Insulation

The Performance of Two Dutch Flat Roof Constructions in the Event of a Fire in a PV System

A White Paper

Contents

Executive Summary

In recent years there have been recorded cases of fires involving roof-top photovoltaic (PV) installations.

Kingspan Insulation commissioned Efectis to conduct two rounds of comparative tests to understand the relative fire performance of flat roof build-ups insulated with one Euroclass A1, dual-density, FM-approved, synthetic rock mineral fibre flat roof insulation product, recommended for use under PV systems, and FM-approved Kingspan Therma™ TR26, a Euroclass E, PIR flat roof insulation product, both from the Dutch market, in circumstances designed to replicate a fire starting in a PV system, using an ignition method based on that given in the test method CLC/TR 50670: 2016.

In the configuration tested (back to back PV panels), in both rounds of tests, there was no significant difference between the extent of horizontal fire spread, caused by the burning PV array installed over the two build-ups. The fire spread beyond the perimeter of the PV array was of very limited extent in all cases.

With the build-ups insulated with Kingspan Therma™ TR26, roof deck temperatures peaked at under 40°C at roughly the same time as the visible roof fire self-extinguished and there was no evidence of localised continuing combustion processes. The damage to the insulation (charring through to discolouration) did not penetrate its complete thickness and did not reach the level of the deck in any location.

With the build-ups insulated with the rock mineral fibre product, after the visible fire had stopped, ongoing smouldering combustion appears to have continued for roughly 2 hours (possibly longer) with roof-deck temperatures reaching as high as 100-200°C, in some thermocouples, before dropping. In places, the damage to the insulation (binder loss) penetrated its complete thickness and reached the level of the deck.

The results herein are specific to the flat roof and PV products and configurations that were tested and the circumstances of those tests, and it should not be assumed that other products, configurations and circumstances will give the same result.

For example, the back to back arrangement of the PV panels is reflective of roof mounted PV systems where the panels are arranged in an alternating East/West configuration. This is the most common arrangement in Northern and Western areas of Europe, but in Central and Southern Europe it is more common to have systems with all panels mounted facing South. The testing detailed in this report is only relevant to this back to back (East/West) configuration, but testing of a roof with 2 rows of panels oriented in the same direction would be quite possible using this test procedure. It is expected that this would result in a less onerous fire load and thus the results shown in this paper may not be representative of that panel arrangement.

However, there is nothing within this testing to suggest that FM-approved Kingspan Therma™ TR26 from the Dutch market should not be permitted for use under PV arrays on flat roofs if Euroclass A1 insulants are permissible.

Introduction

Background

In recent years there have been a number of recorded cases of fires involving roof-top photovoltaic (PV) installations. For example:

Retail Store, Italy

Amsterdam, NL
(courtesy of Amsterdam-Amstelland Fire Brigade)

Insurance Industry Response

In the absence, in most countries and at EU level, of any regulatory response to these fires, some building insurers have responded by expressing a preference for insulants under PV panels to be non-combustible / Euroclass A1 / Euroclass A1 or A2 or, if not, for them to be overlaid with a non-combustible / Euroclass A1 / Euroclass A1 or A2 material.

Objective

Kingspan Insulation commissioned Efectis to conduct tests to understand the relative fire performance, in terms of fire spread and fire penetration, in the event of a fire starting in a PV array, of a typical flat roof assembly insulated with its FM-approved Therma™ TR26 PIR flat roof insulation boards, without the addition of any layers of non-combustible / Euroclass A1 /Euroclass A1 or A2 materials, and the equivalent flat roof assembly insulated with a common Euroclass A1 flat roof insulation product.

Tests

General

Two rounds of tests were conducted, the first on 8 October 2020 and the second on 10 and 11 March 2021. The first round of tests were carried out outdoors and the second round, indoors.

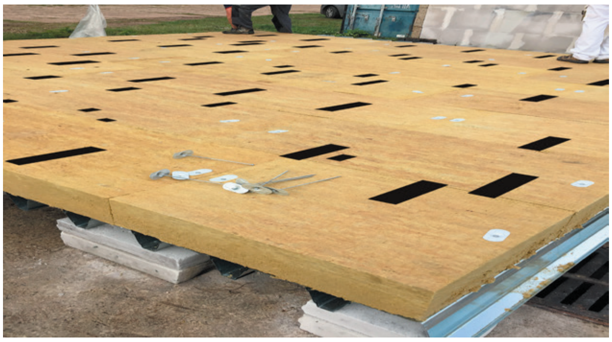
The results of these tests are valid only for the flat roof and PV products and configurations that were tested, and the circumstances of those tests.*

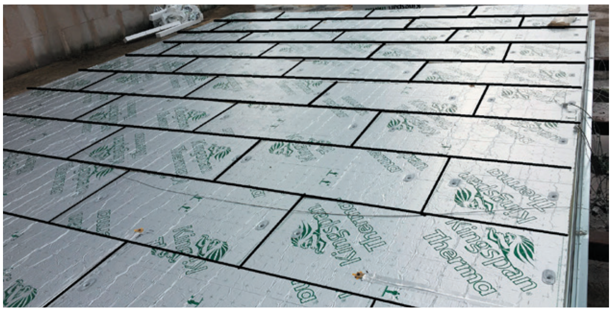
Test specimen

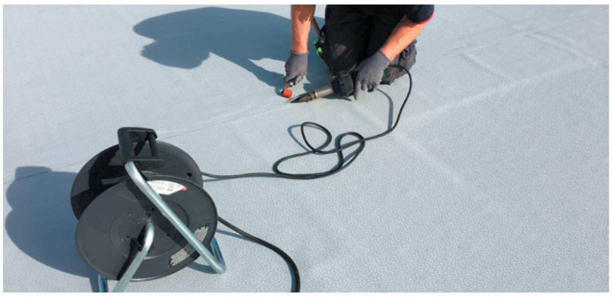
In both rounds of testing the test build-ups comprised:

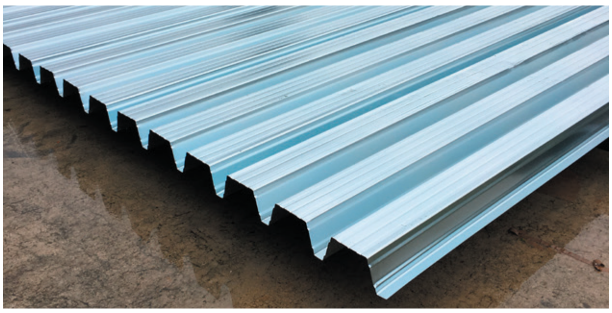
- Monocrystalline Silicon PV modules (Class 1 (UL 1703) / Class C (IEC61730)) with their supporting structure;
- 1.2 mm FM-approved Protan SE LYS GRA F91 PVC waterproofing membrane (joints welded – mechanically fixed to the deck);
- One 180 mm[†] Euroclass A1, dual-density, FM-approved, synthetic rock mineral fibre flat roof insulation product, recommended for use under PV systems, from the Dutch market / 100 mm[†] Kingspan Therma™ TR26, a Euroclass E, FM-approved PIR flat roof insulation product, from the Dutch market – both insulants laid with staggered transverse joints and mechanically fixed to the deck;
- 6 x 4.8 m Joris Ide JI 103-250750 K profiled galvanised steel deck (1.06 mm thick 106 mm deep troughs) mechanically fixed to the structure below; and
- steel structure to support the deck.

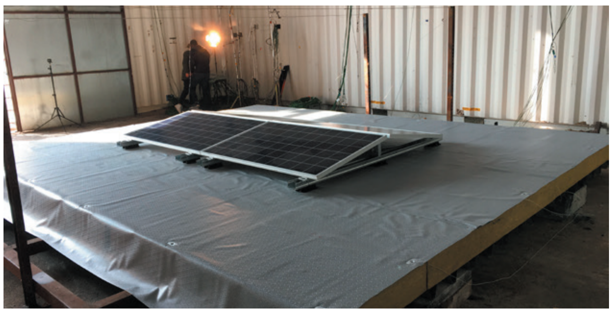
The materials for both rounds of testing, apart from the waterproofing membrane, were sourced at the same time, prior to the first round of tests. Extra waterproofing membrane, of the exact same type, was sourced from exactly the same source, prior to the second round of tests.











Tests

Test procedure

An ad-hoc test method was designed to mimic the scenario, of a fire starting within a PV system (e.g from arcing). It is based on the work of Kristensen & Jomaas[1] who conducted a series of ad hoc tests of flat roof systems with PV arrays mounted on them.

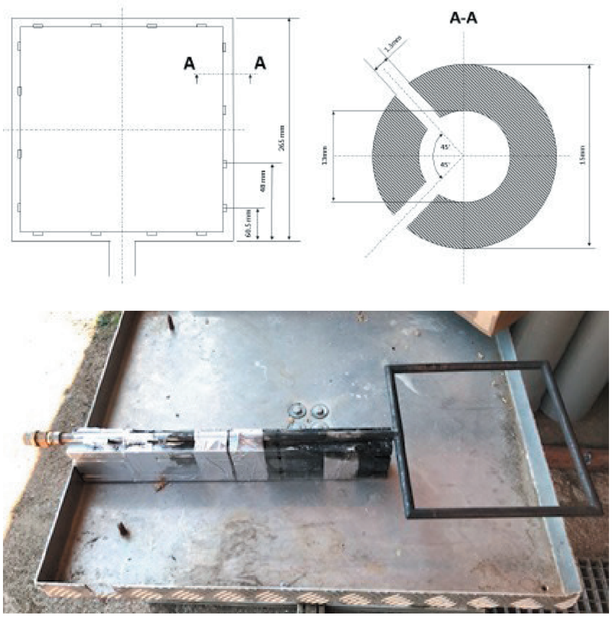
Kristensen & Jomaas' work used roof assemblies that were 2.4 x 6 m and 4.8 x 6 m in size, and 6 PV panels in a back to back arrangement (3 panels in each of 2 back to back rows). In the former, there was little clearance between all four edges of the PV array and the edges of the roof assembly (≈0.2 - 0.5 m). In the latter, this was partially remedied with a larger roof area. However, although there was reasonable clearance (≈1.2 m) between the sides in the larger test, there was still little clearance between the ends of the PV array and the ends of the roof assembly (≈0.5 m). It was possible to make measurements of fire spread over the roof surface outside of the PV panel boundary in the larger of the two rigs used in the above study, but in both of the tests using that sized rig the fire spread right up to the ends of the roof and so the lack of clearance between the ends of the PV array and the ends of the roof was limiting. For this testing, their method was adapted such that the roof assembly was the same size as the larger Kristensen & Jomaas assembly, but only 4 PV panels were used, albeit in the same back to back manner. This meant that fire spread all round PV array could be more fully measured, whilst keeping the dimensional practicality of the Kristensen & Jomaas test.

The back to back arrangement of the PV panels is reflective of roof mounted PV systems where the panels are arranged in an alternating East/West configuration. This is the most common arrangement in Northern and Western areas of Europe, but in Central and Southern Europe it is more common to have systems with all panels mounted facing South. The testing detailed in this report is only relevant to this back to back (East/West) configuration, but testing of a roof with 2 rows of panels oriented in the same direction would be quite possible using this test procedure. It is expected that this would result in a less onerous fire load and thus the results shown in this paper may not be representative of that panel arrangement.

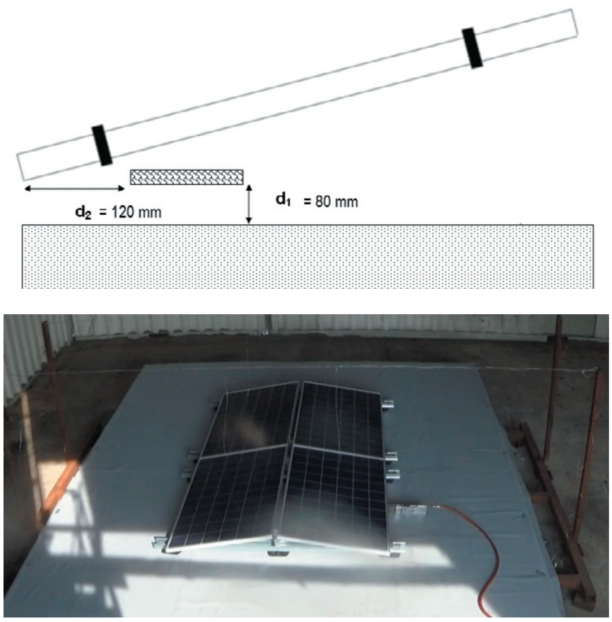
Kristensen & Jomaas originally used a small timber crib for their testing, but that crib remained in place and continued to add localised fire load to the system. In order to ensure the test method was more representative and repeatable, a fire source was sought that would cause reproduceable ignition, but could be retracted, so that the fire load came predominantly from the roof and PV systems.

The 15 kW gas burner as described in CLC/TR 50670: 2016[2] was chosen and is shown below. The burner was ignited only for enough time to ignite the PV panel under which it was located, rather than the 10 minutes of exposure in the CLC/TR 50670: 2016 test. 3 minutes was chosen because of the quick fire development within the PV array that was tested.

The burner was positioned below one PV panel, in the centre of its width, as shown below. This is the identical arrangement as used in CLC/TR 50670: 2016.



Dimensions and design of the gas burner (upper image from CLC/TR 50670: 2016)



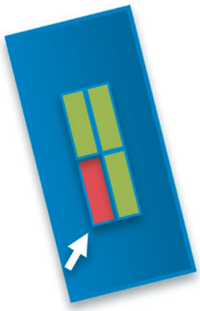
General positioning of the gas burner

Tests

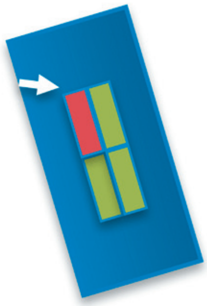
The choice of PV panel under which the burner was located was based on the wind direction at the time of the test, such that the burner was placed on the "up-wind" side of the PV array, so that the fire would spread to the whole PV array. The panel under which the burner was located is shown in red in the diagrams below. The wind direction in the outdoor tests is shown with a white arrow. In the indoor tests, any wind came from the door direction.

The tests were conducted in conditions without rain, fog or snow and with limited wind speed (<3 m/s).

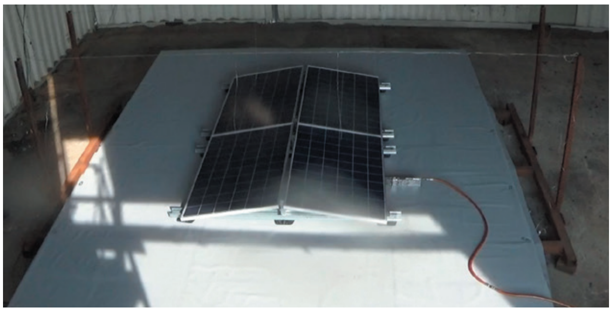
After ignition, the burner was left in position for 3 minutes and then removed, in order to let the PV array and the flat roof components determine the burn time. No external means of extinguishing the fire were applied.

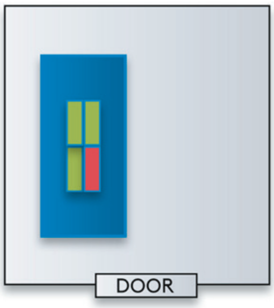


Round 1: Test 1 - Rock Mineral Fibre



Round 1: Test 2 - Therma™ TR26



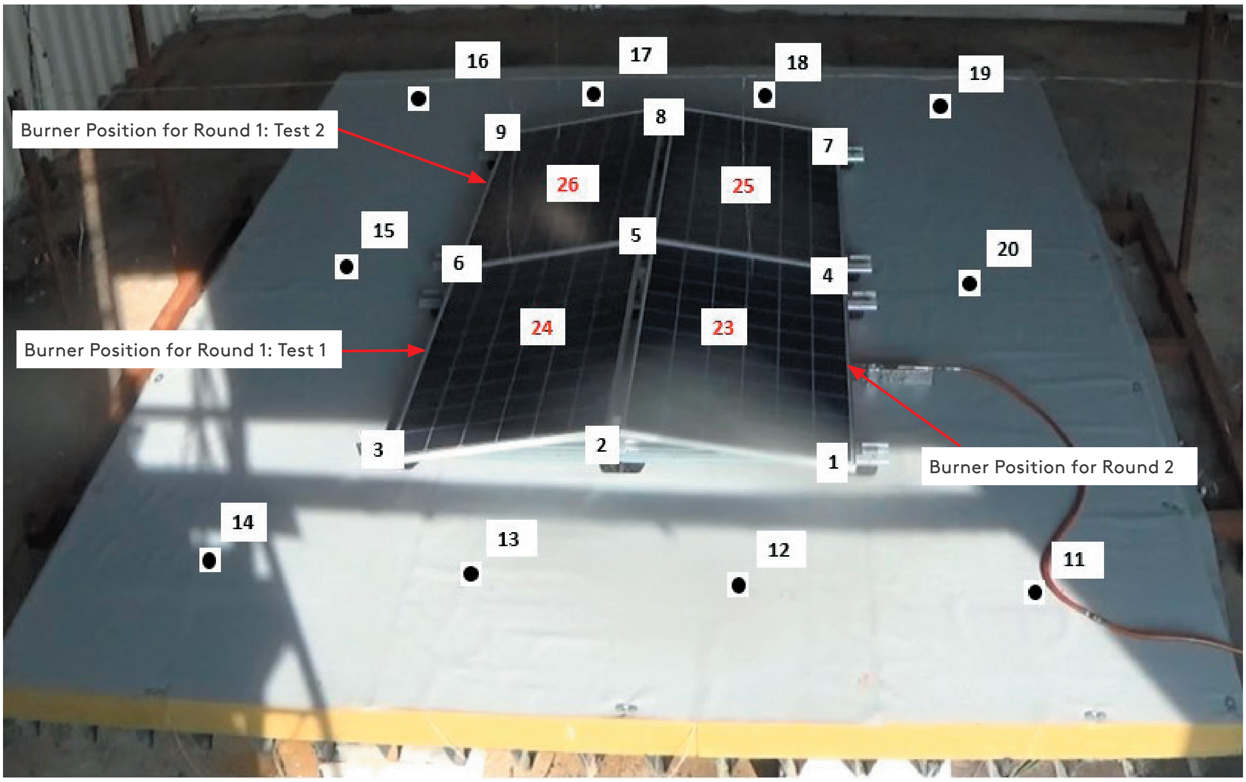


Round 2: Tests 1 & 2

Tests

An array of thermocouples was used to measure temperatures at different locations in the test rig:

- between the steel deck and the insulant, at points corresponding with the periphery of the PV array (TCs 1-9);
- between the insulant and the PVC membrane (TCs 11-20); and
- at 300 mm above the centre of each PV panel (TCs 21, 22, 31, 32 for Round 1 – the equivalent position numbers for Round 2 are 23, 25, 24, 26 – the Round 2 positions are shown in the diagram below).



Results / Observations - Round 1

Test 1 – Build-up Insulated with the Rock Mineral Fibre Product

The wind was 1.4 m/s from the south-west, and so the burner was placed below the PV panel located in the south-west corner.

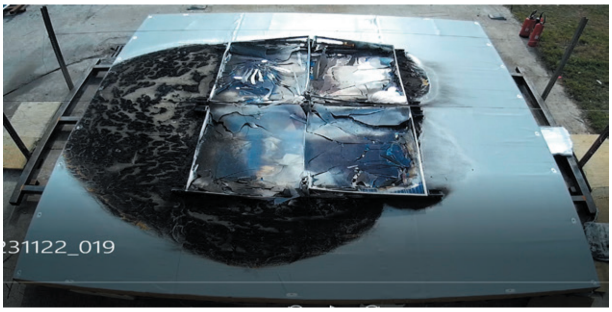
The progress of the fire is illustrated in the images below. The times shown are the elapsed time after burner ignition.

4 mins 49 secs

8 mins 49 secs

12 mins 49 secs

19 mins 39 secs



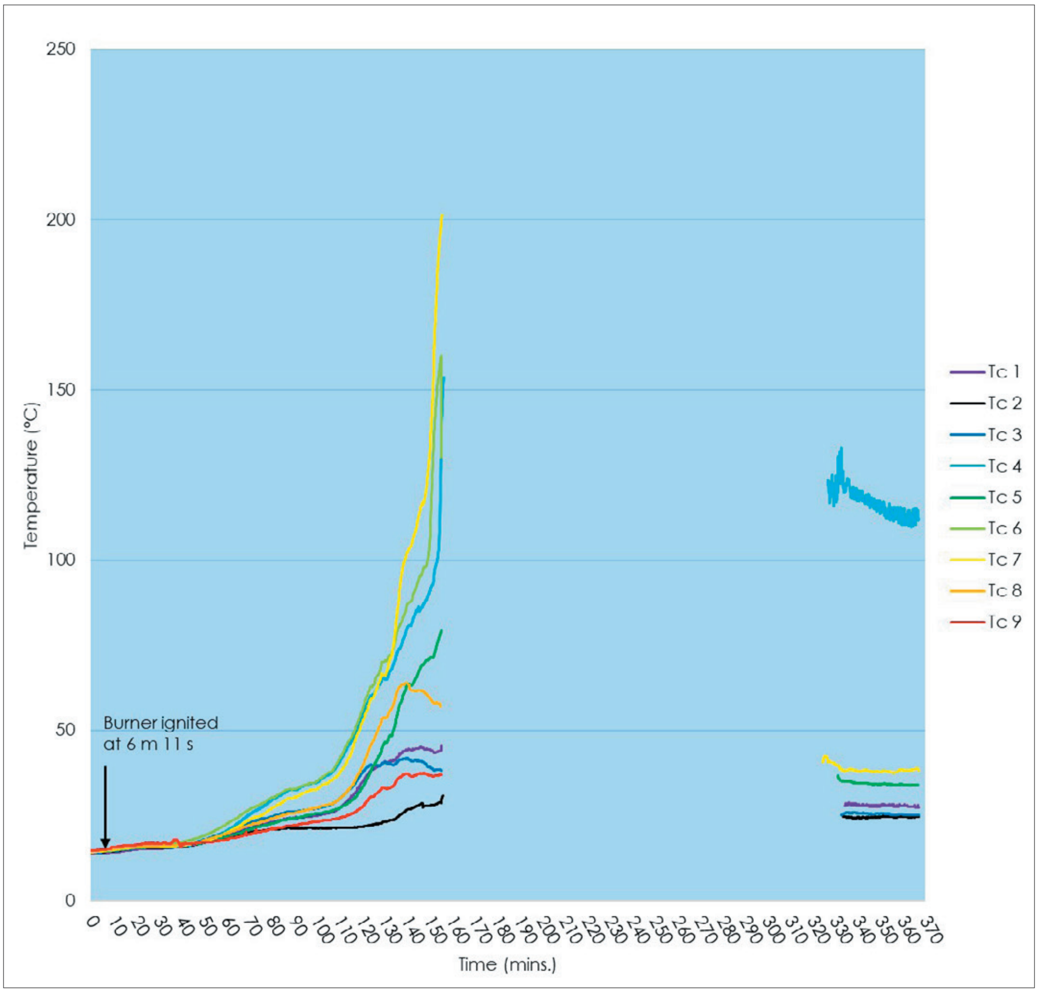
After test

The burnt surface reached the edge of the roof assembly and the extent was around 4600 x 3540 mm. It is noticeable that there was some impact from wind pushing the fire to one side, and causing an asymmetrical pattern of damage to the membrane.

The visible fire ceased at around 40 mins after burner ignition (with the temperature between steel deck and insulation only reaching 20°C). The thermocouple data was being logged but not being monitored by a member of the testing team. Once the visible fire had ended, it was assumed that the test was over, and the testing team broke for lunch. When they returned, without the thermocouple data being monitored, the thermocouples were disconnected so that Test 2 could be conducted using the same data-logger. The fact that the temperature between the steel deck and insulation was still increasing and had reached as high as 200°C in one thermocouple location after around 2 hrs 30 mins after burner ignition (see following page) was not noticed. These observations indicate that continuing smouldering combustion was taking place within the roof system.

After Test 2 had ended (about 5 hrs 20 mins after the Test 1 burner had been ignited), it was noticed that smoke was being produced by the Test 1 rig and so some of the thermocouples between the steel deck and insulation were reconnected to the data-logger. Temperatures of up to 130°C were recorded.

Results / Observations - Round 1



7 hrs 10 mins after burner ignition, smoke was still being released, but there was no visible flaming. The remains of the PVC membrane were removed and the insulation was cut open in cross section to see the pattern of damage. There was an area of shallow damage (binder loss) to the insulation, co-incident with the area of damage to the waterproofing membrane. However, in some areas, localised ovoid patterns of damage penetrated the complete thickness of the insulation.

Given the observation that the temperatures between the steel deck and insulation had risen after the burn-out of the PV array but that no flaming was visible, it seems most likely that this pattern of damage was caused by ongoing smouldering combustion, seeded by heat from the combustion of the PV array.

This behaviour was completely unexpected, which is why the thermocouple data was not monitored closely during this test.

Results / Observations - Round 1

Test 2 – Build-up Insulated with Kingspan Therma™ TR26

The wind was 2.3 m/s from the north-west, and so the burner was placed below the PV panel located in the norh-west corner.

The progress of the fire is illustrated in the images below. The times shown are the elapsed time after burner ignition.

4 mins 22 secs

8 mins 42 secs

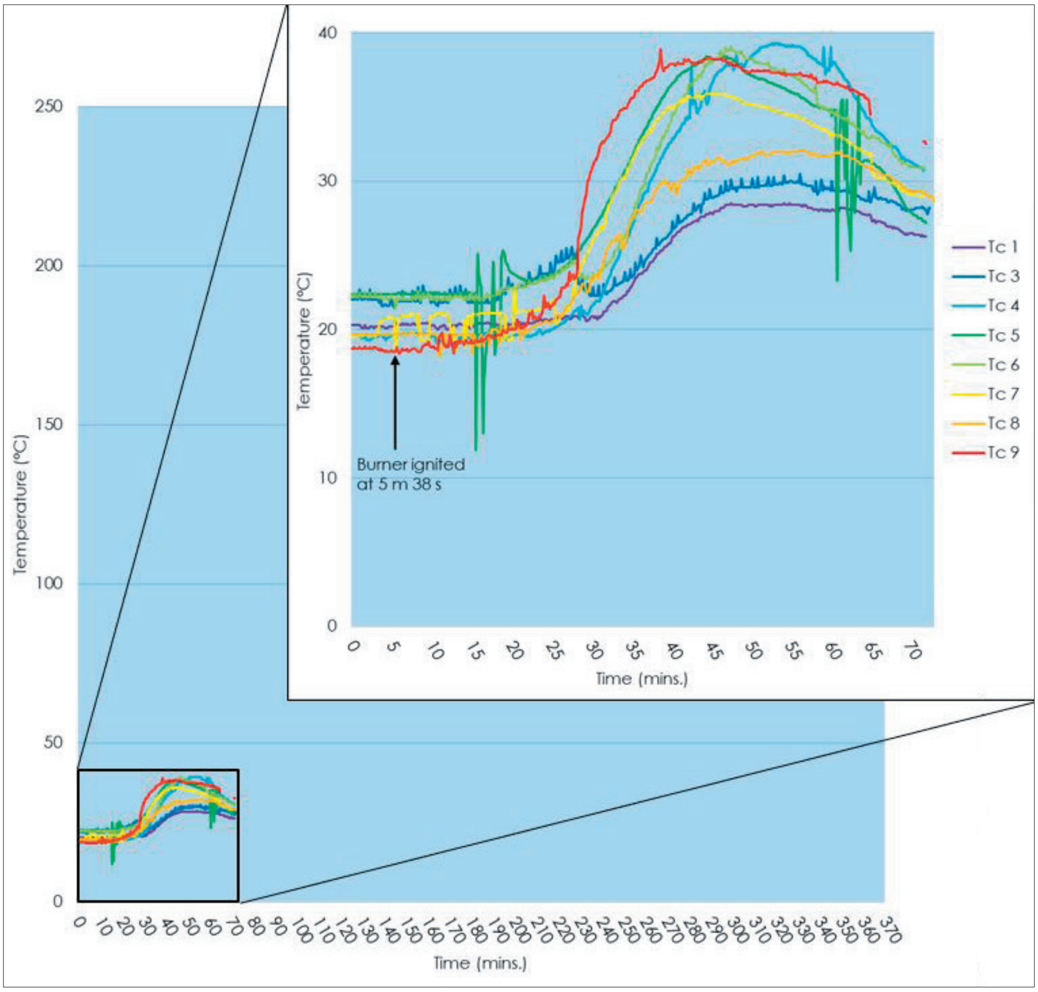
14 mins 47 secs

18 mins 02 secs

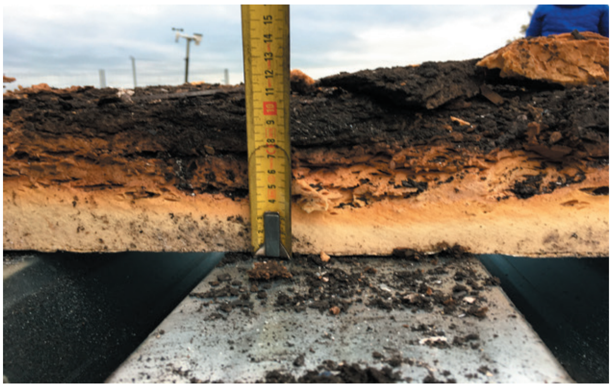
After test

The burnt surface did not reach the edge of the roof assembly and the extent was around 3300 x 5260 mm. It is clear that there was some impact from the wind in wind pushing the fire to one end, and causing an asymmetrical pattern of damage to the membrane, but, despite the higher measured wind speed, far less than in the test of the build-up insulated with the rock mineral fibre product. This disparity between wind speed and its impact may have been caused by sheltering afforded by local obstacles. The visible fire ceased at some point before 50 mins after burner ignition. The temperature between steel deck and insulation peaked at under 40°C in one thermocouple location at around that time before dropping (see following page). The thermocouples were disconnected when the temperatures recorded by all thermocouples had dropped or were falling from their peaks, and the visible fire had ceased. These observations suggest that no continuing smouldering combustion was taking place within the roof system.

Results / Observations - Round 1



Approximately 18 hrs after fire ignition, the remains of the PVC membrane were removed and the insulation was cut open in cross section to see the pattern of damage. There was an area of combustion/heat damage (charring through to discolouration) to the insulation, co-incident with the area of damage to the waterproofing membrane. This damage was roughly lens-shaped, and in some discrete locations the damage penetrated 70% of the thickness of the insulation. There was no evidence of localised continuing smouldering combustion processes



Results / Observations - Round 2

Following the Round 1 tests it was decided to conduct the same tests again to (a) test repeatability and (b) to keep the thermocouples connected for longer in Test 1, so as to characterise the observed smouldering combustion more fully. The tests were conducted indoors, without active smoke extraction, in an attempt to limit the influence of wind.

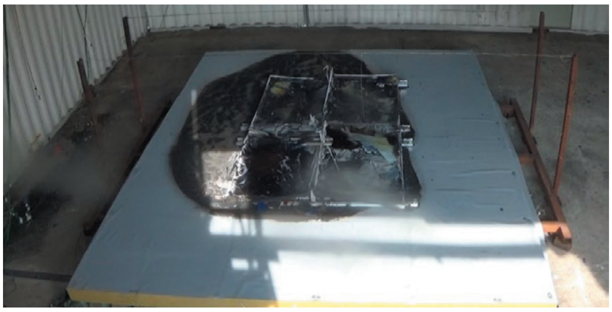
Test 1 – Build-up Insulated with the Rock Mineral Fibre Product

Indoors. The progress of the fire is illustrated in the images below. The times shown are the elapsed time after burner ignition.

4 mins 27 secs

8 mins 27 secs

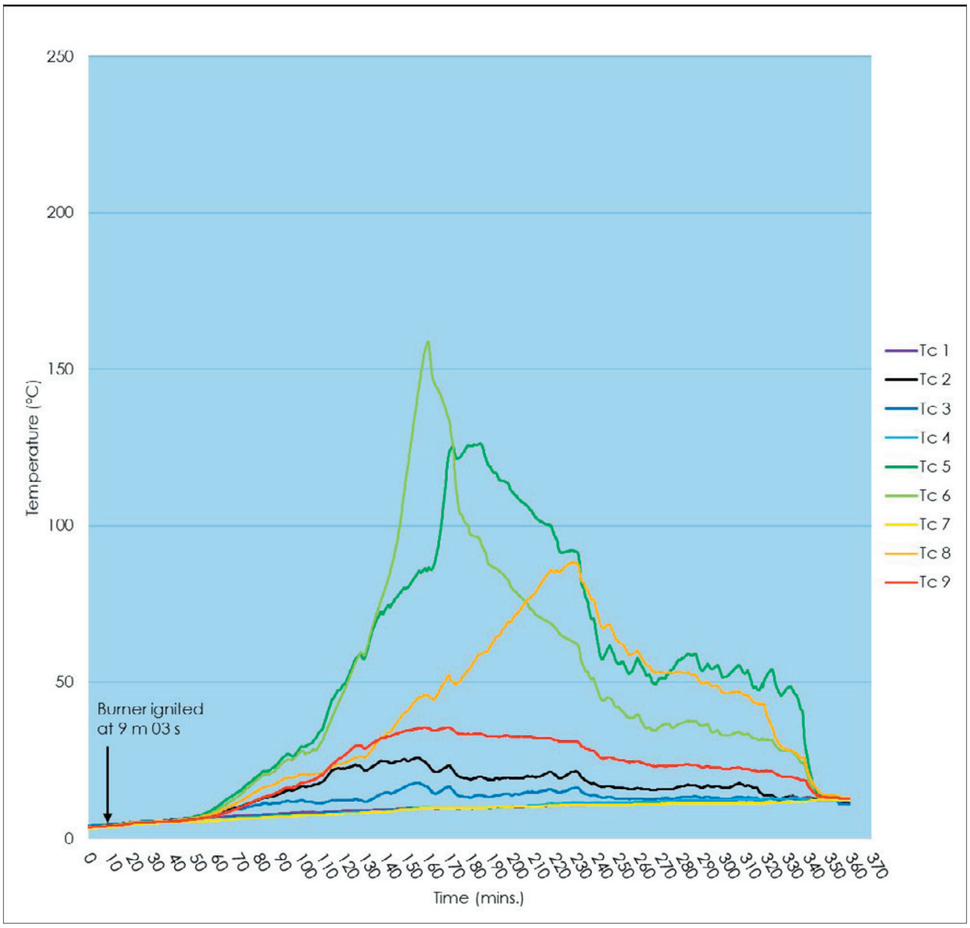
14 mins 57 secs



After test

The burnt surface did not reach the edge of the roof assembly and the extent was around 3120 x 4790 mm. It is clear that because of the open door to the building in which the tests were conducted, there was some impact from the wind, entering though the door, pushing the fire to one corner, and causing an asymmetrical pattern of damage to the membrane, but less so than in the indoor test of the build-up insulated with Therma™ TR26. Despite the visible fire ceasing at around 35 mins after burner ignition (with the temperature between steel deck and insulation only reaching 15°C), the temperature between the steel deck and insulation was still increasing and had reached as high as 160°C in one thermocouple location after around 2 hrs 30 mins after burner ignition (see following page) before falling. These observations indicate that continuing smouldering combustion was taking place within the roof system.

Results / Observations - Round 2



About 4 hrs 20 mins after burner ignition and after removal of the PV system, the damaged surface was measured. About 90mins later, partial dismounting of the flat roof assembly was completed and then the thermocouples within the roof were disconnected. The thermocouples were disconnected when the temperatures recorded by all thermocouples had dropped from their peaks and plateaued. The remains of the PVC membrane were removed and the insulation was cut open in cross section to see the pattern of damage. There was an area of shallow damage (binder loss) to the insulation, co-incident with the area of damage to the waterproofing membrane. However, in some areas, localized ovoid patterns of damage penetrated the complete thickness of the insulation. Given the observation that the temperatures between the steel deck and insulation had risen after the burn-out of the PV array but that no flaming was visible, it seems most likely that this pattern of damage was caused by ongoing smouldering combustion, seeded by heat from the combustion of the PV array.

The day after the test, because they appeared to remain hot, a thermocouple was inserted inside the dismounted rock mineral fibre boards that had been stored outside, and temperatures up to 760°C were recorded.

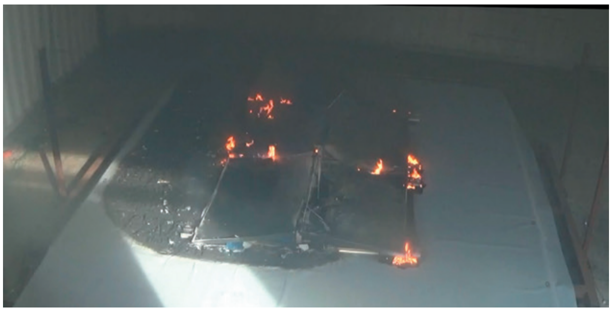
Results / Observations - Round 2

Test 2 – Build-up Insulated with Kingspan Therma™ TR26

Indoors. The progress of the fire is illustrated in the images below. The times shown are the elapsed time after burner ignition.

4 mins 51 secs

8 mins 51 secs

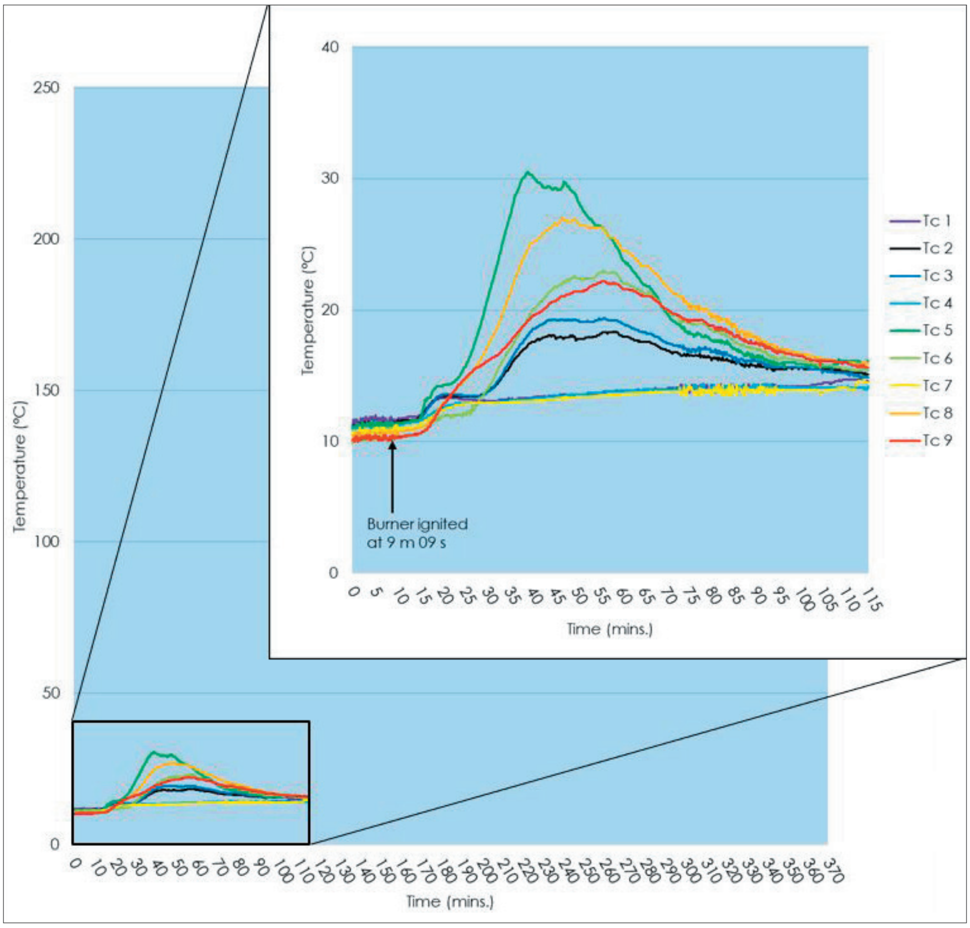


14 mins 51 secs

After test

The burnt surface reached the edge of the roof assembly and the extent was around 3430 x 4800 mm. It is noticeable that, despite largely closing the door to the building in which the tests were conducted, there was somewhat more impact from the wind, entering though the door, pushing the fire to one corner, and causing an asymmetrical pattern of damage to the membrane, than with the test of build-up insulated with the rock mineral fibre product. The visible fire ceased at around 43 mins after burner ignition. The temperature between steel deck and insulation peaked at under 31°C in one thermocouple location at around 31 mins after burner ignition before dropping (see following page). These observations suggest that no continuing smouldering combustion was taking place within the roof system.

Results / Observations - Round 2



About 1hr 40mins after burner ignition and after removal of the PV system, the damaged surface was measured. About 10mins later, partial dismounting of the flat roof assembly was completed and then the thermocouples within the roof were disconnected. The thermocouples were disconnected when the temperatures recorded by all thermocouples had dropped from their peaks and plateaued. The remains of the PVC membrane were removed and the insulation was cut open in cross section to see the pattern of damage. There was an area of combustion/heat damage (charring through to discolouration) to the insulation, co-incident with the area of damage to the waterproofing membrane. This damage was roughly lens-shaped, and in some discrete locations the damage penetrated 90% of the thickness of the insulation. There was no evidence of localised continuing smouldering combustion processes.

Conclusion

In the scenario tested (back to back PV panels), there was no significant difference between the extent of horizontal fire spread, caused by the burning PV array installed over roof build-ups that featured the Euroclass A1, dual-density, FM-approved, synthetic rock mineral fibre flat roof insulation product, recommended for use under PV systems, and FM-approved Kingspan Therma™ TR26, a Euroclass E, PIR flat roof insulation product, both from the Dutch market. The fire spread beyond the perimeter of the PV array was of very limited extent in all cases.

With the build-ups insulated with Kingspan Therma™ TR26, roof deck temperatures peaked at under 40°C at roughly the same time as the visible roof fire self-extinguished and there was no evidence of localised continuing combustion processes. The damage to the insulation (charring through to discolouration) did not reach the level of the deck in any location, even though the insulant was 100 mm thick.

With the build-ups insulated with the rock mineral fibre product, after the visible fire had stopped, ongoing smouldering combustion appears to have continued for roughly 2 hours (possibly longer) with roof-deck temperatures reaching as high as 100-200°C, in some thermocouples, before dropping. In places, the damage to the insulation (binder loss) penetrated its complete 180 mm thickness and reached the level of the deck.

The results herein are specific to the flat roof and PV products and configurations that were tested and the circumstances of those tests, and it should not be assumed that other products, configurations and circumstances will give the same result.

However, there is nothing within this testing to suggest that FM-approved Kingspan Therma™ TR26 from the Dutch market should not be permitted for use under PV arrays on flat roofs if Euroclass A1 insulants are permissible.

References

[1] J. S. Kristensen and G. Jomaas, Experimental Study of the Fire Behaviour on Flat Roof Constructions with Multiple Photovoltaic (PV) Panels, Fire Technol., vol. 54, no. 6, pp. 1807–1828, 2018, DOI: 10.1007/s10694-018-0772-5.

[2] CLC/TR 50670:2017 - External fire exposure to roofs in combination with photovoltaic (PV) arrays – Test method(s).

* Copies of the Efectis test reports are available upon request from the Kingspan Insulation Marketing Department (see rear cover).

† The rock mineral fibre product achieved an R_D of 5.1 and the Kingspan Therma™ TR26 an R_D of 4.5. For thermal equivalence, taking fixings into account, the Therma™ TR26 would have needed to be 126.3 mm thick. However, thermally equivalent thicknesses were not available at the time of acquiring materials for the tests.

In order to verify the validity of the tests, Kingspan commissioned Efectis to advise whether the reduced thickness of Therma™ TR26 would have any effect on the extent of combustion of the product. Based on Heat Transfer Modelling, using SIMU-THERM v8.0 software, Efectis advised that a test with 126.3 mm thick Therma™ TR26 would lead to similar results, in terms of flame spread and charring patterns, as a test with 100 mm thick Therma™ TR26.

A copy of the Efectis heat transfer modelling report is available upon request from the Kingspan Insulation Marketing Department (see rear cover).

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Version 1 | 01/2025