LARGE-SCALE TESTS OF FLAME SPREAD ON ROOF BUILD-UPS WITH PV SYSTEMS

A WHITE PAPER

Document information

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Executive Summary

Over the coming years, the implementation of the EU Energy Performance of Buildings Directive (EPBD) will drive a significant increase in solar panels (PV modules) on roofs across Europe. On flat roofs, fire can propagate in the cavity between the roof surface and the backside of PV modules. Depending on the roof build-up, flames can spread below the panels, and the fire may transfer heat into the roof itself and the underlying fire compartment.

This white paper summarises the findings from seven large-scale fire tests conducted at Twente Safety Campus between October 2024 and April 2025. The tests were performed by KIWA BDA on behalf of IVH, the German Rigid Foam Industry Association and EUMEPS, the European Manufacturers of Expanded Polystyrene. DBI observed all tests and analysed the outcomes based on reports, videos and temperature measurements. All fires were ignited by a gas burner placed under the edge of a 4-module PV array on a 7 m × 7 m roof build-up.

The fire tests were conducted to assess how introducing a 12 mm cement-bonded particle board (CPB) between a combustible B_{ROOF}(t1) roofing membrane and underlying insulation affects fire development, with emphasis on flame spread below the solar panel and heat transfer into the insulation.

Three possible outcomes were observed after the gas burner was turned off: i) flame spread below PV modules and into insulation, ii) flame spread below PV modules, or iii) no self-sustained flame spread.

In the baseline configuration (PVC membrane over glass fleece and EPS), fire spread below the PV modules and initially ignited the EPS, but no self-sustained flame spread developed in the insulation. With the CPB installed between the PVC membrane and EPS insulation, three of four tests showed only localised damage near the burner and no self-sustained flame spread below the PV array, indicating that a CPB board can improve the fire properties of a roof build-up. One test exhibited a self-sustained flame spread, associated with higher wind load. Even when flame spread occurred below the PV array, the EPS insulation was only affected locally beneath the burner location.

Overall, the results support that a correctly installed 12 mm CPB layer between a B_{ROOF}(t1) PVC membrane and EPS insulation can reduce the probability of self-sustained flame spread below building applied PV systems under the tested conditions and can limit heat transfer into EPS insulation even when flame spread does occur.

Introduction

With the introduction of the Energy Performance of Buildings Directive (EPBD) by the European Union, a significant increase in installed building applied photovoltaic (BAPV) systems is expected on the roofs across existing and future buildings [1]. Although the fire-related risk of BAPV systems is acknowledged in the directive, the regulation is left to the national member states [1] and de-facto regulation is carried out by the insurance industry to manage their risk exposure.

Although the fire-related risk of BAPV systems is composed by two factors: i) an increased probability of ignition, and ii) potential enhanced consequences in case of fire [2], [3], [4], the underlying basis for every fundamental fire safety strategy should always be based on *when*, not *if*, a fire occurs.

In case of a fire incident related to a BAPV system, fire can propagate in the cavity between the roof surface and back side of the PV modules [2], [5]. Although the consequences of such incident depend on several parameters, it is acknowledged that the roof build-up plays a significant role in the potential development of two undesired consequences, namely: A) flame spread along the roof, and B) flame spread into subjacent fire compartment [4].

This white paper describes the outcome of seven tests conducted by IVH, the German Rigid Foam Industry Association and EUMEPS, the European Manufacturers of Expanded Polystyrene at the premises of Twente Safety Campus (Troned, NL) between October 2024 and April 2025. KIWA BDA conducted the testing and provided six test reports [6], [7], [8], [9], [10], [11] to IVH and EUMEPS, who shared the reports, videos, and thermocouple data with DBI. DBI also witnessed all tests in person. Based on that, DBI analysed the outcome of the seven tests in two reports [12], [13], which are summarised herein.

Objective of test campaign

A series of seven large-scale test were carried out to examine how the materials below a combustible roofing membrane (B_{ROOF}(t1)) affect flame spread in case of ignition below a BAPV system installed on a flat roof.

The main objective was to assess how the introduction of a 12 mm thick cement-bonded particle board (CPB) between the roofing membrane and the subjacent insulation influenced the consequences. Thus, the roof build-up as a design parameter varied between the seven tests, whereas the remaining key design parameters were fixed.

Test design

Due to the lack of a standardised test method, the seven large-scale tests were similar to the ones conducted by others [14], [15], [16]. All tests were performed on squared roof build-ups with side lengths of 7 m and with non-ballasted East/West-orientated PV arrays with the geometry sketched in Figure 1. Each array consisted of 4 (2 x 2) or 12 (4 x 3) PV modules for respectively the first four [12] and subsequent three tests [13]. 10 minutes of exposure to a 15 kW gas burner represented the initial ignition source in all tests. The squared burner was, as defined in CLC/TR 50670 [17], elevated 80 mm from the roof surface, installed at the midpoint of the long edge below a PV module at the corner of the array, and located with a horizontal distance of 120 mm between the lowest edge of the PV module and the closest edge of the burner.

As defined in the introduction, the outcome of the tests was evaluated with respect to A) flame spread along the roof build-up, and B) flame spread into subjacent fire compartment, which for this work is defined as flame spread into the roof build-up.

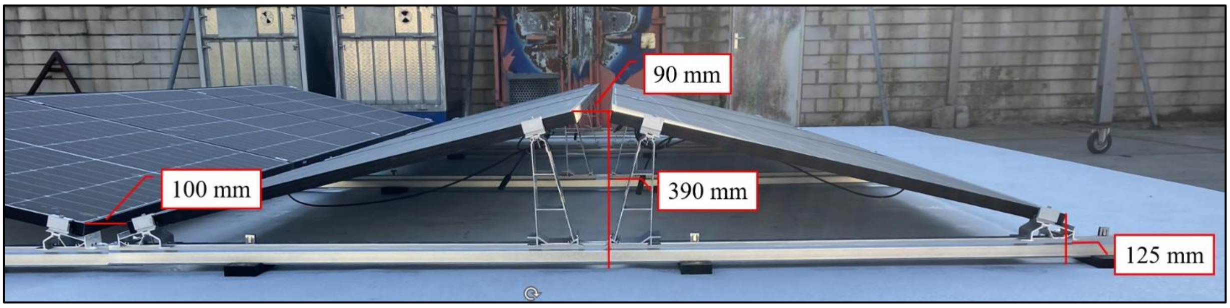


Figure 1 – Partial side view of the East/West-orientated PV array from a test with 12 PV modules [13].

CONSTRUCTION PRODUCTS:

PVC Roofing membrane: Bauder THERMOFOL M18, 1.8 mm, light grey, (B_{ROOF}(t1))

Bitumen membrane: SOPREMA PYE PV 200 S5 EN, 5.2 mm (B_{ROOF}(t1)) & SOPREMA SOPRALENE STICK 30 DUO, 3.0 mm.

Glass fleece: Kettinger GV 120/A2 naturweiss, 120 g/m^2

Cement-Bonded Particle Board: CETRIS BASIC, 12 mm, (A2-s1,d0)

Expanded Polystyrene (EPS) insulation: Brohlburg EPS DAA, 100 mm to 260 mm, Euroclass E

Mineral wool insulation: Rockwool Hardrock 08, 120 mm, Euroclass A1

Test build-ups

With the objective being to examine the effect of the 12 mm thick cement-bonded particle board (CPB), the seven tests were grouped into three categories:

1. Test 1: One baseline test with 1.8 mm thick PVC roofing membrane (B_{ROOF}(t1)), two layers of glass fleece and EPS insulation.
2. Tests 2-5: Four repeated tests with 1.8 mm thick PVC roofing membrane (B_{ROOF}(t1)), the 12 mm thick cement-bonded particle board (CPB) and EPS insulation.
3. Two reference tests:
    i. Test 6: Bitumen roof covering (B_{ROOF}(t1)) with a combined thickness of 8.2 mm instead of the 1.8 mm PVC roofing membrane, the 12 mm thick cement-bonded particle board (CPB) and EPS insulation.
4. Test 7: The 1.8 mm thick PVC roofing membrane (B_{ROOF}(t1)) installed on mineral wool insulation rather than EPS insulation.

Except for the baseline test, where the insulation was installed on top of a cement-bonded particle board, only a plastic based vapour barrier separated the insulation materials from the subjacent trapezoidal steel deck used for structural support. Detailed description of the individual roof build-ups is found in the test reports which also define type and location of moisture membrane [6], [7], [8], [9], [10], [11]. As such, the baseline test represented a roof with a load-bearing concrete deck, while the remaining tests represented roof build-ups with lightweight roof constructions.

For the six tests conducted with EPS insulation, the thickness of the EPS insulation varied from 100 mm to 260 mm across the tests as they complied with the energy requirements of respectively existing, new-built and renovated constructions. Whereas the thickness of the EPS insulation is relevant from an energy efficiency perspective, the short time duration of a fire incident solely renders thermal heat transfer through the uppermost insulation layer relevant if the remaining parameters are unchanged. Thus, the effect of total insulation thickness is therefore not evaluated in this white paper.

Instrumentation

To support visual observations during and after the tests, thermocouples (TCs) were installed below the PVC or bitumen roof covering in all tests besides the baseline test in which the uppermost layer of TCs were installed between the glass fleece and the EPS insulation. Additional layers of TCs were installed between selected layers with a total of 27 or 30 TCs in each test with respectively 4 and 12 PV modules. The number of thermocouples were consistent across test with the same number of PV modules and the exact thermocouple layout is found in the reports [12], [13].

Figure 2 – Baseline test with PVC membrane, two layers of glass fleece and EPS insulation. 10 minutes after ignition. Test 1 in the phase 1 report [12].

Results

The duration of the seven tests varied depending on whether flame spread occurred when the gas burner was turned off after 10 minutes of exposure. A total of three trends were observed: i) flame spread below all PV modules and into the insulation, ii) flame spread below all PV modules, and iii) no self-sustained flame spread after the burner was switched off.

In none of the tests, significant self-sustained flame spread outside the PV arrays was observed. Temporary ignition of the open roof surface solely occurred when the flame from below the PV array were deflected by the wind load as seen in Figure *2*. This corresponds with previous research and tests [14], [15], [16].

In the baseline test, the fire propagated below all four PV modules, through the glass fleece and into the EPS insulation which was initially ignited as seen in Figure 2. However, no self-sustained flame spread was observed in the insulation as the EPS melted away from the flame and self-extinguished.

Introduction of the 12 mm thick cement-bonded particle board (CPB) between the PVC membrane and EPS insulation rendered two different outcomes, as the fire only propagated below all PV modules in one of the three tests as seen in Figure 3b. For the remaining three tests with the CPB only localised damage was observed on the roof surface below the PV module where the gas burner was located.

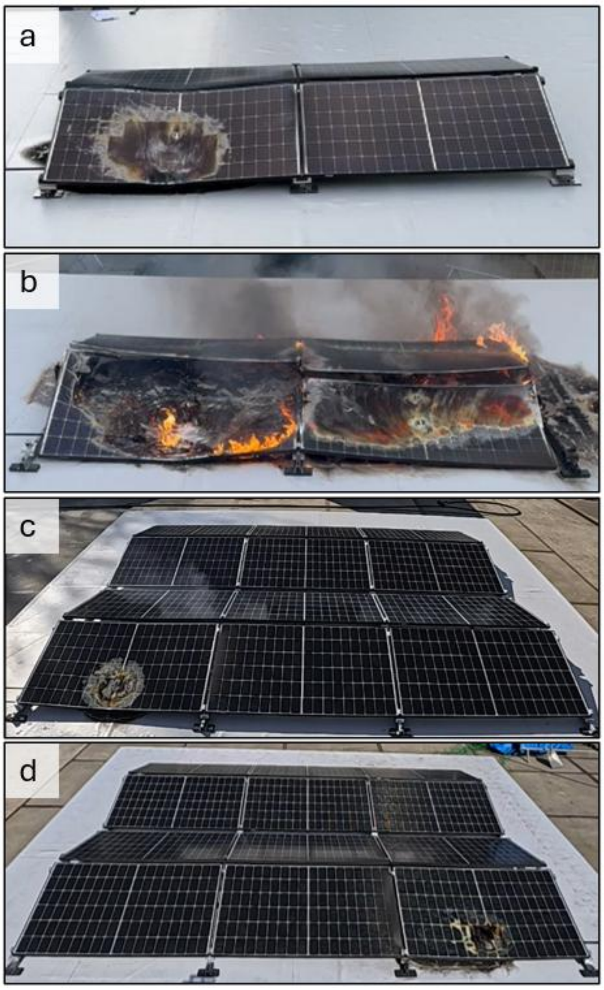


Figure 3 – The four tests with PVC membrane, 12 mm thick cement-bonded particle board and EPS insulation. 10 minutes after ignition. a) & b) are tests 2 & 3 in the phase I report [12], whereas c) & d) and tests 5 & 6 in the phase II report [13].

In those three tests, the PVC membrane was damaged at an area of maximum 1.7 meter times 1.3 meter [10]. From analysis of tests 2 and 3 in the phase 1 report, illustrated in Figure 3a and b, it is concluded that the self-sustained flame spread was caused by a higher wind load in test 3 [12].

Figure 4 – Melted EPS insulation below the cement-bonded particle board in test 3 where the fire propagated below all the PV arrays. [12].

Regardless of whether flame spread occurred in the four tests with the CPB, the subjacent layer of EPS insulation was only affected directly beneath the gas burner location. This is illustrated in Figure 4, which shows a void where the EPS has melted beneath the 12 mm thick mitigation layer.

Thus, the visual observations show that the cement-bonded particle board acted as a heat sink, which: i) in 3 of the 4 tests prevented self-sustained flame spread below the PV arrays by absorbing energy from the preheating zone outside the gas burner's domain, and ii) reduced heat transfer from the pyrolysis zone to the EPS insulation in the single test where the fire propagated below all PV modules.

In the final test with the CPB, where an 8.2 mm thick bitumen roof covering replaced the 1.8 mm PVC membrane, the fire propagated below all modules as seen in Figure 5a. Similar to the other test with self-sustained flame spread on top of the CPB, the EPS insulation was only affected directly below the location of the gas burner.

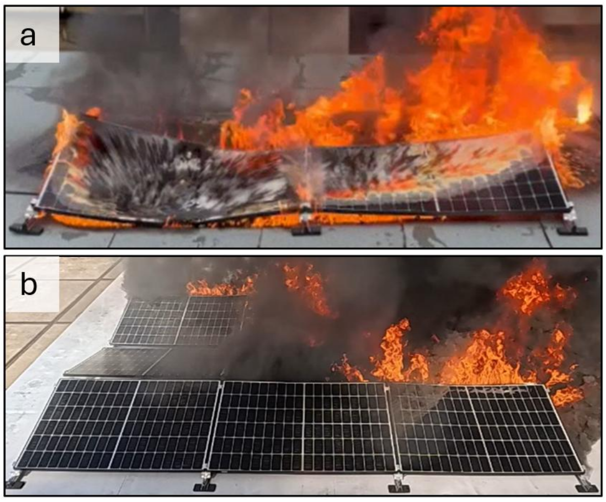
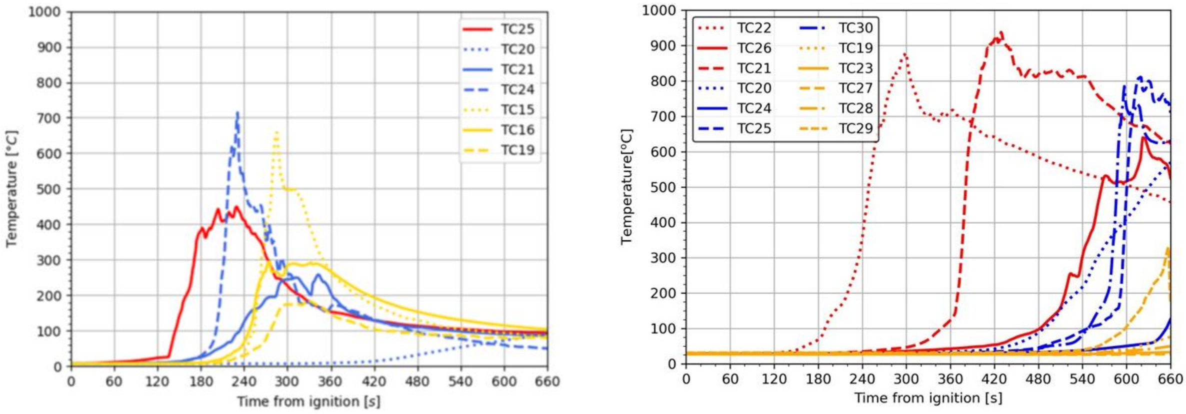


Figure 5 – Reference tests: a) 8.2 mm bitumen roof covering, 12 mm thick cement-bonded particle board and EPS insulation (test 4 in phase I report [12]), and EPS insulation, and b) 1.8 mm PVC roofing membrane on mineral wool (test 7 in phase II report [13]).

Self-sustained flame spread also occurred in the last test with the PVC membrane installed on mineral wool insulation. For environmental and safety reasons, KIWA BDA terminated the test 11 minutes after ignition as it was verified that the fire could propagate from one section of the PV array to another section as seen in Figure 5b.

In the test with mineral wool, the outcome corresponds to the outcome of previous tests [14], [15] and compared to the four tests of the same roofing membrane, 12 mm CPB and EPS insulation, it is concluded that the thermal boundary of the PVC membrane, i.e. thermal properties of the material subjacent to the thermally thin PVC membrane, has a significant influence on the test outcome. For thermally thick membranes, such as the bitumen membrane, the temperature gradient through the membrane itself renders the thermal boundary less crucial.

Examining the temperature development below the PVC membrane in tests 3 and 7 with self-sustained flame spread on top of respectively the CPB and mineral wool in Figure 6, the effect of the thermal boundary layer is illustrated. With self-sustained flame spread occurring in both tests, the thermocouples below the membrane indicate that the temperature at the thermal boundary is lower in test 3 than in test 7. The lower temperatures in the first mentioned also indicates why no self-sustained flame spread occurred in three of the four tests where the CPB served as a mitigation layer between the PVC membrane and EPS insulation.



a) Test 3 – PVC membrane installed on top of 12 mm thick cement-bonded particle board and EPS insulation.

b) Test 7 – PVC membrane installed on mineral wool.

Figure 6 – Temperature development below the PVC membrane in tests 3 and 7. Self-sustained flame spread below the PV modules occurred in both tests as seen in figure 3b and figure 5b. Time from ignition is limited to 660 seconds due to suppression of the fire after 11 minutes in test 7. Note that the distance between the thermocouples varied across the two tests.

Conclusion

From the visual observation and temperature measurements of the seven large-scale tests of roof construction build-ups with building applied photovoltaic (BAPV) arrays, it is found that correct installation of a thick cement-bonded particle board (CPB) between a PVC roofing membrane and EPS insulation renders two things:

i) The thermal properties of the CPB reduce the probability of self-sustained flame spread below the BAPV system, when compared to the test of two roof build-ups with respectively the same PVC membrane, two layers of glass fleece and EPS insulation, as well as the same PVC membrane installed on mineral wool insulation.

ii) If self-sustained flame spread occurred below the BAPV system, as observed in one of the four tests with the PVC membrane and CPB, the CPB acted as a heat sink and prevented significant heat transfer from the fire to the underlying EPS insulation.

Similarly, correct installation of the cement-bonded particle board between a bitumen membrane and EPS insulation prevented significant heat transfer to the EPS insulation, despite self-sustained flame spread below the BAPV array.

The results presented herein are limited to the specific roof construction build-ups tested, incorporating a comparable building-applied PV system. The findings indicate a potential reduction in fire-related consequences when a 12 mm cement-bonded particle board is introduced as a mitigation layer between the roof covering and the underlying EPS insulation.

Accordingly, these results should be regarded as a basis for further technical discussion on mitigating the consequences of PV-related fires, rather than as definitive solutions. The tests were not conducted in accordance with standardised methods, do not represent an approved system configuration, and have not been subject to formal fire classification.

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