Long-time durability of passive house building airtightness

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ABSTRACT

An airtight building envelope ensures not only the energy-efficiency of a building, but also a damage free construction. Important to achieve optimal airtightness are the planning, implementation and materials. Long-term airtightness requires efforts in all three aspects. Airtightness products are being tested under lab conditions but these results cannot be transferred one-on-one onto buildings. To gather more information regarding the durability of the airtightness 17 passive houses were re-measured as part of a research project of the International Energy Agency, "IEA Task 28, Annex 38". The re-measured buildings included various construction types, different building types, e.g. terrace houses and single family houses, and buildings aging from 1.4 to 10.5 years. As all buildings are passive houses, airtightness was a key aspect during the planning phase and the initially measured n_{50}-values were very low. For 16 out of 17 buildings the re-measured results were good to very good with an average n_{50}-value of 0.42 1/h. The re-measurements have shown, that it is rather the planning than the type of construction that has a significant impact on the long-term durability of the airtightness of buildings. In 2016 the first passive house in Darmstadt-Kranichstein, was re-measured again 25 years after it has been built. The two terrace buildings originally reached n_{50}-values ranging between 0.2 and 0.4 1/h, which experts thought not possible at the time. During the first re-measurement in 1999 the level of airtightness has not dropped significantly. After 25 years the sealants for windows and doors, that can be opened were identified as a possible cause for leakage and were replaced. Measurements before and after the replacement presented an improvement due to this very simple measure. Even though many materials were not yet available in 1991, when the passive house in Darmstadt-Kranichstein was built, it could still obtain a high airtightness. This proves the importance and impact of airtight design in early stages of the planning phase onto the long-time durability of passive house building airtightness.

KEYWORDS

Durability, Passive House, Airtightness

1 INTRODUCTION

For damage-free and energy-efficient building, good airtightness of the building envelope is indispensable. Efforts in planning and implementation, and the control with an airtightness test aim at a high quality of the building envelope. It is subsequently assumed that the building airtightness implemented will remain the same throughout the building's life time. Considering this, the following aspects become important:

- **Planning**: airtightness design with detailed planning of all connections, joints, and penetrations
- **Material**: suitability or required characteristics of the products used
- **Implementation**: professional workmanship

Efforts in quality assurance and improvement have been made in all three areas. To test and guarantee the durability of airtightness products (adhesive tapes, foils, sealing tapes, and gunning compounds, etc.), they are, among other things, artificially aged in climatic chambers. However, even the sometimes very long system guarantees given by the manufacturers cannot ensure building airtightness over periods from 30 to 50 years (depending on the building element), although the products themselves may cover such time spans. Together with manufacturers, the working group of the Association for Airtightness in Buildings (Fachverband Luftdichtheit im Bauwesen e.V. / www.flib.de) on adhesive tapes developed criteria for evaluating and testing adhesive tapes. Among other things, these results will be used for drafting the new standard regulating this issue (German Industrial Standard DIN 4108 Teil 11).

2 RE-MEASUREMENT OF AIRTIGHTNESS

Thus far, there is very little information available on the durability of building airtightness in general, that is not only for individual products. This is particularly true for the category of buildings with very good airtightness (n50 < 0.6 h-1). Therefore, as part of a research project of the International Energy Agency, “IEA Task 28, Annex 38”, the airtightness of 17 passive houses was re-measured. In this context, the passive houses represent energy-efficient buildings, where airtightness has been planned before beginning construction – as it should be done in general. For the selected buildings, the airtightness design, as well as the first measurement or the final acceptance test had been well documented. During the re-measurements, this specifically allowed for checking the leakages found during the first measurements. The buildings were also selected so that all common types of structures like solid, lightweight, composite, and concrete formwork construction were represented.

Using this method, the durability of the designs could be tested 1.4 to 10.5 years after their implementation. The tests included terraced houses and single-family homes of the different types of construction at eight locations. Further measurements will be conducted in 2016, testing the first passive house in Darmstadt-Kranichstein 25 years after construction. This paper is a summary of the research report “On the durability of airtightness designs of passive houses. Field measurements.” [Peper/Kah/Feist 2005] published as part of the IEA project.

Figure 1: Exterior view of the buildings tested for airtightness during the study

Table 1: Passive houses, where re-measurements were conducted

#	Passive house project	Architects/		Passive house project
1	terraced houses, Darmstadt-Kranichstein	Bott / Ridder / Westermeyer	solid	2
2	single-family homes, Bretten	Oehler + archkom	lightweight wood-frame	2
3	housing development, Lindlar / Hohkeppel	M. Brausem	lightweight wood-frame (force-fitted)	5
4	single-family homes, Stegaurach / Mühlendorf and Bamberg	Ingenieurbüro Trykowski	lightweight wood-frame	2
5	terraced houses, Hanover-Kronsberg	F. Rasch / P. Grenz	composite	4
6	terraced houses, Rhein-münster and Bühl	Planungsbüro Früh	concrete formwork (solid)	2

For each of the buildings or projects tested, we first described the respective airtightness design with the connections that had been implemented. For a systematic overview, we also drew up a table with the corresponding connections between building components. This was done analog to the tabular overview of connection possibilities by [Peper/Feist 1999]. By way of example, we show the systematic of the passive-house development in Hanover-Kronsberg.

Table 2: Airtight connections of the passive-house development in Hanover-Kronsberg

connection of	base plate	sash	blind frame	AW lightweight	roof
roof				acrylic adhesive tape (connection with PE panel)	acrylic adhesive tape (connection with PE panel)
AW lightweight	PE panel with acrylic or butyl-rubber adhesive tape or butyl-rubber adhesive tape on primed concrete		butyl-rubber adhesive tape with fleece lamination connected to PE panel	acrylic adhesive tape (connection with PE panel)	
blind frame	butyl-rubber adhesive tape with fleece lamination	lip seal			
sash					
base plate	mortar plus smoothing				

In the following, the research report documents the first measurement for each project. To the extent possible, the re-measurements tested for the residual leakages found.

3 EXAMPLE: PASSIVE-HOUSE DEVELOPMENT IN HANOVER-KRONSBERG

In the housing development in Hanover-Kronsberg, four of the 32 terraced houses were re-measured after four years and two months and the measurements documented. In all four houses, residual leakages were found in the following areas: front-door sealings, some window sealings, some glass-strip connections, integration of window and front-door frames in the light-weight wall, some connections of building components as of the exterior walls with the walls separating houses, with base plates, or roof elements, as well as some corners of window reveal/floor.

Most of the residual leakages from the first measurements could still be detected in the re-measurement. An exact allocation of the leakages to the actual leakage point is, however, difficult because of the wall panels and floor coverings. The actual leakage is frequently no longer accessible and only the outlet of the flow path into the room can be located. The leakages detected at front doors and windows can be significantly reduced by re-adjusting. The small leakages at various mitre joints of the glass strips seem to indicate a weakness in window production. However, the leakages are so insignificant that rework is not recommended because it is expensive and time-consuming. Further residual leakages were also tested and evaluated.

The measuring results of the re-measurement are always compared to the first measurements. The different levels of measuring accuracy between both measurements due to the devices used and particularly the effect of wind must be taken into consideration for the final evaluation. In general, having considered the measuring accuracy, the results of the first measurement and the re-measurement overlap. Since any changes range within the measurement uncertainty, neither improvement nor deterioration of the airtightness can be proved.

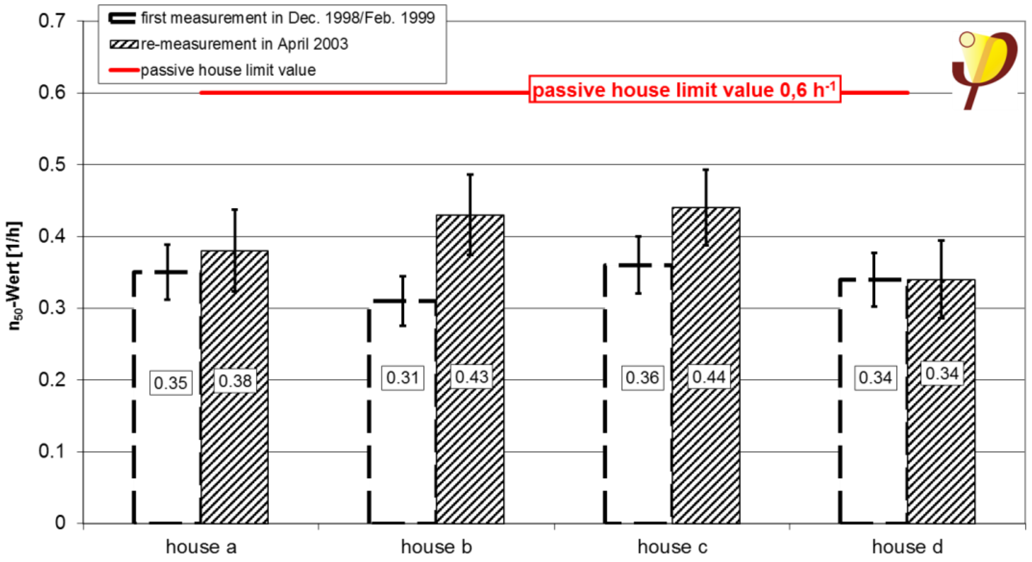

Figure 2: Example of the results of the four airtightness re-measurements in Hanover-Kronsberg in comparison to the results of the first measurements. The bars show the measuring uncertainty of each measurement.

The results of the four re-measurements show that all buildings tested have maintained a very high quality of airtightness. The mean of all four re-measurements is at n_{50}=0.4 h^{-1}. For three of the four buildings, the measuring value has slightly increased, for the fourth, it has remained the same. However, the changes range within the area of the measuring accuracy of the tests. This makes it impossible to make a clear statement on an increase of the n_{50}-values. House B is the exception, because it shows a slight increase of the measuring value even after having considered the measuring accuracy. Overall, the four objects show very high airtightness in the first measurements as well as in the re-measurement.

The principal result of the re-measurements is the high airtightness of the terraced houses proven in the first measurement as well as in the re-measurement. If at all, partial “deteriorations” are mainly detected at windows or front doors and nondurable silicon rework. The airtightness design of these buildings with composite structure can be rated as durable – at least for the time span until the re-measurement. Further relevant reductions in airtightness are not to be expected. The success of this “airtightness in series” in the passive-house development is above all based on the explicit planning of the airtightness. Drawing up detailed models (up to a scale of 1:1) has proven to be useful and expedient for areas where an airtight connection of up to three panels had been planned. This shows that consistent theoretical planning is critical, but the possibilities of a more practical implementation do also have to be carefully considered.

4 OVERALL RESULT

For 16 of the 17 buildings, the results of the re-measurement were good to very good – and that for the strict passive house requirements with a limit of n_{50}=0.6 1/h. These 16 passive houses averaged at a n_{50}-value of 0.42 1/h. In the exception, the main leakages supersede the quality of the other connections. The n_{50}-value was 1.2 1/h. It was not possible to draw conclusions on long-term stability. The architect of the building indicated the lack of a sufficient airtightness design. For the structurally identical subsequent buildings, such a design was available leading to a positive result (see number 4 in Figure 3). For the 16 positive results, the changes between the first and the re-measurement were almost always within the measuring accuracy. Five buildings even showed a significant improvement of the measuring values due to rework following the first pressure test.

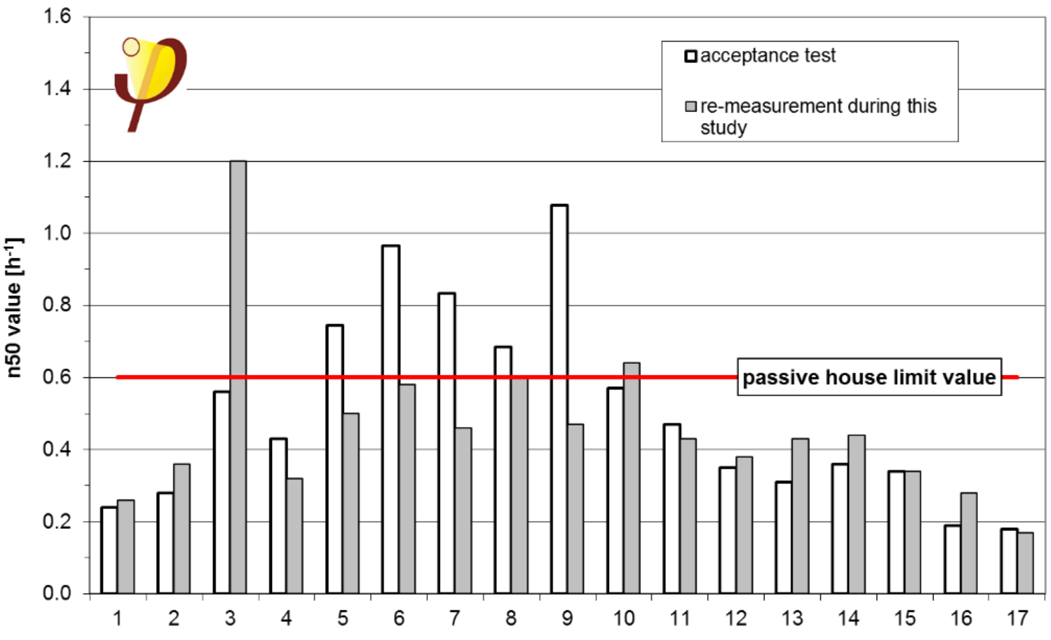

Figure 3: Overview of the measuring results of the airtightness tests of the 17 buildings analysed (acceptance test and re-measurement during this study).

Table 3: Overview of the re-measured buildings and evaluation of the durability of the airtightness in the period assessable

#	Type of construction	Airtight layer	Number of objects	Time span	Evaluation
1	solid	interior plaster / PE-panel / concrete	2	**> 10,5 a**	durable
2	wood-frame	intermittently bonded wood composite boards, PE-panel, concrete	2	**> 3,6**	cannot be evaluated
				> 2,8 a	durable
3	wood-frame (force-fitted)	force-locked, bonded wood composite boards, concrete	5	**> 3,5 a**	durable
4	wood frame	bonded wood composite boards	2	**> 4 and > 4,3 a**	durable
5	composite	PE-panel/ concrete	4	**> 3,1 a**	durable
6	concrete formwork	interior plaster / PE-panel / concrete	2	**> 4,8 and > 1,4 a**	durable

These measurements paint a positive picture of the durability of airtightness designs. The designs and connections selected by the respective planners and architects must be considered successful, at least for the time span between the acceptance test and the re-measurement. All types of structures are to be regarded as equally positive. **It is the quality of planning rather than the type of construction that is decisive for a successful implementation of high airtightness.** This obviously also requires a careful implementation of the plans and is the point when it becomes evident if the planning contains designs that allow for a successful implementation.

We do not assume that airtightness for the buildings analysed will deteriorate significantly over the next few years. They have, after all, been planned and implemented using suitable products and installing them according to recognized quality standards. Considering the respective time spans since construction, most of the expected movements of building components have already passed. According to the results on hand, it is to be expected that the airtightness in the category of buildings with excellent airtightness ($n_{50} < 0{,}6\ h^{-1}$) tested here is durable. For the passive houses tested, a deterioration of airtightness during the first two years as it is described in some of the literature cannot be confirmed.

5 FOLLOW-UP ON THE PASSIVE HOUSE IN DARMSTADT-KRANICHSTEIN

The passive house in Darmstadt-Kranichstein was re-measured again in 2016, 25 years after it has been built (see Figure 4), 15 years after the previously described pressure tests in 1999.

Figure 4: Left: The first pressure test was conducted on 24/26 of May 1991 by Ingenieurbüro ebök once the airtight envelope had been finished. Right: The current Blower Door Test (here in House B) was conducted on 11/12 of February 2016 by the PHI 25 years after construction.

The only significant shortfalls in the two houses were detected at the sealants for windows and doors that can be opened. After 25 years, the sealants have become somewhat inelastic. Adjustments to the windows did not fix the issue sufficiently, so all of the windows and the front door were additionally sealed.

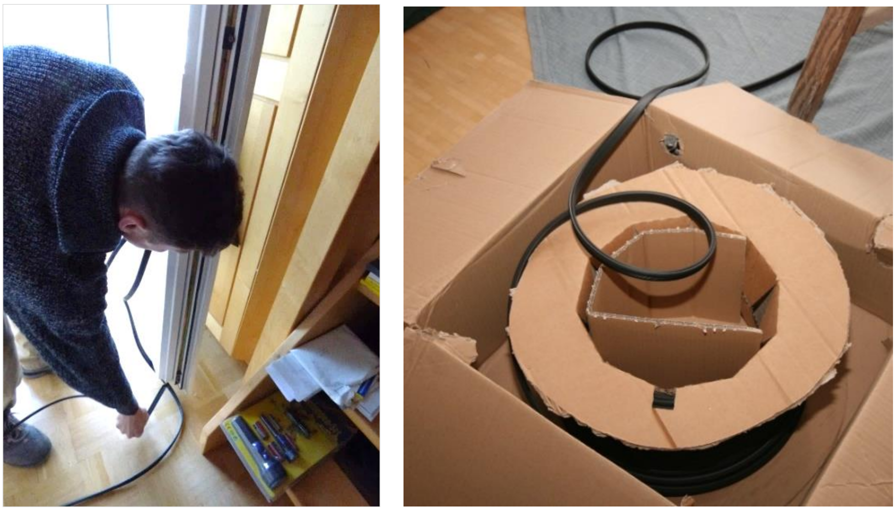

Figure 5: A qualified contractor replacing the window seals in House A on 12/02/2016 and the sealing material used (yard ware).

As a result, the original value has once again been reached in both houses: At n_{50} = 0.21 and 0.35 h^{-1} (see Figure 6), respectively, the extremely good results of the preliminary measurements were reproduced. Detailed inspections of the building component connections revealed how durable they were although the materials available today were not yet on the market in 1991. For instance, the acrylic seals between the window frames and plaster end rails are nearly perfectly airtight everywhere, as is the connection between the airtightness foil in the roof and the wall's interior plaster. For a lack of alternatives at the time, the windows that reach down to the floor slab have a wide silicon joint with backfill material. Aside from a few areas, even this suboptimal sealing is still perfectly airtight.

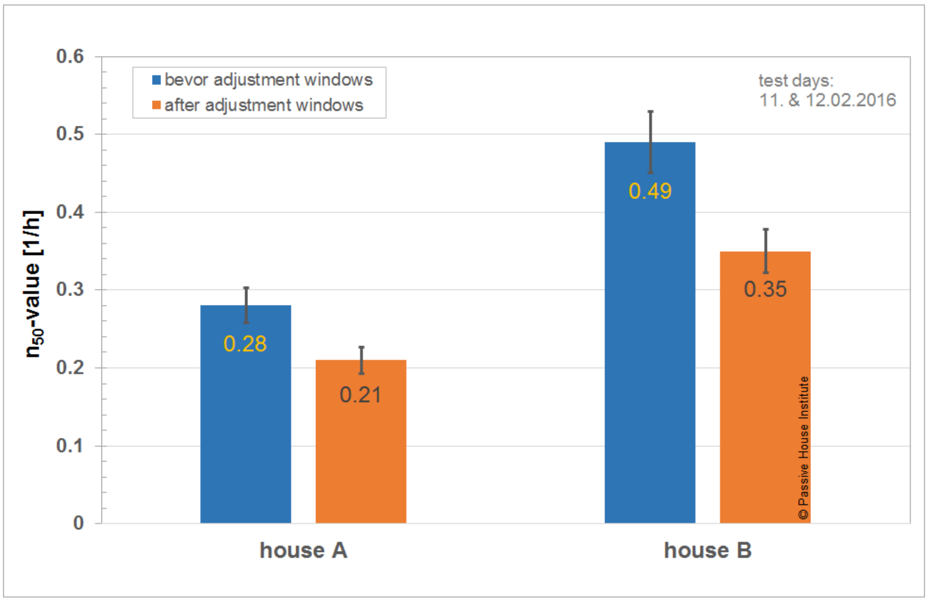

Figure 6: Airtightness tests of the passive house in Kranichstein (Houses A and B) in February 2016, 25 years after construction, before and after replacing the window and door seals.

The terrace houses in Darmstadt-Kranichstein originally had n_{50}-values ranging from 0.2 to 0.4 h^{-1}, which not even experts had previously thought possible. As shown in Figure 3 (buildings number 1 and 2) during the in previous chapter described tests in 1991, the n_{50}-values had not significantly gone down since then (see also Figure 7). The latest measurements in 2016 after 25 years once again revealed extremely good levels of airtightness.

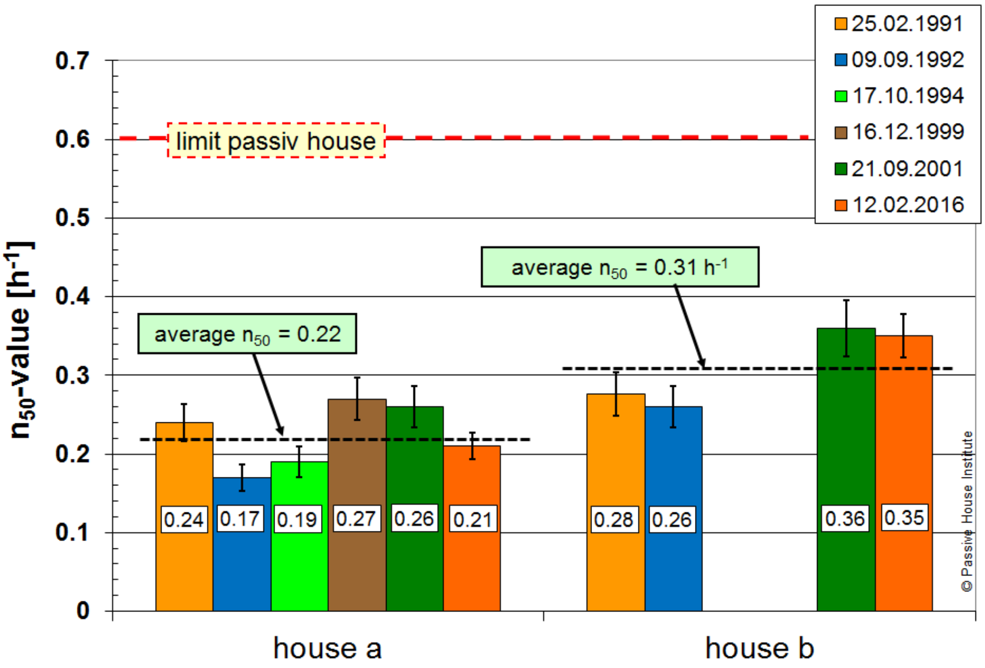

Figure 7: Overview of all pressure tests of two of the four units of the passive house in Kranichstein conducted over the years. The two measurements before replacing the seals are not included.

6 CONCLUSION

In general, it can be stated that the detailed analysis of the connections between building components shows their durability, even though in 1991 the number of materials and construction solutions available was much smaller than today. The very good airtightness results of the building were clearly below an $n_{50} = 0.4\ h^{-1}$ and the data for this long period is secure. A durably airtight building envelope is, above all, a question of planning (see also [Peper/Feist 1999]). Everything depends on the connection of the airtight layers at the edges of building components. There are standard solutions that can be implemented easily, as for example the elastically filled joint (with anti-adhesion “round cord” to avoid three-flank adhesion) or the plastered sealing sheet. These procedures had already been implemented during the construction of the passive house in Darmstadt-Kranichstein and continue to be perfectly airtight even 25 years after construction

7 REFERENCES

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