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BRE Test Report

Wind Uplift Testing of Renusol PV Systems to MCS012

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Table of Contents

1 Introduction

At the request of Nico Schwarze, TUV Rheinland Solar GmBH, BRE issued Proposal P123168 issue 4 on 29th June 2022. This was accepted on 10th August 2022. The tests on the specimens were carried out under the BRE Standard Terms and Conditions of Business under BRE project P123168-1001 between 25th October 2022 and 1st November 2022.

The MCS 012 standard specifies the test procedures which shall be used to demonstrate the performance of PV modules and solar thermal collectors and/or their installation kits under the action of wind loads. These test methods apply to 'in roof' and 'above roof' systems fixed to pitched roofs. They do not apply to systems mounted inclined above flat roofs or mounted on vertical walls.

This report describes the test methods and results for wind uplift testing carried out on four Renusol PV systems to the MCS 012 test method [1].

2 Details of the Test Specimen and Installation

Four Renusol systems were tested. Renusol representatives installed the specimens for the weathertightness testing. Details of the components of each system are described below:

2.1 RH1 Roof Hook

The components of the system tested are outlined in Table 1.

Product Name	Product Number
RH1 Roof Hook	R420171
VS+ Mounting Rail (60mm x 38mm)	R400535
RS1 Module Clamp (end and middle)	R400080
Sparibo 6.0mm x 80mm Sit 30 Pan Head Wood Construction Screw	R900318
2 x PV Panel, 2110mm x 1050mm	Various

Table 1. Components of RH1 Roof Hook System.

A total of six RH1 Roof Hooks were attached to the rafters of the BRE test rig, Figure 1. Three Sparibo 6.0mm x 80mm Sit 30 Pan Head Wood Construction Screw were used per bracket. The bracket arm itself was installed at its highest position, as a worst-case scenario. The brackets were installed in an offset array, as depicted in Figure 2, where the red circles depict the location of each bracket.

Figure 1. Installation of the RH1 Roof Hook to the BRE test rig.

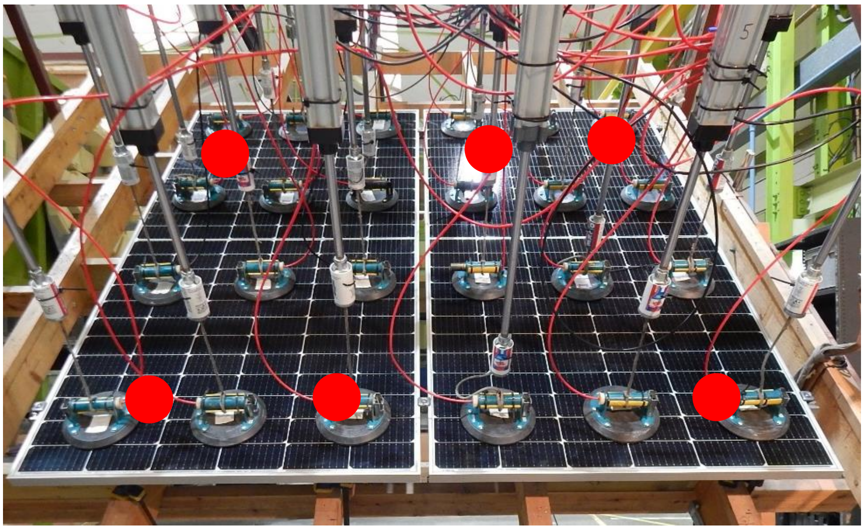

Figure 2. Image to highlight the positions of the RH1 brackets.

The rails were then attached to the brackets with four end clamps and two mid clamps then attached to the rails. Two 2110mm x 1050mm PV panels were then installed in a portrait orientation and fixed in place via the clamps.

The system was installed following the Renusol installation guide, Figure 3.

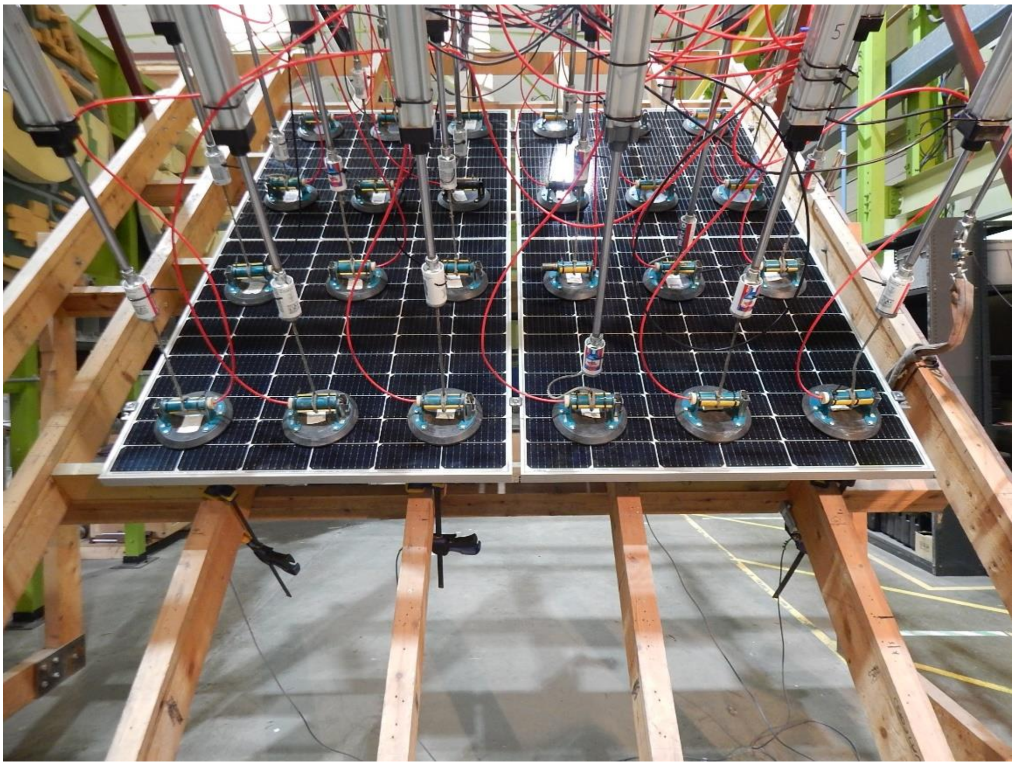

Figure 3. Installation of the RH1 Roof Hook system on the BRE test rig prior to test.

2.2 RH Flat Roof Hook

The components of the system tested are outlined in Table 2.

Product Name	Product Number
RH Flat Roof Hook	R420172
VS+ Mounting Rail (60mm x 38mm)	R400535
RS1 Module Clamp (end and middle)	R400080
Sparibo 6.0mm x 80mm Sit 30 Pan Head Wood Construction Screw	R900318
2 x PV Panel, 2110mm x 1050mm	Various

Table 2. Components of RH Flat Roof Hook System.

A total of six RH1 Flat Hooks were attached to the rafters of the BRE test rig, Figure 4. Two Sparibo 6.0mm x 80mm Sit 30 Pan Head Wood Construction Screw were used per bracket. The bracket arm itself was installed at its highest and most outer position, as a worst-case scenario. The brackets were installed in an offset array, as depicted in Figure 2, where the red circles depict the location of each bracket.

Figure 4. Installation of the RH Flat Roof Hook to the BRE test rig.

The rails were then attached to the brackets with four end clamps and two mid clamps then attached to the rails. Two 2110mm x 1050mm PV panels were then installed in a portrait orientation and fixed in place via the clamps.

The system was installed following the Renusol installation guide, Figure 5.

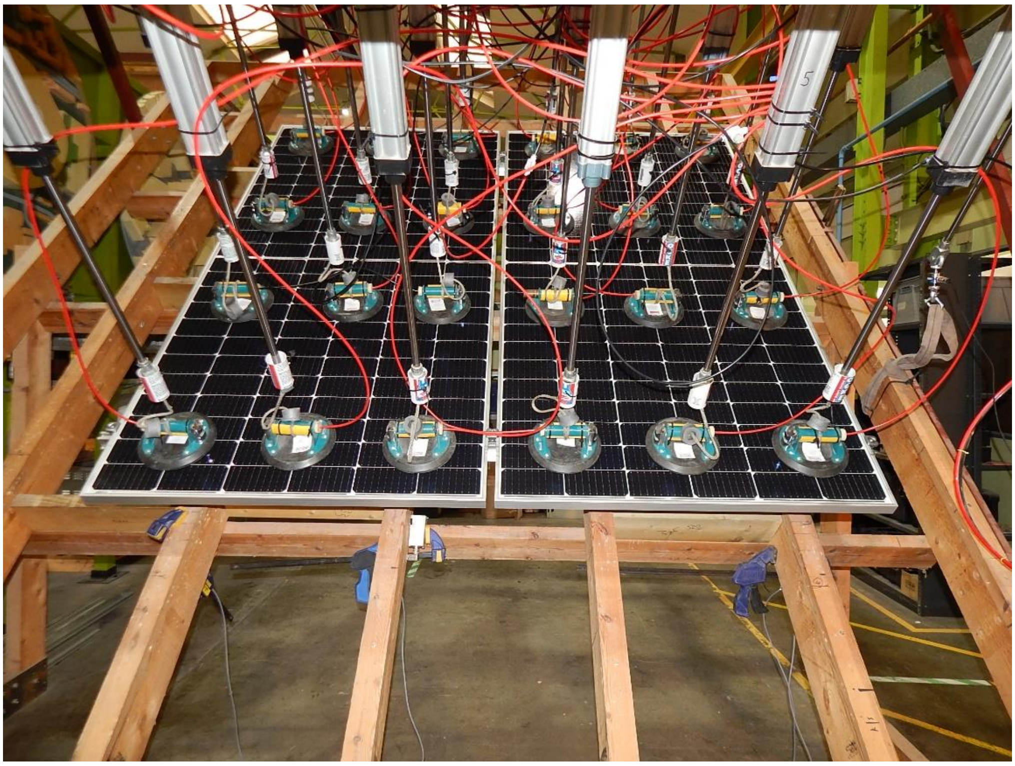

Figure 5. Installation of the RH Flat Roof Hook system on the BRE test rig prior to test.

2.3 Hanger Bolt

The components of the system tested are outlined in Table 3.

Product Name	Product Number
Offset Hanger Bolt M10 x 250mm	R860021 & R860022
VS+ Mounting Rail (60mm x 38mm)	R400535
RS1 Module Clamp (end and middle)	R400080
2 x PV Panel, 2110mm x 1050mm	Various

Table 3. Components of Hanger Bolt System.

A total of six offset hanger bolts (M10 x 250mm) were attached to the rafters of the BRE test rig, Figure 6, which was used to attach two rails.

Figure 6. Installation of the offset hanger bolt to the BRE test rig.

Again, four end clamps and two mid clamps were then attached to the rails. Two 2110mm x 1050mm PV panels were then installed in a portrait orientation and fixed in place via the clamps.

The system was installed following the Renusol installation guide, Figure 7.

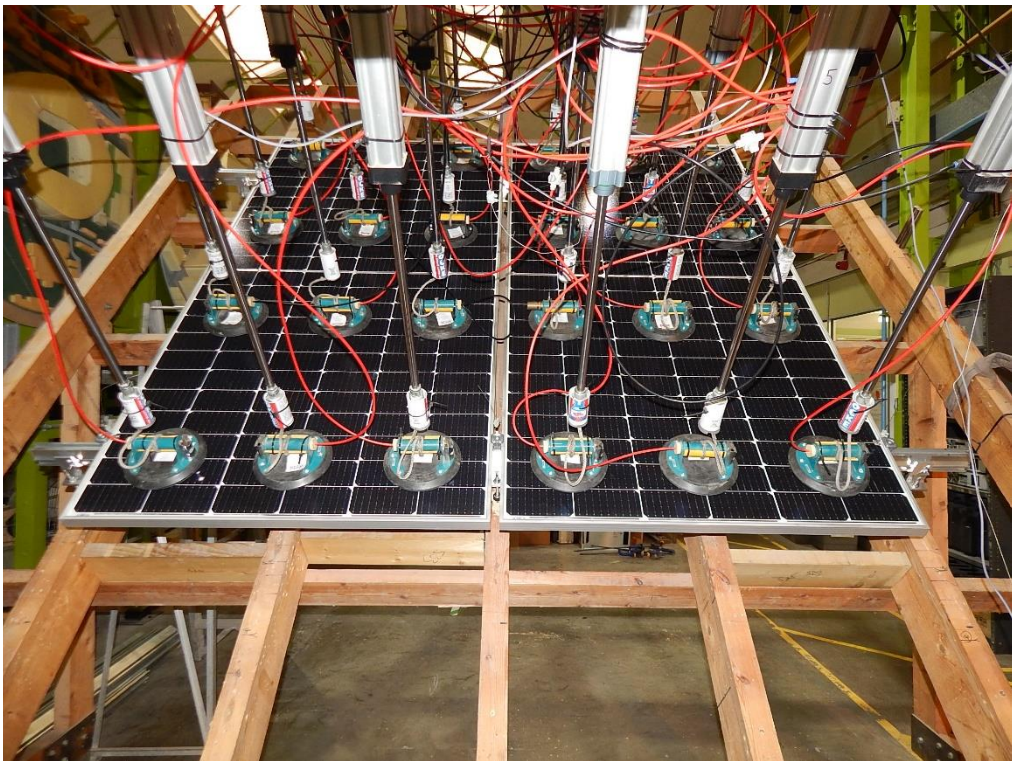

Figure 7. Installation of the Offset Hanger Bolt system on the BRE test rig prior to test.

2.4 Metasole Rail

The components of the system tested are outlined in Table 4.

Product Name	Product Number
MS+ Corrugated rail	R420171
RS1 Module Clamp (end and middle)	R400080
Ejofast Stainless Steel Self Drilling Screws, 5mm x 25mm SW8 E16	R400301
2 x PV Panel, 2110mm x 1050mm	Various

Table 4. Components of Metasole System.

Two sheets of 0.7mm corrugated metal sheeting was attached to the BRE test rig. Six Metasole brackets were attached to the corrugated sheets, Figure 8, which allowed six end clamps to be installed to allow two 2110mm x 1050mm PV panels were then installed in a landscape orientation and fixed in place via the clamps.

Figure 8. Installation of the Metasole bracket to the BRE test rig.

The system was installed following the Renusol installation guide, Figure 9.

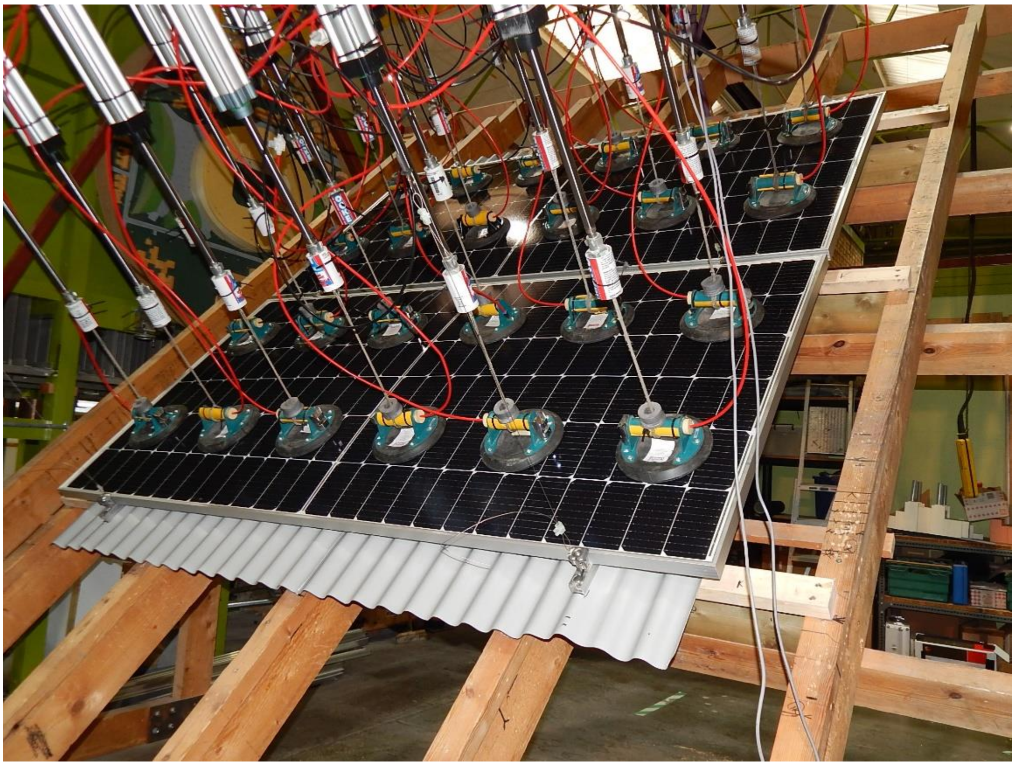

Figure 9. Installation of the Metasole Bracket system on the BRE test rig prior to test.

Please note. The three products were installed in portrait mode (RH1 Roof Hook, RH Flat Roof Hook and Hanger Bolt) with the Metasole Rail installed in landscape mode.

3 Details of the Tests Carried Out

3.1 Test Procedure Specifics

The recommended test method in MCS012 for wind uplift testing is based on BS EN 14437:2004 [2], which is a test method originally designed for test wind uplift resistance of roof tiles and slates. The tests are carried out on a simulated roof structure comprising rafters at a roof pitch of 45º. 12 pneumatic rams with suction cups were attached to each PV panel, a total of 24 pneumatic rams per system, to apply an uplift force to simulate wind uplift loads. For the RH1 roof hook, RH Flat roof hook and Hanger Bolt, this was in 4 rows of 3 suction cups with the PV panels in portrait orientation. For the Metasole system, this was in 4 rows of 6 suction cups with the PV panels in landscape orientation.

The test requirements are as follows:

- Where the flashing or sealing kits provides any uplift resistance then these should be included in the test.
- The roof pitch shall be 45deg +/- 2 degrees.
- A minimum of one solar panel should be tested and the test shall be repeated three times with new fixings each time. If PV panels share components, two PV panels should be tested.
- The uplift load shall be applied using a cable(s) or equivalent methods to provide uniform loads. This\these may be fixed to the solar collector by drilling a hole(s) through the collector or by using suction cup devices attached to the glass cover plate.
- The detailed construction of the test rig in terms of the batten sizes, rafter spacing and all fixings shall satisfy the minimum specification (worst case) of the manufacturer/supplier of the solar panel and all materials shall be of a quality typical of real construction. The minimum requirements of BS 5534 shall also be satisfied.

The load testing was repeated a minimum of three times with new clamps and brackets used for each test. Where PV panels were damaged, new panels were used.

The loads were applied in a minimum of five increments (as required by the standard). After each load was applied it was removed and the residual deflection was measured. Displacement gauges were attached to the systems in various locations according to the system under test to measure the deflection under load and the residual deflection. For the RH1 and RH flat roof hook brackets, displacement gauges were attached to the bend in the bracket, Figure 10, for each of the corner brackets. For the hanger bolt, displacements were measured on the PV panel itself adjoining where the clamp was located, Figure 11. Finally, for the Metasole brackets, displacements were measured on the corner clamps themselves, Figure 12 bre

Figure 10. Image to show the installation of a displacement gauge on the RH1 and RH Flat roof brackets.

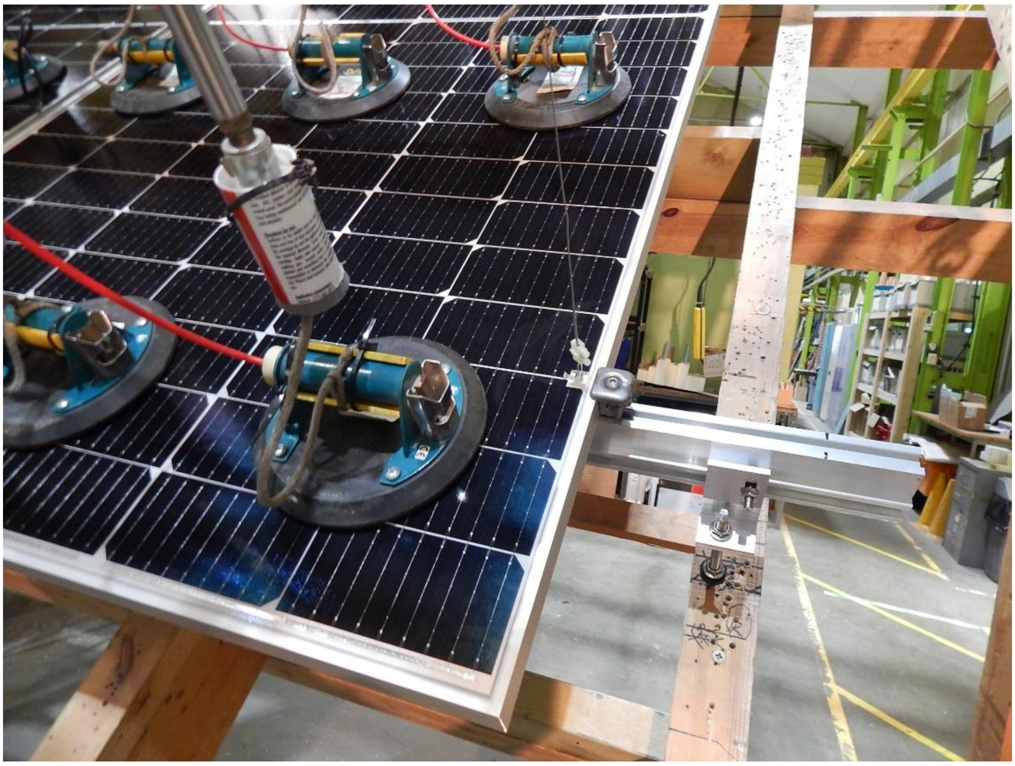

Figure 11. Image to show the installation of a displacement gauge on the PV panels for the offset hanger bolts.

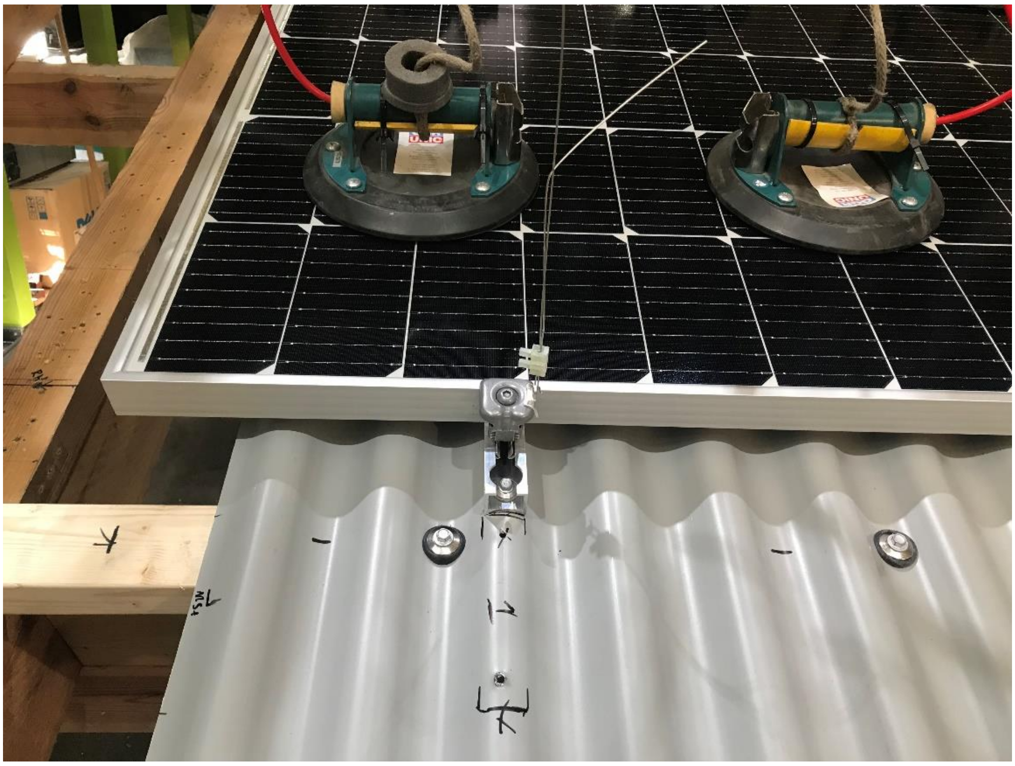

Figure 12. Image to show the installation of a displacement gauge on the Metasole brackets.

The loading cycles were repeated in increasing load increments until failure occurred; where failure is defined as any of the following:

- Breakage of a mechanical fixing between PV module and support frame.
- Pull-out or breakage of the mechanical connection between the support frame and the roof structure.
- Breakage of the PV module.
- The residual displacement exceeds 5mm after releasing the applied load, providing this displacement degrades the weathertightness of the roof
- If the maximum displacement of any roofing element which exposes the under-roof exceeds 75mm.

4 Test Results

4.1 Determination of the characteristic uplift resistance

EN 14437:2004 requires the characteristic uplift resistance R_k to be determined from equation 1:

$R_k = R_x – k_n s_x$ … (1)

Where R_x is the mean uplift resistance determined from $R_x = \frac{1}{n}\sum R_i$

s_x is the standard deviation of the resistance determined from $s_x = \sqrt{\frac{1}{n-1}\sum (R_i - R_x)^2}$

k_n is a statistical factor = 3.37 (for a sample size of 3 from Table D.1 in EN 14437)

R_i is the individual measured value from each test

EN14437 requires that the coefficient of variability given as s_x/ R_x be <0.1 after each batch of three tests. If this value exceeds 0.1 then at least two additional tests must be carried out.

The design wind uplift resistance is determined by dividing the characteristic uplift resistance by a safety factor. MCS012 specifies a range of partial factors to be used to calculate the design resistance of the system as follows:

For an ultimate limit state, i.e. the system fails

- Failure of a metal component: 1.1
- Pull-out of a metal component: 1.25
- Failure in a timber component: 1.44

For a serviceability limit failure (no failure but the system is no longer fit for purpose)

- Servicability failure: 1.0

4.2 Results from tests on the RH1 Roof Hook System

Figure 13 shows the RH1 roof hook system under test.

Figure 13. Image to show the RH1 roof hooks under test.

During the testing of the RH1 roof hooks, there was a large variation in failure loads for the three roof hooks tested, Table 5. The coefficient of variability (s_x/R_x) is >0.1 and so therefore this test is invalid. Upon investigation, it was found that the variation could be accounted for by two different batches of clamps used. Clamps with batch number 29V22 were found to perform worse than clamps with batch number 29H22. Figure 14 shows the failed clamp in situ and Figure 15 compares the failed clamp against a new clamp.

Test configuration	Test number	Measured force (N)	Failure mode
RH1 roof hook	1	13796.784	Panel frames buckled
RH1 roof hook	2	6733.584	Failure of top centre clamp
RH1 roof hook	3	6733.584	Failure of top centre clamp

Mean force (N)	**9088.0**
Standard deviation (N)	**4077.9**
Coefficient of variability	**0.449**

Table 5. Ultimate limit state results from tests on the RH1 Roof Hook System (initial test results with batch 29V22).

Figure 14. Image to show the RH1 roof hook under test.

Figure 15. Image to show the RH1 roof hook under test.

The test was completed with clamps with batch number 29H22 to obtain the test data for the RH1 roof hook system. Table 6 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the RH1 roof hook system.

Test configuration	Test number	Measured force (N)	Failure mode
RH1 roof hook	1	13796.784	Panel frames buckled
RH1 roof hook	2	14291.208	Panel frames buckled
RH1 roof hook	3	14738.544	Panel frames buckled

Mean force (N)	**14275.5**
Standard deviation (N)	**471.1**
Coefficient of variability	**0.033**
Characteristic wind uplift pressure	**5726.9**

Table 6. Ultimate limit state results from tests on the RH1 Roof Hook System with batch 29H22

The characteristic uplift resistance of the system in the tests was 5726.9 Pa. This was determined by dividing the characteristic uplift resistance in Newtons calculated from Equation (1) by the area of the PV panel taken as 2.216m^2 (2.11m x 1.05m) to give the characteristic uplift resistance in Pascals (Newtons per metre squared). Figure 13 shows the RH1 roof hook system under test.

The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. The 5mm residual deflection limit was not exceeded at any measurement location in any of the tests, therefore there was not a serviceability limit state failure of this system.

The failure mode in each test was the buckling of the PV panel, Figure 16, which then led to the pull out of the centre clamp, Figure 17.

For design purposes, the characteristic uplift resistance load is divided by an appropriate partial (safety) factor. This defines the maximum design uplift resistance for the failure mode in the test. The partial safety factor for ultimate failure depends on the failure mechanism and has been taken as a failure of a metal component.

This gives a design wind uplift resistance of 5726.9/1.1 = **5206 Pa**.

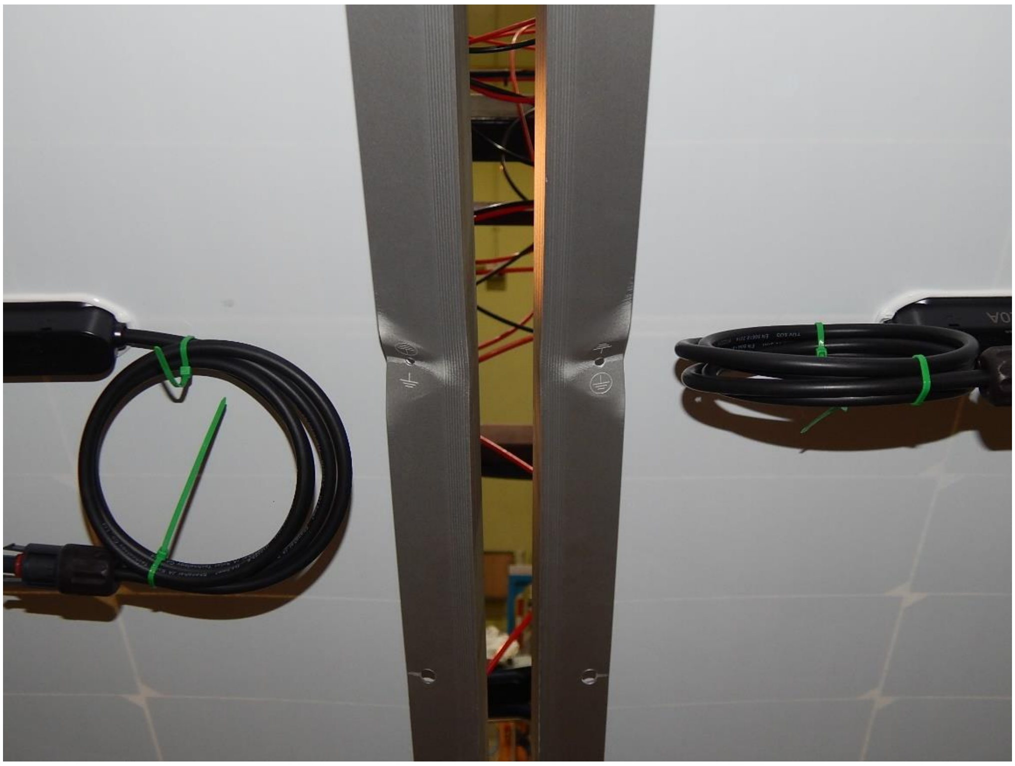

Figure 16. Image to show the ultimate failure of the RH1 roof hook via buckling of the PV panel leading to the failure of the mid clamp for the RH1 roof hook system.

Figure 17. Image to compare the damaged clamp, right, and new clamp, left, after the buckling of the PV panel.

4.3 Results from tests on the RH Flat Roof Hook System

Table 7 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the RH flat roof hook system.

Test configuration	Test number	Measured force (N)	Failure mode
RH flat roof hook	1	7910.8	Failure of bottom right clamp
RH flat roof hook	2	8617.1	Failure of bottom centre clamp
RH flat roof hook	3	8617.1	Failure of both centre clamps

Mean force (N)	**8381.7**
Standard deviation (N)	**407.8**
Coefficient of variability	**0.049**
Characteristic wind uplift pressure	**3162.9**

Table 7. Ultimate limit state results from tests on the RH Flat Roof Hook System

The characteristic uplift resistance of the system in the tests was 3162.9 Pa. This was determined by dividing the characteristic uplift resistance in Newtons calculated from Equation (1) by the area of the PV panel taken as 2.216m^2 (2.11m x 1.05m) to give the characteristic uplift resistance in Pascals (Newtons per metre squared).

The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. The 5mm residual deflection limit was not exceeded at any measurement location in any of the tests, therefore there was not a serviceability limit state failure of this system.

The failure mode in each test was the failure of the roof hook, as shown in Figure 18, in four different locations.

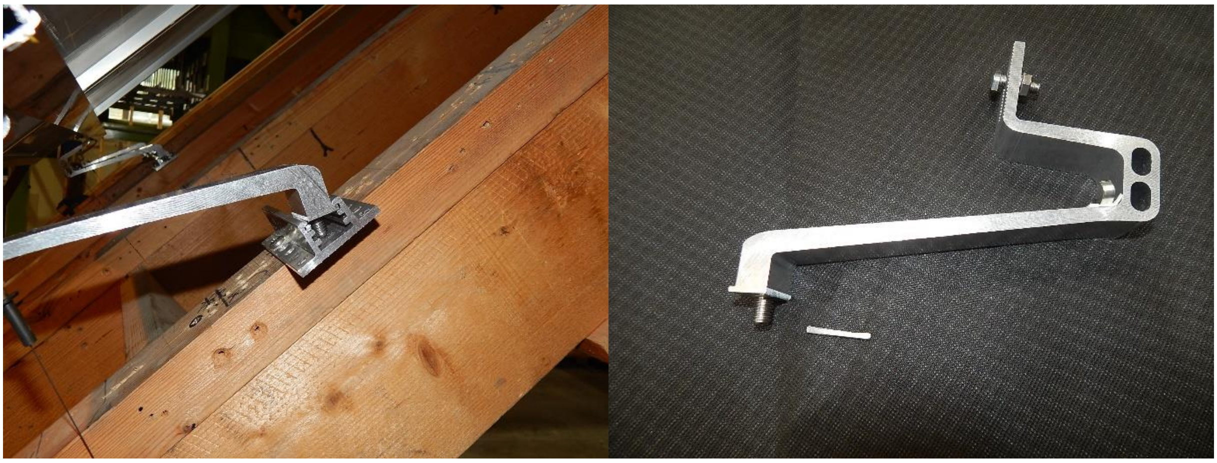

Figure 18. Image to show the ultimate failure of the RH flat roof hook system.

For design purposes, the characteristic uplift resistance load is divided by an appropriate partial (safety) factor. This defines the maximum design uplift resistance for the failure mode in the test. The partial safety factor for ultimate failure depends on the failure mechanism and has been taken as a failure of a metal component.

This gives a design wind uplift resistance of 3162.9/1.1 = **2875 Pa**.

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4.4 Results from tests on the Hanger Bolt System

Figure 19 shows the hanger bolt system under test.

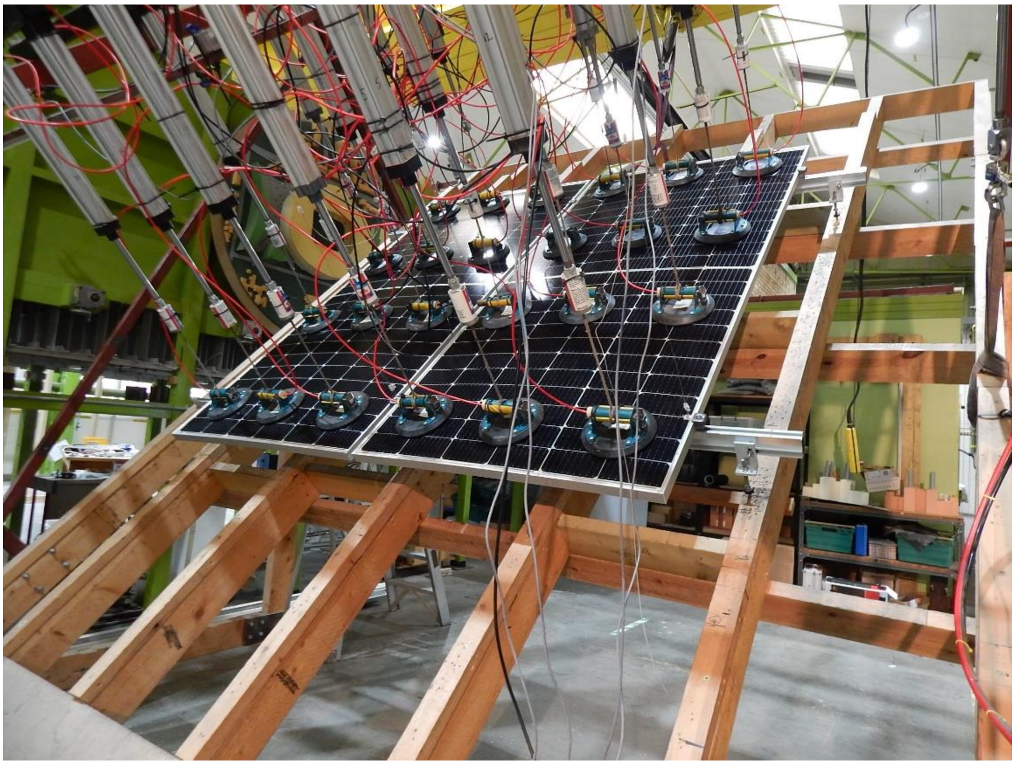

Figure 19. Image to show the hanger bolt system under test.

Table 8 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the hanger bolt system.

Test configuration	Test number	Measured force (N)	Failure mode
Hanger bolt	1	11442.384	Failure of top centre clamp
Hanger bolt	2	13090.464	Failure of top centre clamp
Hanger bolt	3	10265.184	Failure of top centre clamp

Mean force (N)	**11599.3**
Standard deviation (N)	**1419.2**
Coefficient of variability	**0.122**
Characteristic wind uplift pressure	**3076.8**

Table 8. Ultimate limit state results from tests on the hanger Bolt System.

The characteristic uplift resistance of the system in the tests was 3076.8 Pa. This was determined by dividing the characteristic uplift resistance in Newtons calculated from Equation (1) by the area of the PV panel taken as 2.216m^2 (2.11m x 1.05m) to give the characteristic uplift resistance in Pascals (Newtons per metre squared).

The failure mode in each test was failure of the clamps at the top centre location, Figure 20.

Figure 20. Image to show the ultimate failure of the hanger bolt system.

The 5mm residual deflection limit was not exceeded at any measurement location in any of the tests, therefore there was not a serviceability limit state failure of this system. But the coefficient of variability (s_x/R_x) is >0.1 therefore this is an invalid test result. The standard states that and additional two tests should have been completed but the clients did not have additional components.

The design wind uplift resistance has not been calculated.

4.5 Results from tests on the Metasole System

Figure 20 shows the Metasole bracket under test.

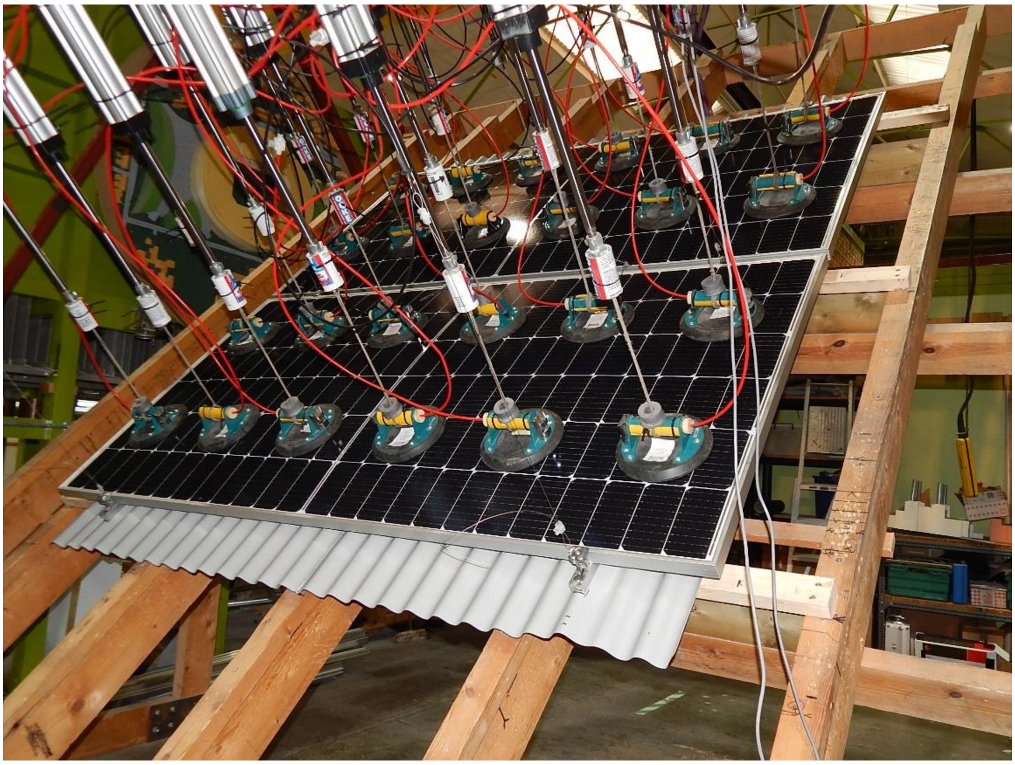

Figure 21. Image to show the Metasole bracket system under test.

Table 9 gives the calculated values of R_k, R_x, s_x and s_x/R_x and the individual failure loads from each of the three tests on the Metasole bracket system.

Test configuration	Test number	Measured force (N)	Failure mode
Metasole bracket	1	10500.6	Left middle mount screws pulled out
Metasole bracket	2	12148.7	Right middle mount screws pulled out
Metasole bracket	3	10346.7	Left middle mount screws pulled out
Mean force (N)		**10998.7**	
Standard deviation (N)		**998.9**	
Coefficient of variability		**0.091**	
Characteristic wind uplift pressure		**3444.9**	

Table 9. Ultimate limit state results from tests on the hanger Bolt System.

The characteristic uplift resistance of the system in the tests was 3444.9 Pa. This was determined by dividing the characteristic uplift resistance in Newtons calculated from Equation (1) by the area of the PV panel taken as 2.216m^2 (2.11m x 1.05m) to give the characteristic uplift resistance in Pascals (Newtons per metre squared).

The coefficient of variability (s_x/R_x) is <0.1 therefore this is a valid test result. The 5mm residual deflection limit was not exceeded at any measurement location in any of the tests, therefore there was not a serviceability limit state failure of this system.

The failure mode in each test was the pull out of the bracket fixings, Figure 22.

Figure 22. Image to show the ultimate failure of the Metasole bracket system.

For design purposes, the characteristic uplift resistance load is divided by an appropriate partial (safety) factor. This defines the maximum design uplift resistance for the failure mode in the test. The partial safety factor for ultimate failure depends on the failure mechanism and has been taken as a pull-out of a metal component.

This gives a design wind uplift resistance of 3444.9/1.25 = **2776 Pa**.

5 Conclusions

This report describes tests carried out of a number or Renusol PV mounting systems to determine the wind uplift in accordance with MCS 012.

The following conclusions can be drawn from these tests:

Wind Uplift

- The design uplift resistance of the RH1 roof hook is **4395 N** (based on ULS and a partial factor of 1.1).
- The design uplift resistance of the RH flat roof hook is **2875 N** (based on ULS and a partial factor of 1.1).
- The coefficient of variability for the Hanger bolt system results was outside of the allowable range. Therefore, the results are invalid and the design uplift resistance was not calculated.
- The design uplift resistance of the Metasole bracket is **2776 N** (based on ULS and a partial factor of 1.25).

6 References

1) MCS012; Microgeneration Certification Scheme, Roof performance tests for solar thermal collectors and PV modules.

Report Ends