RE-SKIN

D3.5 – Lab testing report I

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Deliverable Information Sheet

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1.0	2024-06-28	Final version addressing all further comments	L. Vanhoutteghem (DTI), M. B. Hansen (DTI)

Table of Contents

List of Figures

Disclaimer

1. Executive summary

This deliverable presents the first lab testing report in WP3 and includes the initial lab testing results for following key subcomponents used in the RE-SKIN toolkit: the BIPVT roof system (Chapter 2), the repurposed EV batteries (Chapter 3), and the refurbished PV modules (Chapter 4). The goal is to verify and demonstrate the long-term viability of these components. Novel façade testing is not included in this deliverable but will be reported in the next release of the deliverable (D3.6).

Chapter 2 covers mainly testing of initial mock-ups for the outer layer of the BIPVT roof system to evaluate watertightness under simulated driving rain conditions. Different designs for the T-profiles between PV modules and connections at the mullions were investigated. While water penetration was observed in initial tests, insights were gained on improving the watertightness, resulting in an optimization process and the use of a thinner horizontal profile at connection between the PV modules. At the moment of writing this deliverable, initial testing of watertightness under pulsating air pressure and driving rain conditions with use of this profile have been concluded, indicating the need for further optimization. As a next step, based on an optimized solution, long-term reliability of the system against disruptive weather events like sun, rain, wind, frost, and hail, will be further validated after accelerated ageing and wind tunnel testing.

In Chapter 3, a methodology for initial testing and characterization of the repurposed EV batteries is outlined, including visual inspection, electrolyte loss measurements, voltage tests, and capacity testing. The received battery cells were in good condition. However, initial results from capacity testing showed that the single battery cells had around 70% of their nominal capacity remaining, which was slightly lower than initially expected. Therefore, additional testing on the whole battery pack will be performed and included in the next test report (D3.6).

Chapter 4 presents results from standard testing condition (STC) power measurements on the refurbished PV modules with repaired backsheets. Insulation resistance tests validated the reliability of the backsheet repair coatings before and after accelerated ageing by damp heat exposure. The modules also passed thermal cycling and dynamic load testing according to IEC 61215, results will be included in the next test report (D3.6). The next report will also include results from hail testing.

Overall, these preliminary test results establish a baseline for evaluating the long-term durability and reliability of the RE-SKIN components through further accelerated aging tests and on-site monitoring during demonstration cases. Optimizations are ongoing, particularly for the BIPVT roof system to improve watertightness and drainage based on insights from this initial testing phase.

2. Novel components – BIPVT roof system

The RE-SKIN roof system consists of a Building-Integrated Photovoltaic-Thermal (BIPVT) roofing system. The BIPVT system provides several benefits into a single, modular solution. One of its key benefits is the simultaneous generation of electricity and increased insulation. In addition, is it possible to use the hot air generated behind the PV modules to increase the heat pump's efficiency. Furthermore, the use of refurbished, recycled and bio-based materials, along with flexible installation options, promotes energy efficiency and environmental responsibility. The BIPVT roof system has previously been described in deliverable D5.10 and D5.14, but a brief overview will also be given in this chapter.

To document the performance of the BIPVT roofing system, a test procedure to verify and demonstrate the long-term reliability of the system needs to be defined. Testing procedures will be documented in detail the second release of D3.1 (D3.2 in M24). However, relevant test procedures are briefly mentioned in this deliverable, together with results from already concluded tests. Results from tests concluded until 25th of June 2024 are included in this chapter.

2.1. BIPVT roof system description

The BIPVT roof system entails a modular prefabricated photovoltaic-thermal roof system, consisting of refurbished PV modules, and sandwich panels composed of bio-based insulation core (bio-PUR) and a steel case; both mounted in recycled aluminium profiles (mullions), which are joined to the underlying slab or roof framework. With the integration of these components, the BIPVT roof system is designed to be integrated in common sloped roofs, replacing the external covering, waterproof and insulation layers. An illustration can be seen in Figure 1.

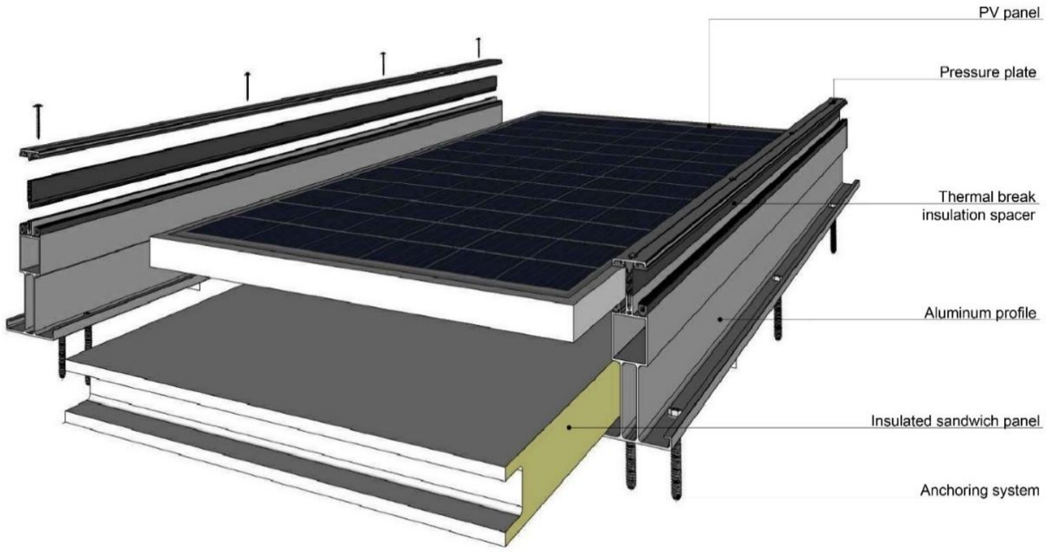

Figure 1. General principle of the BIPVT roof system.

The PV modules are housed at the top of the mullions in the same way as glass curtain façades and the gaskets in the mullions. Furthermore, horizonal T-shaped profiles between the PV modules are installed to protect against water infiltration along the slope direction, see Figure 2 below. In the continuation of the research in the RE-SKIN project, variations in the "T"-shaped profile, as well as different shaped profiles will be examined, with reference to the results obtained during the tests described in this deliverable.

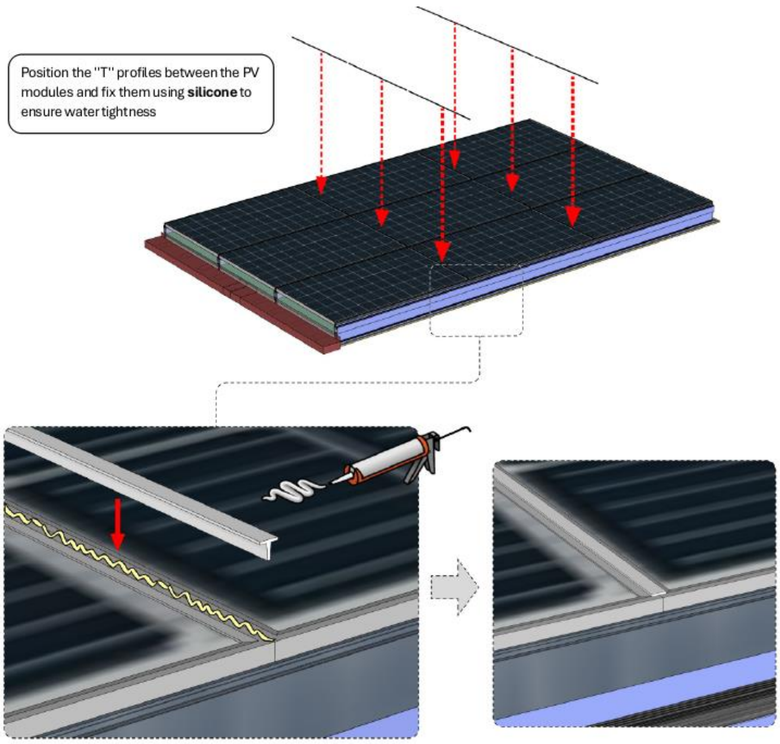

Figure 2. Installation of T-profiles between PV modules as shown in the assembly manual of roof prototype by GAR.

The system is designed to host different sizes of PV module. Within the RE-SKIN project, refurbished PV modules are chosen to match the most popular market dimensions. The PV modules are connected in series, and the mullions serve as housing for the electrical wires of the system. To complete the roof system, where needed special pieces, also called blind panels, will be integrated in the mullions instead of the PV modules.

Between the PV modules and the sandwich panels, housed in the lower part of the mullions, an air gap is present, which enables rear-ventilation of the PV modules, preventing them from overheating, which in turn increases their electrical conversion efficiency. Heat removal and cooling of the PV modules can be facilitated through forced airflow using a fan, or by natural convection. At the same time, excess solar heat within the air gap can be used for increasing the heat pump efficiency in winter or displaced outside in summer for optimal temperature control. Furthermore, a "plenum" is installed at the eaves of the roof to facilitate ventilation and maintain balanced airflow within the BIPVT system, see Figure 3.

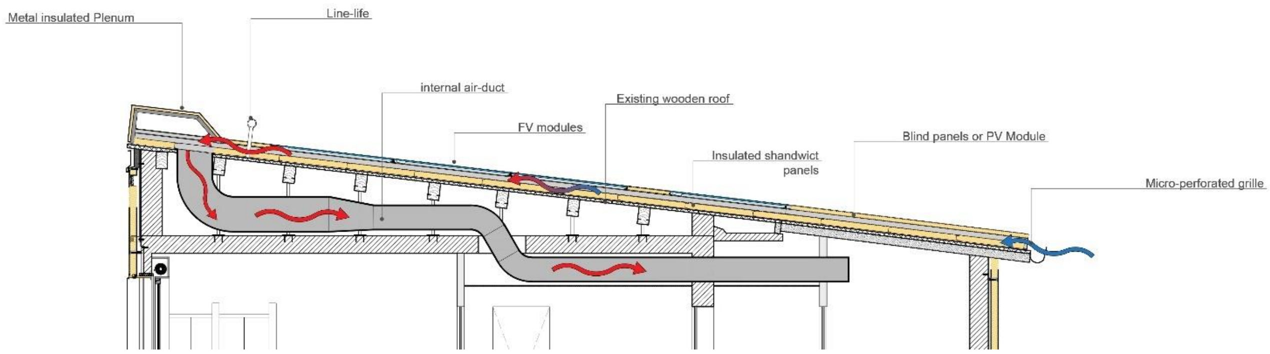

Figure 3. Sections of the BIPVT roof with indication of rear-ventilation and plenum at the eaves.

For more information on the different components in the roof system, and their specific design, see deliverable D5.10, D5.14 and D4.2. For more information on the PV modules, see also chapter 4.

2.2. Relevant test procedures

Based on the design principle of the BIPVT roof system, a thorough testing process to evaluate the system's waterproofing capability is required. Furthermore, it is also important to provide watertightness under varying conditions. At the same time, the BIPVT roof system should as much as possible be able to withstand disruptive weather events and other hazards, e.g. wind suction, and hailstorms, see also deliverable D2.1 and deliverable D3.3. Hailstorms can for example lead to glass breakage due to the impact of hail balls on the PV panels, leading to an increased need for maintenance. At the same time, strong winds might lead to damage at both PV modules and the roof system with fixings in general. Testing for the above will ensure the systems stability and ability to withstand high wind pressures.

A methodology for testing the BIPVT system will be defined in the next release of deliverable D3.1, D3.2 due M24. In the first version of this deliverable D3.1, testing procedures with focus on the novel façade system were proposed. However, a large part of the proposed tests as well as the proposed testing approach for the novel façade system, is also applicable to the BIPVT roof system.

To document the performance of the BIPVT roof system and demonstrate its long-term reliability against disruptive weather events like sun, rain, wind, frost, and hail, as defined within the RE-SKIN project, see also deliverable D2.1, initial tests should be complemented with a set of accelerated ageing tests and tests representing extreme weather conditions. This will allow us to identify the weaknesses in the assembled system when exposed to prolonged extreme weather conditions, which will be used to continuously evaluate and improve the RE-SKIN BIPVT roof system to extend the lifetime of the system. At the same time, the aim is also to reduce maintainability of the system to a small number of man-hours, with low levels of operator specialization and a limited number of low-complexity equipment needed, under safe conditions, see deliverable D3.3.

Deliverable D3.1 proposes a cyclic test procedure, consisting of a) initial testing of physical properties such as watertightness and impact resistance, based on standardised tests, b) accelerated ageing and c) re-testing of initial physical properties and deterioration assessment after ageing to evaluate the long-term durability of the facade/roof components. The physical properties after aging should not degrade significantly compared to initial values.

Relevant standards for testing the BIPVT roof system are shown in Table 1. It should be mentioned that the proposed tests in Table 1 are not final and subject to change during the testing process when new insights are learned and will be further documented in the next release of deliverable D3.1 (D3.2, M24). In D3.2, the exact extreme conditions, size of hail, windspeed etc, to expose the BIPVT roof system to, will be specified in collaboration with the further risk assessment carried out in WP2 (Task 2.6). Determination of how many cycles of ageing will be considered for the BIPVT roof system, will also be made in D3.2. As for now, accelerated ageing will be performed by exposing test mock-ups to 3 daily cycles of alternating exposure to heat, UV, water and frost for at least 30 days, in accordance with the principle and test method for accelerated ageing as described in NT build 495 "Building materials and components in the vertical position; Exposure to accelerated climatic strains".

In Table 1, no testing for impact by windborne debris is included. A test according to ISO/PWI 16316 - Windows, doors, and curtain walling - Impacted by windborne debris in windstorms – Test method and classification, was proposed for the façade system. However, it was considered more relevant for the BIPVT system to perform hail testing than testing for impact by windborne debris. Similarly, a proposed test according to EN 14509 Annex B standard on testing heat and humidity durability for testing the sandwich panels is not planned for the insulation panels used in the BIPVT roof system, as the test is considered more relevant for the proposed façade system within the RE-SKIN project. However, the joints between the insulation panels in the BIPVT roof system are closed with tape. To test the durability of this connection, it is proposed to stress test the joints and expose them to accelerated ageing with regards to humidity and temperature.

Table 1. Proposed testing procedures for the BIPVT roof system.

Standard	Physical property
EN 12153	Air permeability
EN 12155	Watertightness under static pressure
EN 12179	Resistance to wind load
EN 12865	Resistance to driving rain under pulsating air pressure
TI-B 109 (98)	Test method for puncture resistance on 'walkable' surfaces - Protection of persons stepping through roof slabs
NT build 495	Accelerated ageing
EN IEC 61215-2	Hail test – Clause MQT 17 in the standard Wind and snow load – Clause MQT16 in the standard

In the next sections of this chapter, test results from already performed initial tests will be described, with focus on testing the watertightness of the BIPVT roof system. Other tests are either ongoing or need to be further specified/decided upon and will be reported in later deliverables. The next section also includes a description of the test mock-ups. Hail testing according to EN IEX 61215-2 is described in chapter 4 on test of the refurbished components.

2.3. Initial mock-up for BIPVT roof system

In task 3.1, discussions have been ongoing to plan the initial mock-up of the BIPVT system. To be able to test different interfaces, i.e. at connections and joints, an initial mock-up of approximately 4,95 m by 3 m was suggested. This corresponds to a 3 x 3 grid of the refurbished PV modules.

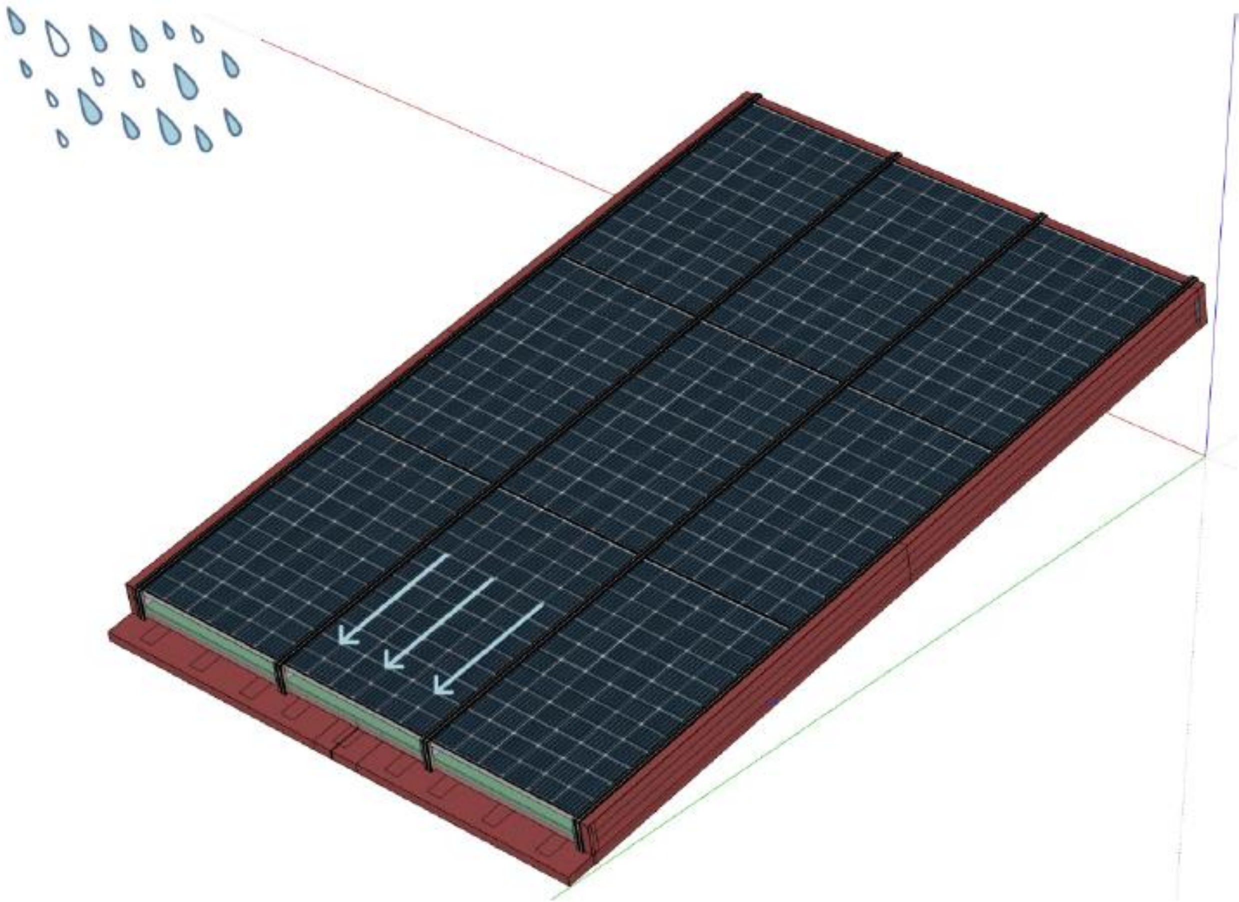

Figure 4. Initially planned mock-up: Mounted roof prototype from installation assembly manual provided by GAR.

In this mock-up, also finishing at sides and bottom of the mock-up could be tested, see also Figure 5 and 6. Furthermore, the size of the initial mock-up was chosen to be able to test for impact resistance on the roof system/PV modules in the middle of the roof.

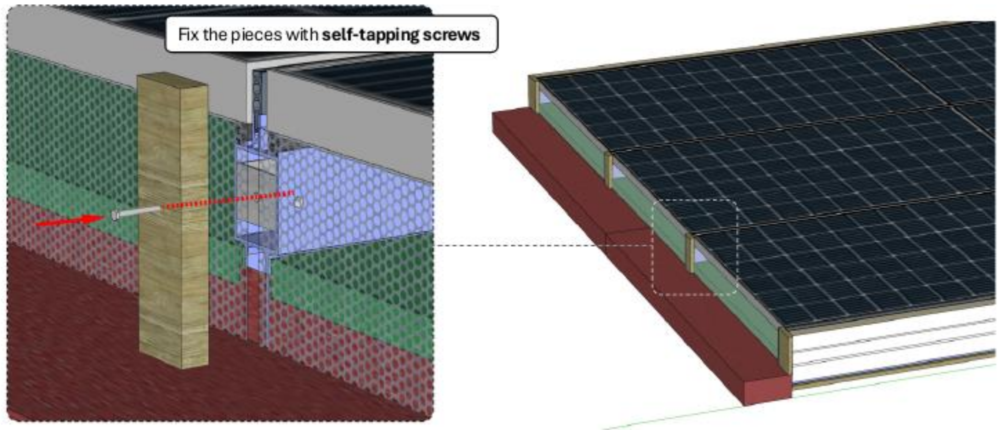

Figure 5. Finishing at bottom of the test mock-up.

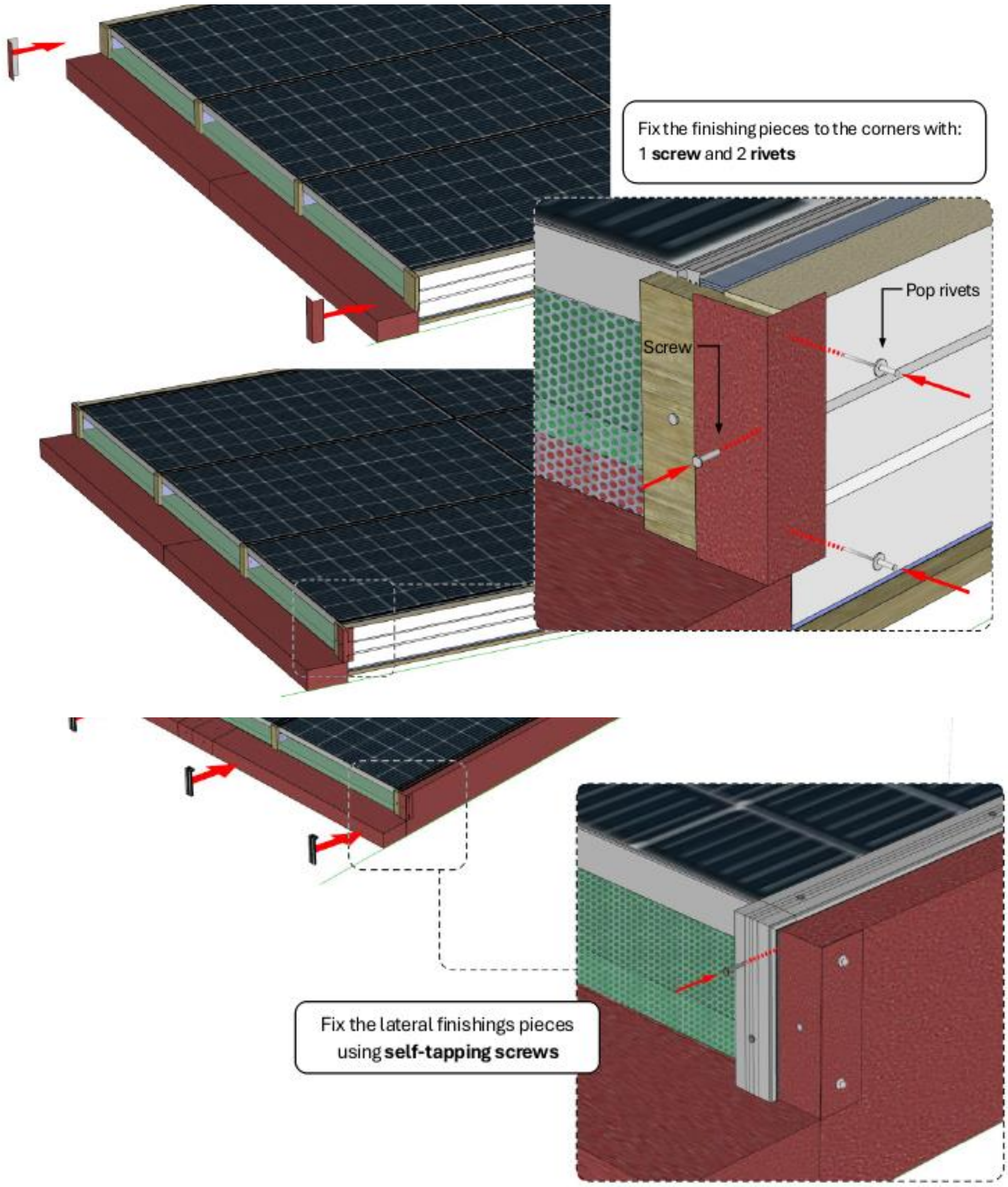

Figure 6. Finishing at corners, before (top) and after installing lateral finishings (bottom).

However, due to issues with dismantling the mock-up after initial testing, delivery of materials, and possibility to perform accelerated ageing, it was decided to start with initial testing of watertightness on 2 smaller mock-ups. Separate stress tests have also been planned on smaller specimens for investigating the connections between the sandwich panels. Further description of the test specimens and mock-ups can be found in the next sections.

Accelerated ageing is planned to be performed on one of the 2 smaller mock-ups, once a satisfying/optimized solution has been found for the connections at the roof system. Furthermore, for testing resilience towards strong winds, it is being considered to either build the originally planned mock-up, or a third slightly smaller mock-up (size 2 x 2 PV modules). Both will also include lateral finishing and finishing at the bottom of the test set-up. This will be further documented in an update to deliverable D3.1 on test procedures (D3.2, M24), as well as D3.6 and D3.7 (Lab testing report II and III).

2.4. Water tightness

Watertightness of external wall systems can be tested by through methods such as air permeability and static air pressure testing (EN 12153 and EN 12155), or by conducting driving rain tests under pulsating air pressure (EN 12865). These tests are performed in almost the same test set-up. However, tests according to EN12865 "Hygrothermal performance of building components and building elements – Determination of the resistance of external wall systems to driving rain under pulsating air pressure'', were also assessed useful for testing of the BIPVT roof system. It is also expected that tests for water tightness of the BIPVT roof system with regards to driving rain under pulsating air pressure, represent reality more accurately than tests under static pressure, and at the same represent a worst-case scenario. The purpose of the tests is to be able to observe if there is any water penetration through the outer layer of the BIPVT roof system (i.e. PV modules, T-profiles and cover plates at mullions), and investigate the drainage function at the mullions, when the outer layer is exposed to a combination of heavy rain and pulsating wind.

Tests on watertightness of the outer layer of the BIPVT roof system in the following are performed approximately in accordance with EN 12865 – Procedure A. For description on the build-up of the test mock-up, see next section. The test mock-ups are individually mounted in the test equipment (driving rain test apparatus at DTI) and the outer layer of the BIPVT roof system is sprayed continuously with water at a specified rate while the pulsating air pressure difference is increased in specified steps, see Table 2 and Figure 7. As can be seen in Table 2 and Figure 7, tests start by applying water spray without air pressure difference for 20 minutes. Afterwards air pressure is increased +150 Pa for each interval (0-150, 0-300 ...... Pa) for 10 minutes per interval.

For each step, the time of water penetration, if any, the maximum air pressure difference applied, and the location of any penetrations are noted. The test can be stopped when water penetration is observed.

Table 2. Intervals for test procedure A, as described in EN 12865.

Pressure difference [Pa]	Time interval [min]	Total time at end of steps [min]
0	20	20
0 to 150	10	30
0 to 300	10	40
0 to 450	10	50
0 to 600	10	60
600 + i · 150, i= 1,2,3,…n	10	60 + i · 10

During the test, the pressure must increase, hold for 5 seconds and then decrease to 0 Pa, which is then held for 5 seconds, see Figure 7. The pressure change must be carried out as quickly as possible, but much depends on the airtightness of the test specimens.

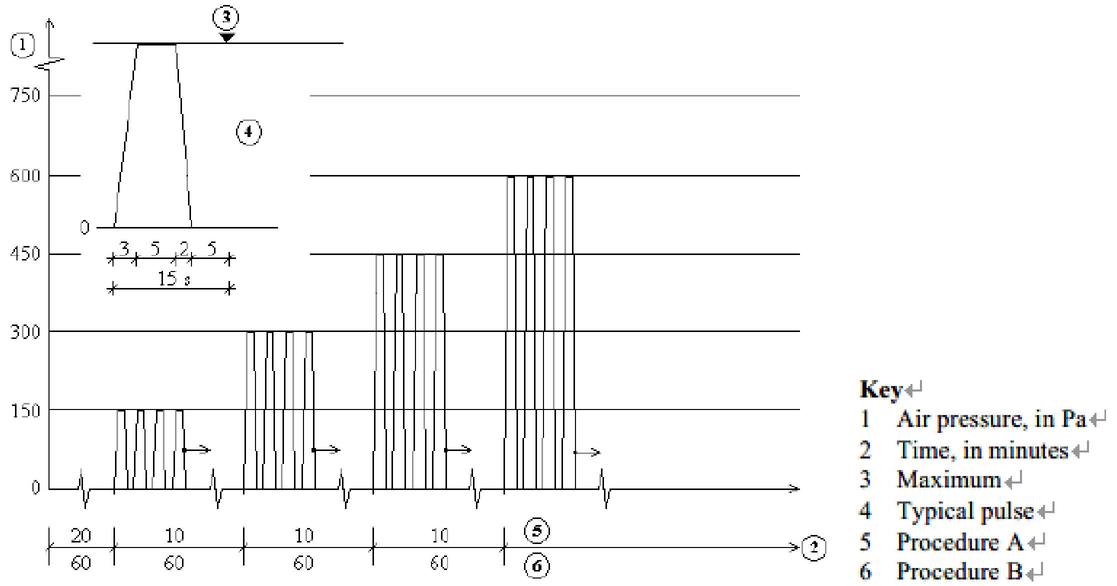

Figure 7. Schematic illustration of test procedures in EN 12865.

To control air pressure during testing, the test equipment uses a PLC-controlled fan, which can be adjusted to reach the targeted air pressure for each step.

The requirement to ensure a continuous water film on the entire tested surface in accordance with EN 12865, has been achieved by placing a series of 6 spray nozzles above the outer layer of the BIPVT roof system, each delivering 2 l/min - a total of 12 l/min. The amount of water remained the same throughout the test, as also defined EN 12865.

2.4.1. Test set-up

As mentioned, 2 smaller mock-ups were made. As one of the important parameters is to ensure watertightness with the outer layer of the BIPVT system (PV modules, T-profiles and connections at mullions with cover plates and gaskets), these 2 mock-ups only consider the outer layer with PV modules and connections with the mullions/blind panels, and not the insulation layer of the BIPVT roof system.
Each of the mock-ups consisted of 2 PV modules and 4 blind panels, with total size of approximately 2 m x 2,4 m. In the final design of the BIPVT-system, the blind panels will consist of sandwich panels with a bio-PUR core and steel casing and will have the same thickness as the PV modules However, as these blind panels were awaiting production at the time of testing, blind panels in the test mock-up consisted of clear float glass, mounted in a metal frame similar to the frame of the PV modules.

Assembly between blind panels and PV modules was covered by T-profiles. At mullions, the cover plate as provided in the system was used. The mullions were directly fastened to a timber frame substructure. An overview of the mock-ups can be seen in Figure 8. Pictures during build-up can be seen in Figure 9.

The slope of the mock-ups was set to 7 degrees (around 12-13%), corresponding to the planned slope in the first demo case. Around the mock-ups, a water-and airtight case was built, in which the row of spray nozzles was mounted. The row of nozzles is placed near the joint of the PV modules and top row of blind panels, see Figure 10.

As only the outer layer of the BIPVT system is constructed in the mock-ups, it was possible to directly observe where, how and when any water penetration occurred on the bottom of the test mock-ups.

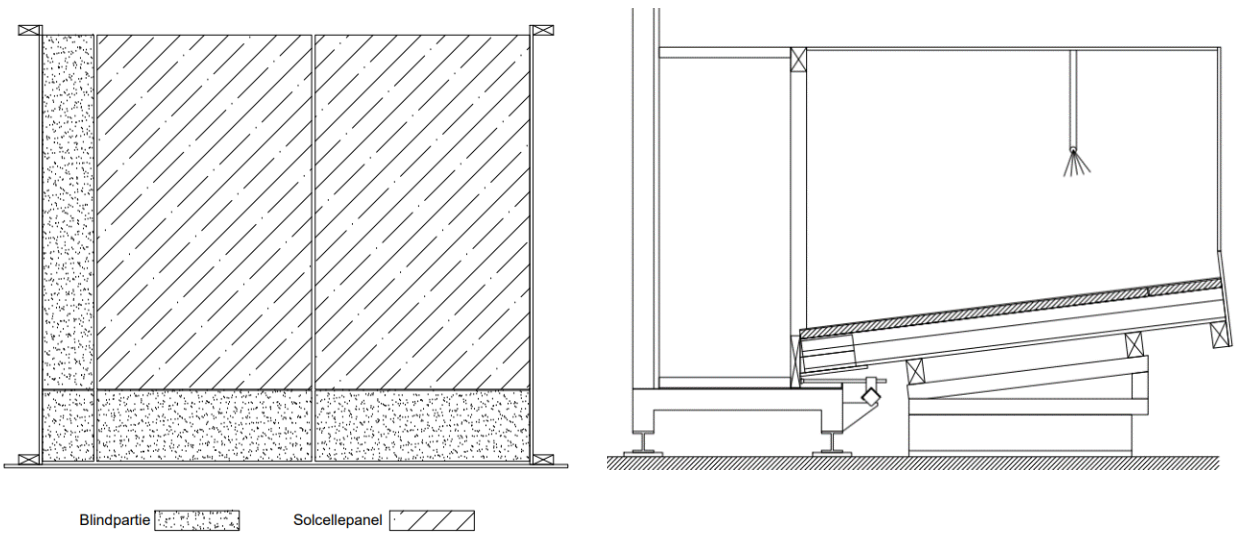

Figure 8. Mock-up for test of water tightness. Left: plan. Right: schematic of test set-up.

The two test mock-ups were constructed the same way. So far, only one mock-up is being used in the initial testing of the watertightness. The second mock-up will later be used in parallel in accelerated ageing tests. On the first mock-up, different solutions for the T-profiles and connections between the PV-panels and blind panels were tested, see also the next sections.

Figure 9. Pictures during build-up of the mock-up. Left: timber substructure frame with mullions. Right: Outer layer consisting of PV modules and blind panels, before installing T-profiles and cover plates.

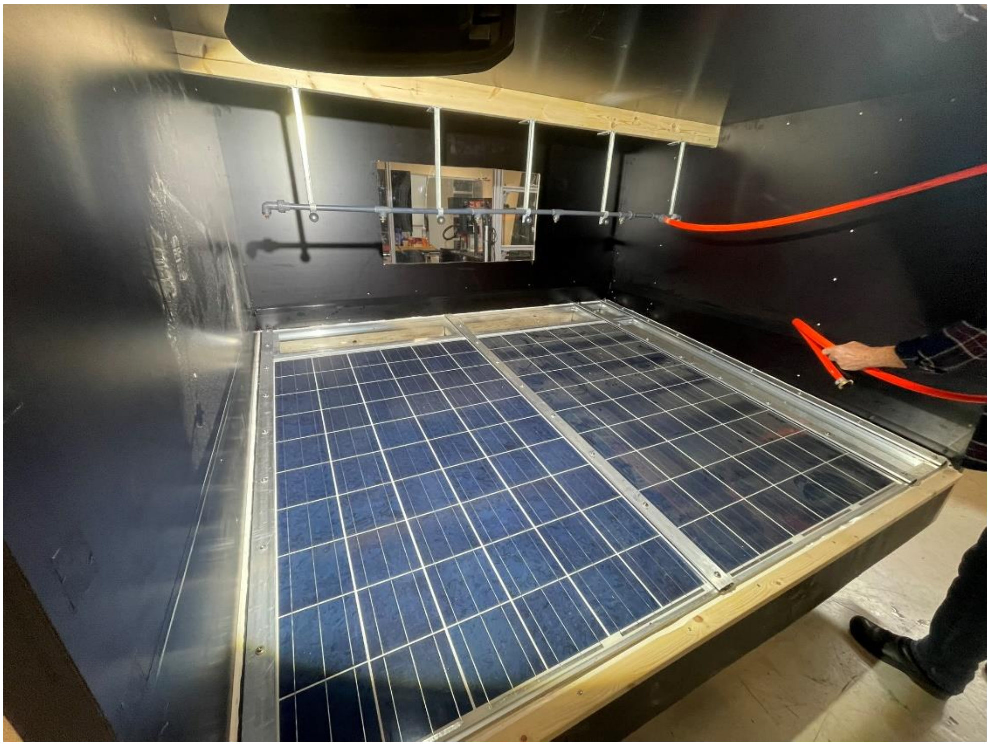

Figure 10. Test mock-up with row of nozzles, before installation in the driving rain test apparatus at DTI.

2.4.1.1. First mock-ups

To account for potential mounting system tolerances and thermal expansion differences, distance between PV modules and blind panels was kept at 5 mm in the first mock-up, see also Figure 11.

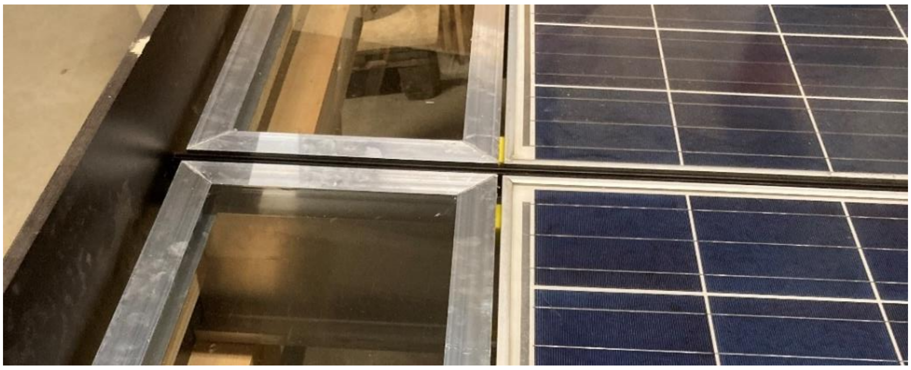

Figure 11. 5 mm tolerance between PV modules and blind panels at connection with T-profile.

Furthermore, the PV modules were inserted as far as possible into the mullions, as also seen in Figure 12 (left) and provided in the assembly manual by GAR. This in contrast to the original drawings, where also distance between the mullions was slightly larger (10 mm). As can be seen in Figure 12, minimizing the distance between PV modules and central part of the mullions, increases the contact surface area between the rubber gaskets in the cover plate and the PV modules (green ellipses). However, at the same time it is important to ensure that the rubber gaskets will not cover, or cast shadows, on the PV cells in the PV modules.

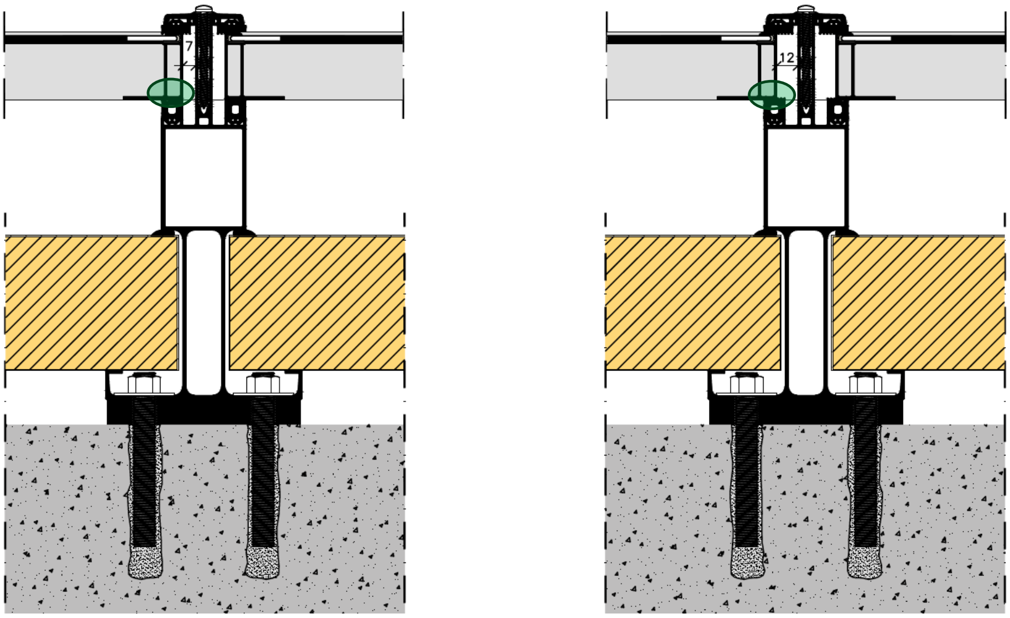

Figure 12. PV modules at the mullions. Left: Distance between mullions is 1015 mm, as indicated in the assembly manual provided by GAR. Distance between PV modules and central part of the mullions is 7 mm. Right: Distance between mullions is 1025 mm, as indicated in ''2301_RM_ARC_310_Sections_Project''. Distance between PV modules and mullions is 12 mm.

In the first mock-up, different variations of the T-profiles and finishing under the cover plate were also considered. As the initial T-profile delivered at the lab was too short, an initial test with a thicker T-profile with thickness of 2 mm has been made and compared to a test with the planned T-profile with thickness of 1,5 mm. Both T-profiles were glued using the provided silicone. After pressing the T-profiles at the connection between the PV modules and blind panels, left over silicone was cleaned. After finished installation with silicone, the T-profiles and silicone layer were measured to protrude approximately 2,58mm and between 1,81-1,88 mm from the upper surface of the PV/blind panel frames respectively for T-profiles with thickness of 2 mm and 1,5 mm, see Figure 15.

Figure 13. Mounting of T-profiles. The T-profile pictured has a thickness of 2 mm.

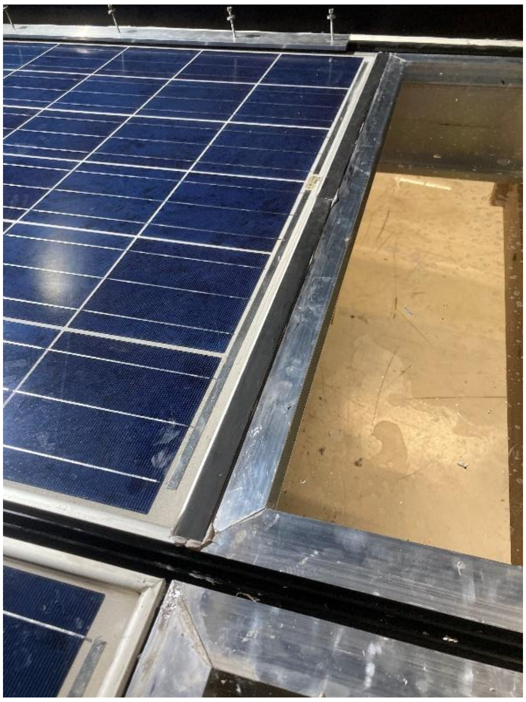

Figure 14. Mounting the T-profiles with thickness of 1,5 mm, before wiping excess silicone.

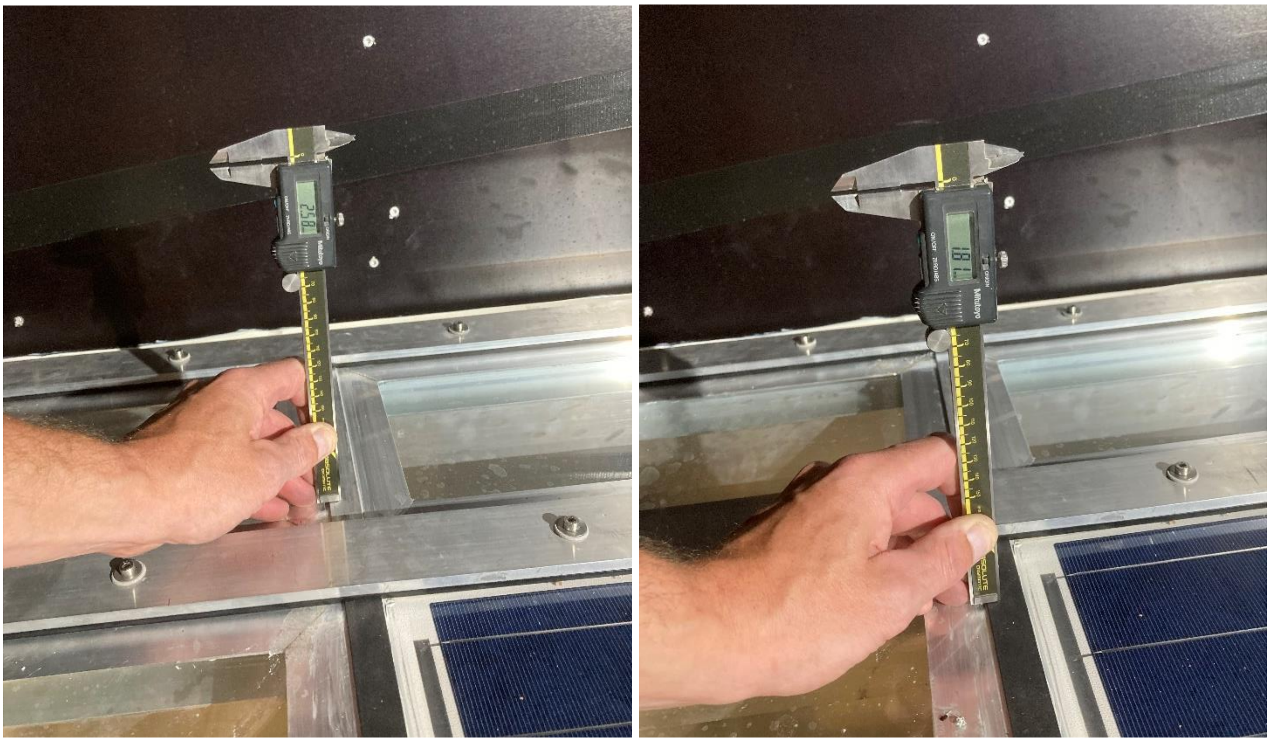

Figure 15. Total height of installed T-profile and silicone, protruding at the PV/blind panel frames. Left: T-profile with thickness 2 mm. Right: T-profile with thickness 1,5 mm

At the same time, a variation in finishing of the T-profiles under the cover plates was considered for the mock-up using the originally planned T-profiles with thickness of 1,5 mm. T-profiles were either the same width as the PV modules, or 10 mm shorter than the PV modules, i.e. with a 5 mm finishing distance from edges of the PV modules on either side, see Figure 16. T-profiles with thickness of 2 mm were as wide as the PV modules.

Figure 16. Finishing of T-profiles at edges of PV modules. Left: T-profiles with same with as PV modules. Right: T-profiles finished 5 mm from edge of the PV modules.

Tests on the mock-up with 2 mm T-profiles installed showed almost immediate water penetration at 0Pa, see Figure 17. Water was running both in the drain channel behind the rubber gaskets, but also on the sides of the mullions. This was considered due to insufficient compression between the rubber gaskets in the cover plate at the mullions and the T-profile, at the edges of the T-profile, due to the thickness of the T-profile and silicone.

Figure 17. Mock-up for T-profile with thickness of 2 mm. Left: water penetration at mullions, bottom of mock-up. Right: Top of the mock-up, connection between T-profile and rubber gaskets in the cover plate at the mullions.

Test on the mock-up with the 1,5 mm T-profiles installed also showed water penetration, already at low pressure variations, see Figure 18. However, where the T-profile was as wide as the PV modules, water was running mostly in the drain channels. Cases where the T-profiles were 10 mm shorter than the width of the PV modules showed water penetration both in the drain channel, but also on the sides of the mullions.

Figure 18. Water penetration for test mock-up with 1,5 mm T-profiles. Left: T-profiles with 5 mm finishing distance from edge of PV-panels. Right: T-profiles same width as PV modules.

Figure 19 illustrates for the mock-up with T-profiles with thickness of 1,5 mm, that the rubber gaskets in the cover plates can be pressed tighter to the T-profiles, but still leave a small area at the edges with insufficient compression and thightness.

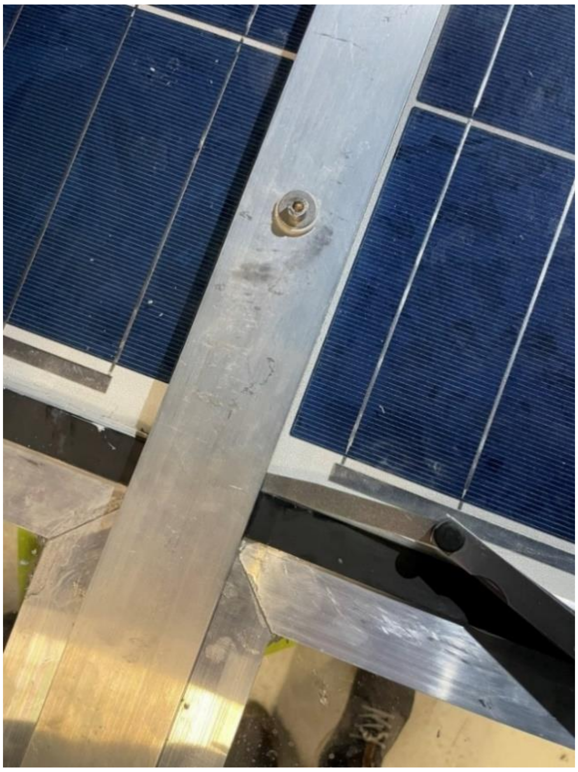

Figure 19. Connection between T-profiles with 1,5 mm thickness and cover plate. It is possible to wedge a feeler gauge under the rubber gaskets, at the edges of the T-profiles.

The above test results highlight the importance of optimizing the outer layer of the BIPVT system to ensure watertightness.

Installation of cable routing for the PV modules was not included in the test mock-ups. Water penetration in the sides of the mullions could result in water penetration in the bottom part of the mullions, where cable routing for the PV modules is planned. To avoid this, use of fitted gaskets around the electrical cables are planned for the final design of the BIPVT system.
Furthermore, any water penetration could also land on the insulation panels. Therefore, their connections must be watertight, and drainage should also be provided for potential water run-off on the insulation panels to avoid accumulation of water in the cavity of the BIPVT roof system. In general, even though an optimized solution reducing water penetration through the outer layer in the BIPVT roof system will be further looked upon, it is important to consider the planning of a well-functioning drainage system, both at mullions and from the surface of the insulation panels, preferably consisting of non-organic materials. This will be looked at in the planned larger mock-up where finishings at the edges of the system also will be mounted.

To improve the water tightness of the outer layer in the BIPVT roof system, and to allow for some tolerances when mounting the T-profiles, it is concluded from the first test results that either the thickness of the T-profiles should be reduced or/and a different quality of the rubber gaskets in the cover plates should be considered. At the moment, the rubber gaskets in the cover plates are quite hard, as the type used is typically used for structural purposes. Looking into softer types might results in better sealing between the rubber gaskets and the T-profiles but could increase the deterioration of the gaskets due to a worse resistance towards for example UV-exposure.

In the following, additional tests on the first mock-up are described with focus on investigating different thicknesses and shapes of the T-profiles.

2.4.1.2. Additional tests

As mentioned, additional tests on the first mock-up consider a reduced thickness of the T-profiles and/or use of different shapes of the profiles. In the additional tests, it was decided to use flat profiles, solely for the purpose of testing the watertightness at connection between the former profiles and the cover plate at the mullions. Watertightness was tested on the mock-up for 20 mm wide flat profiles with thickness of 1 mm, see Figure 20. The profiles had the same width as the PV modules. A profile with thickness of 0,7 mm was also considered, but not tested, as the profile was very flexible and therefor hard to install. In installation of the flat profiles with thickness of 1mm, silicone was applied in the middle of the profiles, after which they were pressed as hard as possible on the connection between PV modules and blind panels. Total thickness with silicone corresponded therefore to around 1,1-1,2 mm.

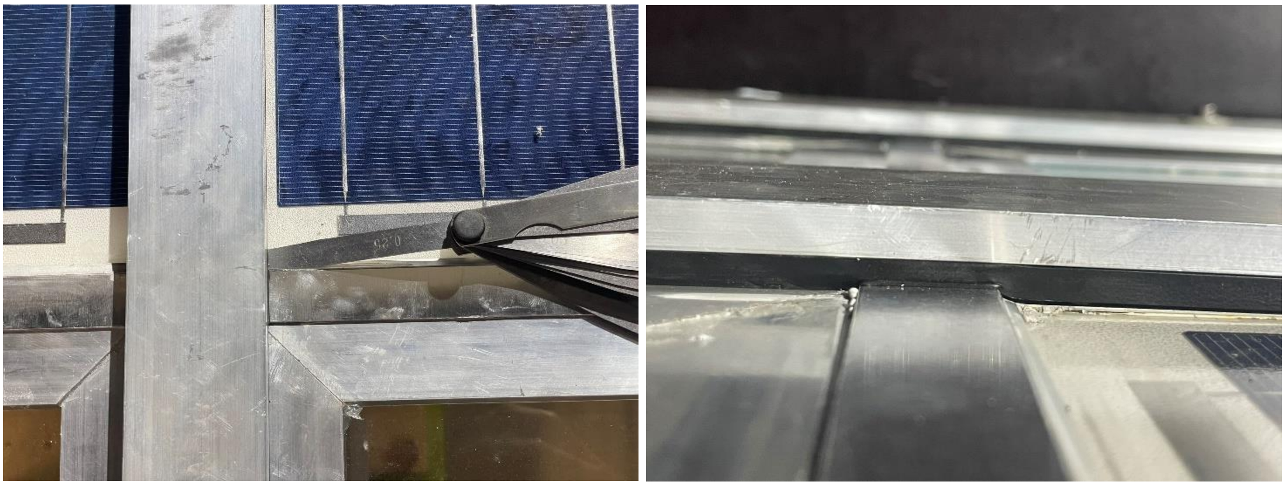

Figure 20. Mock-up with flat profiles with thickness 1 mm. Left: It is still possible to wedge a 0,25-0,5 mm feeler gauge under the rubber gaskets at the connection with the flat profiles, but not as deep as before. Right: view of the connection allong the flat profile towards the cover plate..

In the additional tests, the mock-up was also slightly modified, so there was no distance between PV modules and blind panels, as agreed with the project team based on experience from previous Italian cases. As the PV modules are not fixed to the mullions, it is therefore expected that thermal expansion can be supported by the system. This should be considered for evaluation after performing accelerated ageing tests.

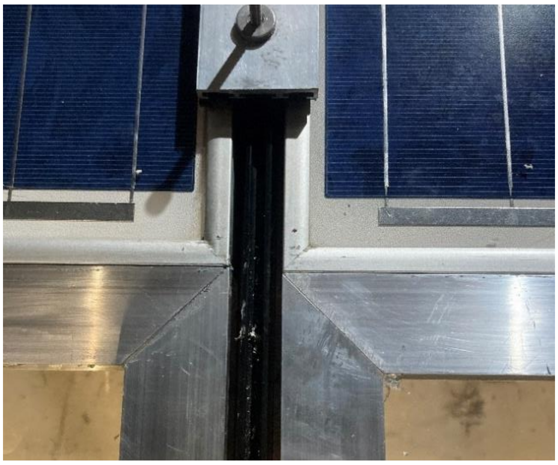

Figure 21. No gap between PV modules and blind panels in additional tests.

Test on the mock-up with the 1 mm flat profiles installed also showed water penetration, starting already at 0 Pa pressure. As illustrated in Figure 20, the rubber gaskets in the cover plates can be pressed tighter to the flat profiles, but still leave a small area at the edges with less compression where a 0,25-0,5 mm feeler gauge could be wedged under the rubber gaskets at connection with the flat profiles. Water penetration was observed at the connection between the blind panels and the PV modules, see Figure 22, but also still at the mullions.

Figure 22. Water penetration at connection between PV module and blind panel for test mock-up with 1 mm flat profiles.

Before an additional test with the 1 mm flat profiles, the screws in the vertical cover plates were tightened to approx. 9 Nm. With the increased compression of the cover plate and gaskets water penetration still occurred, but it could clearly be observed that the amount of water penetration was less than the previous test with the 1 mm flat profiles. This also indicates the importance of providing which torque the screws should be fastened with, to ensure enough compression of the rubber gaskets.

In the additional tests described in this chapter, as little as possible silicone was applied at the flat profiles and the profiles were pressed as hard as possible, to ensure a low thickness of the profiles and silicone. However, as the distance between the PV modules and the blind panels was reduced, this also resulted in possible water penetration at the flat profiles in the connection between the blind panels and the PV modules. Therefore, a new mock-up will consider flat profiles with thickness of 1 mm, but also additional silicone along the flat profiles at connection between blind panels and PV modules. This also represents more realistic on-site installation conditions and allows for investigation of the system tolerances. As mentioned previously, alternatively another softer gasket type should be considered. However, this is not expected to be realistic as the combination of cover plate, mullions and gaskets is provided as a system solution.

Latest discussions under writing of this deliverable considered an alternative solution to avoid water ingress at the connection between the rubber gaskets in the cover plate and the flat or T-shaped profiles. This solution is illustrated in Figure 23 and Figure 24 below and consists of leaving a 1 mm gap between the rubber gaskets in the cover plate and the flat profiles. In the gap, a rubber thread is to be installed and afterwards, the joint should be sealed with silicone or another adhesive, like an expansion joint. Test results on this solution will be reported in the next deliverable D3.6.

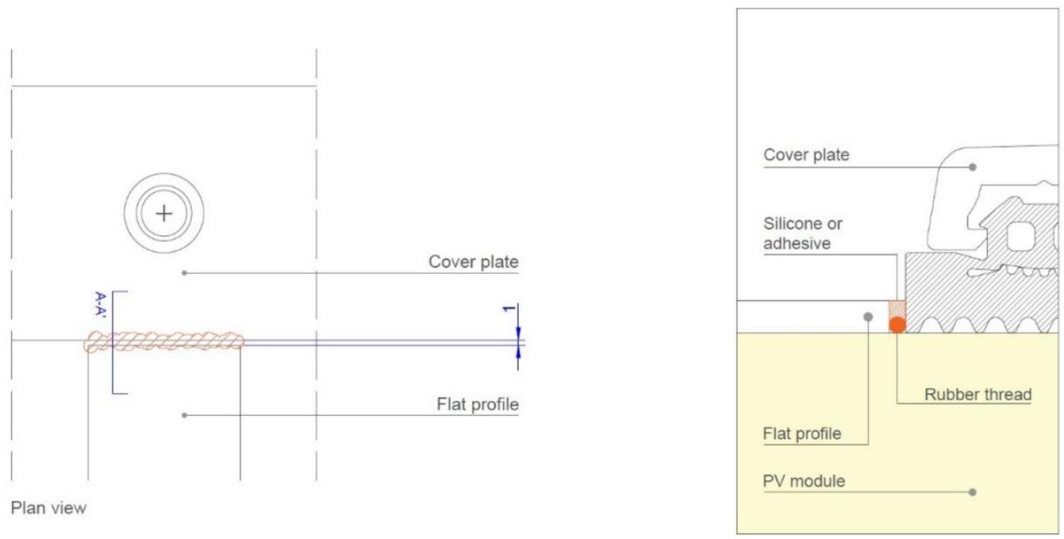

Figure 23. Proposed solution for the connection between cover plate and flat profiles.

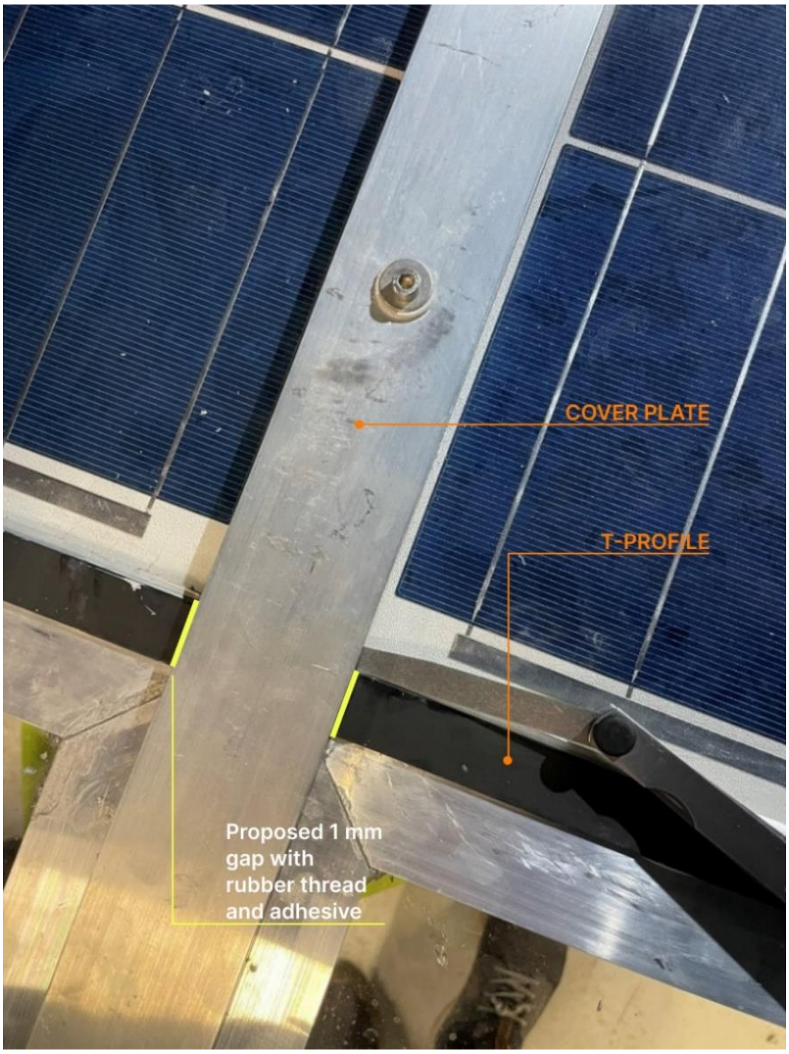

Figure 24. Illustration of proposed solution for the connection between cover plate and flat profiles on test mock-up.

2.5. Impact resistance

Strength of the sandwich panels (tensile strength, compressive strength and shear strength) has been tested for INDRES by Lattonedil, the manufacturer of the sandwich panels, according to EN 14509.

To ensure safety for the workers when installing the system or under maintenance activities, also puncture resistance tests for 'walkable' surfaces are planned to be performed at DTI, on both the sandwich panels and the PV panels. Tests will be performed according to TI-B 109 (98) ''Test method for slip resistance - Protection of persons stepping through roof slabs''. Currently, layout of the test mock-up is under discussion. A further description on the test method and test results will be included in the next deliverables D3.2 and D3.6.

3. Repurposed components - EV batteries

RE-SKIN includes battery repurposing, the re-use of discarded electric vehicle batteries, which no longer have performances suitable for the automotive sector, but are still effective for the construction sector. The battery system has been described in previous deliverables (D4.2, D4.4 and D6.1), but a brief overview will also be given in this chapter.

To document the performance of the batteries and their use for building application, a set testing procedure and documentation of the expected performance is needed. Testing procedures will be documented in detail the second release of D3.1 in M24. However, relevant test procedures are briefly mentioned in this deliverable, together with results from already concluded tests. At the time of this deliverable, initial testing on the individual battery cells has largely been concluded. Tests on the complete battery pack are currently being conducted, and results will be reported in the next release of this deliverable (D3.6).

3.1. Battery system design

The main purpose of the repurposed battery system in the RE-SKIN project is to store electrical energy generated by the PV modules on the BIPVT roof system, to be used to power the DC heat pump, the DC smart fan coils and other auxiliaries (e.g., pumps, fans, etc.) connected to the MIMO unit.

The battery pack it is made of recycled battery cells extracted from Electrical Vehicles (EV). The battery bank for the first prototype will be made with recycled battery cells (LEV40 type) from the Mitsubishi Outlander PHEV, manufactured by the Japanese company GS-Yuasa. The full battery pack for the first prototype will comprise 144 battery cells. Upon arrival, these 144 battery cells were assembled into 18 battery banks, each with 8 cells in series. In the RE-SKIN project, the 144 battery cells will all be placed in series. For safety and mechanical reasons, the full battery bank comprising these cells will be divided in 9 shelves, each with 16 battery cells.

Each individual cell is predicted to have a nominal voltage of 3,75 V (operating voltage range 2,75 to 4,1 V). The battery pack is stated to have a predicted a nominal voltage of 540V (min. voltage 400V and max voltage 590V), an expected nominal power of 15,12 kWh at installation and an estimated capacity of 28Ah from full charge. According to the unique energy storage needs of each building, different battery packs can be connected in parallel to reach the desired capacity. Technical features, operating temperature range etc. of the battery system are described in more detail in deliverable D4.2 and D6.1.

To achieve optimal energy storage, the battery bank will be monitored and controlled by a BMS (Battery Management System), which is integrated into the battery system and facilitates direct communication with the MIMO board. For more specifications on the MIMO and BMS, see deliverable D4.2, D4.4 and D6.1

The battery system will be housed in a contained in a stainless steel/aluminium cabinet meant for outside usage. The cabinet has an IP55 protection rating (dust and water ingress) according to IEC 60 529, ensuring proper operational conditions under varying conditions. Deliverable D6.1 provides more details on the design, assembly, installation, maintenance, and reliability aspects of the repurposed EV battery system for the RE-SKIN project.

3.2. Relevant test procedures

A methodology for testing repurposed EV batteries for building applications will be defined in the next release of deliverable D3.1. However, already performed initial tests at the Solartechno facilities will be reported in this deliverable. Performing initial tests allows for establishing a baseline performance and condition of the repurposed EV batteries. Initial tests may include visual inspection for physical damage, internal resistance measurements, open-circuit voltage measurement and capacity tests, see also section 3.3.

Ideally, to verify the long-term reliability, and to simulate the operating conditions and potential hazards the repurposed EV batteries may encounter in building applications, and particular within the RE-SKIN project, initial tests should be complemented with a set of accelerated ageing or stress tests, as described in for example IEC 62619. However, in production of the batteries, some of these tests have already been performed.

3.3. Initial testing and characterisation of recycled battery cells

At the time of writing this document, following series of tests have been performed by Solartechno to evaluate the initial condition of the individual recycled battery cells:

- Visual inspection for damages
- Smell test for electrolyte leakage
- Weight test to check for electrolyte loss
- Voltage measurement on arrival
- Internal electrical leakage/short circuit test
- Capacity test (charge/discharge cycles)

Cells failing these tests were discarded.

3.3.1. Visual inspection for damages

After dismantling the received battery packs, a visual inspection was made to ensure that the received batteries and battery cells were clean, dry and without defects or damages. Any cells with any kind of visual damages have been discarded. In total, 3 out of 160 received battery cells were damaged during disassembling the battery packs at the Solartechno facilities. However, this was due to some bolts that had been torqued too much by the initial dismantling company. While trying to remove these, some of the batteries were damaged.

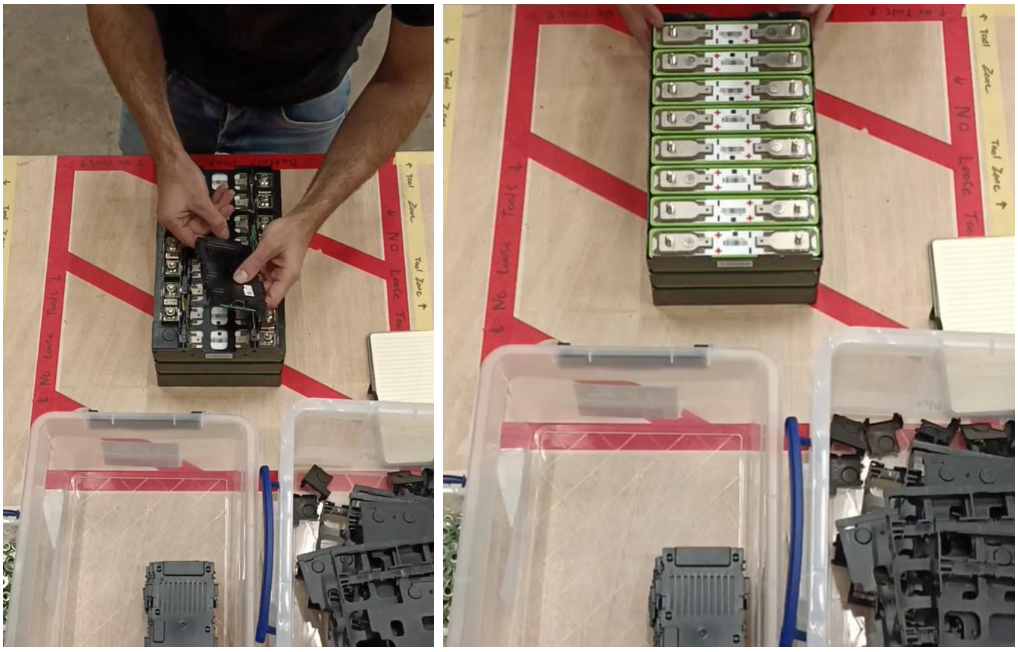

Figure 25. Left: dismantling process of the EV battery pack. Right: battery cells after dismantling the pack.

3.3.2. Electrolyte loss

3.3.2.1. Smell test

A smell tests is performed to quickly be able to identify potential electrolyte leakage. If there can be registered a sweet scent, there is an ongoing electrolyte leakage. If the electrolyte is leaking the battery is no more usable and should be discarded. None of the received battery cells showed signs of electrolyte leakage.

3.3.2.2. Weight test

In addition to the smell test, a weight test is performed to make ensure that no electrolyte leakage has taken place when receiving the batteries. For the weight test, each individual battery cell is weighed. A single battery cell has dimensions of 171 mm (length) x 32.5 mm (width) x 111 mm (height over terminals) and a weight of 1400 g, see also deliverable D4.4. Electrolyte normally should be around 10 to 17% of the weight of the cell, so at least 140 g for the battery cells used in the RE-SKIN project. As a threshold, it was decided to discard batteries with a mass loss of more than 50 g, i.e. batteries with a weight below 1350g should be discarded.

As can be seen from Table 3, none of the weighed cells have a weight below this threshold, and none of the cells have therefore been discarded because of potential electrolyte leakage.

Table 3. Summary of weighing results for the 160 tested battery cells[1)]

	WEIGHT(g)
MIN	1.401
MAX	1.411
Average	1.4059625
Standard Dev.	0,00225117

1) To prevent errors in the weight measurement, the scale was covered with a plastic cover during the measurement.

3.3.3. Electrical performance

3.3.3.1. Voltage measurement at arrival

The operating voltage range for the single battery cells is estimated to be between 2,75 to 4,1V. To check the minimum required voltage of 2,75V, voltage measurements were made on the single battery cells upon arrival at the Solartechno facilities. Cells showing a voltage below 2,75V indicate damages and should therefore be discarded.

Figure 26 shows ongoing weight and voltage measurement on a battery cell. Results from voltage measurements on the single battery cells can be found in Table 5.

Figure 26. Ongoing weight and voltage measurement on a battery cell.

As can be seen in Table 4, none of the voltage measurements are below 2,75V and all cells arrived in optimal voltage condition, even the 3 before-mentioned damaged cells. None of the cells have therefore been discarded due to low operating voltage.

Table 4. Summary of voltage measurements for the 160 tested battery cells

	VOLTAGE
MIN	3,792
MAX	3,839
Average	3,8217875
Standard Dev.	0,00964423

3.3.3.2. Internal electrical leakage/short circuit test

To test for internal electrical leakage, the battery cells were charged to at 90 % measure voltage after 1 day. Afterwards, they were left for two weeks and voltage in the battery cells was re-measured at the end of this period. This test can be used to identify cells with internal electrical leakage, as measurement results after two weeks will show a drop in voltage. Cells showing this behaviour should be discarded.

None of the tested cells showed internal leakage and none of the cells were therefore discarded based on the above criterion.

3.3.3.3. Capacity test (charge/discharge cycles)

During the capacity test, a charge/discharge cycle with Ah/Wh measured is performed on the cells. The tested cells should show an actual capacity after testing above 70% of the nominal declared capacity. Figure 27 shows the test set-up of the capacity test on single battery cells.

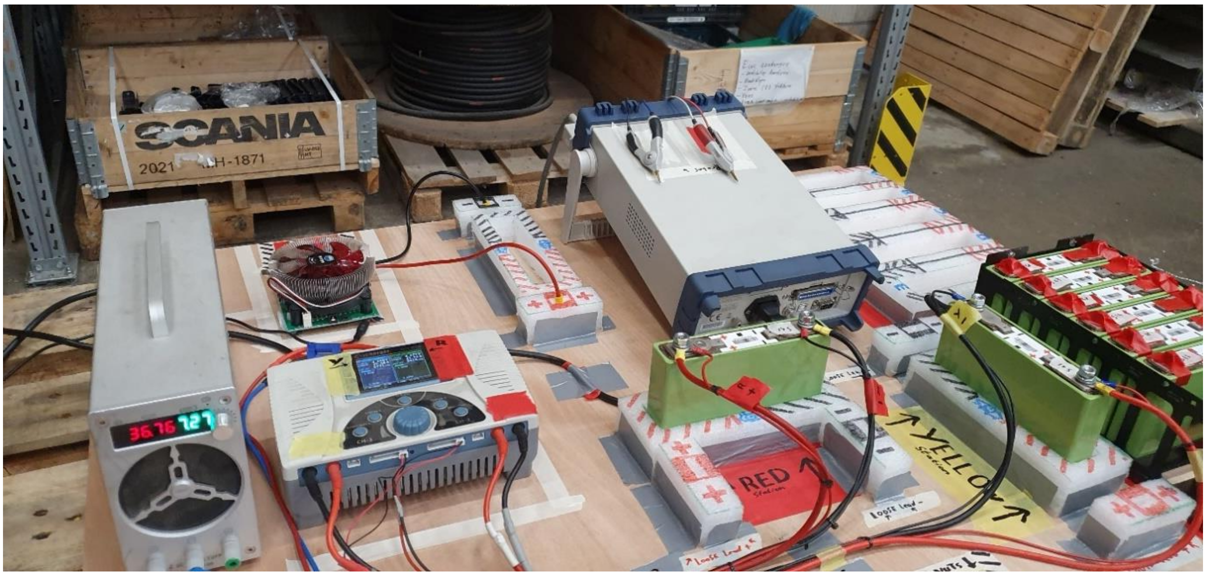

Figure 27. Set-up of the capacity test. Two battery cells are undergoing the charge/discharge process to measure their capacity.

Results showed that the capacity of the tested single cells was around 70% of their nominal capacity as declared by the manufacturer, which is slightly below the initial expectations of 75% of the nominal capacity. Therefore, additional testing will be performed when assembling the battery pack and further results will be included in the next release of this deliverable (D3.6).

As the batteries received at the Solartechno facilities have been still for some time, due to time from extraction from the EV vehicles to receiving and testing the batteries, another test was performed to see if a series of charge/discharge cycles (wake-up cycle), could improve the capacity of the battery cells. Based on experience, not using or activating the batteries for some time can limit the capacity of the batteries during the first few charge/discharge cycles.

Table 5 shows results for a first wake-up cycle test run on a single cell. Tests on this cell, but also the other cells showed that the battery cells were already in good condition at the time of testing since their capacity did not improve from one cycle to the next.

Table 5. Results from first wake-up cycle test run on a single cell (number 41).

Instance (Chrg./Dischrg. --> Cn/Dn)	D1	C1	D2	C2
n	1	2	3	4
Starting Temp (*C):	0	11.1	15.8	20.0
Starting Voltage (V)[1)]:	4.072	3.407	4.059	3.328
Charge Current (A) (initial):	-35	35	-35	35
Time (s) (Charge/Discharge):	2300	4680	2291	4260
Capacity mAh:	22045	21722	21962	22013
Final Voltage (V):	3.167	4.080	2.912	4.081
Final Temp (*C):	0	18.4	26.0	20.8

1) Cells first charged from Storage Voltage to baseline "Full V". First logged Data at Present "First Full Discharge".

4. Refurbished components – PV modules

RE-SKIN includes the use of refurbished PV modules in the BIPVT roof system. The PV modules are briefly described in previous deliverables (D4.2, D5.9 and D5.10), but an overview will also be given in this chapter. To document the performance of these refurbished panels, a set testing procedure and documentation of the expected performance is needed. Testing procedures will be documented in detail in an update to deliverable D3.1 in M24. However, relevant test procedures are briefly mentioned in this deliverable, together with results from already concluded tests.

4.1. PV panel design

The proposed PV modules derive from a refurbishing process that allows worn-out components to be reused, avoiding their disposal. At present, the proposed refurbished PV modules used in the RE-SKIN project are 3 bus-bar PV modules integrating 60 polycrystalline cells, with expected nominal power of 235 W. Size of the proposed modules corresponds to the most popular market dimensions.

The PV modules have an aluminium frame which encloses a front glass and a backsheet laminate. The front glass is tempered and has a thickness of 3,2 mm. The backsheet of the PV modules has been refurbished with a Remisol coating system (polymer varnish). For additional specifications on size and technical features of the PV modules, see D4.2 and D5.9.

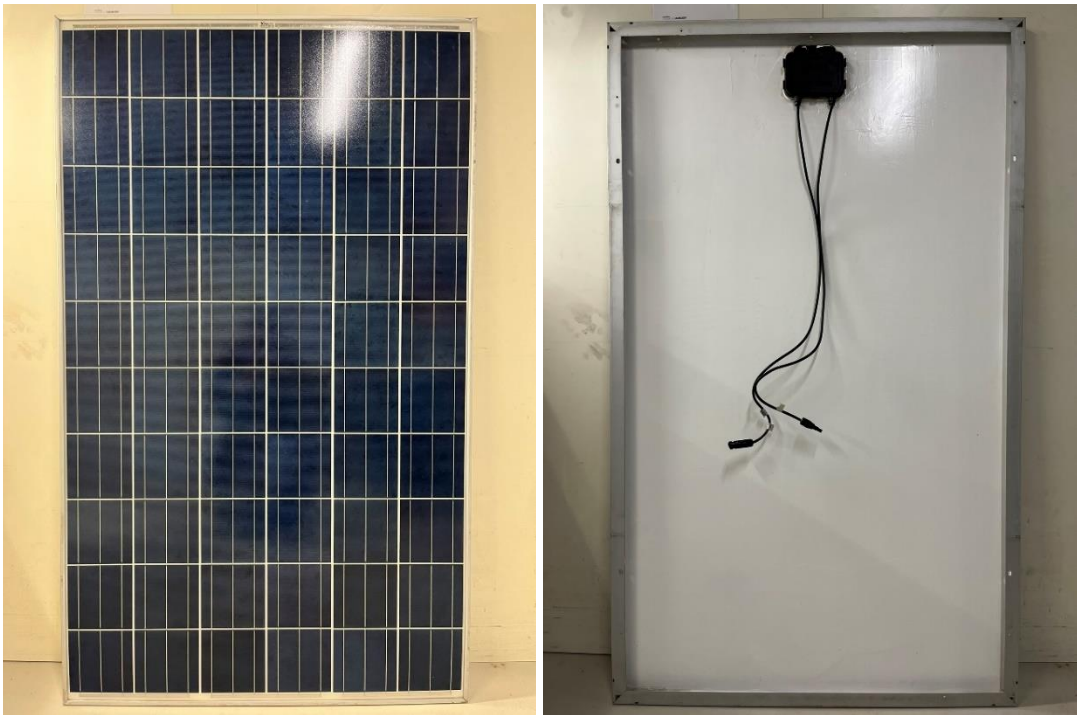

Figure 28. Refurbished PV modules received from RINOVA. Left: front. Right: backside.

4.2. Relevant test procedures

As stated in deliverable D3.1, testing of the performance of the refurbished PV modules will follow the IEC 61215-2 standard. A detailed description of the methodology for testing will be defined in the second release of D3.1 in M24.

Tests include both function and performance tests at external testing facilities, as well as optical function/visual tests, performed at Rinovasol facilities. To determine the electric performance of the panels, it is important to consider degradation, i.e. slow loss of power over time due to diffusion of the doped foreign atoms (n/p - doping), and to test the reliability of the coating system on the backsheet of the PV modules.

To provide sufficient insight into the quality and reliability of the backsheet repair solution, it is important to not only include measurements at standard conditions (e.g. STC power measurements), but also to include tests after accelerated ageing. This includes for example wet insulation testing before and after damp heat exposure.

4.3. Visual inspection

Upon receiving the panels at the Rinovasol facilities, all panels are visually inspected for following pre-defined defects:

- Backsheet cracks
- Broken glass
- Snail shells or trails
- Yellowing
- Diode error

After the inspection, the panels are classified into three categories:
1 – panels with no defects
2 – panels with minor defects
3 – panels with severe defects. A summary of errors is made, and panels are prepared for end-of-life treatment.

Only panels with no or minor defects, for example backsheet cracks, that can be repaired with the backsheet repair solution, are chosen for use in the RE-SKIN project.

4.4. Documentation of performance

4.4.1. STC power measurements before ageing/stress cycle

STC power measurements have been conducted on two PV modules with repaired backsheets from the same batch, to be used within the RE-SKIN project, provided by Rinova/GE4A Group B.V. Testing has been performed at the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW).

The two tested PV modules are both 3 bus-bar PV module integrating 60 polycrystalline silicon cells, with declared nameplate nominal power of respectively 250 and 255 W, see Figure 29.

Figure 29. Declared nameplate nominal power of PV modules (before refurbishment).

Both modules were manufactured during the 1st quarter of 2012 and commissioned in the 3rd quarter of 2012.

The STC (Standard Test Conditions) power measurements were performed according to IEC 61215-2:2021 (MQT 6):

- Conditions: 25°C, 1000 W/m², AM1.5 spectrum
- Equipment: Xenon flash sun simulator (Class AAA, Berger type)
- Reference: Mono-crystalline silicon module with precision calibration by Fraunhofer ISE
- Measurement uncertainty: ±2.1%

The STC power values were measured to 226.9W and 238.4W for the two modules. Considering the nominal power of 250-255W for the modules, the current measured power shows around 10 % degradation, which is to be expected over their 10-year lifetime. As the panels have been commissioned in the 3rd quarter of 2012, this fits with a (linear) degradation of approximately 1% per year.

4.4.2. Reliability of backsheet repair

To document the reliability and effectiveness of the backsheet repair/varnish, insulation resistance measurements have been conducted on 5 PV modules with repaired backsheets before and after accelerated ageing. Testing has been performed at Kansai Helios Austria GmbH.

The 5 tested PV modules all have deep longitudinal cracks and have been repaired with the coating system from Remisol for the repair of backsheets on the PV modules in the RE-SKIN project. The 5 tested PV modules have a nominal power of 235 W and have been in use for 6-7 years in a field installation in Greece.

After application of the repair coating, and allowing a multi-day drying time, the following tests were carried out according to IEC 61215-2:

- Wet leakage current test (MQT 15)
- Climate chamber test (damp heat conditions) (MQT13) - 85°C, 85% RH, test duration 1000 hours
- Wet leakage current test (MQT 15) after climate chamber exposure

Figure 30. Repair process of PV modules. Left: Panels with light cracks on backsheet. Middle: Repair of backsheet. Right: PV panel with repaired backsheet before testing.

Initial values of the wet leakage current test showed an insulation resistance Rwet after coating > 1,000 MOhm. After the damp heat (MQT 13) test, Rwet values dropped, but remained above > 100 MOhm and therefore well above the minimum required 40 MOhm. Additional results from outdoor exposure testing results, showed that panels with initial insulation resistance < 0.1 MOhm, insulation resistance could be restored to > 200 MOhm after coating.

4.4.3. Thermal cycling test

In addition to the before-mentioned tests, the PV modules were also subjected to a thermal cycle stress test (MQT 11) according to the IEC 61215-2 standard. This to determine the ability of the panels to withstand thermal mismatches, fatigue and other stresses caused by repeated changes of temperature. The panels were subjected to 50 cycles, with temperature ranges up to -40°C and + 85°C. The modules passed these tests. However, no further information on the test was provided at this moment but will be included in the next test report (D3.6).

4.4.4. Cyclic (dynamic) mechanical load test

To evaluate if components within the PV modules are susceptible to low levels of mechanical stress, a cyclic (dynamic) mechanical load test (MQT 20) has been performed in accordance with IEC 61215-2 standard. The test has been performed for over 1000 cycles and the modules passed these tests. However, no further information on the test was provided at this moment but will be included in the next test report (D3.6).

4.5. Hail test

As mentioned in chapter 2, to document performance of the PV modules and probability of glass breakage when exposed to hail, a hail test according to IEC 61215-2 (MQ17) will be performed at the DTI test facilities. Several sizes and speed of hail stones are suggested in IEC 61215-2 (MQ17).
Size and speed of the hail stones is currently under discussion and to be agreed upon based on further risk assessment carried out in WP2.

Figure 31 below shows moulds for making the hail stones, and the ballistic chronograph used for speed measurements of the hail stones during testing. A further description on the test method and the size and speed of the hail stones will be included in the next deliverables D3.2 and D3.6.

Figure 31. Hail test. Left: ballistic chronograph used for speed measurements of the hail stones. Right: Moulds for making hail stones in different sizes.