Feasibility of Using Wind Barriers as Air Barriers in Wood Frame Construction

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ABSTRACT

Airtightness of building envelopes is one of the most important properties of low-energy buildings. For lightweight construction, an airtight building envelope is commonly realized by an interior air- and vapor-tight barrier. Realizing an interior air barrier is, however, often labor intensive due to many internal joints and potential penetrations for electrical and plumbing services.

Based on recent improvements to the airtightness of wind barriers, the idea arose to move the air barrier to the outside of the building envelope. Moving the airtight layer to the outside of the building envelope means fewer joints and less risk for penetrations.

This paper investigates the air permeability of a wind barrier during consecutive construction stages of a wood-frame passive house located in Belgium. The wind barrier consists of asphalt-impregnated fiberboard. Measurements were taken before and after sealing the joints in this exterior layer. In total, 12 pressurization tests were carried out. The results reveal that by sealing only the most critical joints of this outer shell, a sufficient level of airtightness can be achieved. The proposed solution may therefore have significant potential to reduce labor costs for airtightness in low-energy buildings.

INTRODUCTION

Due to the growing concerns of global warming, energy consumption, and sustainability, considerable progress has been made in the last decades to make buildings more energy efficient. Apart from sufficient thermal resistance, good overall airtightness of the building envelope is a prerequisite to realize a low-energy or passive building (Wouters and Carrié 2008; Jokisalo et al. 2009; Bankvall 2007; Feist et al. 2005). As a result, higher recommendations and standards have been introduced in Europe regarding airtightness, such as an n_{50}-value of 1 1/h for buildings with heat recovery systems and 0.6 1/h for passive houses. Consequently, pressurization tests have become more and more common practice to measure the level of airtightness of newly erected buildings.

In cold and moderate climates, an airtight building envelope in lightweight constructions is commonly realized by a continuous interior air- and vapor-tight barrier. Realizing an interior air barrier that fulfills the stricter requirements is, however, very labor intensive due to many internal joints, such as interior walls and intermediate floors, and perforations necessary for electrical and plumbing devices (Kalamees 2007; Aho et al. 2008; Sandberg and Sikander 2005).

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 a 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 (Janssens and Hens 2007). Therefore, the joints in the wind barrier are usually left unsealed.

As a result of the recent improvements of the airtightness of wind barriers—mainly to avoid windwashing and unwanted airflows in the insulation layer—pressurization tests have shown that wind barriers can have a significant impact on airtightness in timber-frame buildings. Compared

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to the interior air- and vapor-tight barrier, the wind barrier shows fewer joints and perforations. Since pressurization tests are only performed at the end of the construction phase, little information is found in the literature that allows further quantification of the importance of the wind barrier on the overall airtightness. Myhre and Tormod (2004) performed pressurization tests on three wood-frame buildings after a spun-bonded wind barrier was installed as well as when the interior air barrier was installed. With only minor modifications of the wind barrier connections, the airtightness in the windtight stage was lower than 1.5 air changes per hour (ach) at 50 Pa in all three cases. After installing the interior air barrier, the level of airtightness did not significantly improve. Consequently, the authors emphasize the potential for using wind barriers to decrease the air leakage in low-energy wood-frame buildings.

In the current paper, the feasibility of an exterior air barrier is investigated for a recently built passive house in Ghent, Belgium. Pressurization tests were conducted during the various construction stages of the building envelope. The results are discussed in this paper. With the straightforward technique of reductive sealing, described by Liddament (1996), the contributions of the different leakage paths through the building envelope are examined.

DESCRIPTION OF THE 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 guest rooms on the ground floor. Figure 1 shows an overall view of the project. The heated volume of the house is 1083 m^3 (38246 ft^3). The house has a lightweight timber frame construction with I-profile wood studs between the internal oriented strand board (OSB) (15 mm [0.59 in.]) and external asphalt-impregnated fiberboard (18 mm [0.71 in.]). The studs are spaced at 400 mm (1.31 ft) and the space in between is filled with blown in cellulose fiber insulation. Apart from its structural purpose, the internal OSB plates act as a vapor retarder. Traditionally, the air barrier is created by sealing the internal tongue-and-groove connections between the plates, which have overall dimensions of 575 × 2400 mm^2 (1.87 × 7.87 ft^2). The air permeability of the OSB, which has been determined on three specimens of 30 × 30 cm^2 (0.98 × 0.98 ft^2), is 0.0012 $m^3/m^2/h/Pa$ (6.56 10^{-05} $cfm/ft^2/Pa$). To avoid ductwork penetrations through this layer, a service zone of 50 mm (0.16 ft) is provided to install the electrical and plumbing devices. This cavity is filled with flax fiber insulation and covered with gypsum-cellulose sheathing at the interior.

The wind barrier, consisting of asphalt-impregnated fiberboard, has a special watertight bitumen impregnated layer on the exterior face, which makes a significant contribution to the airtightness of the material. The air permeability of this soft fiberboard, which has been determined on four specimens of 30 × 30 cm^2 (0.98 × 0.98 ft^2), is 0.0051 $m^3/m^2/h/Pa$ (2.78 10^{-04} $cfm/ft^2/Pa$). Notwithstanding this high air resistance, the boards have a high vapor permeability (sd-value of 0.27 m (12 perm) at 30% RH and 0.14 m (24 perm) at 80% RH), which makes them applicable as breather membranes on the outside of thermal insulation. The standard board has overall dimensions of 575 × 2400 mm^2 (1.87 × 7.87 ft^2) with tongue and groove profiles on all four sides.

The exterior surface of the house is 630 m^2 (6781 ft^3) and contains 90 m^2 (969 ft^2) windows. It should be noted that the tested house did not contain a chimney or skylights. The lengths of the external joints are presented in Table 1. Normally, these joints between soft fiberboards are left unsealed. However, to improve the airtightness of the wind barrier in this study, all the joints in this layer were sealed before each subsequent measurement. This allows assessment

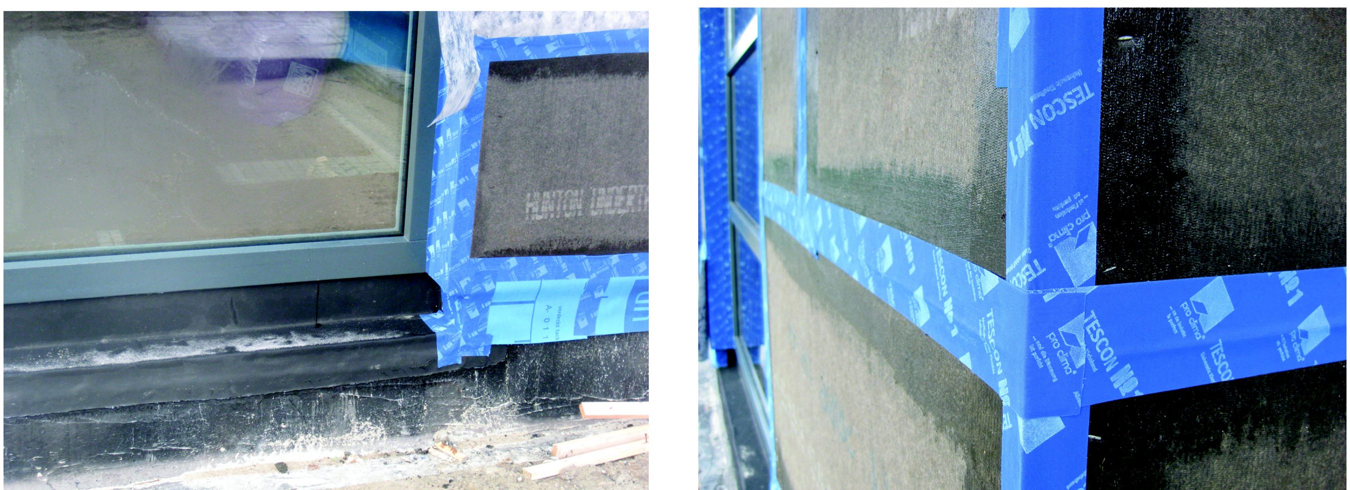
(a) (b)

Figure 1 *(a) Wind barrier during construction stage and (b) overall view of the finished house (west and south façades).*

Table 1. Distribution of the Joints in the Wind Barrier in m (ft)

	North	South	West	East	Roof	Total
Wind barrier to window	32 (105)	68 (223)	17 (56)	15 (49)	—	132 (433)
Wind barrier to foundation	17 (56)	18 (59)	10 (33)	11 (36)	—	56 (184)
Wall-to-roof	23 (76)	24 (79)	10 (33)	11 (36)	—	67 (220)
Wall-to-wall*	—	15 (49)	—	—	—	32 (105)
Tongue-and-groove joint	243 (797)	206 (676)	48 (158)	48 (158)	448 (1470)	993 (3258)

* Most of the joints are located at the corners of the house. Consequently, they cannot be assigned to an orientation in this table. Only the south façade contains wall-to-wall joints, as depicted in Figures 1a and 1b.



(a) (b)

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

of the leakage through the different joints and estimates the maximum level of exterior airtightness achievable by using these boards.

Figure 2a shows how the wind barrier is sealed at the windows and at the foundation. Figure 2b illustrates the sealed tongue-and-groove joints and the connections between two walls. To ensure adhesion of the tape on the external fiberboard, a frost-free primer is applied to the joints before sealing.

As shown in Figure 3, the connection between the wall and the roof is continuous, which makes the sealing of this joint relatively easy. When the wind barrier joints were completely sealed, the cellulose insulation was blown from the inside through holes in the OSB.

The hygrothermal effect of using an exterior air barrier in cold and moderate climates is as yet unstudied. Therefore, out of precaution, it was decided to create an interior air barrier by sealing all the interior joints. Figure 3b shows how in the last step the inflation holes and the tongue-and-groove connections were sealed along the interior. In addition, this provides the opportunity to compare the airtightness of the exterior barrier to the traditional interior air barrier.

TEST RESULTS

To investigate the importance of the different leakage paths, pressurization tests were conducted in accordance with NBN EN 13829 (IBN 2001) during the consecutive construction stages of the wind barrier. Since the differences in airtightness between the different construction stages are expected to be small, the measurements were conducted with great care by the same person and under the same circumstances in order to achieve more consistency. In all tests, the same Minneapolis BlowerDoor, Model 4, with DG-700 was used.

A pressure difference from 25 Pa up to 70 Pa was realized across the building envelope in steps of 5 Pa. During this stepwise increase of the pressure difference, the airflow rate and associated pressure difference across the building envelope were measured. The data sets gained in this way are curve fitted to the power law (Etheridge and Sandberg 1996):

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

where g_a (m^3/h) refers to the airflow, ΔPa (Pa) stands for the pressure difference across the building envelope, a (m^3/h/Pa) is the air permeance coefficient, and b (dimensionless) is the air permeance exponent of the specimen. The airtightness was measured in both over-pressure (OP) and under-pressure (UP), except for four measurements where 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 Equation 1, corresponding with 50 Pa divided by the total heated volume (1083 m^3). The results of the pressurization tests are detailed in Table 2.

When the first measurement took place, after installation of the wind barrier, the joints between windows and walls were

(a) (b)

Figure 3 *(a) Connections between wall and roof during sealing phase and (b) sealed tongue-and-groove connection between OSB and sealed inflation holes.*

Table 2. Airtightness of the Building Envelope during Different Construction Stages

Step	Construction Stage	OP, n_{50},1/h	UP, n_{50},1/h	Average, n_{50},1/h
	Exterior			
1	Wind barrier installed*	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†	—	0.79	0.79
6	North, West and South facade sealed‡	—	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 fiber insulation installed	0.20	0.20	0.20
11	Inflation holes sealed**	0.17	0.17	0.17
12	Finished state	0.14	0.14	0.14

* At the moment of the first measurement, seven window joints were injected with polyurethane (PU) foam. The value of step 1 is calculated from this measurement taking into account the length of PU foam injected into the joints.
† All the corner joints of the wind barrier were sealed, except for 11 m (36 ft) wall-to-roof joints.
‡ 496 m (1627 ft) of 990 m (3248 ft) joints.
** At this stage, some of the internal surface joints between the OSB plates were sealed.

already injected with polyurethane (PU) foam at seven windows. This implies that there is no measured value available with only the wind barrier installed and none of the joints sealed. Nevertheless, as will be shown later, 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. In step 3, all window and door joints were sealed onto the wind barrier (Figure 2a).

In step 4, the wind barrier was connected to the foundation. The next step consisted of sealing all the wall-to-wall and roof-to-wall joints. Since there were only three scaffolds on-site, this step was split into steps 5 and 7. In between, the tongue-and-groove connections in the wind barrier on the north, west, and south façades were sealed. In step 5, already 88 m of the joints were sealed and in step 7 the last 11 m (36 ft) were taped. These corner joints should be differentiated between the ones that describe an angle of 30° (21 m [69 ft]) and the joint that describes an angle of 90° (77 m [253 ft]). Unsealed, less air will escape through the corners of the 90° angle since these joints have more contact and are supported over the entire length by the studs, as depicted in Figure 4.

After step 7, the measurement was repeated within the same construction stage. The only difference between steps 7 and 8 are the weather conditions. Measurement 7 was taken on a sunny afternoon, while measurement 8 was executed the next workday when it was raining.

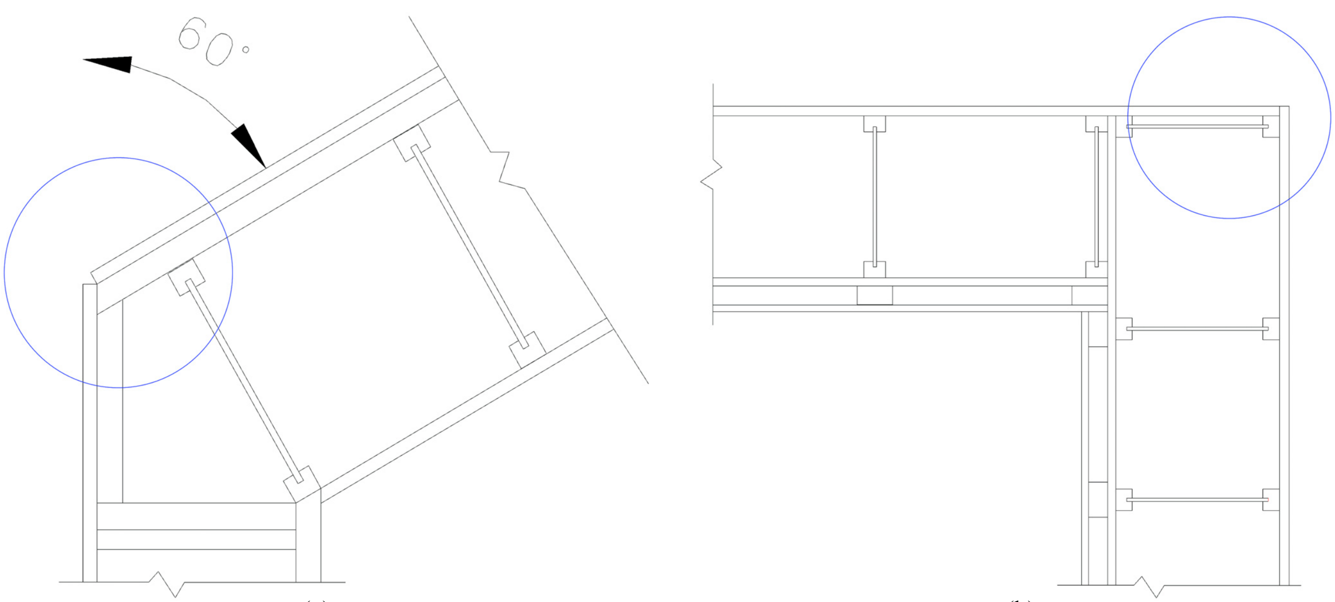
The step to investigate the influence of sealing the tongue-and-groove connections of the wind barrier was split into steps 6 and 9. During the construction, the window and door flashings were temporary nailed onto the wind barrier. To seal the tongue-and-groove joints under these flashings, the nails had to be removed, each time resulting in a small hole. Prior to measurement 9, all these small gaps were filled with silicone. Therefore, the benefits of the sealed tongue-and-groove joints between the wind barrier boards in step 6 are only visible at measurement 9.

After the wind barrier was completely sealed, the cellulose fiber insulation was blown through the interior holes in the OSB corresponding to measurement 10. The next measurement was performed when the interior inflation holes were sealed. It should be mentioned that due to practical reasons, at the time of this measurement, also the tongue-and-groove joints between the OSB were already sealed in some of the rooms. The final test, when the whole building was finished, was performed a few months later. The final n_{50}-value of the passive house, when all the interior joints were sealed, was 0.14 ach 1/h.

ANALYSIS

Comparing steps 1, 2, and 3, it can be concluded that injecting the joints between windows and walls with PU foam has a large impact, while the very labor-intensive external sealing of the windows-to-wind-barrier does not contribute to the overall airtightness of the house.

After connecting the wind barrier to the foundation in step 4, the averaged n_{50}-value surprisingly increased by 17%. This unexpected increase can most probably be attributed to the different weather conditions. At the time the pressurization tests were conducted, the wind barrier boards were



(a) (b)

Figure 4 *(a) Wall-to-roof connection (30°) of the wind barrier in the west and east façades (21 m [69 ft]) and (b) connections between the walls (90°).*

not protected by any exterior cladding. Consequently, rain could have been absorbed by the wind barrier, affecting its airtightness.

To visualize the influence mentioned above, the evolution of the airtightness is plotted against the daily horizontal precipitation (mm) and the daily outdoor relative humidity (%) in Figure 5. The measurements were performed during the winter, corresponding to high outdoor relative humidities (75%–98%). These averaged weather data were collected every 5 minutes from a Davis Vantage pro 2 station located 3 km from the tested house.

It can be seen that although increased air sealing improvements were completed at each stage, the n_{50}-value increased between steps 3 and 4 and between steps 5 and 6. Those results can be attributed to the corresponding drying of the wind barrier during these steps. Furthermore, the importance of the moisture content of the wind barrier on the airtightness is confirmed by measurements 7 and 8. Both measurements were conducted in the same construction stage, with the weather being the only variable. At this level of airtightness the increased moisture content of the wind barrier reduces the overall airtightness by more than 30%.

When all the exterior joints were sealed in step 9, an n_{50}-value of 0.32 1/h was measured. Hypothetically, if all exterior joints were perfectly sealed, one would expect, based on the air permeability of the wind barrier boards and exterior surface, an n_{50}-value of 0.12 1/h. It is interesting to note that, despite the joints having been carefully sealed, more than 60% of the air leakage is through unforeseen leakage paths.

After the wind barrier was completely sealed, the cellulose insulation was blown through the interior holes in the OSB. Although the air permeability of cellulose insulation (Yarbrough and Wudhapitak 1992) is four orders of magnitude larger compared to the permeability of the wind barrier boards, a considerable influence was measured. The n_{50}-value decreased from 0.32 to 0.20 1/h. In theory, the overall airtightness of a building component is determined by the most airtight layer in a series. In contrast, since real building envelopes always contain three-dimensional air leakage paths, the presence of insulation increases the length and tortuosity of these paths, resulting in an extra pressure drop in the wall. Similar results were found by Bauwens (2009), where the influence of insulation between an intermediate floor in laboratory conditions was studied.

Although a very high level of airtightness was achieved with the exterior barrier, it was decided that an interior air barrier would be provided as well. As previously mentioned, the hygrothermal effect of building envelopes with only an exterior air barrier in cold and moderate climates is as yet unstudied. The interior air barrier was realized by sealing all the tongue-and-groove joints along the OSB and connecting the foils provided around the interior wall and intermediate floor junctions. The final airtightness of the house was 0.14 1/h. From this we conclude that the level of airtightness achievable with an exterior sheathing membrane is comparable with that achieved with an interior air barrier.

Deduced from the pressurization tests, the most significant leakages are estimated in Table 3. As previously noted, when the first measurement took place, already 7 windows were injected with PU foam (64 m [210 ft]). Therefore, the leakage through the connection between the wind barrier and the windows given in Table 3 is deduced from measurements 1 and 2, taking the length of the injected joints between these measurements (68 m [223 ft]) into account. As can be derived

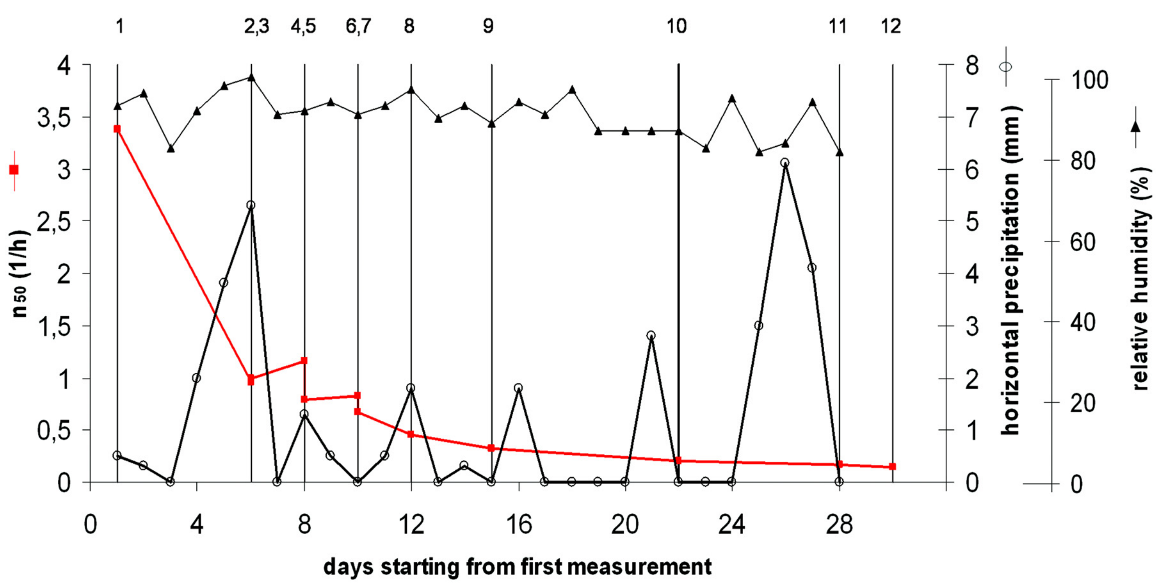


Figure 5 *Evolution of the airtightness in the consecutive construction stages (corresponding with Table 2) against the daily horizontal precipitation (mm) and relative humidity (%).*

Table 3. Air Leakage through the Different Joints

	V_{50}, m^3/h (cfm)	Leakage at 50 Pa, $m^3/h/m$ (cfm/ft)	Workmanship, manhours
Wind barrier to window	2615 (1540)	0.4 (0.07)	21
Corner joints (90°)	243 (143)	3.1 (0.55)	3
Corner joints (30°)	330 (194)	15.7 (2.82)	1
Tongue-and-groove joints	342 (201)	0.4 (0.07)	56

from Figure 5, this is most probably a small overestimation due to the increasing moisture content of the wind barrier during this period.

Because the weather influence on the leakage through the joints between the wind barrier and the foundation is relatively high, it was impossible to derive the leakage of this joint. Therefore, this joint could not be included in Table 3.

The calculation of the corner joints leakage is not disturbed by the weather. The leakages are straightforwardly deduced from steps 4 and 5 and from step 6 and 7, taking into account the length of the joints as described previously.

As mentioned, the leakage through the tongue-and-groove joints in Table 3 is immediately calculated from the combined values obtained in steps 6 and 9.

In addition to the estimated leakages, Table 3 also includes the man-hours spent for each enhancement.

DISCUSSION

Traditionally, the airtightness in wood-frame passive houses in Belgium is realized by sealing the joints of the interior structural boards. However, new building materials make it possible to improve the airtightness of the wind barrier. To investigate the prospects of using wind barriers as air barriers, in total 12 pressurization tests were performed during the construction of a passive house. Measurements were carried out before and after all joints in the wind barrier were sealed to quantify the impact of the different air leakages sites. The results show that without any major effort, an overall airtightness lower than 1 ach at 50 Pa was achieved. The joints between adjacent walls and between the walls and the roof appear to be the most significant (3.1–15.7 $m^3/h/m$ (0.55–2.82 cfm/ft at 50 Pa). It was determined that by sealing only these joints, the n_{50}-value decreased by 0.5 1/h for this case study. By sealing all the exterior joints, an n_{50}-value of 0.32 1/h was measured, which fulfills the passive house standard of 0.6 1/h at 50 Pa. Furthermore, the effect of the loose fill insulation on the airtightness should not be neglected. Even at the current level of airtightness, the presence of the blown-in insulation decreased the n_{50}-value by 0.13 1/h at 50 Pa. The final n_{50}-value, with the interior lining sealed, was 0.14 1/h.

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 boards were not protected by any exterior cladding. As a result, rain could be absorbed, increasing the airtightness of the wind barrier. 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 needed to meet the passive house standard. Therefore, when analyzing pressurization tests performed at the windtight stage, it is recommended that weather conditions be considered.

It should be noted that the results reported in this work correspond to only one building. To increase the reliability of the findings, additional testing is required. To substitute for these expensive tests, the assessment of the air permeability of the different joints and the influence of the moisture content can also be studied in laboratory conditions. Preliminary results of the laboratory test measurements, related to this case study, can be found in (Langmans et al. 2009).

For this case study, sealing the wind barrier was time-consuming. 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 primer. Furthermore, exterior airtightness allows using boards with larger dimensions, which reduces the length of joints. Finally, this solution is suitable for prefabrication of building components.

Improved airtightness of the wind barrier will reduce the risk for interstitial condensation as a result of the decrease of forced exfiltration through the building envelope. It can be questioned whether the interior air barrier is still required when the wind barrier is sufficiently airtight. Further research is necessary to investigate the hygrothermal impacts of moving the air barrier to the exterior of lightweight constructions.

CONCLUSION

This paper investigates the air permeability of a wind barrier for the recent construction of a passive house in Ghent, Belgium. The wind barrier consists of asphalt-impregnated fiberboard. The impact of the different leakage paths is deduced from 12 pressurization 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 wind barrier can have a significant airtightness. The case study demonstrates that with good workmanship and appropriate materials, an exterior airtightness lower than 1 ach at 50 Pa can be reached without major additional effort. For the wind barrier in this instance, the joints between the adjacent walls and between the roof and walls are the most critical. Sealing only these connections already led to a level of airtightness that fulfils the requirements of the passive house standard (< 0.6 ach at 50 Pa).

It was found that the air leakage through the tongue-and-groove connection between the soft fiber wind barrier board depends to a high degree on the moisture content. Therefore, when analyzing pressurization tests performed at the windtight stage, it is recommended that weather conditions be considered.

The results presented in this paper indicate that the proposed solution has potential to reduce labor costs required to reach sufficient airtightness.

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