Component leakage: potential improvement graphs and classification of airpaths

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ABSTRACT

Last years, interest in airtightness increases among all construction fields and airtightness becomes a major issue in the reduction of energy consumption in buildings. Nevertheless, there is a lack of understanding of air displacements through weak spots in buildings (airpaths). Firstly we develop first the concept of **P**otential **I**mprovement **G**raph (PIG chart). These graphs represent the "improvement curves" of a given airpath (airflow indicator against airpath parameter). As an airpath can have multiple significant parameters, PIG charts can be n-dimension graphs. Such curves could be used by the contractor to anticipate the impact of a corrective measure on the airflow. Secondly we define three types of airpaths: opening, junction and residual. We suggest that a discontinuity in the air barrier can always be defined as a function of these three types of airpaths. This paper concludes on opportunities given by this work. (1) It could be used as a basis for other projects on air leakage at airpath scale. Such projects would force the researcher, and help the reader, to understand issues of air displacements. (2) This work can also be used as a basis for the development of tools to help field actors to deal with airtightness. Such tools would encourage their users to think in terms of air displacement.

KEYWORDS

Airtightness ; Air leakage path ; Air displacement ; Classification ; Component leakage

1 INTRODUCTION

Projects and research aiming to reduce energy consumption in buildings are encouraged for several years now. First years, air leakage issue was hardly tackled in these projects, even if it could be responsible for up to 30% of the heating demand in winter (Kalamees, 2007) (Meiss & Muñoz, 2015). However, recently requirements about airtightness increasingly appear in regulations or in specifications for buildings. Airtightness becomes a big issue for many actors in the construction field, which are often powerless to deal with this little known concept.

The complexity of creating new airtightness predictive models and using existing ones has already been highlighted (Prignon & van Moeseke, 2017). The same paper highlighted the capabilities of single component models to be used as suitable tools for practical use. To develop these models, there is a need to focus on the understanding of air displacements around "airpaths". We define here an airpath as a spot in the building where air can leak (e.g. porous surfaces or flaws in building components among others).

Single component models study individually different airpaths of the building and consider the total building leakage as a sum of all these airpaths. Interesting point in these models is that they focus on the understanding of air displacements. Such understanding could help to interpret some observations made as the difference between results of tests in pressurization or in depressurization (d'Ambrosio Alfano, Dell'Isola, Ficco, & Tassini, 2012). Unfortunately, existing single component models are often outdated (Orme, Liddament, & Wilson, 1998) or currently not enough developed (Hassan, 2013).

This paper is part of the "AirPath50" project which aims to develop the understanding of air displacements at airpath scale. In this paper we present first the concept of PIG charts (airflow against a chosen parameter). Secondly, we suggest the classification of airpaths in 3 main types covering all different situations of air barrier discontinuity encountered in practice.

2 PIG CHARTS

We stress the importance of understanding air displacements at weak spots of the building. Graphs develop in this context represent the airflow (or an airflow indicator) against a main airpath parameter. These graphs give a powerful visualization of the airpath both in a theoretical and a practical point of view. In a fundamental way, these graphs describe different phenomena (equations, models) governing the displacement of air and they develop the limits between different phenomena. In a practical way, a contractor can extract from these graphs the potential impact of one or another airpath on the building air leakage. Thus he can prioritize its actions as function of their impact, this is why we called these graphs "**P**otential **I**mprovement **G**raphs" (PIG charts).

We develop the case of a circular opening in a plate to give a better understanding of these graphs. In this example, the PIG chart represents the airflow against the radius of the opening (Figure 1). For the creation of this PIG chart we consider a theoretical case of a plate of 1m x 1m, of 0.5 m width, with a medium porosity of 10^{-12} m² and a discharge coefficient of 0.6. Air density and air velocity are taken at 275K. A pressure difference of 50 Pascal is applied between both sides of the plate and the air can flow only through the surface and the opening. Four different behaviors are considered and explained hereafter (I, II, III and IV on the figure).

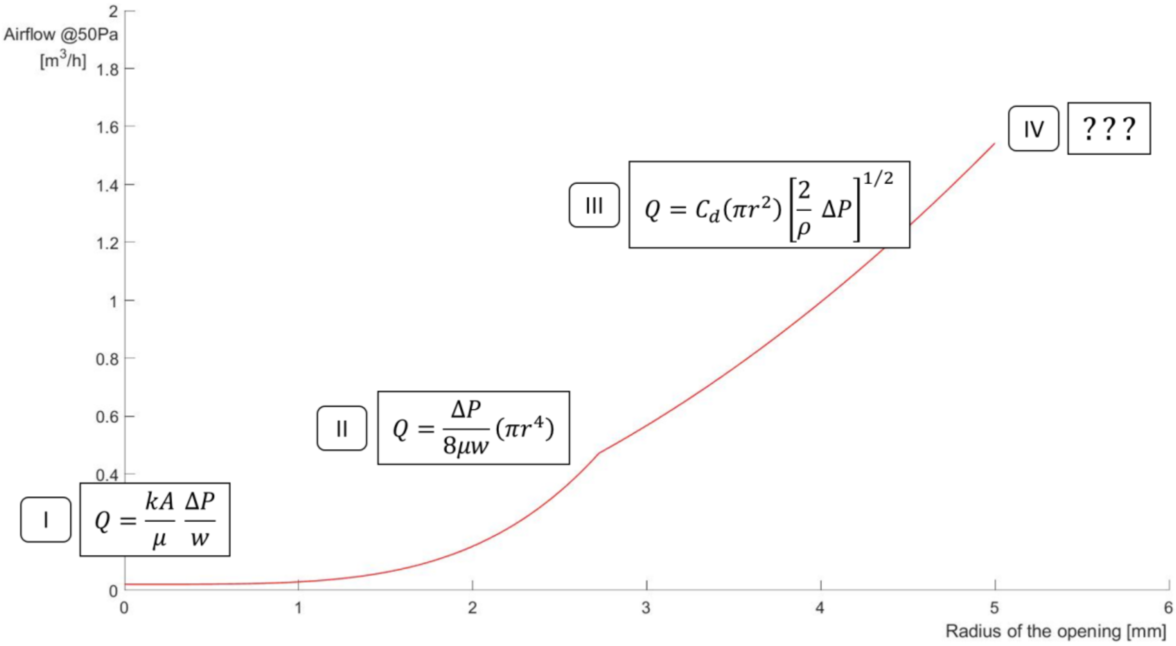


Figure 1: PIG chart for the case of a circular opening in an infinite plate

- When the radius is zero, air flows only through the surface and is computed with Darçy's law (equation 1). It depends then on the permeability of the porous medium (k), the area of the surface (A), the dynamic viscosity of the fluid (μ), the pressure difference (ΔP) and the width of the plate (w). We consider the air flow through only one square meter of plate.

$$Q = \frac{kA}{\mu}\frac{\Delta P}{w} \quad (1)$$

- Once the radius increases, air looks for the path of least resistance and flows through the hole. When the radius is very small, the flow can be modeled by equation 2 (flow through a cylinder). In this case airflow is highly depending on the radius (r^4) of the opening.

$$Q = \frac{\Delta P}{8\mu w}(\pi r^4) \quad (2)$$

- At some point, flow is governed by the orifice equation (equation 3). The airflow depends less on the radius (r^2) but depends on the air density (ρ) and discharge coefficient (C_d). The discharge coefficient takes into account the fact that the opening is not an ideal nozzle. It takes positive values lower than 1 (1 is for the perfect nozzle).

$$Q = C_d(\pi r^2)\left[\frac{2}{\rho}\,\Delta P\right]^{1/2} \quad (3)$$

- When the radius is very large, two issues can be encountered and the model becomes much more complex. First, the airflow becomes too important for the hypothesis. Until here, airflow models consider the pressure difference between both sides as constant. But if ratio between volume and airflow is too small, the problem is not static anymore and the pressure difference can vary in time. This is never the case if both volumes are considered as infinite, but it can still be encountered in practice and must be mentioned. Second, often in multilayers surfaces only the layer responsible for airtightness (air barrier) is considered since its resistance is much higher than other layers. But when the resistance of this layer becomes too small, other layers have to be taken into account as new airpaths hidden behind the air barrier.

In the example, a clear break between behaviors II (flow through a cylinder) and III (flow through an orifice) can be seen (Figure 1). In real cases, the transition would be much smoother and the PIG charts would be more like Figure 2.

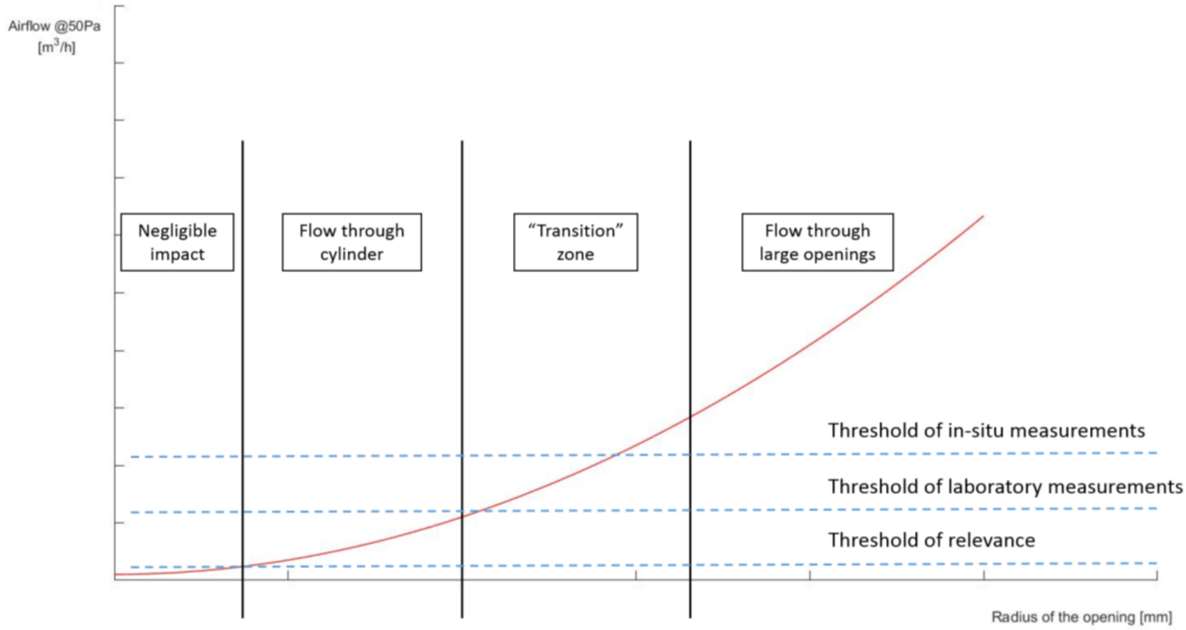


Figure 2: Smooth PIG chart with transition zone

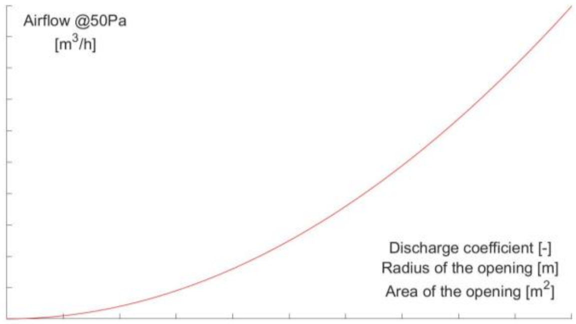
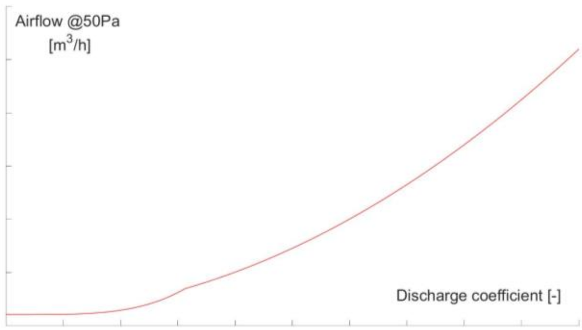
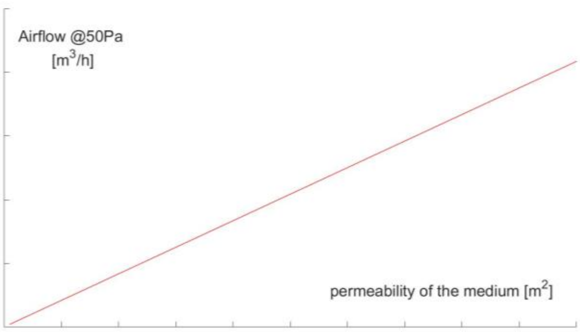
Some point of the PIG chart are not relevant since their values are too low to have a significant impact on total building airtightness (threshold of relevance). There are also two thresholds related to measurement equipment and measurement conditions (thresholds of in-situ and laboratory measurements). These three threshold are represented with dot lines on the graph Figure 2.

The “AirPath50” project aims to establish PIG charts through numerical simulations, in-situ tests and laboratory tests. We have to tackle many scientific issues related to these graphs. First, the issue of uncertainties in the case of in-situ and laboratory measurements (necessary to establish two thresholds). Second, the issue of the definition of a minimum “relevant value” in practice (necessary to establish the third threshold). Third, the issue of limits between behaviors and of “transition zones”. Fourth, the issue of variability of parameters (as discharge coefficient in the above example) with main parameter variation (radius of the opening in the same example). Fifth the issue of parameter identification. Indeed, in the example of circular opening in infinite plate, we show the study of only one parameter (radius of the opening). Other graphs could be obtained for the same airpaths with other parameters (e.g. the width of the plate (w)). PIG charts should be n-dimensions graphs (with n parameters).

3 CLASSIFICATION OF AIRPATHS

In a perfect world, each airpath of each site should have its own PIG Chart. We try to make an exhaustive list of airpaths based on in-situ observations (tracer gas during fan pressurization testing), discussions with relevant professionals (one architect and three contractors) and reading of reports (Relander & Holøs, 2010) (Carrié, Jobert, & Leprince, 2012) and guides (Jaggs & Scivyer, 2009) (Mees & Loncourt, 2015). This list brings out many different situations, but all discontinuities in the air barrier can be simplified in a function of three main types of “theoretical airpaths” (Table 1).

Table 1: three types of airpath, example of real cases and suggested PIG charts

Description and example of theoretical airpaths	Expected PIG chart
Opening In this airpath, the air flows through the element responsible for the discontinuity. Abscissa from PIG charts can depend on the component. This value can in some cases be obtained by the manufacturer. <u>Ex:</u> electrical outlet, window, door, ventilation ducts.	 Figure 3: PIG chart in the case of an opening airpath
Junction In this airpath, the air flows through the junction between the air barrier and the element responsible for the discontinuity. This element can be another air barrier. <u>Ex:</u> junction between two air barriers, junction between an air barrier and a window or a door	 Figure 4: PIG chart in the case of a junction airpath
Residual In this airpath, the air flows through the remaining surface behind the discontinuity. It depends on the permeability of the medium. <u>Ex:</u> remaining layers behind an electrical outlet	 Figure 5: PIG chart in the case of a residual airpath

We suggest in this work that airflow passing through a discontinuity in the air barrier can always be described as a function of the three airpaths presented above. Three real cases are hereafter described in terms of airpaths:

- An electrical outlet appears in three categories: air flows through the openings of the electrical outlet itself (opening), through the junction between the box and the wall (junction) and through the remaining layers of the wall behind the electrical outlet (residual).
- A window appears only in two categories: air flows through the junction between window and wall (junction) and through the window flaws (opening). Airflow in the window depends on its class and on its surface.
- A ventilation duct appears in two categories: air flows through the tightening around the duct where air barrier is cut (junction) and through the flaws in the ducts (opening). Airflow through the ventilation duct depends on its class, on its perimeter and on its total length in the airtight envelope. Indeed, for the part of the duct inside the envelope, the duct itself becomes the air barrier.

Most of these cases are already known by contractors. For example, outlet are often encased in plaster to reduce the permeability of the medium of the “residual airpath”. Plaster also increases the quality of the junctions between the outlet and the wall. Nevertheless the plaster is sometimes not perfectly set (bottom of the box, Figure 6) and leaks can be observed at these points. PIG charts could be helpful for contractors to understand and quantify the impact of a poor execution.

Figure 6: electrical outlet encased in a wall[1]

A component can have many different airpaths, thus many different parameters. This is why study of local air leakage is complex and time consuming.

4 CONCLUSION AND FURTHER WORK

In this paper, we present first the concept of PIG charts. These graphs represent airflow indicator against a chosen parameter. An airpath often depends on more than one parameter thus complete PIG charts can have n-dimensions. “n” is the number of parameters having a significant impact on airflows. Such graphs fit well in the “Airpath50” project since it helps to visualize air behavior at airpath scale. We define then three types of airpaths. We suggest that a discontinuity in an air barrier can always be defined as a function of these three types of airpaths.

[1] Picture from http://www.selfmatic.be

We highlight many issues in chapter 2 which have to be tackled early in the project:

- Calculation of uncertainties in the case of in-situ and laboratory measurements (necessary to establish two thresholds).
- Definition of a minimum “relevant value” in practice (necessary to establish the third threshold).
- Establishment of limits between behaviors and of “transition zones”.
- Study of variability of parameters (as discharge coefficient in the above example) with main parameter variation (radius of the opening in the same example).
- Identification of “n” parameters.

Further research could use this work as a basis to develop works on air leakage at building component scale. Such works would force researchers to understand issues of air displacements which are sometimes missing in current research. This work can also be used as a basis for the development of tools to help the contractor or the designer dealing with airtightness. Such tools would encourage their users to think in terms of air displacement.

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