New findings on measurements of very airtight buildings and apartments

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ABSTRACT

The trend in European countries, such as Belgium, France and Germany is that the quality of the airtightness of the building envelope is getting better and better. This is true for small, airtight apartments, Passive houses and some large buildings with an excellent airtightness due to special requirements, e.g. oxygen reduction or fire protection. This good quality leads to new challenges in the performance of airtightness tests: Knowledge about an adapted way of measuring with a lot of patience.

What has to be taken into account in order to perform measurements of very airtight buildings? The different causes, solutions and tips are presented in this paper.

KEYWORDS

airtightness test, very airtight buildings, apartments, blowerdoor, test procedure, air permeability measurement, very low air-change rate

1 INTRODUCTION

Over the last decades, airtightness has become a necessary and important characteristic of the building envelope. Extensive experience as well as expertise in the production of good air barriers frequently lead to building airtightness of excellent quality. Large buildings with specific airtightness requirements, as for example oxygen reduction in warehouses for chemicals or food items, show air-change rates as low as 0.03 h^{-1}. Passive houses and apartments in some instances achieve n_{50}-values significantly below 0.03 h^{-1}.
It can be observed that the usual measuring procedures for airtightness tests are coming up against their limits when measuring these extremely airtight objects, creating new challenges for measuring technology and technicians alike.

This article will look at the measuring procedure in such cases and give recommendations on how to achieve reliable and repeatable measuring results.

2 DESCRIPTION OF THE PROBLEM

There is little experience as to how long it takes to establish a stable and constant pressure differential when testing air permeability of buildings with very low air-change rates, in some instances even starting with a n_{50}-value below 0.6 h^{-1}. The automated measurement in such objects may reach its limits. One indication is when the desired building pressure cannot be achieved, and the measurement is interrupted. If the individual measuring points are widely scattered around the line of best fit (the correlation coefficient in this case is significantly lower than 0.98), this is further indication, because sometimes the measuring values are recorded before achieving the target pressure.

Using calculations and experience from measurements, the following section will show which waiting times have to be planned when building up pressure in buildings with very low air-change rates (n_{50}-values).

3 TESTING VERY AIRTIGHT OBJECTS

3.1 Real-time display of the measuring values from an airtightness test of a very airtight building

In order to explore the reasons behind the limitations we recorded the measurements of different buildings with low and extremely low air-change rates with a data-logging program (TECLOG). This program shows the building pressure differentials and the measuring values of the BlowerDoor fan (air flow and fan pressure) over time in real time. The progression of the curves with measuring intervals of one second allow you to understand how the building pressure is established. This makes it possible to adequately react to specific measuring situations.

3.2 Example of a very slow pressure build-up

The following object is an example of how the building pressure of a measuring point is built up in a very airtight building. Figure 1 shows a warehouse with an interior volume of V = 46,600 m³. At 0.03 h^{-1}, the air-change rate n_{50} is impressively low. For reasons relating to food technology, the necessary input of nitrogen must be kept at a minimum. This allows for keeping the oxygen-reduction equipment small and for minimizing electricity consumption.

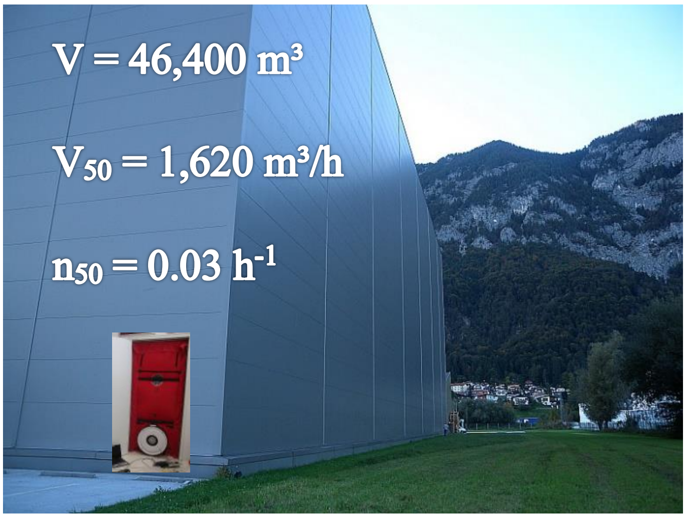

Figure 1: Warehouse for herbs with an air-change rate $n_{50} = 0.03\ h^{-1}$

How the building pressure is built up after turning on the measuring fan can be seen in the following diagram (Fig. 2). The horizontal timeline runs the time during the measurement and the y-axis shows the pressure differential in Pascal. The green curve shows the progression of the building pressure differential and the red one the fan pressure at the measuring fan resulting in the air flow as a function of the measuring ring.

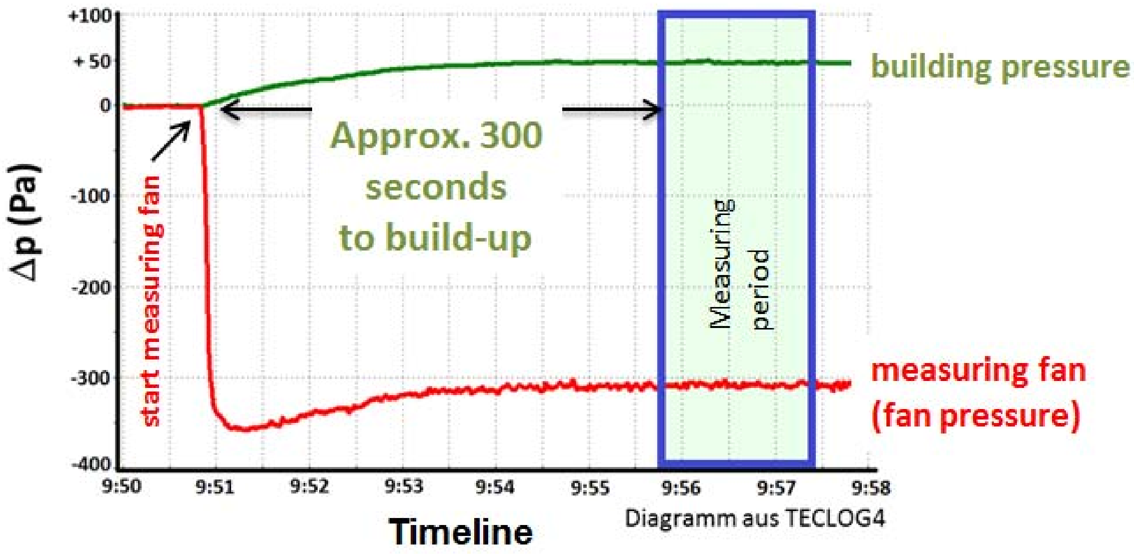

Figure 2: Approx. 300 seconds build-up time from 0 Pa starting pressure to 50 Pa building pressure (green curve from approx. 9:51 to 9:56)

Slightly before 9:51, the red curve for the fan pressure strongly declines from 0 Pa to ca. -350 Pa, indicating that the measuring fan (Minneapolis BlowerDoor Model 4, B Ring) has been turned on. The green curve for the building pressure increases comparatively slowly from the 0 Pa starting pressure to the target pressure of approx. 50 Pa. The closer the curve comes to the 50 Pa, the flatter it becomes (asymptotic progression).
At 9:56, after about 5 minutes (300 seconds), the target pressure has been reached and is sufficiently accurate, because both measuring curves are now running parallel to the timeline and indicating that no further serious changes are to be expected. Only as of this moment can we assume stable and constant conditions.
The measuring values for this measuring point that will later be included in the regression calculation can now be recorded.

3.3 Calculating the time for establishing building pressure differential

In order to optimally control the measurement, it is necessary to know the build-up times for the pressure differential of very airtight objects. Calculations by [Zeller] on the basis of the ideal gas equation, the equation for the leakage curve of a building, and assuming a constant air flow (independent of the building pressure) show that the time for reaching a specific pressure differential is inversely proportional to the air-change rate at 50 Pa (n_{50}). Figure 3 shows the build-up times from a starting pressure of 40 Pa to the target pressure of 50 Pa for different air-change rates. The flow exponent n of the leakage curve is 0.67.

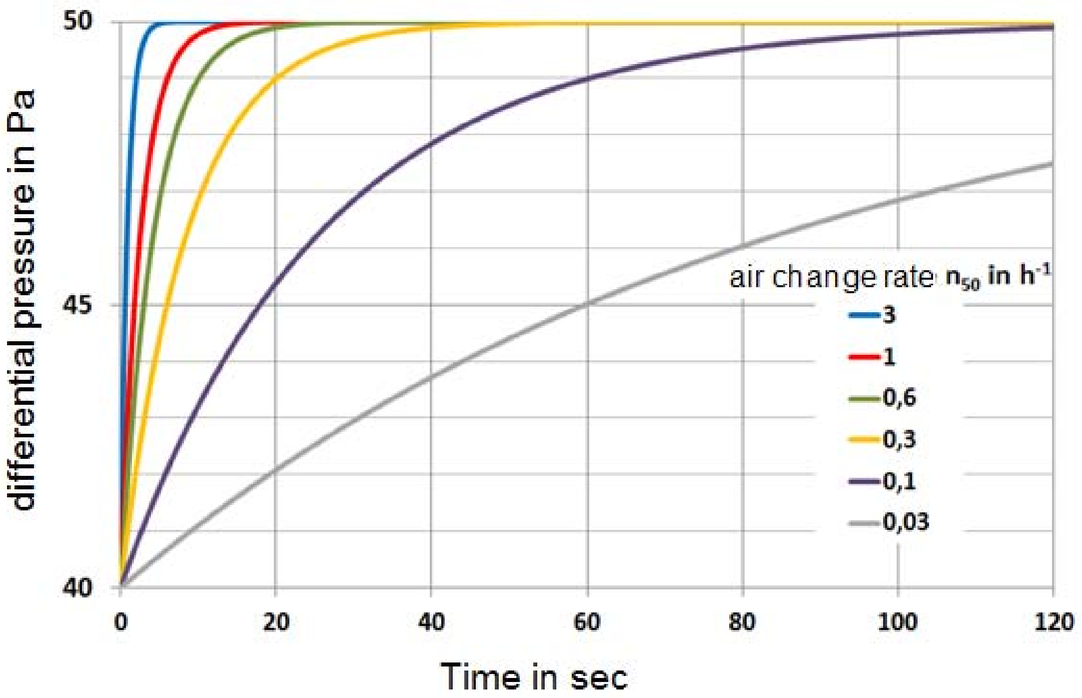

Figure 3: Build-up times from 40 Pa to 50 Pa building pressure differentials for different air-change rates at 50 Pa (n50). Boundary condition: The flow exponent n of the leakage curve is 0.67 [Zeller]

The diagram clearly shows that small air-change rates lead to an increase in the time for reaching a stable building pressure differential. At a n_{50}-value of 3 h^{-1} (blue curve), the 50 Pa differential pressure is established within a few seconds. In comparison, at 0.03 h^{-1} (grey curve), and after the 120 seconds displayed here, the target pressure is still far from being reached.

For the measuring practice, the following equation [Zeller], helps you to estimate the minimum waiting time that must be planned for achieving repeatable and robust results.

$$t\ (s) = \frac{9\ (s/h)}{n_{50}(h^{-1})}$$

t: waiting time in seconds
n_{50}: air-change rate in h^{-1}

Boundary conditions:
- The pressure differentials for the measuring series are ca. 10 Pa apart.
- The flow exponent is 0.67.
- The target pressure is reached with a tolerance of +/- 0.5 Pa.

Example:
The desired air-change rate is 0.1 h^{-1}.

t = 9 s/h / n_{50} (1/h)
= 9 s/h / 0.1 h^{-1}
= 90 s

The calculated times may deviate from the actual waiting times during the measurement. The time for building up the pressure differential is actually reduced, when the measuring steps of 10 Pa (70 Pa, 60 Pa, 50 Pa, etc.) are decreased to 5 Pa (70 Pa, 65 Pa, 60 Pa, etc.). A smaller flow exponent of the leakage curve increases the time.

3.4 Comparing the calculations with the real-life example

For comparisons, the pressure build-up time for the building presented before is calculated. The air-change rate is 0.03 h^{-1} and the flow exponent of the leakage curve n is 1. The diagram in Figure 4 shows the pressure build-up from 0 Pa starting pressure to a building pressure of 50 Pa.

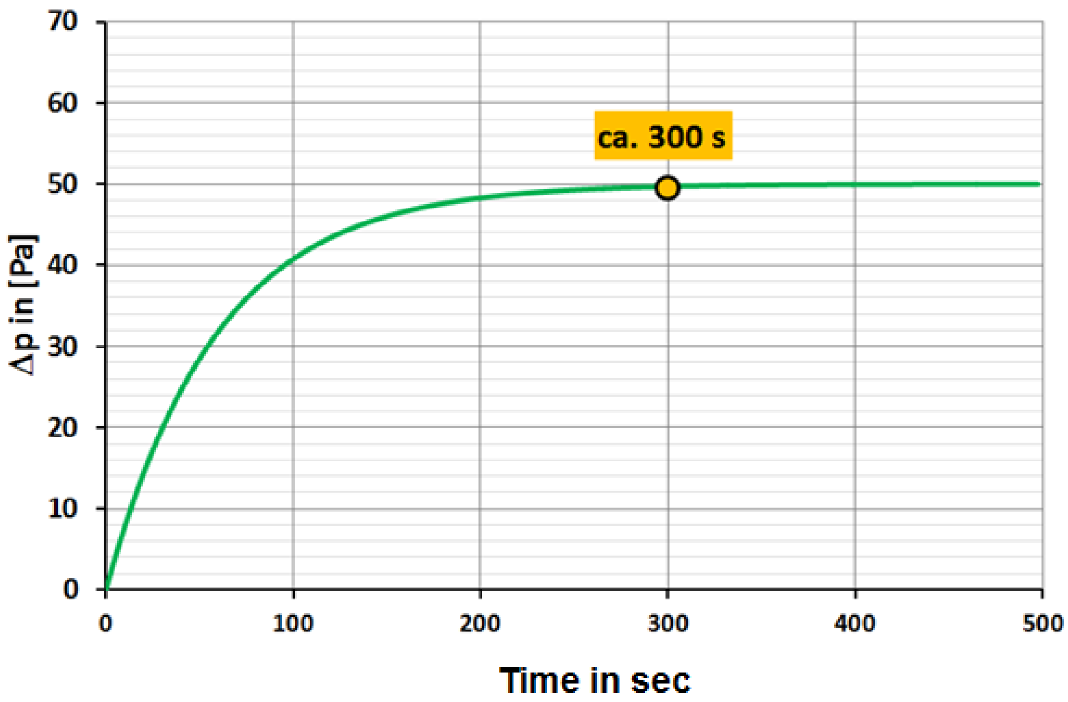

Figure 4: Calculated time for building up the building pressure differential from 0 Pa to ca. 49.5 Pa

The 49.5 Pa are reached after a good 300 seconds. In the actual measurement, we had started recording the measuring values for this target pressure after approx. 300 seconds. This means that the calculations correspond very well to the experience in real life.

4 WIND IMPACT

Variations in the pressure at the building envelope caused by wind make it more difficult to determine the time, when a sufficiently accurate target pressure has been achieved. It is thus absolutely necessary to follow the recommendations given in the testing standards [EN 13829 and ISO 9972] to conduct air permeability measurements preferably at wind speeds of 6m/s or less or a maximum wind force of 3 Beauforts. The stronger and gustier the wind, the larger and more irregular the fluctuations. The diagram in Figure 5 shows the oscillations of the natural pressure differentials at a median wind speed of 4.5m/s.

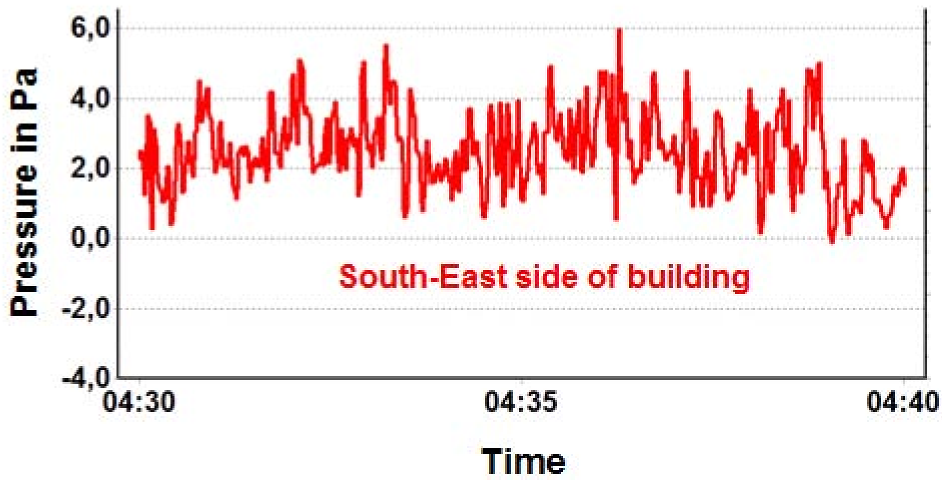

Figure 5: natural pressure differentials at one side of the building caused by wind with a median speed of 4.5m/s

These fluctuations reoccur at all pressure stages of the measuring series. This makes it more difficult to achieve a stable and constant pressure differential. In windy conditions, it helps to place the measuring location for the reference pressure on the downwind side (lee side) [Brennan et al.] and to increase the measuring time for each measuring point. The latter improves the accuracy of the leakage curve. The rapidly changing pressure fluctuations can also be compensated by a lower reaction speed of the measuring fan.

5 IMPACT OF MOVING FOILS

Another factor of influence sometimes making the measurement more difficult are large foils inside the building like the PE vapor barriers on the top floor of passive houses or in penthouse apartments, which at the time of measurement have not yet been covered by gypsum board. Another example are PE vapor barriers above the suspended ceilings in supermarkets.

Other than, for example, a fix brick wall, the foil will move when building up pressure. At negative pressure, it will slowly bulge until stretched. This flexibility may disrupt the automated control of the measuring fan. However, this effect can also be compensated by longer waiting times.

6 RECOMMENDATIONS

6.1 Build-up times for a pressure differential (target pressure) at low air-flow rates

In order to obtain reliable and repeatable results, you should plan with the times for establishing specific pressure differentials listed in Table 1.
At very low air-change rates, it is enough to wait until the target pressure is reached with a ±0.5 Pa tolerance.

Table 1: Minimum times for building up a pressure stage with a tolerance of ± 0,5 Pa as a function of the air-change rate of 50 Pa, based on calculations by [Zeller].

Air-change rate at 50 Pa	Build-up time for pressure stage
1.0 h^{-1}	> 9 s
0.8 h^{-1}	> 12 s
0.6 h^{-1}	> 15 s
0.4 h^{-1}	> 23 s
0.3 h^{-1}	> 30 s
0.2 h^{-1}	> 45 s
0.1 h^{-1}	> 90 s
0.08 h^{-1}	> 115 s
0.06 h^{-1}	> 150 s
0.04 h^{-1}	> 225 s
0.03 h^{-1}	> 300 s
0.02 h^{-1}	> 450 s
0.01 h^{-1}	> 900 s

The build-up times have been determined for the following boundary conditions: change of pressure stage from 70 Pa to 60 Pa plus a flow exponent of 0.67.

When controlling pressure stages in extremely airtight buildings (n_{50}-values < 0.1 h^{-1}), any change in the measuring fan settings will lead to significantly longer build-up times for the pressure stages. Any interventions in the control basically mean a new start for the build-up. This is why it makes sense not to readjust the measuring fan.

6.2 Measuring at very low air-change rates

At very low air-change rates, the usual measuring programs with the standard settings come up against their limits. In comparison to the testing volume, the required air-flow rate is extremely low, and it is difficult to control the measuring object to obtain stable and constant measuring values.

At air-change rates between 1 h^{-1} and 0.6 h^{-1} it helps to slow down the fan.

At air-change rates between 0.6 h^{-1} and 0.3 h^{-1} a semiautomated measurement will provide good results. During these types of measurements, the user can adjust the fan and determine when the building pressure is sufficiently stable to begin with recording the measuring values [BlowerDoor Standard Manual].

If the n_{50}-values are smaller than 0.3 h^{-1}, it helps to display the curve progressions for building pressure and air-flow rate in a data-logging program. They can be observed in real time and the measuring points can be selected as required [BlowerDoor Multiple Fan Manual].

6.3 Recommendations for wind

At windy conditions, it helps to install the measuring equipment on the downwind side (lee side) of the building and to measure the outside building pressure there. The measuring series should also include several measuring points above 50 Pa [EN 13289 and ISO 9972]. To compensate the irregular pressure fluctuations, the different pressure stages should be controlled more slowly and possibly allow for a greater tolerance. To increase the accuracy of leakage curves, the measuring time for each measuring point is extended. The usual measuring times for a measuring point are 10 to 15 seconds. They can be extended to 30 seconds without any problem and during gusty winds even to 60 to 120 seconds.

6.4 Recommendations for foils (vapor barrier)

The target pressures are to be adjusted more slowly, so that the foil can slowly bulge until stretched.

7 CONCLUSIONS

Airtightness tests of very airtight objects like large warehouses with air-change rates of 0.03 h^{-1} due to oxygen reduction or passive houses and apartments with n_{50}-values below 0.6 h^{-1} require a different approach for recording the measuring values than buildings with high air-change rates. The time for setting up a stable pressure differential suitable for recording measuring values is significantly longer. The user may sometimes have to wait several minutes until the pressure differential is sufficiently accurate.
If it is also windy during the time of measurement, the building pressure differentials will fluctuate. A slower control of the pressure stages and a longer measuring time for each measuring point will help to record a measuring series with sufficiently accurate results. Another influencing factor is a building envelope with large, moving foils like vapor barriers. A careful control of the measurement will also help in this case.

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