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Potential of using wind barriers to assure airtightness of wood-frame low energy constructions

Jelle Langmans[a,]*, **Ralf Klein**[b], **Michel De Paepe**[c], **Staf Roels**[a]

[a] *Department of Civil Engineering, Laboratory of Building Physics, Catholic University of Leuven*
Kasteelpark Arenberg 40 - bus 02448, BE-3001 Heverlee, Belgium
[2] *Sustainable Building Research Group, Departement of Industrial Engineering, Catholic University College Sint-Lieven*
G. Desmetstraat 1, BE-9000 Ghent, Belgium
[3] *Department of Flow, Heat and Combustion Mechanics, Ghent University-UGent*
Sint-Pietersnieuwstraat 41, BE-9000 Ghent, Belgium

* *Corresponding author. Tel: +32 16 321348; fax: + 32 16 32 19 80.*
E-mail address: jelle.langmans@bwk.kuleuven.be (J. Langmans)

Abstract

This paper investigates the air permeability of a wind barrier during the consecutive construction stages of a wood frame passive house, located in Belgium. The wind barrier consists of a promising new type of bituminous mixed wood-fibres plates. To quantify the different leakage paths, the study applies the reductive sealing technique. In total 12 pressurization tests have been conducted during the construction process. In addition to these field tests on the entire building, the paper discusses the results from laboratory measurements on specimens of the windbreaker including typical joints, in order to verify the influence of different possible types of local air leakage paths.

The results reveal that the external wind barrier contributes significantly to the final airtightness of the tested building. Moreover, by sealing only the most critical joints of the outer shell the level of airtightness of the whole building envelope can fulfil the requirements of the passive house standard (less than 0,6 air changes per hour (ACH) at 50 Pa). The results presented in this paper, thus, indicate that the proposed solution has potential to reduce the labour costs required to reach a sufficient level of airtightness.

Introduction

Energy consumption and sustainability is a growing priority for house owners, so, particularly in the last decade, considerable progress has been made to improve the energy efficiently of buildings. In the European Member States the Energy Performance of Buildings Directive (EPBD), which includes a calculation method to estimate the energy demand of buildings, is well established [1]. Furthermore, labels introduced in some countries, such as ‘Passive House’ in Germany and ‘Minenergie’ in Switzerland, to certify standardised low energy buildings are becoming increasingly applied in Europe [2,3]. Apart from adequate thermal insulation, the corresponding calculation tools emphasise the importance of a good overall airtightness of the building envelope [4]. Compared to conduction through building components, the convective heat transfer as a result of air movement through the building envelope becomes relatively more important in well-insulated buildings [5,6]. Both, the ‘Passive House’ as the ‘Minenergy’ label explicitly require a threshold level of airtightness (0.6 Air Changes per Hour (ACH) at 50 Pa). As a result, pressurization tests are becoming common practice to control the level of airtightness of newly erected buildings.

In light weight constructions an airtight building envelope is commonly realised by an interior air barrier system. The term ‘air barrier’ refers to the material layer which prevents air leakage between inside and outside through the building envelope. Consequently, the most important property of this layer is the overall continuity, which leads to the requirement of sealing all the joints and intersections in this layer. In cold and moderate climates, such as North-West European areas, the air barrier function is often combined with the vapour retarder. Realising a good airtightness with an interior barrier however, is very labour-intensive due to many internal joints, intersections and perforations for electrical and plumbing devices [6-10].

To protect the insulation layer from unwanted infiltration of outside cold air by natural or forced convection a ‘wind barrier’ is provided at the outside of the insulation. In addition, this exterior layer serves as drainage plane to prevent water infiltration into the structure. The performance criteria for wind barrier systems regarding air permeance are less severe than for air barriers [11]. Therefore, the joints in the wind barrier are usually left unsealed.

As a result of the recent improvements of the airtightness of wind barriers, pressurisation tests showed that wind barriers can make a major contribution to global airtightness in timber-frame buildings. Compared to the interior air barrier, the wind barrier shows fewer joints and perforations. However, since pressurization tests are only performed at the end of the construction phase, a lack of information in the literature prevents further quantification of the importance of the wind barrier on the overall airtightness. In Norway, Myhre and Tormod [12] performed pressurisation tests in three wood-frame buildings both after a spun bonded wind barrier was installed, and when the interior air barrier was installed. The results showed that through careful installation of the wind barrier connections, the airtightness in the windtight stage was lower than 1.5 ACH at 50 Pa in all three cases. Consequently, the authors emphasise the potential of using wind barriers to decrease the air leakage in low energy wood frame buildings.

This research paper studies the prospects of using wind barriers as air barrier in wood-frame low energy buildings. In total 12 pressurisation tests were conducted during the construction stage of a recent passive house in Ghent, Belgium. Measurements were carried out before and after the joints in the wind barrier were sealed. This reductive sealing technique [13] allows quantifying the contributions of the different leakage paths through the building envelope. Besides the *in situ* pressurisation tests of the entire building, laboratory measurements on specimens of the wind barrier including typical joints were carried out. The study entailed two different test-setups to measure the air permeability on material and assembly level. Hence, this creates the opportunity to investigate the feasibility of extrapolating laboratory air permeability measurements on building materials to the airtightness of real buildings, as supposed in [14].

Description of the tested passive house

The passive house investigated is located in Ghent, Belgium. It is a detached, three story single family house with two bed and breakfast guestrooms on the ground floor. Figure 1 shows an overall view of the project. The heated volume of the house is 1083 m³. The house has a light-weight timber frame construction with I-profile studs between the internal OSB and external wind barrier. The I-profiles have an intermediate distance of 400 mm and the space in between is filled with blown cellulose fibre insulation. The external walls are made of 300 mm I-profiles and the roof of 400 mm I-profiles. Apart from the structural purpose, the internal 15mm OSB plates are used as a vapour retarder. Sealing the internal tongue and groove connections between the plates creates an interior air barrier (Figure 3b). To avoid ductwork penetrations through this layer a service zone of 50 mm is provided to install the electrical and plumbing devices. This cavity is filled with flax fibre insulation and covered with gypsum-cellulose plates at the inside.

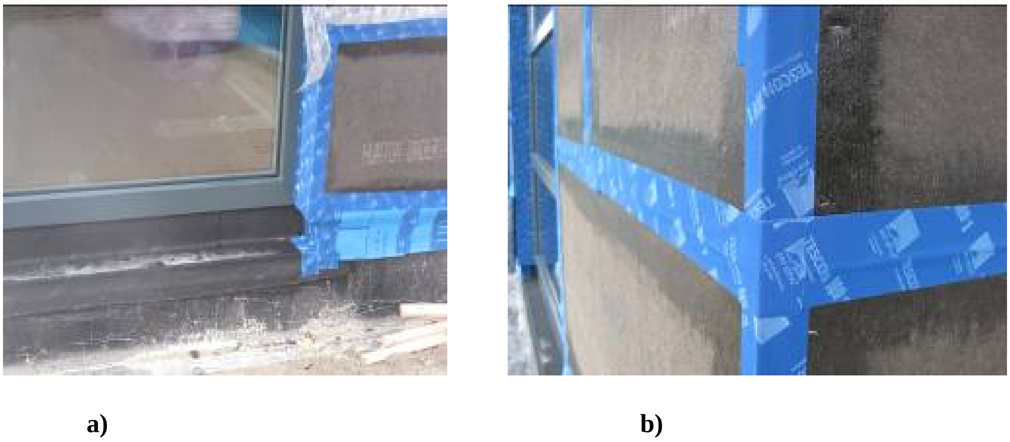
The wind barrier consists of 18 mm thick bitumen impregnated soft fiberboards. The boards have a special watertight bitumen impregnated layer on the top face, which has a significant contribution to the airtightness of the material. Nevertheless the high air resistance, the boards have a high vapour permeability (sd-value of 0.27 m at 30% RH and 0.14 m at 80%) what makes them applicable as breather membranes on the outside of thermal insulation. The standard board has overall dimensions of 575 by 2400 mm with tongue and groove connection on all four sides [15].

a) **b)**

Figure 1 (a) Wind barrier during construction stage (b) overall view of the finished house (East and South façade).

The exterior surface of the house is 630 m² and contains 90 m² windows. Table 1 presents the length of the external joints. Normally, the joints between soft fibre boards are not sealed. However, to improve the airtightness of the wind barrier in this study, all the joints in this layer were sealed in between the different measurements. This allows assessing the leakage through the different joints and leads to an estimation of the maximum level of exterior airtightness, achievable with these boards.

The left hand side image of Figure 2 shows how the wind barrier is sealed on the windows and on the foundation. The image on the right hand side illustrates the sealed tongue and groove joints and the connections between adjacent walls. To ensure the durability of the tape on the external fibre board, a frost-free primer is applied to the joints before being sealed.



a) **b)**

Figure 2 (a) Wind barrier sealed to foundation and window (b) sealed connection between adjacent walls and sealed tongue and groove joint.

As shown in Figure 2b and 3a, the connection between the wall and the roof is of a continuous nature what makes this joint easy to seal with tape. The absence of a chimney and roof windows are other advantages of this specific case study regarding airtightness.

With the wind barrier totally sealed, the cellulose fibre insulation was blown in from inside through holes in the OSB. Figure 4b shows how in the last step the inflation holes and the tongue and groove connections were sealed at the inside.

a) b)

Figure 3. (a) Continuous connection between wall and roof (b) sealed tongue and groove connection between OSB and covered inflation holes

TABLE 1. Distribution of the joints in the wind barrier (m)

	North	South	West	East	Roof	Total
Wind barrier to window	32	68	17	15	-	132
Wind barrier to foundation	17	18	10	11	-	56
Wall-to-roof	23	24	10	11	-	67
Wall-to-wall[1]	-	15	-	-	-	32
Tongue and groove joint	243	206	48	48	448	993

In-situ pressurization test

Method and accuracy

Pressurisation tests have been conducted during the consecutive construction stages of the wind barrier, described above, to investigate the importance of the different leakage paths. With the straightforward technique of reductive sealing [13] the contributions of the different leakage paths through the building envelope can be examined. In total 12 tests have been performed in accordance to NBN EN 13829 [16]. A pressure difference from 25 Pa up to 70 Pa was realised across the building envelope in steps of 5 Pa. During this stepwise increase of the pressure difference, the air flow rate and associated pressure difference across the building envelope was measured. The data sets gained in this way are curve fitted to the power law [17]:

$$g_a = a\Delta P_a^b \tag{1}$$

where g_a (m³/h) refers to the airflow, ΔPa (Pa) stands for the pressure difference across the building envelope, a (m³/h/Pa) is the air permeance coefficient and b *(-)* the air permeance exponent of the specimen. The value of the

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[1] Most of the joints are located at the corners of the house. Consequently, they can not be assigned to an orientation of this table. Only the South façade contains wall-to-wall joints, as depicted in Figure 1.

permeance exponent indicates the type of flow and should be between 0.5 (corresponding to a perfect turbulent flow) and 1 (a perfect laminar one). The airtightness was both measured in over-pressure (OP) and under-pressure (UP), except for four measurements were lack of time impeded further measurements. In the remainder of this paper all air leakage rates will be expressed in term of n_{50}-values (1/h); the airflow rate calculated from Eq. (1), corresponding with 50 Pa divided by the total heated volume (1083 m³).

Measurement errors regarding fan pressurisation measurements can be divided in two subdivisions: (1) bias errors and (2) precision errors [18]. The former refers to systematic errors, such as recurring human errors and accuracy of the equipment. The latter indicates the reproducibility of measurements which can be estimated by the standard deviation of repeated measurements. All tests have been performed with the same Minneapolis BlowerDoor, Modell 4 DG-700. The accuracy of the used pressure gauge is +/- 1%. The volumetric air flow is derived from the measured pressure drop across a calibrated orifice. As a result the airflow is also determined with an accuracy of 1%. Because of the used orifice principle, the airflow rate needed to be corrected according to the inside and outside air density. The same person conducted with great care and under the same circumstances the measurements in order to reduce the precision errors. Measuring only at calm weather conditions- never exceeding 3 Beaufort- the influence of wind is minimised. In order to reduce the precision errors further, the software tool Tectite Express was used. This program, which allows an automatic run of the measurements, calculates the average of 100 air flow measurements in each pressure step. When the pressure varies with more than 2 Pa during this process, the measurements restarts in order to reduce disturbances by wind gusts. However, workmanship is the most decisive source of error in this experimental field situation. It can not be excluded that because of this, apart from planned improvements, other (small) leakages are created or sealed between the successive measuring steps. Therefore the total measuring error on the field tests is estimated to be less than 10%.

Test Results

This section discusses the results of the different pressurisation tests (Table 2). When the first measurement took place, at seven windows the joint between window and wall was already injected with PU-foam. This implies that there is no measured value available with only the wind barrier installed and none of the joints sealed. Nevertheless, this value can be derived from the measurement with only seven windows injected and the measured value with all windows injected, taking into account the length of the joints.

Comparing step 1, 2 and 3 leads to the conclusion that an injection of the joints between windows and walls with PU-foam has a large impact on the overall airtightness. However, the very labour-intensive external sealing of the windows to wind barrier does not contribute much to the airtightness of the house. The reason for this result is that at the time of the measurement the PU-foam was only recently been injected and acted temporarily as an airtight barrier. When PU-foam dries, it becomes more brittle and will probably crack in time due to small displacements of the house. Small cracks in the PU-foam would lead to a decreasing airtightness, justifying the extra sealing around the windows.

TABLE 2: Airtightness of the building envelope (n_{50} (1/h)) during different construction stages

	Construction stage	OP	UP	Average
step	Exterior			
1	Wind barrier installed[2]	3.38	3.37	**3.38**
2	PU-foam injected around doors and windows	0.98	0.94	**0.96**
3	Windows sealed to wind barrier	1.04	0.94	**0.99**
4	Wind barrier connected to foundation	-	1.16	**1.16**
5	Corner joints sealed[3]	-	0.79	**0.79**
6	North, West and South facade sealed[4]	-	0.83	**0.83**
7	Last corner joints from step 5 sealed	-	0.67	**0.67**
8	No improvements undertaken	0.46	0.46	**0.46**
9	East facade and the roof sealed	0.30	0.33	**0.32**
	Interior			
10	Cellulose fibre insulation inflated	0.20	0.20	**0.20**
11	Inflation holes sealed[5]	0.17	0.17	**0.17**
12	Finished state	0.14	0.14	**0.14**

In step 4, after connecting the wind barrier to the foundation, the averaged n_{50}-value surprisingly increased with 17%. This unexpected increase can most probably be attributed to the different weather conditions. Rain and higher outdoor humidity can influence the air permeability of the wind barrier board and might cause swelling of the

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[2] At the moment of the first measurement, already seven windows were injected with PU-foam. The value of step 1 is calculated from this situation bringing the length of PU-foam injected joints into account.

[3] All the corner joints of the wind barrier were sealed, except from 11m wall-to-roof joints.

[4] 496 m of 990 m joints.

[5] At this stage already many of the internal surface joints between the OSB-plates were sealed.

joints. To visualise this, Figure 5 plots the evolution of the airtightness against the daily horizontal precipitation (mm) and outdoor relative humidity (%). The averaged weather data were collected every 5 minutes from a 'Davis Vantage pro 2 station' located 3 km from the tested house.

Interestingly, the n_{50}-value has increased between step 3 and 4 and between step 5 and 6 (Figure 5). Furthermore, measurements 7 and 8 confirm the importance of the moisture content of the wind barrier on the airtightness. Both measurements were conducted in the same construction stage, with the weather being the only variable. Measurement 7 was performed on a sunny Friday afternoon, while measurement 8 was executed after that weekend on a rainy Monday morning. At this level of airtightness the increased moisture content of the wind barrier reduces the overall airtightness with more than 30%. To quantify the importance of the weather influences, additional air permeability tests of the wind barrier as function of the moisture content were performed in laboratory conditions. The results will be discussed in the following paragraph.

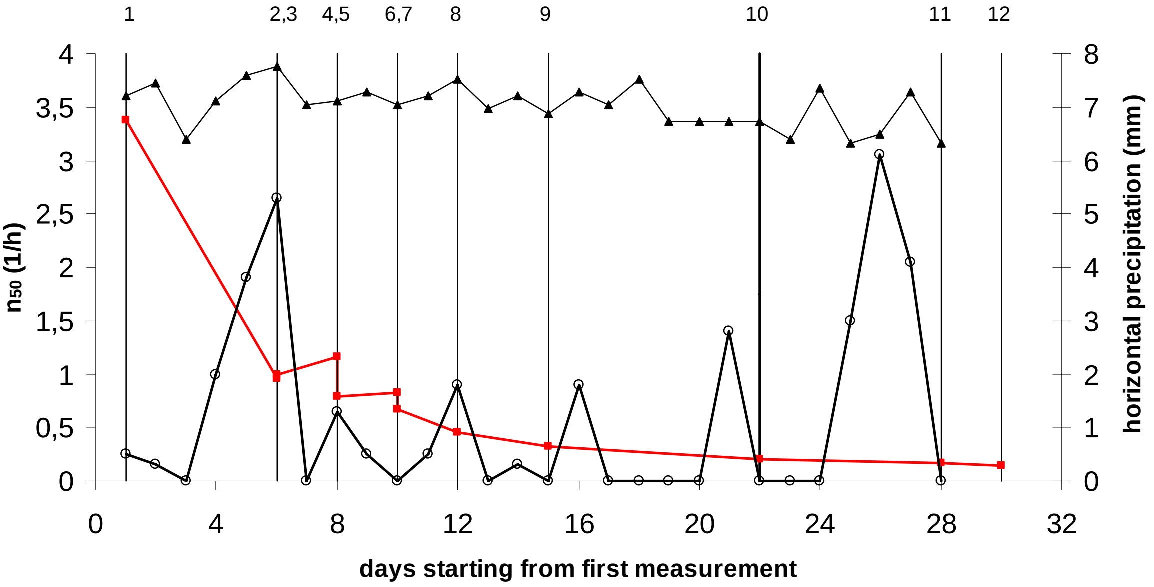
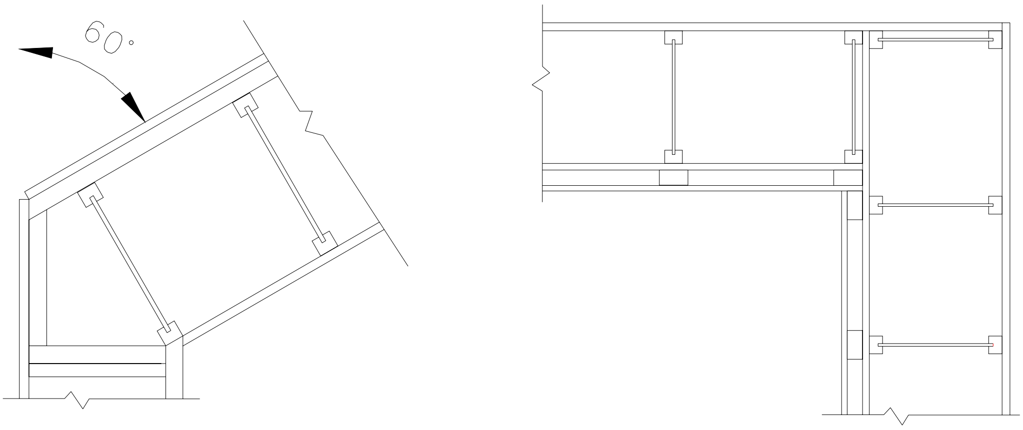


Figure 4 Evolution of the airtightness in the consecutive construction stages against the daily horizontal precipitation (mm) and relative humidity (%)

After connection the wind barrier to the foundation, the next step consisted of sealing all the wall-to-wall and roof-to-wall joints. Since there were only three scaffoldings this step was split up in step 5 and step 7. In between, the tongue and groove connection in the wind barrier in the North, West and South façade were sealed in step 6. In step 5 already 88 m of the corner joints were sealed and in step 7 the last 11 m were taped. The joints should be differentiated between the ones describing an angle of 30° (21 m) and those describing an angle of 90° (77 m). Less air will escape through the corners of 90°, as these joints have more contact and are supported over the entire length by studs (Figure 5).

As explained before, the step to investigate the influence of sealing the tongue and groove connections of the wind barrier is split up in step 6 and 9. Table 2 seems to indicate that sealing the joints in step 6 has no effect. This can be explained by the window and door flashings, being temporary nailed on the wind barrier during this part of the construction. To seal the joints under these flashings, the nails had to be removed, each time resulting in a small hole. It is very probable that the leakage through these holes is comparable with the effect of sealing the tongue and groove connection resulting in a zero operation. Just before the measurement of step 9 all these small gaps were filled with silicone. As a result, both the enhancements of sealing the tongue and groove joints in step 6 and 9 between the wind barrier boards are ascribed to step 9.



a)

b)

Figure 5 (a) Wall-to-roof connection (30°) of the wind barrier in the West and East façade (21 m) (b) connections between the walls (90°).

With the wind barrier totally sealed, the cellulose fibre insulation was blown in through the interior holes in the OSB. As loose fill insulation is far from airtight, it was not expected that this process would considerably improve the airtightness of the building envelope. The measurements indicate, nevertheless, that the influence of the insulation should not be neglected. The presence of the insulation increases the length of the leakage path and introduces an extra pressure drop in the wall. Bauwens [19] found similar results, where the influence of insulation between an intermediate floor in laboratory conditions was studied.

Step 11 corresponds to the situation where the interior inflation holes were sealed. It should be noted that, at the time of this measurement, due to practical reasons in some of the rooms the tongue and groove joints between the OSB were already sealed. The final test was performed a few months later than the previous test, after the whole building was finished. The final n_{50}-value of the passive house was 0.14 ACH 1/h.

The most significant leakages in the wind barrier are estimated in Table 3. Here, the leakage through the corner joints and the tongue and groove joints are straightforward deduced from the corresponding in situ tests, taking into account the length of the joints. For the leakage through the corners joints, both measurements were performed under the same weather circumstances. Therefore the deduced leakage is not influenced by the moisture content of the wind barrier. For the leakage through the tongue and groove connection on the other hand, the leakage is calculated from measurement 5 and 9. A small difference between weather conditions exist which might lead to an underestimation of the corresponding leakage. In addition to the estimated leakages, Table 3 includes also the man-hours spent for each enhancement.

TABLE 3: Air leakage through the different joints

	V_{50}, m³/h	Leakage at 50 Pa m³/h/m	Workmanship, manhours
Corner joints (90°)	243	3.1	3
Corner joints (30°)	330	15.7	1
Tongue and groove joints	342	0.4	56

Laboratory measurements

Method and accuracy

In addition to the *in situ* pressurisation tests on the entire building, laboratory measurements on specimens of the wind barrier, including the most significant joints were carried out. Two test-setups were designed to investigate the air permeability on material and assembly level.

The first test setup consisted of a metal frame box open at one side to measure specimens with a size of 0,27 by 0,27 m (figure 6a). This box is used to characterise the air permeance of the materials and the typical tongue and groove connections of the board products. The second apparatus was designed for specimens of 0,85 by 0,95m and allows to mount larger specimens and 3D-construction details in a test rim on the airtight box (figure 6b). This box is used to test the corner joints between the fibreboard at an angle of 90° (as in the wall junctions) and 30° (as in the wall to roof junctions). To avoid unwanted air leakages through the perimeter joints between specimen and airtight boxes, closed cell EPDM with a thickness of 2 cm on both sides of the specimen was used to seal the specimen airtight with a metal frame against the airtight box.

Figure 6 Laboratory test equipment to determine air permeability on material and assembly level.

After installing the specimen on the airtight box, under-pressure was created in the box. This resulted in an air flow passing through the specimen. For a stepwise increase of the pressure difference across the specimen, the air flow rate and associated pressure difference across the specimen were measured. The data sets gained in this way are curved fitted with Eq. (1). The airflow g_a (m³/m²/h) can also be written as an air permeance K_a multiplied by the pressure drop across the specimen ΔP_a. After recombination with Eq.(1), the air permeance K_a (m³/m²/h/Pa) is expressed as a function of the pressure drop across the specimen [20]:

$$g_a = K_a \Delta P_a \quad \text{with} \quad K_a = a \Delta P_a^{b-1} \tag{2}$$

The construction junctions are assumed to be a parallel circuit of air resistances. Hereby, the air permeance of a joint K_{joint} (m³/m/h/Pa) can be deduced from the measured air permeance of the specimen K_{spec}, given that the air permeance of the material K_{mat} (m³/m²/h/Pa) is known from test-setup 1 [21]:

$$K_{joint} = \frac{(K_{spec} - K_{mat}).A_{spec}}{l_{joint}} \quad (3)$$

In the remainder of this paper all permeability's were fitted with Eqn. (2) to determine the permeability at 50 Pa. This allows a direct comparison with the field measurements of the case-study.

For the small test setup a pressure gauge 4 DG-700, with an accuracy of 1% was applied. The flow rate was determined with a Vögtlin variable area flow meter. In a range from 0,02 m³/h to 0,900 m³/h the flow rate could be measured with an accuracy of 2%. The overall leakage of the test setup itself, including the ductwork connections, was estimated to be 0,0035 m³/h at 50 Pa[6]. The bigger test-setup also applied the same pressure gauge. Here, the flow rate was measured with an turbine flowmeter (Trigas FI) measuring in a range from 3,4 m³/h to 36 m³/h with an accuracy of 0,6%. The leakage of the bigger apparatus was 9,94 m³/h at 50 Pa[7]. Because of this significant leakage, each test was repeated covering the sample with plastic foil. The difference between both measurements, allowed the permeability of the samples to be calculated. Consequently, the fitting parameters *a* and *b* lose their meaning and are therefore excluded from table 4.

Test results

Table 4 lists the results for the air permeability of the used fibreboards in the case study and the corresponding joints which are depicted in figure 7. In addition to the used asphalted impregnated fibreboards (AIF^a), the same material was also measured (AIF^b), however without a top layer. Table 4 reveals that the asphalted impregnated fibreboard becomes twenty times more permeable without top layer. Furthermore, this table shows that the asphalted impregnated fibreboard (AIF^a) is five times more air permeable than the used OSB. It was also found that the air permeance of the tongue and groove connection between the plates of the AIF and the OSB are of the same order of magnitude, as long as they are perfectly installed. When the spacing between the boards increases due to bad workmanship, this influences most significantly the OSB. Furthermore, the corner joints of the wind barrier depend even more on the execution. Table 4 shows that the air permeance can vary with a factor up to 20 depending on the spacing between the boards.

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[6] Deduced from (1) with the corresponding parameters; a=0,000113 m³/h/Pa and b=0.88.

[7] Deduced from (1) with the corresponding parameters; a=0,55 m³/h/Pa and b=0.74

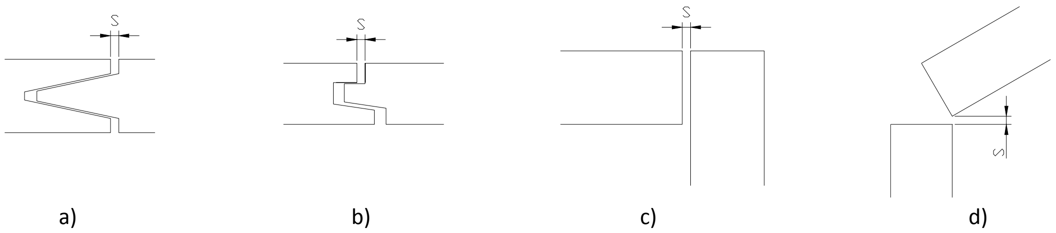

Figure 7 Geometry of the tested joints: (a) AIF tongue and groove joint, (b) OSB tongue and groove joint, (c) AIF corner joint (90°), (d) AIF corner joint (30°)

TABLE 4: Air permeance on material and assembly level (T=23°C, RH=50%)

material	**$K_{mat,50}$ $(m^3/m^2/h/Pa)$ (20°C, 54% RH)**	**a $(m^3/m^2/Pa)$**	**b (-)**
AIF[a]	0,005	0,005	0,99
AIF[b]	0,109	0,123	0,97
OSB	0,001	0,001	0,97
S (mm)	**$K_{joint,50}$ $(m^3/m/h/Pa)$ (20°C, 54% RH)**	**a $(m^3/m/Pa)$**	**b (-)**
	Tongue and groove joint: AIF		
0	0,0094	0,010	0,99
2	0,0184	0,022	0,96
4	0,0260	0,036	0,92
	Tongue and groove joint: OSB		
0	0,008	0,009	0,96
2	0,027	0,044	0,88
4	0,096	0,172	0,85
	Corner joint AIF: 90°		
0,5	0,013	-	-
2,5	0,116	-	-
4	0,222	-	-
	Corner joint AIF: 30°		
0,5	0,270	-	-
2,5	0,755	-	-

Air permeability as function of the moisture content

From figure 4 it is clear that the influence of the weather on the permeance of the wind barrier should be considered. To investigate the importance of the moisture content of the wind barrier, this study performed two additional laboratory test series with the small apparatus, examining the air permeability of the material and tongue and groove joints as function of the moisture content. Prior to the air permeability test, the specimens were conditioned to constant moisture content: first a known water volume was applied to each specimen and secondly the specimens, wrapped in plastic foil, were stored for 4 weeks. The analysis made use of three samples of 0.35 by 0.35m for the investigation on material level. Figure 8 plots the results from these tests. This figure shows that in equilibrium conditions the air permeability of the AIF is not affected by its moisture content in this range.

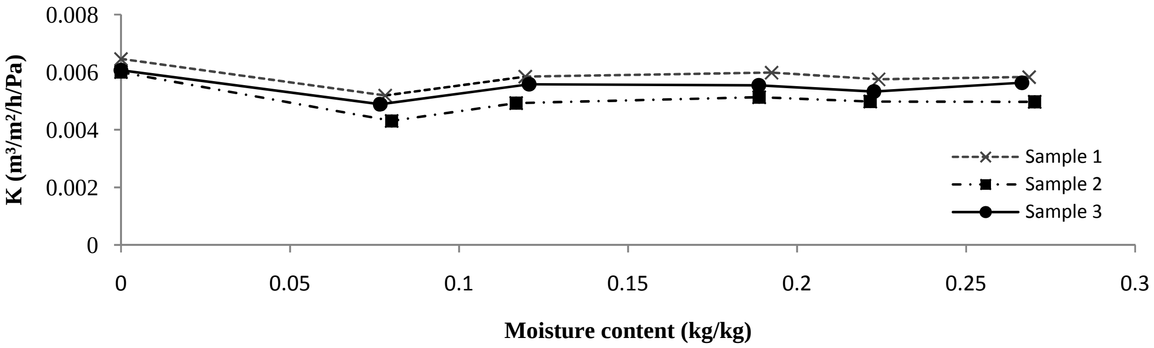

Figure 8 Wind barrier board as function of the moisture content (in equilibrium)

When the *in situ* measurements were performed, the moisture content of the wind barrier can not be in equilibrium with the fluctuating outdoor relative humidity. During or short after a period of rain, water will be drained from the wind barrier. To simulate this effect in laboratory conditions, the specimens were sprayed on the top layer until water starts to drain. Both, immediately after this wetting process and 30 minutes later, the permeability was measured. For all three samples the permeability, straight after wetting was reduced within a range from 51-58% compared to the dry situation. However, after 30 minutes, the permeance reached again 91-96% of the level in dry conditions. From this we can conclude that permeability at material level is rather independent of moisture content. Only short after wetting the board, the influence should be considered.

In addition also the behaviour of the tongue and groove joint was studied. Four specimens of the wind barrier with a tongue groove joint were mounted on a plastic frame. The specimens were only fixed parallel to the joints, to assure the joints' possibility to swell. Three of the joints were attached perfectly and one was fixed creating a joint of 2mm. The same wetting procedure as described above was applied to condition the specimens. Figure 9 depicts the results from the tests with the moisture content in equilibrium. It appears that only the joint of 2 mm was significantly influenced by the moisture content of the boards.

In a second step, the specimens were sprayed with water and measured. This showed that the permeability of the joints was affected with less than 5%, both immediately after and 30 minutes after the specimens were sprayed. Hence, we conclude that the air permeance of the joints is only significantly affected by its moisture content, if the joints do not perfectly fit due to bad workmanship.

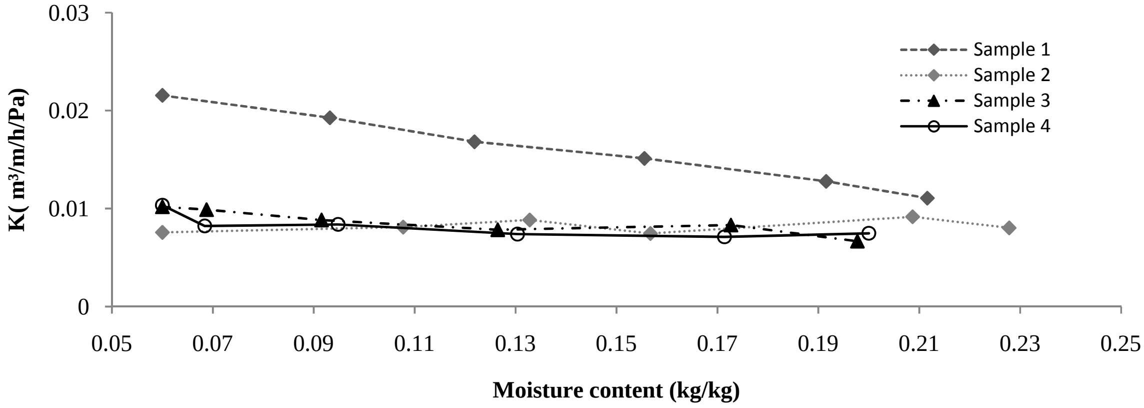

Figure 9 Tongue and groove joints through the wind barrier as function of the moisture content (in equilibrium)

Comparison laboratory and on site measurements

This section compares the results of the laboratory measurements of table 4 to the field data in order to verify how accurate the n_{50}-value can be predicted from laboratory tests (table 5). In this table the air permeability of the asphalted impregnated fibreboard obtained from the field data ($g_{50,house}$ = 0,6 m³/m²/h) is deduced from the situation where all the joints of the wind barrier were sealed. From the comparison with laboratory tests, it appears that this value is too high which can be ascribed to unforeseen leakage paths. This reveals that even when the wind barrier is sealed with great care it is impossible to avoid unexpected air leakages.

TABLE 5: Comparison between the leakage in laboratory and on site conditions

	$g_{50,house}$ (m³/m²/h)	$V_{50,house}$ (m³/h)	$g_{50,lab}$ (m³/m²/h)	$V_{50,lab}$ (m³/h)
asphalted impregnated fibreboard	0,6	341	0,19-0,26	102-156
tongue and groove connection AIF	0,4	342	0,47 - 1,30	465 -1287
corner joints (90°)	3,1	243	0,63 -11,09	49 – 865
corner joints (30°)	15,7	330	13,51 - 37,75	284 – 793

Given the uncertainties on the field tests, the *in situ* leakage through the tongue and groove connection between the wind barrier board corresponds relativity good with the lower limit found from the laboratory tests. This was expected since the distance between the tongue and groove joints was minor, corresponding with the lower limit from the laboratory tests. The *in situ* measured leakage through the corners joints lies between the upper and lower limit determined in the laboratory. However, it is very difficult to predict the real leakage from laboratory tests since the range between the upper and lower limit is too large.

Discussion

The results from the case study show that without any major effort, an overall airtightness lower than 1 ach at 50 Pa can be reached. The joints between adjacent walls and between the walls and the roof appear to be the most significant (3.1-15.7 at 50 Pa). It was found that by sealing only these joints, the n_{50}-value decreases by 0.5 1/h for this case study. Sealing all the exterior joints, an n_{50} value of 0.32 1/h at 50 Pa was measured, which meets the 'Passive House' and 'Minenergy' standard of 0.6 1/h at 50 Pa. Furthermore, the effect of the loose fill insulation on the airtightness should be considered. Even at a relatively high level of airtightness, the presence of the insulation decreases the n_{50} value by 0.13 1/h at 50 Pa. The final n_{50}-value was 0.14 ach 1/h, when the interior lining was also sealed.

Laboratory measurements on specimens of the wind barrier classify the different leakage in the same order of importance. However, a direct comparison of the *in situ* and laboratory measurements leads to the conclusion that laboratory tests are only suitable to predict the lower limit of the overall airtightness of buildings. Air leakages depend to a very high degree on the craftsmanship. Consequently, the uncertainty on a single leakage becomes too large to derive n_{50}-value of buildings from their summation. On the other hand, it should be noted that laboratory measurements regarding air permeability are useful to compare different solution techniques.

It was observed that the air permeability of the wind barrier is influenced by its moisture content. At the time the pressurization tests were conducted, the wind barrier was not protected by any cladding or tiles, resulting in rain directly wetting the boards. Laboratory measurements reveal that this influence is a result of the decreasing air permeance of the wind barrier boards during, or short after, a rain shower. In contrast, higher overall moisture contents in equilibrium conditions did not affect the permeability of the board material, nor of the tongue and groove joints. In this study this phenomenon influenced the n_{50} value by more than 30%. At high levels of airtightness this can determine whether the building exceeds the threshold of 0.6 ACH at 50 Pa. Therefore, when pressurization tests are performed at the windtight stage, it is recommended to measure at dry weather conditions.

For this case-study sealing the wind barrier was still time-consuming, however. To ensure durability of the tape, prior to the sealing a frost-free primer was applied. As a result every exterior joint required double work. Nevertheless, we conclude that this technique has prospects to reduce labor costs in that, for example, the production process of boards can already provide the frost-free primer. Furthermore, exterior airtightness allows using boards with larger dimensions, which reduces the length of the joints. Finally, this solution is suitable for prefabrication of building components.

An improved airtightness of the wind barrier will reduce the risk of interstial condensation as a result of the decrease of forced exfiltration through the building envelope. Moreover, the question rise whether the interior air barrier is still required if the wind barrier is sufficiently airtight. Moving the air barrier to the exterior of light weight construction will influence the hygrothermal behaviour. Hence, before this technique can be applied in practice, further research is essential to investigate its hygrothermal consequences.

Conclusion

This paper investigates the air permeability of a wind barrier for the construction of a recent passive house in Ghent, Belgium. The impact of the different leakage paths is deduced from 12 pressurisation tests, conducted during consecutive construction stages of the building envelope.

In Europe, it is common practice for low energy and passive houses to rely on the air resistance of the interior lining. In contrast, this study shows the significant contribution of a wind barrier to the overall airtightness. The case study demonstrates that with good workmanship and appropriate materials, an airtightness level lower than 1 ach at 50 Pa can be reached. For the current wind barrier, the joints between adjacent walls and between the roof and walls were found to be the most critical. Sealing only these connections led to a level of airtightness which fulfils the requirements of the ‘Passive House’ standard (< 0.6 ACH at 50 Pa). Additional laboratory tests revealed that the permeance of the wind barrier can be significantly affected by rain. Thus, the research’s recommendations are to only perform pressurization tests under dry weather circumstances when measuring the windtight stage. Finally, the results presented in this paper indicate the proposed solution can potentially reduce labour costs required to reach sufficient airtightness.

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