Field study on the evolution of air tightness in 30 Belgian dwellings

Vandenbogaerde Lukas[1], Verbeke Stijn[1,2,3*], Swinnen Joost[1] and Audenaert Amaryllis[1]

1 University of Antwerp
Energy and Materials in Infrastructure and Buildings (EMIB), G.Z.335
Groenenborgerlaan 171
B2020 Antwerp, Belgium

2 Unit Smart Energy and Built Environment, Flemish Institute for Technical Research (VITO)
Boeretang 200
B-2400 Mol, Belgium

**Corresponding author: stijn.verbeke@uantwerpen.be*

ABSTRACT

This study sets out to investigate to what extent the air permeability of a building envelope of a dwelling remains constant over longer periods of time. This was evaluated by executing an air pressurisation test in 30 dwellings located in Belgium and comparing these results to the initial measurement results obtained shortly after the construction of the buildings. The time span between both measurements ranges from 293 days to 4045 days. On average, the air infiltration rate of the building envelope increased with 24%, i.e. an increase of 64 m^3/h at a 50 Pa pressure difference. In 9 of the 30 case study buildings, the building envelope appeared more airtight compared to the initial measurements. Most of the buildings in this study have been conceived as relatively airtight, with an initial air infiltration rate n50 of 1.2 h^{-1}. As a result, the projected impact of the change in air tightness on the annual heating energy demand is relatively limited, with an estimated average increase of 4.1%.

KEYWORDS

Airtightness, air leaks, blowerdoor, NZEB

1 INTRODUCTION

Over the last decade, the construction industry has been under pressure to improve the energy performance of buildings, in Europe most notably through the national implementation of the European Energy Performance of Buildings Directive (EPBD). Building designers can use a number of design strategies for enhancing the energy performance of buildings. Apart from conventional energy efficiency measures such as thermal insulation and more efficient technical installations, improving the air tightness of the building envelope can have an important contribution to the overall building performance. The energy performance of a building can increase up to 5-10% due to an improved airtightness of the building envelope, and even more in low-energy dwellings (Miszczuk, 2017). In the EPBD regulations of the region of Flanders in Belgium, a default value for v_{50} of 12 $m^3/h.m^2$ is assumed in the calculation of the energy performance score of a building. This value can be replaced by measured data retrieved from a fan pressurisation test since this default value is quite high for the average newly constructed Flemish buildings. Typically, newly constructed buildings achieve a value between 6 and 12 $m^3/h.m^2$, but can even be reduced to 2-6 $m^3/h.m^2$ with a well-thought-out design and a meticulous execution. Obtaining a value of less than 2 $m^3/h.m^2$ requires thorough expertise in the field of airtightness. It remains to be evaluated whether the reported airtightness after the initial measurement – typically shortly after the initial construction of a dwelling -

remains stable over time. Prior studies reported in literature have indicated that significant changes in air permeability might effectively be expected (Bassam et al.; 2018; Bracke et al; 2016; Ademe, 2016; Philips et al, 2011). There are indications that the airtightness decreases in the short-term and then stabilises (Leprince et al., 2017). The main reasons for short-term degradation may be the shrink of mastics when heating for the first time, mastics shrinkage when the joints are not filled, settlement of the dwelling and unsuitable conditions for adhesives and mastics (cold/dusty) as well as a greater chance of actions by occupants e.g. drillings. Furthermore, W . Feist et al. found out that most of the products used to ensure airtightness appear to degrade only to a very limited extent in the long-term (Feist et al., 2016). However, windows and door seals will degrade more likely hence a replacement is generally recommended after a maximum period of 25 years. The reason could be the ageing of the seals, the sagging and deforming of the frames or a combination of these two. Finally, previous research shows that occupants' behaviour, i.e. actions undertaken by the occupants that affect the airtight barrier of a dwelling, is an important reason for the variation of the reported changes in air permeability (Lux, 1987). Most studies, reported in literature, found a general degradation of the airtightness of dwellings in the short-term and mid-term but no exact correlation was found. Therefore, in this research, follow-up airtightness tests were carried out in order to investigate the evolution of 30 dwellings. In addition, it was attempted to locate the source of the main air leaks and compare these results to other sources.

2 METHOD

Fan pressurisation tests were carried out in 30 different dwellings located in the region of Flanders (Belgium). In accordance to European Standards NBN EN ISO 9972:2015 and Belgian technical specification STS P71-3, the discharge or suction flow is measured when applying a pressure difference of 50 Pascal. This value is interpolated by a range of values between 10 and 60 Pascal. For this research, the Minneapolis Blower Door with a DG-700 pressure monitor was used for the second measurement of the dwelling for a comparison with the original evaluation. The original fan pressurization test was reproduced as accurately as possible by measuring the corresponding door or window. Methods to find locations of air leaks, i.e. using a thermographic camera FLIR T640 and smoking pen, were used in combination with the Blower Door Test to map the different air leaks. Furthermore, a questionnaire was used to ask about some of the characteristics of the dwellings and whether any changes had been made to the dwelling after the original measurement.

3 RESULTS ON OVERALL EVOLUTION OF AIR PERMEABILITY

Table 1 provides an overview of the statistics of the initial measurements in the 30 test cases. A mean specific infiltration rate v_{50} of 1.75 $m^3/h/m^2$ indicates that the buildings under investigation are relatively airtight compared to current building practices, and especially if compared to the air infiltration of the current building stock at large. The default value in the Flemish EPBD calculation procedures is 12 $m^3/h/m^2$, whereas for the newly constructed buildings that actually measured air infiltration rates as part of the energy performance certification process, an average value of 3.2 $m^3/h/m^2$ is reported by the Flemish Energy and Climate Agency (building permit requests of 2019). 12 out of the 30 case study buildings would comply to the requirements of Passive House Institute demanding a maximum air infiltration rate value of 0.6 ACH50.

Table 1: Statistics on 30 case study buildings

Time between tests [days]	Envelope area [m²]	Volume [m³]	q_{E50} [m³/h.m²]	n_{50} [m³/h.m³]
Min: 293	Min: 212	Min: 294	Min: 0.27	Min: 0.21
Max: 4045	Max: 1028	Max: 1534	Max: 6.65	Max: 3.64
Mean: 1923	Mean: 518	Mean: 768	Mean: 1.75	Mean: 1.15

The difference in absolute air infiltration [m³/h] at a 50 Pa pressure difference between the first and second test is plotted in Figure 1. It is apparent that the air infiltration for this set of buildings is not a stable value over time. The average change in air flow rate q_{50} is a 64 m³/h increase, with a mean of 55.7m³/h and a standard deviation of 253. The relative permeability q_{E50} increases on average with 0.13 m³/m²·h with a mean of 0.14 m³/m²·h and standard deviation of 0.50.

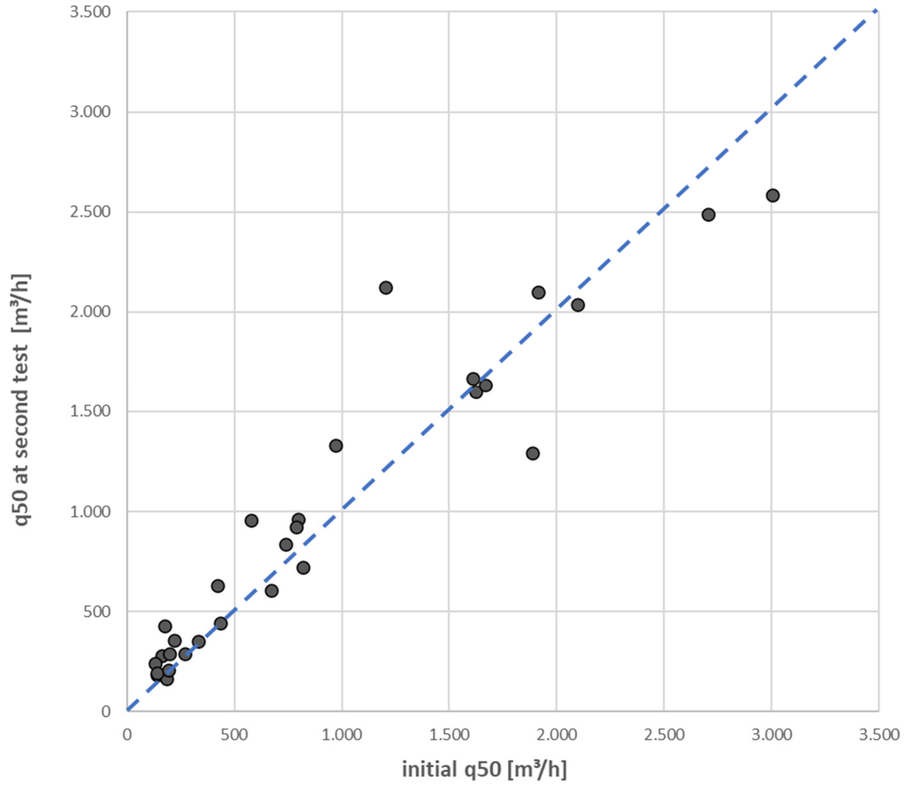


Figure 1: Measured air permeability [q_{50}] in first test shortly after construction and renewed test

The average increase of 24% air infiltration rate at 50 Pa is comparable to the results of Bracke et al. who reported a median increase of 25% in the evaluation of 15 passive houses in Belgium (Bracke et al. 2016), and the results of the Fraunhofer Institute for Building Physics which also report an average increase of 24% in their evaluation of 52 passive houses (Reiß and Erhorn, 2003; Erhorn et al, 2008). In the field studies of the French Durabilitair project, Moujalled et al. report a change in air leakage rate q_{50} of +18% for a sample 30 newly constructed dwellings followed over a 3-year period, respectively 20% for a sample of 31 dwellings that was measured again with an interval of 3 to 10 years compared to the initial assessment. These reported changes in air permeability are clearly higher than the estimated measurement uncertainty of 10% (Moujalled et al, 2021).

Interestingly, 9 out of the 30 cases show a reduction of air permeability over time. A similar observation was made in a previous measurement campaign where 4 out of 41 cases showed an reduction in air infiltration compared to the original measurement (Verbeke, 2020). A potential explanation for this improvement of the envelope could be the timing of the initial test. If this test was carried out prior to the completion of some interior finishing, this test might have reported an underestimation of the actual air tightness. Further research is required to investigate the actual cause.

Figure 2 and Figure 3 plot the absolute and relative changes in air permeability against the time interval between the two measurements. The results indicate a wide spread and no apparent direct relation between the timing between two measurements and the change in envelope air permeability for the case study dwellings.

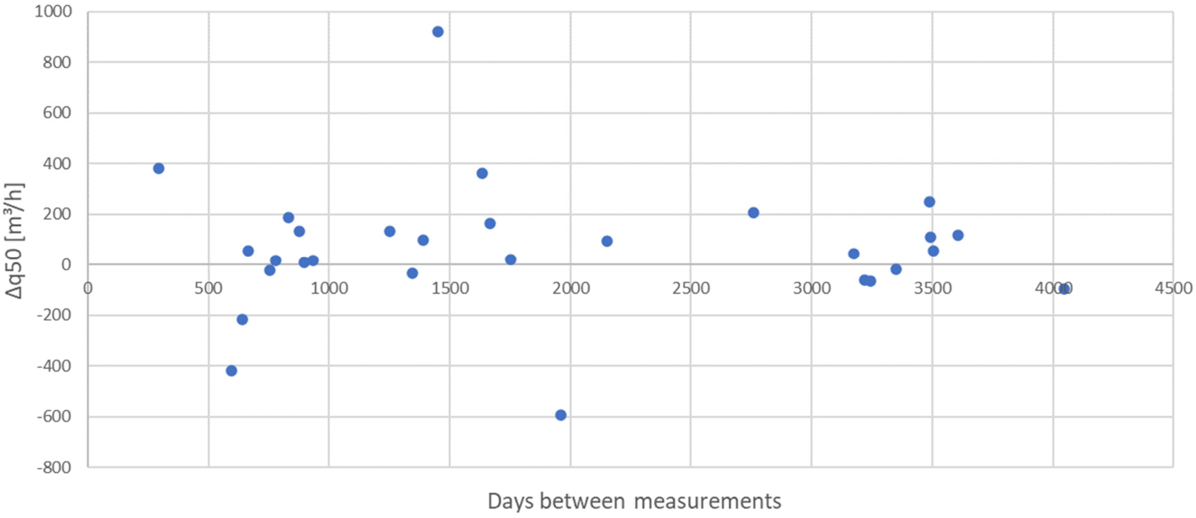


Figure 2: Absolute evolution of envelope air permeability [Δq_{50}] in relation to the time interval [days] between initial airtightness evaluation and renewed test.

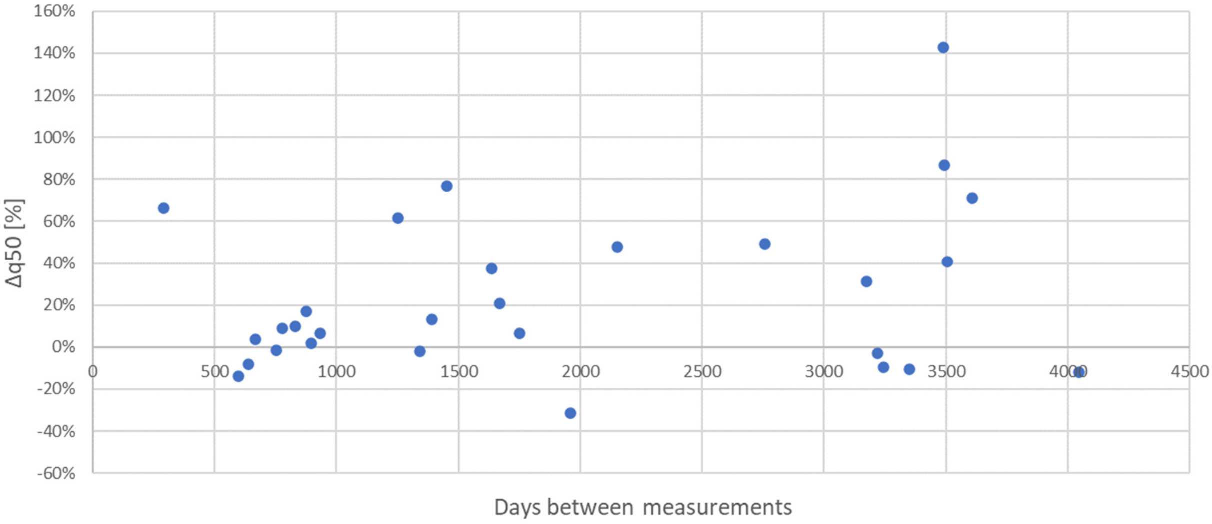
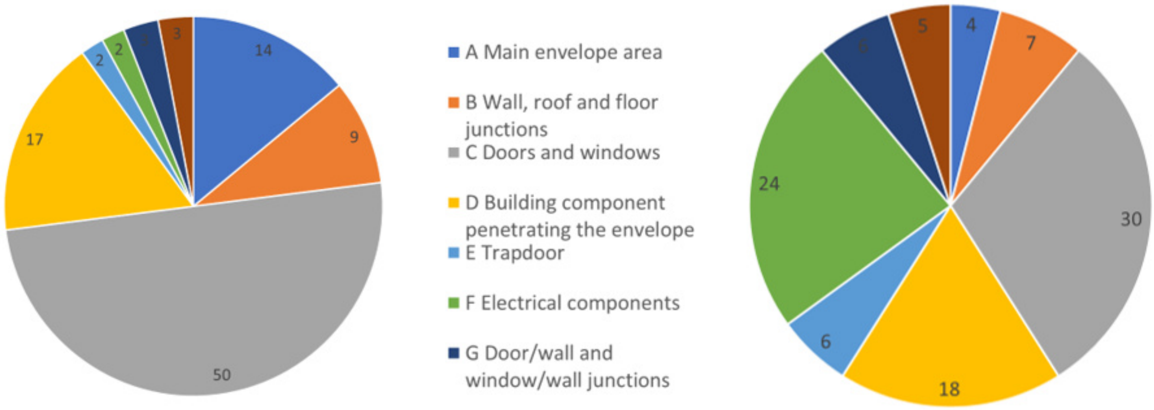


Figure 3: Relative evolution of envelope air permeability [Δq_{50}] in relation to the time interval [days] between initial airtightness evaluation and renewed test.

4 LOCALISATION OF AIR LEAKS

It was attempted to locate the main sources of air infiltration. This was done using the classification system of the STS P 71-3 guideline. The highest percentages of air leaks appear to occur at exterior joinery and penetration of the building envelope. Namely, almost 79% of the tested dwellings have air leaks at external doors and 83% of the dwellings at windows. 14% of the tested dwellings had air leaks around skylights. Additionally, 17% of the measured dwellings have air leaks when a wall or a floor slab is punctured and 24% where the vapour barrier is punctured.

To compare these results with the French study DURABILIT'AIR, with an extensive dataset of 35 382 single-family dwellings, the detected air leaks were categorised using the same criteria (Bailly, Guyot and Leprince, 2015). Figure 4 compares the relative occurrence of air leaks in dwellings in this study and the DURABILIT'AIR dataset. In the latter, a proportion of 30% of the leaks was found around windows and doors and 24% around electrical components. All building components penetrating the envelope, i.e. ventilation terminal devices, pipes and ducts are also an important source of air leaks since 18% of all air leaks are observed at these locations. The significant differences between the two datasets require further investigation, amongst others by expanding the datasets. Possible explanations include differences in local building traditions and differences in the practical application of the assessment protocols for locating the air leaks.



(a) (b)

Figure 4: Relative occurrence of air leaks (in percentage of reported air leakage locations). (a) Left part of the figure displays the 30 Belgian dwellings, (b) right part of the figure displays the Durabilitair results.

5 IMPACT ON HEATING ENERGY CONSUMPTION

The changes in air permeability of the building envelope will have an impact on the energy demand for heating. The actual change in energy consumption depends on several uncertain factors, including the actual outdoor temperature and solar gains, occupant behaviour patterns, etc. Hence, the annual difference in energy loss is not exactly know, but instead estimated based on the calculation method of the Flemish EPBD regulations. This analysis is carried out for six buildings where sufficient data could be obtained. The results reported in Table 2 indicate that all six dwellings have a reasonably low initial air permeability ($q_{E50} < 0.5$ m^3/h.m^2) and show some variation in respect to their evolutions in airtightness. The largest absolute increase is found in dwelling 3 where the change will cause an increase in characteristic annual primary energy consumption (CAPEC) of 417 MJ. However, the yearly additional cost of the increased heating demand due to the change in airtightness is only 40.19 €, assuming an electric heater with average energy cost of 0.347 €/ kWh; and even lower in case of more efficient heating installations such as condensing gas boilers or heat pumps.

Table 2: Heating energy consumption estimated according to initial air tightness and

Dwelling n°	**1**	**2**	**3**	**4**	**5**	**6**
$q_{E50\text{-}initial}$	0.36	0.38	0.47	0.29	0.24	0.28
$q_{E50\text{-}retested}$	0.41	0.33	0.7	0.64	0.35	0.44
$CAPEC_{initial}$ [MJ]	18758	-3971	8338	-2347	28776	4650
$CAPEC_{retested}$ [MJ]	18854	-4006	8755	-2045	29022	4940
ΔCAPEC absolute	96	-35	417	302	246	290
ΔCAPEC relative	0.51%	-0.88%	5.00%	12.87%	0.85%	6.24%

6 CONCLUSIONS

By carrying out an air pressurisation test a few years after initial construction and comparison with initial measurements, the evolution of the air permeability of 30 Belgian dwellings was assessed. The results demonstrate that the air permeability is indeed subject to change, but no clear relation with the time span between two measurements could be established. On average, the air permeability of the building envelope increased with 24%, but for 9 out of 30 buildings a reduction of air permeability was found. With construction years ranging from 2011 to 2020, all of the buildings are fairly recent and they adhere to the local energy performance regulations. Furthermore, their initial air permeability was rather low. Although the relative changes in air permeability can be high – up to 143% for one specific dwelling – the absolute changes in air permeability are relatively limited, with a maximum increase of the specific air permeability of 1.57 $m^3/h.m^2$ and an average change of + 0.13 $m^3/h.m^2$. As a result, the projected impact of the change in air tightness on the annual heating energy demand is relatively limited, with an estimated average increase of 4.1% for 6 of the analysed dwellings.

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