Qualification of Fire Risks at PV Systems

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TÜV Rheinland Group Introduction

More than 140 Years of Innovation.

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For your success. With certainty.

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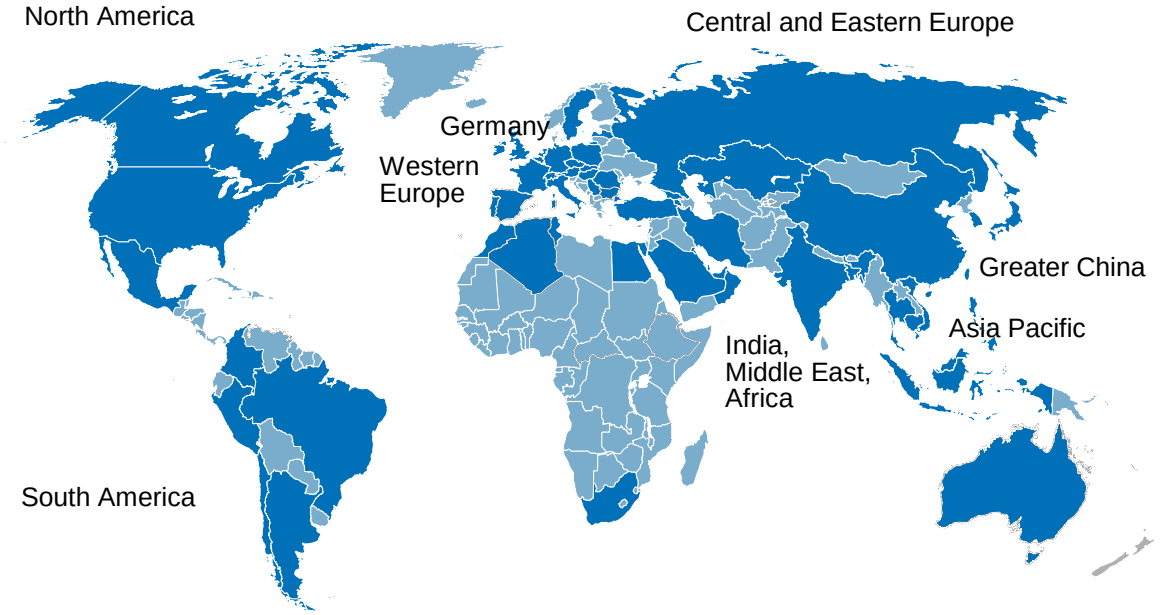
Service Scope: Testing Inspecting Certifying Consulting Public Training

Global Network

GERMAN AT HEART – GLOBAL IN MIND.



Key facts

8	Regions
500	Locations
>200	Laboratories
20,000	people around the globe work for TÜV Rheinland
12,000	of them work outside Germany
2 Bill €	Turnover in 2018

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Global Network for Photovoltaic Products

Testing, Certification and Advisory

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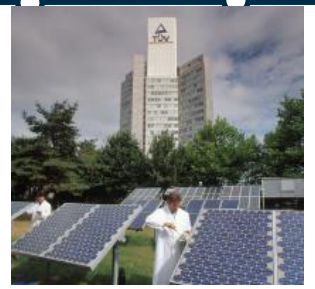
Milestones in the Global Solar Business.

More than 35 years of experience in photovoltaic.

1982 – R&D and PV product lab in Cologne

1990 – Project leader for the monitoring of the 1,000 Roof Program in Germany

1992 – Laboratory for PV module testing in Arizona (former ASU-PTL)



1996 – First type-approval certification of a crystalline PV module

1998 – Active in IEC standardization for PV products and systems

2000 – Renewable energy law implemented in Germany

2006 – New, high-tech R&D and PV product lab in Cologne

2006 – Solar operation initiated in Japan

2007 – Provide testing and certification service in Greater China

2009 – Golden Sun project initiated in China

2012 – Renewable energy law implemented in Japan

2012 – Battery testing lab in Nuremberg

2012 – PV lab established in India

2013 – OSHA accreditation according to UL1703

2014 – Solar operations start in Brazil and UAE

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TÜV Rheinland – Solar Energy Worldwide

Quality, safety and reliability around the world

OUR GLOBAL PV NETWORK

No 1 in PV module and component testing worldwide

35 Years experience in PV product testing

27 Years experience in Power plant inspections

6 PV test laboratories + several outdoor test fields

> 250 PV Experts

> 20 GW Inspected PV projects

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Content

- Introduction
- Solar Basics
- Principle of fire and solar module operation
- Arc situation with in-roof constructions
- Fire test method for PV modules on roofs during external fires
- Summary and outlook

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Photovoltaics - Basics

PV Modules, Cells, Systems

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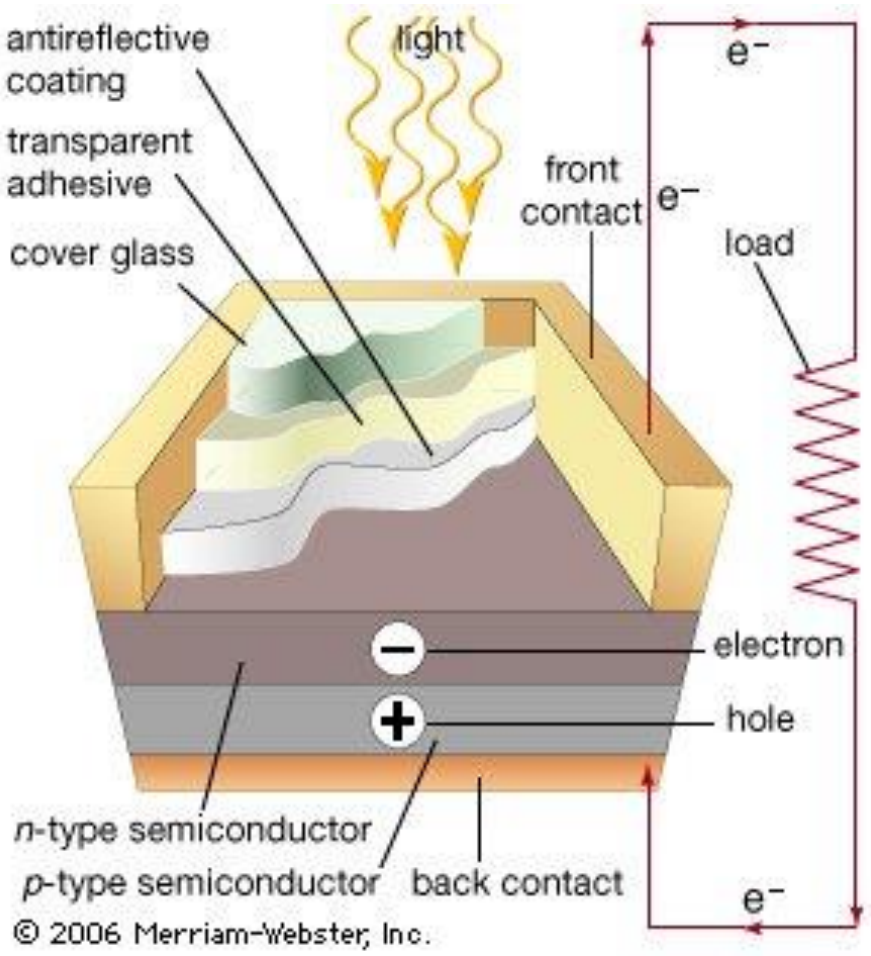
Principle Set-up of Solar Cell

- Sunlight strikes a solar cell, an electron is freed by the photoelectric effect
- The two dissimilar semiconductors possess a natural difference in electric potential (voltage), which causes the electrons to flow through the external circuit, supplying power to the load.
- The flow of electricity results from the characteristics of the semiconductors and is powered entirely by light striking the cell.



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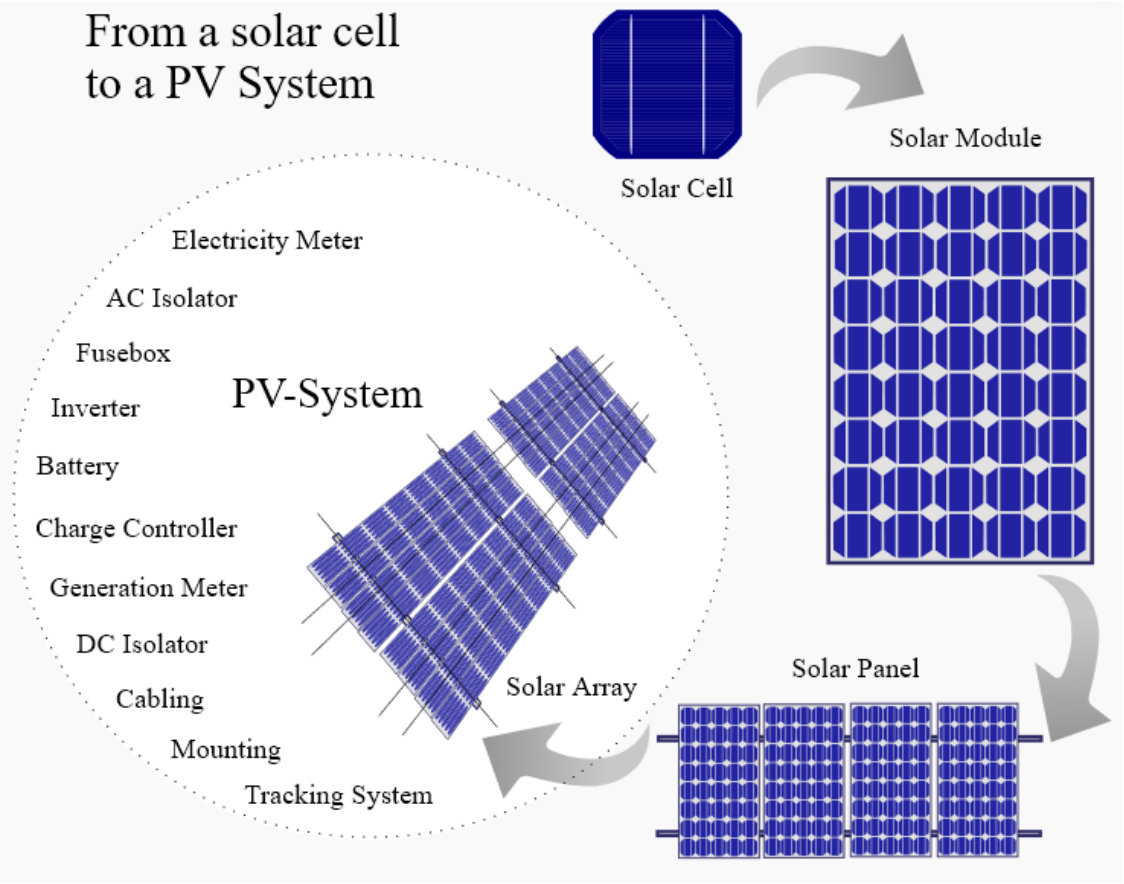
From a Solar Cell to a PV System



Source: Wikipedia

Source: First Solar

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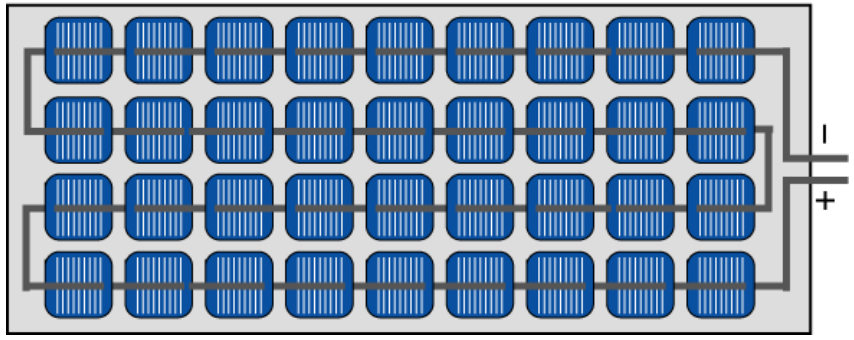
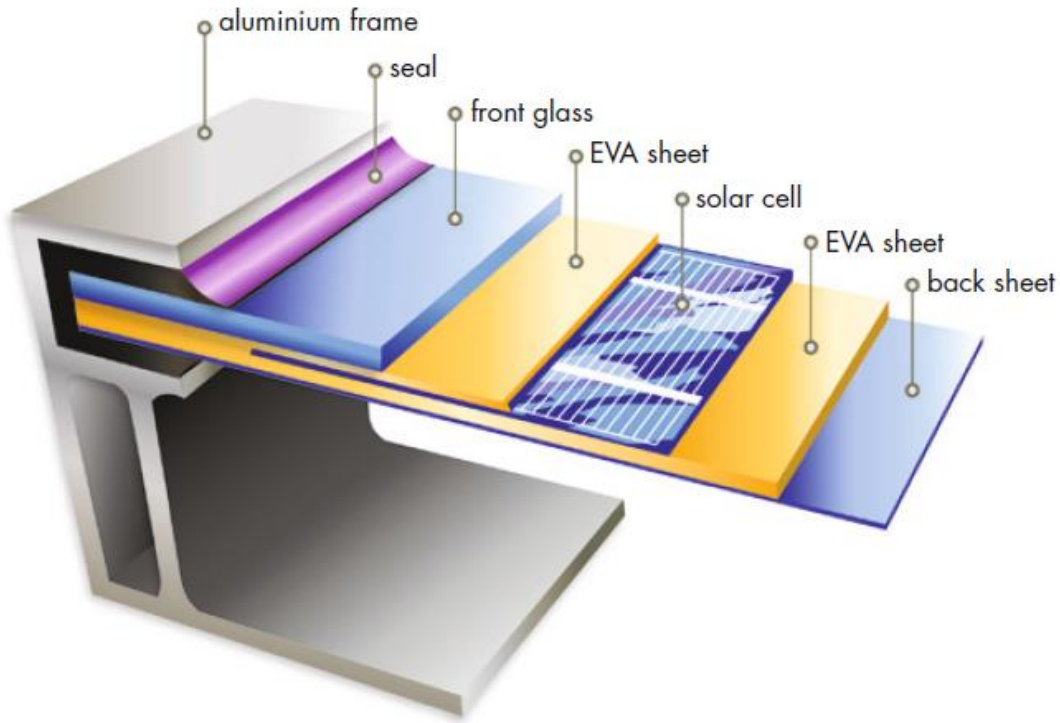
Setup of a PV Module

- Voltage from the PV module is determined by the number of solar cells and the current from the module depends primarily on the size of the solar cells
- Parallel to the strings, bypass diodes are used, in order prevent overheating of cells from partial shading

A typical module has 36 cells connected in series



https://www.pveducation.org



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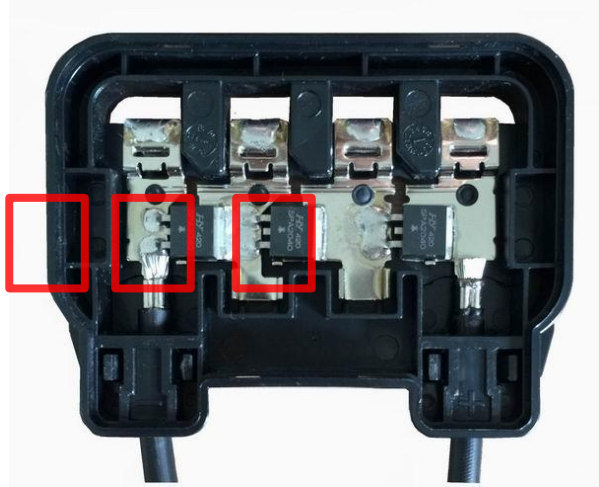
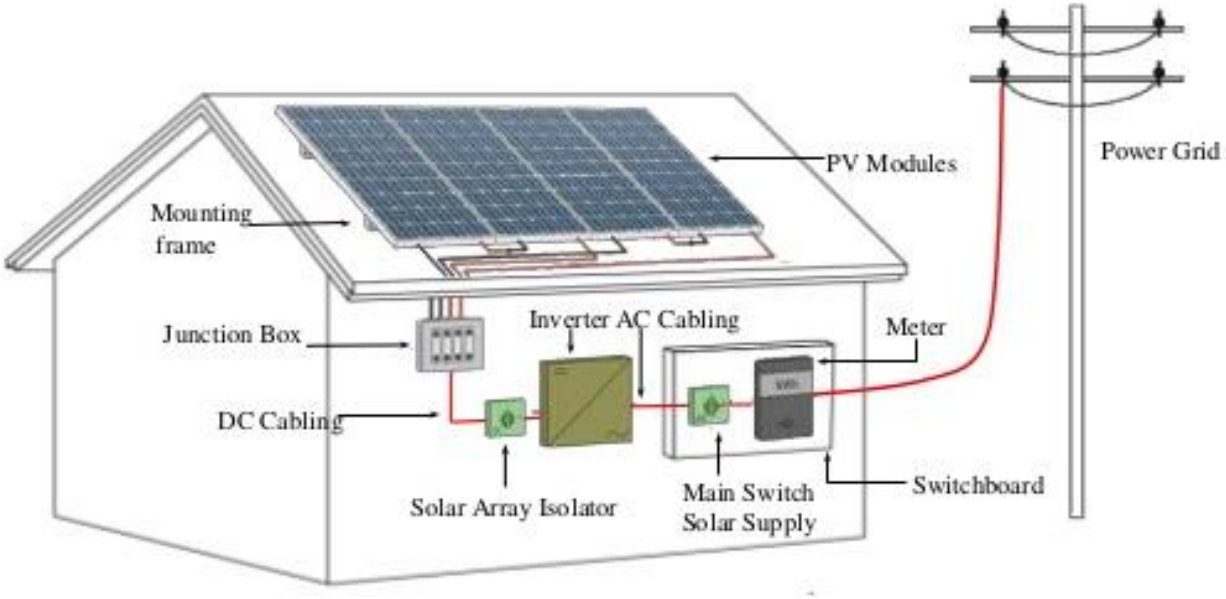
PV module technology
Junction box

- The PV junction box is the **output interface** of the PV module, which is attached to the back side (TPT or glass) with silicone adhesive.
- For c-Si modules it usually includes electrical terminals, to which the 4 leads of the solar cell interconnection circuit, the bypass diodes and the module cables are connected.
- The junction box must provide sufficient protection against dust and low pressure water jets. This property is expressed in the IP (Ingress Protection) rating, which shall be minimum IP65.
- Most junction boxes have bypass diodes. Their function is to protect solar cells from hot-spot heating in the case of shading or cell breakage.



Diodes inside and opened junction box

System Components



Source: www.usaid.gov/

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Fire Incidents on PV

Statistics, Examples of Installation Errors

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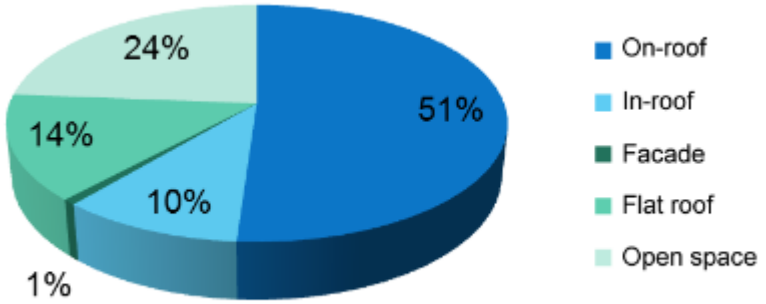
! 50% of the errors could be attributed to installation defects

Fire risk on solar systems
Survey from 2011-2013 in Germany

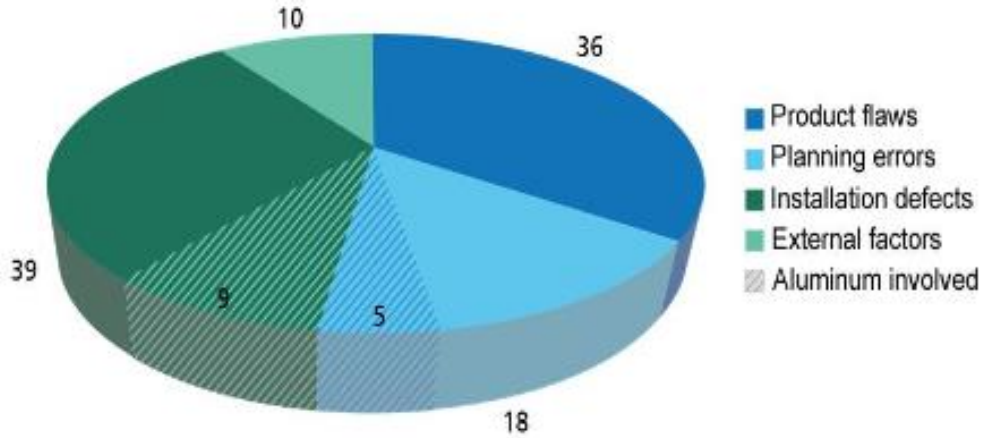
More than 210 known cases where faults in the PV system caused a fire

- approximately 430 cases of fire or overheating in PV systems,
- about 220 cases thereof with external causesof fire
- about 210 cases with the cause of fire lying in the PV system

2013: in Germany 1.3 Million PV Systems



Breakdown of damage according to system type (based on 139 incidents of damage)



Number of causes of damage for more than 100 cases

Source: BMWi _ Project "Determination of fire risks in solar systems" (2011-2014) - http://www.pv-brandsicherheit.de

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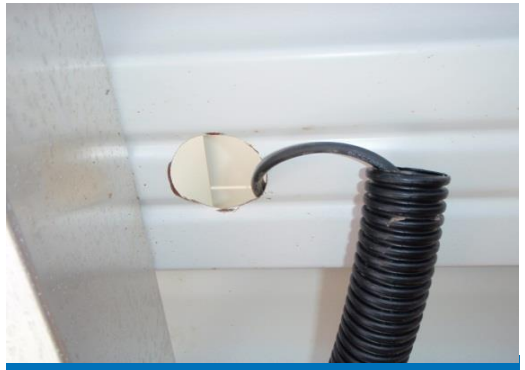
PV System Quality

Examples for PV system failures from fault installations

Improper cable routing



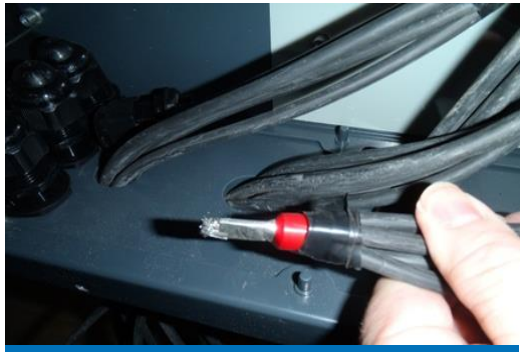
Missing edge protection

Defective cable fastening

Damaged cables

Improper cable routing

Cable corrosion



Improper cable connection

Improper cable connection

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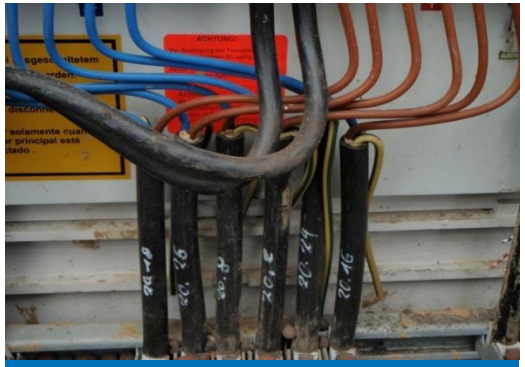
PV System Quality

Examples for PV system failures

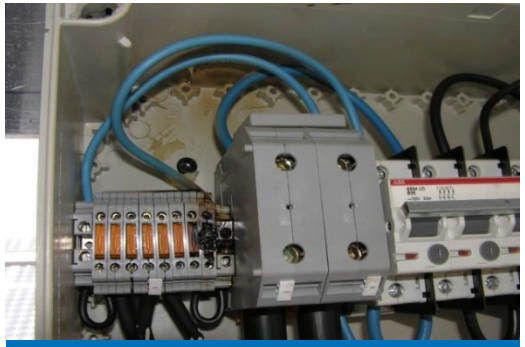
Improper cable routing

Lightning protection neglected

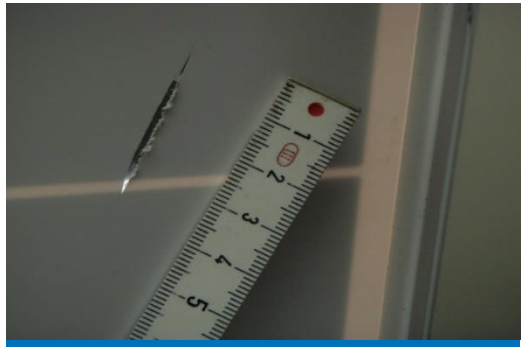
Improper cable fittings



Wrong cable type used



Bad connection / arc



Damaged module back

Water in connection box

Water in connection box

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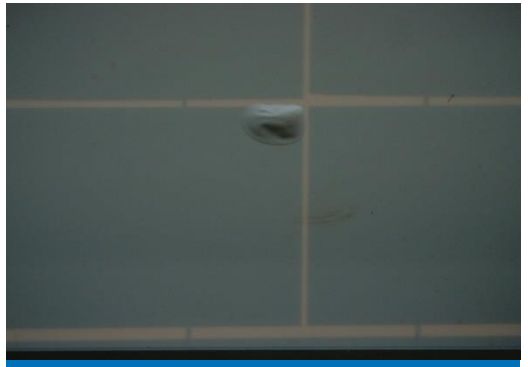
PV System Quality

Examples for PV system failures

Delamination of backsheet



Blistering after hot spot

Improper under construction

Installation specification not fulfiled

Broken Connector

Damaged frame (snow)

Broken Module

Broken Connector

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PV System Quality

Examples for PV system failures

Displaced Module

Melted connector

Corrosion at grounding point

Erosion

Cell breakage with Hot spot

Burned cable/terminal

Burned cable/terminal

Loose Cables

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PV System Quality

Examples for PV system failures

Gunshot marks (grains of shot)

Improper planning

Shading

Shading by vegetation

Shading by vegetation

Bad Foundation

Corroded socket /plug

Bad connection / Arc

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PV Module Product Quality

Examples for PV module failures

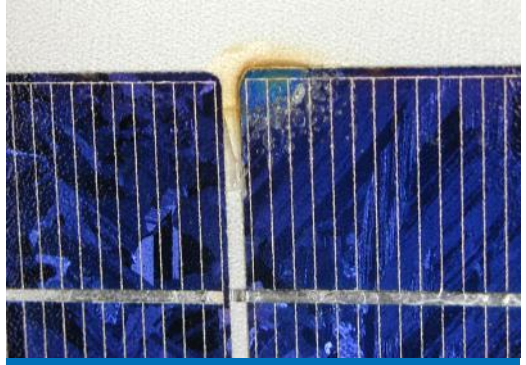
Different Connectors

Solder joint failure

Browning

Backsheet cracks

“Snail trails”



Hot-Spots

Connectors

Backsheet “chalking”

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External Fire or Electric Arcing

Preventive Fire Protection and Risk Reduction

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Preventive fire protection

Installation, choice of materials & operation of the plant

- **§14 of the MBO (Germany): Construction works are to be arranged, erected, modified and maintained in such a way that the occurrence of a fire and the spread of fire and smoke (spread of fire) is prevented and in the event of a fire the rescue of people and animals as well as effective extinguishing work are possible.**
- ***The quantity of all fire prevention measures is composed of many requirements from the installation, material selection and operation of the system in general and with specific requirements*:**
  - Compliance with building and installation regulations, building regulations of the federal state
  - Obtaining advice from specialist authorities on fire protection issues
  - careful planning with qualified personnel
  - high-quality material and components
  - professional execution and acceptance Plant maintenance

Cause and effect of fires in PV systems

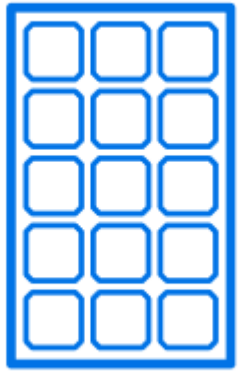
Electrical system as a trigger for fires

1) Triggering of a fire/fire by the PV system due to arcs at defective contact points in the module or system:

- cell connector
- cell connections
- connecting cables
- bypass diode
- plug connector
- Combiner box...

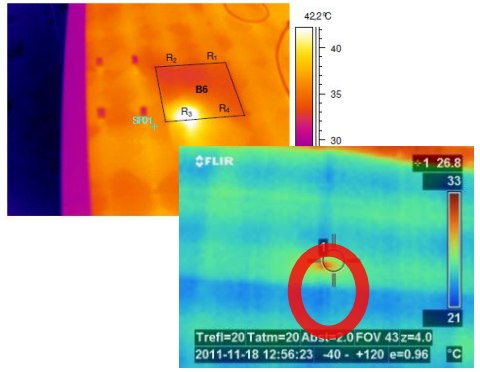
influence of the materials:

- Arc ignition
- Fire propagation during the arc
- Fire propagation after the arc has extinguished



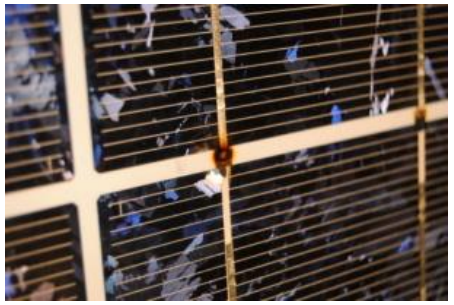
Cause and effect of fires in PV systems

Mutual interference at defective contact points



Increased contact resistance/heating of the contact point

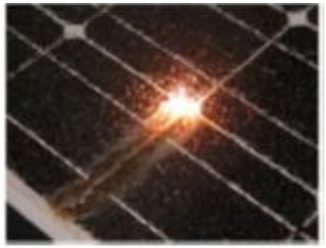
Heating and softening of the surrounding insulating material



Interruption of contact points

Reduction of air and creepage distances

Inflammation of the surrounding materials



smoldering, flashing or electric arcing

Possible flame preservation or stop after arc extinction on surrounding material

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Reduction of Arcing Risk

Flammability of materials

2) External causes cause a fire in or at the building. As a component of the building, the PV system is "affected" by the fire. The development of the fire therefore also depends on the material properties of the PV system.

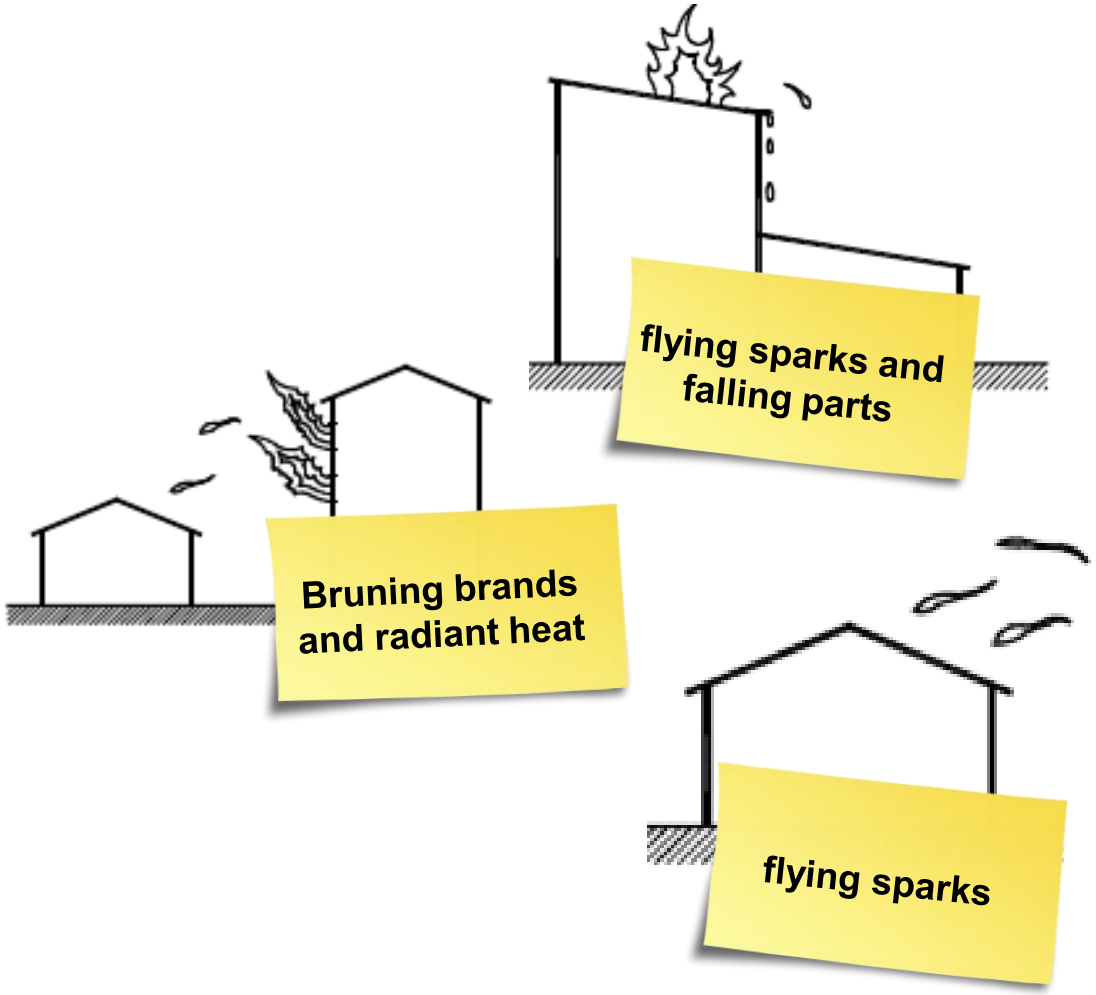
- flying sparks
- Radiant heat
- Burn-through
- flame flashover

Aspects for materials in fire propagation:

- Fire protection layer (prevention of forwarding)
- Burning dripping / falling off
- Glow/afterglow
- Smoldering
- Release of pyrolysis gases

Influencing Fires on Roofs

External Fires and Arcs



Quelle: BMU-Projekt von TÜV Rheinland und Fraunhofer ISE: "Bewertung des Brandrisikos in Photovoltaik-Anlagen und Erstellung von Sicherheitskonzepten zur Risikominimierung", Förderkennzeichen 0329639. Weitere Informationen unter: http://www.pv-brandsicherheit.de

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Electric Arcing

Preventive Fire Protection and Risk Reduction

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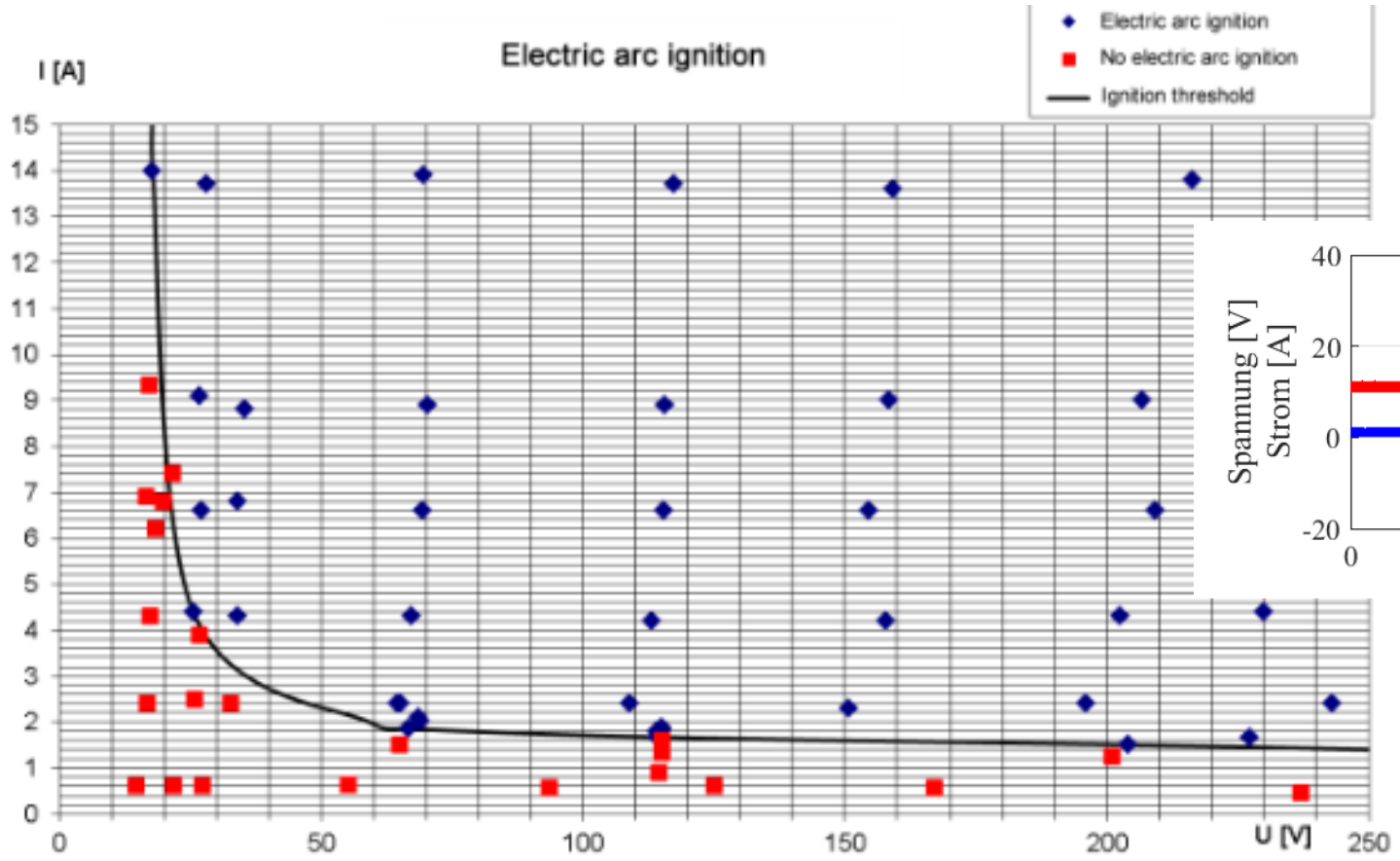
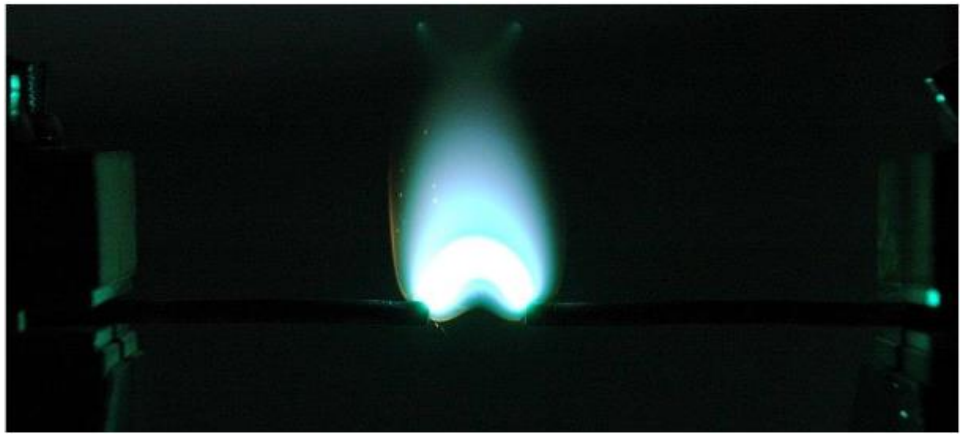
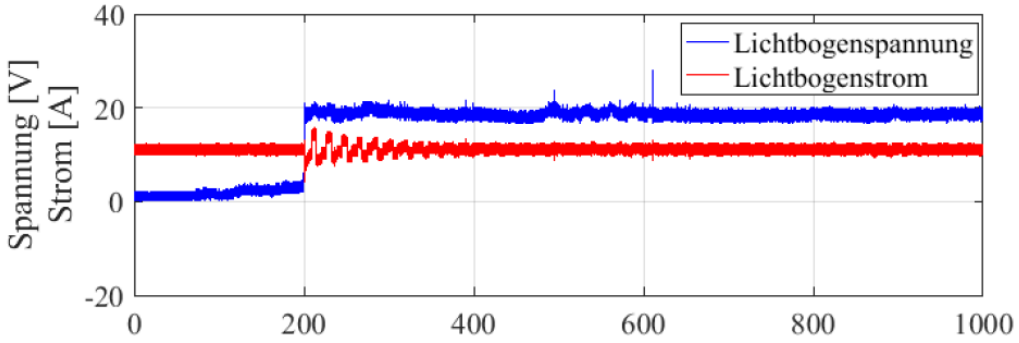
Electric Arc Ignition







Current standard development on IEC level for arc detectors: IEC 63027

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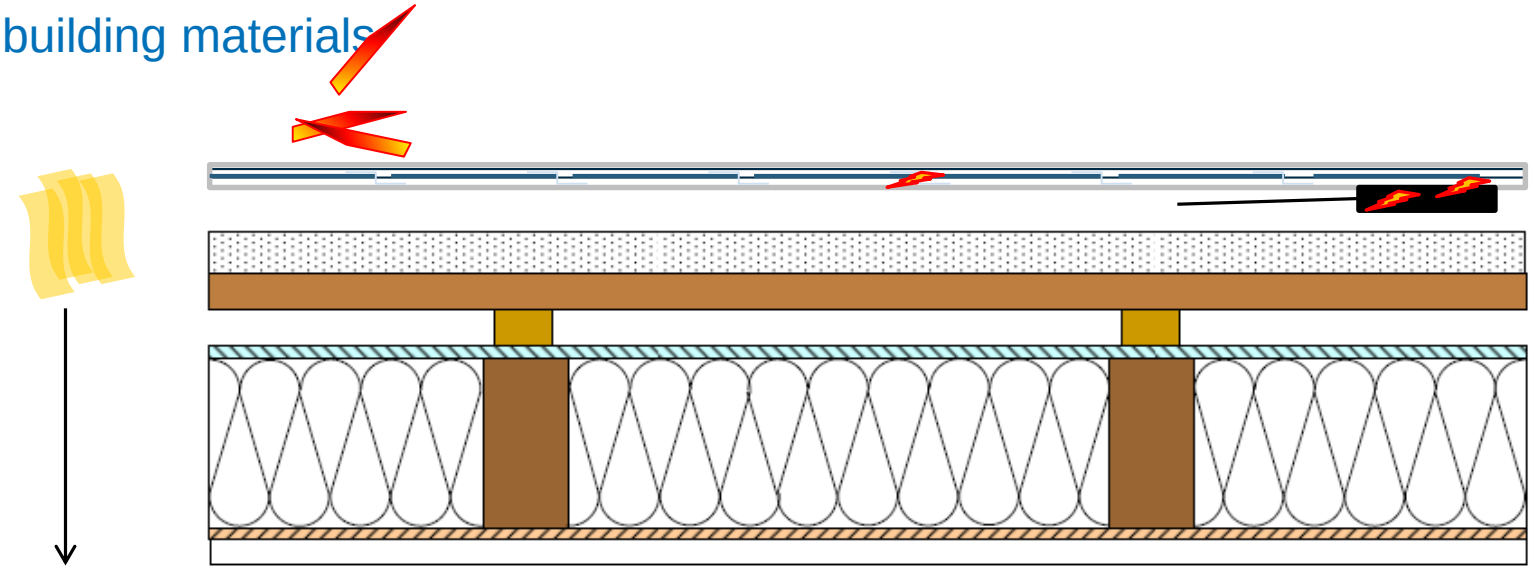
Fire Safety at BIPV

Influence on building materials



- Risk of ignition of materials by arcing: high temperatures
- Fire propagation risk due to ignited materials of the PV system (flame propagation, fire drip properties)

Arc at critical points with defective contacts or cables (schematic)

Flying sparks/ burning brands

Radiant Heat

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Building Integrated Photovoltaics (BIPV)

Roof structures and fire requirements

Classification acc. to DIN EN 13501-1	Designation by Building Authorities
A1	Non-combustible (excluding shares in combustible building materials)
A2 s1 d0	Non-combustible (with proportions of combustible building materials)
A2 s3 d2 B s3 d2 C s3 d2	Low flame spread
D s3 d2 E d2	Normal inflammability
F	Easily flammable

s1, s2, s3 - Additional classification regarding smoke development
d0, d1, d2 - Additional classification regarding burning dripping / falling off

Building Integrated Photovoltaics (BIPV)

Roof structures and fire requirements

insulating materials

Material	building material classes flammability
Glass wool, rock wool	A1, A2
Flax, hemp, coconut fibres	B1, B2
Wood fibres, wood wool	B1, B2
cellulose	B2, E (with boric salt)
sheep's wool	B2 (with boric salt)
Polyurethan	B1, B2
Polystyrol	B1, B2

vapour barrier

Material	building material classes flammability
Polyethylene foil	E
Polypropylene foil	E
Polyester fleece	E
vapour control board	B2

Sarking membranes

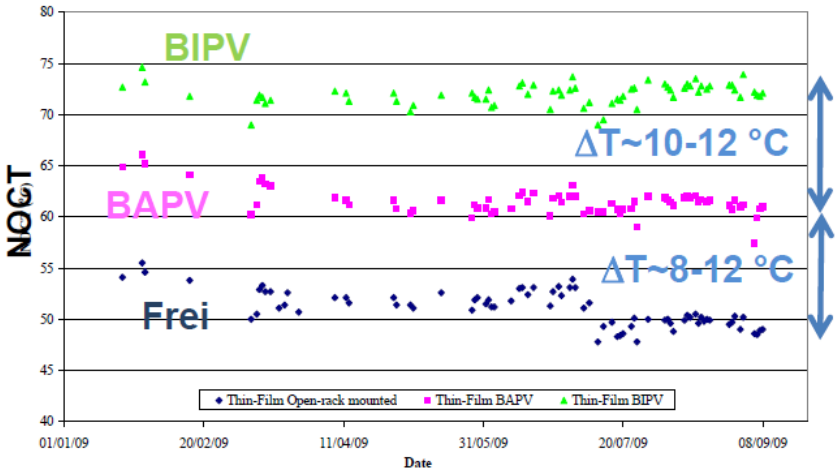
Material	building material classes flammability
Polyelofine	E
Polyestere fleece	B1, E
Polypropylene-spunbonded fabric	E

Fire Safety at BIPV

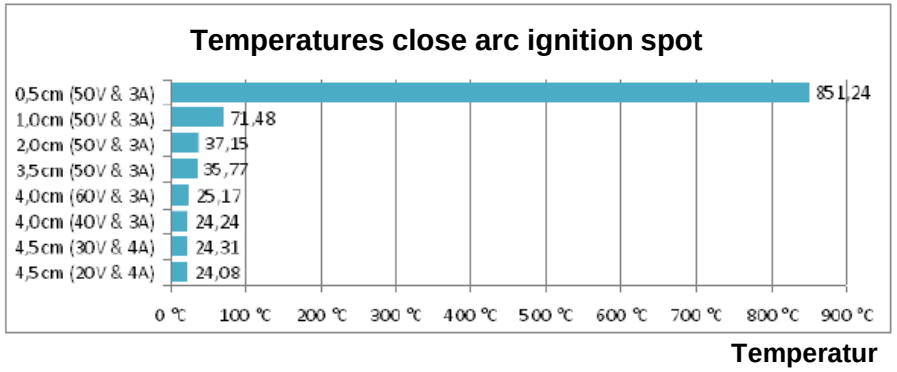
Influence on building materials

- Measurements on isolated and ventilated systems in comparison have shown temperature differences of ΔT=8...20K.

- Rear ventilation lower compared to roof-parallel systems: consideration of the interaction with temperature rise in junction box



T. Sample, A. Virtuani: 24th EUPVSEC, Hamburg, 2010



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Burning Behavior of Backsheets

Normative State of the Art

- FSI 100 through ASTM E 162 is used as pre-evaluation method for backsheets
- Determination of flame spread and propagation, evaluation of burning velocity and exhaust gas temperatures
- Standard characterizes only the single product

- RnD test series:
  - Comparison of different international standards
  - More detailed characterization of backsheets (also from both sides)
  - Derivation of end-product oriented test method

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Burning Behavior of Backsheets

Set-up of test series

- Use of different foils: ETFE, TPT, PPE etc.
- Comparison with building components (sarking membrane (PA)), class B2→ European E (EN 13501-1)
- Backing materials (clamped) with CaSi-plate at ASTM E 162 and ISO 11925-2
- Comparison to European construction product classification with ISO 11925-2 on module level
- Also, testing of inner side of the backsheet foils (resulting from experiences of UL 790 tests)

Prüfung	Maße	Dicke	Material
UL 94	200*50	0,43	APA
ISO 11925-2	250*90	0,43	APA
ISO 5658-2	800*155	0,43	APA
95/28 EG	560*170	0,43	APA
ASTM E 162	457*152	0,1	ETFE-frontsheet-F1
ISO 11925-2	250*90	0,1	ETFE-frontsheet-F1
ISO 5658-2	800*155	0,1	ETFE-frontsheet-F1
95/28 EG	560*170	0,1	ETFE-frontsheet-F1
ASTM E 162	457*152	0,28	TPT
ISO 11925-2	250*90	0,28	TPT
ISO 5658-2	800*155	0,28	TPT
95/28 EG	560*170	0,28	TPT
ASTM E 162	457*152	0,35	PPE
ISO 11925-2	250*90	0,35	PPE
ISO 5658-2	800*155	0,35	PPE
95/28 EG	560*170	0,35	PPE
ASTM E 162	457*152	0,06	PA (Dampfsperre)
ISO 11925-2	250*90	0,06	PA (Dampfsperre)
ISO 5658-2	800*155	0,06	PA (Dampfsperre)
95/28 EG	560*170	0,06	PA (Dampfsperre)
UL 94	200*50	0,06	PA (Dampfsperre)

ASTM E 162, ISO 11925-2, ISO 5658-2, UL 94

Burning Behavior of Backsheets

Results, Derivation of Measures

- Quality and burning behavior can be determined well through all methods: quality of each foil type can be seen with same results in all methods.
- Foil types always react equally good or bad throughout the tests.
- Strong deviations: with and without backing materials of CaSi
- Best results: Single foils (frontsheet of ETFE)
- Thin foils: material abstracts from the flame . Critical in end-product: encapsulant is exposed quicker.
- All tests are suitable for pre-selection, but not for end-product-based conclusions.

Test method on ISO 11925-2 was integrated in latest IEC 61730-2 standard (safety standard) for PV modules

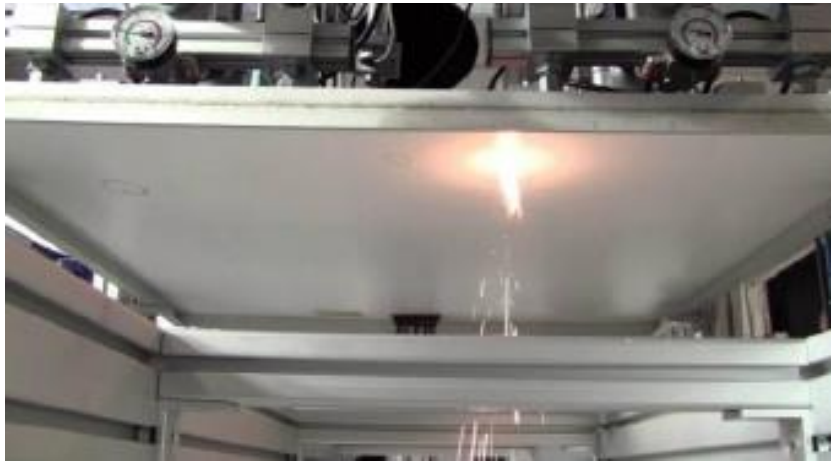
Risk Determination of Cell Connectors and Cells

Derivation of Stress Tests for Modules

- Test series with 30 modules:
  - Damaged modules from the field (failures at cell connectors, hot-spots were generated), technique: 2 bus bars.
  - Faultless modules, 2&3 bus bars.
- Determination and application of appropriate stress test method for reproduction of field failures. Intentionally induced stress on cell connectors under the influence of electrical, thermal and mechanical loads.

- Bypass-diodes were not dismounted

→ Risk minimization on product level.



Initial Measurement

Pre-conditioning: TC 400

Intermediate Measurement

Dynamic loads with forward bias

Final Measurement

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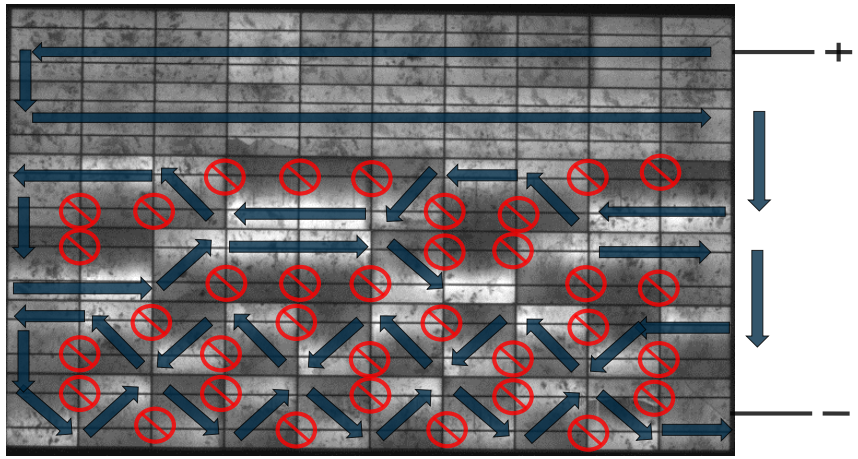
Risk Determination of Cell Connectors and Cells Example:

worst-case-scenario (double failure)

- Example: Intentionally induced contact failures, meanderwise cutting of cell connectors. Directed current flow through the cells.
- Result after forward bias and dynamic loads: fire damage along the microcrack.



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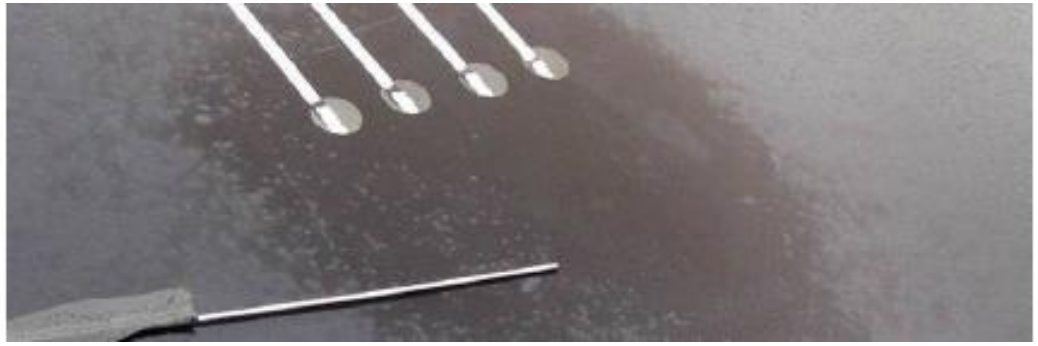
Fire Safety at Roof-Integrated BIPV

Test series – Provoked Ignition of Electric Arcs

- Miniature of regular rafter roof, wood as construction material
- Damp barrier and sarking membrane with classification of E acc. To EN 13501-1
- Insulation materials have classification ‚A‘ acc. To EN 13501-1 (‚hardly flammable‘)
- Provoked ignition of electric arcs at several contact spots, such as j-box and bus-bars
  - Burning dripping of housing materials
  - Undercarriage was ignited and burned.
  - Flame spread quickly via the underlayment
  - Flame propagation due to induced arcing stronger than in standard tests
  - Thermal insulation has not been ignited
  - Electric arcs have generated high pressure inside the AS box, "bursting" the lid
  - Largest risk with cable connections



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Enhanced Fire Safety at BIPV

Derivation of Construction and Installation Measures

Proposals have to been seen always as additional measures next to standardized requirements for products (modules, components etc.)

Fehlerfall	Auswirkung	Betrachtung von Ge[illegible] baulich, konstruktiv)
Arc at cable or plug	ignition of the roof foil	- Professional installation - Additional protection tubes - Suitable choice of roofing materials/constructions - ….
Hotspot on cell connectors or cells with arc ignition	Possible ignition of rafters	- Use of protective tubs and mats - Use of protective varnishes - …
Arc at cable clamp with open cover and burning dripping material	Ignition of the roof foil, fire	- Constructive: Consideration of the behaviour of j-box when igniting an arc, prevention of oxygen supply to an arc - Improvement of the inflammation properties of the plastic parts, strain relief - …
Defective or detached bypass diode (possibly with arc ignition)	Heating of the affected cell string possible in case of shading	- Ensuring sufficient heat dissipation (distance control, rear ventilation) - Reduction of fire hazard due to diodes (electronics, “smart j-box”?) - …
Arc at cable clamp with open cover and hot dripping material.	defective module, holes in the roof foil, leakage	- Suitable choice of substructure materials (consider building material classes: consult roofer.), use of protective varnishes for wood to question... …
…		

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Fire test acc. to ANSI/UL 1703 with UL 790 (also formerly IEC 61730-2)

- Spread of Flame (gas flame) and Burning Brand
- Test method of UL 790 Standard – Fire test for roofs.
- Three classes to be tested:
  - **Class A/B:**

    Burner class 369 kW - 387 kW

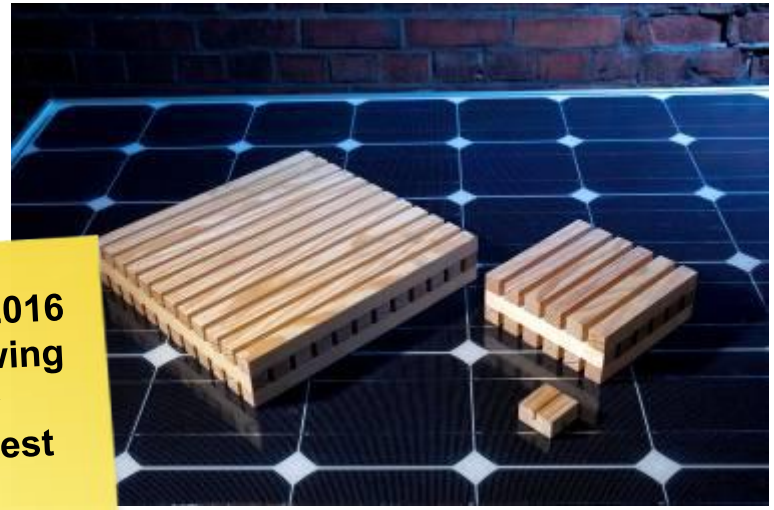
    Flame duration 10 min

    Brand A: 2000 g, B: 500 g
  - **Class C:**

    Burner class 316 kW - 334 kW

    Flame duration 4 min

    Brand C: 10 g



Latest edition in IEC 61730-2:2016 Fire test mandatory, but following UL 790 non-compulsory → reference to locally existing test codes, also EN/TS 1187…

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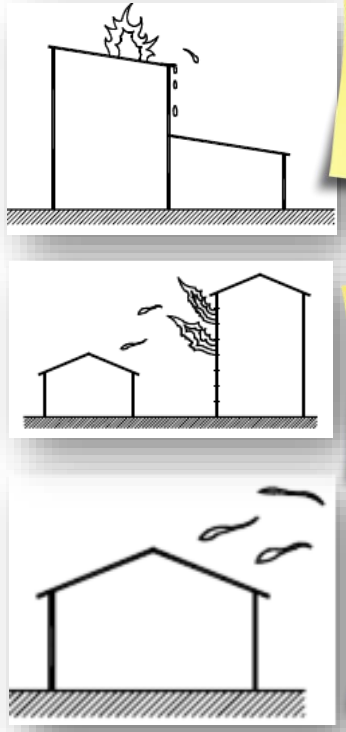
Fire Testing for Roofs / Roof Applications in Europe

Test methods for ENV 1187 with classification of EN 13501-5

- The test sequences differentiate: source of ignition, inclination and general application (test duration, radiant sources, wind velocities)

Sources of ignition from CEN/TS 1187-1…-4



Flying Sparks and burning droplets

Flying Sparks and radiant heat

Flying Sparks

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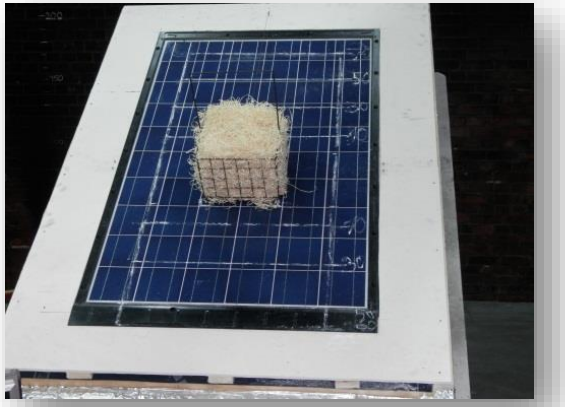
Common Technical Challenges for BIPV

Influences of temperatures

- Various measurements on the backsides of the modules lead to the following temperatures from CEN/TS 1187-1:
  - Glass/Backsheet: 200 °C
  - ETFE/Backsheet: **125 °C**
  - Glass/Glass: **500 °C**
  - Glass/Backsheet: 160 °C
  - Glass/Backsheet (laminate): 160 °C

Further test methods in Europa with CEN/TS 1187-2, -3 and -4: No harmonization yet!

Fire exposure tests here are all done from the top surface.



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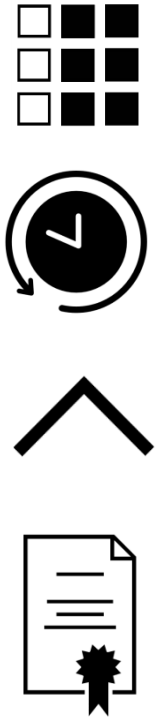
Main Challenges for European Standard/TR for PV Modules

Main challenges:

- Positioning of sub construction and source of ignition
- Time duration
- Slope (acc. to slopes from EN 13501-5 with the used materials of the sub construction)
- Classification criteria for roof (EN 13501-5) → Harmonization to existing standards?



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Standard Situation on PV Modules

with regards to fire from external sources

- IEC 61730-: Fire resistance requirements for a PV module intended for building applications are defined in local or national building codes
→ Annex B of standard enables various test set-ups and standards

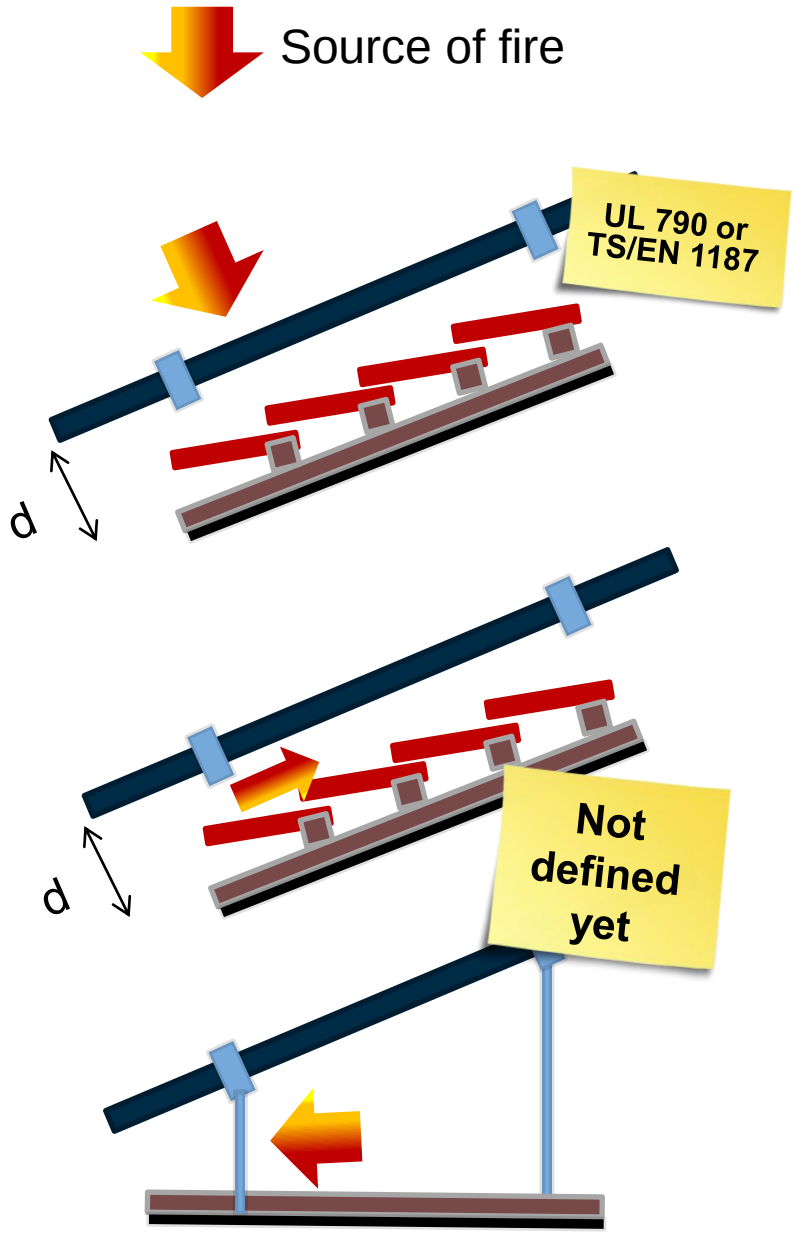
- EN 61730-2 states ‘fire test under discussion’

- Standard situation on roof tests in Europe harmonized, but still range of different test methods (CEN/TS 1187-1…-4)

- BIPV is replacement of roof → CEN/TS 1187

- Roof-added and mutual reaction of PV modules to roof with source of ignition: undefined

- ABCSolar project in the US has experimented with set-ups also placing the source of ignition between modules and roof (roof-added)



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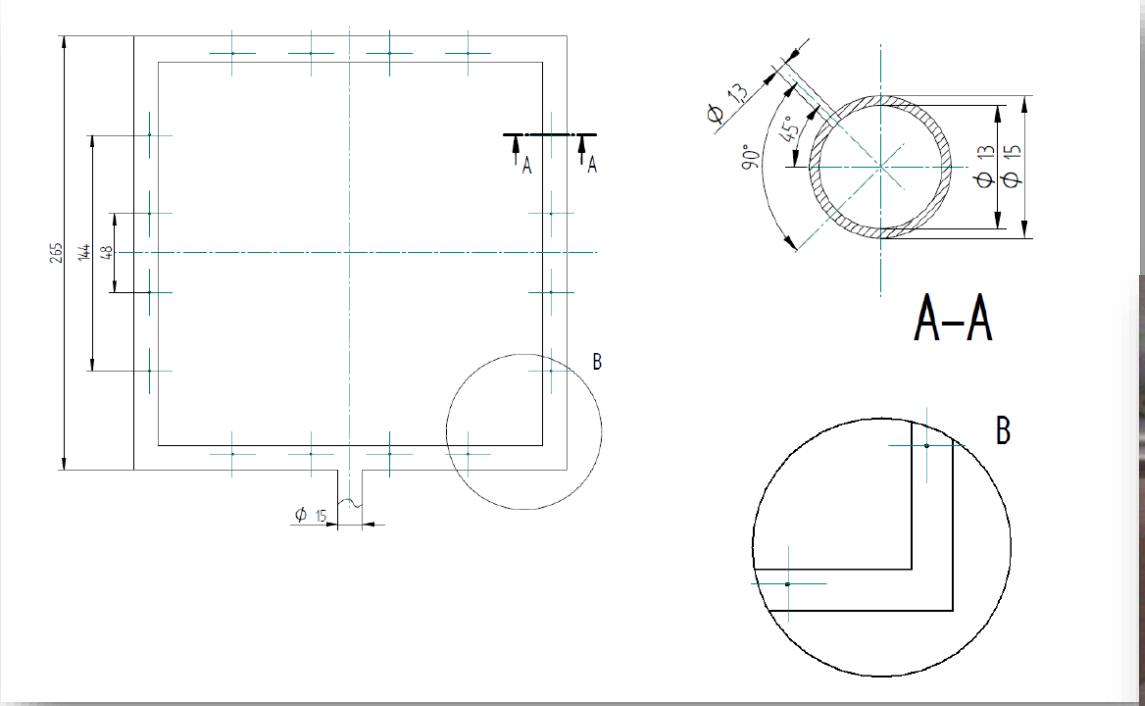
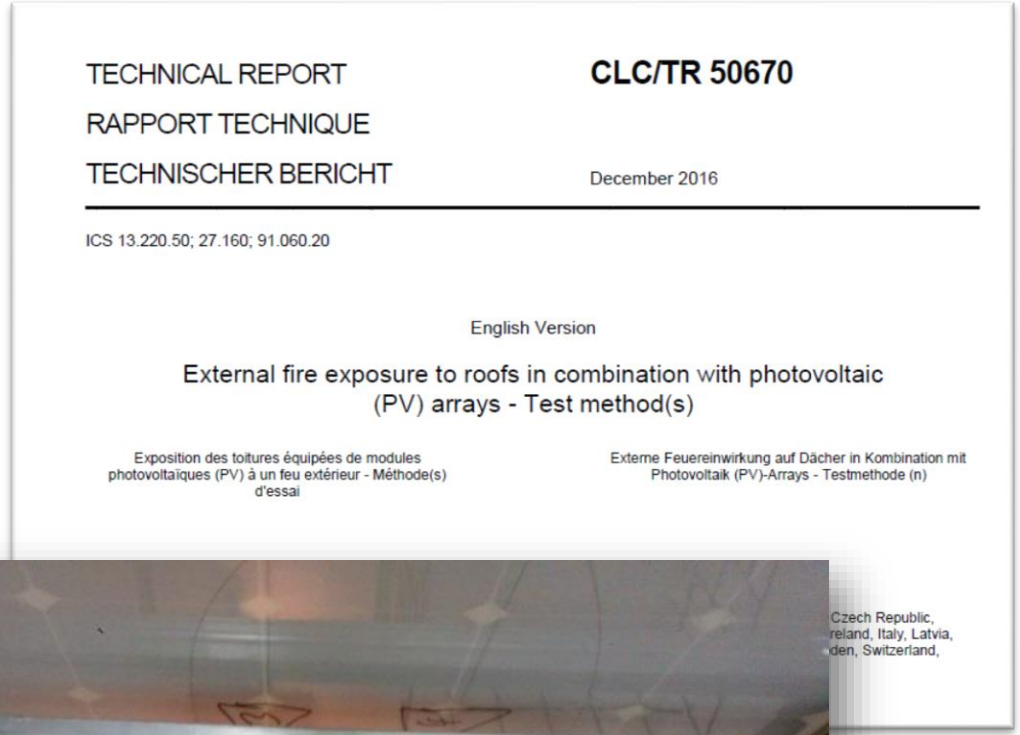
CLC/TR 50670

Set-up of Gas Burner





TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CLC/TR 50670

December 2016

ICS 13.220.50; 27.160; 91.060.20

English Version

External fire exposure to roofs in combination with photovoltaic (PV) arrays - Test method(s)

Exposition des toitures équipées de modules photovoltaïques (PV) à un feu extérieur - Méthode(s) d'essai

Externe Feuereinwirkung auf Dächer in Kombination mit Photovoltaik (PV)-Arrays - Testmethode (n)

Czech Republic,
reland, Italy, Latvia,
den, Switzerland,

Gas Burner of CLC/TR 50670 in comparison to EN 1187-1 wired basket

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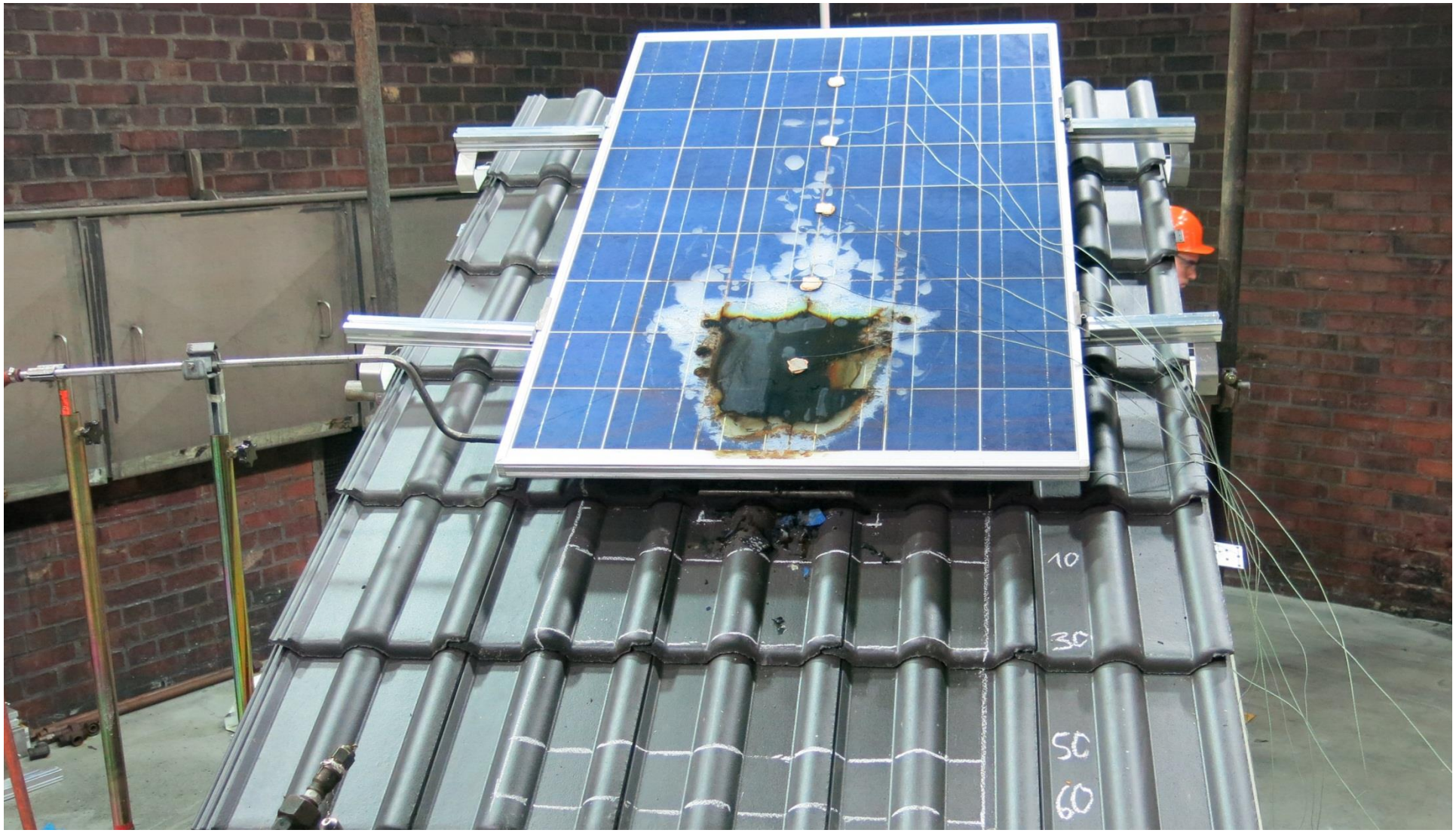
Results from Testing of Roof-Parallel PV Installation



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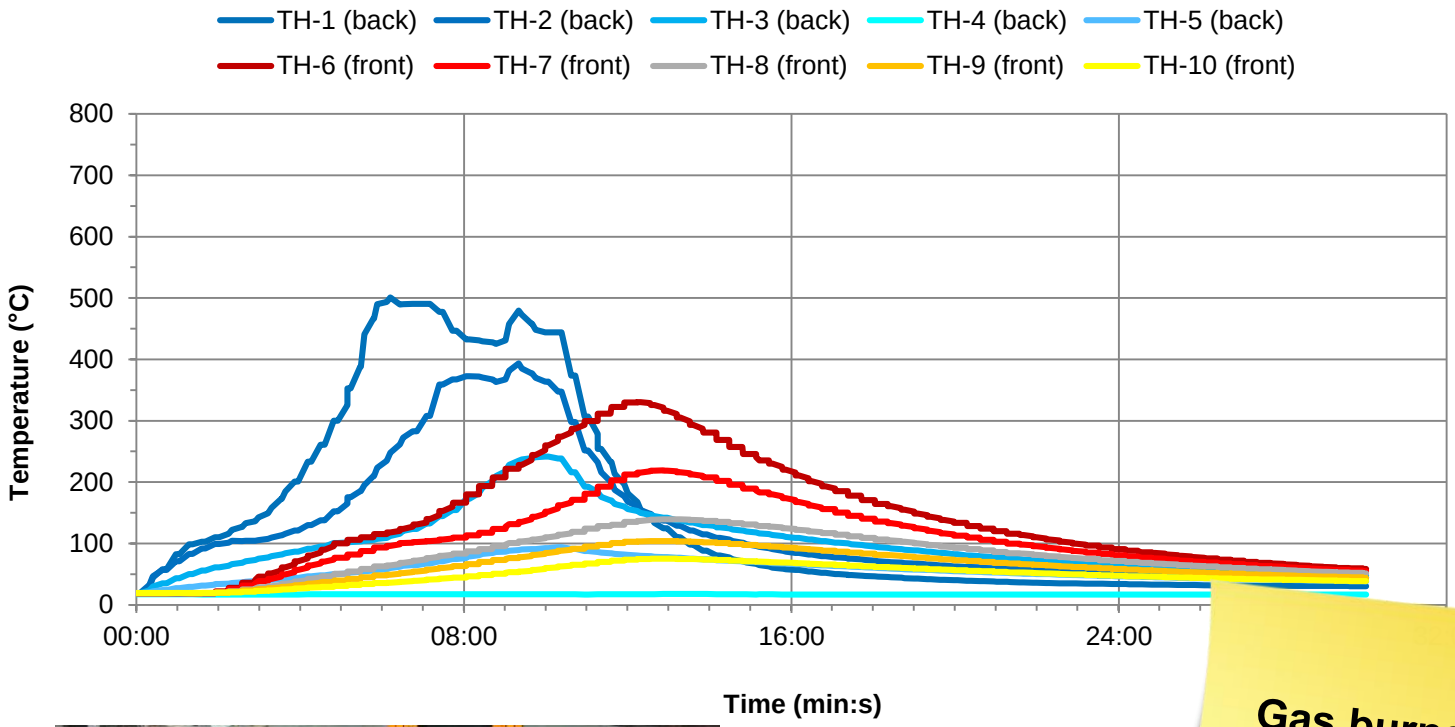
Results from Testing of Roof-Parallel PV Installation

- No roof inflammations or critical fire transmissions at the module
- Classification of the roof remained unchanged
- Damaged area was approx. 20cm



Gas burner

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Results from Testing of Roof-Added PV Installation (PVC+Stone Wool) / Flat-Roof

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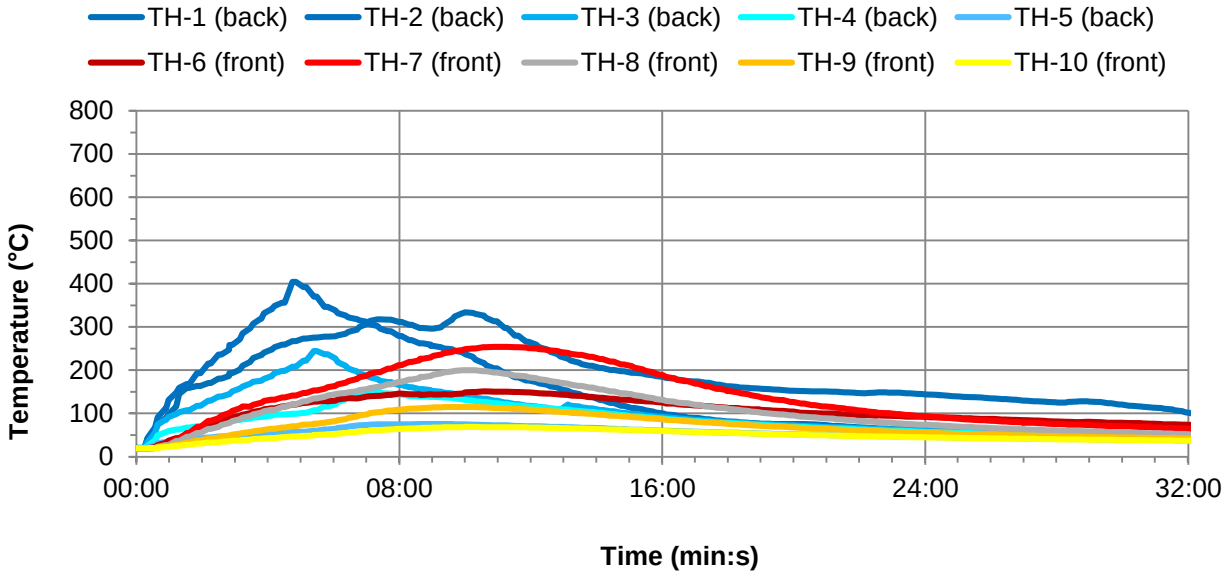
Results from Testing of Roof-Added PV Installation (PVC+Stone Wool) / Flat-Roof

- For wood wool baskets, the roof structure remained BROOF (t1), for gas burners FROOF (t1)
- For gas burners: lateral flame propagation reached the edge of the measuring zone
- Both attempts: No burn-through, no significant spread of fire



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Results from Testing of Roof-Added PV Installation (2 layers Bitumen+PIR)

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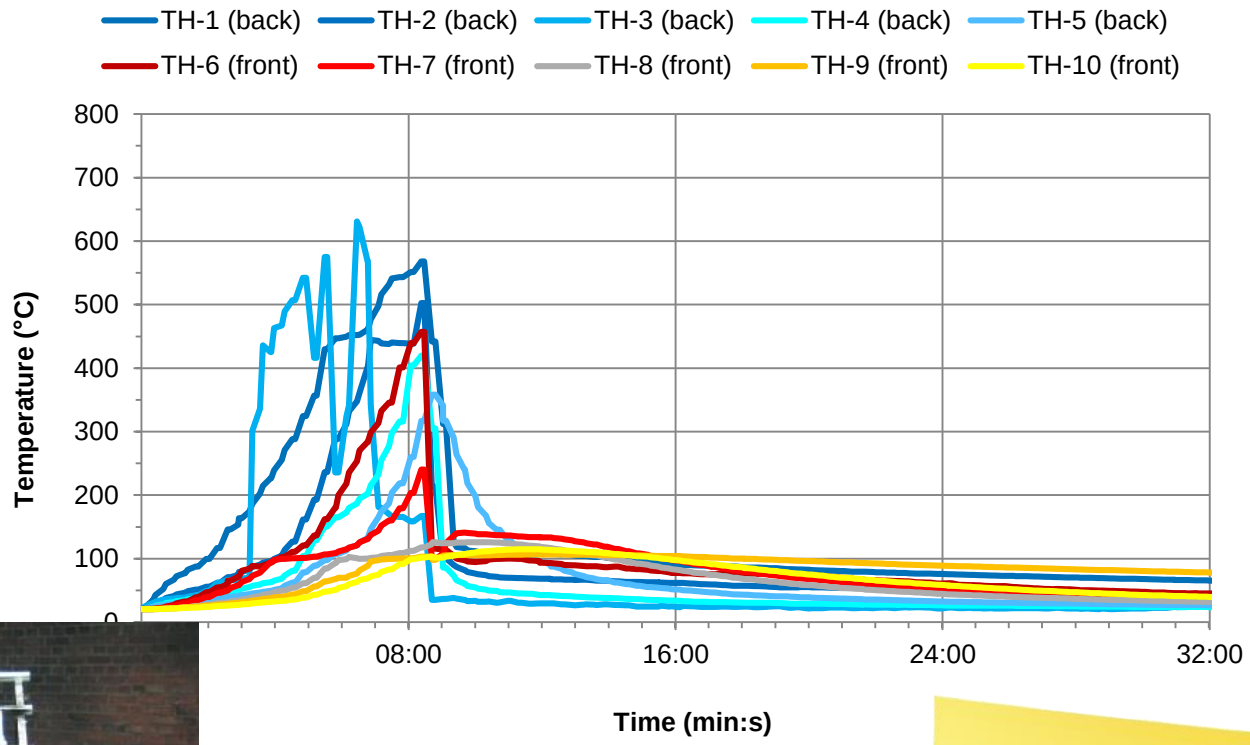
Results from Testing of Roof-Added PV Installation (2 layers Bitumen+PIR)

- Exceeding the measuring marks (upwards and downwards)
- For gas burners and wood wool baskets it led to a class FROOF (t1).
- Impairment of PIR was low



Gas burner, module type B

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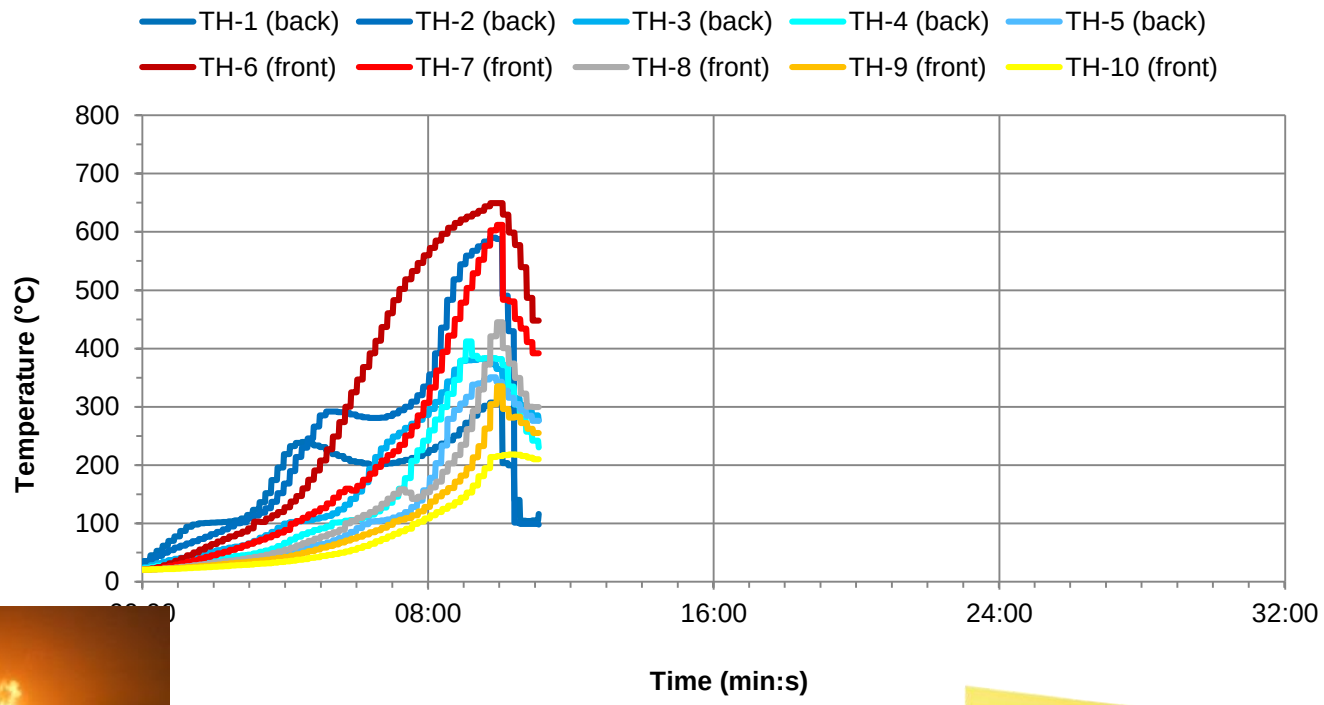
Teilergebnisse Aufgeständert (Bitumen+PIR, zweilagig)

- Exceeding the measuring marks (upwards and downwards)
- For gas burners and wood wool baskets it led to a class FROOF (t1).
- Early cancellation/ termination, ignition after 10min



Gas burner, module type A

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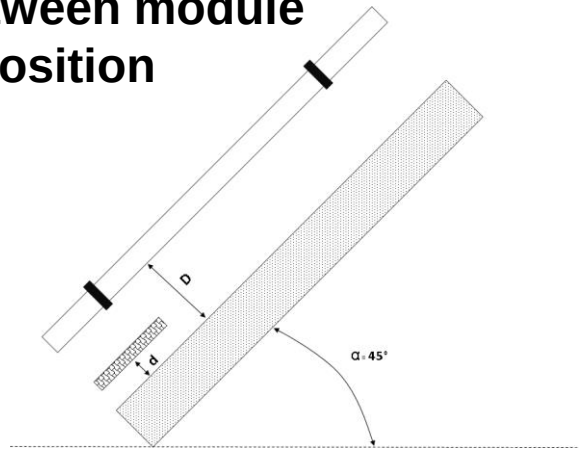
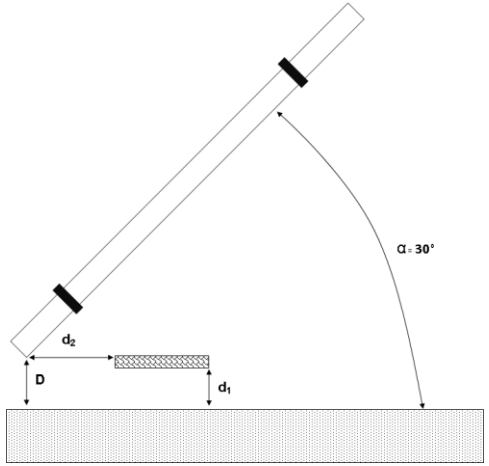
Orientation of Burner Placement in CLC/TR 50670

Placement of the burner between module and roof position



Placement of the burner between module and roof position (flat roof)



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Conclusions

- Work presents single test series out of German research project: ‚Determination of Arcing Risks at PV Systems and Minimization Measures‘ and ‘Development of Fire Test Procedure for BIPV and BAPV Systems’
- Evaluation of ignitability of different materials/components and derivation of **additional requirements**
- Transfer of results to potential adaptions of (inter-)national standards (e.g., test inclination, focal spots for ignition, stress procedures etc.) for further **risk minimization** and **fire safety enhancements**
- Observation of mutual properties to building materials in case of fire and electric arc
- Presentation of European TR 50670 for PV Modules for Risk Evaluation of different roofing constructions with PV

- **The most important key: AWARENESS!**

ENGLISH VERSION of INDUSTRY GUIDELINE: CLICK!

Credits

Icons used:
- https://thenounproject.com/search/?q=fire%20prevention&i=325463
- https://thenounproject.com/search/?q=solar%20module&i=1660689
- https://thenounproject.com/search/?q=house%20fire&i=7386

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Thanks for your Attention

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