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Rain resistance of windows – Lessons learned from two decades of laboratory testing

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Abstract. Windows are important in buildings intended for human activities as they let in daylight and provide views. However, they may also be vulnerable in terms of heat loss, air leaks, rain tightness, and durability. In Nordic climates featuring severe driving rain exposure, water tightness is of outmost importance. SINTEF has for many decades been testing windows as part of the Norwegian yearly product control. Air permeability and water tightness are tested according to NS-EN 1026 and NS-EN 1027, respectively. The windows are then classified as described in NS-EN 12207 and NS-EN 12208. This paper summarises experiences from the last two decades of testing, presenting the results of 1130 tests of windows' air permeability and rain tightness. The overall trend is that air and rain tightness performance of the windows have improved over time. Certain hinge configurations are clearly better than others, with tilt and turn windows performing the best and top hung casement windows the poorest. There is a clear trend that highly rainproof windows also exhibit lower air permeability. Multiple-window screens fail the test more often since they feature longer perimeters of opening. The contribution of weather sweep seals to the water tightness is significant as it makes an extra rain barrier to the joint between casement and frame. In general, leakage between the frames of double windows and in the joints of the frame occurs at lower air pressures than leakages between casement and frame. The lessons learned from the survey may guide future development of weatherproof windows.

1. Introduction

1.1. Background

In Norway, wind-driven rain presents a major challenge in weathertightness of buildings [1]. The combination of wind and rain can push precipitation water into openings and cavities and cause leaks that invite further problems such as microbial growth, corrosion, or other material degradation. The challenge is exacerbated by climate change, which is expected to bring larger amounts of precipitation and wind to Norway [2]. Climate adaptation of buildings is becoming necessary to face the current and future expected climatic challenges [3]. As the climatic loads on a building change, the building design must be adapted to withstand them.

To ensure building integrity, materials used in the building envelope are required to document weathertightness performance to be deemed suitable for use in the Norwegian building sector. Additional certification systems for suitability and documentation of adequate performance are widely used. While these certifications are not legally mandatory, building contractors frequently mandate the use of certified products in their projects.

Investigations into building defects have found intrusion of precipitation water to be the most significant cause of damage in Norway [4,5]. The insertion of windows into the wall frame has been singled out as a weak point in seveal studies [6–9]. However, the window assemblies themselves may also be vulnerable to defects and leakages, resulting in the need for a quality control scheme for products. The Norwegian Door and Window Control (NDVK) is a voluntary product marking scheme for windows and doors sold in the Norwegian market. Members are awarded the right to label products that comply with assessments and testing of their performance [10]. Wind- and watertightness tests are conducted according to NS-EN 1026 [11] and NS-EN 1027 [12], respectively, the performance of the windows and doors are classified according to NS-EN 12207 [13] and NS-EN 12208 [14]. To achieve NDVK certification, a window must achieve air permeability class 4 and water tightness class 9A. These classes require the window to withstand a test pressure of 600 Pa without leaking air or water.

A Belgian study of window test reports from 1997 to 2012 summarizes relative strengths and weaknesses of different window types [15]. A similar summary from Canada points out common leakage paths [9]. At SINTEF in Trondheim, Norway, similar tests of windows and doors have been conducted on behalf of NDVK for many years, with reports from 2001 onwards being digitized. The tests have all employed NS-EN 1026 and NS-EN 1027 using the same methodology, apparatus, and test parameters. This consistency enables comparisons of window performance over many years.

1.2. Objective and scope

Accordingly, this paper summarises the last 20 years of test reports on the rain- and airtightness of windows as determined through laboratory studies at SINTEF. Data is obtained from test reports, systemized, and analysed to assess the influence on different aspects on overall weathertightness of windows. The tests and reports concern the window as a delivered building element, and not the sealing along the perimeter or its insertion in wall frames. The work is structured around the following three research questions:

- Where do leaks most commonly occur in window elements, and at which levels of exposure?
- What share of windows experience problematic levels of leakage?
- How can the weathertightness of windows be improved?

The present study collects data from 741 test reports found in SINTEF’s archive. The reports contain the results of 1130 tests of various windows and doors according to NS-EN 1026 and NS-EN 1027. No other sources of data have been consulted. No laboratory tests were conducted with the present study in mind. The insertion of windows is considered beyond the scope of this study.

2. Methodology

2.1. Terminology of windows

The terminology of windows and window components is found in NS-EN 12519 [16]. An illustration including the most relevant terms for the present paper is shown in Figure 1.

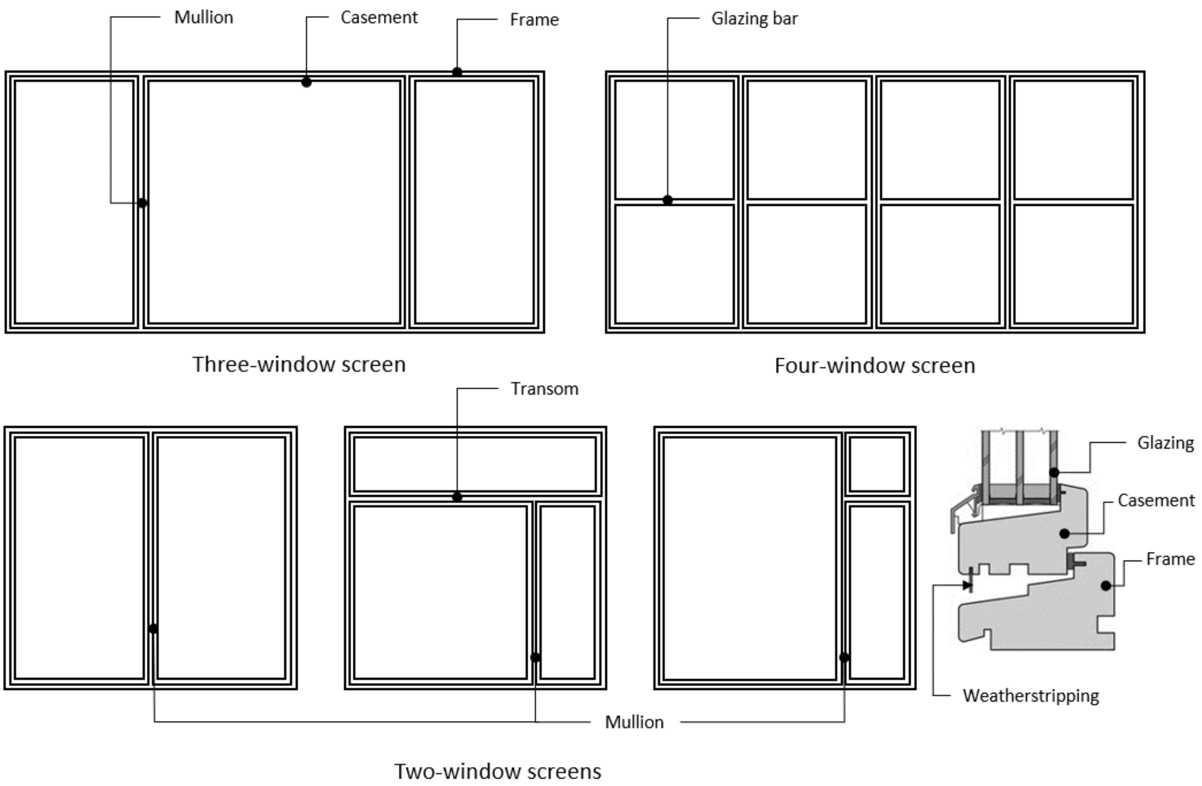

Figure 1: Window terminology, from EN 12519:2018 [16]. Figure based on [17].

2.2. Air permeability test

The air permeability test is described in NS-EN 1026. The specimen window is mounted in a frame which is fitted in the wall of a test chamber. The insertion joint between the window frame and the wall segment is firmly sealed at the wind barrier layer (exterior side) using tape, as the purpose is to test the permeability of the product and not the frame joint. The window must be fully operable while mounted in the frame and must be opened and closed at least once before the test if applicable. The air pressure in the test chamber is then increased, in steps of 50 Pa relative to the ambient air pressure until a level of 300 Pa. Then the pressure is increased by 150 Pa for each step. The air flow required to maintain the pressure is the same as the air permeability of the specimen window. The air permeability at different pressures, normalized to a reference pressure and temperature, and to the size of the window, is used to classify the window according to NS-EN 12207. The reference air permeability is calculated using two metrics: related to the window's overall area, with the unit $m^3/(h\times m^2)$, and related to the length of opening joints, with the unit $m^3/(h\times m)$. Both metrics are classified on an associated scale featuring identical classes from 1 to 4. The classification of the window is determined by the most favourable metric, provided they are not too dissimilar. To meet the requirements for certification by NDVK, the window must achieve air permeability class 4, which corresponds to a reference air permeability < 3 $m^3/(h\times m^2)$ or < 0.75 $m^3/(h\times m)$, at a maximum test pressure of 600 Pa.

2.3. Water tightness test

The water tightness test is described in NS-EN 1027. Like in the air permeability test, the specimen window is mounted in a frame fitted in the wall of a pressure test chamber. The frame joint is sealed as described in Section 2.2. Note that in certain other countries, i.e. Sweden, the common practice is to seal windows into the frame at the vapour barrier (interior) side. This excludes leakage paths through the window assembly to the adjacent wall assembly from the testing procedure.

A constant spray of water is then applied to the external surface of the specimen while the pressure is incrementally increased at regular intervals. For the first 15 minutes of the test, water spray is applied at ambient pressure. The pressure is then increased in steps of 50 Pa every five minutes until 300 Pa is reached, after which the pressure is increased in steps of 150 Pa every five minutes until 600 Pa is reached. The window is classified according to the pressure level at which water penetration occurred. There are ten classes, 0 to 9, determined by the pressure levels, as well as special classes E for pressure levels exceeding 600 Pa. The highest pressure for which the window passes the test is denoted next to the E classes, i.e., E750 or E900. Figure 2 shows an example of a window mounted in the test chamber.

Two variants of the test procedure exist: Method A for unshielded windows, and method B for shielded windows, in which twice as much water is sprayed onto the specimen and the spray nozzles are positioned differently. Method A is the most widely used for windows, as Method B is mostly used for exterior doors, which tend to be located beneath an overhanging roof. Of the 1130 test results analysed for this article, only six tests employed Method B, all of whom were testing exterior doors. Leaks were visually identified, and their locations noted in the test report as described in NS-EN 1027 [12].

2.4. Analysis methods

The results of 1130 tests were found across 741 test reports, dating back to 2003. A spreadsheet was created, wherein the following parameters were noted for every test: Product names, dimensions, hinge configurations, number of windows in the screen, total length of opening perimeters, air permeability class, watertightness class, whether the test was continued until leakage occurred, the location of leaks, and the load level at which leaks occurred.

Not all tests had continued to higher pressures after the window passed the criteria for NDVK certification. Some multiple-face windows had their test continued after one window failed while the other(s) did not, while other tests were aborted at this stage. Some tests were carried out as part of product development, wherein the same products were tested multiple times even if they passed the criteria. The data does not distinguish between product control testing, type approval testing, or re-testing. Hence, it is not known whether any of the windows were re-designed or modified between multiple tests.

3. Results

The general distribution of rain tightness classifications over time is shown in Figure 3. Note that the dark green bars comprise all classes that meet the NDVK recommendations, ranging from class 9A to E1500. It can be seen from the trend line that tested windows over time have generally exhibited better rain tightness, with fewer windows failing the test at lower pressure levels and more windows meeting the recommendations. All types of leakages decrease in prevalence over time. It may be generally concluded that manufacturing quality has improved over the years.

Figure 2: Window specimen mounted in test chamber. Left: Window interior side. Right: exterior.

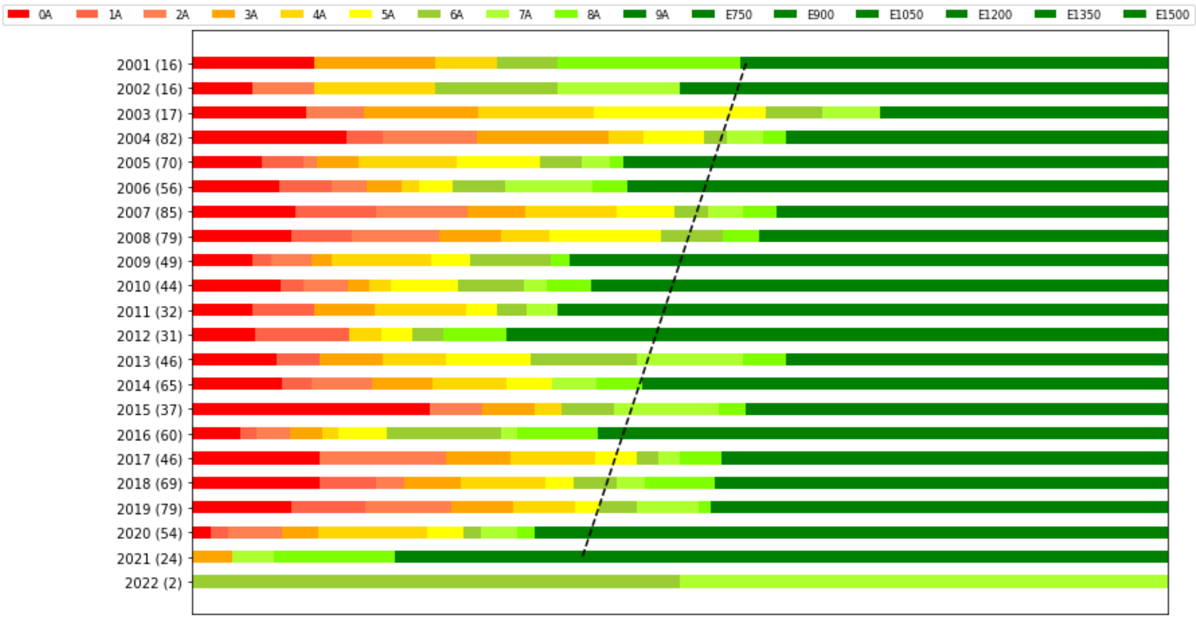

Figure 3: Distribution of rain tightness classifications over time. The number of tests per year is shown in brackets on the Y axis. Since only two reports were available for 2022, the numbers from that year were not included in the calculation of the trend line.

The distribution of rain tightness classifications for every window type is shown in Figure 4. Note that for some of the window types, only a handful of tests have been performed, creating a skewed image of their performance. Excluding the window types with few (<10) tests that skew the data, casement doors and top-hung casement windows stand out as the types with the relative poorest performance. Apart from fixed windows, tilt and turn windows stand out as performing the best with the highest portion of the windows passing the tests. In general, however, the difference between window configurations does not appear to be substantial.

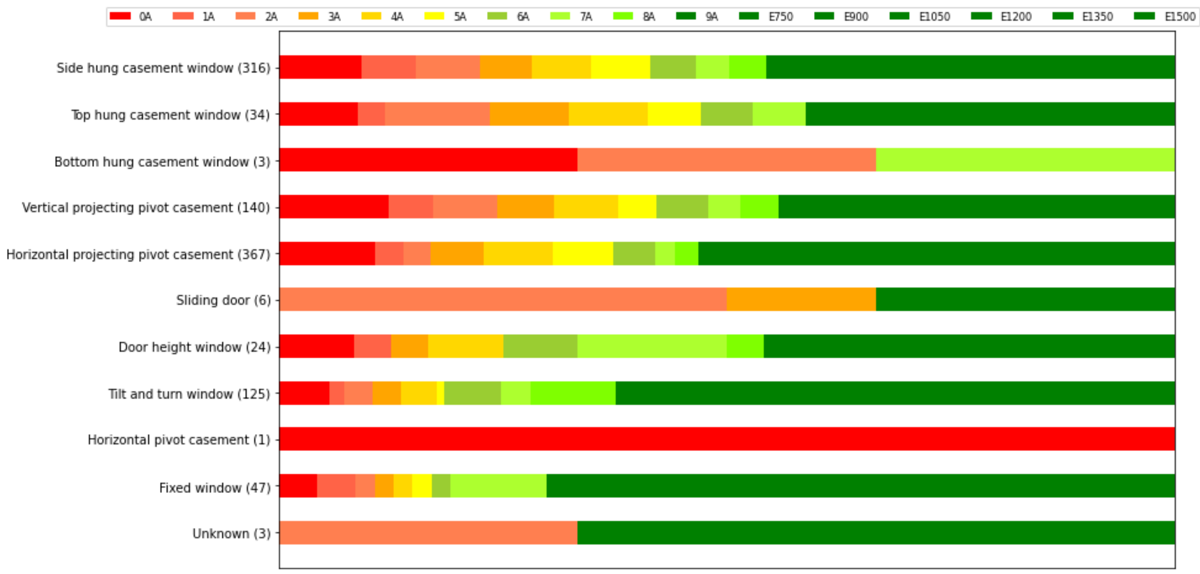

Figure 4: Distribution of rain tightness classifications by window configuration.

A comparison of watertightness class and measured air permeability was also conducted (not illustrated here). The results indicate a correlation between watertightness and airtightness, which is in agreement with previous research on the topic [15]. Windows in the lower watertightness classes tend to have higher rates of air leakage.

Figure 5 shows the distribution of rain tightness classification related to the number of opening edges that are sealed with weatherstripping gaskets. Among tested windows, it is more common not to use weatherstripping, and where it is used, it is common to limit it to one edge. The data appears to show that windows that feature weatherstripping along one edge are on average *less* rain tight than ones without weatherstripping at all. However, the average is somewhat skewed by the inclusion of fixed windows in the category of "no weatherstripping". The trend line in Figure 5 otherwise shows that rain tightness is generally higher for windows featuring weatherstripping along more opening edges.

In Figure 6, nine categories of leak locations and their prevalence are presented. Note that the locations are illustrative for the categories and not necessarily the actual location of each leak. The load levels at which the leak occurred is indicted by the colour of the dot. The size of the big circles indicates how many leaks occurred of each type (also indicated in brackets). The colour of the circles indicates the average load level at which leaks occurred in that category (also indicated below the name of the category). As can be seen, corner joints constitute a major risk of leaks, as this category contains the largest number of leaks, and they occur at a relatively low pressure level on average. No clear correlation is observed between window clearance and rain tightness.

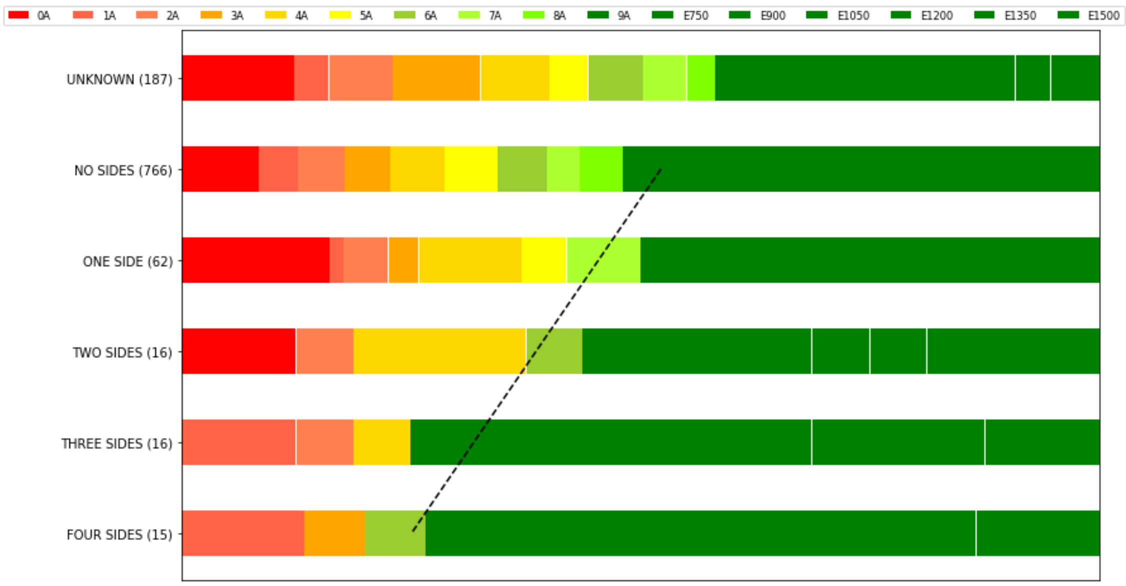

Figure 5: Distribution of rain tightness classification by number of sides of the casement that feature weatherstripping.

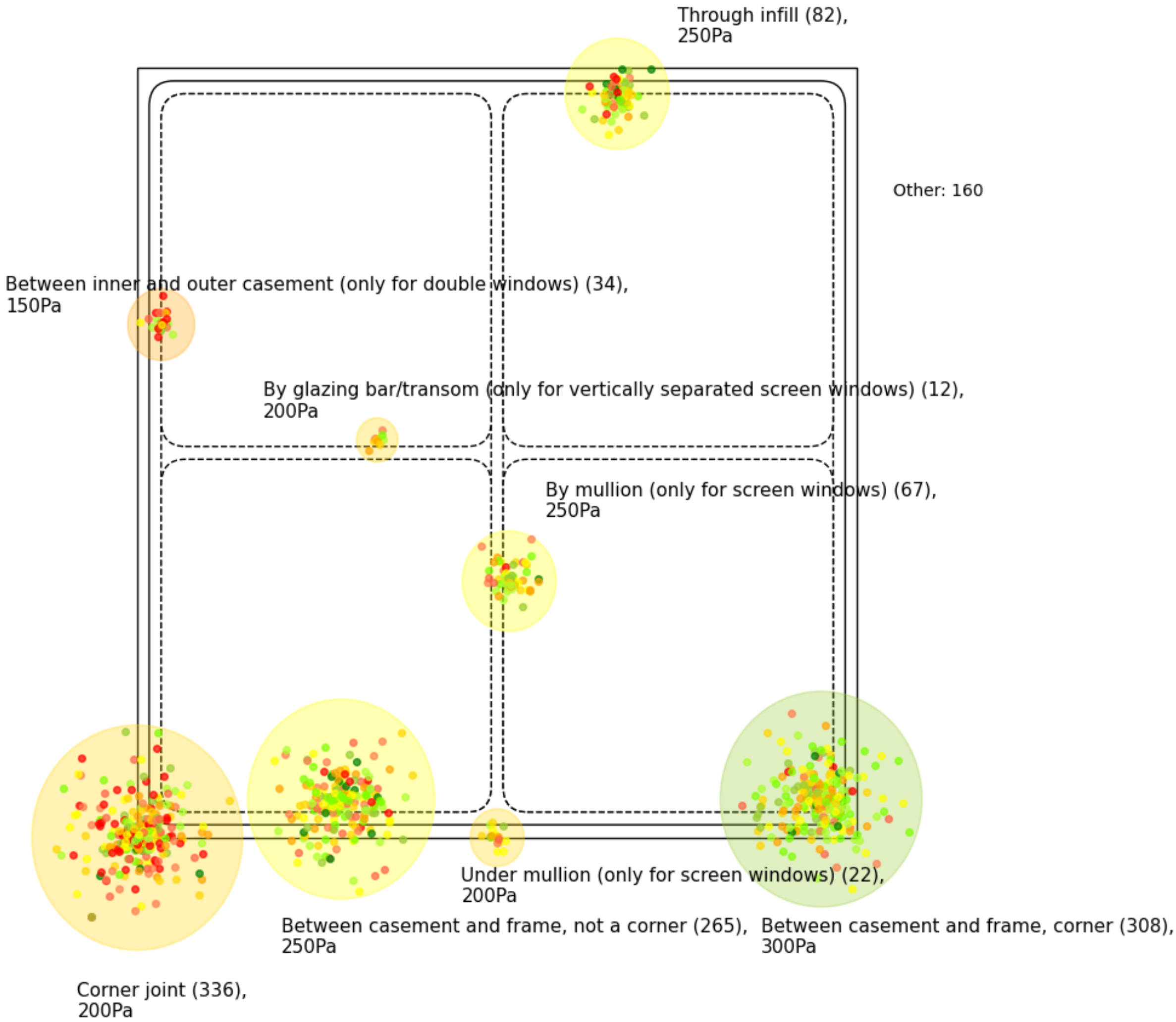

Figure 6: Location of leaks and the load levels at which they occur. The colour of the circles indicates the average load level at which the leak type occurs, also shown beneath the description of each leak type. The number in brackets is the number of recorded leaks of this type.

4. Discussion

4.1. Where do leaks most commonly occur in window elements, and at which levels of exposure?

The results indicate that the corner joints of the casement or the frame is the most common location of leaks, and also where leaks are initiated at the earliest levels of testing. Second most common are leaks penetrating the joint between the casement and frame, here too primarily in corners. Note that leakages in the corner joint of window frames present a particularly high risk of building defects, since the leak is not readily visible when the window is mounted in a wall. Water may then seep in over time and create large moisture defects before the leak is noticed. The data also shows a clear correlation between a high score of airtightness and a high score of watertightness. A similar trend was observed by van den Bossche and Janssens [15], although this was not investigated quantitatively in their article. The Canadian study [9] points out that the consequential risk of building defects is the greatest for leakage paths that allows the water to enter the adjacent structure, without being visible on the interior side.

4.2. What share of windows experience problematic levels of leakage?

Leakage rates are found to depend on the window type and hinge configuration. As might be expected, fixed windows perform better than openable windows, as they do not feature an opening for water to penetrate through. Among openable windows, certain hinge configurations stand slightly out with a higher performance, with tilt and turn windows passing the largest share of tests. The literature review and laboratory investigations by van den Bossche and Janssens came to the same conclusion [15]. Top hinged casement windows exhibit the lowest share of passed tests, although vertical projecting casement windows have the highest share of failure at low levels. The data are inconclusive as to whether side hung or top hung windows perform better, but practical differences may be more apparent in use when the windows are open.

However, all common types of windows (tested more than 10 times) exhibit a largely similar rate of passing tests, spanning approximately 40-60%. This is to be expected, as window types that stand out with substantially inferior performance than others would presumably be phased out of production.

4.3. How can the weathertightness of windows be improved?

Windows that feature weatherstripping gaskets along several opening edges tend to have a higher score than windows that only feature it along one or two edges. Windows with less clearance in the opening between the frame and casement do not necessarily perform better than ones with more clearance. It is believed that this is partially caused by capillary effects, which become substantial for very narrow openings. Hence, it is recommended that windows focus more on improving the extra barrier provided by weatherstripping, than to reduce the clearance in the opening. Note however that the opening should not be so large that the weatherstripping gasket cannot achieve a proper overlap [15].

It should be noted that reducing the share of manufacturing defects would also improve the average window performance. However, this research primarily concerns the design of windows and not their manufacturing process, and so cannot make any recommendations in that regard.

A limitation to the data set is that it does not necessarily identify leaks that appear in different windows *in situ*. Leaks due to poor workmanship will typically not appear in a laboratory setting. Building defect cases are commonly handled between the client and the contractor, while cases involving defect products will be forwarded to the manufacturers without involving NDVK. This dataset may hence not be usable to assess whether window defects constitute a problem in the Norwegian building sector at large.

5. Conclusions

The data from 1130 tests of various windows indicate that corners pose a consistent challenge to the manufacturing of rain tight windows. Defects in the joints of frames and casements are shown to be the most common route for leakages, followed by water penetrating through the corner of the opening between frame and casement.

While all window types exhibit largely similar performance in terms of the share of passed tests, differences can be discerned. Among openable windows, tilt and turn windows perform better than simple casement windows and projecting pivot casement windows.

The presence of weatherstripping gaskets along the opening edges of casements and window frames is found to substantially improve rain tightness. However, reducing the clearance in the openings does not appear to improve rain tightness.

Future work on the topic should aim to analyse specific features of windows and measures to improve air and rain tightness, possibly in conjunction with laboratory tests, to determine and quantify the impact of each feature.

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