A new method to measure building airtightness

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ABSTRACT

In this paper a new methodology is presented to determine airtightness of buildings. The common method for airtightness testing is through fan pressurization with a blower door test. The new methodology also uses fan pressurization. Instead of an external fan, it uses the building fan system to pressurize the building.

The new airtightness tester device is no more than a pressure sensor, a reference vessel, communication hardware and an app. The flow rate of the ventilation system can easily be measured with an airflow meter. The fan pressurization of the building is measured relative to the pressure in the reference vessel which is the building pressure with the building ventilation system turned off. Measuring the reference pressure inside the building has the advantage that there is no need to use a building opening for an outdoor pressure measurement and pressure variations over the building envelope due to wind are averaged out.

Using the building fan system reduces the price of the measuring device and the time for an airtightness test. This makes it feasible to measure the airtightness of all buildings in a housing project instead of taking a few samples as currently is common practice in the Netherlands. Our new method allows both a one-point and a multiple-point test as described in the RESNET-380-2016 [1]. Here we only discuss the one-point test because this method is very efficient whilst also giving adequate results.

Validation of the new method has been carried out based on airtightness tests in buildings with both the blower door test and our new method. When taking the uncertainty of both methodologies into account, both pass or fail nearly all the same buildings. Preliminary results also seem to support the notion that the new method is less affected by wind, as measurements could be done on a windy day where this was not possible with the blower door test.

KEYWORDS

Airtightness, fan-pressurization, blower door.

1 INTRODUCTION

The development of the airtightness tester is part of the Securevent project. The purpose of Securevent is to guarantee the integral performance of air installations by developing simple measuring instruments and methods for the professional market, with which the air volume flow and the sound level of the ventilation system and the air tightness of the building can be tested quickly and affordably.

The standard method of measuring airtightness is through fan pressurization with a blower door test. A blower door is a combination of an air moving fan, an airflow meter and a covering to integrate the fan in a building opening. At least in the Netherlands it is not common practice that the airtightness of all newly built houses in a construction project are measured. In most cases only a couple of buildings of a housing project are measured, and if these buildings pass the set requirements, it is assumed that all buildings are sufficiently airtight. The reasons given against testing all buildings are the price, complexity and time it takes to perform such measurements with the blower door.

The goal of the new device and new measuring method is to reduce the time it takes to perform an airtightness measurement, making it realistic to measure all houses in a larger project or more cost effective in a single housing project. This time reduction can be achieved by shortening the time it takes to do the measurement itself, but also by reducing the time it takes to setup the system.

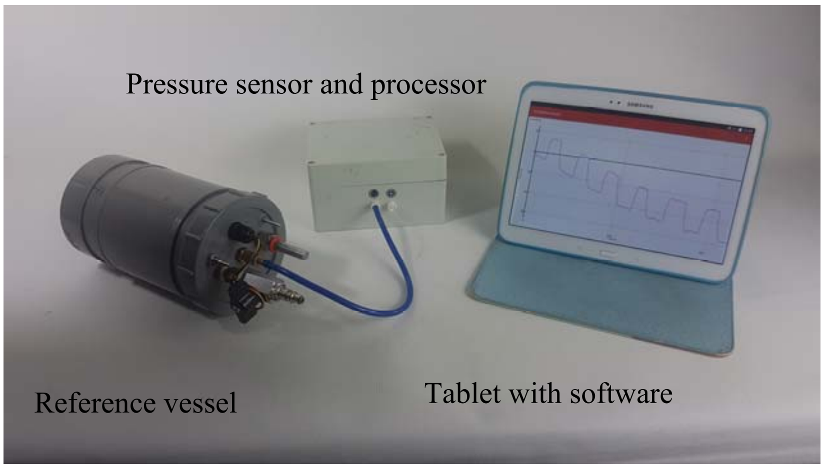

Figure 1: Prototype of the device used in this paper

The new method also measures through fan pressurization. Instead of an external fan and frame, it uses the fan system in the building, as described in ISO 9972[2], the international standard for the fan pressurization method. The main advantage of using the building ventilation system is a reduction in time for the setup and the measurements. Note that the ISO 9972 does not allow a one-point test whereas the RESNET 380-2016, the official US standard for testing airtightness of buildings, does allow it. Of course, one could use the different ventilation settings to do a multiple-point test. Given the increased complexity of the method and the extra time this would require we decided to concentrate on the one-point test.

The use of an indoor reference vessel and the building fan system instead of the blower door set up also has technical advantages. The new method is less sensitive to wind pressure fluctuations, as these fluctuations average out over the whole building envelope. No opening in the building envelope is required, meaning that the whole building envelope, including the exterior door, is measured.

At the start of the measurement, the vessel is closed when the ventilation system is turned off and will remain closed for the duration of the measurement. The pressure inside the vessel is now equal to the pressure of the building with the ventilation system turned off. When the ventilation system is turned on, a pressure difference will occur between the reference vessel and the building itself. This pressure difference, together with the flow rate of the ventilation system, is a measure for the airtightness.

This paper reports on our newly developed method and whether it obtains a reliable result for the airtightness. By measuring buildings with both the blower door test and the new device the new method is validated. The uncertainties of both methods are considered in the comparison.

2 THEORY BEHIND THE NEW DEVICE

A value for the airtightness can be calculated at a specified reference building pressure with

$$q_{v,P_r} = q_{v,sys} \cdot \left(\frac{P_r}{\Delta P} \right)^n \tag{1}$$

where

$q_{v,Pr}$	:	airtightness at the referenced building pressure	[l/s]
$q_{v,sys}$	:	volumetric flow rate of the ventilation system	[l/s]
P_r	:	specified reference building pressure	[Pa]
ΔP	:	measured differential pressure	[Pa]
n	:	flow exponent.	[-]

Compared to a blower door, the pressure difference (ΔP) generated by a ventilation system can be relatively low. Therefore, multiple cycles are taken and averaged when measuring. The minimum amount of cycles used is five. If the measured pressure difference is low, or a signal has a lot of noise, more cycles can be taken to improve the result. Note that if a pressure difference is very low, the accuracy of the measurement is no longer relevant, as it probably can already be concluded that the building is not going to pass the requirement.

Because the airtightness is measured at only one pressure difference and flow rate, it is not possible to determine the flow exponent. This means that an assumption must be made on the flow exponent. The flow exponent in houses typically ranges between 0.55 and 0.75[4]. The average flow exponent is determined to be 0.66[3]. As prescribed in the RESNET380 standard measurements one could also use 0.65. Given the uncertainty of the flow exponent this does not make a difference (see section 2.1). If the airtightness is below the requirement when calculated with both a flow exponent of 0.55 a flow exponent of 0.75, it can be concluded that, regardless of the actual flow exponent, the building passes the requirement.

2.1 Uncertainty of the new method

In our view, determining whether a building passes or fails the airtightness requirement can only be properly done when the uncertainty of a measurement is taken into account. As seen in equation 1, the airtightness calculated with the new method is dependent on three variables: the volumetric flow rate of the ventilation system, the measured pressure difference and the flow exponent. Each of these variables introduces an uncertainty in the total measured airtightness, making the equation for the total uncertainty

$$\sigma_{q_{v,P_r}} = \sqrt{\left(\frac{\partial f}{\partial q_{v,sys}} \right)^2 \cdot \sigma_{q_{v,sys}}{}^2 + \left(\frac{\partial f}{\partial \Delta P} \right)^2 \cdot \sigma_{\Delta P}{}^2 + \left(\frac{\partial f}{\partial n} \right)^2 \cdot \sigma_n{}^2} \tag{2}$$

To calculate the airtightness with this method, the volumetric flow rate of the ventilation system must be known. The uncertainty of this flow rate is largely dependent on the device used to measure the flow. However, in general the uncertainty will be uniformly distributed, making the total uncertainty of the ventilation system

$$\sigma_{q_{v,sys}} = \sqrt{\frac{1}{12} \cdot (b_1 - a_1)^2 + \frac{1}{12} \cdot (b_2 - a_2)^2 + ...\frac{1}{12} \cdot (b_n - a_n)^2} \tag{3}$$

where

b_n	:	the maximum value for the measured flow of a valve	[l/s]
a_n	:	the minimum value for the measured flow of a valve.	[l/s]

The uncertainty introduced by the pressure difference is calculated from standard deviation between the pressure difference measured in each cycle

$$\sigma_{\Delta P} = \sqrt{\frac{\sum_{i=1}^{N}\left(\Delta P_i - \overline{\Delta P}\right)^2}{N-1}} \tag{4}$$

In general, a N of 5 is sufficient for an accurate result. However, when a signal has a lot of noise, it can be useful to take more samples.

The use of an average flow exponent is considered in the uncertainty. By calculating the airtightness at 0.55, 0.66 and 0.75, an airtightness value is obtained at each reasonably possible flow exponent value. The range of possible airtightness values is taken into the calculation for the total uncertainty, (3rd term in equation 2).

2.2 Impact of the uncertainty

Here we discuss for each of the three variables the impact of its uncertainty on the airtightness. The effects of changing each of the three variables from -20% to +20% on the airtightness is shown in figure 2. The change in airtightness as a result of the changed variables is calculated at a pressure ratio (in Eq.1) of $P_r/\Delta P$=0.66.

It is important that the flow rate is determined as accurate as possible, as the figure shows that this value has a one to one impact on the result: when the flow measurement is off by $\pm$20%, the measured airtightness value will be off by $\pm$20% as well.

The impact of the pressure difference uncertainty depends on the flow exponent. The impact will be the higher when the flow exponent is higher. When a flow exponent of 0.66 is used, and the pressure is changed by +20%, the airtightness will roughly change -11%. When the pressure is changed by -20%, the airtightness will roughly change +16%.

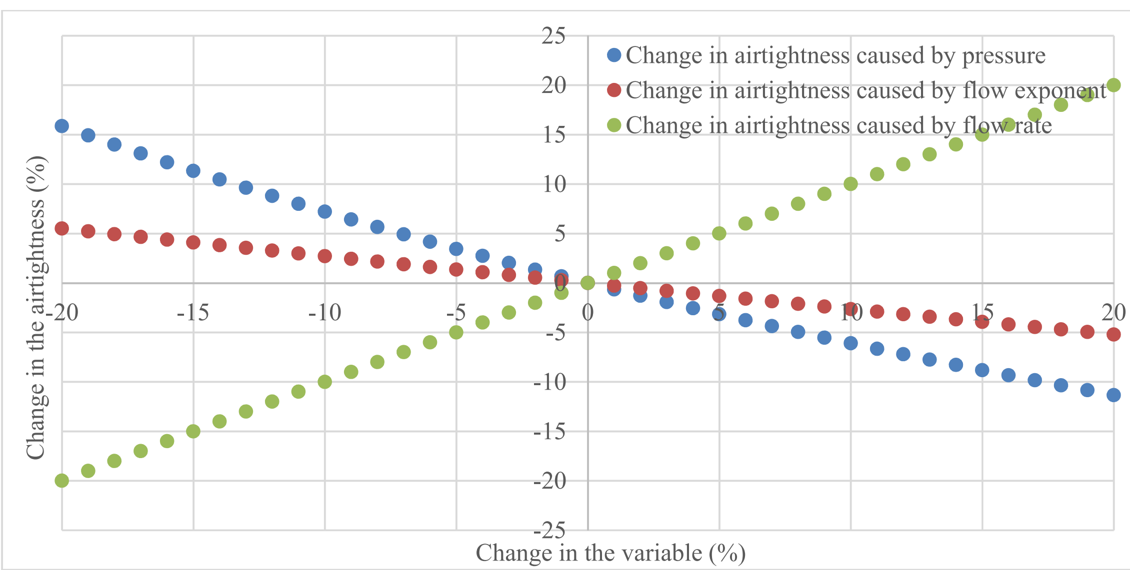

Figure 2: Change in airtightness, caused by changing one of the three variables.

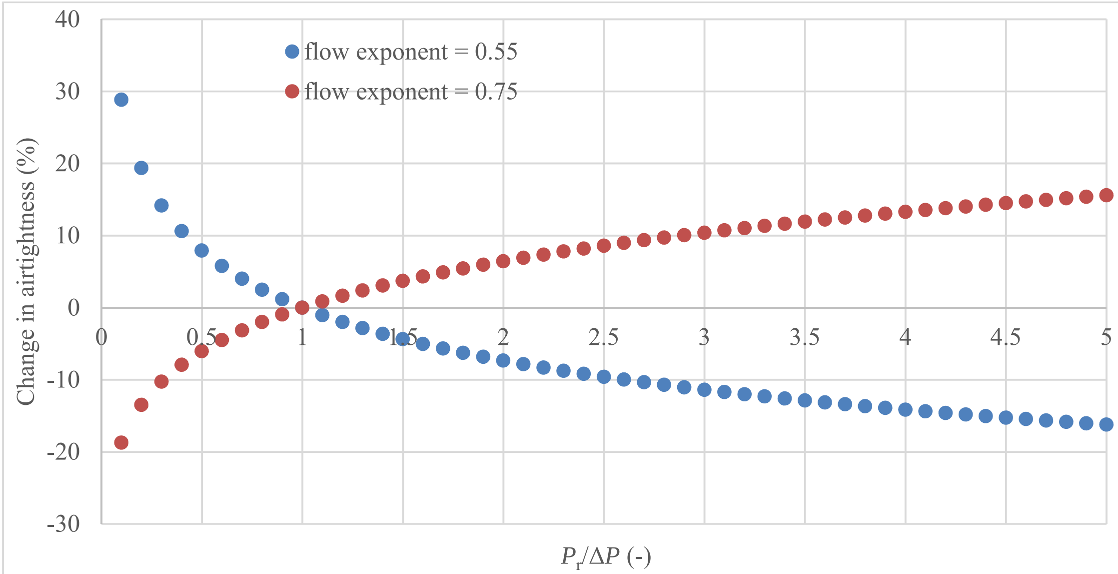

Figure 3: Deviation in airtightness as a function of the flow exponent.

The influence of the flow exponent on the total uncertainty is largely dependent on the difference between the referenced building pressure (P_r in Eq. 1) and the measured differential pressure (ΔP in Eq. 1). The bigger the difference between these pressures, the bigger the uncertainty caused by the flow exponent will be, as shown in figure 3.

From figure 3 it can be concluded that, to keep the uncertainty caused by assuming the flow exponent to a minimum, a ventilation setting should be chosen where, if possible, the ratio between P_r and ΔP is close to 1.

2.3 Measurement protocol

All test measurements presented in this paper have been performed using the following measurement protocol, taking the relevant points from ISO 9972:

1. Place the reference vessel in the house with the venting valve opened.
2. Close all exterior doors and windows.
3. Open all interior doors.
4. Check that water traps in plumbing systems are correctly filled or sealed.
5. Prepare the ventilation system.
    a. In case of balanced ventilation, close off either the supply or exhaust side.
    b. Confirm how to turn the system on and off.
6. Close the reference vessel.
7. Connect the reference vessel to a phone or tablet via Wi-Fi using the software.
8. Turn the ventilation system on and off in cycles of roughly 10 seconds (dependent on the start-up time of the ventilation system) for 5 cycles. In case of low pressure measurements or measurements with a lot of noise more cycles can improve the quality of the result.
9. Measure the flow of the ventilation system before returning the ventilation system to its original state and input this in the software.
10. Save the measurement.
11. Return the ventilation system to its original state.

The flows are determined using a powered flow hood with an uncertainty of ±3 m^3/h when the measured value is below 100 m^3/h and ±3% when the value is above 100 m^3/h. The measured objects were buildings with mechanical or balanced ventilation systems. Note that with a balanced ventilation system one could determine the airtightness for pressurization and depressurization.

All measurements with the new methodology are done directly after the blower door test with the blower door still in place, ensuring that both tests are done in similar conditions. To show the impact of using an assumed flow exponent, the calculation for the airtightness with the new methodology is done with both the calculated flow exponent from the blower door test, and the assumed flow exponent of 0.66.

The new method has a reduced setup time, as it is not necessary to build a frame into the door for a fan. It is necessary to measure the flows of the ventilation system, something that is not needed for the blower door test. Because the new method uses only a reference vessel and software on a phone or tablet, the setup can very easily be transported between buildings, saving time when multiple buildings are going to be measured.

Figure 4: The powered flow hood

3 RESULTS

The uncertainty for a measurement done with the blower door is calculated using the recommended procedure for estimating uncertainty described in ISO 9972[1]. Three sets of buildings have been measured, each set having its own airtightness requirement. An example of what a measurement using the new method looks like is provided in figure 5.

As can be seen in this figure, the signal has a downward trend. This trend is caused by small changes in the volume and temperature of the reference vessel. The pressure difference is automatically calculated by the software and takes this trend into account. Different algorithms have been tested and have shown that the trend makes little difference on the result.

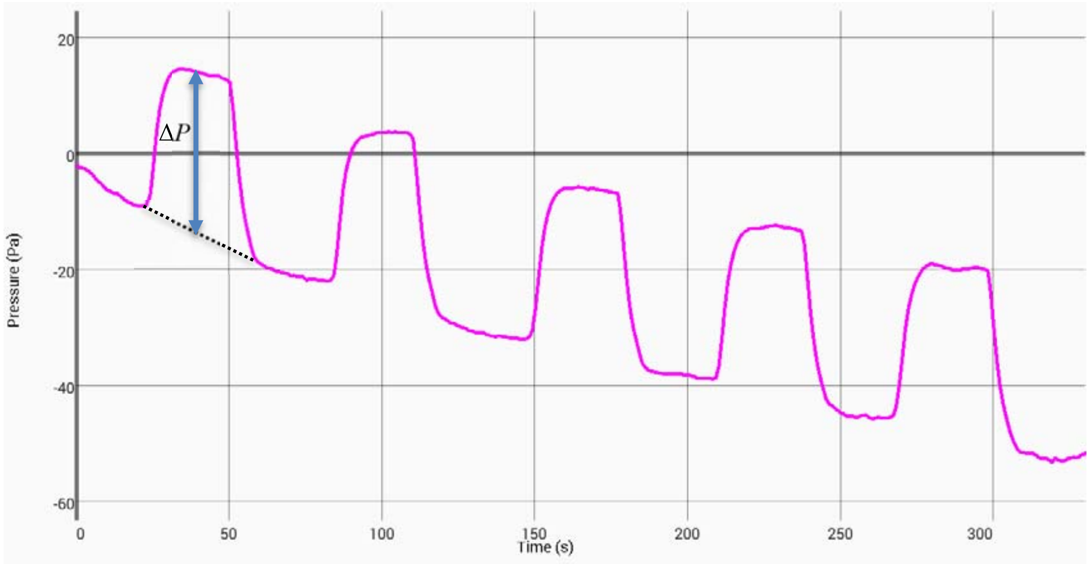

Figure 5: Example of what a signal on the new methodology looks like.

In the tables 1 to 3 the results of the measurements are shown per set. Each result has been colour coded in one of three colours:

Green	The building meets the requirement.
Blue	The building only meets the requirement when the uncertainty is not considered.
Red	The building does not meet the requirement.

The first column shows the building number. The second column shows the result of the blower door measurement. The third column shows the airtightness measured with the new method, using the flow exponent measured with the blower door for the calculation. The last column shows the airtightness with the new method, calculated with a flow exponent of 0.66.

Table 1: First set of buildings, balanced ventilation, airtightness requirement of 22.3 l/s at 10 Pa.

Building no.	q_{blower} **(l/s)**	$q_{new,nmeas}$ **(l/s)**	$q_{new,nfixed}$ **(l/s)**
1	24.8±1.4	25.0±0.5	27.4±2.9
2	25.0±1.4	27.2±0.5	29.7±3.2
3	25.6±3.6	30.9±0.8	33.4±3.0
4	34.3±4.2	34.8±0.7	34.9±2.5
5	29.1±2.7	32.0±1.1	33.1±3.4
6	27.6±3.3	26.1±0.6	28.2±3.5
7	27.5±3.6	29.1±0.6	29.6±3.1
8	23.7±4.6	26.9±0.8	30.4±3.7
9	25.8±2.4	28.2±0.8	30.9±3.2
10	20.7±2.5	23.3±0.9	27.1±3.1

In the first set of houses only building no. 10 passes with the blower door test and fails when using the new method. The measurement with the blower door test only passes when the uncertainty is not taken into account.

Table 2: Second set of buildings, mechanical ventilation, airtightness requirement of 30.0 l/s at 10 Pa.

Building no.	q_{blower} (l/s)	$q_{new,nmeas}$ (l/s)	$q_{new,nfixed}$ (l/s)
11	12.9±1.6	15.5±0.7	17.1±2.6
12	14.8±1.5	16.8±0.7	17.7±3.7
13	17.2±2.8	20.6±0.8	20.9±3.2
14	16.3±2.9	17.0±1.0	19.0±3.9
15	14.4±2.4	17.7±0.8	20.1±2.7
16	16.8±3.6	18.6±0.7	19.8±2.6
17	24.4±1.9	25.4±0.5	23.7±4.3

In the second set of measurements, all buildings pass, even when the uncertainty is taken into account.

Table 3: Third set of buildings, mechanical ventilation, airtightness requirement of 18.1 l/s at 10 Pa.

Building no.	q_{blower} (l/s)	$q_{new,nmeas}$ (l/s)	$q_{new,nfixed}$ (l/s)
18	9.9±1.2	10.3±0.4	12.0±1.6
19	10.6±1.5	11.0±0.5	10.8±1.4
20	14.8±1.2	17.7±1.4	18.0±1.6
21	20.0±1.2	19.6±0.5	21.2±2.9
22	17.5±1.1	18.9±0.4	20.0±2.9
23	12.2±2.3	14.1±0.5	17.1±2.8
24	10.9±0.7	12.3±0.3	14.8±2.5
25	12.5±1.3	14.3±0.6	16.8±2.0
26	14.0±1.7	14.9±0.5	14.9±1.6
27	10.8±1.4	11.2±0.4	13.4±2.0
28	9.8±1.6	11.2±0.6	12.1±1.5

In the last set of measurements there is a bit more disparity. Building no. 20 passes with the blower door test, but only passes with the new test when the uncertainty is not considered. Building no. 22 passes with the blower door test when the uncertainty is not considered, and fails with the new test regardless of the uncertainty. Building no. 23 and 25 only pass with the new test with a flow exponent of 0.66 when the uncertainty is not taken into account, though these buildings do pass with the blower door test and with the new test with the measured flow exponent.

3.1 Measurement on a windy day

There is one particular measurement that is interesting to show here. At the time of this measurement there was a wind force of 7 Beaufort. It was impossible to perform a stable measurement with the blower door in these conditions. With our new method, we could perform a good measurement.

The result of the measurement was a $q_{v,10}$ of 34.0±4.8 l/s using a flow exponent of 0.66. This building was measured with the blower door on a different day, giving a $q_{v,10}$ of 33.4±1.6 l/s, indicating that the measurement done on the windy day on the new method gave a reliable result. The requirement for this building was 22.3 l/s, so with both methods the same conclusion can be reached: the building does not pass the requirement.

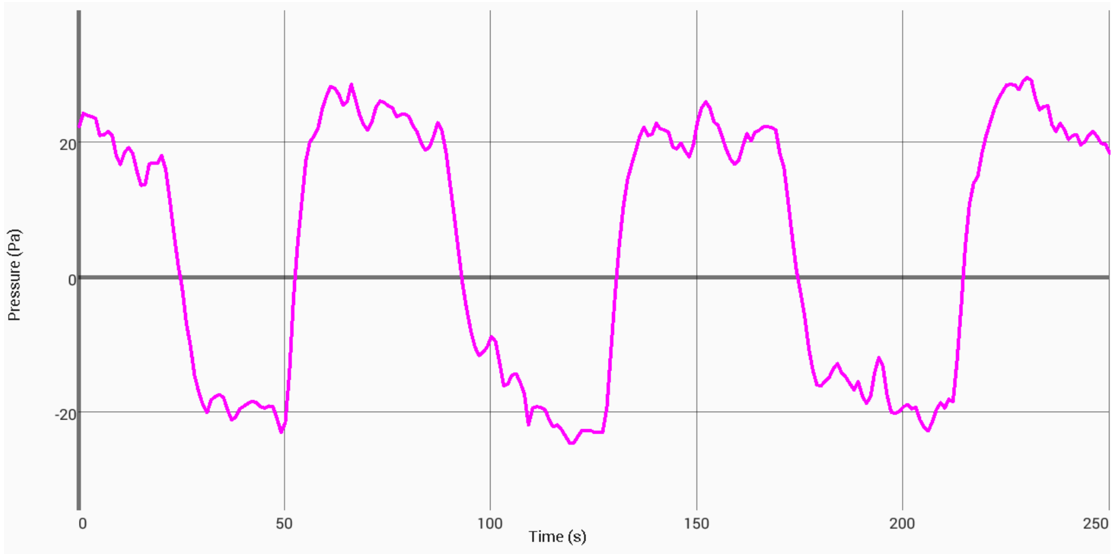

Figure 6: Signal of the measurement performed under windy conditions.

3.2 Using a different specified reference pressure

In the Netherlands the airtightness is expressed at a reference pressure of 10 Pa. In most EU countries however, a reference pressure of 50 Pa is used [4]. In table 4 the results of the third set of measurements from table 3 are shown again, only calculated at a specified reference pressure of 50 Pa instead of 10 Pa.

Table 4: The results of the third set of buildings, calculated at a specified reference pressure 50 Pa.

Building no.	q_{blower} (l/s)	$q_{new,nmeas}$ (l/s)	$q_{new,nfixed}$ (l/s)
18	34.6±1.8	36.3±1.5	34.8±1.8
19	30.0±1.8	31.2±1.3	31.3±1.7
20	39.9±1.4	48.0±3.8	52.0±11
21	63.3±1.6	62.5±1.6	61.4±2.3
22	53.6±1.4	58.4±1.1	58.0±1.6
23	42.5±3.7	49.6±1.6	49.5±1.5
24	37.3±1.0	42.4±1.1	42.7±1.1
25	45.5±2.1	52.0±2.1	48.5±3.0
26	40.7±2.2	43.1±1.5	43.1±3.0
27	38.1±2.1	39.4±1.2	38.7±1.3
28	31.6±2.1	36.2±2.0	34.9±2.6

Compared to the results at a fixed flow exponent in table 3, the results in table 4 almost all have a lower uncertainty. The exception is building no. 20, which has a bigger uncertainty. Also noticeable is that the difference in uncertainty between a calculation with a measured and a fixed flow exponent is smaller. The exception again being building no. 20.

The cause of this exception can be explained by looking at figure 3 and equation 1. The bigger uncertainty is caused by the fact that the ratio between the reference pressure (P_r) and the measured pressure difference (ΔP) got further away from 1 at 50 Pa than at 10 Pa. Therefore a measurement closer to 50 Pa can reduce this uncertainty. It could be interesting to research if there is a relation in flow exponent and airtightness, this could lead to more accurate result. It could be expected that tighter dwellings have a higher flow exponent.

4 CONCLUSIONS

In this paper a methodology for airtightness measurements through fan pressurization is described, using a single-point pressure measurement. This methodology measures the airtightness through the ventilation system of the building itself, as described in ISO 9972. This method makes it possible to measure the entire building envelope, including the front door. To validate this method, comparisons have been done by measuring buildings with both the blower door test and the new methodology. In this paper all measurements on the new method were taken with the blower door in place, to ensure an as accurate comparison as possible.

When taking the uncertainty into account, the new method passes 95% of the same buildings as the blower door at a measured flow exponent. At a fixed flow exponent, the new method passes 80% of the same buildings. When the uncertainty is not taken into account the new method passes 90% of the same buildings for both a measured and fixed flow exponent. Early results also seem to support the notion that the new method is less affected by wind, as measurements could be done on a windy day where it was not possible with the blower door test.

There can be a big difference in the uncertainty between a calculation done at a specified reference pressure of 10 Pa and 50 Pa. From this it can be concluded that, to minimize the uncertainty caused by assuming the flow exponent, a pressure difference should be achieved that is as close to the specified reference pressure as possible.

Our new method is a one-point test and therefore does not fully comply with the ISO-9972. However there seems to be good grounds to also allow a one-point test given that the RESNET 380-2016 and the draft for the RESNET 380-2018 does allow such a test. Both standards also require an outdoor pressure measurement. We think that our solution with the reference vessel is equally valid.

5 ACKNOWLEDGEMENTS

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