Assessment of durability of airtightness by means of repeated testing of 4 passive houses

Jiří Novák*[1]

1 Czech Technical University
Faculty of Civil Engineering
Thákurova 7
166 29 Prague, Czech Republic
**Corresponding author: jiri.novak.4@fsv.cvut.cz*

ABSTRACT

In this study, durability of building airtightness was assessed by means of repeated airtightness testing of the studied houses. This approach generally involves the following issues which complicate the comparison of the test results:

- a lack of knowledge about the modifications of the air barrier system between two tests
- differences in building preparation
- differences in testing procedure and equipment if the tests are performed by different technicians
- different conditions during each test

In this study, all the tests were performed by the same technician using the same equipment. The technician always prepared the building in the same way and followed the same measuring procedure. The majority of the tests were carried out in the same period of year under similar climatic conditions. Therefore, the differences between the test results should reflect namely the impact of ageing and the impact of the air barrier system modifications. Information concerning interventions to the building envelope was collected from the building users or the caretaker. Therefore, the impact of such interventions on the building airtightness is traceable.

The studied buildings were built in 2007 using the same construction system with an emphasis on the quality of execution of the air barrier system. They have a very similar size, the same timber structure and the same air barrier system (PE foil, butyl tapes). Building A and D are an inhabited single family houses. Building B is a showhouse of the construction company and the building C serves as training centre and conference room. This allows a comparison of the potential impact of different users' behaviour on the airtightness durability. The buildings A and B were tested at the commissioning, 3 years after and then each 2 years or even each year. The buildings C and D were tested only twice, at the commissioning and 11 years later.

In all the buildings, airtightness has deteriorated over 11 years. The n_{50} of buildings A and B increased from 0.5 h^{-1} to 0.7 h^{-1}. The n_{50} of building C and D increased more significantly from 0.5 h^{-1} to 1.3 h^{-1} and from 0.7 h^{-1} to 1.4 h^{-1} respectively (due to improper repair works after a failure of the sewage water system and due to a refurbishment carried out with little concern about airtightness). The results show that a good airtightness durability (relatively small increase of the n_{50} value) can be achieved if:

- the air barrier system is designed and executed carefully
- the users respect some basic restrictions concerning the modifications of the building envelope which aim to protect the air barrier system
- all interventions into the air barrier system that can occur e.g. during refurbishment or repair works are properly repaired (inversely, improper interventions can significantly deteriorate the airtightness)

The results confirm that the airtightness decreases namely during the first years of the building service (e.g. in building B, the n_{50} increased from 0.5 h^{-1} to 0.65 h^{-1} during the first 3 years and from 0.65 h^{-1} to 0.7 h^{-1} during the next 7 years).

KEYWORDS

Air leakage, airtightness durability, airtightness testing, air barrier system, passive house

1 INTRODUCTION

Several field studies of the building airtightness durability are reported in (Leprince 2017). The authors usually compare the results of the airtightness tests of the same building performed at different stages of its life cycle (typically just after the completion and after several years of the buildings service). Besides, the repeated testing, information about the conditions of the buildings service over the period between the successive tests is collected in order to explain the differences between the test results. This approach generally involves the following issues and limitations which complicate the comparison of the test results:

- a limited knowledge or even a lack of knowledge about the modifications of the air barrier system between the two successive tests
- significant modifications of the building carried out between the two successive tests making the comparison of the test results complicated (e.g. an extension of the building or an extensive refurbishment)
- differences in the building preparation for the two successive tests
- differences in the testing procedure and the equipment used if the tests are performed by different technicians
- different conditions during the tests – differences in the indoor and outdoor climatic conditions not only influence the accuracy of measurement and its result (e.g. wind) but might cause some deformations of the building structure which may affect the airtightness itself (certain authors point out the seasonal variation of building airtightness)

In this study, the durability of airtightness of 4 passive houses was assessed using the same approach. The buildings were tested several times over a period of 11 years. Relatively frequent testing provides an insight into the evolution of the airtightness during the first years of the building service which seem to be critical according to certain authors (Leprince 2017).

All the tests were performed by the same technician using the same equipment and following the same measuring procedure. The buildings were prepared in the same or a very similar way (the differences are traceable). Most of the tests were carried out in the same period of year under similar climatic conditions. Therefore, the influence of the issues mentioned above on the reliability of the assessment was minimised and the differences between the test results should reflect mainly the impact of ageing and the impact of users´ interventions.

The studied buildings have a very similar size and were built using the same construction system, by the same construction company in the same place and within a short period of time. Therefore, one can expect a very similar impact of ageing of the air barrier system components on the durability of airtightness. However, the studied buildings are used by different users for different purposes. For most of the buildings, the users´ interventions, potentially affecting the building airtightness are well documented. This allows for a reliable assessment of a potential impact of different users' behaviour on the airtightness durability.

2 METHOD

The same technician carried out all the tests reported in this study according to (ČSN EN 13829). The measurement procedure was identical for all the tests. The sequence of induced pressure differences was always the same, the measuring device was fastened into the same opening (the entrance door) and the external pressure tap was placed in the same position. The same measuring device (a blower door) was used for all the tests. The pressure sensors were calibrated yearly. The blower door fan was not calibrated in the course of the study.

The details concerning the building preparation were recorded for each test. These records allowed the technician to prepare the building for testing always in the same way (method B according to (ČSN EN 13828)). Nevertheless, in the case of all the buildings studied, the preparation for the first test differed from the preparation for the successive tests – before the first test, the attic hatch was closed and sealed with an adhesive tape, while before the successive tests it was only closed but not sealed.

The test results (air change rates at 50 Pa, n_{50} [h^{-1}]) were calculated according to (ČSN EN 13829). The uncertainty of the n_{50} values reported in this study includes the uncertainty of the internal volume and an estimate of the effect of the wind.

Information concerning later interventions to the building envelope was collected from the building users or the caretaker by means of a questionnaire. Some of them were interviewed. However, for the building D, only limited information is available.

3 BUILDINGS TESTED

All the 4 tested buildings were built from 2006 to 2007 as a part of a pilot project of a development of 13 passive houses (fig. 1). The construction company leading this project aimed at evaluation of the design and serial production of their first construction system complying with the criteria for the passive houses. The airtightness of the building envelope was identified to be one of the key issues from the initial phases of the project. Therefore, a special attention was paid to the airtightness throughout the design and construction process.

Figure 1 The studied buildings. Left – construction process. Right – completed buildings in 2007

The buildings have the same shape and nearly identical size, typical for single-family houses in the region. They have the same wooden skeleton structure assembled on-site (fig. 1). The building envelope is insulated by means of mineral wool thermal insulation. The buildings are equipped with the same balanced ventilation system with heat recovery. The buildings serve for different purposes (see below).

The air barrier system was designed with a special care. The designers consulted the solutions with a technician who had a previous experience with design and airtightness testing of passive houses. The air barrier layer of the slab on the ground consists of bitumen sheets (waterproofing membrane) with welded joints. The air barrier layer of the external walls and the roof consists of the PE foil sheets. The joints of the sheets are sealed with butyl adhesive tapes and secured with wooden battens. In order to minimise the number of penetrations, the electrical and other building installations are led in a cavity between the PE foil and the internal cladding (gypsum boards). Special products e.g. the butyl tapes, the “window tapes”, rubber sleeves were designed for sealing the connections of the PE foil to other building components and for sealing the penetrations.

Usually, in similar wooden frame buildings, the air/vapour barrier layers of the external wall of the 1st and the 2nd floor are connected with a piece of foil running over the ends of the ceiling joists lying on the top of the 1st floor wall. However, in this construction system, such a solution would seriously complicate the building process and presented a risk of air leakage due to damage of the connecting piece of foil during the construction process. Therefore, two separate air barrier systems were designed for the 1st and the 2nd floors (fig. 2).

The air barrier system was executed with an emphasis on the quality of the workmanship. Its execution was supervised. Several preliminary airtightness tests were carried out in order to identify the sources of the air leakage with subsequent repair. However, several leakage paths were not completely eliminated and persisted in a major part of the buildings.

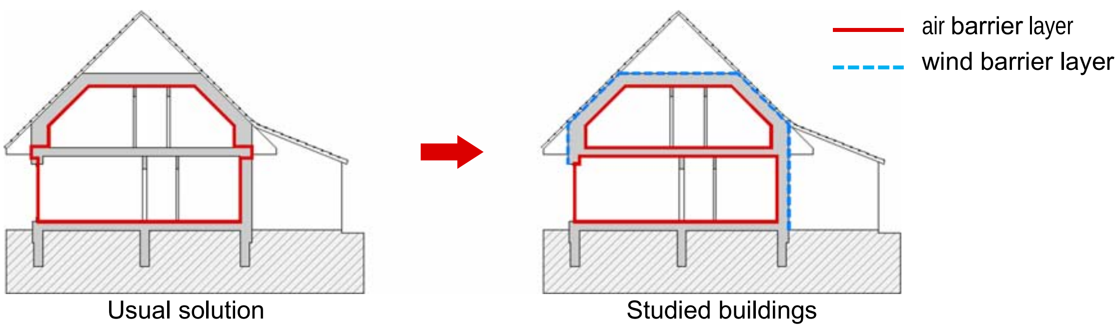

Figure 2 The air barrier system of the studied buildings. Cross section, schematic representation

4 BUILDING A

4.1 Use of the building

The building A (fig. 3) is an inhabited single-family house. The owner is a technician with a good knowledge of the principles of passive houses. He is well aware of the importance of the airtightness, therefore he always managed the works in the house in order to preserve the integrity of the air barrier system. Otherwise, the users' behaviour is typical for a single-family house.

4.2 Service life

The building has been continuously inhabited since 2007. The furniture and household equipment were fastened without any intervention to the air barrier system (the owner supervised the works). In 2013 a new heat source was installed - again, without any intervention to the air barrier system. The owner did not report any other interventions potentially affecting the air barrier system (refurbishment, repair or maintenance works). On the other hand, the owner claims a poor airtightness of the attic hatch which seems to deteriorate over time.

4.3 Testing and test results

The building was tested first at the moment of commissioning in 2007, then in 2010, in 2014 and then regularly with a period of 2 years, in 2016 and 2018. For the building preparation, see tab. 1. All the tests were carried out in spring or summer. Therefore, one can expect a minimal impact of the seasonal variation of the building airtightness on the test results. The test results are given in tab. 1 and fig. 4.

Figure 3 The building A in 2018

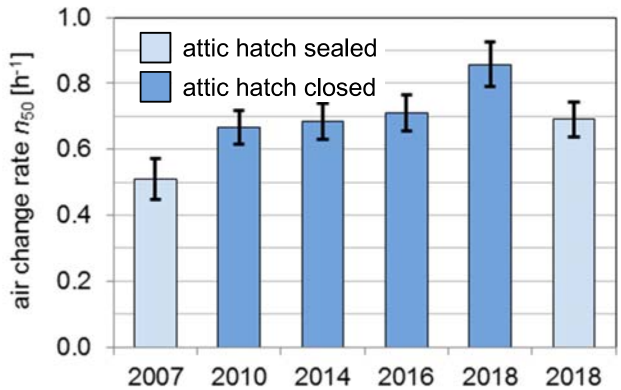

Figure 4 Repeated testing results for building A

Table 1: Building preparation and repeated testing results for building A

Test No	Test date	Building preparation			Test result
		ventilation system	chimney flue	attic hatch	n_{50} [h^{-1}]
1	31.7.2007	sealed	sealed	<u>sealed</u>	0.51 ±12 %
2	19.6.2010	sealed	sealed	closed	0.67 ±8 %
3	29.5.2014	sealed	sealed	closed	0.68 ±8 %
4	7.6.2016	sealed	sealed	closed	0.71 ±8 %
5	31.5.2018	sealed	sealed	closed	0.86 ±8 %
6	31.5.2018	sealed	sealed	<u>sealed</u>	0.69 ±8 %

4.4 Comments

The airtightness of the building A has deteriorated over the 11 years - the n_{50} value rose from 0.51 h^{-1} in 2007 to 0.71 h^{-1} in 2016. The n_{50} value increased mostly in the first 3 years, between 2007 and 2010 (from 0.51 to 0.67 h^{-1}). It is not clear whether the difference between the test results from 2007 and 2010 is due to the effect of ageing or rather to different building preparation (sealed attic hatch). Between 2010 and 2016 the n_{50} value increased slightly, but the differences between the test results are lower than the uncertainty. Between 2016 and 2018 the n_{50} value increased suddenly and significantly. A defect or accelerated degradation of the attic hatch gaskets are very likely causes of this change as shows the result of the second test carried out in 2018 with sealed attic hatch.

5 BUILDING B

5.1 Use of the building

The building B serves a “show house” of the construction company exhibiting the construction system and building technologies to the potential clients. It is not inhabited permanently. The presence of people is limited to some short intervals (excursions and other similar events). The effects resulting from the activities of the inhabitants which can influence the airtightness durability are only minimal in this house (e.g. generation of heat and moisture, their fluctuations, fastening of furniture, etc.)

Once per year (since 2010) the building is used for the round-robin testing of the local airtightness testers network (Association Blower Door CZ). During this event (from 2 to 3 days) the participants (approx. 10 technicians) perform in total 10 to 20 airtightness tests according to (ČSN EN 13829). The cyclic pressure load induced by the measuring devices may act as a factor which accelerates ageing of the air barrier system.

5.2 Service life

The building was commissioned in 2007. At that moment, the household equipment and furniture which are usually fastened to the building structure and involve a risk of a damage of the air barrier system, were not installed (fitted kitchen, cupboards). In 2016, the building was partly refurbished and furnished:

- the internal cladding of the 1st floor walls was removed as well as the 1st floor flooring
- the connection of bitumen sheets of the slab on the ground to the PE foil air/vapour barrier of the 1st floor walls was repaired and sealed again
- a new heat pump was installed, involving the penetrations of the pipework through the air/vapour barrier of the 1st floor walls
- the new external venetian blinds were installed involving the penetrations of the electrical wires through the air/vapour barrier of the 1st floor walls
- the new electrical lighting system was installed in the 1st floor involving the penetrations of the electrical wires through the air barrier layer of the 1st floor ceiling
- the new flooring of the 1st floor and internal cladding of the 1st floor walls were installed
- the new fitted kitchen, cupboards and other pieces of furniture were installed

The quality of the execution was supervised, the presence of leakages was checked during the process. No other interventions to the air barrier system were made from 2007 to 2018.

Figure 5 The building B in 2018

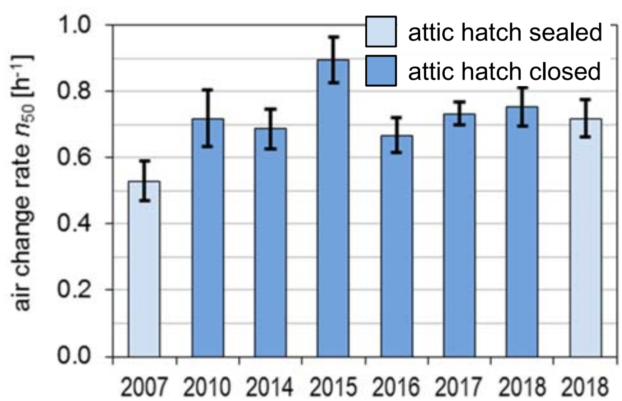

Figure 6 Repeated testing results for building B

5.3 Testing and test results

The building was tested first at the moment of commissioning in 2007, then in 2010, in 2014 and then regularly each year. For the building preparation, see tab. 2. All the tests were carried out in spring or summer, so minimal impact of the seasonal variation can be expected. The test in 2016 was carried out before the start of the refurbishment. The refurbished building was first tested in 2017. The test results are given in tab. 2 and fig. 6.

Table 2: Building preparation and repeated testing results for building A

Test No	Test date	Building preparation			Test result n_{50} [h^{-1}]
		ventilation system	chimney flue	attic hatch	
1	30.8.2007	sealed	sealed	sealed	0.53 ±12 %
2	18.6.2010	sealed	sealed	closed	0.72 ±12 %
3	28.5.2014	sealed	sealed	closed	0.69 ±9 %
4	9.6.2015	sealed	open	closed	0.90 ±8 %
4	6.6.2016	sealed	sealed	closed	0.67 ±8 %
4	12.6.2017	sealed	sealed	closed	0.73 ±5 %
5	31.5.2018	sealed	sealed	closed	0.75 ±8 %
6	31.5.2018	sealed	sealed	sealed	0.72 ±8 %

5.4 Comments

The n_{50} value rose from 0.53 h^{-1} in 2007 to 0.75 h^{-1} in 2018. The most significant increase occurred between 2007 and 2010 (from 0.53 to 0.72 h^{-1}). Unlike in the case of the building A, the difference between the test results from 2007 and 2010 seems not to be a consequence of a different building preparation (sealing of the attic hatch has a little influence – see the test results of 2018). Between 2010 and 2018 the airtightness of the building remained almost at the same level (the test of 2015 should be disregarded because of a different building preparation). Surprisingly, the n_{50} decreased between 2010 and 2016 but the differences between the test results are lower than the uncertainty. After the refurbishment in 2016, the n_{50} increased, but the increase is not really significant with regard to the measurement uncertainty. The n_{50} measured in 2017 and 2018 is very similar to the value of 2010.

6 BUILDING C

6.1 Use of the building

The building C serves as a training centre of the construction company. The company organises workshops for its employees and conferences in the conference room, which occupies most of the 1st floor area. The presence of people in the building is limited to some short intervals (typically one or several days). During the events lasting several days, the participants may be accommodated in the bedrooms situated in the 2nd floor. Like in case of the building B, the impact of users on the durability of the air barrier system does not represent a pattern typical for residential buildings.

6.2 Service life

The building was commissioned and furnished in 2007. No information is available whether the installation of numerous pieces of furniture and household equipment was supervised or not. The caretaker reported an accident of sewage water system between 2007 and 2018. The repair of the damaged pipework required a partial disassembly of the external wall and involved interventions to the air barrier system. The repair was carried out urgently, without any special supervision.

6.3 Testing and test results

The building was tested only at the moment of commissioning in 2007, and in 2018. Unfortunately, the tests were not carried out in the same season (see tab. 3). The test results are given in tab. 3 and fig. 8.

6.4 Comments

The n_{50} value obtained in 2018 is substantially higher than in 2007. The most likely cause of this increase is neglected sealing of the air barrier layers during the repair of the sewage water system failure. An improperly sealed penetration the sewage water pipework (significant leakage path) was found in an accessible installation gap. Perhaps, similar leakage paths resulting from improper repair works remained undiscovered in inaccessible parts of the external wall as well.

Figure 7 The building C in 2018

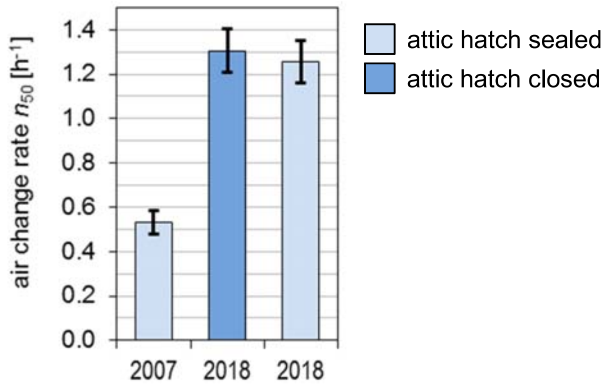

Figure 8 Repeated testing results for building C

Table 3: Building preparation and repeated testing results for building A

Test No	Test date	Building preparation: ventilation system	chimney flue	attic hatch	Test result n_{50} [h^{-1}]
1	30.9.2007	sealed	sealed	sealed	0.53 ±10 %
2	14.2.2018	sealed	sealed	closed	1.31 ±8 %
3	14.2.2018	sealed	sealed	sealed	1.26 ±8 %

7 BUILDING D

7.1 Use of the building

The building D (fig. 9) is an inhabited single-family house. Several years after the completion, the building changed the owner. Both families used the building in a typical way and without any special concern about the airtightness and its durability.

7.2 Service life

Before moving in, the second owner changed completely the 1st floor plan including the electrical and water installations. The information about this refurbishment is limited, however, it is clear that the airtightness related issues were not taken into account, e.g. no airtightness tests were performed during the execution.

7.3 Testing and test results

The building was tested only at the moment of commissioning in 2007 and in 2018. The tests were carried out in summer and spring respectively. The test result obtained in 2018 with the sealed attic hatch is only indicative. The test results are given in tab. 4 and fig. 10.

Figure 9 The building D in 2018

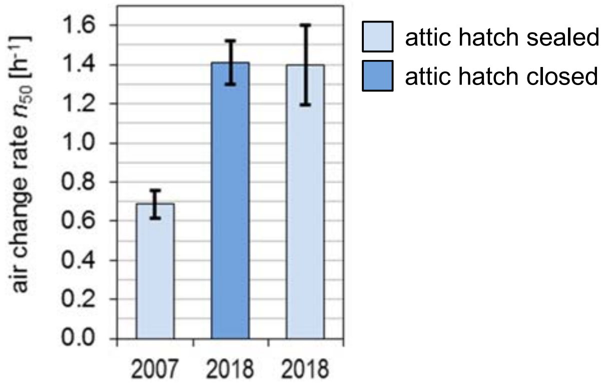

Figure 10 Repeated testing results for building D

Table 4: Building preparation and repeated testing results for building D

Test No	Test date	Building preparation			Test result n_{50} [h^{-1}]
		ventilation system	chimney flue	attic hatch	
1	2.8.2007	sealed	sealed	sealed	0.69 ±10 %
2	30.5.2018	sealed	sealed	closed	1.41 ±8 %
3	30.5.2018	sealed	sealed	sealed	1.40 ±15 %

7.4 Comments

The n_{50} value increased significantly between 2007 and 2018. Very likely, this increase results from the refurbishment carried out without any special concern about the airtightness.

8 DISCUSSION AND CONCLUSIONS

Despite the effort made during the design and the construction process, the initial level of the n_{50} was generally rather high. The unusual concept of the air barrier system did not prove the expected performance. In the next generation of the construction system, the complicated details were optimised (e.g. the connection of the air barrier layers of the 1st and the 2nd floor).

The airtightness of all the studied buildings has deteriorated over the 11 years of monitoring, but not uniformly. In case of the buildings A and B the n_{50} value increased namely during the first 3 years of the service and then remained almost stabilised. In the building B the n_{50} did not change significantly between 2010 and 2018 despite rather extensive refurbishment. In this case, the refurbishment works were supervised and executed with the aim to preserve or improve the airtightness. The total increase of the n_{50} value was rather small for both buildings A and B. In these buildings the air barrier system has proved its long term performance. Inversely, in the buildings C and D the total increase of the n_{50} value was significant, despite the quality of the air barrier system design and execution was similar to the buildings A and B. Unlike in buildings A and B, the later interventions into the building envelope were carried out with a little concern about the airtightness. The results obtained in buildings A and B strengthen the conclusions of other authors concerning the basic prerequisites for durability of building airtightness: detailed design and conscious execution of the air barrier system using appropriate products (Peper 2017). The example of the buildings C and D shows that in order to achieve the durability, it is essential to maintain the concern about the integrity of the air barrier system over the whole service life of the building, namely at the moments of furnishing, repairs or refurbishment. The example of building B shows that if these conditions are met fulfilled, the durability may be achieved even under higher mechanical loads (represented in this case by the round-robin testing).

Even in buildings A and B where the prerequisites for airtightness durability were met the n_{50} increased of about 0.2 h^{-1} (about 30 % of the initial value). It makes sense to set stricter target value for the initial airtightness in order to maintain the n_{50} below the required value of 0.6 h^{-1} during the whole life span of the building.

The cause of more pronounced increase of the n_{50} value during the first 3 years remains unclear. It seems not to be directly linked neither with the users´ behaviour nor with the rheology of the buildings load-bearing structure. The increase of the n_{50} of the buildings A and B was very similar during the first 3 years, although the building A was furnished and inhabited during this period while the building B was not. The air barrier system is composed of tensile materials (PE foil, butyl tapes) and therefore it should be able to withstand standard deformations of the structure without any substantial loss of airtightness.

The total increase of the n_{50} between 2007 and 2018 may involve an increase of heat demand of about 10 % with reference to the heat demand corresponding to the level of airtightness in 2007 in case of the buildings C and D and about 3 to 5 % in case of buildings A and B. This estimation is based on a numerical study of the impact of airtightness on the heat demand of a typical single-family passive house in the climate of the Czech Republic (Vlk 2017). The deterioration of the airtightness would not cause a dramatic increase of the heat demand, however it may involve a serious risk of interstitial condensation and consequent structural damage (like e.g. in the building C where the air leakage is probably concentrated into one or few large leakage paths resulting from improper repair works).

9 ACKNOWLEDGEMENTS

This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605.

10 REFERENCES

ČSN EN ISO 13829:2000. Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurisation method. Czech Office for Standards, Metrology and Testing

Leprince, V., Moujalled, B., Litvak, A. (2017). Durability of building airtightness, review and analysis of existing studies. *Proceedings of the 38th AIVC conference, 13nd – 14th September 2017, Nottingham, UK,* ISBN : 978-2-930471-51-8, *1 - 14*

Peper, S., Kah, O., Feist, W., (2017). Long-time durability of passive house building airtightness. *Proceedings of the 38th AIVC conference, 13nd – 14th September 2017, Nottingham, UK,* ISBN : 978-2-930471-51-8, *381 - 390*

Vlk, A., Novák, J. (2017). Impact of airtightness on the heat demand of passive houses in central European climate. *Proceedings of the 38th AIVC conference, 13nd – 14th September 2017, Nottingham, UK,* ISBN : 978-2-930471-51-8, *381 - 390*