Comparative Tests on Roofs with Photovoltaic Systems

CEI - TS 82-89 - ANPE - Istituto Giordano

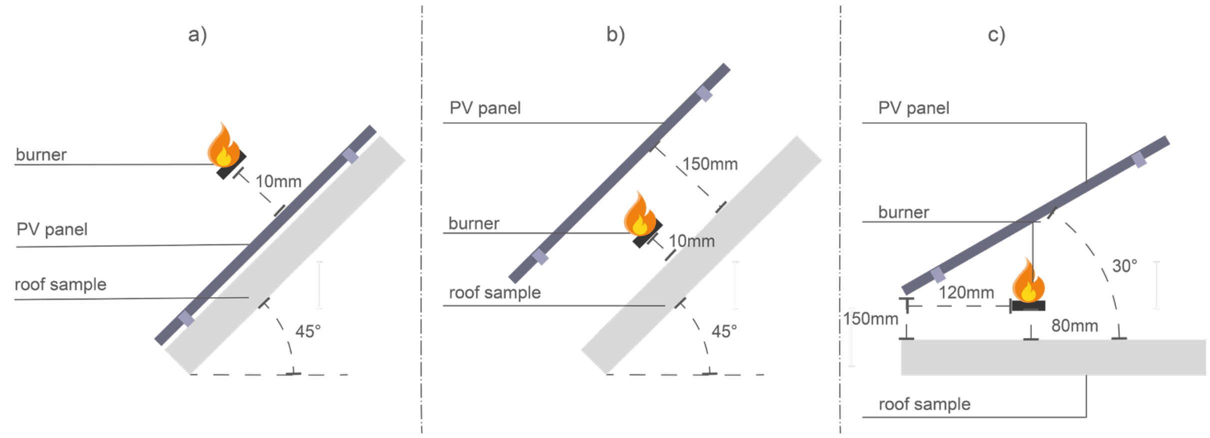
In May 2023, the technical specification **CEI TS 82-89** was published: *"Fire risk in photovoltaic systems - Fire behavior of photovoltaic modules installed on building roofs: test protocols and classification criteria"*. This replaces the **Technical Report CEI 82-89:2021-04** and outlines test protocols and classification criteria for evaluating the fire behavior of photovoltaic modules (PV) and roofing assemblies.

The motivation for developing this technical specification was the need to evaluate, using medium-scale methods and widely available equipment, the possible interactions between the fire behavior of the electrical system components (PV) and the roof on which they are installed. This approach differs from previous guidelines, which combined results from tests performed on single components (e.g., PV modules classified as B installed on roofs classified as Broof (t2), (t3), or (t4)).

Testing Methodology

The developed methodology utilizes CEN EN 13823 (SBI) test equipment, originally designed for the Euroclass reaction to fire classification system (from A2 to E) for construction products. The equipment was modified in its burner component and sample supports to evaluate specimens measuring 800 x 600 mm, composed of a photovoltaic panel and well defined standard substrates or tested roofing top layers with a maximum thickness of 50 mm (100 mm for these tests).

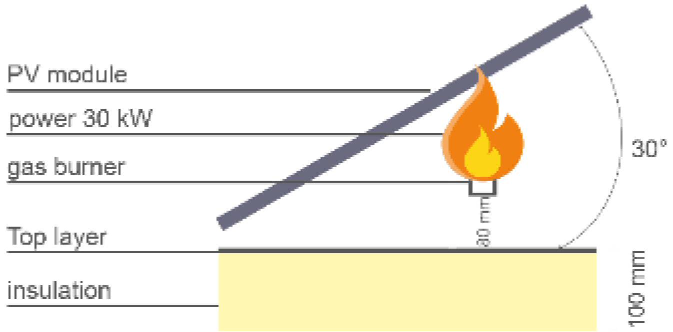
Three test protocols (a, b, c) are defined, differing in the burner's position (above or below the PV module), as well as the module's inclination and distance from the roof.



Test protocols

The resulting classification system evaluates the photovoltaic panel and roofing as a whole, always referring to a specific use condition. As a result, different combinations of the same components may achieve different classifications.

In spring 2024, ANPE conducted experimental tests following the CEI TS 82-89 method to evaluate the potential contribution of different insulation materials to the fire behavior of roofing assemblies with photovoltaic systems. The tests focused on flat roofs and were conducted using the protocol (c).



Test setup

The same materials were used across all tests, with the only variable being the type of insulation material.

- The top finishing and waterproofing layer was a synthetic TPO membrane, widely used in the national market and certified as B_{roof} (t2) roofing systems.
- All tested insulation materials are suitable for installation under waterproofing membranes and differ in thermal conductivity, density, and fire classification—ranging from Class E (PU panels with multilayer aluminum-based facing) to Class A1 (non-combustible rock wool).
- The selection aimed to determine how the fire of an individual component influences the overall fire behaviour of the entire roofing system.

PV Panel				
Glass upper layer and polymeric back-sheet – Italian fire reaction class 2				
Waterproof membrane				
Waterproofing layer - TPO, Thickness mm 1.8 – B_{roof} t2				
Insulation				
	PU	PU	MW Glass	MW Rock
Euroclass	E	B s1 d0	A2 s1 d0	A1
Thickness	100 mm	100 mm	100 mm	100 mm
λ_D	0.022 W/mK	0.025 W/mK	0.037 W/mK	0.037 W/mK
Density	34 kg/m^3	47 kg/m^3	80 kg/m^3	110 kg/m^3

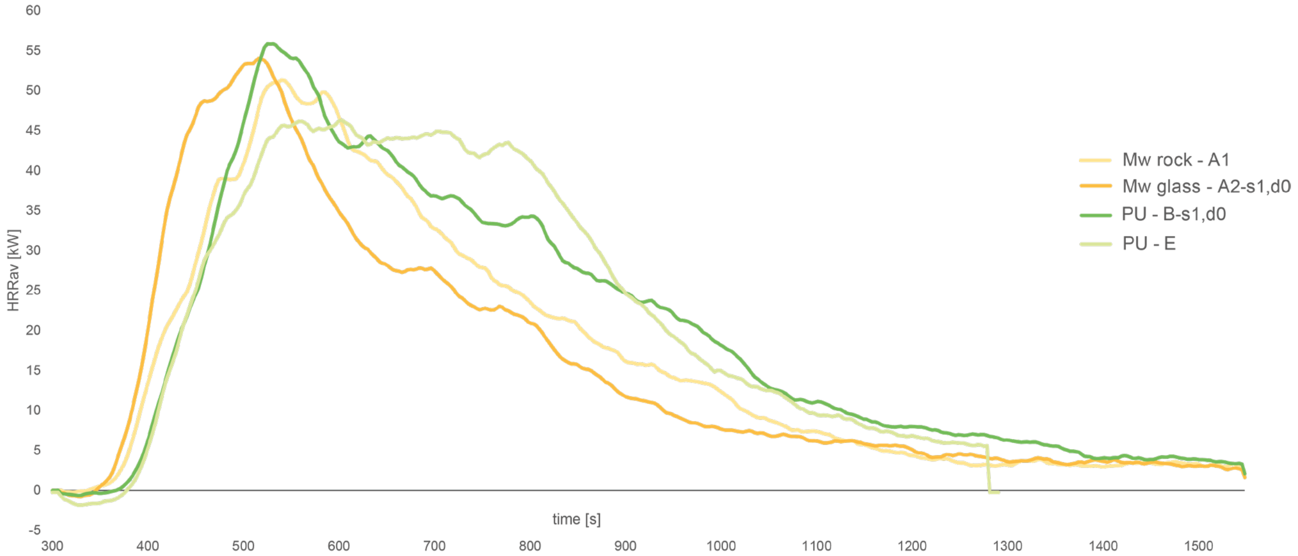
Tested materials

<u>Test Findings:</u>

- Roofing systems classified as B_{roof} (t2) showed similar damaged areas, limited to those areas affected by falling burning debris from the photovoltaic panels. In no case did the damage reach the outer perimeter of the sample.
- The classification system placed all four samples in Class C, regardless of the fire of the insulation material.
- The photovoltaic panel tested on a non-combustible support (calcium silicate) received a B classification, though it was close to the limit for that category.
- Heat release rate curves showed similar trends, with minor differences in growth rate and total extinction time.
- Fire penetration into the insulation material varied significantly:
    - PU samples showed only surface charring.
    - MW samples experienced damage throughout their entire thickness.
    - Glass wool samples exhibited a thickness reduction of approximately 20 mm.

Roofing system	PV+TPO+PU		PV+TPO+MW		Only PV on calcium silicate
PV Panel	glass upper layer and polymeric back-sheet – Italian reaction to fire class 2				
Waterproofing membrane	1.8 mm TPO synthetic membrane B_{roof} (t2) on non-combustible and combustible support				No waterproofing membrane
Reaction to fire class [EN13501-1]	E	B s1 d0	A2 s1 d0 MW Glass	A1 MW Rock	No insulation
FIGRA 0.2 MJ/(W/s)	195	250	316	225	179
FIGRA 0.4 MJ/(W/s)	195	250	316	225	179
THR 600 s/(MJ)	19	18.3	16.2	16.8	7.7
SMOGRA/(m^2/s^2)	10	9	13	8	6
TSP 600 s/(m^2)	62	47	41	41	17
CEI 82-89 Class	**C**	**C**	**C**	**C**	**B**

Results and classification



Average Heat release curves

	
PU E	MW Glass A2 s1 d0
	
PU B s1 d0	MW Rock A1

Damaged areas

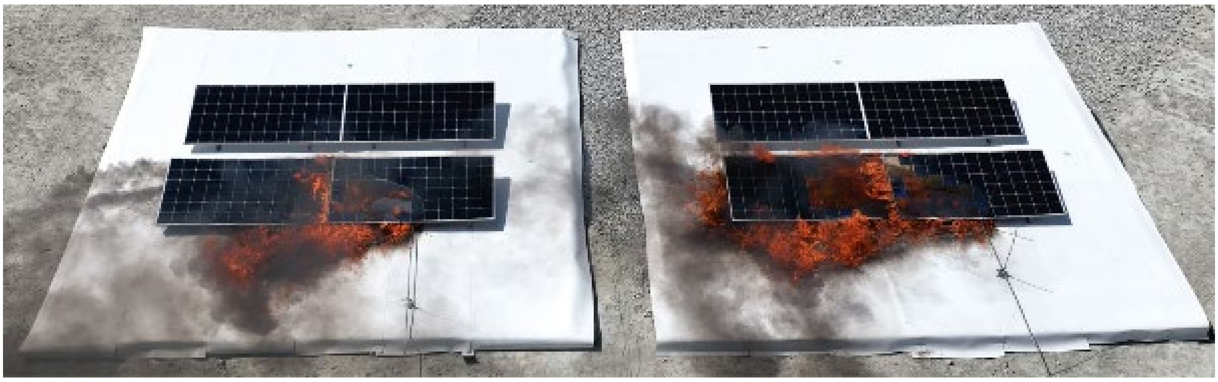
	
PU E	MW Glass A2 s1 d0
	
PU B s1 d0	MW Rock A1

Degree of penetration of the fire on the thickness

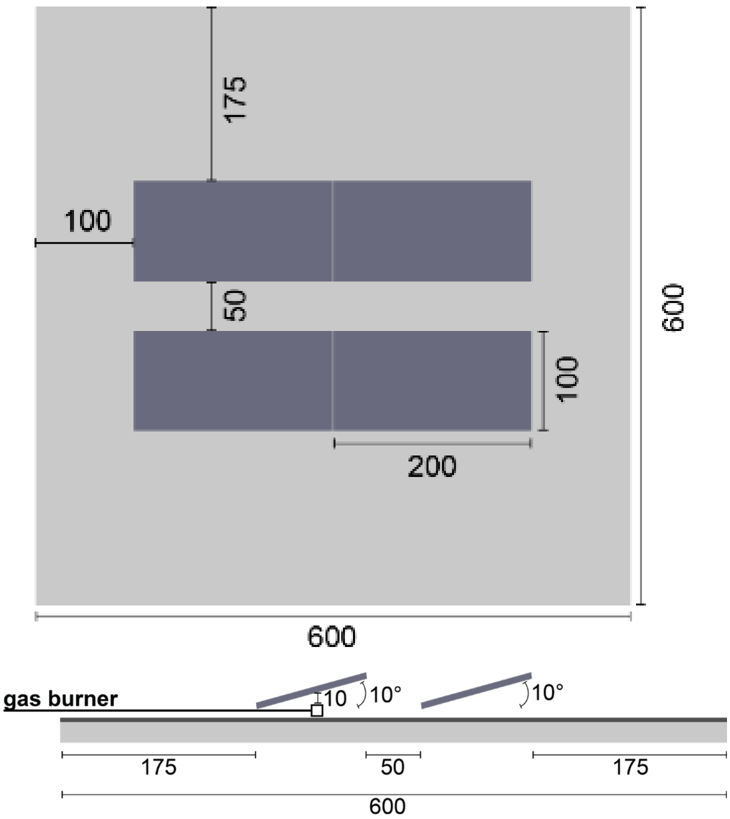
Large-Scale Experimental Test – ANPE - Istituto Giordano

In May 2024, at the EMIR Spa quarry in Verrucchio (RM), a full-scale comparative test was carried out, partially similar in configuration and purpose to the one conducted by PU Europe and KIWA BDA Testing in 2021.

Two roof samples measuring 6 m × 6 m were built, and both were tested simultaneously to avoid different weather conditions, wind direction and speed, to allow to compare the results directly.



Test configuration



Test configuration (quote in cm)

The test was conducted under the following weather conditions:

- Temperature: 17°C
- Relative Humidity: 68%
- Wind Speed: 2 m/s

The installation system of the photovoltaic panels (PV) reflect those most commonly used in Italy on flat roofs:

- Two rows of two modules each
- Spaced 50 cm apart
- Distance from the perimeter of the samples: 1 m laterally and 1.75 m vertically (see diagram).

The PV panels were installed with an inclination of 10° relative to the roof, with a minimum gap between the roof and the panel of 100 mm and a maximum gap of about 280 mm.

The two samples were built (assembled) using the same materials and installation methods, except for the insulating layer, which consisted of:

- PU panels with a reaction to fire class of B s1 d0
- Non-combustible MW Rock with a reaction to fire class A1

<table>
<tr><th colspan="2">PV panel</th></tr>
<tr><td colspan="2">PV panel in Italian class 2 of reaction to fire</td></tr>
<tr><th colspan="2">Waterproof membrane</th></tr>
<tr><td colspan="2">synthetic TPO in class B $_{roof}$ t2, thickness 1.8 mm</td></tr>
<tr><th>PU</th><th>MW Rock</th></tr>
<tr><td>Euroclass B s1 d0</td><td>Euroclass A1</td></tr>
<tr><td>Thickness 100mm</td><td>Thickness 100 mm</td></tr>
<tr><td>Density 47 kg/m^3</td><td>Average Density 110 kg/m ^{3}</td></tr>
<tr><td colspan="2">Polyethylene vapour barrier, thickness 0.2 mm</td></tr>
<tr><td colspan="2">Corrugated steel sheet support (ribs filled with same insulation tested)</td></tr>
</table>

Tested materials

Also for this test, a TPO synthetic waterproofing membrane was used, both to provide additional experimental data compared to those obtained from the PU Europe research (which used a PVC membrane) and because it is considered particularly significant for the Italian market.

The components of the samples are listed and described in the table.

Underneath the insulation panels, above the vapor barrier, and inside the insulation layer, thermocouples were installed to measure the temperatures during and after the test.

The gas burner was positioned centrally under a single panel per roof at about 8 cm above the roof.

For the test a burner was used, which delivered 15 kW for a duration of 10 minutes.

During and after the test, qualitative observations were recorded, as shown in the next table with time references.

Time	Observation PU	Observation MW Rock
0 (h15:05)	Burner ignition	Burner ignition
1 min	Ignition of the roof and PV panel near the burner	Ignition of the roof and PV panel near the burner
5 min		propagation to the second PV panel
6min	propagation to the second PV panel	
7min 30s	Flames emerge from the area of the second PV panel, but without damage to the roof membrane	The flame reaches the outer edge of the roof membrane
9min	The flames reach the outer edge of the roof; however, the TPO remains intact for a few centimeters	Fire curve in a declining phase
10min	Burner shutdown	Burner shutdown
14min	Flames no longer sustained, only the presence of faint flames outside the PV panel area	Flames no longer sustained, only the presence of faint flames outside the PV panel area
47min	Temperature peak under the insulation (95°C)	
1h 35min		Temperature peak under the insulation (192°C)

Test highlights

Among these, the following were highlighted:

- The flames on the PV panels and on the roof ignited after about 4-5 minutes.
- The wind intensity was approximately 2 m/s, and the direction caused the flames to move from the burner towards the second adjacent PV panel.
- The flames did not spread to the panels in the second row, remaining channeled between the two PV panels and the roof.
- The flames on the MW Rock roof reached the extreme edge of the roof, damaging the membrane even on the corner, thus traveling 1 m beyond the PV modules with a flame height of at least 1.5 m.
- On the PU roof, the flames stopped about 5-10 cm from the edge, showing great intensity as it exited the channel formed by the PV panels and the roof, with significant flame height, similar to that observed on the MW Rock roof.

- It is evident that the wind plays a crucial role in the spread of the flame, along with the formation of a cavity/channel created by the installation of photovoltaic modules on the roof.

Between 20 and 40 minutes:

- There were weak residual flames on the PU roof outside the PV structure.
- On the MW Rock roof, a more intense flame was present near the burner, due to the continuous interaction between the PV panels and the roof, causing flame propagation on the PV panels in the opposite direction to the wind.

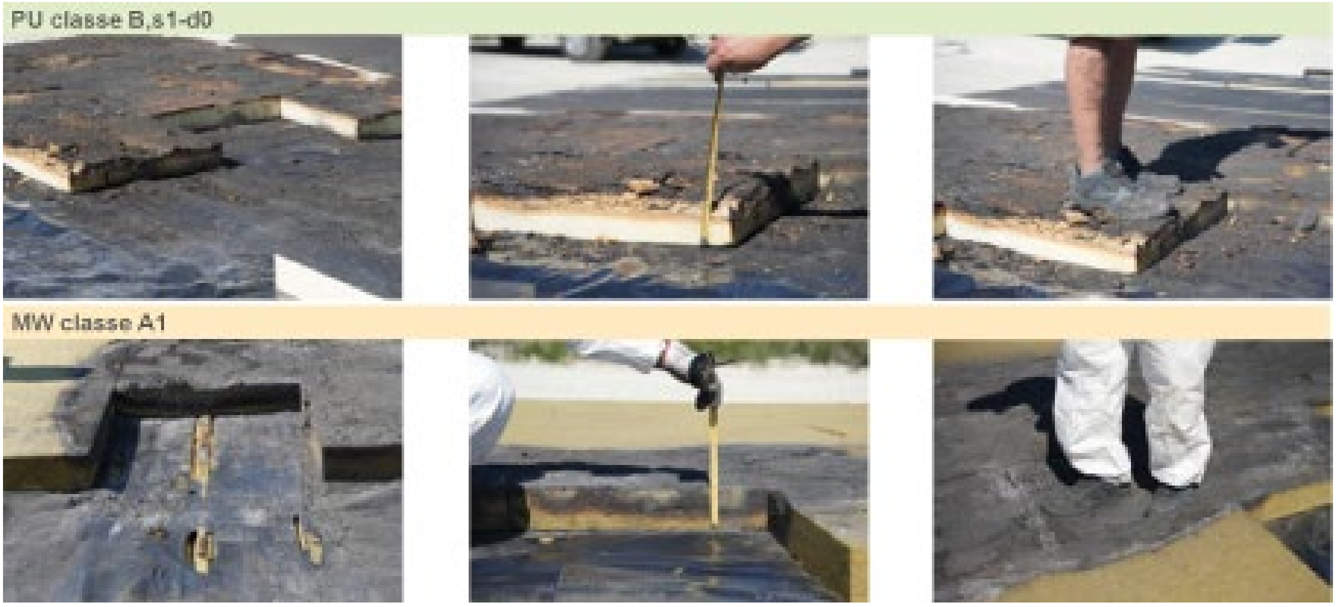
Once the PV modules and membrane layer were removed, it was observed that:

- The size of the damaged area was similar on both types of insulation.
- However, in terms of depth, greater penetration was observed in the MW Rock insulation.
- From a purely visual perspective:
  - The damaged thickness in PU measured approximately 4-5 cm.
  - The damaged thickness in MW Rock measured about 8-9 cm.

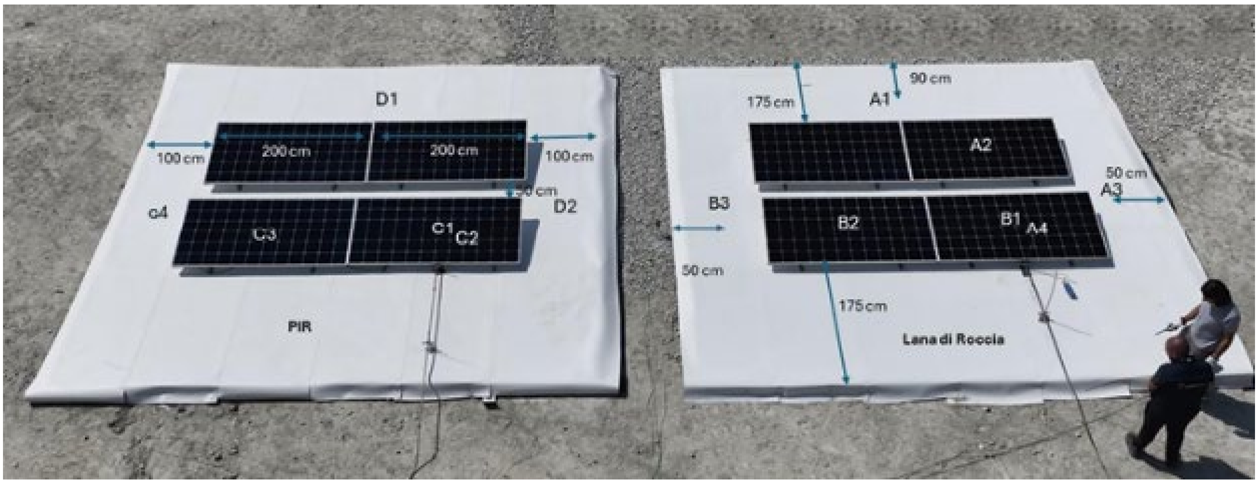
Beneath the rock wool insulation, the polyethylene vapor barrier was melted, and even the wool battens that were used to fill the corrugations showed signs of charring in multiple areas.

On the PU roof, both the vapor barrier and the filling battens appeared intact everywhere.

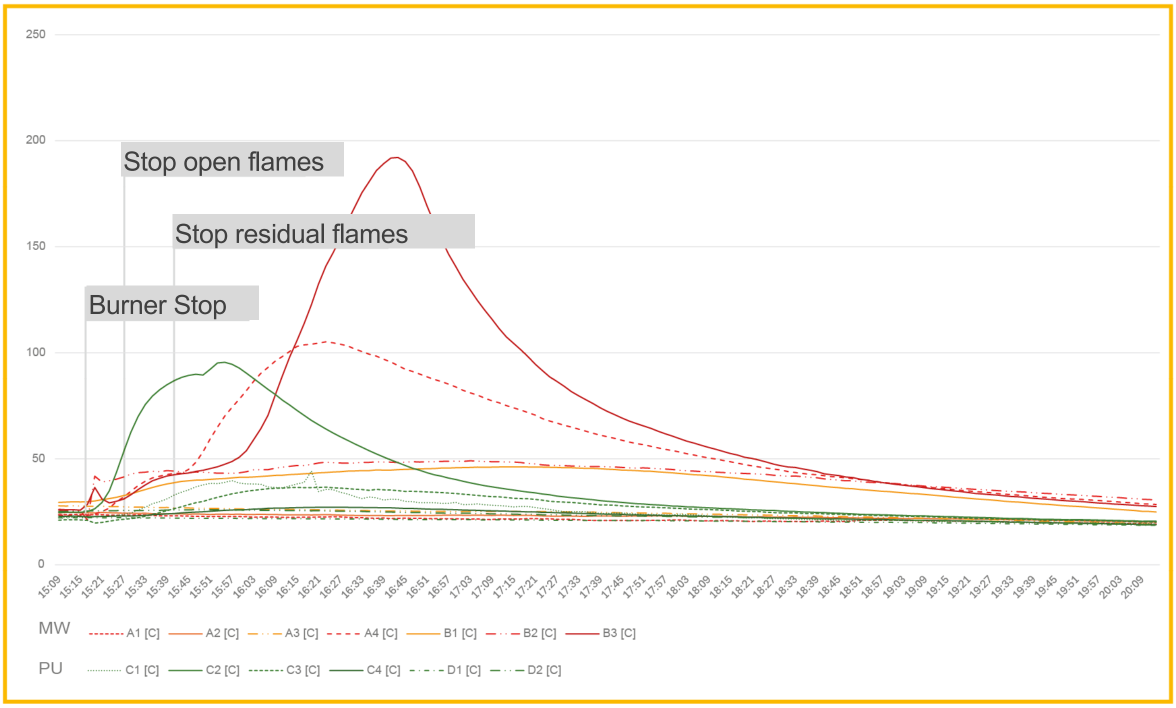
Damaged areas



Different conditions of the vapor barrier and filling battens, the thickness of the damaged insulation, and the retention, for the PU sample, and the loss, for the MW Rock sample, of mechanical properties (note how the operator's shoe sinks into the layer of burnt mineral wool)



Test setup and thermocouples position



The temperature curves recorded by the thermocouples. The highest values were recorded for the MW sample, explaining the greater damage to the thickness of the rock wool, the melting of the vapor barrier, and the partial carbonization of the battens that were used for filling the greeks

Final Considerations

The various research projects comparing construction assemblies insulated with PU and others with non-combustible MW Rock have led to the same observations:

- In both cases, Broof (t2) roofs limited flame spread beyond the fire-affected areas, which self-extinguished.
- Flame propagation was similar and not influenced by the reaction to fire classification of the insulation.
- The fibrous nature of mineral wool allows the penetration of molten material from the waterproofing layer, leading to greater flame penetration and higher temperatures on the underside.
- The charring of polyurethane foam hinders both lateral and downward flame spread.