In-situ measurement of building component using direct component testing

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ABSTRACT

Nowadays, the indirect method is the most common method for measuring airtightness of building components. This method is easy to setup in practice, but it can lead to substantial uncertainties. In laboratory, many authors use the direct component testing. However, it can be difficult to perform in-situ and, to our knowledge, no recent studies used it to quantify airtightness of building component in real buildings. This research aims at evaluating the practicability of the direct component testing. The method is applied to measure airtightness of installed windows in three different configurations. These tests highlight specific point of attention and possible limitations of the method. Direct component testing is then compared to indirect method. This paper concludes on the potential of the direct component testing method and mentions important limitations related to its setup. Further work should focus on repeatability studies for direct component testing and its practicability when measuring other building components than windows.

KEYWORDS

Building component airtightness, direct component testing, indirect method

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. First, a better understanding of air displacements through building components can lead to an improvement of construction best practices. Second, not all the leakages have the same consequences. For example, some leakages will have a strong impact on acoustic comfort while other have more impact on hygrothermal performances of insulation or on indoor air quality. Therefore, characterizing leakages locally can help dealing with specific consequences of poor airtightness. Third, airtightness predictive models based on single component airtightness are promising and they could be further developed if single component databases were up to date (Prignon and Van Moeseke, 2017).

There are different methods for the quantitative determination of building component airtightness, depending on the element tested and on the accuracy needed (Roulet and Vandaele, 1991). The guard-zone technique, for example, was recently used to isolate internal from external leakages (Rohr et al., 2018). New methods are also developed such as the leakage quantification using infrared thermography (IRT) (Barreira et al., 2017) or the use of acoustic methods (Raman et al., 2014, Duray and

Michaux, 2015). However, the most used in-situ measurement technique is known as the indirect method. It consists in measuring the airtightness of building component by progressive sealing. The whole building airtightness is measured twice: once with the building “completely unsealed” and once when the component of interest is sealed. The permeability of the component is determined by the difference between both tests. This method was recently used to measure the airtightness of multiple building components in-situ (Almeida et al., 2017, Pereira et al., 2014, Pinto et al., 2011, Hong and Kim, 2018). The indirect method is easy to implement but it can lead to substantial uncertainties.

The direct component testing consists in isolating the building component from the rest of the building and by pressurizing it alone (Roulet and Vandaele, 1991). This method is often used in laboratory measurements. For example, it was recently used to measure airtightness of window frames (Van Den Bossche and Janssens, 2016), window-wall interface (Van Den Bossche et al., 2012) or envelope building joints (Kalamees et al., 2017, Kayello et al., 2017). 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 analyses three in-situ applications of direct component testing and deduces limitations of the method from it. The first section presents the method and the three applications. The second section briefly analyses a series of ten repeated tests using the method, and compares the results obtained with the indirect method. The paper concludes on the next steps required to make direct component testing appropriate for in-situ measurements.

In-situ measurement using direct component testing

Direct component testing consists in isolating the element of interest using an airtight pressure chamber. The pressurization and depressurization of the chamber provides the airtightness of the element if the chamber is perfectly airtight. In this study, all the tests were performed using the same equipment from BlowerDoor (Figure 1 to Figure 4). This equipment has a range of airflow measurement between 0.17 and 78.5 m³/h, and a measurement accuracy between 0.04 m³/h and 5% of the reading, depending on the disk placed. The manometer measures the pressure difference between the inside and outside of the pressure chamber with an accuracy between 0.2 Pa and 1% of the reading and it has a resolution of 0.1 Pa. The last calibrations are dated April 2017 and October 2018 while the tests were performed between April and November 2018.

Figure 1 – Fan used to pressurize and depressurize the pressure chamber

Figure 2 – flexible duct used to connect the fan to the pressure chamber

Figure 3 – “Micro Leakage Meter” for airflow measurement

Figure 4 – Manometer for airflow and pressure measurements

The direct component testing method was used to measure the total leakage through installed windows (i.e., leakages through the window frame and through the window-wall interface) in three different configurations. This chapter describes the measured element, presents the results obtained and highlights the limitation related to the measurement technique, for each configuration.

Loose Pressure Chamber – Masonry Structure

The first test was performed on an aluminum-frame class 4 window of 1.64 m² (0.80 x 2.05). According to the European norm NBN EN 12207, a class 4 window implies that the manufacturer guarantees a maximum airflow at 50 Pa of 1.89 $m^3/(h.m^2)$ (NBN EN 12207, 2017). The window is installed on a wall made of plastered concrete blocks. An airtight membrane guarantees the airtightness of the window-wall interface.

Figure 5 shows the equipment placed during this first experiment. The pressure chamber is made of an airtight plastic membrane fixed on the plaster with tape. The fan used for the pressurization and depressurization is linked to the chamber with a flexible duct. The manometer, the Micro Leakage Meter and the computer are used to record pressure/airflow couples and to process the data. Two points in the configuration should be mentioned: (1) the flexible duct should go straight from the Micro Leakage Meter to the pressure chamber to avoid any pressure loss in the duct and (2) nothing should prevent the pressure chamber to inflate in pressurization or deflate in depressurization (i.e., this is a loose pressure chamber).

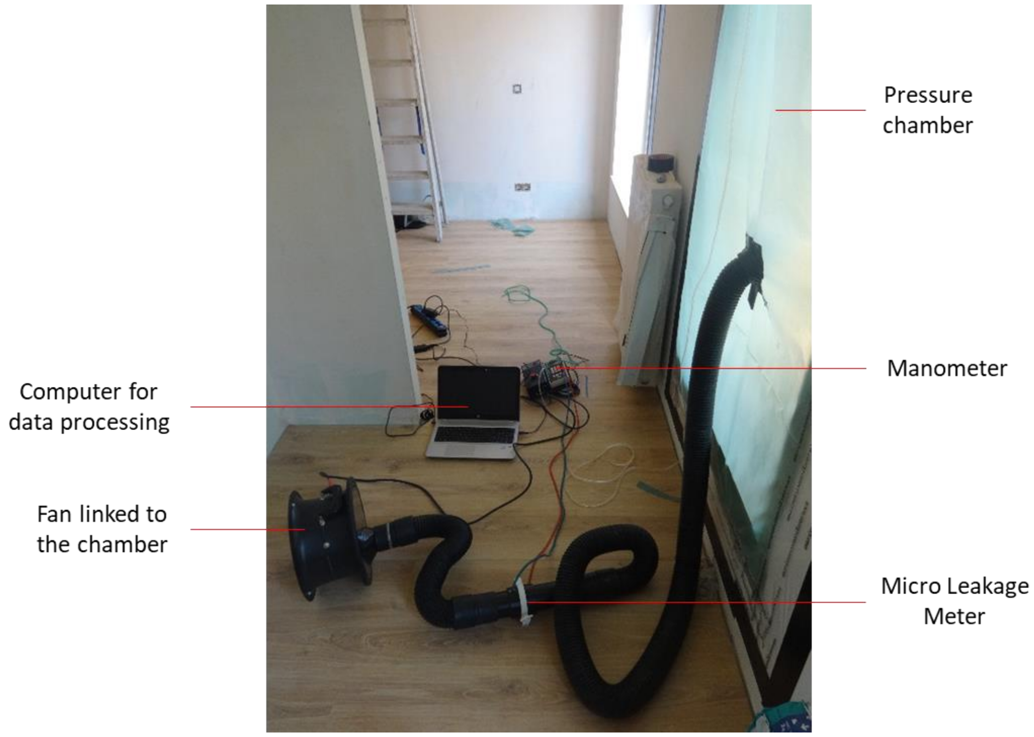

Figure 5 – setup of the experiment in the measurement of newly-installed windows (class 4) on a masonry wall using loose pressure chamber

When it inflates or deflates, the loose pressure chamber induces high constraints on the tape used to maintain it (especially in pressurization). In this case, it limits the pressure differences to 50 Pa in depressurization and to 45 Pa in pressurization. Therefore, it induces a bias in the measurement compared to a test that would go up to 70 or 80 Pa. In addition, there is probably another bias in the airflow measurement due to the pressure loss in the flexible duct.

The result of the test was $q_{50,-} = 5.12$ m³/(h.m²) with $R^2 = 0.987$ in depressurization and $q_{50,+} = 6.46$ m³/(h.m²) with $R^2 > 0.999$ in pressurization (average of $q_{50} = 5.79$ m³/(h.m²)). The difference between pressurization and depressurization is probably due to the weakening of the pressure chamber in the pressurization due to its inflation.

Fixed Pressure Chamber – Brick Wall with Wood Boards

The second test was performed on a wood-frame class 4 window of 1.44 m² (1.6 x 0.9). The wall is made of bricks with wood boards. Airtightness at the window-wall interface is guaranteed with an airtight membrane fixed on the window frame on one side and on air barrier behind the wooden boards on the other side.

Figure 6 shows the equipment placed during the single component testing. In this test, a fixed pressure chamber was created using equipment from fan pressurization measurement. It allows to prevent the large inflation or deflation of the pressure chamber. Therefore, the system can handle higher pressure differences than in the first case. It was possible to go up to + and – 70 Pa.

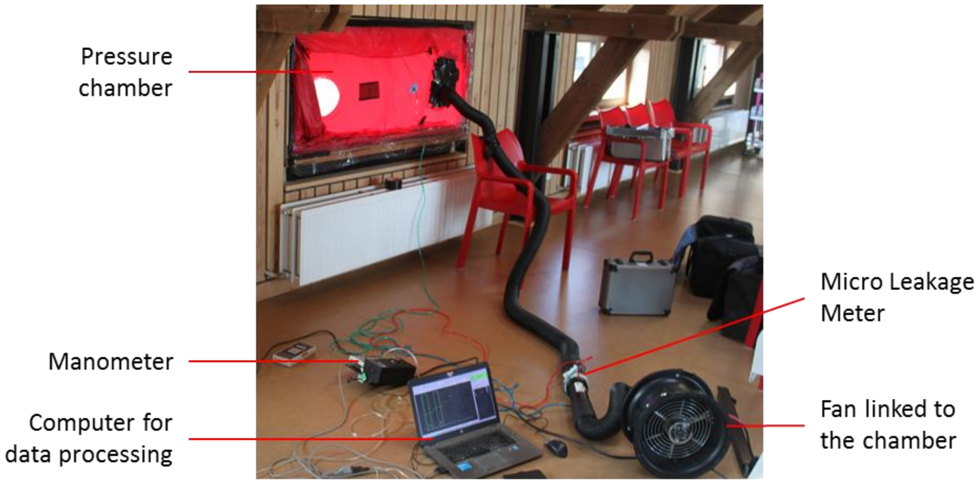

Figure 6 – setup of the experiment in the measurement of newly-installed windows (class 4) on a brick wall with wood boards using a fixed pressure chamber

The results of the test is $q_{50,-} = 27.06$ m³/(h.m²) with $R^2 = 0.999$ in depressurization and $q_{50,+} = 29.77$ m³/(h.m²) with $R^2 > 0.999$ in pressurization (average of $q_{50} = 28.41$ m³/(h.m²)). This value is much higher than expected and is inconsistent with the measured element. By studying the element and the pressure chamber with smoke detector, it was possible to understand that part of the measured airflow was irrelevant because it flows inside the building. Figure 7 shows that the air goes behind the wood panels and comes back in the building instead of flowing outside.

Figure 7 – identification of air path for air going back inside the building

Fixed Pressure Chamber – Masonry Structure

The third test was performed on a wood-frame class 4 window of 1.40 m² (0.81 x 1.73). The wall is made of sand-lime blocs and the airtightness at the window-wall interface is achieved without any membrane. Airtightness continuity is simply ensured by the contact between the plaster and the window.

The system of fixed pressure chamber used is the same as for the second test. Smoke detectors were used to ensure that only the air leaking through the window frame and the window-wall interface was measured. It was possible to go up to $+$ and $-$ 70 Pa in pressurization and depressurization.

The results of the test is $q_{50,-} = 4.42$ m³/(h.m²) with $R^2 = 0.998$ in depressurization and $q_{50,+} = 4.84$ m³/(h.m²) with $R^2 = 0.997$ in pressurization (average of $q_{50} = 4.63$ m³/(h.m²)). This time, the difference between depressurization and pressurization ($\Delta q_{+,-} = 0.42$ m³/h) is lower because the pressure chamber was more airtight and less sensitive to inflation/deflation than in the first case. This difference can be due to the pressure chamber, to the element itself or simply due to the measurement uncertainty.

Repeated direct component tests

A series of 10 tests were performed on the same day by the same operator and with the same equipment to evaluate the uncertainties of this method. These tests were done on the window of the third case presented previously (fixed pressure chamber in masonry structure). Unfortunately, a constant increase between airtightness was observed due to the weakening of the pressure chamber. Therefore, uncertainty could not be deduced from repeated tests.

Figure 8 presents the results of the ten repeated tests. The same pressure chamber was used for the first six tests, but it was strengthened between the 4th and the 5th tests. The operator removed and re-built the experimental setup between 6th and 7th tests, and this second setup was used for the last four tests.

Results show a strong increase of air leakages during the first six tests and a slight increase in the last four ones. This increase of air leakages is due to the weakening of the pressure chamber when repeating multiple tests. This series of tests highlights a difficulty in performing a repeatability study for the direct component testing. Indeed, it is difficult to isolate the equipment uncertainty because of the pressure chamber weakening.

The standard deviation of the results is $\sigma_{1:6} = 0.99$ m³/h for the first 6 tests and $\sigma_{7:10} = 0.28$ m³/h for the last four ones. These values provide an indicator of the results variability and illustrate the need for airtight and strong pressure chamber. However, these values cannot be considered as uncertainties because of the increasing trends of the results (no repeatability conditions).

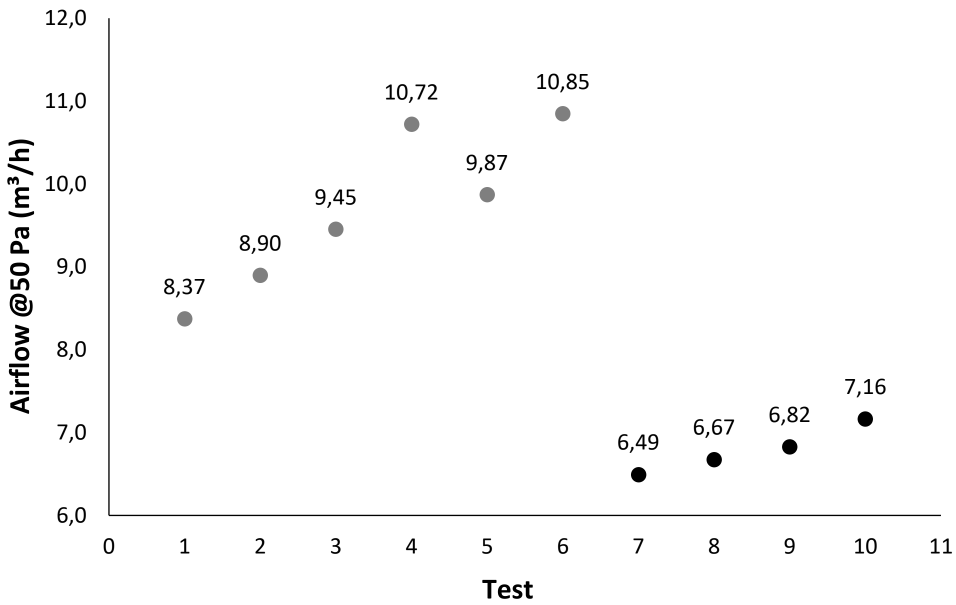

Figure 8 – results of the repeatability test of the single component testing without removing the pressure chamber between each measurement

Uncertainties in the indirect method

The main drawback of the indirect method is its substantial uncertainty. The indirect method consists in measuring the airtightness of the unit twice (e.g. house, apartment or room). The first test is performed in normal conditions and the second one when the element of interest is sealed. Airtightness of the element is deduced from the difference between both measurements. Therefore, the uncertainty of element airtightness is also related to uncertainties of the whole unit. Equation (1) shows uncertainty in element airtightness as a function of uncertainties on the unit tests before $u(Q_1)$ and after the sealing $u(Q_2)$. This equation is only valid if $u(Q_1)$ and $u(Q_2)$ are uncorrelated. This is not an acceptable hypothesis because of the really close climatic conditions between two successive tests. However, if Q_{u1} and Q_{u2} are defined as successive tests with short climatic variation (and therefore the uncertainties $u(Q_1)$ and $u(Q_2)$ take it into consideration), the hypothesis is acceptable.

$$u(Q_e) = \sqrt{u(Q_1)^2 + u(Q_2)^2} \qquad (1)$$

If it is assumed that the airflow measured in the first and the second fan pressurization tests are close (i.e., the airflow through the element is small compared to the airflow through other parts of the tested unit), the uncertainty in the measured element is given by equation (2) with $u(Q_u)$ being the uncertainty of the tests.

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

Multiple studies on repeatability testing showed that uncertainties in airtightness measurements using fan pressurization method were between 1.1% and 2.3% of the measured airtightness (Persily, 1982, Kim and Shaw, 1986, Delmotte and Laverge, 2011, Novak, 2015, Bracke et al., 2016, Prignon et al., 2018). These could be reduced to 0.6% when climatic conditions are close during the repeatability period (Novak, 2015). Therefore, in this use of airtightness results, $u(Q_u)$ could be considered as $0.006 * Q_u$.

The main difference between both methods regarding the uncertainties are the sources of uncertainty. For the direct component testing, uncertainties are mainly due to the pressure chamber setup. As shown in Figure 8, the variation can be reduced to small values (0.29 m^3/h) if the chamber is strong and airtight. For the indirect method, the uncertainties are mainly due to the measured airflow (Q_u) and therefore highly depends on the tested unit. As an example, a passive apartment of 200 m^3 has an airflow of maximum 120 m^3/h leading to an uncertainty of 1.02 m^3/h.

About practicability

On one hand, the indirect method has great advantages compared to the direct component testing. Indeed, it is easy to setup in practice and it allows multiple measurements without re-creating a new pressure chamber at every step. In their recent work, Hong and Kim use it to measure multiple building elements at the same time (Hong and Kim, 2018). However, multiple elements induce higher airflows measured in the room (Q_u) and therefore higher uncertainties (Equation (2)).

On the other hand, the indirect method suffers of an important drawback compared to the direct component testing: the access to the whole unit must be blocked during the test. This can be a problem, especially in construction periods when multiple workers are working simultaneously.

Conclusion

In this paper, three tests were performed to evaluate the practicability of the direct component testing. It also highlights the limitations of the method and allows to compare both methods regarding the practicability. In addition, a series of repeated tests were performed to evaluate the uncertainties related to the direct method. From these tests, some conclusions were drawn:

- Direct component testing can be used to measure the airtightness of building components directly on site but requires particular attention.
  - The pressure chamber must be airtight and strong enough to resist pressure differences higher than 50 Pa. Loose chamber should be avoided.

  - The flexible duct linking the fan to the pressure chamber should be straight to avoid pressure losses.
  - The element tested should be clearly identified and tape should be put on undesired leakages. A smoke test can be used prior the measurement to avoid undesired leakages from the pressure chamber.

- Direct component testing has two main advantages compared to the indirect method: it reduces the uncertainties on the result and it does not require blocking a whole room during the test. However, it is more difficult to set up in practice and one pressure chamber cannot be used to measure multiple elements at once.

Further work on the use of single component testing should first focus on a well-realized repeatability testing (re-creating the pressure chamber between each test) and its comparison with a repeatability testing using the indirect method on the same element. Second, it should focus on the creation of pressure chambers on other elements.

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