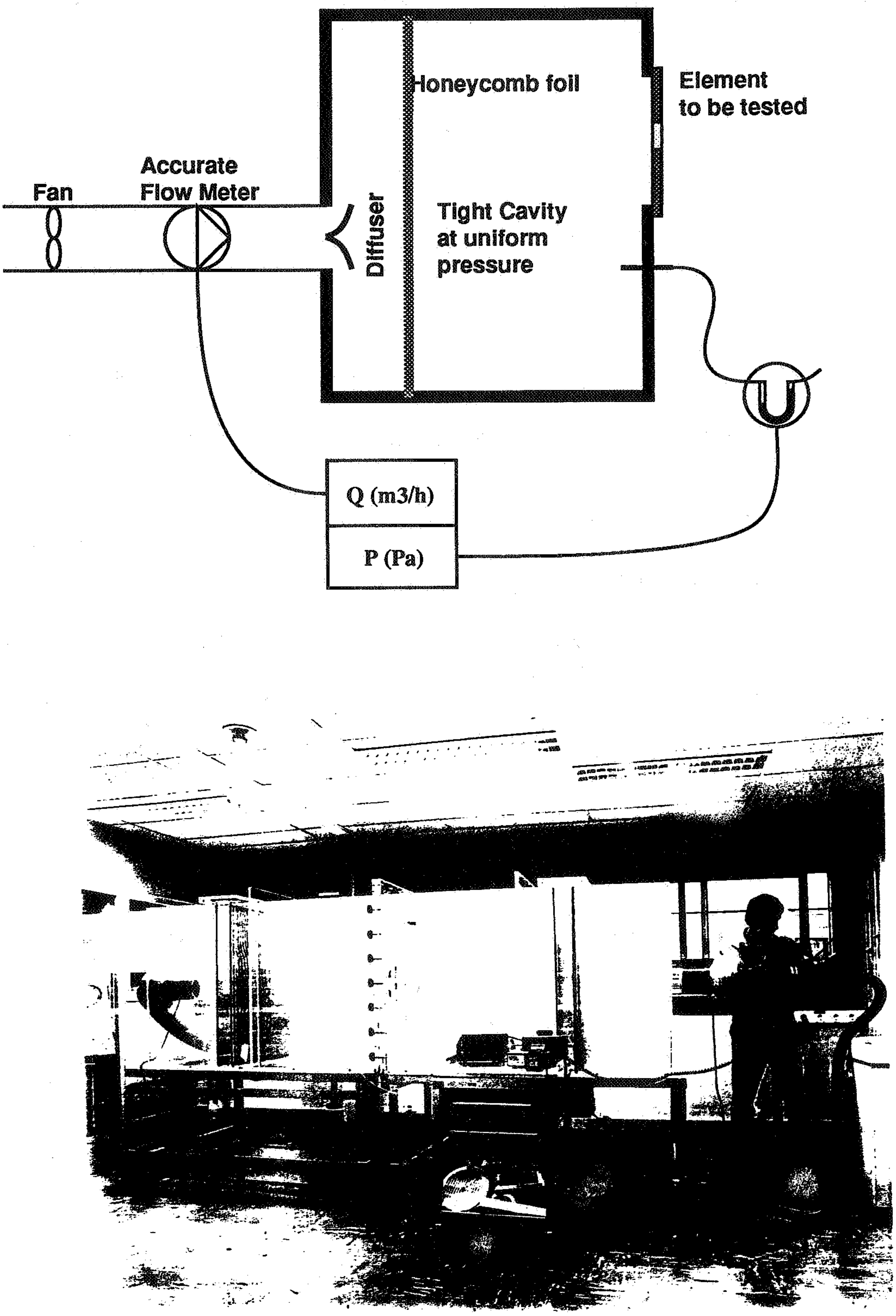


Figure 3 : View of the test facilities

4.3 Experiments

Different cracks of various sizes have been tested in order to evaluate the coefficient Ca. From our set of experiments (Figure 4), we get : $\frac{1}{Ca^2} = 114 \frac{L}{Re\, Dh} + 2.0$

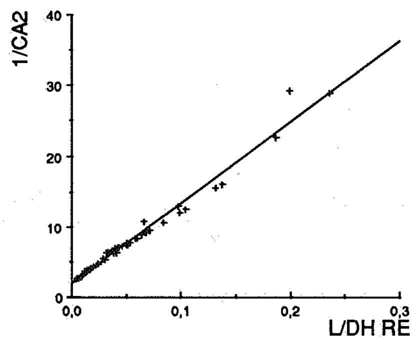


Figure 5 : Evolution of the discharge coefficient

The equation (2) is therefore well appropriate for our experimens and the correlation is closed to Etheridge and Baker's analysis.

Etheridge [6] proposed for a planear opening $\frac{1}{Ca^2} = 95.7 \frac{L}{Re\, Dh} + 1.5$

and Baker [5] $\frac{1}{Ca^2} = 103 \frac{L}{Re\, Dh} + 1.4$

Pressure models require an analytical expression of the flow rate as a funtion of the pressure difference. Unfortunately, equation (1) or (2) do not satisfy this condition. In order to overcome this problem, Etheridge expressed (1) in an other way :

$$Q = K\,\Delta P^{n(\Delta P)}$$

with

$$n = \frac{1}{2}\left(1 + \frac{1}{\left(1 + 4\left(\frac{B}{A^2}\Delta P\right)\right)^{0.5}}\right)$$

Homna [7] also found that n should vary with ΔP and proposed :

$$n = \frac{1}{2 - \exp(-\beta k\,\Delta P)}$$

In building situations, typical pressure differences range from 0 to 20 Pa inducing that the power law with constant exponent is not well adequate.

From this preliminary investigation, it seems than a quadratic law or a power law with a variable exponent is more appropriate in the low ΔP range but extensive experiments have to be conducted to propose a general law. Therefore, it is preferable to characterize a component by the couples (Q,ΔP) in the entiere ΔP range including below 20 Pascals instead of fitting the data with a power law.

6 CONCLUSION

The need for improved knowledge of the hydrodynamic behavior of building components has been pointed out in this paper. Three levels of approaches are exposed to answer specific objectives. Their use will help to better understand the flow behavior through building elements and will increase the databasis used in numerical simulations.

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