Watertightness of window frames: experience of notified bodies

N. Van Den Bossche, A. Janssens & J. Moens
Ghent University, Department of Architecture and Urban Planning, Faculty of Engineering, Ghent, Belgium

ABSTRACT: The research facility for testing building envelope elements at Ghent University has been testing the air- and watertightness of windows for over 30 years. As a certified lab a lot of tests are done for the industry according to standard procedures. This paper presents the results and analysis of about 200 tests that were carried out throughout the last 10 years. Is the overall performance of the window correlated with the construction material? And does a good airtightness guarantee a corresponding watertightness?

All too often the test samples delivered by the industry are an exception to the rule: while a grade A window is delivered to the lab, poor quality is general practice. Clients, architects and contractors need clear-cut specifications concerning performance assessment in order to obtain a high-quality product, and if there are apparent indications of defects or flaws the specifications should provide the possibility to put a randomly chosen window to the test. Based on the experience of the test lab as notified body guidelines for quality management in low-rise and high-rise buildings are developed.

1 INTRODUCTION

In the current globalizing world where the limits of free trade are expanding, the local building construction industry is an exception to the rule. Although more and more standards, mandatory guidelines and performance assessment criteria arise, the overall quality of a building remains predominantly the responsibility of the architect and the (sub)contractors. As no two buildings are identical, every product needs to be adjusted and fine-tuned to fit the design of the architect. In order to have some kind of control on the products that are placed on the marked and to create free trade in construction elements, the European Community created the European product standard: the Construction Product Directive (CPD) in 1988 and the Construction Product Act (CPA) in 1998.

A uniform test and classification to achieve a CE-mark is thus a type of license for the product, however it is not a quality mark. Based on factory production control (FPC - establishment and maintenance of procedures and product processing) and initial type testing (ITT - a notified testing body evaluates the performance characteristics of a product) a manufacturer can obtain CE marking for his products. This would imply that every manufacturer is required to put every product to the test. In order to minimise the verification effort, a certain level of transferability is foreseen in the standard: the results of the specimen which is the most unfavourable for the performance characteristics can be transferred to similar products within a product family or procuring system.

In November 2006 the new European standard for windows and external pedestrian doors EN 14351-1 (CEN, 2006) was notified: in 2009 every window manufacturer needs CE-marking with a FPC. It allows shared and cascading ITT to reduce the number of tests: a number of partners can join hands to conduct the tests required for the ITT and each partner receives an ITT report. The adjective ‘cascading’ refers to a licenser/licensee contract which defines the use of the licenser ITT for the assembler in a manner covered by private law without a repeat test being carried out (Rossa, 2005).

But does it make any sense to allow shared and cascading ITT whit regard to windows and doors? Looking both at scientific research and practical experience of notified bodies one might even consider whether ITT has a solid basis.

2 SHARED AND CASCADING ITT

2.1 *Belgium*

A lot of manufacturers of windows and doors are Small and Medium Enterprises (SMEs), and this is especially true for manufacturers of wooden window frames. Hence the Belgian Building Research Institute (BBRI), SECO (Technical Control Bureau for Construction) and the employers' federation of carpenters have initiated a joint research program to develop shared and cascading initial type testing according to EN14351-1 in the Belgian context. In the first phase research is concentrated on thermal performance, watertightness, airtightness and resistance to wind loads, and only the most common window types are taken into account (turn/tilt windows, double hinged window and sliding windows). According to annex F of EN 14351-1 results of those window types can be extrapolated to less complex window types: the goal of this project is to cover about 80% of all windows that are produced in Belgium. As no statistical data on window production are available a survey was sent to 663 manufacturers in Flanders, of which 92 responded with a complete survey form (13.9%). The most interesting results are listed below:

- Meranti is the lumber type which is most frequently used: 59%, followed by Sipo (16%), Afzelia (8%), Merbau (6%) and Padoek (3%). Each other type of lumber represents less than 1% of the total quantity.
- The average dimension of a turn/tilt window is 1286mm by 915mm. As the acoustical performance is determined on a 1480mm by 1230mm window these dimensions are used as an average (this covers over 90% of all reported dimensions).
- The wooden frame is 58mm (78%) or 68mm (12%) wide and the sash and frame are about 80mm high (61%, the range 75mm-85mm covers more than 95%)
- 96 % of all windows are assembled with a double mortise and tenon joint. The other windows have a dowel (pinned) connection or a single mortise and tenon joint.
- Only 34% of all manufacturers report they weld the airtightness gasket in the corners, the other 66% cut and fold the gasket in the joint.
- A solid 91% uses silicone paste to install the insulated glass unit into the frame, 9% uses an extruded PVC or EPDM gasket. The height of the glazing groove is 18mm.
- The shape of the wheep holes is predominantly round (84%), slits account for 16%. The diameter of the round wheep holes is 8mm (41%), 6mm (38%), 10mm (8%), 5mm (5%) or 4mm (5%). The maximum distance between 2 wheep holes varies a lot: 600mm (43%), 500mm (16%) or 400mm (11%), but also 740mm, 800mm and 980mm are reported values. Only 55% of all manufacturers use vents in the top of the frame to ventilate the cavity.

It is particularly striking to see that the key parameters to obtain a good watertightness have the most scattered distribution. The right number, shape and dimensions of wheep holes are unclear and 45% of all manufacturers report they do not drill vents in the frame.

Based on the results of the survey, the committee decided to test 16 windows. Following parameters are altered to test their influence:

1. depth of the profile (58 or 68mm)
2. type and brand of the watertightness gasket (2 brands, each brand 3 types, both cut and welded)
3. type and brand of hinges, joggles, fittings (4mm: 2 brands / 12mm: 2 brands)
4. decompression cavity (present / not)
5. type of lumber (2 types)

The results of these experiments should be available at the end of 2008.

Table A.1 of the EN 14351-1 states the profile of the sash and frame (area and shape of the cross sections, assembly, ventilation devices) has a clear influence when it comes to watertightness, air permeability and resistance to wind load. The hardware on the other hand 'may' have an influence on those characteristics and evidence of interchangeability of hardware can be admissed to avoid re-testing.

One should consider the fact that if the 'average' window is selected, with the average parameters and average specifications one may end up with a window that has never been built before. There may be a strong correlation between different parameters that is not covered here.

The organizing committee is planning to use the results of these tests as ITT and claims transferability to a large extent: the ITT-reports will be placed on a website open for members of the employers' federation of carpenters and they in turn will autonomous decide whether their products do in fact have the same characteristics to be a member of the tested product family. This project is a local example of how shared and cascading ITT can be used to obtain CE-marking for a range of products.

2.2 *Europe*

The ECWINS-project was initiated by the “Fachverband des Tischlerhandwerk” from Northrhine-Westphalia (Germany) – together with 30 other partners from 8 different EU-countries – and was approved to be supported by the Sixth Framework Programme of the EU.

The program has the ambition to develop a CE-based Assessment Model to calculate the CE-performance characteristics whereby physical testing would be minimised. Hence more innovative window designs can be developed especially for SMEs and craft firms. That will in turn strengthen the competitiveness of the SME with regard to the industrialized window manufacturer. In the experimental test set-up 56 windows from 8 countries are tested, subdivided into three categories: turn/tilt windows (18), composed windows (19) and ‘specials’(19). The results show that both airtightness as well as resistance to wind load show good repeatability and reliability. Watertightness on the other hand does not give sufficiently consistent results: the repeatability is not good, in place repetition and remounting can give different levels of watertightness, and it is hard to predict the watertightness level based on the constructional configuration (ECWINS, 2008).

The aim of the program is to develop a model (which is based on a parametrical analysis with neural networks of the experiments on those 56 windows) that will predict the performance characteristics of any given window, so there is no modelling of the physical phenomena is required. There are only about 18 windows per window type, manufactured in 8 different countries, made out of different materials (wood, aluminium, vinyl) and have a lot of varying characteristics: opening inwards/outwards, shape of the profile, number of closing points, wheep holes and vents, types of gaskets, cavity volume etc. The results show that the different labs do not succeed in reproducing the results of their own experiments, so how can this information be used to predict the watertightness of other windows?

3 EXPERIENCE WITH CERTIFIED TESTING

3.1 *Survey on 207 windows*

The test centre for façade elements of Ghent University was founded in 1952 in order to do research on watertightness of windows. Between 1952 and 2008 the test facility has tested a lot of windows including their performance regarding watertightness, airtightness and resistance to wind loads. As test results are only kept in archives during a limited period of time, we were able to retrieve 207 test reports, containing tests of 136 aluminium windows (66%), 52 vinyl windows (25%) and 19 wooden windows (9%). These experiments where all done according to current European standards. For more information on watertightness testing see (Van Den Bossche et al. 2008). While the aluminium windows achieve high levels of watertightness more frequently than the other materials, many wooden windows seem to fail at very low pressure differences.

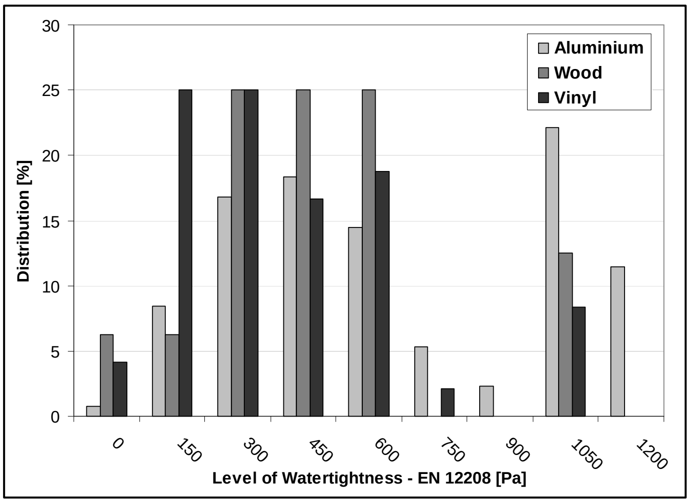

Figure 1. Watertightness of window frames - materials

The difference in performance between the three types of windows has little to do with material properties. Every material has it own specific construction methods and technology to achieve watertight windows, in that way every material generates other advantages and potential problems. The type of material is also correlated with the scale of the production process. The investment in order to manufacture wooden window frames is relatively low and the necessary training is instructed at most schools where courses of carpentry are organized. Therefore most of the manufacturers of wooden windows are rather small workshops with only a few employees. Vinyl and aluminium window frames require more advanced technology and much higher investment costs. Those enterprises are bigger and the technology transfer is primarily located within the company itself. While big companies rely on subdividing the construction process into little and easy steps in an assembly line and use quality control systems, small workshops rely more often on craftsmanship and may have a larger risk for errors to occur.

Looking at the results of experiments on aluminium and vinyl windows during the last 15 years some evolutions concerning airtightness and watertightness can be analyzed. The average performance fluctuates very strongly throughout that period (this is not caused by statistical flaws e.g. too small sample group). Vinyl windows have improved significantly especially since 2001, going from an average watertightness of 300 Pa between 1997 and 2001 to somewhere between 500 and 650 Pa in the last 5 years. Aluminium on the other hands shows a slightly downward trend regarding average watertightness (from 800 Pa in 1994 to 600 Pa in 2007). Before 2001 there was a clear difference in performance between the two types of materials, but since 2001 this difference has declined significantly and practically vanished. The total sample group of wooden windows is too small to analyze.

Airtightness does not give the same result as watertightness: aluminium windows achieve the highest airtightness levels, followed by wooden and vinyl windows. The airtightness of the windows is specified by a level according to EN 12207 ranging from 1 to 4, level 4 being the most airtight class.

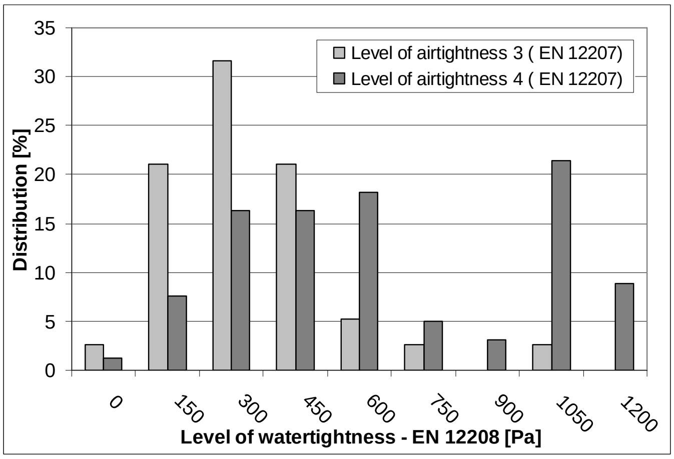

Figure 2. Watertightness vs airtightness level

Figure 2 shows the correlation between airtightness and watertightness of windows: this clearly indicates that the level of airtightness is a stipulation for good watertightness because only 6% of the windows of level 3 achieve a watertightness level above 600 Pa (for the airtightness level 4 windows that percentage is 38). A close examination of those results shows that at least airtightness level 3 is required for watertightness levels above 150 Pa, level 4 is required for watertightness above 450 Pa, and all the windows with a watertightness of 1200 Pa have an air leakage which is about half of the permissible leakage to attain level 4. Figure 3 shows the air leakage per meter of joint length in function of the air pressure across the window for 29 windows. 14 windows remained watertight up to 150 Pa (light grey lines), the other 15 windows reached a watertightness level of 1200 Pa (black lines). This clearly indicates that airtightness is a condition to reach a certain level of watertightness.

The correlation between mechanical resistance to wind loads (the deformation when submitted to a certain pressure difference) and watertightness is slightly less explicit, but more rigid frames do achieve a better watertightness performance, and more slack windows (relative sag under a 1000 Pa load is bigger than 1/350) apparently do not reach a watertightness level above 600 Pa.

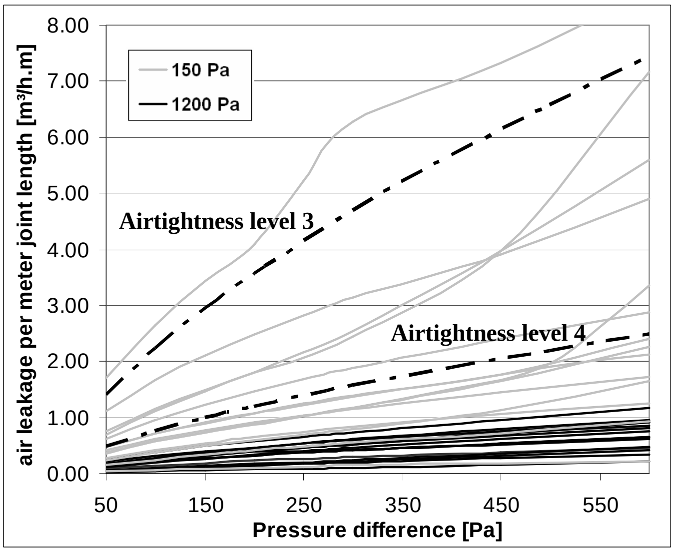

Figure 3. Required maximum air leakage rate to obtain a certain level of watertightness

Good pressure equalization and watertightness depend on the collaboration between the frame, hardware and gaskets. Apparently the gaskets in the less rigid frames are not able to follow the bigger deformation: either this is a physical limitation, or none of those windows had gaskets adjusted to the type of frame. The mechanical resistance is a combination of the stiffness of the frame and sash, the fine tuning of operating hardware and the number of hinges, stays and other elements that connect the sash to the frame. More information on relaxation of the gasket and its influence on pressure equalization, especially during gust effects, can be found in (Van Den Bossche, Janssens & Moens, 2007).

In order to analyze the influence of the positioning of the gaskets in the profile (inside, central or outside) the results of the aluminium windows were analyzed. Some results were excluded from the statistical analysis to avoid distortion due to infiltration problems which are not related to the gaskets. Most aluminium windows have at least two gaskets, and the most common systems are: inside-central, inside-outside, inside-central-outside, central-outside. The window frames with an inside-outside gasket configuration clearly perform less well compared to the other systems, as only 25% of these windows achieve a watertightness level above 600 Pa. On the other hand 43% of the windows with gaskets central-outside reach that level, and 41% of those with gaskets inside and central. Windows with three gaskets apparently perform slightly less good than the types above. This is probably caused by tolerance problems to position the sash correctly in relation to the frame, hence the compression of the gasket will also be less uniform over the perimeter. The overall conclusion for aluminium windows is obvious: two gaskets of which one is centrally located in the cavity between the sash and frame provide the best configuration for watertightness.

3.2 *Practical limitations for experimental research*

It is very difficult to make a parametric analysis based on the results of these experiments. Although the sample group is relatively large, there are too many parameters that change: dimensions, number of wheep holes and vents, material, type of window opening (turn-tilt, side-hung, sliding, pivot, composed…), type of gasket, number of closing points etc. The failure of a window can rarely be traced back to one particular parameter that initiated failure. Based on experience in the lab the most common errors that cause water infiltration are:

- the size of the sash is not well adjusted to the size of the frame
- the sash is not correctly positioned in respect to the frame, or the sash is not level
- a T-joint connection in the frame is not watertight
- the airtightness gasket on the inside is not continuous or the mitre joints of the gaskets at the bottom of the frame are not sealed properly.
- a mitre joint of the frame is not properly sealed.
- the removable glazing stop of the IGU is too short causing a high air leakage rate at the corners and hence water infiltration.

The craftsmanship and attention of the manufacturer will be the first bottle neck for the watertightness performance. However, these types of failure can not be traced back by a parametric analysis: when comparing different results of experiments on windows one should always find out what initiated failure.

3.3 *Parametric analysis of operating hardware*

During 2006 Ghent University did a series of tests on the interchangeability of hardware in collaboration with the BCCA. For these tests 7 identical vinyl windows were manufactured, with identical size, sections, reinforcements, gaskets, glazing type, etc. Only the hardware was altered: 7 different types of hardware (4 brands) were installed in the turn-tilt windows. This also meant that not every window had the same amount of closing points: this varied from 9 to 12. However, every single window was constructed by a different manufacturer. Each window was handled with kid gloves and brought to the testing facility. Out of 7 windows only 2 did in fact reach the watertightness level that was achieved during initial type testing of that particular frame (1200 Pa). Two windows initially did not even reach the required level for windows in low-rise buildings (<10m height) in coastal area's (450 Pa).

Most failures were traced back to construction errors of the manufacturers. With some guidance and a number of follow-up experiments eventually all windows (one sash had to be replaced) were able to reach a satisfactory level (600 Pa), but eventually only 3 windows achieved the same watertightness level as during ITT. Further analysis points out that the resistance to water infiltration is slightly correlated with the airtightness of the window, but no relation with the type of hardware, number of closing points or brand could be made. Why does one window perform better than another? Although only one parameter was changed that was probably not the dominant influence on the system. This clearly underlines that ITT is only an indication of the potential performance of a certain window type.

Another example of the influence of craftsmanship was obtained during other tests on interchangeability of hardware: two different brands were installed in identical double side-hung casement windows. Initially the results were not that good (both windows failed at 600Pa), but when just one closing tap was adjusted 1mm, the windows achieved watertightness levels of 750Pa and 1200Pa. These kinds of differences cannot be traced, because even the required force to bolt the gearbox did not change a great deal after the adjustment of the closing tap.

4 TOWARDS HIGH PERFORMANCE WINDOWS

4.1 *Quality control*

Most European countries have guidelines or mandatory standards concerning watertightness of window frames. Currently the only possible benchmark to compare different types or brands of windows is the ITT. As stated before this is only an indication of how a window type 'could' perform under optimal conditions. Every SME should develop a factory production control system in order to analyze every step during the construction process. This will enhance the technology transfer within the company itself, and possible flaws will be discovered sooner. The experience of the testing facility of Ghent University points out that the actual assembly of the window frame and sash is crucial to the overall quality, and that most window failures can be traced back to this.

Due to global warming, higher energy prices and more strict energy requirements the construction technology of window frames has changed throughout the last few decades. However, the challenges we are facing right now are not to be underestimated.

This will in turn affect the way windows are designed, how the hardware works, how well the cavity is pressure moderated and which materials are used. For example: a better thermal performance can be obtained if the central gasket is placed more in front, therefore the cavity will be smaller - the resistance to gust effects might be slightly improved - but the performance under static pressure difference will probably go down (the water buffering capacity is smaller). It is a whole system and everything is interrelated. If only one parameter is changed, the whole design should be evaluated. Implementing new technology and materials with old craftsmanship has often lead to failing constructions…

Testing any window according to current EU standards is very time-consuming and hence very expensive. So how does one obtain some kind of quality control on site?

4.2 *Architects*

The architect is the main actor in the building process responsible for quality control on buildings, building components and materials. A visual inspection of all windows is the first step towards a quality management system. However, what should the architect look at? As no window manufacturer has any publications on strict boundary conditions to obtain high quality windows, the architect does not know which are the dominant characteristics of a window. First of all architects should learn more about the way windows work and how they are assembled. Secondly, the industry should produce clear-cut information and design guidelines for the different types of windows. That way an architect can see how many hinges, closing points, wheep holes etc. should be present according to the design guidelines. These guidelines already exist in many companies, but are not accessible for architects nor clients.

The experience of the notified test lab points out that the watertightness level for windows in low-rise buildings can be achieved in most cases if no major construction errors are made. For those buildings a visual inspection by the architect should be sufficient as quality control. If there are indications that the windows are not made according to the specifications of the window producer, other measures can be taken.

4.3 *On site testing*

Windows for high-rise buildings are subjected to higher pressure differences, so a higher watertightness level is necessary. A lot of windows do not reach that level of watertightness during lab-testing without retrofitting the test specimen. On top, the difference between a good window and an excellent window may not be visible to the naked eye. Depending on the number of windows, the height of the building and possibly indications of poor quality the architect or client should have the opportunity at their disposal to test a limited number of windows on site. In order acquire information on the sensitivity of the results with respect to the accuracy of the measuring equipment a number of tests were done with varying water spray rates and pressure differences. During repeated testing of a window according to standard procedures there may be a small deviation of the results (the moment of failure can occur a few minutes faster or slower) so a performance change of 1 level is acceptable, which is supported by experiments in the lab. The results of the experiments point out that a band width of 10% on the water spray rate or the pressure difference does not significantly influence the performance. Measuring equipment with this kind of error bar is cheap and does not need a lot of maintenance. Next to the measuring equipment also the test procedure can be changed to speed up the test. If a window should reach a watertightness level of 750 Pa for example, one can impose a pressure difference of 750 Pa for 5 minutes before spraying water on the surface. For the different window configurations tested that way this gave the same result as the whole test protocol (or in some cases 1 level difference). Even though the results are only an indication for testing according to current standards, the obtained information can be very useful to trace flaws.

5 CONCLUSIONS

CE-marking of windows based on shared and cascading initial type testing may be a good idea in theory, but in practice it will overshoot the mark. Results of one specific window of one manufacturer will be extrapolated to a whole series of windows produced by other manufacturers. This will not make windows better in general, it will only increase the mass of paperwork. The most common causes of water infiltration will simply be ignored and the fundamental scientific base to justify the extrapolation due to shared and cascading ITT is imaginary. In essence, the Construction Product Directive of 1988 was meant to deal with serial production like bricks, insulation or roofing membranes, so the scope of the standard might even supersede the custom-made windows manufactured by SMEs.

The experience in the test centre of façade elements of Ghent University as notified body throughout a number of decades can be summarized into a few guidelines concerning general quality management:

- good ITT is no warranty for good windows

- most water infiltration problems can be traced back to incorrect measurements and poor craftsmanship
- both internal as external knowledge transfer in the window industry are too limited
- A watertightness level of 450 Pa should be feasible for most windows produced by adequately skilled manufacturers (except for sliding windows for example)
- Although lab-conditions can not be achieved during on-site testing, the experiments can be very useful and give a good indication of the overall quality

Furthermore the analysis of a large sample group of windows shows that a statistical reliable parametric analysis is very hard. Some general conclusions can be found, but this is only a qualitative approach, quantitatively no reliable conclusions can be drawn.

Summarizing, quality management of windows should depend on the application: windows for low-rise buildings (<10m), or buildings up to 18 meters in a shielded environment can in most cases be produced by skilled manufacturers without testing and most common errors can be found during visual inspection (although the architect needs specific training). Windows for applications with more severe circumstances and submitted to pressure differences above 450Pa should be tested on site. More research on the reliability of on-site testing is needed, but preliminary research suggests that the accuracy of the measuring equipment is not that important. Cheaper testing devices will raise the viability of on-site testing and allow firms to cut back on retrofitting just after completion due to failing fenestration.

6 ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to the Test Centre for façade elements of Ghent University, especially to Mr. Huwel and Mr. De Poortere. Without their extensive experience, counseling and guidance this work would not have been possible.

Furthermore, the authors would like to thank the Belgian Building Research Institute (BBRI), SECO (Technical Control Bureau for Construction) and the employers' federation of carpenters for the results of the Flemish project on shared and cascading initial type testing.

7 REFERENCES

CEN, 2000. EN 1027. Windows and Doors. Watertightness Test Method

CEN, 2000. EN 1026. Windows and Doors. Airtightness Test Method

CEN, 2006. EN 14351-1. Windows and doors – Product standard, performance characteristics – Part 1 : Windows and external pedestrian doorset without resistance to fire and/or smoke leakage characteristics

ECWINS, 2008. *Minutes of the General Assembly Meeting*. Fachverband des Tischlerhandwerks – NRW, Brussels, Belgium.

RDH Building Engineering Limited 2002. Water penetration resistance of windows, study of manufacturing, building design, installation and maintenance factors, CMHC, Vancouver, Canada

Rossa M., 2005. *From the Ü-mark to the CE-mark. National implementation of product standards*. International Rosenheimer Window & FacadeConference 2005, proceedings pp. 71-75

Suresh Kumar K. 2000. Pressure equalization of rainscreen walls: a critical review, *Building and Environment*, Vol. 35, pp.161-179

Van Den Bossche N., Janssens A., Moens J., 2008. *Pressure equalisation as design strategy for watertight windows*. Nordic Building Symposium, Copenhagen, Denmark