Laboratory investigation on the durability of taped joints in exterior air barrier applications

Jelle Langmans[*1], Tadiwos Zerihun Desta[2], Lieven Alderweireldt[2] and Staf Roels[1]

[1] Department of Civil Engineering
Building Physics Section, University of Leuven
Kasteelpark Arenberg 40 – bus 02447
BE-3001, Heverlee, Belgium
**Corresponding author:*
jelle.langmans@bwk.kuleuven.be

[2] Redco nv
Kuiermansstraat 1
B-1880 Kapelle-op-den-Bos, Belgium

ABSTRACT

In timber frame construction in Europe air barrier systems are typically realised at the interior side of the building envelope. Yet in some applications such as renovation projects it can be easier to provide the air barrier layer at the exterior. This way, the air barrier system – typically board materials in which the joints are sealed with tape – is exposed to outdoor weather conditions. The aim of the present article is to investigate the impact severe climatic conditions on the airtightness of typical taped joints. The airtightness of thirty two wood-fibre cement board samples have been investigated. Each specimen has a 2mm wide joint. Two different kinds of commercially available tapes were used to seal the joints. Airtightness of all specimen has been tested before and after accelerated aging procedures that mimics real exterior climate conditions. Three different aging protocols were selected: 1) temperature cycles, 2) temperature, rain and frost cycles and 3) UV exposure under high humid conditions. For the first two test conditions, the specimens had a size of 0.71m by 0.71m. Due to sample size restrictions of the UV exposure cabin, the specimens of the third test run were smaller (0.35m by 0.35m). All specimens had thickness of 12mm. The present paper will discuss the durability of the two tapes by comparing the air permeability of the specimens before and after the three accelerated aging exposures.

KEYWORDS

durability, airtightness, tapes, exterior air barrier

1 INTRODUCTION

Robust air barrier systems are one of the prerequisites to achieve energy efficient buildings. In light weight construction, the air barrier layer is commonly positioned close to the interior finish. This layer often also incorporates the vapour barrier functionality. Contrary to the popular practice, in some projects (e.g. renovations) it can be easier and faster to place the air barrier layer at the exterior side of the building envelope (Langmans et al. 2010). This implicates that the taped joints are exposed to outside environmental conditions. Especially during the construction phase when the air barrier layer gets the least protection, these taped joints need to withstand high levels of temperature, humidity and UV radiation.
The available international literature regarding building airtightness durability is very limited. Few studies report variations in the global building airtightness within a time interval of several months or years. Bracke et al. (2013) showed a reasonably stable overall air leakage

level for buildings with a high level of airtightness. In contrast, others reported significant deviations from the original value with the building ages (Hansén, 2012), or seasons (Borsboom and de Gids (2012) and Kim et al. (1986)). However, these studies evaluated the global building airtightness and do not provide detailed information regarding the key parameters influencing airtightness durability. To the authors knowledge only two studies have been investigating the durability of tapes used for building airtightness applications. Both Ackermann (2012) and Gross & Maas (2011) developed a method based on the 180° peel test according to BS EN 1939:1997[1]. This standard is used to investigate the peel adhesion of self-adhesive tapes. The prepared specimen are loaded into a tensile testing machine in which the tape is peeled from the substrate in a 180° direction. This test essentially provides information on the adhesion strength of the taped connection.
Gross & Maas (2011) studied the peel force for several tapes and substrate materials (foils, wood and fibre cement boards). Before the peel test, artificial aging of the specimen was established by pre-conditioning the samples at a temperature of 65°C and 80% relative humidity. Their results clearly show that the level of peel force depends on the substrate and the curing time of the adhesive. Moreover it is shown that the stress resistance of the adhesives in combination with a PE foil is significantly lower than with other bonding materials. Gross & Maas (2011) also showed that solvent-free adhesives correspond to higher values in peel force. In addition, the authors remarkably noted that with progressive accelerated aging, the majority of the adhesives analysed show an increased peel force.
The second study in this kind was performed by Ackermann (2007,2012) at FIW in Munich.
Similar to Gross & Maas (2011), Ackermann (2012) conditioned the samples before the peel test at a temperature of 65°C and 80% relative humidity. The impact of 21,40 ,80 and 120 days preconditioning on the adhesive strength was investigated. Instead of a static peel test, he developed a method which allows alternating the loads in order to imitate the dynamic wind conditions. Yet his paper mainly focusses on the development of the test method rather than on the research findings.

In summary it can be stated that the available literature on the durability of air barrier sealing products is very limited. The only information currently available is related to the relation of static artificial aging tests on the peel force of the sealing. The applied methods are based on standardised peel tests, and thus, provide only information on the adhesive strength of the connecting. These methods can be applied to compare the adhesion durability of different kinds of taped joints. Yet the outcome of such tests do not provide information on the impact of artificial aging on the air permeability of the taped connection.
The aim of the present study is to explore the possibilities to investigate the impact of weather conditions on the actual air permeability of taped joints. Samples with a taped joints will be tested before and after artificial aging. The study explores the behaviour of two different types of tapes on a wood fibre cement board substrate. Herein three different artificial aging methods will be applied: a) thermal loads, b) hygrothermal loads and c) combined UV and vapour loads.

---

[1] BS EN 1939:1997 self-adhesive tapes – Measurements of peel adhesion from stainless steel or from its own backing

2 TEST SETUP AND METHODOLOGY

The air permeability of in total thirty two samples with taped joints are measured before and after conditioning. Two different tapes, two spacing materials and three different sample conditioning schemes are investigated. The following sections describe the applied materials, the conditioning schemes and the air permeability apparatus.

2.1 Test materials and samples

The tests are performed on medium density wood-fibre boards[2] with taped joints. These boards are composed of a coarse core, faced on each side with a fine smooth top layer. They consist of mainly Portland cement, water and wood fibres. The test samples are either 0.71 by 0.71 m² or 0.35 by 0.35 m² depending on the sample conditioning (see section 2.2). Figure 1 illustrates that each specimen consists out of two part which are connected with two spacers leaving a joint of 2 mm in between. Two different spacer materials are used: a) aluminium and b) wood. These two spacer material are chosen because of their different thermal and hygric expansion coefficients. This will induce different loads on the tapes during the sample conditioning (see section 2.2).

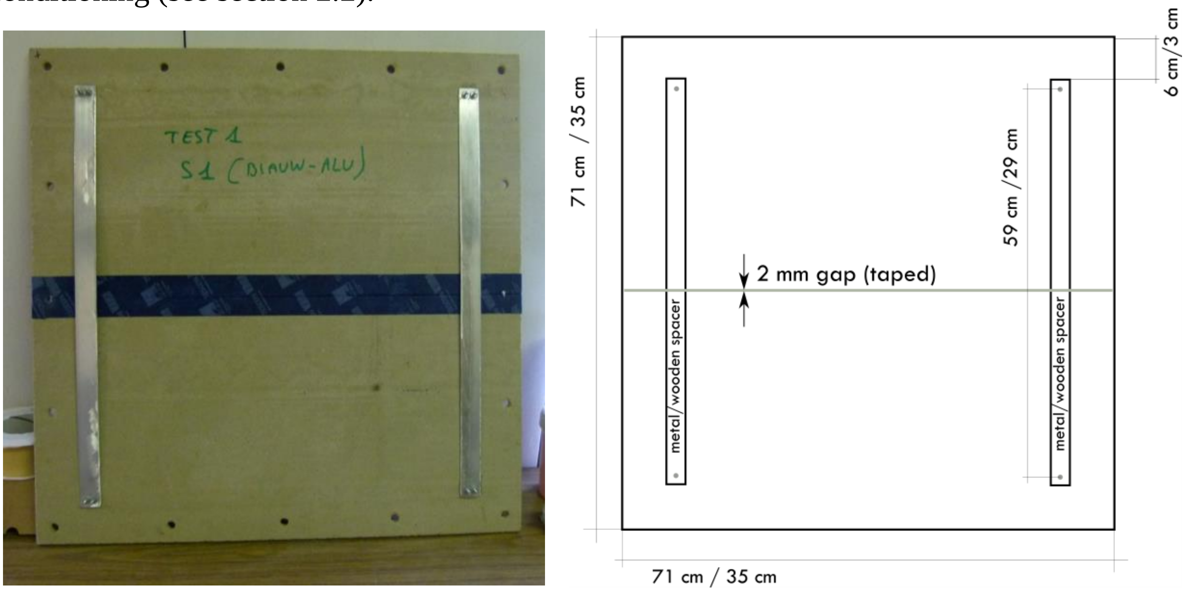

Figure 1: Test samples: left) sample of 0.71 by 0.71 m with aluminium spacer and right) dimensions for the big/small samples.

The tests are performed for two different commercially available airtightness tapes: Tape A) and Tape B). Table 1 summarizes the sample configurations. Next section will outline the conditions to which these samples are exposed.

Table1: Summary of test program.

TEST SERIES	TAPE	Spacer	Number of samples
A	Tape A	Aluminium	8
B	Tape B	Aluminium	8
C	Tape A	Wood	8
D	Tape B	Wood	8

[2] Duripanel of Eternit

2.2 Sample conditioning

This section outlines the three different conditioning schemes to which the samples are exposed (see Table 1).

Test 1: Temperature cycles

The first batch of samples (0.71 m by 0.71 m) are exposed to temperature cycles at ambient relative humidity levels. The aim of this conditioning scheme is to expose the samples to high temperature differences. For two weeks cycles of 24 hours at 70°C are followed by 24 hours at 15°C. Indirectly, in addition to the thermal load, this scheme corresponds to a mechanical load. This is induced by the thermal expansion of the spacer which is only fixed at the end points. For aluminium, which has a thermal expansion coefficient of 23.2 10^{-6} m/m/K this corresponds to a displacement of 0.74 mm. For the wooden spacer with a thermal expansion coefficient of 5 10^{-6} m/m/K this is only 0.2 mm.

Test 2: Temperature, rain and frost cycles

The second conditioning scheme has an increased load in that the samples (0.71 by 0.71) are now also exposed to water and freezing conditions. First the samples are exposed to 40 heat-rain cycles (3 hours temperature increase (70°C), 1 hour rain and 2 hour repose). Thereafter two frost cycles are imposed (8 hours 50°C followed by 16 hours of freezing (-20°C). This scheme corresponds to half of the normal hygrothermal cycles of ETAG004[3].

Test 3: UV-light cycles

During the construction phase exterior air barrier tapes will, in addition to hygrothermal loads, be exposed to solar radiation. This is often combined or alternated with periods of high moisture contents due to rain or condensation on the building envelopes surface. These conditions are simulated in the third conditioning scheme in which samples (0.35 by 0.35 m) are exposed to UV-light alternated with periods of vapour exposure based on ASTM G-154[4]. Herein the samples are exposed to 56 cycles of 8 hours UV-exposure (40°C) followed by 4 hours of vapour exposure (60°C). The UV-light is transmitted by a UVB-313EL[5] lamp corresponding to wavelengths between 280-400nm and an intensity of 0.7 W/m²/nm. All three accelerated climatic exposures are summarised in Table 2.

Table 2: Summary of test conditions.

Test series	Type	Total time	Conditions
TEST 1	Temperature	2 weeks	6 x (24h 70°C and 24h 15°C @30% RH)
TEST 2	Temperature, rain, frost	12 days	40 x (3h 70°C - 1h rain - 2h repose) - 2 x (8h 50°C - 16h -20°C)
TEST 3	UV-exposure, vapour	4 weeks	56 x (8h UV (40°C) and 4h vapour exposure (60°C))

3 Guideline for European technical approval of external thermal insulation composite systems with rendering.
[4] Operating Fluorescent Light Apparatus for UV Exposure for Nonmetallic Materials
[5] QUV weathering tester (Q-lab)

2.3 Air permeability test-setup

The air permeability of the samples are measured in laboratory conditions (20°C,50%RH) both before and after the sample conditioning. Two similar test-setups have been applied for these measurements. The first test setup was designed to measure the air permeability of the samples with a dimension of 0.71 by 0.71 m. This box is applied for the samples corresponding to TEST 1 and TEST 2 (see table 1). In addition a smaller box with a test frame of 0.35 by 0.35 m is used for the samples which were exposed to the UV-light (TEST 3). Both setups, which are designed according to the EN12114 standard, consists of a metal frame box open at one side to install the specimen to be measured (Figure 2).
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 have been used to seal the specimen airtight with a metal frame against the airtight box.

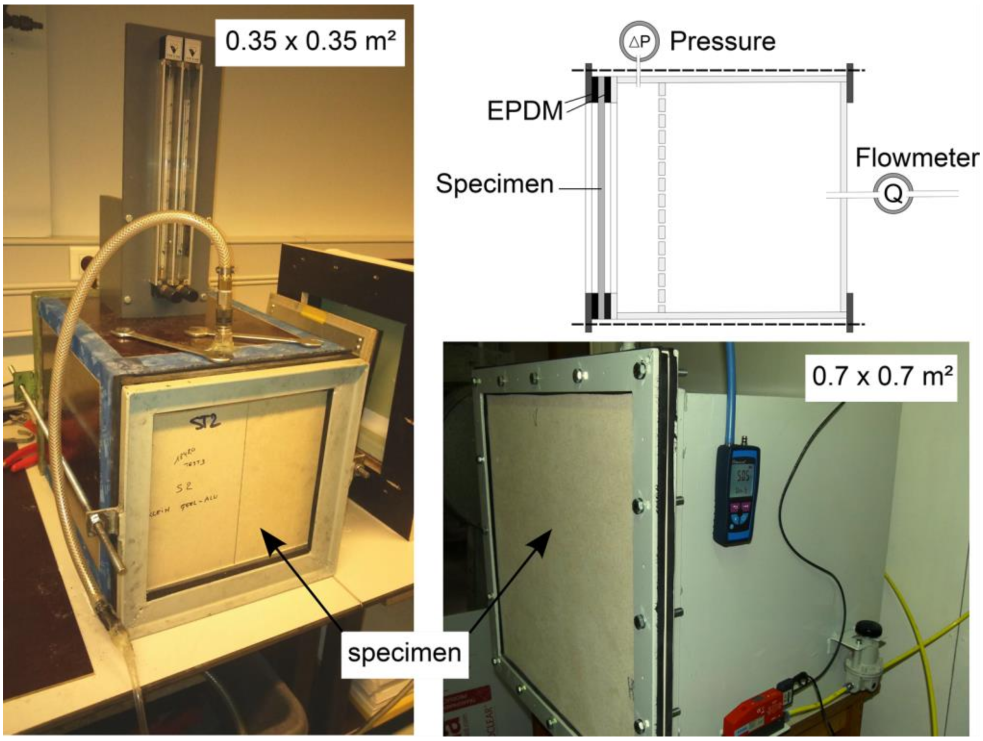

Figure 2: Laboratory test set-up.

After installing the specimen on the airtight box, over-pressure was created in the box. This resulted in an air flow passing through the specimen. By stepwise increasing the pressure difference across the specimen and measuring the corresponding air flow rate and pressure difference across the specimen a data set was obtained. The airflow g_a ($m^3/m^2/h$) can be expressed as an air permeance K_a multiplied by the pressure drop across the specimen ΔPa (Hens 2007):

$$g_a = K_a \Delta P_a \tag{1}$$

The construction junctions are assumed to be a parallel circuit of air resistances. Hereby, the air permeance of a joint K_{joint} ($m^3/m/h/Pa$) can be deduced from the measured air permeance of the specimen K_{spec}, given that the air permeance of the material K_{mat} ($m^3/m^2/h/Pa$) is known from the small test-setup (Hens, 2006):

$$K_{joint} = \frac{(K_{spec} - K_{mat}).A_{spec}}{l_{joint}} \tag{2}$$

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 m^3/h to 0.900 m^3/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 m^3/h at 50 Pa. For the bigger test-setup a BlueLine S2600 pressure transducer with an accuracy of 1% was used. Here a digital flowmeter (Vögtlin GSM-C) with a measuring range from 0 m^3/h to 0.36 m^3/h and an accuracy of 0.3% was applied. The leakage of the bigger apparatus was 0.0032 m^3/h at 50 Pa.

3 TEST RESULTS

This section discusses the measuring results. First, the air permeability of the board material and the taped joints before the ageing procedure will be outlined. Thereafter the impact of the 3 artificial ageing tests on the specimen's air permeability will be presented.

3.1 Air permeability of the board and taped joints

First the air permeability of the 12 mm wood fibre cement board is measured on specimen without joints. This air permeability of the boards (1.04 10^{-4} $m^3/m^2/h/Pa$) is than subtracted from the air permeability of the specimen with taped joints in the same test-setup before artificial ageing according. The results reveal that the air permeability of the taped joints is very low; 3.1 10^{-6} $m^3/m/h/Pa$ for Tape A and 3.9 10^{-7} $m^3/m/h/Pa$ for Tape B.
In the following section the impact of the artificial ageing on the permeability of the taped joints will be discussed.

3.2 Impact of artificial ageing

The previous section showed that the air permeability of the taped joints is very low before the samples are exposed to artificial ageing for both tapes. This section investigates the impact of the 3 accelerated ageing protocols on the joints air permeability. Figure 4 plots the difference between the air permeability before and after the artificial ageing test. The bars in the figure correspond to the averaged values and the error bars refer to the minimum and maximum value.

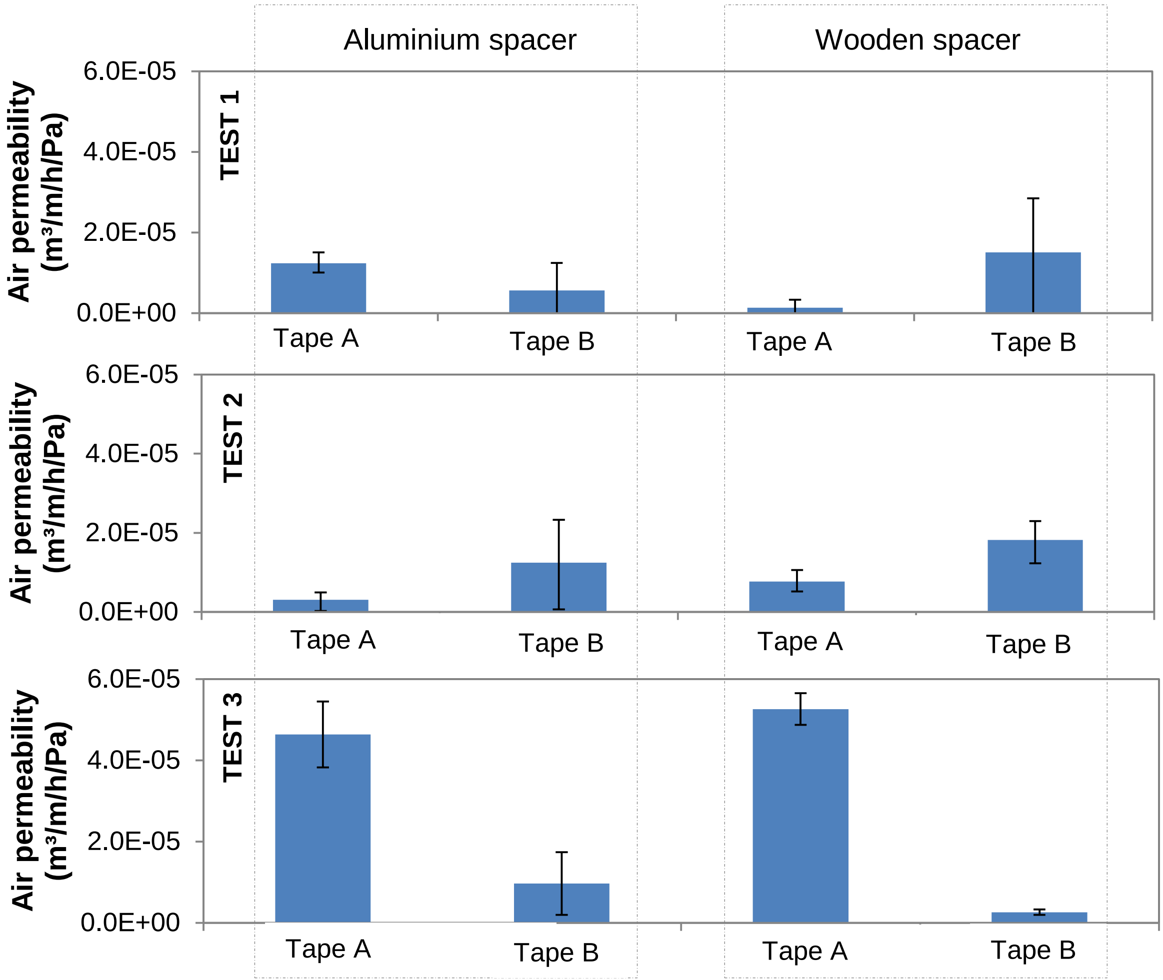

Figure 4: Increase in air permeability of the joints after the artificial ageing of the samples.

The results indicate that the increase in air permeability is limited to 2 10^{-5} m³/m/h/Pa for the first two ageing procedures. Nevertheless the second procedure is much more severe including rain and frost cycles, the impact on the permeability remains in line with the first procedure. In addition no significant differences between the different spacing methods nor the different tapes is noticed. For the third ageing protocol, in contrast, Tape B seems to perform better than Tape A. However, it should be noted that the increase of the air permeability is limited to 4-6 10^{-5} m³/m/h/Pa which is still very low.

4 DISCUSSION AND CONCLUSIONS

Exterior air barrier systems can – in contrast to traditional interior barriers - be exposed to severe weather conditions. These outdoor conditions may have an impact on the durability of sealed connections. The article at hand proposes a methodology to study the durability of taped joints based on air permeability testing and artificial ageing tests. In this study two different commercially available tapes are applied which are exposed to three accelerated ageing protocols ranging from a) temperature cycles, b) temperature, rain, frost cycles up to c) UV and vapour exposure. The joint's air permeability was measured before and after being exposed to these conditions.

The results reveal that the permeability increase is limited for both tapes tested. For the temperature, rain and frost cycles the increment stays below 2 10^{-5} m³/m/h/Pa. For the UV and vapour cycles a slightly higher impact was noticed for Tape A (4-6 10^{-5} m³/m/h/Pa). Yet it should be stressed that this increase is still very small. To get an idea of the order of magnitude this increase in permeability can be translated to a share of the overall n_{50}-value of a building. Langmans et al. (2010) studied the airtightness of a detached house with an exterior air barrier. The total length of the joints in this exterior layer was 1280 m and the volume of this building was 1083 m³. For this case study an increase of the air permeability of 6 10^{-5} m³/m/h/Pa would correspond to an increase of the n_{50}-value of only 0.003 1/h. This is two orders of magnitude smaller than the threshold value applied in the Passive house standard (0.6 1/h).

The present article is limited to taped joints which are installed in perfect conditions. Further research to investigate the influence of the weather impact on the durability of non-perfectly taped joints is recommended. Interesting parameters to investigate in future research can be the pressure applied on the tape during installation, effects of dusty surfaces and the use of primers.

5 ACKNOWLEDGEMENTS

Research funded by a Postdoctoral Innovation Mandate (grant number 140695) of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen).

6 REFERENCES

Ackermann, T. (2007). *Untersuchungsergebnisse zur Dauerhaftigkeit von Verbindungen und Anschlüssen bei Luftdichtheitsschichten mittels Klebemassen und Klebebändern*. In Europäisches BlowerDoor-Symposium: Dichte Gebäudehülle, Thermografie und Wohnungslüftung (pp. 109–119).

Ackermann, T. (2012). *Alternating loads – a method for testing the durability of adhesives in air tightness layers*. Proceedings of the AIVC-TightVent international workshop, 28-29 March 2012, Brussels, Belgium. pp. 61-66.

ASTM G-154 : Operating Fluorescent Light Apparatus for UV Exposure for Nonmetallic Materials.

Bracke, W., Laverge, J., Bossche, N. Van Den, & Janssens, A. (2013). *Durability and measurement uncertainty of airtightness in extremely airtight dwellings*. In AIVC Conference Proceedings.

Borsboom, W. and de Gids, W. 2012. "Seasonal variation of facade airtightness: field observations and potential impact in NZEB". Proceedings of the AIVC-TightVent international workshop, 28-29 March 2012, Brussels, Belgium. pp. 77-84.

Etherridge, D. W., & M, S. (1996). *Building Ventilation: Theory and Measurements*. John Wiley & Sons, New Jersey.

ETAG 004 (2009) guideline for European technical approval of External thermal insulation Composite systems with rendering

Gross, D. R., & Maas, A. (2011). *Qualitätssicherung klebemassenbasierter Verbindungstechnik für die Ausbildung der Luftdichtheitsschichten*. In *6th International BUILDAIR.*

Hansén, M. 2012. “Changes in airtightness after 10-20 years”. Proceedings of the AIVC-TightVent international workshop, 28-29 March 2012, Brussels, Belgium. pp. 67-75.

Hens H. (2007) *Building Physics- Heat, Air and Moisture*, Wilhelm Ernst & Sohn, Berlin. Germany, 2007

Hens H. (2006) *The vapor diffusion resistance and air permeance of masonry and roofing systems*, Building and environment 41 :6, 745-755.

Kim, A., Shaw, C., Saum, D., Shaw, J. & Colliver, D. (1986), ‘Seasonal variation in airtightness of two detached houses’, ASTM special technical publication 904, 17–32.

Langmans, J., Klein, R., De Paepe, M., Roels, S. (2010). *Potential of wind barriers to assure airtightness of wood-frame low energy constructions*. Energy and Buildings, 42 (12), 2376-2385.

Laverge J. et al. 2010. Airtightness assessment of newly build single family houses in Belgium. In: Proceedings of Buildair 2010, pp. 8.

Michaux B., Loncour X., Mees C. (2012), *Assessment of the durability of Airtightness and impact on the Conception of building details*, Proceedings of the AIVC-TightVent international workshop, 28-29 March 2012, Brussels, Belgium. pp. 85-91.

Weissmueller A. and Frédéric Delcuve F. (2013) Evaluation of the long term durability of adhesive tapes and its substrates: Requirements and testing. Webinair AIVC TIGHTVENT