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Watertight insertion of heavy sliding doors in exterior walls

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Watertight insertion of heavy sliding doors in exterior walls

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Abstract The joints around heavy terrace doors are considered a weak point in rain-exposed façades, as it is vulnerable to defects in design and construction. The insertion process of heavy sliding doors is a notable challenge. Design recommendations from manufacturers as well as national advisory agencies are currently lacking. This paper presents a full-scale laboratory study on the water tightness of heavy sliding doors with joints waterproofed according to five different solutions. The door assembly is mounted in a pressurized cabinet with water spray nozzles to simulate wind-driven rain. The interior side of the joint around the door is monitored for moisture leaks at steadily increasing pressure levels. It was found that leaks most often occur in the corners of the frame. Sealant mounted before the door itself was hoisted in place tended to be twisted or distorted as the door was adjusted in the frame, spoiling the waterproofing. A common feature of the most watertight solutions was that the sealant was mounted after the door itself was fastened to the frame. The sealant should be continuous, flexible, mounted in a single plane, and preferably be accessible during the assembly process. Waterproofing recommendations for the design and insertion of sliding doors should account for practical challenges brought on by the heavy weight.

1. Introduction

Three-quarters of building defects in Norway are caused by moisture [1]. Defects caused by precipitation water constitutes an increasingly large share of building defects in Norway [2]. Further, a changing climate is expected to bring increasing amounts of precipitation [3], with implications for the time available for structures to dry [4].

The primary source of precipitation stress on a building façade is wind-driven rain [5]. Wind-driven rain is commonly managed in Norway using dual-barrier weatherproofing [6], where the building's cladding acts as a main rain barrier, shielding a wind barrier which stops air penetration. The two are separated by an air cavity that allows the materials to dry. However, elements that penetrate the façade, like windows and doors, create vulnerable discontinuities in the rain and wind barriers. Waterproofing the joints around windows and doors is a key challenge to creating climate adapted buildings. Norwegian building design recommendations state five overall principles for preventing moisture damage: 1) Limit the supply of exterior moisture, 2) Limit the supply of interior moisture, 3) Limit built-in moisture, 4) Provide drying capacity, 5) If moisture cannot be kept out, use moisture-resilient materials [7]. Watertightness of joints against driving rain is achieved by limiting the number and size of openings. However, sealing the joints completely is not a feasible approach, as it prevents drying. In joints, dual-barrier weatherproofing is achieved by covering the exterior opening of the joint, typically using a board or weather-protective flashings [8], and providing airtightness by liquid or rubbery sealant inside the joint. The elasticity of the sealant maintains its weatherproofing functions despite movements of the joints. Weatherproofing can also be achieved using tape on the exterior side of the joint, but with certain limitations: the tape needs to be flexible to provide sufficient resistance to movement, and the substrate surface needs to be smooth enough for tape to stick.

Sliding terrace doors have been singled out as a particularly challenging building element [9]. The use of this type of door in residential buildings has increased, as they allow views regardless of whether they are open or closed, and the sliding mechanism takes little space. When the sliding door is open, its large opening connects the terrace seamlessly to the building interior (typically a living room). Sliding terrace doors typically consist of triple-paned glazing and have to be mounted in a double-width frame, which makes them very heavy (> 150 kg). The requirement of universal design necessitates that the floor inside and outside the door keep the same elevation without a threshold in the middle. While this feature makes it easier to move through the door, it also complicates waterproofing design. The weight and universal design requirements create challenges to the process of inserting the door and fitting it into place. Figure 1 shows a typical detail for the bottom joint of a sliding door.

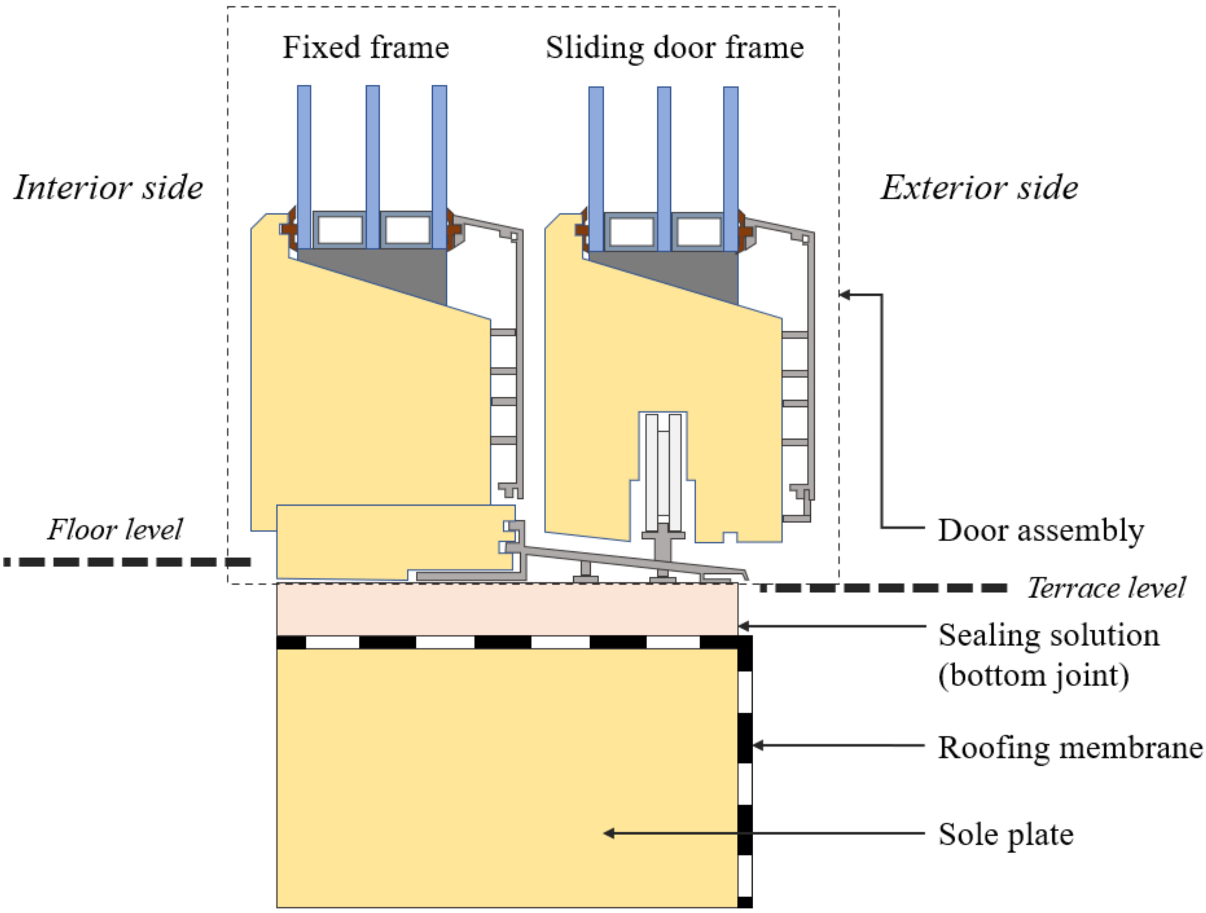


Figure 1: Typical bottom joint detail for a sliding door (not to scale).

Weatherproofing the joint around doors, and how it is affected by the door insertion and sealing process, is a topic that has hitherto received little attention. During construction, the weatherproofing is usually left to workers on-site, without clear recommendations being presented from design engineers. [9]. Norwegian national building recommendations, the SINTEF Building Design Guides [10], do not sufficiently address the process of weatherproofing doors as they are inserted and adjusted.

Manufacturer recommendations tend also to be inconsistent on this issue [11]. Moreover, sliding doors are found to be troubled by water intrusion through the door assembly itself. In sum, sliding doors present a number of technical challenges and have been seen to cause multiple conflicts between involved parties in several construction projects [9].

The present study aims to address the deficiency of information on weatherproofing of door insertion, by subjecting recommendations from literature to standard air- and water tightness tests in a laboratory. Heavy sliding doors are evaluated to be the most challenging type of door due to their heavy weight compared to hinged doors. The building industry has also requested more knowledge on this type of door. To address these concerns, the following research questions are evaluated:

- What challenges exist related to the insertion and weatherproofing of the joints around heavy doors inserted in a building envelope?
- Which measures may contribute to a higher weatherproofing performance of the joints, and simplify the insertion of heavy doors?

Norwegian literature and manufacturer recommendations have been consulted to find recommended weatherproofing strategies for the joints. A preliminary literature study uncovered no relevant results in English, so an in-depth search was not conducted. Door/wall assemblies were built and tested in a laboratory and may not accurately reflect conditions of assembly on a construction site in terms of accessibility of the details, as well as allowed time and attention to detail by the personnel. However, the investigated strategies should be feasible to implement on a building site and lessons learned in the laboratory still apply. Finally, only a single test was performed for each configuration of the door/wall joints.

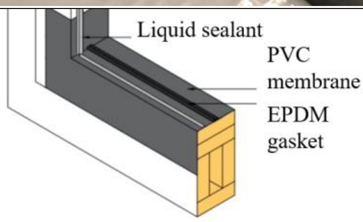
2. Methodology

The standard water tightness test for windows and doors is described in NS-EN 1027 [12]. The door is mounted in a frame which is fitted into the wall of a pressure chamber. The air pressure in the chamber is increased beyond the ambient pressure in steps of 50 Pa until it reaches 300 Pa. From that point the pressure is increased in steps of 150 Pa. Nozzles spray water onto the assembly, simulating rain. The water tightness classification of the door/window, described in NS-EN 12208 [13], is given according to the pressure level at which water penetration occurs. Obtaining a certificate of recommendation from the Norwegian Door and Window Control requires a that water penetration does not occur until the 600 Pa step [14].

The door, including its frame, measured 1988 mm wide by 2088 mm tall, and weighed 200 kg. The door and the outer frame are illustrated in Figure 2. In conventional tests, the edge joints around the door are sealed using vapour barrier and tape while the water tightness of the door and door frame are assessed. In the present study, the tightness of the door is ignored while the assessment focuses on the weatherproofing of the joints between the door frame and the building frame. The setup of the test is not affected due to this change, only what is registered in the test report. As is common practice, a PVC roofing membrane is placed on the sole plate to protect it from intruded moisture. The dark grey membrane can be seen underneath the door in Figure 2.

Five different configurations of weatherproofing were tested according to NS-EN 1027. An overview of the key parameters of the tests are listed in Table 1.

Table 1: Overview of performed tests.

Test no.	**Weather-proofing of bottom joint**	**Illustration of bottom joint sealant**	**Weather-proofing of side/top joints**	**Other notes**
1	Neoprene gasket, attached using double-sided tape		Wind barrier tape Additional liquid sealant in corners	Initial airtightness test performed before water tightness test
2	Liquid sealant, three parallel lines		Wind barrier tape	
3	Flexible adhesive sealing strip		Flexible adhesive sealing strip	Wind barrier mounted on sole plate instead of PVC membrane (to fasten sealing strip)
4	EPDM rubber gasket		Liquid sealant, one line	Not dismantled after testing
5	EPDM gasket and liquid sealant, one line (applied after door was mounted in frame)		Liquid sealant, one line	Modification/ extension of Test 4

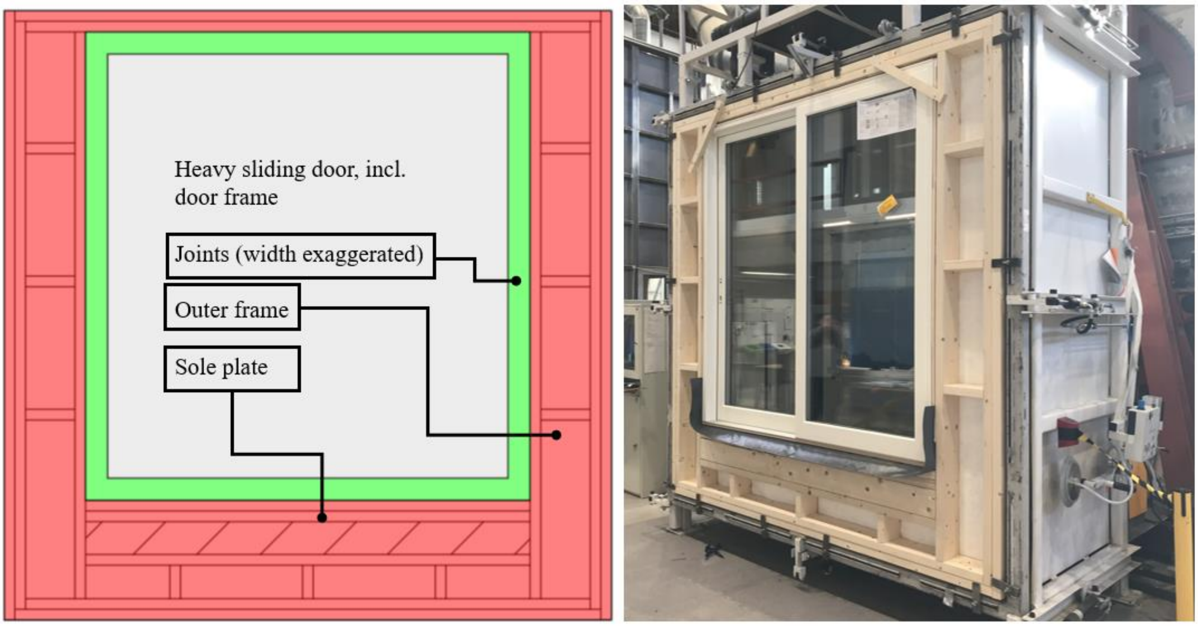


Figure 2: Test assembly and frame, illustrated (left), mounted in pressure test apparatus (right). The door's exterior side is facing into the chamber; hence the interior side is visible in the picture.

3. Results

3.1. Test 1: Neoprene gasket and tape

The first test was performed with a neoprene gasket in the bottom joint of the door, with the top and side joints covered with tape. This solution is recommended by the SINTEF Building Research design guidelines for exterior doors [15]. Sealing the corners was found to be difficult using this strategy, and injection of liquid sealant was required to close visible openings in the assembly. A qualitative airtightness test using smoke revealed multiple air leaks even afterwards. The watertightness test revealed leaks in the corners of the assembly already at a pressure level of 50 Pa. The test was aborted after the pressure had reached 200 Pa.

Disassembly after the test revealed that the neoprene gasket had not adequately covered the corners of the frame, and that the liquid sealant injected after mounting had failed to seal the observed holes. The neoprene gasket had also been twisted by the insertion of the door, ripping it free of the double-sided tape that attached it to the sole plate. During the watertightness test, leaks had been observed in this location.

3.2. Test 2: Liquid sealant and tape

This test was similar to Test 1, but the neoprene gasket was replaced with three lines of liquid sealant. The solution was found in design recommendations by a major building material supplier. Additional sealant and tape were used to seal the corners of the door frame. However, the corners once again proved to be the weakest point of the assembly. Water penetration in the corners occurred at 200 Pa, but the test was continued until a pressure level of 600 Pa to provoke leaks in different locations than those observed in Test 1.

Post-test disassembly showed that the weight of the door had squeezed the liquid sealant completely flat, to the point it resembled a layer of paint on the PVC substrate. Much of the sealant was squeezed out of the joint entirely. Water leakage through the sealant was observed at 450 Pa.

3.3. Test 3: Flexible adhesive sealing strip

A flexible adhesive sealing strip was attached around the door frame before insertion. The solution was developed as part of the research project "Verkøykasse for klimatilpasning av boliger" ("A toolbox for climate adaptation of dwellings"). The sealing strip consists of a 100 mm wide breather membrane substrate, covered in butyl adhesive on alternate sides as illustrated in Figure 3. One side of the substrate is folded like an accordion and features flexible adhesive. Thus, it can be stretched to fit around corners, then attached to the outer frame like tape once the door is inserted. It was necessary to fix a piece of wind barrier along the sole plate for this test, as the butyl glue is not able to adhere directly to the PVC membrane.

Figure 3: Flexible adhesive sealing strip. Note the adhesive on alternate sides of the strip.

The test was continued beyond the threshold for recommendation since the solution appeared completely watertight at 600 Pa. Water leakage was observed along the top joint at a pressure level of 1050 Pa. Leaks occurred in the outer frame of the assembly at lower pressure levels, but these are outside the test specimen and thus the scope of the study. The leak along the top joint occurred between the door frame and the adhesive.

Disassembly revealed that the adhesive strip had moved slightly relative to the door frame, presumably due to the high static pressure. Had the pressure been sustained for a longer time, more substantial leaks might have occurred as the strip could have been torn loose. However, this is not a major concern for the operation of the door, as such high static pressures do not occur for long in nature.

3.4. Test 4: EPDM gasket and liquid sealant

This test largely resembled Test 1, but with liquid sealant along the top and side edges instead of tape. The gasket was also different; a double D-profile of EPDM rubber. This gasket features adhesive on the rear side, making it possible to adhere directly to the PVC membrane on the sole plate and up about 2 cm in the corners. The liquid sealant was allowed to harden over a weekend prior to the tests.

However, leakage again initiated quickly in the corners, at pressure levels as low as 100 Pa for the lower corners. Leakage occurred in the upper left corner at 150 Pa. The test was continued to a pressure level of 600 Pa. No leaks occurred elsewhere than in the corners throughout the test. The setup was not disassembled after the test. Close inspection of the joints indicated that the sealant had kept the joints dry along the edges.

3.5. Test 5: Liquid sealant

Test 5 was a continuation of Test 4, but with an additional line of liquid sealant injected on the exterior side of the EPDM gasket. This line was laid as a continuation of the sealant lines in the side joints and inserted while the setup of Test 4 was assembled in the frame.

Lone droplets of water were discovered in the corners as soon as the test started, but it is assumed that these were left over from Test 4 since no more droplets appeared in that location during the test. A minor leak was discovered in the top edge at 450 Pa, developing into more substantial leaks at 600 Pa. An air current was felt in the lower right corner, but no water intrusion was detected.

Disassembly after Tests 4 and 5 showed that the EPDM gasket had lost adhesion to the side joints, and thus did not provide watertightness in the lower corners. The liquid sealant had not been squeezed out of the bottom joint like in Test 3 since it had been applied while the door was already resting on the sole plate.

4. Discussion

4.1. Challenges related to the insertion and weatherproofing of heavy doors

The tests suggest that two primary challenges exist relating to the insertion of heavy doors: First, it remains challenging to achieve watertightness in the corners of the joints between the door frame and the outer frame. Second, the weight of heavy doors may compromise weatherproofing solutions put in place before the door is inserted.

The weight of the door necessitates a different weatherproofing solution in the bottom joint than the top and side joints. Joining the sealant solution in the side joints to that of the bottom joint is challenging even with easy access to the door from both sides. In practice, labourers on a construction site may not easily access these joints to adjust the sealant in the corners after the door is inserted.

While being inserted, the door must move without much wiggle room, and its position must be adjusted while in place. These movements may squeeze out liquid sealant or tear loose rubber gaskets, creating gaps where air or water may pass through the joint.

The side joints maintained their integrity without issue through all tests, suggesting that these joints are not prone to the same level of challenges as the bottom joint. Water intrusion in the door assembly also continues to pose problems, such as between the door leaf and frame, or in corner joints of the door frame [9]. These challenges appear to be related to the manufacturing of the doors. However, moving the assembly on the construction site may also create potential leakage points. Fitting the door to be exactly level and plumb is very challenging. Even small divergences from the vertical or horizontal plane were found to create air and moisture leaks in the door assembly, around the joint gaskets. The door should therefore be handled and mounted with care.

4.2. Recommendations to improve weatherproofing

Solutions that run continuously in the joint corners are found to vastly improve watertightness in the corners over more disjointed solutions. The flexible sealing strip and the continuous line of liquid sealant both displayed vastly better watertightness performance in the corners than the other solutions.

It is essential to maintain the integrity of the sealing solution in the bottom joint as the door is inserted. The neoprene gasket was twisted out of place as the door was inserted, and the liquid sealant was squeezed too flat to be of any use. Tests where the bottom joint seal was carefully maintained performed much better than those where the insertion could damage or compromise the seal.

The side joints were found to be comparatively easier to waterproof, with no recorded leaks across any of the tests. However, it should be noted that preventing water intrusion is only one part of the waterproofing strategy. The assembly must also be permitted to dry, which may be challenging to facilitate. Wind barrier tape on the exterior side of the joints may prevent water from entering, but may be too vapour tight to facilitate sufficient drying [16]. This remains a challenge to be solved.

5. Conclusions

The laboratory study explored many of the challenges related to waterproofing heavy sliding doors. The performance of any solution depends largely on details of the execution. The bottom joint, which bears the weight of the heavy door, requires a weatherproofing solution that is not compromised by the heavy loads during insertion. Joining the weatherproofing of the bottom joint to that of the side joints is also found to be challenging in practice, making the corners weak points prone to air and water intrusion.

Accordingly, the solutions with the best performance were those that involved a continuous loop of adhesive or sealant in a single plane around the entire door, and that could be fitted or modified after the door had been hoisted into place. However, maintaining the integrity of the corners remained a challenge. A solution that achieves sufficient watertightness while also maintaining drying capacity is yet to be found.

Future work on the subject should seek to further improve and field test the best-performing solutions in a practical setting. Conditions are different on a building site than in a laboratory, and the solutions must be verified as practically feasible to build in an industry setting. The durability of the different solutions in the long term should also be investigated. Finally, the results of the present study should be verified to give further documentation to update the design recommendations.

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