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Practicability and reliability of direct component testing for in-situ measurement of building component airtightness

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Abstract. Airtightness at building component scale deserves much more focus than it gets. Unfortunately, the most popular method (i.e., indirect method) for its in-situ measurement suffers from substantial uncertainties. An alternative method is the direct component testing: a pressure chamber isolates the component from the rest of the building. This paper presents the method performed on three different newly-installed windows. These applications highlight three difficulties encountered: the chamber must resist to pressure differences higher than 50 Pa, the duct linking the fan to the chamber should be straight and the measured leakage should be perfectly identified. Then, authors performed two series of tests (10 and 12) in repeatability conditions. These allow to compare the uncertainty of the direct component testing (0.29 m³/h, 9.7%) with the expected uncertainty of the indirect method for a similar case (1.53 m³/h, 51.2%). These findings indicate a strong potential for the direct component testing to be used for in-situ measurements. Further work should tackle three limitations of this study identified by authors: other building component should be tested; other repeatability tests should be performed to identify factors responsible for the results variation; and both methods (i.e., direct and indirect) should be compared on the same case.

1. Introduction

In both research and practice, the focus is set on the measurement of whole building airtightness. However, the measurement of airtightness of building component deserves much more attention than it gets. Firstly, a better understanding of air displacements through building components would lead to an improvement of construction best practices. Secondly, not all the leakages have the same consequences. For example, external leakages will increase heating or cooling demand while internal leakages have more impact on acoustic or odor transport [1]. Locally characterize air leakages can help dealing with specific consequences of poor airtightness. Thirdly, the building components permeability values are needed to develop CFD in the context of airtightness [2]. Fourthly, airtightness predictive models based on single component airtightness have strong capabilities and they could be further developed if single component databases were up to date [3].

There are different methods for the quantitative determination of building component airtightness, depending on the objective and on the accuracy needed. These can be divided in three categories: numerical simulations, laboratory measurements and in-situ measurement. Although other categories have their advantages, only in-situ measurements take uncertainties due to workmanship into account. Since this factor is known as having a massive impact on airtightness [3, 4], this study focuses on in-situ measurements.

There are many different in-situ measurement methods [5]. The guard-zone technique, for example, was recently used to isolate the internal leakages from external leakages through building components [1]. New methods are also developed as such as the leakage quantification using infrared thermography (IRT) [6] or the use of acoustic methods [7, 8]. The most used in practice is known as the indirect method. It consists in performing two different pressurization measurements: once with the component



of interest sealed and once unsealed. The permeability of the component is given by the difference between both tests. This method was used to measure in-situ the airtightness of multiple building components [9-12]. The indirect method is easy to implement but its uncertainty depends on the uncertainty in fan pressurization test, which can be substantial in large units.

An alternative is the direct component testing that consists in the pressurization of a chamber isolating the component of interest. This method is often used in laboratory measurements. For example, it was used to measure airtightness of window frames [13], window-wall interface [14] or envelope building joints [15, 16]. However, it can be difficult to implement in practice and no recent studies use it to quantify airtightness of building components in-situ.

This paper focuses on the description and the characterization of the direct component testing. The first section presents the method, the second describes three applications and highlights the difficulties encountered during them and the third presents and analyzes the results of two series of tests made in repeatability conditions. In the discussion, the direct component testing is compared with the indirect method regarding their reliability and practicability. This paper concludes on the impact of the study, its limitations and the further work in the field.

2. Direct component testing

Direct component testing consists in isolating the element of interest from the rest of the room with an airtight chamber. This pressure chamber is linked to a fan that can pressurize or depressurize it and the pressure between inside and outside the pressure chamber is measured. As in a usual fan pressurization test performed on a building, the airflow through the measured element is determined by performing a regression based on multiple measured airflow/pressure couples. The setup of the equipment is shown as an example in Figure 1.

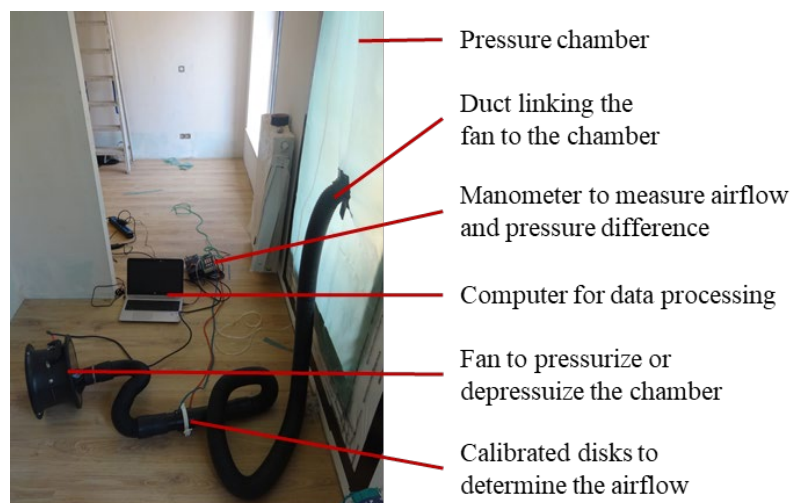


Figure 1 – Setup and equipment used in the direct component testing.

The tests performed during this study were made using *BlowerDoor* equipment. It has a range of airflow measurement between 0.17 and 78.5 m³/h, and its accuracy is between 0.04 and 5% of the reading, depending on the disk placed. The accuracy of the manometer used to measure pressure difference is the maximum between 0.2 and 1% of the reading and its resolution is 0.1 Pa. Last calibrations were done in April 2017 and in October 2018 (tests were performed between June and November 2018).

3. Application of the single component testing

In this study, the direct component testing was used to measure the airflow through three different types of newly installed windows (i.e., leakages through the window frame and through the window-wall interface). The results in pressurization ($q_{50,+}$), in depressurization ($q_{50,-}$) and general comments on each test can be found in Table 1. The tests are detailed in following sections.

Table 1 – Results of the three direct component tests performed on newly installed windows.

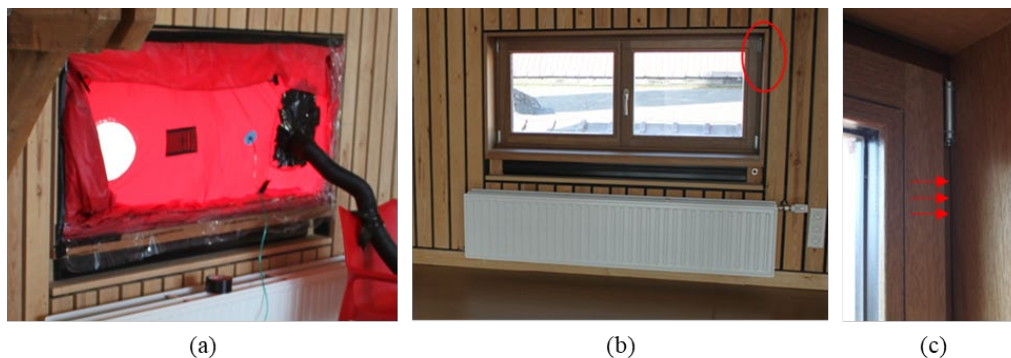
	$q_{50,+}$ [m ³ /(h.m ²)]	$q_{50,-}$ [m ³ /(h.m ²)]	q_{50} [m ³ /(h.m ²)]	Comments
Test 1	6.46	5.12	5.79	Loose chamber and pressure losses in the duct
Test 2	29.77	27.06	28.41	Irrelevant airflow measured
Test 3	5.84	4.42	4.63	No specific comment

3.1. Test 1

The first test was performed in June on an aluminum-frame class 4 window of 1.64 m² (0.80 x 2.05). The wall is made of plastered concrete blocks and the window-wall interface is guaranteed by an airtight membrane. The pressure chamber was realized using airtight plastic membrane and tape (Figure 1). As it can be seen on the figure, nothing was added to prevent the pressure chamber to inflate or deflate. When inflating or deflating, the loose pressure chamber induces high constraints on the tape. It limits the pressure difference to 50 Pa in depressurization and to 45 Pa in pressurization. Above these, small holes appeared in the tape maintaining the pressure chamber, making the measurement unreliable. In addition, the duct connecting the calibrated disk and the chamber is not perfectly straight. This can induce pressure losses, meaning that the airflow measured may not be exactly the airflow responsible for the pressure difference.

3.2. Test 2

The second test was performed in October 2018 on a wood-frame class 4 window of 1.44 m² (1.60 x 0.90). The wall is made of bricks (covered by wood boards) and the window-wall interface is guaranteed by an airtight membrane fixed on the window on one side and on the air barrier between the bricks and the wood boards on the other side. In this case, the pressure chamber was made fixed using a frame of blower door equipment (Figure 2a). The blower door frame was placed in the window opening and tape was added on its contour to avoid side leakages. Table 1 shows unexpectedly high values for the airflow through the windows. A deeper investigation of the case showed that part of the airflow measured was going inside the building behind wood boards and was therefore irrelevant (Figure 2b and 2c).

**Figure 2** – pressure chamber (a) and identification of the irrelevant measured airflow (b and c).

3.3. Test 3

The third test was performed in October 2018 on a wood-frame class 4 window of 1.40 m² (0.81 x 1.73). The wall is made of plastered sand-lime blocs and the airtightness at the window-wall interface is guaranteed by the contact of the plaster and the window frame (without any airtight membrane). The same system of fixed pressure chamber was used in tests 2 and 3.

4. Uncertainties in direct component testing

Two series of tests (10 and 12) were conducted in repeatability conditions to evaluate the uncertainties of the direct component testing.

The first series of 10 tests was performed on the case presented in section 3.3. All these tests were performed by the same operator, the same day and using the same equipment. In addition, the equipment was left in place between tests. A constant increase of the airflow was observed, meaning that pressurization / depressurization cycles undermined the pressure chamber. The constant increase of the airflow makes impossible to consider the standard deviation of the series of tests as the uncertainty of the testing method.

The second series of 12 tests was performed between the 27th and the 30th of November on a wood-frame class 4 window of 2.42 m² (1.10 x 2.20). The wall is made of concrete on one side and sand-lime blocs on the other side, and the airtightness is ensured with an airtight membrane under plastering. In this case, the equipment was removed between each test to avoid weakening of the chamber. Consequently, no constant increase of the airflow was observed (Figure 3). The standard deviation of the airflow measured at 50 Pa was 0.29 m³/h (9.7 %). The change in points scattering between tests is probably due to changes in climatic conditions. In fact, tests 1 and 2 were performed on the 27th, tests 3 to 5 on the 28th, tests 6 to 10 on 29th and 11 and 12 on 30th of November.

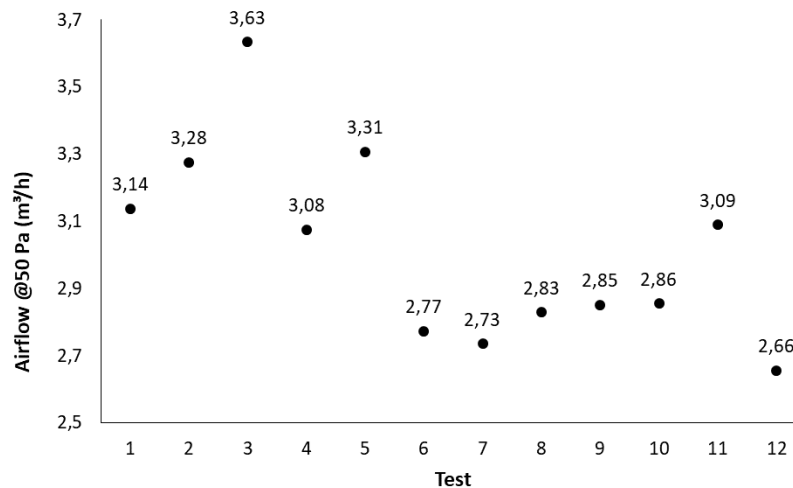


Figure 3 – Airflow measured for 12 tests made in repeatability conditions.

5. Discussion

Contrary to the direct component testing, the uncertainty on the results obtained with the indirect method depends on the uncertainties of the fan pressurization tests. In the indirect method, the airflow through the building component (Q_c) is obtained from the measurement of whole volume pre- (Q_1) and post- (Q_2) component sealing. Consequently, the airflow through building component ($u(Q_c)$) is obtained by the propagation of uncertainty in whole volume pre- ($u(Q_1)$) and post-sealing ($u(Q_2)$). If the airflow through building component is small with respect to airflow measured for the whole volume, then uncertainty in $u(Q_1)$ and $u(Q_2)$ can be assumed equal and $u(Q_c)$ is given by Equation 1.

$$u(Q_e) = \sqrt{2} * u(Q_1) \quad (1)$$

Multiple studies on repeatability of fan pressurization method have shown that uncertainty in airtightness measurements using fan pressurization method is between 1.1 % and 2.3 % of the measured airtightness [17-20]. This is reduced to 0.6 % when tests are performed on the same day (i.e., when climatic conditions between different tests are close) [18]. For a passive ($n_{50} = 0.6 \text{ h}^{-1}$) house of 300 m³, the airflow measured with the fan pressurization is 180 m³/h. Therefore, the uncertainty in the airflow of the element using the indirect method is 1.53 m³/h compared to 0.29 m³/h for the direct component

testing. For the second window tested, these airflows correspond to 9.7% for the direct component testing and 51.2% for the indirect method.

Although its uncertainty is high, the indirect method has two main advantages. Firstly, it is easier to setup in practice. Indeed, it is easier to make a perfectly airtight sealed for the element of interest than making a perfectly airtight chamber because of the insertion of the duct in the chamber. Secondly, it allows to make multiple tests with the same equipment. In fact, the airtightness of all the elements of the unit measured can be determined with this method. However, a unit with many different leaky elements would have higher airflows and thus the indirect method would lead to substantial uncertainties.

6. Conclusion

In this paper, authors highlight the need for single component airtightness values and identify issues related to their measurement. They describe the direct component testing method and present its application on three different newly-installed class 4 windows. These tests allow them to point out two main difficulties encountered in the realization of the method. First is that the pressure chamber must be able to sustain pressure differences higher than 50 Pa without any weakening. Second is that it is important to understand exactly what the measured leakage is and to verify its relevance for the objective of the measurement. These are case-by-case considerations since different building components can be handled differently in different building design. It is important to understand how air flows through building components to understand the measurement performed. One way to check the airflow measured is to combine direct method with smoke detector. Then, authors present the results of two series (10 and 12) of tests in repeatability conditions for the direct component method. With the first series, they found that maintaining the equipment between tests lead to a weakening of the chamber and thus standard deviation of the results could not be used as an uncertainty. They performed the second series of tests removing the equipment between each test and found a standard deviation of 0.29 m³/h (9.7% of the measured airflow). This value was then compared to the calculation of uncertainty using the indirect method in a similar case (1.52 m³/h, 51.2%).

These findings indicate the strong potential of the direct component testing and that it deals with the reliability issue of indirect method. However, indirect method should not be abandoned. In fact, when such measurement is performed, the method should be decided depending on the needs. The direct component testing provides good accuracy results but requires more attention in the setup while indirect method is easy to setup but provides only the magnitude of airflow.

Three limitations should be acknowledged before transferring the knowledge: two related to direct component testing and one to the comparison with indirect method. Regarding direct component testing, only newly-installed windows were tested while this method could be applied on numerous different building components. In addition, the uncertainty was determined based on only one series of 12 tests. This does not allow to find the main factors responsible for uncertainty. Authors expect the operator (i.e., the rigor in chamber realization) to be the most important factor. Regarding the comparison, the measured uncertainty for the direct component testing is compared with a theoretical calculation of uncertainties for the indirect method.

Further works in the field should tackle these limitations by: applying direct component testing on other building components, performing other repeatability studies to identify main factors influencing the standard deviation and compare the repeatability of indirect method and direct component testing on the same element.

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