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LABORATORY STUDY OF DRIVING RAIN RESISTANCE OF FOUR FAÇADE SYSTEMS WITH WINDOW FITTINGS – EXPERIMENTAL RESULTS OF LEAKAGE FLOWS

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Abstract

Façades generally experience leaks and driving rain is considered to be a significant source of moisture, which should be taken into account when carrying out moisture calculations for exterior walls. Water can leak into the exterior walls and façades to a greater or lesser extent. However, we lack specific information with details on the amount of penetrating water.

Four façade systems have been examined. Three of the façade systems were different in that there was one ventilated system, one single-stage sealing system and two drained systems. To better understand the exact importance of seals and variations in installation and workmanship, these factors have also been studied.

The measurements show significant water leakage where seals are absent. Even in cases with seals present, there are leakages. Although the installations were performed by professionals, it was still leaky which shows that façade systems with window fittings should be designed and tested for any anticipated defects in order to ensure that the exterior wall are not subject to moisture damage.

Keywords: *driving rain resistance, water leakage, façade, windows, EN 12865*

1 Introduction

Water can leak into exterior walls and façades (1–4) to a greater or lesser extent. Window connections are the most common features in façades and laboratory studies have revealed that the frequency of leakage in Sweden is about 70% (5). It is relatively common for windows to leak along the window structure itself (6, 7). However, there is no specific information available on the quantity of water that might be expected to penetrate the window connections in façades.

There are currently no reliable theoretical analysis tools for fully designing and assessing the moisture safety in an exterior wall, with façade details such as window connections, if the specific data is unavailable (8). Standard assessments are often used, for example based on the percentage of driving rain that penetrates the façade (9), distributed per square meter, which is an important factor in gaining a more detailed understanding of how to assess the moisture safety. The quantity of leakage appears to have a very high level of uncertainty or risk which is why more knowledge is needed to measure this in more detail (9–12). In order to use correct input data in theoretical simulations, extensive data and experience probably is required, based both on field and laboratory experiments and tolerance assessments, or specific tests for the solution in question.

Consequently, more knowledge is needed to be theoretically capable of designing, planning and assessing new or commonly occurring solutions and structures in a reliable way. Given the need for more knowledge about how the façades and solutions work in general but also more specifically in driving rain, four façade suppliers were asked if they would make their systems available for a range of laboratory experiments. The purpose of this study was partly to observe leakage rates through possible leaks at the connections between the façade and windows, and partly to study the impact the various solutions and variations in assembly have on driving rain resistance.

2 Materials and methods

A standardized testing method has been used to study driving rain resistance and the flow of leakages in experimental trials on four façade systems with windows connections. Two of the façade systems have been given deliberate defects. The rear wall elements (thermal insulation and interior finishes) were not put in place, which allowed the rear of the façade systems to be accessible for visual inspection. This means that the walls may have been exposed to higher pressure difference compared than a complete wall (with thermal insulation and interior finishes). Additionally, adaptations are needed on the inside of the façade to allow collection devices to determine the quantity of water leakage. Note that several of the systems are designed with rain seals in multiple steps, which means water may leak through the outer façade layer but not reach the structure. Therefore, several of the systems work adequately even when measuring leakage through the façade layer, provided that it does not reach the structure. The impact of leakages on the entire wall has not been included in the study.

2.1 Instructions for the configuration of the experiment

Prior to assembly or configuration, the façade suppliers were given the following information. Each façade system (experimental wall) should be built up in three vertical sections (**Fig. 1**). The horizontal rows of windows are meant to simulate each floor level for a three floor building. Section 1 is built up in the best possible way by specially trained installers. This will form the base level for driving rain resistance or leakage. In sections 2 and 3, introduction of a number of possible and verified working procedure defects (5–10 pcs) based on interviews, for example, with system developers, trained installers and experiences gained from testing and investigative activities. The section 3 was expanded in order to allow installation by a carpenter without any specialized knowledge of specific systems, but with access to the installation instructions.

Each experiment wall should be fitted with both wooden and metal-clad wooden windows supplied and installed by the façade supplier, with the dimensions 600 x 600 mm. Additionally, the option to also use plastic windows and metal windows was available. All windows were openable. Collecting devices for leakage were installed by laboratory staff and located under each window and section.

2.2 Four experimental walls

The laboratory provided a steel test frame with a wooden stud frame. The façade suppliers each installed or built an experimental wall. Each experimental wall had the dimensions 3 x 3 m. In total, four walls were made available and each comprised of a specific façade system, at least in section 1. Sections 2 and 3 include some intentional defects.

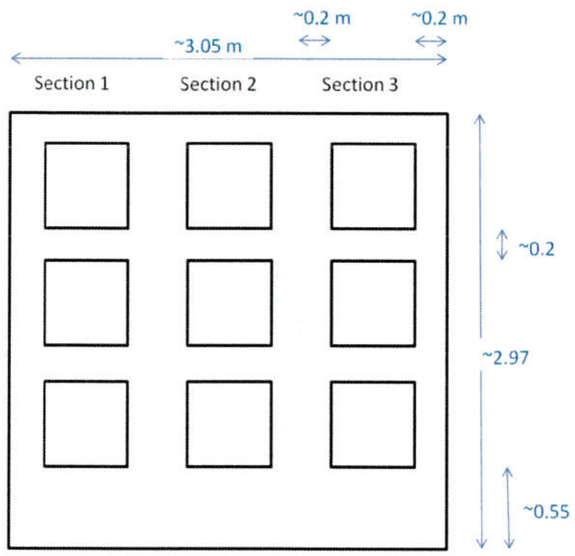

Fig. 1 *Sketch of experimental wall*

Walls (numbered 1-4) were constructed as follows (seen from outside):

1. Façade boards (polymer composite board), outdoor air gap, 300 mm mineral wool insulation (with drainage ducts), plywood and plastic foil (**Fig. 2**). Exterior window sills (metal) were about 100 mm wider than the windows on each side. Connections at the windows were sealed with sealing compound. Rubber strips were fitted behind the façade board joints to metal battens. The bottom of the wall had a waterproofing mat (base flashing) to channel water away. Exterior window sills were sealed to windows with sealing compound.
2. 15 mm prefabricated high-performance concrete element (**Fig. 3**), 15 mm of mineral wool insulation, 100 mm XPS-insulation. Element joints and connections to windows were sealed using sealing compound. No backer rod was fitted to the vertical joints or to the horizontal joints in the bottom wall. Gaps around the windows were filled with the sealing foam. Additionally, a sealing strip was fitted to the outer section of the space between the sealing foam and sealing compound, around the window, apart from at the bottom of the window connection.
3. 20 mm rendering, 200 mm mineral wool insulation with drainage possibility and weather barrier of water-resistant gypsum board (second line of defence) (**Fig. 4**). Joints in the weather barrier and connections to the window were sealed separately. Under the windows and exterior window sills, water discharges (window flashing) were installed directing water away from the wall and discharging just below the front of the exterior window sills. Base flashing were also installed in the bottom wall. Sealing compound was applied to seal between the exterior window sills and windows. The assembly for section 2 deviates from the installation instructions in the sense that the sealing compound has been intentionally omitted between the rear edge of the exterior window sill and the window. In section 3, the installation of the weather barrier and exterior window sills was performed by an experienced carpenter who had not had any special training on the system. However, the carpenter had access to the installation instructions and had the option of observing the assembly of the other sections.
4. 8–10 mm rendering, 100 mm EPS-insulation with drainage possibility, weather barrier (second line of defence) of paintable waterproofing and cement fibre board (**Fig. 5**).

Joints in the weather barrier and connections to windows were sealed separately using the paintable waterproofing system. Under the windows and exterior window sills, water discharges (window flashing) were installed directing water away from the wall and discharging just below the front of the exterior window sills. Base flashing were also installed in the bottom wall. Connections between the rendering and windows and exterior window sills were sealed separately using compressed sealing tape. Sealing compound was applied to the rear edge of the exterior window sills to the window. The other sections differ from the installation instructions in that section 2 has a flashing that has been intentionally omitted, and in section 3 the compressed sealing tape between the windows and rendering and between the exterior window sill and rendering has been intentionally omitted.

Nine openable windows (4–5 wooden windows and 4–5 metal-clad wooden windows) were installed per object except for object 2 which was reduced to two windows (both of wood of which one openable).

2.3 Methods

The experimental walls were docked to the rain chamber consisting of three wall sides along with floor and ceiling. Laboratory staff sealed between the steel test frame and the façade's vertical sides and top edge but not the bottom. The experimental walls represented the fourth wall side with the façade facing inwards, towards the rain chamber, and the rear of the wall facing out of the laboratory. The air temperature in the laboratory was about 20°C, air humidity was 30–40% RH, and the general air pressure was between 980 and 990 hPa. Laboratory staff air-sealed objects 1, 3 and 4 on the inside gap of the window-wall interfaces, with transparent tape.

The test method used was SS-EN 12865 “Determination of the resistance of external wall systems to driving rain under pulsating air pressure” according to Procedure B (13). However, pressure stages (0, 0–150, 0–300, 0–450, 0–450 Pa) have been restricted to a maximum of 450 Pa. In addition, there has been an additional run at 0–450 Pa for wall 2, 3 and 4 and at this stage the bottom line of spray nozzles were moved up 100 mm for one of the walls. The test period was 60 minutes per pressure stage. Rain intensity was 1.5 $l/(min\text{-}m^2)$ and runoff water was deposited on top of the wall at 1.2 l/(min-m), in line with the method. The rain chamber had a device that both created air pressure and was able to check this in the chamber. In addition, there was a rack with spray nozzles that produced a certain flow depending on a given water pressure. The water temperature was in the range of 8–12°C.

The method includes a description whereby the wall (test specimen) can be weighed before and after the testing procedure in order to determine the total absorption of water. This has not been applied, partly because the measurement uncertainty tends to be greater than the measured quantity of leaks and partly because it does not give any answers as to whether water has actually penetrated through the actual façade layer, where the water has accumulated, or how much water has penetrated at any leakage point. Laboratory staff fitted catchment chutes just below each window with dimensions of 400 x 30 x 30 mm (which covered half the window width and two chutes were used in the lower windows in each section) as well as a catchment chute close to the bottom of the wall under each section with the dimensions 780 x 200/100 x 15 mm, which has been adapted to suit the thickness of the insulation (**Fig. 7**).

Fig. 2 *Front façade of wall 1*

Fig. 3 *Front façade of wall 2*

Fig. 4 *Front façade of wall 3 installed in the rain chamber*

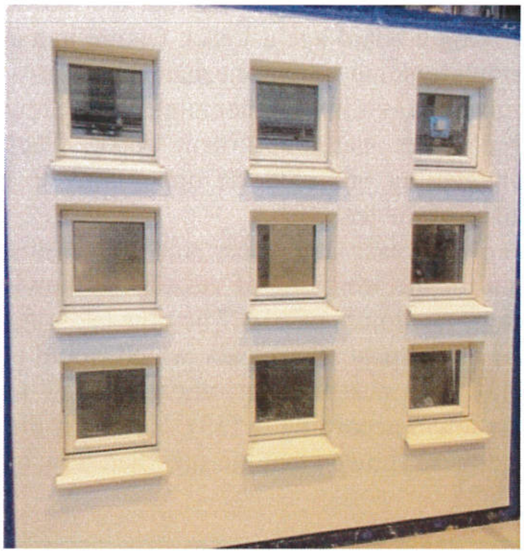

Fig. 5 *Front façade of wall 4*

Moreover, collection trays with the dimensions 620 x 120 x 15 mm were positioned under each window frame (**Fig. 6**), except in the wall 2 with only two windows. Wall 2 was delivered in four smaller prefabricated elements and was assembled by the supplier in the steel test frame. Under each window and joint, laboratory staff installed collecting funnels made of plastic sheeting that were taped and sealed to the rear façade. Each funnel opened into a glass basin for collecting water. Additionally, two catchment chutes were fitted to vertical joints at the rear façade and moisture indicators at the bottom of the exterior of the wall frame.

Fig. 6 *Photo of collection trays that were placed in the driving gap under the window frame*

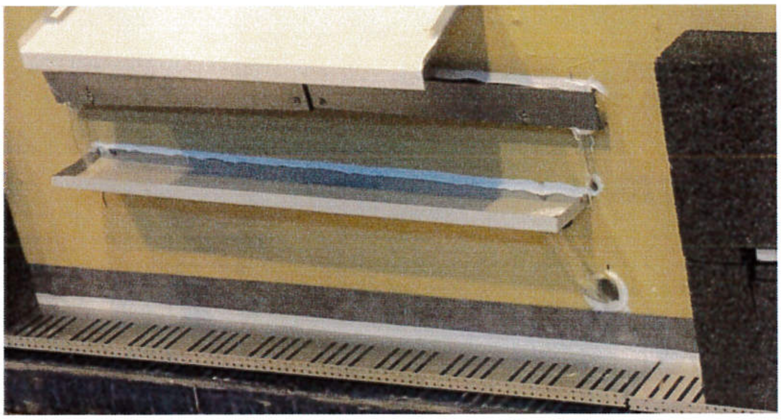

Fig. 7 *Photo of catchment chutes positioned on the outside of the weather barrier both just below the exterior window sill as well as a bigger one just above the bottom of the wall for each section. To the right of the image, you can see the installation of insulation in progress (EPS-insulation).*

Before the experiments started, the façade features/details were subject to 5–10 impacts by striking a board against each feature in a similar way to when nailing. This was conducted to simulate some of the mechanical stresses to which the features will be exposed in reality. Immediately after the completed rain simulation, the exterior of the façade was dried of any free water using absorbent paper. The façade and the features were then uncovered. Uncovering provided the opportunity to examine both the prevalence of leakages and the cause of the leakages.

The estimated uncertainty of measurement of the pressure difference (Pa) was max ±5%, and for the weighing of vessels and bowls with water, ±1g. Evaporation from the collection trays, maximum of ±1g. The time taken for starting and stopping the rain and wind load could vary by almost 30 seconds, which would give a maximum variation in leakage flow (l/min) of ±1%. The measurement uncertainty of the applied rainfall intensity and its distribution is unknown, according to (13). However, the flow of water from the nozzles was sample tested and these showed that the specified flow had a measurement uncertainty of max ±3%.

3 Results and comments

The results show the collected water quantity and leakage flow. Generally speaking, a little more water leaked out than has been quantified due to water leaking into and accumulating in the material on the way to the collection devices or that the water has followed and been led out via the underside of the exterior window sill.

The measured values and the actual differential pressure across the leaks or façade layer cannot be reported for each measurement point due to confidentiality agreement with the manufactures. Leakage has occurred in all objects and the leakage flow has been measured at 12 measuring points. The flow is reported for the six measuring points with the largest flow (**Fig. 8**).

Tab. 1 *Number of collection trays and amount of collected water (under the window) over a period of 4–5 hours, from the three walls with nine windows each.*

Number of trays	Mass of water leakage [g]
1	182
1	89
1	79
1	70
1	35
1	24
1	15
1	11
2	8
1	5
5	< 5, >0
11	0

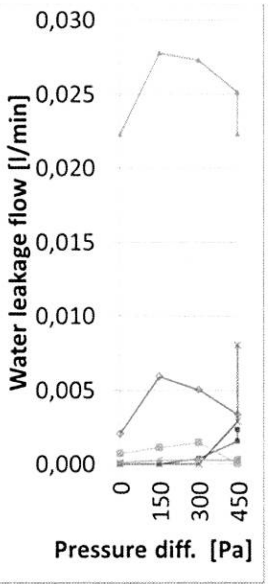

Fig. 8 *The diagram shows six of the 12 measurement points (with collector of catchment chutes or funnels) that had the largest flow of leaks [l/min]. Total pressure difference across the test objects is shown.*

The largest flow of leaks was 0.028 l/min (**Fig. 8**). The second and third largest flow were between 0.006–0.008 l/min. Water leakage began already at 0 Pa, i.e. without any wind loads. Moreover, in many cases the water leakage was not proportional to the pressure differences, which indicates that there are other critical forces for rain penetration such as gravity and kinetic energy etc. The leakage appears to have arisen randomly but the quantity of leaks was generally less where seals were installed.

Out of 27 tested window-wall interfaces 16 had measured water leakage (**Tab. 1**). However, the amount of water leakages was not less for section 1 compared to the other sections (2 and 3 with deliberate defects). Many of the leakages started already at 0 Pa.

In general, the leakages were small and imperceptible, probably difficult to avoid when installing, which may be one reason why no clear distinction could be seen between the different sections.

4 Conclusions

In practice it is very difficult or impossible to produce and ensure sealed window-wall interfaces regardless of the type of façade. It is more of a rule than an exception that leakage occurs. The results show a substantial flow of leaks, in the order of 0.01 to 0.03 l/min following strong driving rain, through small imperceptible leaks. In several cases, the pressure load is negligible or is of no importance to the flow of leaks. The leaks appear to occur intermittently providing a concentrated flow of water at these points, particularly if the materials inside the wall are moisture absorbent. These results could then be used as point sources in two or three dimensional calculations. The window-wall interfaces is an extremely sensitive point as the wooden structure is often unprotected behind the exterior window sill, and an imperceptible leak therefore allows substantial amounts of water to penetrate to the structure. The water should be discharged and any water that adheres to surfaces and materials must be able to dry out fast, before any moisture critical conditions arise.

Acknowledgement

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