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BRE Test Report

Rain Penetration Tests on Manthorpe Single Pantile Vent

Prepared for: Ben Hales

Date: 18th April 2016

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Executive Summary

This report describes rain penetration tests carried out on a Manthorpe Single Pan Tile Vent to assess its resistance to driving rain. The vent was tested at roof pitches of 17.5º and 20º. The tests were carried out using a monopitch roof test rig according to the procedures in CEN standard FprEN 15601. The test roof was positioned in the exit air flow of the BRE No.3 Boundary Layer Wind Tunnel. Two sets of test conditions were used, as follows:

- Sub test B - High rainfall with high wind speed
- Sub test D - Deluge - simulating maximum rainfall with no wind

These test conditions represent typical worse case conditions expected in Northern Europe during a 50 year return period. The following main conclusion can be drawn from this testing:

- The weathertightness performance of the Manthorpe Single Pan Tile Vent is better than that of the surrounding concrete pan tiles.
- The Manthorpe Single Pan Tile Vent will perform satisfactorily at a minimum roof pitch of 17.5º.
- The Manthorpe Single Pan Tile Vent does not leak before the surrounding Fenland concrete pan tiles at roof pitches of 17.5º and 20º. As weathertightness performance improves with roof pitch, the Manthorpe Pan Tile Vent is expected to also perform satisfactorily at roof pitches above 20º.

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1 Introduction

This report describes rain penetration tests carried out on the Manthorpe Single Pan Tile Vent when installed with Redland Fenland concrete tiles. The tests reported herein were carried out at BRE, Garston Watford during April 2016 at roof pitches of 17.5º and 20º.

This test is based on BRE Proposal No. P104059 dated 17th March 2016, which was accepted by Mr Ben Hales.

The testing was witnessed by:

Mr Ben Hales and Mr Jed Brown from Manthorpe Building Products Ltd.

2 Objective

The objective of these tests was to assess the driving rain performance of the Manthorpe Single Pan Tile Vent when installed with Redland Fenland concrete tiles according to the procedures given in CEN standard FprEN 15601: Hygrothermal performance of buildings: Wind-driven rain on roof coverings with discontinuously laid small elements – test method.

Tests were carried out at roof pitches of 17.5º and 20º, the testing was carried out using the following wind and rain combinations:

- High rainfall with high wind speed (defined in FprEN 15601 as the type B test)
- Deluge - simulating maximum rainfall with no wind (defined in FprEN 15601 as the type D test)

3 Test Specimen

The vent and tiles were installed on the BRE test rig by Manthorpe employees. For these tests Redland Fenland concrete tiles were used. Figure 1 shows the vent installed in the rig.

Figure 1 Single Pan Tile Vent installed with Redland Fenland tiles

The performance of the roof vent was investigated using a purpose-built monopitch test roof of nominal size 2m x 2m. On the underside of the test roof, and central to it, a 1.8m wide x 1.6m long shallow Perspex box (open area 2.88m^2) was mounted. It was this box that allowed the pressure underneath the tiles to be controlled. This test rig fully complies with the requirements laid down in FprEN 15601:2006 and has been calibrated to give the required uniformity of wind speed and rain flow across the test specimens. Results of the calibration tests on the BRE test rig and details of the turbulence intensity in the flow are presented in Annex B. Figure 2 shows the roof vent and tiles under test.

Figure 2 Manthorpe Single Pan Tile Vent with Redland Fenland tiles under test

4 Test Procedure

Tests were carried out on the roof tiles with no vent in order to obtain the benchmark performance of the tiles. The tests were then repeated with a single vent tile in place with surround roof tiles. Then test specimens were installed on the BRE test rig positioned at the wind tunnel outlet. On the underside of the test rig, a Perspex pressure box enabled the pressure difference across the tiles to be varied during the testing. The edges around the pressure box were sealed to prevent the ingress of water during the rain penetration testing; this sealing also provided an effective aerodynamic seal between the air flow conditions above and below the tiles.

The wind tunnel velocity was measured using a Pitot-static tube placed in the wind tunnel free stream. A calibrated micro manometer was connected to this Pitot - static tube, and monitored the wind tunnel velocity during the testing.

The pressure in the Perspex box was increased or decreased by the use of a variable speed fan. The pressure difference between the static pressure above the roof and the pressure inside the pressure box was measured using a second calibrated micro manometer.

The test procedures complied with those set out in FprEN 15601. The tests were carried out with the test roof mounted at the exit of BRE's No.3 Boundary Layer Wind Tunnel so that the wind flow was directed perpendicular to the eaves. Two horizontal spray bars were mounted at the exit from the tunnel, so that water could be sprayed into, and mixed evenly with the air stream. A schematic diagram of the test arrangement is shown in Figure 3.The test conditions represent the worst case wind and rain combination likely to occur in Northern Europe during any 50-year period.

A spray nozzle was mounted above the roof so that water could be sprayed down onto the roof to provide deluge rain. The wind tunnel was not running during deluge rain testing.

To simulate a typical 7 metre rafter length, a sparge bar was mounted across the top edge of the roof. The sparge bar was used to provide the quantity of runoff water that could be expected from a further 5 metre run of roof up to the ridge.

It should be noted that the variable speed fan used to generate the pressure difference across the roof has a finite performance range. Hence the conditions stated below represent test conditions that are usually attainable. If these conditions could not be achieved (e.g. because the air leakage through the roof system is too great), conditions as near to the limits as possible were tested. Full details of the tests undertaken are given in the running sheets in Annex A.

i) High wind speed and High rainfall combination (FprEN 15601 Test B)

Water is sprayed at a rate equivalent to rainfall of 60mm/hour over the test area plus the run-off bar with a flow equivalent to 60mm/hour over the rest of a typical 7m roof. The wind speed was 13m/s. This represents conditions that on average will only occur once in any 50 year period in Northern Europe.

ii) Deluge Test – Maximum rainfall with no wind (FprEN 15601 Test D)

Water was sprayed onto the roof, with no wind, at a rate equivalent to a rainfall of 225mm/hour over the whole 2m square roof. The run-off spray bar at the top of the test section simulated a rainfall of 225mm/hour over the rest of a typical 7m roof. The test lasts for two minutes with an observer, beneath the box, checking for leaks. This represents conditions that on average will only occur once in any 50 year period in Northern Europe.

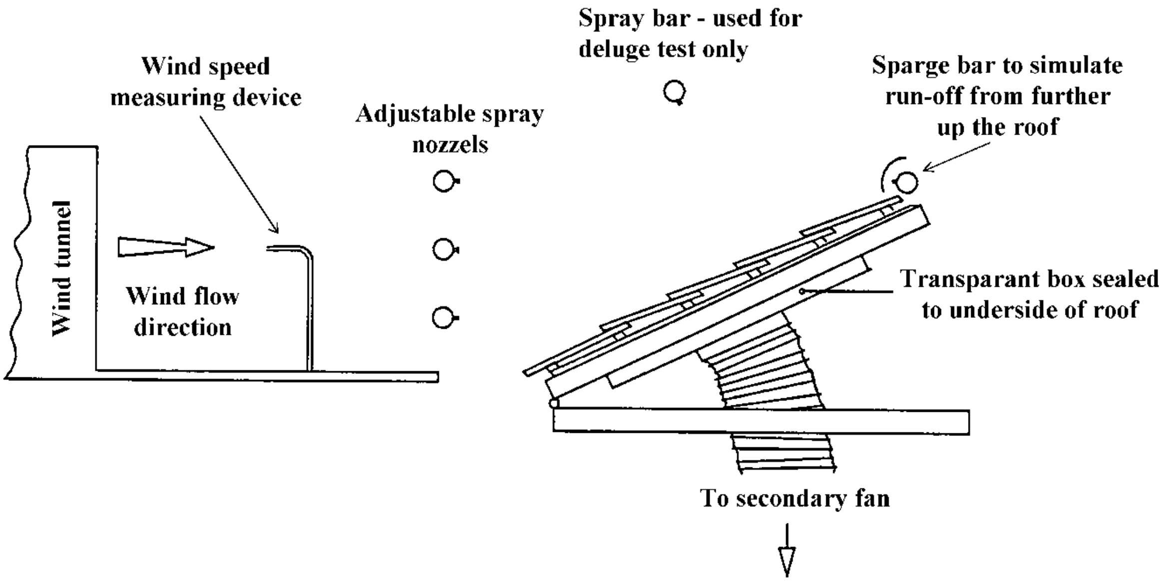

Figure 3 Schematic view of the BRE Rain Penetration Test Rig

The tests start with the pressure in the test box at the appropriate wet sealed box pressure (WSB), as described in Section 4.1. The pressure inside the box is then decreased by 10 Pascals increments and the cycle is repeated until the amount of measured leakage water exceeds 10gr/m^2/5min or as otherwise agreed with the customer.

4.1 Determining the wet sealed box pressure (WSB)

Before the driving rain testing starts, the WSB pressure must first be determined. This is the pressure that occurs within the pressure box at the appropriate wind speed and with the roof covering fully wetted (the pressure box is sealed during these measurements). This represents ambient conditions likely to occur on a real roof for the tiles under test. The WSB pressure is adopted as the reference zero pressure for subsequent testing according to the procedure given in FprEN 15601.

5 Results and Discussion

There is no pass-fail criterion given in FprEN 15601; this standard requires performance of a test product to be compared with the performance of a reference product which has known satisfactory performance under the same wind-rain conditions. Informative Annex C of this standard titled ‘Use of test results’ states that ‘For satisfactory performance of the product, the applied suction required to cause leakage of 10g/m2 per 5-minute step in the test specimen shall not be less than the applied suction value of the reference product test specimen at the same leakage rate and wind-rain conditions.’

For these tests the performance of the Pan Tile Vent is compared with that of the surrounding Fenland concrete tiles tested without the Pan Tile Vent.

Copies of the result sheets filled in during the tests and giving observations made at the time are contained in Annex A.

5.1 Deluge Test – Sub-test D

At roof pitches of 17.5º and 20º there were no leaks observed during the deluge test on either the tile roof or the tiles roof with Pan Tile vent at any part of the roof or from the tile vent.

5.2 Wind and Rain test – Sub-test B

In Fpr15601 the pressure (or suction factor) at which $10g/m^2/5$ min of water leakage occurs is taken as the measure of the water tightness in these tests. Table 1 shows the pressure factors for the Manthorpe Pan Tile Vent with Fenland tiles and for the Fenland tiles installed on their own without the vent.

The pressure factors given in Table 1 show the relative performance of the product, the larger (or more positive) the pressure factor the better the relative performance of the roof under wind driven rain conditions.

Figure 4 shows the pressure-leakage curves for the Manthorpe Pan Tile Vent.

It can be seen from Table 1 and Figure 4 that there is no significant difference in performance for the Manthorpe Pan Tile Vent installed with Fenland tiles and for the Fenland tiles on their own without the vent.

At a roof pitch of 17.5º the pressure factors are 26Pa and 26Pa with and without the Pan Tile Vent. At a roof pitch of 20º the pressure factors are 28Pa and 26Pa with and without the Pan Tile Vent.

The log sheets in Appendix A showing observations made during the testing show that no rain leakage was observed coming through the vent at normal suction pressures. Some drips were observed from the vent at high suction pressures. However, at these high suction pressures there was significantly more leakage from the surround concrete pan tiles. The Manthorpe Pan Tile Vent did not cause any leakage at the tile interfaces or worsen the weathertightness performance of the roof.

Product	Pitch (°)	Pressure factor (Pa)
Fenland tiles no vent	17.5	26
Fenland tiles no vent	20	28
Fenland tiles with Manthorpe Pan Tile Vent	17.5	26
Fenland tiles with Manthorpe Pan Tile Vent	20	26

Table 1 Pressure factors for the tiles and Manthorpe Pan Tile Vent at a leakage rate of 10g/m^2/5min

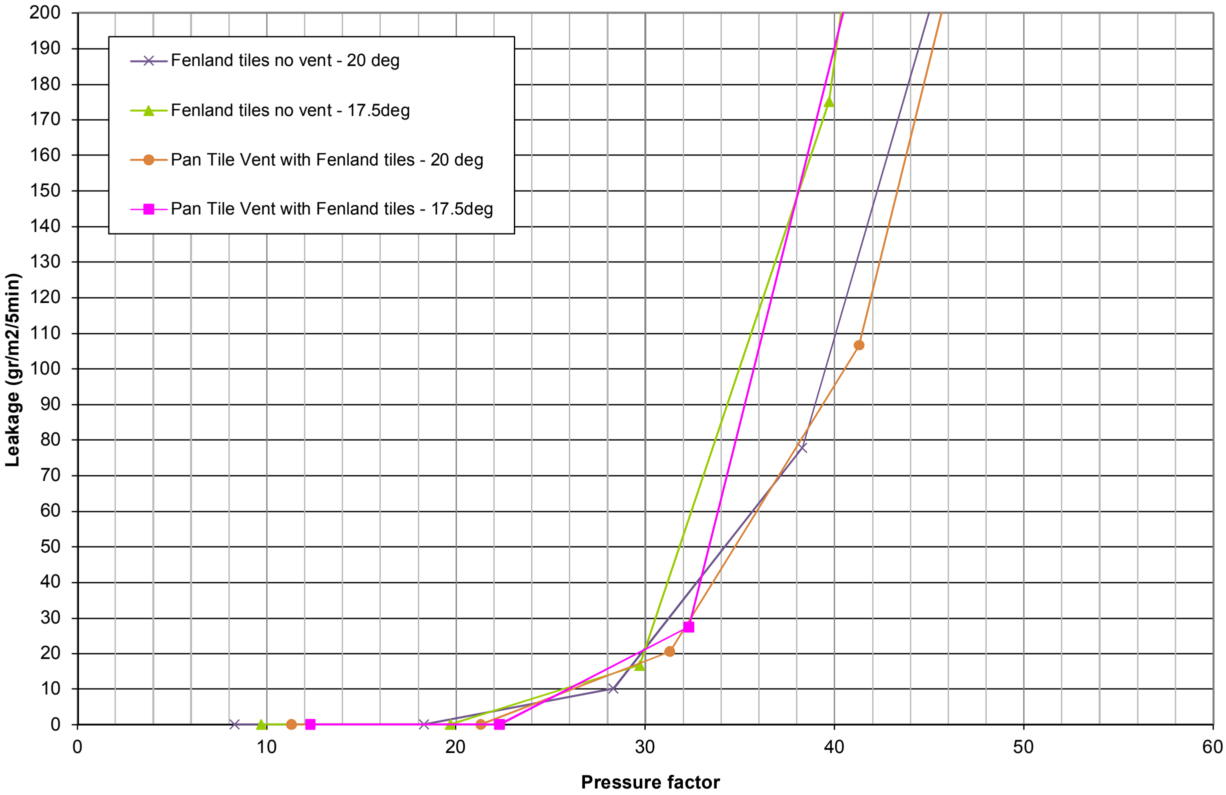

Figure 4 Pressure factor v leakage curves for the Fenland tiles and Manthorpe Pan Tile Vent

6 Summary

Tests to assess the relative performance of Manthorpe Pan Tile Vent were carried out according to the procedures of the wind-driven rain test method FprEN15601. The Manthorpe Pan Tile Vent was tested with Redland Fenland concrete tiles at roof pitches of 17.5º and 20º.

The results show that the weathertightness performance of the Manthorpe Pan Tile Vent is better than that of the surrounding concrete roof tiles. At high suction pressures some drops were observed falling from the vent but at these pressures the surrounding roof was leaking heavily.

The Manthorpe Pan Tile Vent did not cause the surrounding concrete pan tiles to leak earlier than they leaked without the vent in place.

The Manthorpe Pan Tile Vent will perform satisfactorily at a minimum roof pitch of 17.5º.

As weathertightness performance improves with roof pitch, the Manthorpe Pan Tile Vent is expected to perform satisfactorily at pitches above 20º.

Appendix A - Test report sheets for the Manthorpe Pan Tile Vent and Fenland tiles

Roof Pitch 17.5º - Fenland tiles – no vent

1.Product name: Redland Fenland Tiles (Vent not included)	2.Client: Manthorpe
3. Bond: Straight	4.Lap: 100mm
5. Batten Gauge: 281mm	5.Material: Concrete – Redland Fenland
7. Fixing: Nailed	6. Pitch: 17.5
9. Date commenced: 05/04/16	7: Other remarks: Witnessing the testing

Dry seal box pressure:	17.5	
Wet seal box pressure relative roof:	9.7	
Wet seal box pressure relative to the lab:	7.4	
Manometer instrument number(s):	3508	

Test : D Deluge				
Rainfall rate : 225mm/hr		Wind speed :0m/s		
Deluge bar flow rate:22 l/min		Run off bar flow rate:37 l/min		
Date of test:				
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)	Comments:
0	0	2	0	No Leak

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Test : B High wind speed with high rainfall rate					
Rainfall rate:60 mm/hr			Wind speed 13 m/s		
Top bar flow rate:3.9 l/min			Bottom bar flow rate:4.4 l/min		
Runoff bar flow rate: 11 l/min			Date of test:		
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)		
0	0	5	0	No leak Some spray on the back of tiles	
-10	5	10	0	Spray on bottom of tiles forming droplets, central 3rd & 4th course and RHS 2nd, 3rd & 4th, starting to fall towards end of 5 minutes.	
-20	10	15	48	LHS 1st & 4th course droplets coming through side lock every 5 seconds. RHS 1st course droplets coming through side lock almost constant, 2nd course very damp, droplets falling every 15 seconds, increasing towards end of 5 minutes. 4th course all sections very damp, droplets falling from build-up of spray.	
-30	15	20	456	As above, all areas increasing. RHS 1st course constant flow through side locks, 2nd course droplets forming and falling constantly. LHS 4th course constant flow of droplets through side lock. Central 1st course steady flow of water though side locks, 3rd and 4th beginning to drip steadily every 2-5 seconds.	
-40	20	25	1137	Central courses 1, 2, 3 & 4 heavy leak through side lock, 1st constant flow of water, 4th constant flow towards end of 5 minutes. RHS 1st course heavy constant flow through SL. 2nd, 3rd & 4th beginning to leak through side lock, steady flow of droplets coming from all, 4th course becoming constant towards end of 5 minutes. LHS 4th course as above, 1st course droplets falling constantly.	

Roof Pitch 17.5º - Fenland tiles – with Pan Tile Vent

1.Product name: Single Pan Tile Vent	2.Client: Manthorpe
3. Bond: Straight	4.Lap: 100mm
5. Batten Gauge: 281mm	5.Material: Concrete – Redland Fenland
7. Fixing: Nailed	6. Pitch: 17.5°
9. Date commenced: 05/04/16	7: Other remarks: Witnessing the testing

Dry seal box pressure:		
Wet seal box pressure relative roof:	12.3	
Wet seal box pressure relative to the lab:	10.5	
Manometer instrument number(s):	3508	

Test : D Deluge				
Rainfall rate : 225mm/hr	Wind speed :0m/s			
Deluge bar flow rate:22 l/min	Run off bar flow rate:37 l/min			
Date of test:				
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)	Comments:
0	0	2	0	No Leak

Test : B High wind speed with high rainfall rate				
Rainfall rate:60 mm/hr			Wind speed 13 m/s	
Top bar flow rate:3.9 l/min			Bottom bar flow rate:4.4 l/min	
Runoff bar flow rate: 11 l/min			Date of test: 05/04/16	
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)	
0	0	5	0	No leakage. Some spray forming towards end of test at corner of vent and tiles directly above.
-10	5	10	0	Some droplets forming at bottom right of vent, beginning to fall towards end of 5 minutes. Tiles directly above vent very damp, droplets forming and beginning to fall. Droplets forming at RHS 1st course and LHS 3rd course.
-20	10	15	79	As above, more frequent droplets coming from corner of vent. Tiles above vent droplets falling every 10 seconds, increasing throughout the 5 minutes. RHS 1st course steady flow of droplets coming in.
-30	15	20	610	AS above, increasing. Tiles above vent soaked, droplets falling constantly from build-up of spray as well as leakage coming through side locks. Droplets falling from corner of vent every 5 – 10 seconds. RHS 1st course steady flow of water coming in. Tiles directly below vent very damp, droplets falling every 5 seconds. LHS 3rd course constant flow of droplets from side locks.

Roof Pitch 20º - Fenland tiles – No Vent

BRE – Rain penetration Test Record

1.Product name: Redland Fenland Tiles (Vent not included)	2.Client: Manthorpe
3. Bond: Straight	4.Lap: 100mm
5. Batten Gauge: 281mm	5.Material: Concrete – Redland Fenland
7. Fixing: Nailed	6. Pitch: 20°
9. Date commenced: 05/04/16	7: Other remarks: Witnessing the testing

Dry seal box pressure:		
Wet seal box pressure relative roof:	8.3	
Wet seal box pressure relative to the lab:	12.5	
Manometer instrument number(s):	3508	

Test : D Deluge				
Rainfall rate : 225mm/hr	Wind speed :0m/s			
Deluge bar flow rate:22 l/min	Run off bar flow rate:37 l/min			
Date of test:				
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)	Comments:
0	0	2	0	No Leak

Test : B High wind speed with high rainfall rate					
Rainfall rate:60 mm/hr			Wind speed 13 m/s		
Top bar flow rate:3.9 l/min			Bottom bar flow rate:4.4 l/min		
Runoff bar flow rate: 11 l/min			Date of test: 05/04/16		
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)		
0	0	5	0	No leak	
-10	5	10	0	Spray forming on RHS 2nd & 3rd course and Central 3rd course.	
-20	10	15	29	RHS 1st, 2nd, & 3rd droplets falling, 1st course coming from side lock, others from build-up of spray. Central 2nd course droplets forming and falling every 15 seconds. LHS 4th course beginning to form droplets, falling every 30 seconds.	
-30	15	20	195	As above, increasing. RHS 1st & 2nd course constant droplets coming through side lock. 1st course becoming constant flow towards end of 5 minutes. Central 1st & 2nd course constant flow of droplets through side lock. LHS 4th course, tiles very damp, droplets constantly falling from build-up of spray, starting to bubble through side lock.	
-40	20	25	526	As above, increasing. RHS 1st, 2nd, 3rd & 5th course constant droplets through side lock. 1st and 2nd course steady flow through side locks. LHS 4th course heavy leak, constant droplets coming from side lock, 2nd course beginning to leak through side lock. Central 1st, 2nd & 5th course heavy constant flow of droplets through side lock.	

Roof Pitch 20º - Fenland tiles – with Pan Tile Vent

1.Product name: Single Pan Tile Vent	2.Client: Manthorpe
3. Bond: Straight	4.Lap: 100mm
5. Batten Gauge: 281mm	5.Material: Concrete – Redland Fenland
7. Fixing: Nailed	6. Pitch: 20°
9. Date commenced: 05/04/16	7: Other remarks: Witnessing the testing

Dry seal box pressure:	16.9	
Wet seal box pressure relative roof:	11.3	
Wet seal box pressure relative to the lab:	13.7	
Manometer instrument number(s):	3508	

Test : D Deluge				
Rainfall rate : 225mm/hr	Wind speed :0m/s			
Deluge bar flow rate:22 l/min	Run off bar flow rate:37 l/min			
Date of test: 05/04/16				
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)	Comments:
0	0	2	0	No Leak

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Test : B High wind speed with high rainfall rate					
Rainfall rate:60 mm/hr			Wind speed 13 m/s		
Top bar flow rate:3.9 l/min			Bottom bar flow rate:4.4 l/min		
Runoff bar flow rate: 11 l/min			Date of test: 05/04/16		
Pressure difference (Pa)	Time (min:sec) Start	End	Water collected (g)		
0	0	5	0	Some droplets forming on the bottom right corner of vent tile from spray. Spray starting to build up on tiles above vent tile.	
-10	5	10	0	Spray continuing to form on the course of tiles directly above the vent. Droplets beginning to fall from the damp tiles towards the end of the 5 minutes, every 30 seconds. Droplets are now falling from the bottom right corner of the vent from build-up of spray.	
-20	10	15	59	As above. Tiles above vent becoming very damp, some droplets beginning to fall. Droplets falling more commonly now from the corner of the vent, every 15 seconds. RHS 1st & 2nd course droplets falling every 10-15 seconds. All tiles on 2nd & 3rd course damp from spray, droplets beginning to fall.	
-30	15	20	248	All areas increasing. More droplets coming from edge of vent, every 5 seconds, more than one droplet forming. Tiles directly above vent socked from spray, constant droplets falling, water beginning to bubble over and leak from their side locks. RHS & central 1st course heavy droplets from side locks. N2d and 3rd course tiles very damp from spray, constant droplets coming in along course.	
-40	20	25	618	As above, leaks from RHS & Central 1st course increasing, becoming constant flow of water. Steady flow of droplets coming from side lock of tiles directly above vent. LHS 3rd course droplets coming through side lock constant. Constant droplets falling from the edge of vent, all from build-up of spray. No leak through the vent itself.	

Appendix B - Calibration results for the BRE test rig

FprEN 15601 requires details of the rig calibration to be included in the test report. The following information provides a brief description of the calibration of the BRE test rig.

FprEN 15601 has specific calibration requirements for the test facility to ensure that the distribution and magnitude of the wind speed, driving rain and runoff water are all within required limits. The requirement for the wind speed generation is a fan system capable of generating wind blowing parallel to the rafters of the test specimen with a spatial variation of the wind speed over the specimen of not more than 10 %. This is achieved by measuring the wind speed at not less than 9 positions uniformly distributed at a height of 200 + 10 mm over a flat boarded area which replaces the test specimen, at the relevant roof pitch. The calibration wind speed shall be 10 + 0.5 m/s at the centre of the test specimen. Figure B1 shows the end of the BRE wind tunnel and Figure B2 shows the wind speed calibration of the BRE test rig using ultrasonic anemometers.

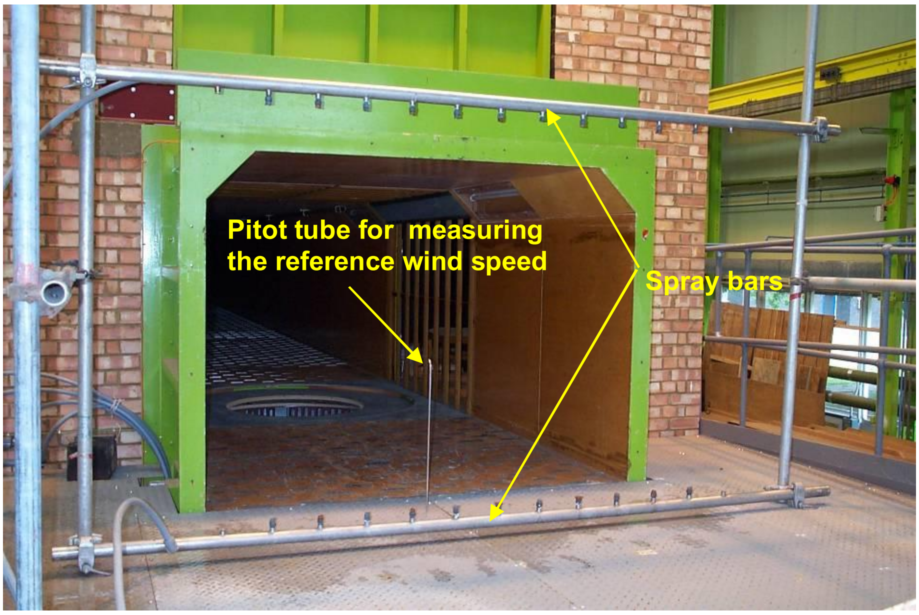

Figure B1 The end of the BRE wind tunnel

Figure B2 Calibration of the wind speed over the test specimen area

The standard requires the turbulence intensity (*t*) in the oncoming wind to be less than 10 %. The turbulence intensity *t* (%) is expressed as t = 100u/U, where *u* and *U* are the RMS and mean wind speeds respectively, measured over a duration of not less than 5 minutes. *u* and *U* are defined as shown below:

RMS (root mean square) wind speed $u = \sqrt{\frac{\sum_{i=1}^{n}(v_i^2 - U)}{n-1}}$

Mean wind speed $U = \frac{\sum_{i=1}^{n} v_i}{n}$

Where v_i is the individual wind speed measurement over the specimen;

n is the number of measurements

Table B1 shows the calibration measurements. The maximum turbulence intensity across the specimen is 5.57% and occurs at location 5 in the centre of the specimen. In all cases the turbulence intensity is within the limit of 10% allowed by the draft standard.

10m/s nominal speed

	mean wind speed			Variation from mean %	Turbulence intensity		
Location	U	V	W	U	u'	v'	w'
1	9.83	0.90	-0.69	-0.98	0.03	0.01	0.02
2	10.21	1.29	-0.30	2.85	0.03	0.02	0.02
3	9.56	0.10	0.83	-3.67	0.03	0.02	0.02
4	9.64	1.44	-0.26	-2.88	0.03	0.02	0.02
5	10.48	1.68	0.02	5.57	0.03	0.01	0.01
6	9.66	0.87	0.85	-2.69	0.03	0.02	0.03
7	9.86	1.02	0.60	-0.71	0.03	0.02	0.02
8	10.14	1.40	0.48	2.14	0.04	0.02	0.02
9	9.96	0.32	0.31	0.37	0.03	0.02	0.03
Mean	9.93	1.00	0.21				

locations (facing tunnel)

1	4	7
2	5	8
3	6	9

Table B1 Calibration measurements of wind speed in the BRE wind tunnel facility

The requirements for the rain generating device are a capability for generating a stable rain fall rate for the roof pitch under test. The spatial variation of rainfall must be not more than ±35% over the area of the test specimen during a time period of 5 min±10s. During the same time period of 5 min ±10s the rainfall rate shall vary by not more than ±2%. The actual rainfall rate that should be applied depends on the geographical location. Rainfall conditions are given in the draft standard for three climates: Northern European Coastal, Central Europe and Southern European. In all cases the rainfall rain varies with pitch angle. This means that the test rig must be calibrated for every pitch angle that is likely to be used. The variation in rainfall rate with pitch angle can be very small, for example in the Northern European climate Sub-Test A the rainfall rate varies between 124mm/hr and 130mm/hr for pitches between 15° and 45°. In practice it is not possible to control the rainfall rate on the roof to such small tolerances. The degree of variation in rainfall rate allowed by the draft standard is ±35% which is generally much wider than the range of rainfall rates specified for each pitch angle.

Figures B3 to B6 show the calibration of the driving rain in the BRE test rig. The results of the calibrations for Sub-Tests A, B and C for the Northern European Coastal climate are shown in Table B2. From Table B2 it can be seen that the degree of variability in Sub-Tests A, B and C is close to but just within the allowable limit of ±35%.

% variation of water collected in buckets			
Bucket No	Test C	Test B	Test A
1	-3	-11	-7
2	-3	-21	-26
3	14	9	-22
4	-29	9	26
5	11	-2	22
6	16	-9	24
7	34	24	19
8	29	28	29
9	-17	-15	5
10	-22	3	-1
11	-8	7	-16
12	30	13	-4
13	-21	-29	-21
14	-18	-2	-28
15	-5	-5	-21
16	-9	3	23
Maximum %	34	28	29
Minimum %	-29	-29	-28

Table B2 Calibration of driving rain variability


Figure B3 Bottom spray bar


Figure B4 Top spray bar


Figure B5 View of the test rig at the end of the tunnel


Figure B6 View of the 16 rainfall collection buckets on the test rig

Report Ends