Applicability of a simple and new airtightness measuring method and further comparisons with blower door measurements

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ABSTRACT

The building airtightness is essential to achieve a high energy performance. In most countries however, it is not mandatory to measure the airtightness. In the Netherlands it is common practice to just take several samples in a housing project. These samples do not give a good indication for all the buildings in a project. It is therefore important to measure the airtightness of all the buildings.

Current methods for airtightness measuring are too expensive and time consuming to make this feasible. A method with a new device, the AirTightnessTester (ATT), is proposed. By using the buildings ventilation system, a reduction in price and time can be achieved. The ATT measures in compliance with RESNET-380-2016.

The ATT makes use of the ventilation system of the building. It will be explained when and how the ATT makes use of a ventilation system. We have looked at the different ventilation systems that are commonly used in new housing projects in somewhat more detail to analyze the feasibility of our method in practice. It is concluded that several systems can be used as they are now. Some ventilation systems cannot be turned on and off easily. For these ventilation systems a setting switching method has been developed. The theory behind this method, and some preliminary results using this method will be presented.

To validate measurements with the ATT, comparisons have been done to the blower door. Preliminary results were already presented during the 2018 AIVC conference (Lanooy et al, 2018) but further validation was still necessary. The measurements with the blower door are multi-point measurements and are all done in compliance with ISO9972[2]. The measurements done with the ATT are all single-point measurements. The comparisons are made with the blower door, because since it is the most used method for airtightness measuring. To get a fair comparison, the uncertainty of both methods is taken into account.

Overall the blower door and the ATT give show similar results for the airtightness. In 23 of the 37 measurements it was found that the measured air leakage with the ATT was slightly higher than the measurement compared to the result with the blower door. When switching between a low and a high flow, it was found that 10 out of 12 measurements with the ATT were higher.

KEYWORDS

Airtightness, Single-point, blower door, RESNET

1 INTRODUCTION

The building airtightness is essential to achieve a high energy performance. In most countries however, it is not mandatory to measure the airtightness. In the Netherlands it is common practice to just take several samples in a housing project. These samples do not give a good indication for all the buildings in a project. It is therefore important to measure the airtightness of all the buildings. Current methods for airtightness measuring are too expensive and time consuming to make this feasible. A method with a new device that uses the buildings ventilation
system, the AirTightnessTester (ATT), is tested. By using the buildings ventilation system, a reduction in cost and time can be achieved.

Measuring the airtightness with the ventilation system of the building is not a new method, and has been researched before. This research concluded that proper results were attainable with a prerequisite that the fan can be controlled and the air flow can be measured\[^{8,9}\]. Measuring by using the buildings ventilation system is also described in the RESNET-380-2016\[^{3}\]. What the ATT does different from these methods, is the use of an indoor reference vessel. Instead of measuring the pressure differential between the inside and the outside of the building, the pressure differential is measured between the reference vessel and the inside of the building.

The use of an indoor reference vessel and the ventilation system has some technical advantages. No opening in the building envelope is necessary, meaning the whole building envelope, including the exterior door, is measured. Another advantage is that the reference is an average of the pressure over the whole building, instead of a reference at one point, which is the case with a blower door. The fact that the reference is an average over the whole building envelope, and is measured indoors, also makes the measurement with the ATT less susceptible to wind\[^{1}\].

To validate measurements with the ATT, comparisons have been made to the blower door. Preliminary results were presented during the 2018 AIVC conference (Lanooy et al, 2018\[^{1}\]). Some ventilation systems cannot be turned on and off easily. For these ventilation systems a mode using two fan positions (high and low) has been developed. The theory behind this method as well as some preliminary results using this method will be presented.

2 METHOD

2.1 General workings of the ATT

At the start of the measurement, the ventilation system is turned off and the reference vessel is closed. The reference vessel will remain closed for the duration of the measurement. The pressure inside the vessel ($P_v$) is now equal to the pressure in the building ($P_b$) with the ventilation system turned off. The reference vessel is connected to the negative input of the differential pressure meter, while the positive input measures the pressure in the building.

When the ventilation system is turned on, there will be a difference between the pressure in the reference vessel ($P_v$) and the pressure in the building ($P_b$). This pressure difference ($\Delta P$), together with the flow rate of the ventilation system ($q_{v,sys}$), is a measure for the airtightness (equation 1).

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

where:

- $q_{v,P_r}$: airtightness at the reference pressure $P_r$\(^{(1)}\) [l/s]
- $q_{v,sys}$: total flow of the ventilation system [l/s]
- $P_r$: reference pressure\(^{(1)}\) [l/s]
- $\Delta P$: $P_b - P_v$, pressure difference between the building and the vessel [Pa]
- $n$: air flow exponent. [-]
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\(^\text{[7]}\). The average flow exponent is determined to be 0.66\([1,6]\). Multiple cycles of turning the ventilation system on and off are done. In figure 1 a typical measurement signal is presented.

By taking multiple cycles an uncertainty can be calculated and errors caused by pressure variations can be reduced. The total uncertainty of a measurement done with the ATT is calculated through propagation of error. All uncertainties involved in this calculation are independent.

\[
\sigma_{q_{\text{sys}}'} = \sqrt{\left(\frac{\delta q_{\text{sys}}}{\delta q_{\text{sys}}'}\right)^2 \cdot \sigma_{q_{\text{sys}}'}^2 + \left(\frac{\delta q_{\text{sys}}}{\delta \Delta P}\right)^2 \cdot \sigma_{\Delta P}^2 + \left(\frac{\delta q_{\text{sys}}}{\delta n}\right)^2 \cdot \sigma_{n}^2}
\]

The uncertainty in the flowrate of the ventilation system depends on the device used to measure this flow. The uncertainty of the air flow exponent is an assumed value of ±0.10\([1,7]\). The uncertainty of the pressure differential is equal to the standard deviation of the average of the block signals. This uncertainty contains the most information in terms of the measured signal itself. Deviations between block signals may be caused by various factors.

Factors that can cause momentary fluctuations are variations in wind speed, wind direction and variations in the flow of the ventilation system caused by variations in the wind direction and wind speed. It cannot be determined which of the factors is the cause of a variation in the block signal. The most likely scenario is that it is a combination of the factors mentioned.
2.2 Equations for the adjusted ATT measurement method

In practice it has been noticed that with some of the most commonly used ventilation systems in new buildings, it is not always possible to turn the ventilation system on and off without causing a long start up sequence. This sequence can negatively impact the measured signal, making it impossible to get a proper pressure signal for the calculation. This is especially the case when the start up sequences includes a temporary pause at a different flow than the end flow. In theory only a small modification to most systems would be necessary by the manufacturer, a way to bypass a start up sequence. To not be dependent on modifications by a manufacturer, an alternative method has been theorized.

Instead of measuring between the ventilation system turned on and off, a measurement can be done by switching the settings of the system between a high and a low flow. This way a long start up sequence can be avoided. The equation to calculate the airtightness needs to be altered to take an additional flow into account (equation 3). It should be noted that in this situation, the reference vessel is closed at the low flow. The measured pressure difference is therefore between the building at low flow and high flow.

\[ q_{v, P_r} = \left( q_{v, \text{high}} - q_{v, \text{low}} \right)^{\frac{1}{n}} \cdot \left( \frac{P_r}{\Delta P} \right)^n \]  

(3)

It can be observed that when \( q_{v, \text{low}} = 0 \) is filled into this equation, the original ATT equation (equation 1) is regained. The extra flow also brings an extra uncertainty, resulting into the total uncertainty as calculated through propagation of error:

\[ \sigma_{q_{v, P_r}} = \sqrt{\left( \frac{\delta q_{v, P_r}}{\delta q_{v, \text{high}}} \right)^2 \cdot \sigma_{q_{v, \text{high}}}^2 + \left( \frac{\delta q_{v, P_r}}{\delta q_{v, \text{low}}} \right)^2 \cdot \sigma_{q_{v, \text{low}}}^2 + \left( \frac{\delta q_{v, P_r}}{\delta P_r} \right)^2 \cdot \sigma_{P_r}^2 + \left( \frac{\delta q_{v, P_r}}{\delta n} \right)^2 \cdot \sigma_n^2} \] 

(4)

Due to the additional flow uncertainty and multiple occurrences of the flow exponent in equation 1 (in general the largest uncertainty of measurement done with the ATT), it is expected that the total uncertainty with this method will be higher in as compared to a measurement done where the ventilation system is turned on and off.

2.3 Uncertainty of a measurement with the blower door

All measurements with the blower door are done in compliance with the ISO9972 standard. With regards to the uncertainty, this standard only gives a recommended procedure for estimating the uncertainty in the air leakage coefficient and air flow exponent. This procedure does not take into account the uncertainty in the flow and the pressure measurement.

A method to calculate the total uncertainty of a blower door measurement, taking into account all variables, has been described before (Delmotte, 2013[4]). These variables include the bias pressure, external temperature and internal temperature. It also correlates the errors in the air leakage coefficient and air flow exponent. Two equations are derived, one for depressurization (equation 5) and one for pressurization (equation 6).
\[
\sigma_{q,P} = \sqrt{\left(\frac{\delta q_{v,P}}{\delta n}\right)^2 \cdot \sigma_n^2 + \left(\frac{\delta q_{v,P}}{\delta b}\right)^2 \cdot \sigma_b^2 + \left(\frac{\delta q_{v,P}}{\delta T_e}\right)^2 \cdot \sigma_{T_e}^2 + 2 \left(\frac{\delta q_{v,P}}{\delta n}\right) \left(\frac{\delta q_{v,P}}{\delta b}\right) \sigma_n \sigma_b r(n, b) }
\]

(5)

\[
\sigma_{q,n} = \sqrt{\left(\frac{\delta q_{v,P}}{\delta n}\right)^2 \cdot \sigma_n^2 + \left(\frac{\delta q_{v,P}}{\delta b}\right)^2 \cdot \sigma_b^2 + \left(\frac{\delta q_{v,P}}{\delta T_i}\right)^2 \cdot \sigma_{T_i}^2 + 2 \left(\frac{\delta q_{v,P}}{\delta n}\right) \left(\frac{\delta q_{v,P}}{\delta b}\right) \sigma_n \sigma_b r(n, b) }
\]

(6)

where:

- \( n \): air flow exponent [-]
- \( b \): natural log of the air leakage coefficient [-]
- \( T_i \): internal temperature at the time of measurement [K]
- \( T_e \): external temperature at the time of measurement. [K]

All blower door uncertainties in this paper are calculated with these equations. To determine the uncertainty in \( n \) and \( b \), a weighted least-square calculation is used. This calculation takes into consideration the uncertainties in the flow and pressure measurement in the regression calculation for \( n \) and \( b \) (Cantrell, 2008[5]). This method requires an iterative calculation, which is done via Excel.

### 3 RESULTS

All of the measured buildings were newly built and a mix of semi detached and terraced houses. The measurements were all done in the same order. First a blower door measurement is done in compliance with ISO9972[2], including closing off the buildings own ventilation system by disconnecting the ventilation channels and sealing them. After the blower door measurement is done, the blower door remains setup installed, with the blower door fan closed off in the same way as is done for a bias measurement. This is done to get the situation as comparable as possible. Also, the measured buildings did not always have a front door. The buildings own ventilation system was then reconnected and an ATT measurement was done, either by switching the ventilation system on and off (paragraph 3.1) or by switching between a high or a low setting (paragraph 3.2).

The datasets contain measurements done with both depressurization and pressurization. No distinction is made in the presentation of the results. The comparison between measurements are always done with the flow in the same direction, meaning a depressurization measurement done with blower door is compared to a depressurization measurement done with the ATT and vice versa. All air leakage values are calculated at a reference pressure \( (P_r) \) of 10 Pa, which is the reference pressure used in the Netherlands.
3.1 ATT measurements done by switching the ventilation system on and off

Most of the data was obtained via the original ATT measurement method, switching the ventilation system between on and off. For readability the collected dataset of comparison is sorted from lowest to highest values and split into two figures, figures 2 and 3. The uncertainty has been plotted as error bars. To give an indication of the impact of using a fixed air flow exponent of 0.66, the calculation with the ATT has been done with both the flow exponent as measured with the blower door and a flow exponent of 0.66.

Figure 2: ATT measurement with a measured and fixed flow exponent compared to the blower door set 1.

Figure 3: ATT measurement with a measured and fixed flow exponent compared to the blower door set 2.

In 23 out of 37 measurements it was found that the measured air leakage with the ATT was slightly higher as compared to the measurement with the blower door when using the flow exponent determined by the blower door. When using an average flow exponent, 24 out of 37 measurements are higher. Together with the data collected and presented in the first paper regarding the ATT\(^1\), it can be concluded that this increase appears to be systematic and needs to be further researched. The current theory is that this is caused by the difference in reference pressure, as the blower door takes the reference in one place and the ATT takes its reference as an average over the whole building.
3.2 ATT measurements done by switching the ventilation system high and low

In figure 4 the results of measurements done with the ATT using a high and a low ventilation system flow are plotted, together with the blower door measurement. Note that these are different buildings and measurements then used in figures 2 and 3.

The air leakage value as measured with ATT with a measured flow exponent is higher in 10 out of 12 cases. The airtightness when using a fixed flow exponent, is higher or lower depending on whether the actual flow exponent is higher or lower than 0.66.

It can be observed that when using a measured flow exponent, the ATT and the blower door have similar uncertainties. The uncertainty when using a fixed flow exponent is always higher, which is expected.

From this dataset it can be concluded that measuring with the ATT by changing the flow between a high and a low setting does not give any big differences with the blower door measurement. The method can therefore be used as an alternative in case of a situation where the ventilation system cannot be turned on and off without causing disturbances in the measured signal.
3.3 ATT measurement with on/off compared to measurement with high/low

Six measurements have been done where a building was measured twice with the ATT, once by switching the ventilation system between on and off and once by switching between high and a lower setting. The results from these measurements are in table 1.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>$q_{v,10}$ on/off (l/s)</th>
<th>$\Delta P_{on-off}$ (Pa)</th>
<th>$q_{v,10}$ high/low (l/s)</th>
<th>$\Delta P_{high-low}$ (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30,9±3,2</td>
<td>27,5</td>
<td>32,4±4,4</td>
<td>22,4</td>
</tr>
<tr>
<td>2</td>
<td>28,2±3,5</td>
<td>34,6</td>
<td>32,0±5,7</td>
<td>20,2</td>
</tr>
<tr>
<td>3</td>
<td>27,4±2,9</td>
<td>28,7</td>
<td>30,3±4,9</td>
<td>15,9</td>
</tr>
<tr>
<td>4</td>
<td>29,9±4,8</td>
<td>48,6</td>
<td>28,7±5,0</td>
<td>25,1</td>
</tr>
<tr>
<td>5</td>
<td>30,9±3,2</td>
<td>27,5</td>
<td>32,1±5,2</td>
<td>17,8</td>
</tr>
<tr>
<td>6</td>
<td>35,9±5,0</td>
<td>39,5</td>
<td>41,3±6,1</td>
<td>27,5</td>
</tr>
</tbody>
</table>

As expected, the uncertainty is higher when using switching between a high and a low setting in comparison to switching the system on and off. This is caused by the second flow and the lower pressure signal. However a lower pressure signal can also reduce the uncertainty, because the uncertainty by the flow exponent can decrease in case the measured pressure difference gets closer to the reference pressure of (in this case) 10 Pa. This explain the small difference in uncertainty in measurement 4.

4 CONCLUSIONS

In this paper a methodology for airtightness measurements through fan pressurization is described. This methodology measures the airtightness using the ventilation system of the building itself as ‘blower door’. This makes it possible to measure the entire building envelope, including an exterior door. Instead of measuring the pressure between the inside and the outside of the building, the ATT measures the pressure differential between the inside of the building and an indoor reference vessel.

Measurements with the ATT were further validated by comparing measurements done with the ATT with a blower door measurement. In general, it can be concluded that a measurement with the ATT gives a slightly higher air leakage value than a blower door measurement in 23 of the 37 measurements. More research is performed to determine the cause of the difference. The current theory is that this is caused by the difference in reference pressure, as the blower door takes the reference in one place and the ATT takes its reference as an average over the whole building.

In this paper an adjusted method for measuring was also presented. Instead of switching the ventilation system on and off, it is possible to switch between a high and low flow. Switching between high and low is not the preferred method of testing, because of the increase in uncertainty caused by the extra flow in the calculation as well as the lower pressure signal. The increase in uncertainty is however not significant to the extent that the measurement becomes unusable as a quick tool to judge whether a building passes its airtightness requirement, as long as the uncertainty is considered in this judgement. It can therefore be used when it is not possible to do a measurement by switching between on and off.
5 REFERENCES


