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Rain Resistance of Open-joint Facade Claddings – Experiences from Laboratory Measurements

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Abstract. Façade claddings with open joints are commonly used in large buildings in Norway. Plane façade panels of fibre cement and high-pressure laminate boards are usually fabricated using joint width of 5 – 10 mm, while solar panel claddings may have joints up to 20 mm. Vertical joints are relatively raintight because the boards are mounted to vertical battens with rubber gaskets placed in between. In contrast, horizontal joints are typically mounted with open joints. The building guidelines recommend that horizontal joints should be protected by small metal profiles to provide rain protection in Norwegian climate. This is unpopular amongst architects as it affects the aesthetics of the horizontal profiles. This study aims to determine the rain resistance of typical open-joint façade claddings, particularly for horizontal joints. The rain testing was performed according to NS-EN 1027:2016 on six different claddings with different horizontal joint openings of 3, 5, and 8 mm. In addition, three horizontal profiles used for protection were tested. Twenty-five different tests were performed. The rain testing demonstrated that the penetration of water through the joint increased with an increase in the joint width. In the case of open horizontal joints, it is impossible to prevent the seepage of water through the joints. The experimental investigation conducted on metal profiles exhibited peculiar results. Two of the three profiles resulted in an increased water seepage behind the panel cladding than that of the open horizontal joints. This was due to the geometric design of the joint profile and the inability to achieve an effective compression between the facade panel and profile. An innovative profile design and supplementary rain testing are required to develop aesthetically acceptable rain tight profiles for open-joint façade claddings.

INTRODUCTION

Plane façade cladding such as fibre cement, glass fibre, and high-pressure laminate (HPL) boards are commonly used in large buildings. A distance of 5 – 10 mm is provided between each board to account for moisture and thermal induced expansion. In Norway, these boards are usually mounted on vertical battens to enable the formation of a ventilated and drained air layer. A batten and rubber gasket are present behind each vertical joint [1]. Therefore, vertical joints are relatively raintight, whereas horizontal joints are prone to rain penetration behind the cladding if additional measures are not considered. The experimental work conducted by Recatala et al. [2] demonstrated that 98% of the water penetration through the façade occurred through horizontal joints when open vertical and horizontal joints were used for façade cladding.

Rain leakage through façade cladding might not be a problem if; 1) the volume of water seepage is low, 2) most of the rain leakage flows down on the rear side of the façade cladding and do not reach the back wall and 3) the backing wall and the wind barrier system is extra robust in regard to rain penetration. However, it has been observed that moisture damage is a common occurrence in these types of claddings with open joints [3]. Therefore, Norwegian recommendations state that open joints should not be used in these claddings, particularly in cases with significant driving rain such as that for tall buildings or coastal and rainy locations [1]. The protection of metal profiles is recommended for horizontal joints to reduce the seepage of rain and block direct UV-radiation at the wind barrier system. Labyrinth-shaped metal profiles that facilitated both rain protection and air ventilation of the horizontal joints

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were reported by Herbert and Harrison in 1974 [4]. Effective rain protection by h-shaped metal profiles was tested by Bassett and Overton [5]. However, the metal profiles used for rain protection are unpopular amongst architects owing to their aesthetic implications. Therefore, such profiles are not extensively used [6]. Metal profiles that do not extrude out of the joint, thereby having an "invisible" aesthetic appearance are commercially available. However, the rain tightness of these profiles are has not been investigated.

The optimal joint width should be determined when open joints are selected. The driving rain tightness of open horizontal joints for claddings has been investigated by several studies [7, 8]. The study conducted by Isaksen [7] formed the basis for the Norwegian recommendations, wherein a joint width of approximately 5 mm was considered to be optimal. A joint width in the range of 7 – 10 mm resulted in significant rain leakage to the wind barrier. Therefore, an additional robust back wall and wind barrier is required. A joint width of less than 5 mm increased the risk of standing water in the joint which was followed by algae or microbial growth. Conversely, Mas et al. [8] recommended a joint width of 8 mm to achieve pressure equalizing of the air gap behind the cladding, and thereby reducing an important driving force of rain leakage. The effect of joint width, joint depth, and volume of rain was further investigated by Dordá et al. [9] and rain penetration was observed for a joint width of 1 mm. However, the effect of joint depth was not sufficiently documented by the test program.

The aim of this study is to experimentally investigate the rain tightness of open horizontal joints and propose possible measures to improve the tightness. The objectives of this study are:

- Investigate the effect of different joint widths in the range of 3 – 8 mm for different combinations of board materials and surface structures
- Investigate the effect of protecting metal profiles

LABORATORY TESTS

General

The purpose of these tests was to investigate the rain tightness of horizontal joints in typical plane façade panels (thickness 6 – 8 mm). Open joints and joints protected by small metal profiles were investigated. The effect of various types of board material with different values of surface roughness, width of the open joints (3 – 8 mm) and protecting horizontal metal profiles were tested. A test wall with dimensions of 2.76 m × 2.76 m was constructed. The test wall had two separate test sections that were installed and tested in a driving rain apparatus as shown in Fig. 1. A transparent polycarbonate board was used as a wind barrier to visually observe rain leakage through the cladding. The water was collected at the bottom to ensure quantitative measurement. The measurements were conducted according to [6] and were performed in the laboratories of SINTEF Community and NTNU during spring 2020.

FIGURE 1. The test wall installed in the driving rain apparatus undergoing visual inspection for rain penetration. The rear of the wall is facing to the laboratory.

Experimental Set-up

The test wall configuration with two test sections is shown in Fig. 2. The test wall was built as a wooden frame with external dimensions of 2.76 m × 2.76 m, using 48 mm × 98 mm studs (cc 600 mm) and sills. A transparent polycarbonate board (Lexan) was used instead of a wind barrier. The façade panels were fastened to 30 mm × 48 mm vertical wooden battens (cc 600 mm) on the exterior side of the polycarbonate board and an air gap of 30 mm was provided behind the panels. The panels had dimensions of 0.8 m × 1.2 m and each test section consisted of three panels, which made two horizonal joints available for rain penetration. The boards were mounted on rubber tightening bands along the vertical perimeter of the boards as recommended and supplied by the producers.

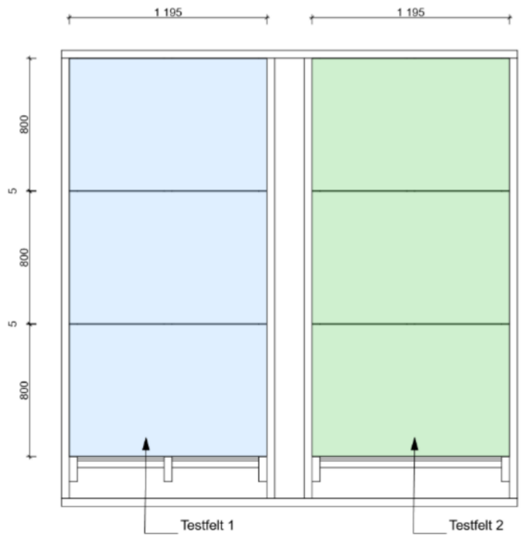


FIGURE 2. Front side of the test wall (with two test sections).

Tested Products and Solutions

Façade claddings

The board materials tested are commonly used in large buildings in Norway. Additionally, they were selected to have a certain span over type of material and type of surface, refer Table 1. The screws and tightening bands (for vertical joint) were supplied by the producers. While describing the relative roughness/smoothness of the surfaces, No. 4 can be characterized as "very rough", No. 1 as "rough", No. 2 as "smooth", and No. 3 and No. 5 as "very smooth".

TABLE 1. Tested board materials.

No	Material	Surface	Dimension B×H (mm)	Thickness (mm)	Joint Width* (mm)
1	Fibre cement	Sandblasted	1192×800	8	5
2	Fibre cement	Painted	1192×800	8	5
3	Glass fibre	Painted	1195×840	6	5
4	Glass fibre	Crushed stone	1195×840	6	5
5	High-pressure laminate	Painted	1200×800	8	8

*As recommended by the producer. In the tests the joint widths are varied between 3 – 8 mm.

Horizontal metal profiles

Three types of metal protecting profiles were tested for the horizontal joints as shown in Fig. 3. The metal profiles were made of 1-mm thick aluminium and had a width of 30 mm. Profile No. 1 and No. 3 did not extrude out of the joints. Therefore, these might be typically preferred by architects in an attempt to avoid visible profiles. The profiles are recommended to be installed in joints with a width of 8 – 10 mm. These types of profiles are generally recommended by the producers and the Norwegian design guides “SINTEF Building Research Design Guides” to be used for horizontal joints, and particularly at geographical locations with significant driving rain. The width of the horizontal joints while using these profiles was 8 mm. In contrast, the HPL boards were mounted with a width of 5 mm.

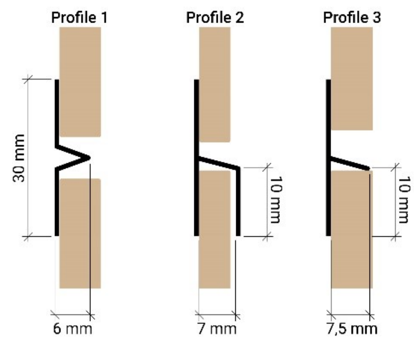


FIGURE 3. Three types of horizontal metal profiles were tested. The rain load is introduced from right.

Driving Rain Testing

The driving rain cabinet was originally set up to test the driving rain tightness according to NS-EN 1027:2016. However, the present test was not entirely tested according to the standard. The cabinet had a spraying system with several horizontally positioned water spray nozzles at a distance of 400 mm as shown in Fig. 4. The nozzles were vertically adjusted and had two inclinations. The nozzles were permanently mounted at a distance of 150 mm above the upper horizontal joint and 200 mm from the external surface of the cladding, and at an inclination of 24° to the horizontal. Although most of the water impinged over the upper horizontal joint, a small volume of water directly impinged on the joint. The bottom horizontal joint only received water that flowed down the board above. This means that it is only in connection with the upper joint that raindrops can penetrate directly to the wind barrier (polycarbonate board). Each nozzle yielded 2 L/min that impinged on the test object in a circular area. This provided 5 L/min per meter, or 6 L/min per test section.

FIGURE 4. Test wall observed from the inside of the driving rain cabinet. The water spray nozzles can be observed at the top.

A pressure difference was not applied over the façade panels or wind barrier. This condition was selected because the façade panels are ventilated at the top and bottom part of the wall. Additionally, open horizontal joints enhance the ventilation. Therefore, a pressure equalized air gap behind the panels is expected in most cases. However, in the case of tall buildings, this might not be applicable when the run-off gives water bridges over the joints (particularly when the joints are small) or when tightening horizontal profiles are used. Therefore, the test case might underestimate the rain leakage observed in practical applications.

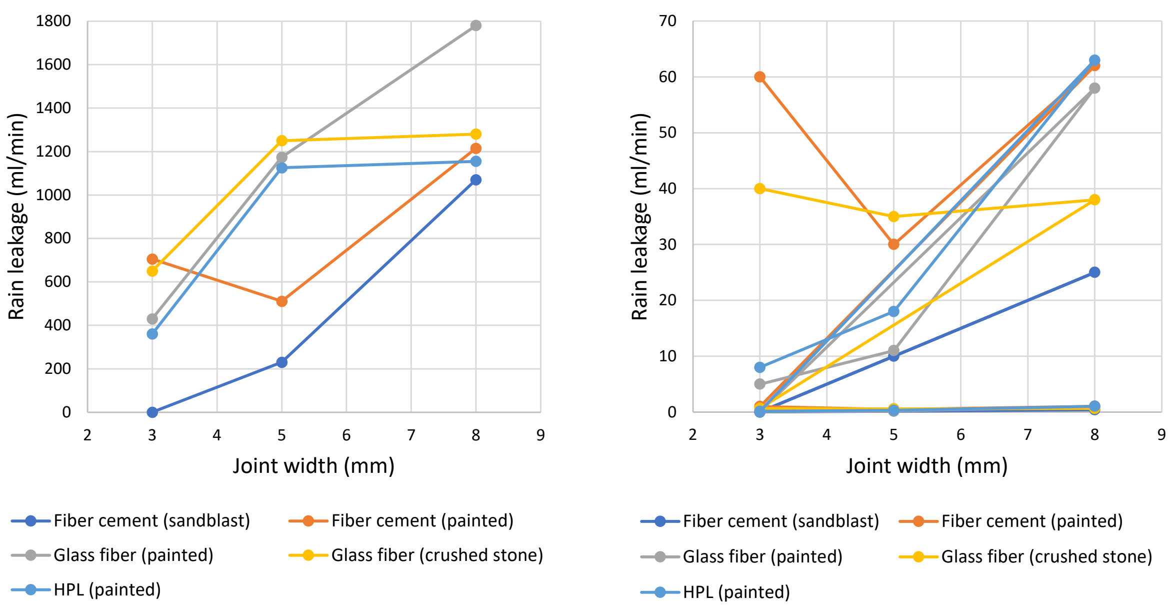
Measurements and Visual Observations

The test sections were sprayed with water 10 min before measuring the volume of leakage water to avoid water absorption at the board surfaces disturbing the measurements. The water leaked through the two horizontal joints were collected at the bottom of the wall section by metal ducts at two locations, one taped to the rear of the façade board and one taped to the outer surface of the wind barrier (polycarbonate board). The metal ducts were mounted with slope to one side of the test section, where the water was drained by plastic tubes to closed collection trays. The measurements were performed for 60 s and were not repeated. The leakage patterns were observed through the transparent polycarbonate board during testing as shown in Fig. 1.

RESULTS AND DISCUSSION

Ordinary Open Joints

The results of rain leakage as a function of board material, surface, and joint width are shown in Fig. 5. The average rain leakage measured at the rear of the façade board (for the test set shown in Fig. 5) in % of the total amount of water striking the test section (6000 mL/min) was 7, 14, and 22 % for the joint widths of 3, 5, and 8 mm, respectively. The leakage spans for the entire test set from 0% (for sandblasted fibre cement) to 30% (for painted glass fibre).



(a) (b)

FIGURE 5. The measurement of rain leakage through the façade board. (a) Rear of the façade board, (b) Outer surface of the wind barrier (polycarbonate board).

The rain leakage increased with an increase in the joint width. A joint width of 3 mm was optimum according to Fig. 5(a). However, observations demonstrated that water filled the joint for a long period of time after the test, which increased the risk of discoloration and microbial growth. With 3 mm joint the possibility for water filling the entire joint during a rain incident is very high, and the assumption of pressure equalization of the air gap might become invalid. Therefore, the pressure difference over the façade board might lead to higher leakage rates in the case of

3 mm joint width than shown in Fig. 5(a). With that background, the optimal joint width is probably around 5 mm, which verify previous investigations and recommendations [7].

The fibre cement boards, particularly the sandblasted type, had the lowest total leakage at a joint width of 5 mm. The difference was probably due to the different values of roughness/smoothness of surfaces at the exterior face and/or at the edges. The surface at the exterior face affected the run-off speed, or the path (concentrated flows or evenly distributed) of water running down the façade. However, it was difficult to determine if the application of a rough exterior surface (as for instance the sandblasted fiber cement) was advantageous because the very rough surface of glass fibre board with crushed stone exhibited the highest leakage at a joint width of 5 mm. It is therefore to be expected that the surface at the board edges, and how it interacts with the surface tension of the rainwater, plays an important role in how the water flows past the horizontal joint. However, the difference between the various boards at a joint width of 8 mm was not distinct.

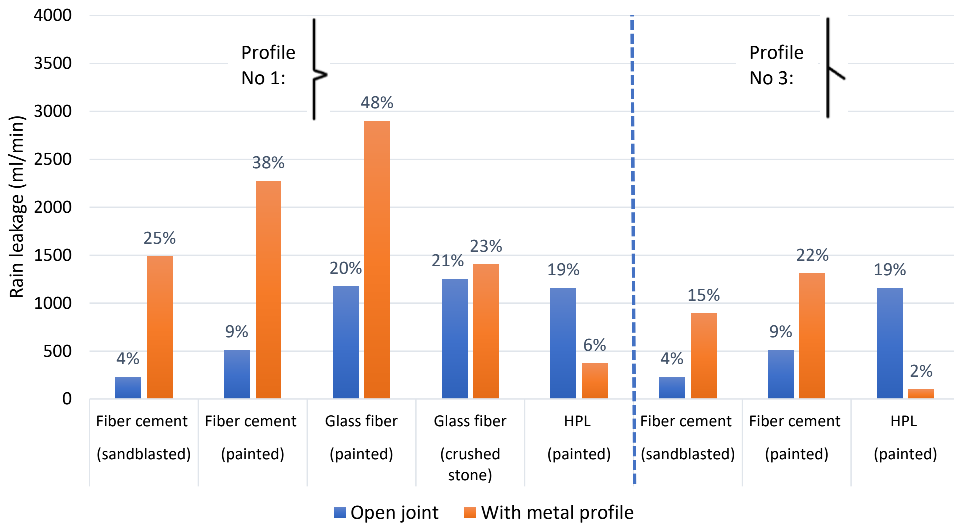
The average rain leakage at the wind barrier was 0.4, 0.3, and 0.8% for joint widths of 3, 5, and 8 mm, respectively. The leakage spans for the entire test set from 0% (for sandblasted fibre cement) to 1.1% (for HPL).

Effect of Protecting Metal Profiles

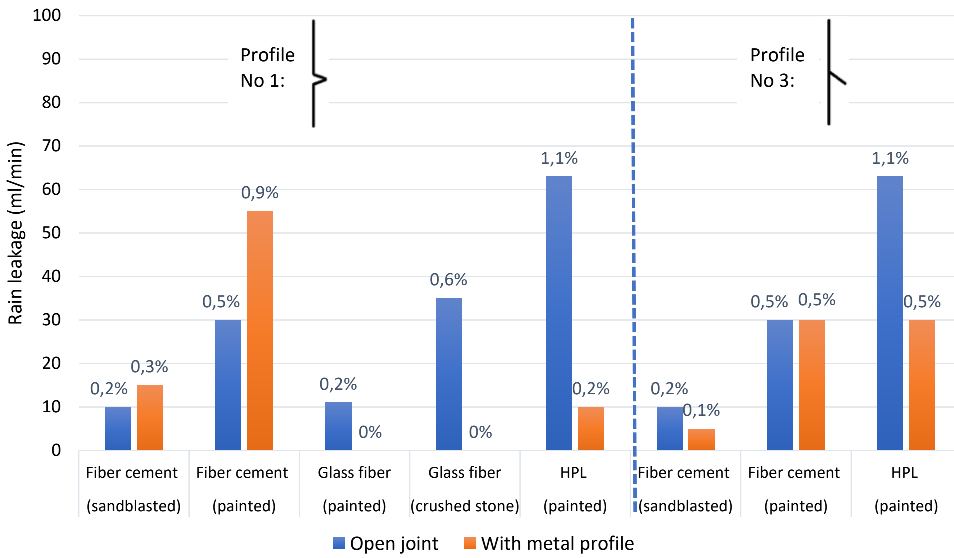
Metal profile No. 2 was tested for the two variants of glass fibre boards and rain leakage through the façade boards was not observed, i.e., the rain leakage was effectively reduced by 100%. The profile was adopted specifically for façade boards with a thickness of 6 mm as were the thickness of the glass fibre boards. However, the remaining two profiles were significantly less effective. The measurement results of these two profiles were compared with that of the results with open joints (as shown in Fig. 5), refer Fig. 6. The total rain leakage (rear of the façade board + at wind barrier) increased for all tests. However, the HPL-boards exhibited a decrease in the rain leakage from 19% to 2 – 6%. In the case of profile No. 1, the total rain leakage increased 4 – 6 times for the fibre cement boards and up to 2 times for the glass fibre boards. The total rain leakage reached 48% of the volume of the sprayed water at the façade for one of the cases. In the case of profile No. 3, the total rain leakage increased 2 – 4 times for the fibre cement boards. A minimum of 97 – 100% of the total rain leakage for the cases with profile No. 1 and No. 3 were run-off on the rear of the façade board. An exception applied for HPL board with profile No 3, wherein significantly low total rain leakage (130 mL/min) was observed, and only 77% were run-off on the back side of the façade board.

One possible explanation for the increase in the rain leakage while using profile No 1 and No. 3 is that the metal profiles did not offer reliable tightening such as rubber gaskets between the metal and board material. In addition, the profiles were not fastened between the vertical battens. Since they have a limited stiffness, it is impossible to achieve effective compression between the facade panel and profile. In between the vertical battens giving some compression, a distance of a few mm could be present between the board and profile. It seems that the profiles were disrupting the normal run-off past the horizontal joint in the absence of reliable tightening, which led to the increased seepage of water behind the façade board. A possible reason to why the profiles had a good tightening effect for the HPL-boards, could be due to the fact that the joint width used for these boards are 5 mm instead of 8 mm, giving possibly a tighter connection between the profile and the boards. Additionally, the difference between the surface properties of the HPL-boards and the other type of boards probably resulted in different run-off pattern on the exterior surface.

The metal profiles protected the wind barrier from the direct impact of raindrops through the joints, but minor water leakage at the wind barrier (less than 1% of the total rain leakage) was observed. This was probably due to leakage water running down the vertical battens and thereby reaching the wind barrier. The rain leakage at the wind barrier with and without metal profiles is shown in Fig. 6(b). It can be observed that three test series out of eight test series exhibited higher or equal rain leakage for metal profiles compared with that of open joints. It should be noted that these three test series consisted of fibre cement boards. In the case of glass fibre or HPL boards, a high reduction of rain leakage was observed at the wind barrier while using metal profiles, particularly for glass fibre boards with profile No. 1 wherein rain leakage did not reach the wind barrier.



(a)



(b)

FIGURE 6. Rain leakage with and without metal profiles. The joint width recommended by the producer for the "open joint" is used as a comparison, i.e., 5 mm for fibre cement and glass fibre, and 8 mm for HPL. Note: Profile No. 3 was not tested for the glass fibre boards. The rain leakage is represented as a percentage of the total amount of spray water (6000 mL/min) hitting the façade. (a) Back side of façade board, (b) Outside of wind barrier (polycarbonate board).

Limitations and Sources of Error

There are several limitations and possible sources of error associated with this laboratory experiment. One relevant uncertainty was the system for water collection, i.e., the water ducts and the plastic tubes. Particularly for the collection of water at the wind barrier (polycarbonate board), the small measured volume in the range of approximately 5 – 70 mL makes the results vulnerable for not being entirely drained (or leaking from) the collection system or more stochastic behaviour of the water flow. However, it was ensured that the effect of these sources of error was reduced.

The boards had insufficient time to dry before conducting a new test. A few of the boards, particularly fibre cement boards, absorbed a greater volume of water after each test. This possibly affected the flow of water on the material surfaces.

The testing was performed without a pressure difference over the façade cladding, i.e., pressure equalization of the air gap behind the cladding was assumed. This might be invalid for high buildings and claddings with small joint width (e.g. 3 mm) were water fills up the joint or when metal profiles are used in the horizontal joints. Additionally, sudden wind gusts might result in a pressure difference over the cladding, even with appropriate ventilation.

CONCLUSIONS

Rain tightness testing of typical façade claddings with open horizontal joints was performed, and the effect of board material, type of surface, and joint width was investigated. In addition, the effect of protecting metal profiles in the horizontal joints was investigated.

Although a pressure difference was not applied over the façade claddings, the rain leakage for ordinary open joints was substantial and up to 30% of the total volume of rain impinging on the cladding seeped through the open joints. The water penetration increased with an increase in the joint width. An average rain leakage of 7, 14, and 22% was observed for the joint widths of 3, 5, and 8 mm, respectively. The joint width of 3 mm was prone to the risk of standing water in the joint, which enhanced the risk of microbial growth. Therefore, the joint width of approximately 5 mm was considered optimal. This verified the results of previous investigations. Most of the rain leakage flowed down along the rear of the claddings, and typically less than 1% of the total volume of rain impinging on the façade reached the wind barrier. Additionally, the results indicated that the type of façade board or surface affected the rain leakage through the open joints.

The application of protecting metal profiles demonstrated surprising results. The profiles that did not extrude out of the joints, thereby having an "invisible" architectural appearance, did in most of the tests lead more water in behind the façade panels than the ordinary open horizontal joints. The total rain leakage was increased up to six times compared with that of open joints, and for one of the tests with metal profiles, approximately 50% of the rain impinging on the façade leaked into the joints. This demonstrated that such profiles should not be used without special consideration, and further development is required for reliable and aesthetically acceptable rain tight profiles.

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