

# Fire test method for flat roofs with photovoltaic (PV) modules



This Testing Procedure is published in English. A version in any other language with approved translation by ZAG has the same status as the official version.

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## **Foreword**

This document has been prepared in the Department for Fire-safe Sustainable Built Environment (FRISSBE) at ZAG (The Slovenian Building and Civil Engineering Institute).

Attention is drawn to the fact that this document has references to documents and their elements that may be the subject of patent rights. ZAG shall not be held responsible for identifying any or all such patent rights.

This document is the first edition.

## Introduction

In the context of photovoltaic (PV) fire safety, most of the European and National standards focus on material and product testing. This testing procedure (TP) focuses on testing an assembly of all elements of the roof and the applied PV system representing a more realistic scenario.

This TP aims to define a harmonized procedure for testing a system that is made of PV modules on a flat roof. The document focuses on the necessity of building specimens in a representative manner and takes into account crucial elements such as the use of anchors or glue, welding of the waterproofing membranes, use of ballast, or other specific elements. The determination of system parameters and fire behaviour is important to evaluate if an intensification of a fire threat can be expected. Building integrated PV systems is not part of this TP.

The document contains information related to material preparation, specimen assembling, measurements, specimen disassembling, and damage assessment.

The methodology outlined in this document is grounded in findings from a series of extensive test campaigns carried out at the ZAG Fire Laboratory in Logatec. These campaigns were conducted for several external clients, as well as for internal research activities. The work was carried out from 2023 to 2025 and it provides a thorough exploration of fire safety and related technologies, combining practical applications from client projects with innovative research to enhance the understanding of fire dynamics connected to rooftop PV installations and their safety measures.

A wood crib is used as an ignition source, similar to the ones used in the CEN/TS 1187:2012 tests, with more details described in subsection “4.5 Ignition source”. It represents the fire caused by the non-qualitative installation of PV elements, arc, and/or any other source of heat that could appear under the PV module.

This TP does not contain information about the installation of PV modules or roof elements but represents the testing method and approach for damage assessment.

**CAUTION — The attention of all persons concerned with managing and carrying out these tests is drawn to the fact that fire testing can be hazardous and that there is a possibility that toxic and/or harmful smoke and gases can be produced during a test like that. An assessment of all potential hazards and risks to health should be made and safety precautions should be identified and provided. Written safety instructions should be issued. Appropriate training should be given to all relevant personnel. Laboratory personnel should ensure that they follow written safety instructions at all times.**

## 1 Scope

The Testing Procedure specifies tests in two different scales for determining the performance of the system that involves PV modules and a flat roof exposed to an external fire source.

The tests assess the fire spread across the surface of the roof, the fire spread within the roof, damage to the PV module(s), mounting system(s), and roof elements.

The test methods described in this document are only applicable to building applied PV (BAPV) installations or geometrically irregular roofs. Building integrated PV (BIPV) systems are not covered by this document.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the references document (including any amendments) applies.

ISO 13943:2008 (E), *Fire safety – Vocabulary (ISO 13943:2008)*

ISO 13501-5:2016 (E) – *Fire classification of construction products and building elements - Part 5: Classification using data from external fire exposure to roofs tests*

CEN/TS 1187:2012 (E) – *Test methods for external fire exposure to roofs*

CLC/TR 50670:2016 - *External fire exposure to roofs in combination with photovoltaic (PV) arrays - Test method(s)*

FM 4478:2021 – *Examination Standard for Roof-Mounted Rigid Photovoltaic Module Systems*

SFPE “*Handbook of Fire Protection Engineering*” 2016 (5th Edition)

McAllister, S.; Grumstrup, T. 2023. *Burning rate of wood cribs with controlled airflow*. Fire Technology. 59: 3473-3492.

### **3 Terms and Definitions**

For the purposes of this document, the terms and definitions given in EN ISO 13943:2008 Fire Safety – Vocabulary apply.

#### **3.1**

##### **material**

basic single substance or uniformly dispersed mixture of substances (e.g., metal, stone, wood, bitumen, concrete, mineral wool)

#### **3.2**

##### **product**

the finished product (PV module, insulation, roof covering, etc.) about which information is required

#### **3.3**

##### **mitigation layer**

the layer of non-combustible material that separates two layers of the roof structure to reduce the negative consequences and downward fire spread through the roof layers

#### **3.4**

##### **smouldering combustion**

combustion of a material without flame or without visible light

NOTE: Smoldering combustion is generally evidenced by an increase in temperature and/or by fire effluents

#### **3.5**

##### **glowing combustion**

combustion of a material in the solid phase without flame but with the emission of light from the combustion zone

#### **3.6**

##### **test deck**

test deck on which the PV module will be mounted

#### **3.7**

##### **damaged material**

##### **3.7.1**

##### **damaged material including melting**

material that was burnt, charred, melted or otherwise visually changed by heat.

NOTE: Discoloration and soot deposits should not be regarded as damage. Areas of the roof covering the surface in which combustion has not occurred should not be regarded as damaged (e.g., areas that have only become shiny or only have tiny occasional holes or bubbles).

### **3.7.2**

#### **damaged material not including melting**

Material that has been burnt or otherwise visually changed by heat, excluding melting

NOTE: Discoloration and soot deposits should not be regarded as damage. Areas of the roof covering the surface in which combustion has not occurred should not be regarded as damaged.

### **3.8**

#### **thermal decomposition**

process whereby the action of heat or elevated temperature on an item causes changes to the chemical composition

### **3.9**

#### **thermal degradation**

process whereby the action of heat or elevated temperature on an item causes a deterioration of one or more properties

### **3.10**

#### **burnt material**

material that has been destroyed by combustion or pyrolysis

### **3.11**

#### **specimen**

representative section of the roof/roof and PV system (including the mounting system) prepared for the test

### **3.12**

#### **flame spread**

propagation of a flame front

### **3.13**

#### **melting behaviour**

phenomena accompanying the liquefaction of material under the influence of heat

NOTE: This includes deforming and dripping, but not flaming.

### **3.14**

#### **opening**

appearance during the test of any hole greater than 25 mm<sup>2</sup> in area or any crack greater than 2 mm wide, which penetrates completely through the specimen and would allow burning material to fall through the roof

### **3.15**

#### **internal damage**

extent of damaged material in each layer inside the specimen, measured from the edges of the projection of the ignition source in the upward directions with respect to the pitch of the roof

### **3.16**

#### **joint**

kind of connection or link within a layer in the roof, such as overlap or seams

### **3.17**

#### **roof covering**

uppermost layer (single or multiple layers) of a roof

### **3.18**

#### **non-combustible substrate or deck**

substrate or deck classified A1 or A2-s1,d0 according to EN 13501-1

### **3.19**

#### **roof pitch**

inclination of the roof surface to the horizontal

### **3.20**

#### **ignition source**

source of energy that initiates combustion

## 4 Test methods

### 4.1 Test deck

The test deck serves as a substrate for the test specimen. It is designed to allow unobstructed observation of the burning behaviour of the test specimen, to evaluate the effects of the PV system on the roof and the underlying materials, to ensure safety in the laboratory, and to allow for easy handling of the test specimens.

The test deck shall consist of corrugated steel, aerated concrete blocks or other noncombustible support materials that can act as a holder for the plasterboards. These then serve as the substrate for the designated roof buildup for each test (insulation layers, membranes, anchors, mounting system...).

Suggested designs for the mid-scale and large-scale tests are presented in Figure 1 and Figure 2.

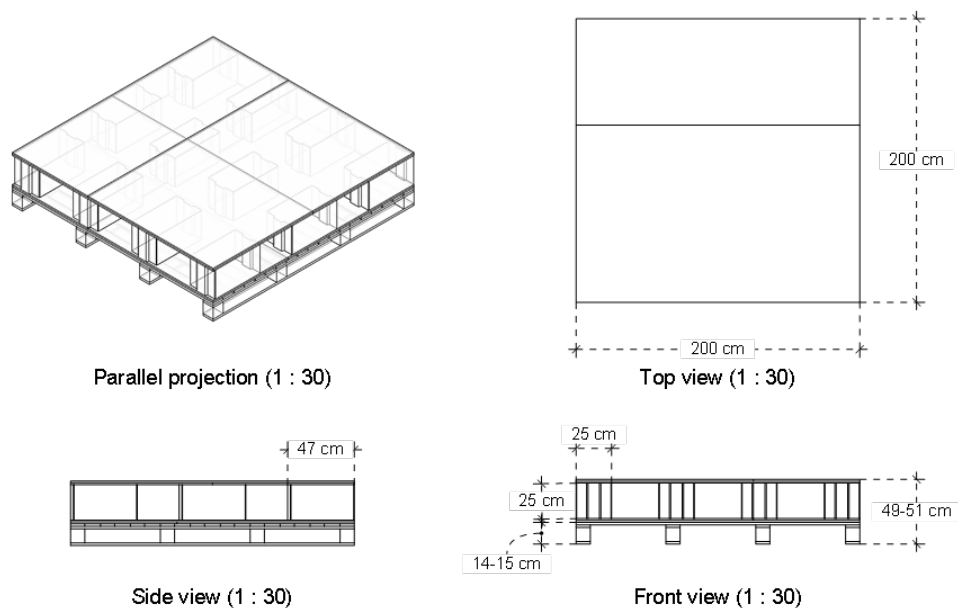
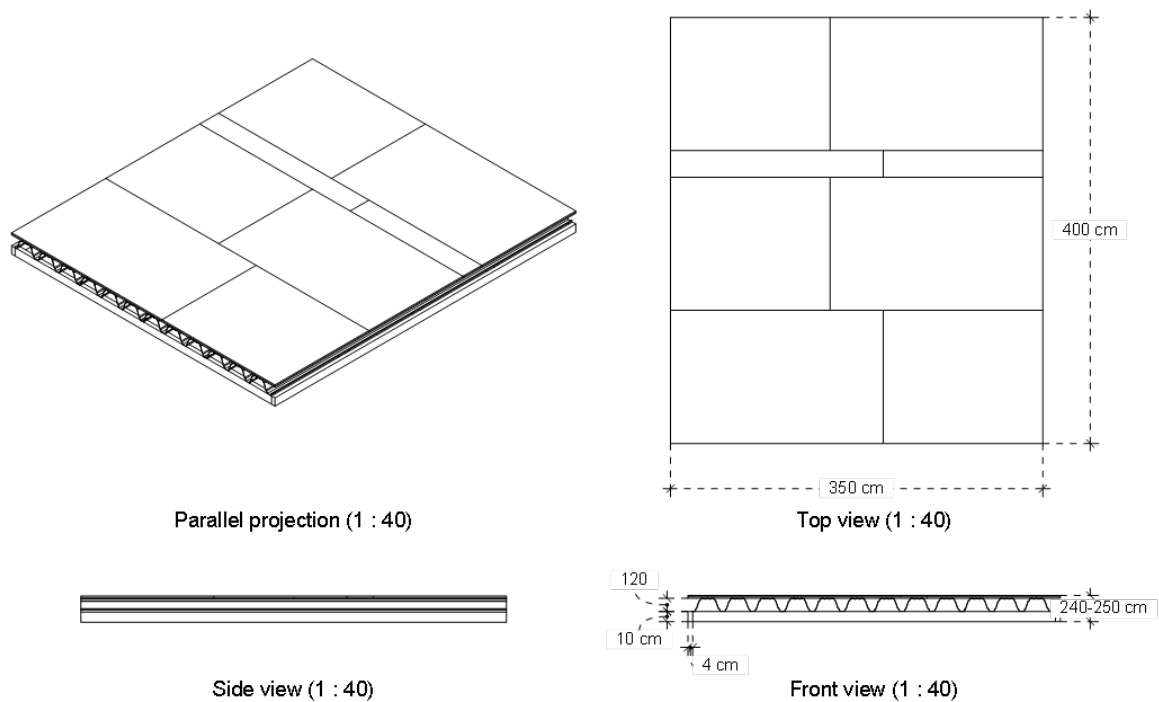


Figure 1 – Deck design for the mid-scale specimen



**Figure 2 – Deck design for the large-scale specimen**

## 4.2 General

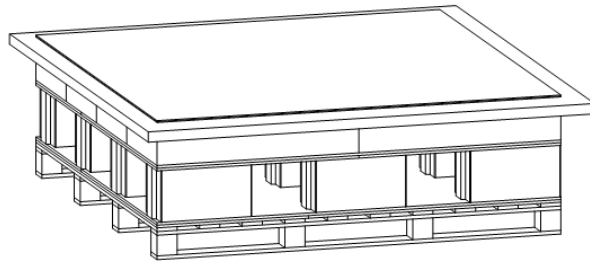
The test method mimics a scenario where a fire starts on the roof membrane below the PV system, thereby representing a failure in the PV electrical components or an external source of fire spreading to that point (flying brands from neighbouring buildings, wildfire). The ignition source should create enough energy for the fire to propagate outside of the initial area of the ignition source, typically in a period of  $10 \pm 5$  min.

The described test method applies to PV modules not greater than 1.8 m by 1.2 m due to the dimensions of the mid-scale test deck, while in the large-scale the PV modules should also not stretch beyond the test deck.

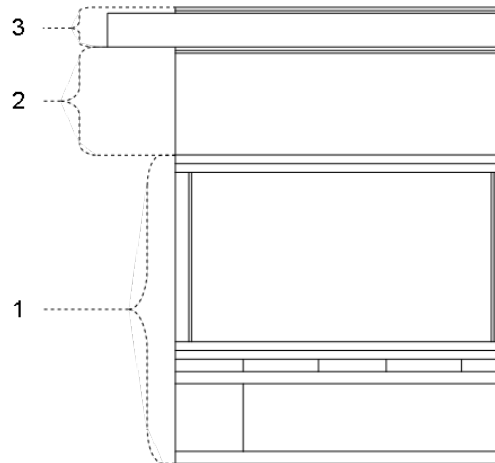
For testing purposes, two different scales are proposed in this TS.

## 4.3 Mid-scale test

The mid-scale test is designed to perform a test with one PV module representing a south-orientated installation. Dimensions of the specimen are 2 m by 2 m. An illustration of the specimen is shown in Figure 3 and Figure 4.



**Figure 3 – Schematic view of the specimen**



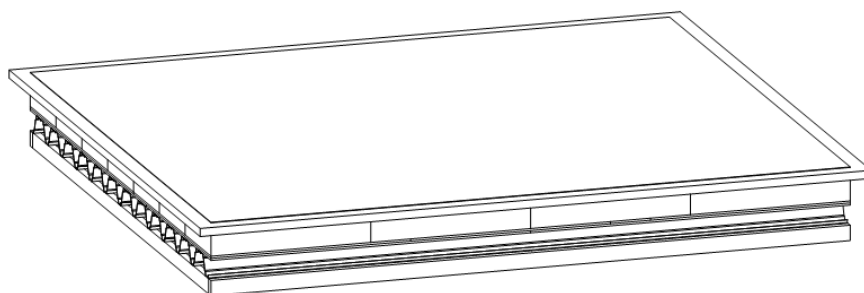
**Figure 4 – Illustration of the roof layers**

- 1 – test deck
- 2 – roof buildup (details must be specified in the test report)
- 3 – mitigation layer with a roof membrane

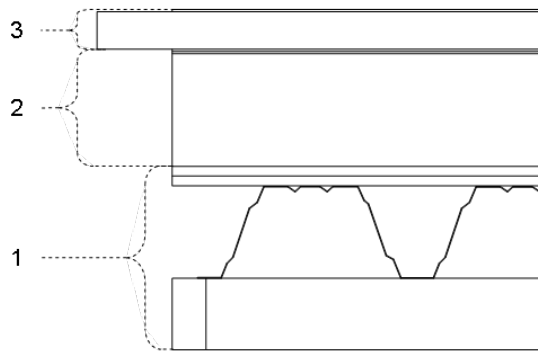
The mitigation layer, if used, should be extended on the sides horizontally to protect underlying materials from flame influence coming from the sides. A thin layer of non-combustible material can cover the open sides of roof buildup to lower the influence of heat on it.

#### **4.4 Large-scale test**

The large-scale test is designed to perform tests with east-west and south-oriented PV installations. Four PV modules are possible to install on this specimen. Dimensions are 4 m by 4 m (note that this is slightly larger than the deck shown in Figure 2). An illustration of the specimen is shown in Figure 5 and Figure 6 .



**Figure 5 – Schematic view of the specimen**



**Figure 6 – Illustration of the roof layers**

1 – test deck

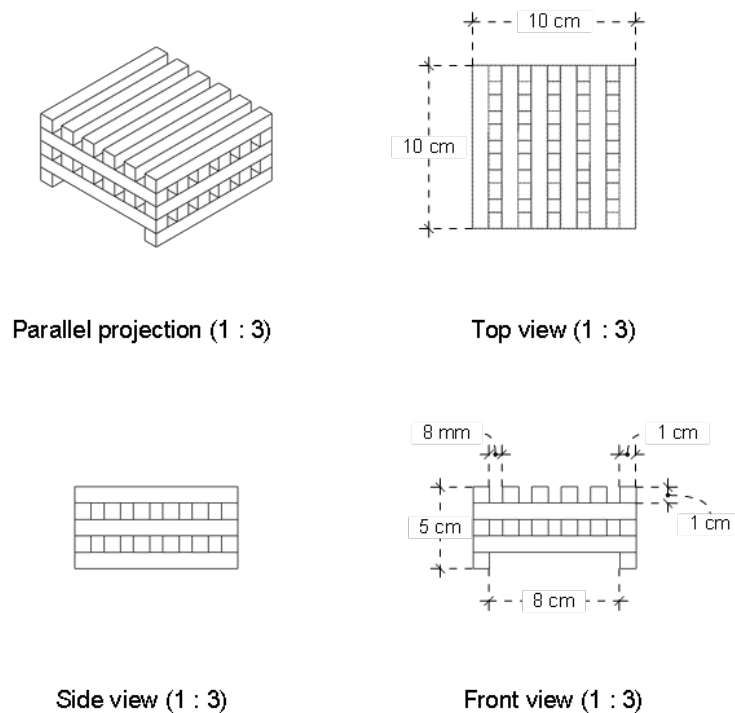
2 – roof buildup (details must be specified in the test report)

3 – mitigation layer with a roof membrane

If possible, the mitigation layer should be extended horizontally to protect underlying materials from flame influence coming from the sides.

#### 4.5 Ignition source

The ignition source is designed taking into account requirements for testing from standards CEN TS 1187, ISO 13501-5, and CLC/TR 50670:2016. The designed ignition source has a theoretically calculated heat release of 16.56 kW and is made of four layers of spruce wooden sticks with two supporting sticks under it (see Figure 7). Each wood stick's dimension should be 10 cm × 1 cm × 1 cm. The expected duration of burning for a dried wood crib on a non-combustible surface without any obstructions above it is around 6 min.



**Figure 7 – Illustration of the wood crib**

A nail gun with appropriate nail length should be used to nail all wood sticks together. Each wood stick is nailed with a maximum of two nails, one at each end.

The heat transfer of a wood crib goes in all directions, and includes all forms of heat transfer to the top layer of the roof (conduction, convection, radiation), and creates a fire that is in direct contact with the roof covering.

The equation for the calculation of the maximum heat release rate (HRR) of wood cribs is presented below:

$$HRR = \Delta h_c \times MLR = 12000 \text{ [kJ/kg]} \times 0.00138 \text{ [kg/s]} = 16.56 \text{ [kW]}^1 \quad [1]$$

Where:

$\Delta h_c$  – effective heat of combustion, [kJ/kg].

MLR – mass loss rate, [kg/s] (experimentally obtained value).

#### **4.5.1 Wood drying**

For drying of wood, a ventilated oven capable of maintaining a constant temperature of  $(105 \pm 5)^\circ\text{C}$  shall be used. A desiccator is used for storing the dried wood cribs after drying to keep the sticks at a constant moisture level.

Constant mass is considered to be reached when two successive weighing operations, carried out at an interval of 24 h, do not differ more than 0.1 % of the mass of the specimen or 0.1 g, whichever is greater.

The balance is used to weight the wood cribs. It shall have a nominal capacity of at least 100 g and an accuracy of  $\pm 0.1$  g.

#### **4.6 Test environment and measurements**

The ambient temperature within the laboratory shall be  $(20 \pm 10)^\circ\text{C}$  before the start of each fire test. If any measures are taken to remove products of combustion from the test laboratory, they shall be in operation during the calibration period and maintained during the test. The time between leaving the conditioning atmosphere and testing shall not exceed 4 hours.

##### **4.6.1 Velocity measurements**

The horizontal wind speed around the specimen should not exceed 0.5 m/s.

#### **4.7 Conditions**

The materials used for specimen preparation should comply with the manufacturer's specifications. All materials shall be conditioned before assembling. After assembling, the specimen should be cured following the manufacturer's instructions.

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<sup>1</sup> SFPE Handbook of Fire Protection Engineering” 2016 (5th Edition), page 799

## 5 Test procedure

### 5.1 General

Measuring equipment and techniques that are not mentioned in the text are permissible to use if it does not affect the testing method, specimen representative design, or outcome of the test. When possible, the equipment should be calibrated and certified.

### 5.2 Placement of the ignition source

The wood crib has to be placed on the top of the roof cover, below the PV module. The distance between the rear side of the PV module and the roof covering at the centre of the wood crib shall be approximately 12 cm. The objective of the test is to establish the robustness of the test, so if there is no ignition, the distance to the crib should be reduced. It is therefore recommended that a small test is done in advance to establish a distance that ensures spread. The goal of the test is to assess the damage to the roof elements due to fire propagation on the roof surface; it is not an ignition test. Ensuring spread can also mean that the ignition source should be enlarged (layer to an existing crib or another crib). The preferable location of the ignition source is shown in Figure 8.

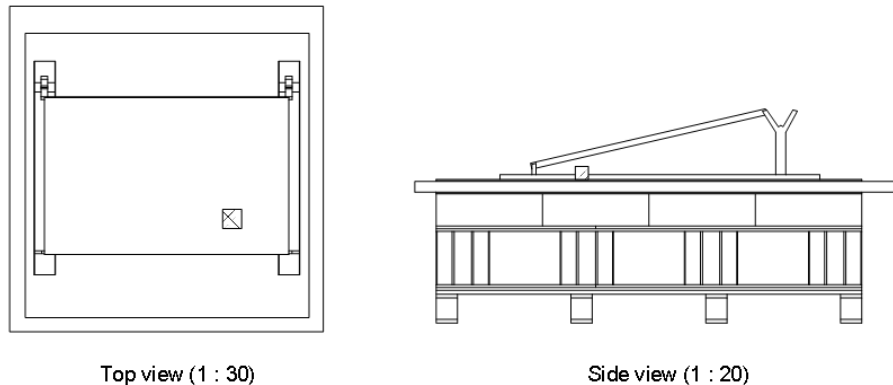


Figure 8 – Approximate location of the ignition source in the mid-scale setup

### 5.3 Start of the test

After positioning the specimen under the exhaust hood, measuring the air velocity, and preparing data logging equipment, 5 – 10 mL of isopropyl alcohol shall be poured onto the ignition source. The ignition source shall be placed at the ignition location immediately. Ignition shall be done with an igniter.

### 5.4 Cooling phase

The damage should be assessed throughout the test for the external, visible parts of the tested system. The eventual detailed 'forensic' inspection is done at least 150 min after flaming combustion has stopped. Note that the temperature measurements should take place for the entire cooling phase.

### 5.5 End of test

The test shall be terminated and the fire extinguished when any of the following events occurs:

- a) there is a risk to safety of personnel or impending damage to equipment;
- b) a period of discussed time for the test is reached;

- c) fire spread inside the roof layer. There is no risk for personnel or equipment.
- d) Reignition with flaming combustion during the cooling phase.

In any test where water is used to extinguish, the test is considered to be abandoned and can thus not be used for assessment purposes.

### **5.6 Specimen disassembling and discharge of materials**

The specimen should be disassembled layer by layer. All materials shall be separated and discharged according to National legislation rules.

## **6 Observations and measurements**

### **6.1 Air velocity**

The air velocity should be measured 10 cm above the roof covering, 10 cm in the center of PV module surface, 10 cm from the roof covering at the lowest and widest sides of PV assembly.

If during the test speed of the fan was changed, additional measurements should take place at the described above locations.

### **6.2 Temperature recordings**

Thermocouples should be placed at each layer (including in the middle of mitigation/insulation layer if possible) under the ignition source.

In addition, one surface thermocouple should be placed in the center of PV module from the top side.

### **6.3 Marking**

For damage assessment and flame spread calculation, additional marks can be added on the PV module surface, PV support system, roof covering, or other specimen material.

### **6.4 Timing device**

A timing device with an accuracy of  $\pm 1$  s/h shall be used to record events during the test.

All time observations are made by technicians and are expressed in minutes (e.g., 2-3 min – ignition of roof covering). Any visual observations shall be noted.

### **6.5 Recording equipment**

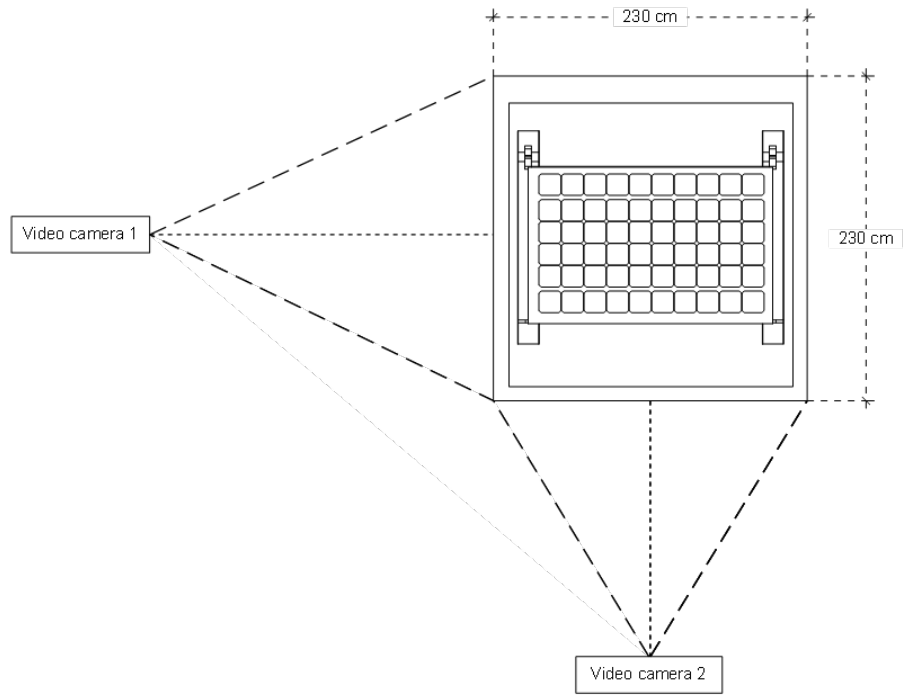
During the test, any equipment with a photo option shall be used for documenting purposes. The minimum resolution of photos should be  $1920 \times 1080$  pixels. Photos of any events during the test shall be taken for future analysis purposes.

For recording purposes, two video cameras with a resolution of at least  $1920 \times 1080$  pixels must be used. The cameras must have a minimum x20 zoom that will allow the placement of equipment at a safe distance from the test specimen. The position of the cameras can be changed in case it can cause damage to equipment or cause danger to people involved in testing. The ignition event is used to synchronize the timeline of the two videos.

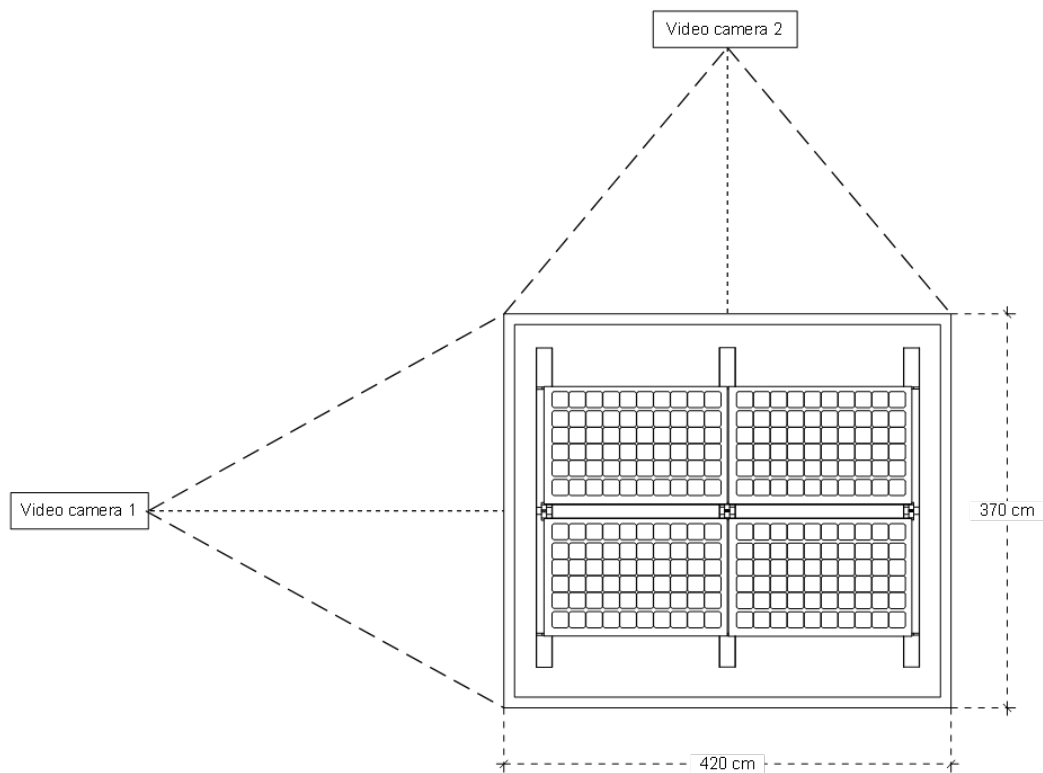
Cameras should be leveled and capture all essential elements of the specimen. In addition, the camera should capture approximately predicted areas of flames that will be released during the test.

The angle of the camera should be chosen to ensure the roof covering is at least partially visible.

The approximate position of the cameras is shown in Figure 9 and Figure 10 .

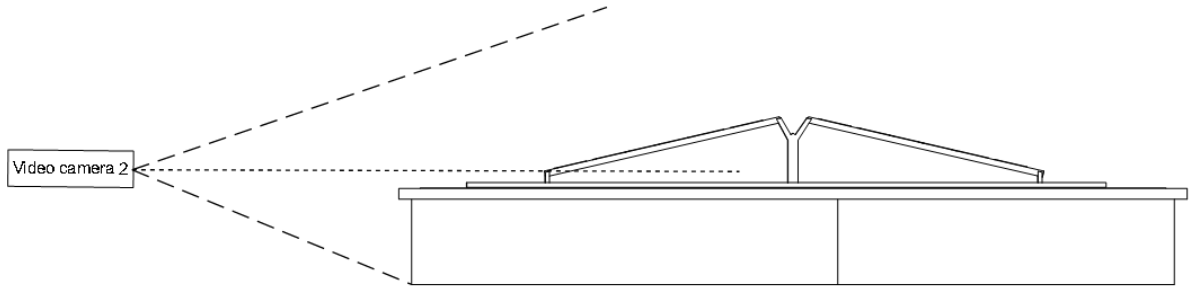


**Figure 9 – Approximate placement of video cameras for the mid-scale test**

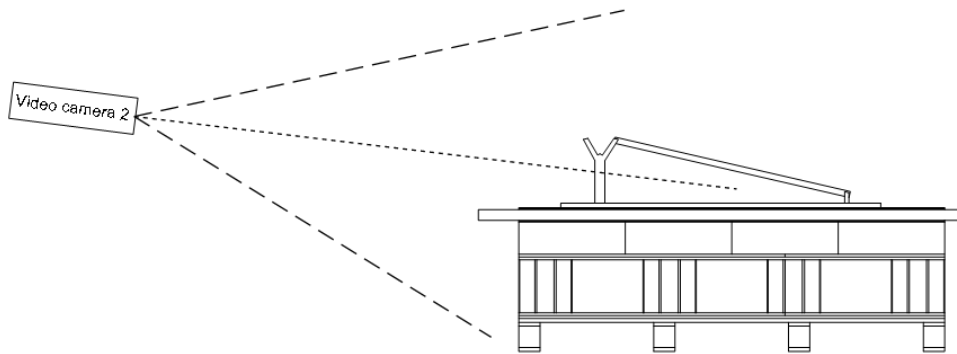


**Figure 10 – Approximate placement of video cameras for the large-scale test**

The position of video camera 2 should be adjusted to face the PV module as shown in Figure 10 (from the side of an ignition source) or adjusted to face the gap between PV module and roof surface (see Figure 11 and Figure 12).



**Figure 11 – Position of the video camera for the large-scale test**



**Figure 12 – Position of the video camera for the mid-scale test**

## 6.6 Damage assessment

Damage shall be assessed after the test or after the cooling phase has finished.

Photos of the damage on the PV system (mounting system elements, state of the PV module) and each layer shall be taken.

Measurements of damaged material, damaged surface area, burnt material, appeared openings, the size/volume of burnt/melted materials, or its colour that is different from the original shall be documented.

The examples of damage to be assessed and reported:

- Ignition of other elements
- Visible changes/deformation of specimen elements (parts of roof / PV assembly)
- Visual changes/deformation of materials (change of colour/melting/smouldering etc. of materials in the mitigation layer, insulation layer, vapour barrier etc.)
- Enlarged gaps between materials (mitigation, insulation, etc.) compared to their initial state
- Damage caused due to the use of additional elements, such as ballast, anchors, glue, etc.
- Area of fire spread
- Area/depth of the damages to the materials (insulation layer...)
- Any other detectable changes

## 7 Reporting

The test report shall provide all information relevant to the selected procedures, the products tested and the results obtained.

The structure of the report can be done in free form and depends on the company's preferences, but it shall comprise:

- date and identification number of the report;
- name of employees responsible for report writing, reviewing, and approving;
- name and address of the testing laboratory;
- name and address of the customer;
- purpose of the test;
- overview or reference to used test method, ignition source, used materials, specimen design, and other relevant information related to the test execution;
- illustration of designed specimen and distribution of thermocouples, if needed;
- description of the specimens, including a substrate, mounting system, and attachment;
- relevant to the test information about used materials;
- day and time of the test;
- temperature during the test;
- roof pitch;
- test results:
  - time of all events;
  - photos of the specimen and crucial elements before testing;
  - photos during the test;
  - photos of assessed damage on the materials;
  - calculated flame spread to upward and sideward directions;
  - measurements of damaged area on materials;
  - information about malfunctioned thermocouples;
  - observation of smouldering or glowing combustion;
- conclusion section;
- reference section.