Fire Safety Guideline for Building Applied Photovoltaic Systems on Flat Roofs

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ZAG FRISSBE

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Photo on the cover: ASKO warehouse fire in Vestby, Norway in 2017, copyright Tor Aage Hansen/ROCKWOOL Group

Summary

Installing a PV system on the roof of a building introduces new fire risks to the building or damages to the system. First, the PV installations have been shown to increase the chances for ignition through the failure of any of the electrical components of the system. Second, the PV installation can increase the consequences by enabling a fire on the roof to spread faster and over a larger area. Thus, PV systems increase both the probability and the consequence of a roof fire. In addition, a PV system on a roof will cause a change in firefighting tactics because they create a substantial physical hindrance and because precautions have to be made when fighting a fire in the proximity of a permanent current carrying installation.

In order to successfully mitigate the consequences of PV-related fires and reduce the probability of them, effective safety measures need to be put in place. If the proposed safety measures are to adequately serve their purpose, their effectiveness should be confirmed via reference to sound data from reliable scientifical experiments or statistics. Until we have sufficient knowledge about the mechanics of fire risks and how to mitigate them, a precautious approach in the design should be applied.

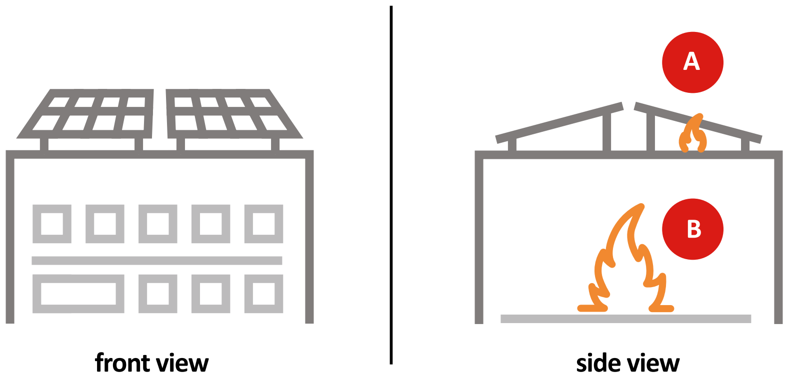
In terms of PV installations on flat roofs, the risk can be mitigated through reduced ignition probability and reduction of consequences. Good installation practice and maintenance are both necessary for achieving a risk reduction. The quality and layout of the roof construction are cornerstones with respect to fire consequence reduction and for firefighter safety. With respect to limiting the consequences of a fire, it has been shown in experiments that the roof membrane and the type of PV panel plays a minor role compared to the type of insulation material. Thus, for both renovation and newbuilds, the main recommendation is to use non-combustible insulation materials to stop the fire from spreading over a large area and avoid the insulation material contributing to the fire. If other solutions are considered, these solutions should show a similar robustness in experiments where the entire system (roof segment and PV modules) is tested as it will be built, and at a scale that involves several modules.

Scope

In the current guideline, the focus will be on buildings with flat roofs that have photovoltaic (PV) systems on them, i.e., building applied photovoltaic (BAPV) systems. Building integrated photovoltaic (BIPV) systems are not considered in this guideline, but several aspects apply to such systems as well, particularly if installed on roofs. BIPV systems that are installed vertically should also consider fire safety aspects related to facades.

The types of fires related to PV systems on roofs can be placed in two main categories (illustrated in the figure below), namely:

A: Fires with origin on the roof of the building
B: Fires with origin inside the building



As fires starting from the inside should already be addressed in national building codes and/or fire regulation, they are given less focus here, but are mentioned in association with a later discussion on array configuration. If the case of a fire with origin inside the building is to be considered for risk reduction purposes, insurance companies are often setting the premises. For example, in the UK, it could be foreseen that testing according to LPS-1181-1 for approval by the Loss Prevention Certification Board (LPCB) would be required. Passing this type of test will typically require a non-combustible roof construction.

Finally, as the specifics of ignition are described in detail in several other guidelines and reports, the focus here will be more on the three other aspects, namely fire dynamics, roof construction and firefighting.

1. Introduction

As part of the REPowerEU plan, the EU Commission has defined an ambitious strategy for making installation of rooftop solar energy compulsory for all buildings. This is now being implemented via the Energy Performance of Buildings Directive (EPBD) requiring solar energy installations on most buildings in the future.

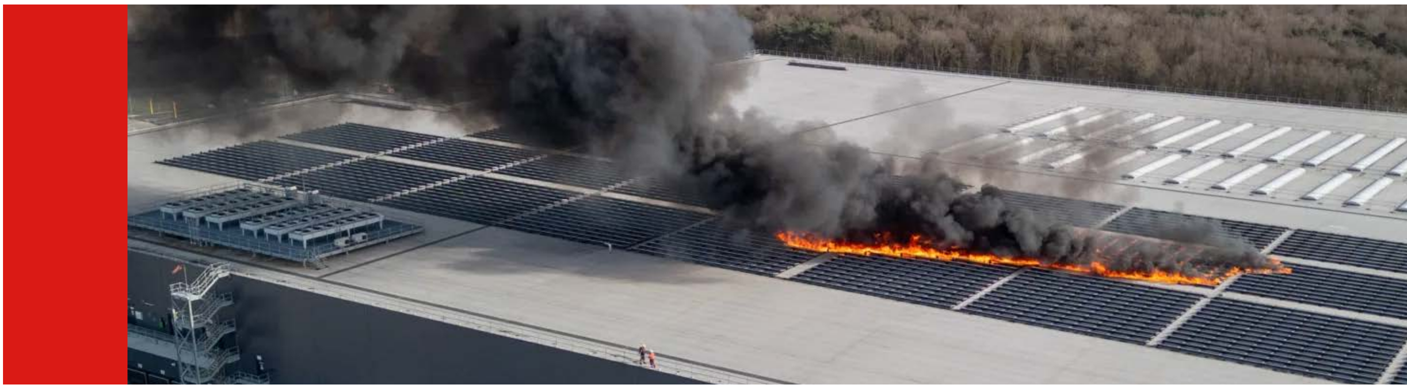


Photo credits: www.cambsnews.co.uk and Terry Harris

Member States shall ensure the deployment of suitable solar energy installations as follows:

from 2027	from 2028	from 2029	from 2030	from 2031
on all new public and non-residential buildings > 250 m²	on all existing public buildings > 2000 m² & on existing non-residential buildings > 500 m², where the building undergoes a major renovation	on all existing public buildings > 750 m²	on all new residential buildings and on all new roofed carparks	on all existing public buildings > 250 m²

This will result in the unprecedented transformation of European building stock and a significant uptake in photovoltaic (PV) panel technology on rooftops. This transformation has the potential to have significant benefits from a climate and energy perspective, but it will also bring new safety challenges that should be anticipated and addressed upfront.

Initial findings indicate that risk related to the installation of PV panels is not only associated with increased fire load and possibility of ignition, but also with how a fire develops on a roof. This change in fire behaviour will, if not addressed accordingly, increase the extent and speed of the fire spread and thus also the intensity and consequences of fires. At the same time, the presence of electrically charged PV modules and physical obstacles poses an additional challenge for firefighters dealing with such rooftop fires.

Large international insurance companies that assess fire risk in buildings have already recognized the additional fire risks of PV systems installed on roofs and published recommendations on how to mitigate these risks posed to buildings, investments, and human life:

- **Allianz Risk Consulting:** Fire Hazards of PV systems
- **AXA Property Risk Consulting Guidelines:** PV systems
- **RSA Risk Control Guide:** Photovoltaic Panels
- **HIROC Risk Note:** Rooftop Solar Panel System
- **Zurich Article:** The challenges and risks of solar panels
- **IF Article:** Put your roof to work in a safe manner
- **Generali:** Photovoltaic panels on roofs and fire risks (in French)
- **FM Global:**
    - FM 4478 (Update), Roof-Mounted Rigid Photovoltaic Module Systems
    - Systems and FM Global Property Loss Prevention Data Sheets 1-15

Many of the insurance companies also acknowledge that existing tests are not suitable and that the fire behaviour of roofs with PV systems is not adequately understood today. A typical recommendation for existing roofs is to limit fire spread by using a non-combustible layer below PV modules.

The key objective is to have the right conditions in place to ensure a safe large-scale rollout of PV systems. Recommendations from the insurance industry are generally applied for large industrial and commercial projects such as shopping malls. Nevertheless, these fire safety measures should also apply to high-rise and high-risk public buildings such as schools, museums, and hospitals. Recommendations from insurance companies have yet to be considered by national regulations and EU legislation.

Statistics regarding PV-related fires

A fault tree analysis by Mohd et al. (2022) of fires on rooftops with photovoltaics estimated that the expected number of fires are 29 fires per installed GW of PV per year. This indicates that tens of thousands of fires related to PV systems are to be expected per year in the EU alone. Given that the expected number of fires is so large, the aim of this guideline is to provide guidance on how to avoid that the consequences of a PV fire on a roof becomes significant.

Further to that, the Clean Energy Associates (CEA) has performed more than 600 safety audits for rooftop PV installations, and it was found that 97 percent of the systems had safety concerns related to ignition hazards. More details of their findings can be seen in the bar chart below. Based on these investigations, it can be hypothesized that at least one ignition event is inevitable in the lifetime of any PV installation. These results are in line with findings by FM Global, who has reported that they continue to see ignition and fires in buildings that follow their recommendations.

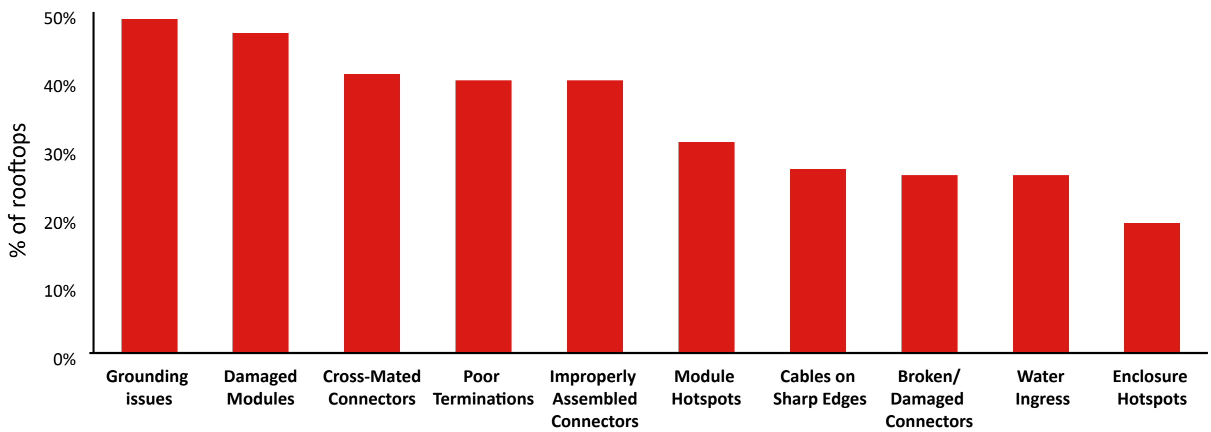
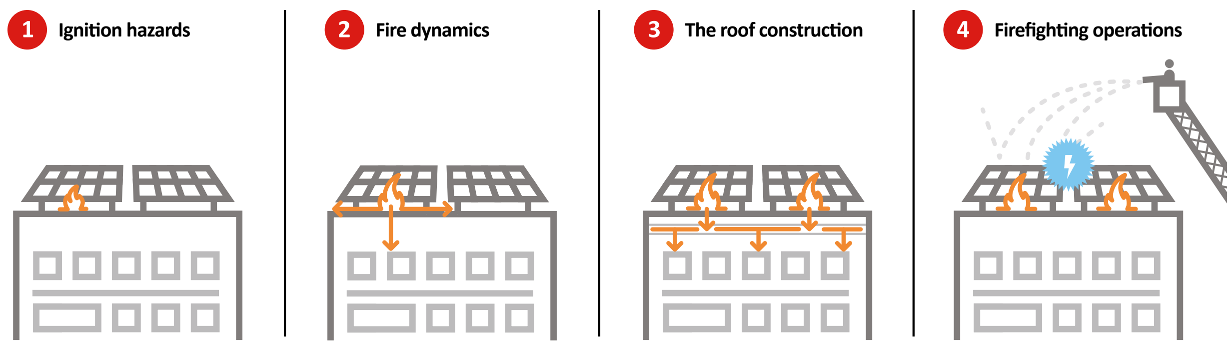


Figure 1: Overview of the failures reported by the Clean Energy Associates (CEA) [(https://www.cea3.com/cea-blog/top-10-pv-rooftop-safety-risks)](https://www.cea3.com/cea-blog/top-10-pv-rooftop-safety-risks) in 2023.

However, it is not only the ignition hazard that must be addressed when it comes to rooftop PV installations. The widespread installation of solar PV arrays on rooftops has raised concerns over new fire hazards that generally fall into four broad categories, as illustrated and described below.



1 Ignition hazards:

PV systems have multiple potential failure modes that present ignition hazards. There have been numerous cases where fire causes have been associated with electrical faults in the wiring of PV arrays, as well as other causes linked to the PV installations (e.g., contact degradation or strain on cables and connections due to weather movement of PV panels). The degradation of PV systems is one of the key factors to address to reduce the cost of the electricity produced by increasing the operational lifetime of PV systems. Finally, PV component aging can also have a significant impact on fire safety (Mohd Nizam Ong et al., 2021).

2 Fire dynamics:

Introducing a PV system onto a fire-rated roof changes the dynamics of fires that develop. If a fire develops on a roof with a PV system, the presence of the modules can keep the released energy closer to the roof and increase temperatures and heat fluxes to the roof. Thus, fires that could otherwise remain limited can thus progress faster and therefore have a higher fire risk.

Introducing a PV system onto a fire-rated roof adds additional fuel to the roof structure. PV modules are typically constructed from glass and aluminium frames with polymeric backing materials and encapsulants that add some additional fuel load to the roof.

The installation of a PV system on the roof also means the possibility of fire progressing through skylights and over a fire wall, especially if it is not extended sufficiently above the roof level.

3 The roof construction:

There are many different types of roof constructions that PV systems are considered for installation on. The type of roof and materials used interact with the PV modules installed on top of the roof in case of a fire. This interaction can increase the fire spread on the roof and the development of the fire. This scenario is different than the one assessed for the roof construction without PV systems. Besides the covering parts of the roof there are also many types of insulation materials, and each has its own degree of combustibility. Combustible membranes and insulation can contribute to the development of a fire and to the flame spread of the roof assembly and it also happens in a concealed area between the PV system and the roof itself. Due to an interaction between PV and roof constructions, the wrong combinations can pose a high fire risk in case of a fire and must be given high attention.

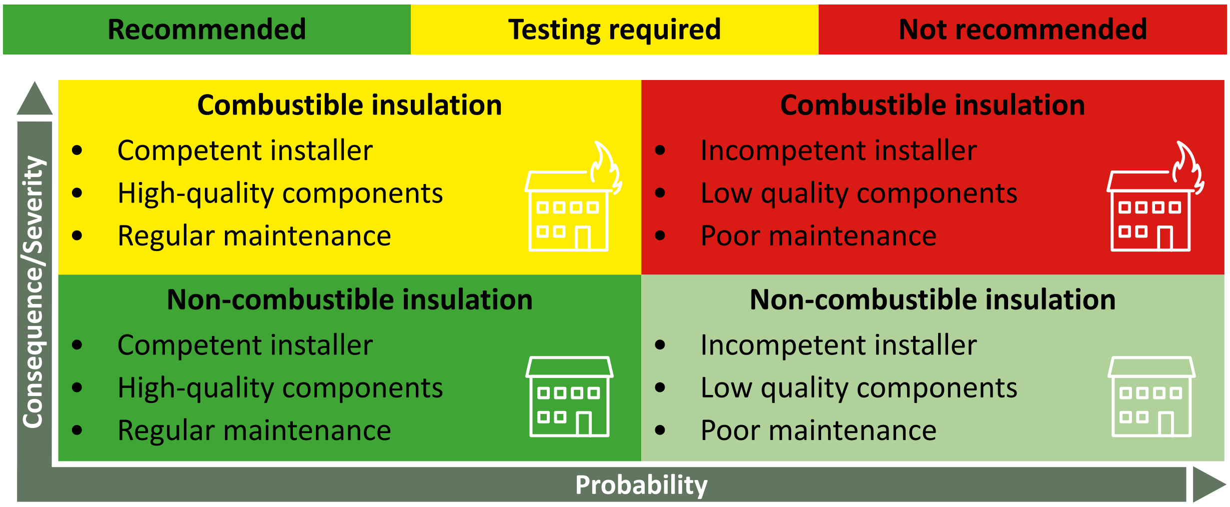
4 Firefighting operations:

PV systems present an obstacle for fire service when fighting fires. When fighting structural fires, firefighting tactic involves ventilation of the building. Vertical ventilation techniques will often entail opening the roof near the peak over hot spots which request easy access on the roof.

Electrical hazards - PV systems and disconnects may not be properly labelled, and firefighters may not be familiar with them (if not switched off they could power circuits even after the main meter is pulled).

Explosion and chemical hazards – a fire may involve large backup battery banks that can pose additional chemical hazards (e.g. sulphuric acid and hydrogen fluoride) and explosion risk (hydrogen gas).

The probability of PV fires on roofs relates to installation quality and management, while the consequence of the fires relates to the panel geometry and the roof combustibility, and particularly the insulation layer immediately below the roof membrane (which is combustible). Note that the option of 'no mitigation layer' between a roof with EPS insulation and a PV system has not been included, as it should not be an option due to its extremely high consequence, even for 'perfect' installation.



Adapted from ZRS:
https://www.renew-able.co.uk/wp-content/uploads/2024/03/Zurich-whitepaper-Photovoltaic-systems-on-buildings-20231102-US42.pdf

KEY TAKEAWAYS:

Building integrated photovoltaics (BIPV) and building applied photovoltaics (BAPV) are different systems, also when it comes to fire safety.

- The current guideline focuses on the fire safety of BAPV on flat roofs.

One should separate between fires with origin inside a building and fires occurring on the roof with BAPV. The latter is the focus in this guideline.

Many fires are expected for roofs with PV installations.

- Research has estimated that 29 fires will occur per GW of PV solar installed.
- An ignition event in the system's lifetime appears inevitable, thus managing and limiting the consequences of a fire is key.
- The entire system, including the roofing materials must be considered, as combustible roofing membranes, combustible components (such as mountings), and combustible insulation materials have the potential to contribute significantly to a fire.

The key aspects to consider for fire safety of rooftop PV installations are:

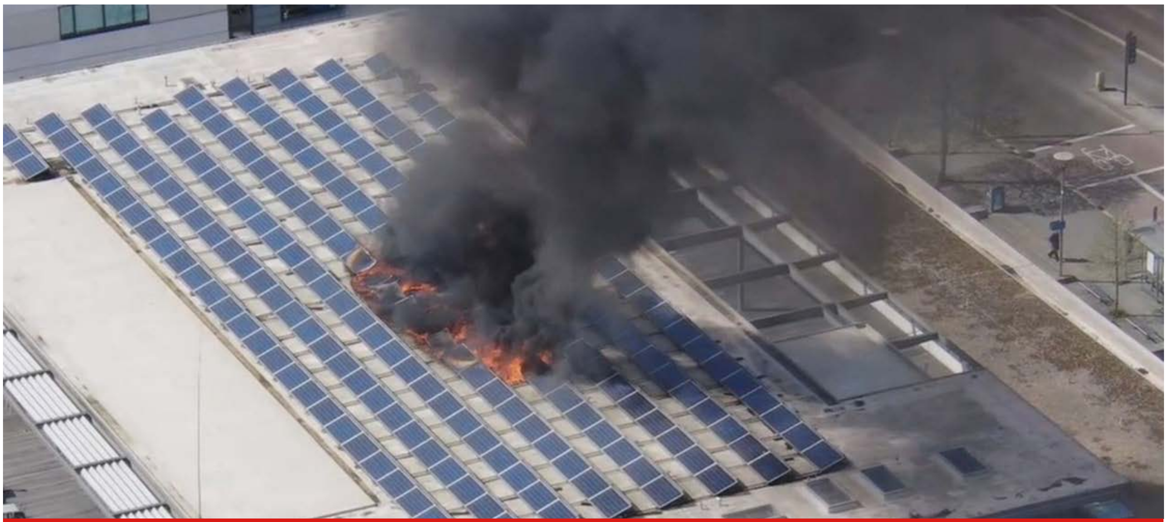
- Ignition
- Fire dynamics
- Roof construction – membrane and insulation type
- Firefighting

2. Fire Risk of PV Systems on Flat Roofs

There is insufficient data to distinguish between the fire risks associated with different types of installations: those installed horizontally, those facing south, or those facing East-West, so no such distinction will be made herein.

The following three fires highlight some of the challenges related to fires on roofs with PV.

- Bristol (UK) - We the Curious (Millen & Morgan, 2022) – caused by a bird crashing into panel. Since the fire, the building has been under restoration from the water damage associated with putting out the fire. The building will reopen in July 2024.
- McKesson, New Jersey (US) (Goldman, 2023) – fire spread across significant PV array gap.
- Traiskirchen (Austria) (Zach, 2019) – industrial complex where more than 50 firefighters were involved to prevent spread to other buildings.



Bristol, UK (Millen & Morgan, 2022)

Photo credit: Avon and Somerset Police
Note: As labeled in the video in this news story:
https://www.itv.com/news/westcountry/2022-05-12/we-the-curious-in-bristol-to-remain-closed-after-birds-cause-fire

McKesson, NJ, USA (Goldman, 2023)

Photo credit: Robbinsville Township Fire Department
https://www.facebook.com/RTFD40

Traiskirchen, Austria (Zach, 2019)

Photo credit: https://www.facebook.com/einsatzdoku/

As shown below in a basic Fire Safety Concepts Tree, which is a risk analysis method developed by the National Fire Protection Association (NFPA), the main issues to address for avoiding a large consequence from a PV fire on a roof are related to ignition and fire spread.

It is also important to point out that ignition typically relates to component and product level failures, whereas the fire spread must consider system level effects. Despite the components and products being closely monitored through electrical test standards, and panels being tested for combustibility, statistics show that there is an abundance of ignition events for PV systems on roofs. However, the interaction between components remains a challenge. This indicates that the ignition problem is for the main part associated with insufficient quality of the installation and maintenance schemes.

In terms of fire spread, there is no standard for testing the entire system, including the roofing membranes and insulation below. Thus, this remains the biggest unsolved problem related to fire risk mitigation of PV systems on roofs.

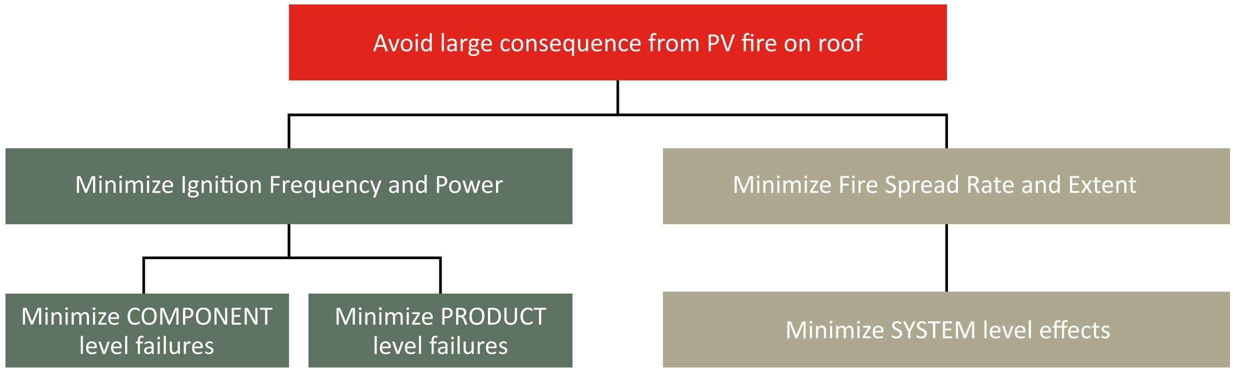


Figure 2: A basic fire safety concepts tree (NFPA 550) for PV fires on roofs.

Ignition

To make sure the production of electricity runs as expected, each PV installation consists of an extensive electrical installation (AC and DC networks with a plethora of electrical components/devices), in addition to the panels and their mounting system. For ease of illustration, a schematic of a simplified PV system is shown in Figure 3. Different cables, junction boxes, charge controllers, by-pass diodes, inverters all make up PV system. All these electrical components can fail for various reasons, thus leading to an ignition source and the possibility of a subsequent fire.

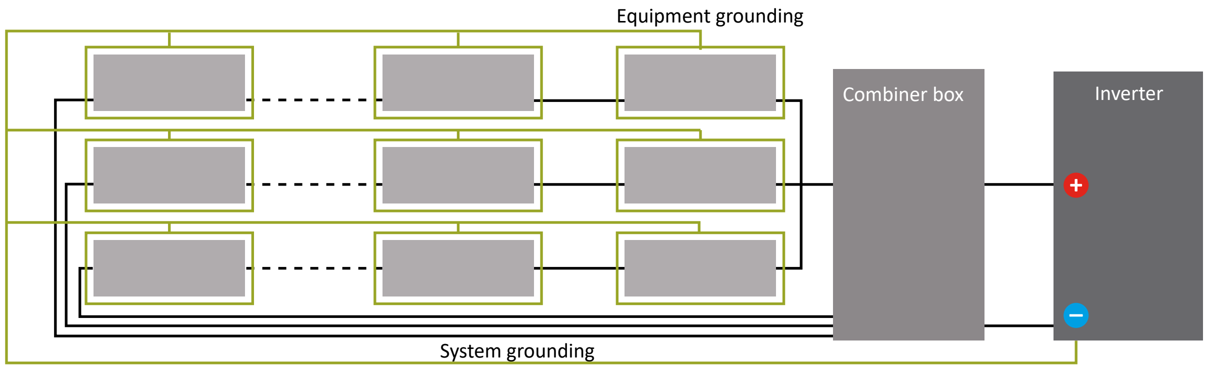


Figure 3: A PV system is a complex system with many components. Inspired by Alam et al., 2013.

The failure leading to ignition can be intrinsic to the components, or it can be external to them. While internal causes for failure usually arise from low quality products (frost cracks in glass, hot spots etc.), poor installation technique or inadequate maintenance; the external causes for the failure of the components also vary significantly. They can range from soiling, shading, movement (e.g., due to wind), impacts (birds, hail...) to the ignition from firebrands from wildland fires etc.

It is of significance that most of these sources of ignition do not originate in the PV panel themselves, but in other areas of the installation (see Figure 4). Given then that most of these identified ignitions are centred on the switchgear, this need protecting the most. One solution is to monitor for excessive (but pre-ignition) resistive heat on a continuous basis.

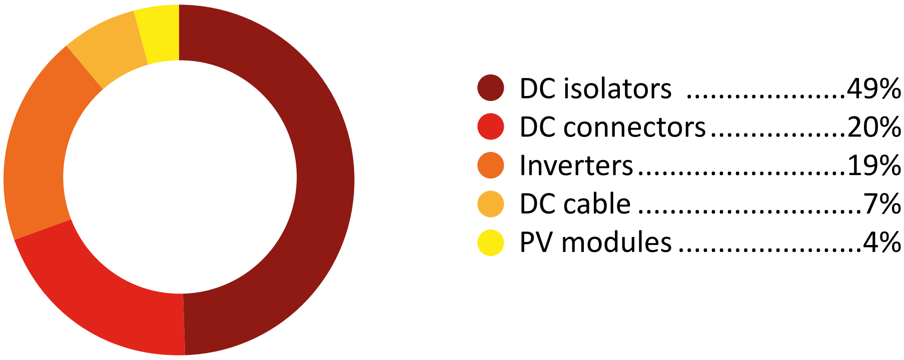


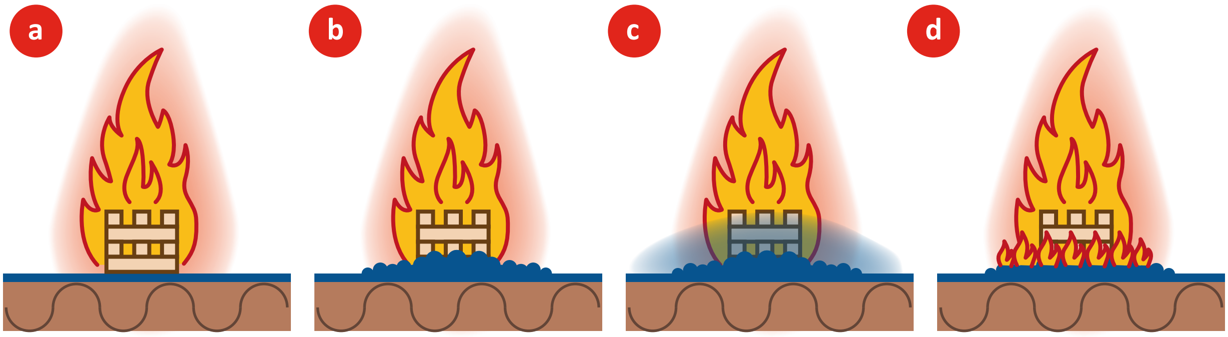
Figure 4: Origin of PV fires as reported by BRE (2017).

Fire Spread

There are numerous aspects that govern the fire dynamics of a roof with a PV installation. Research has established that assessing the fire risk of a PV installation solely based on the assessment of individual materials and components of the individual products can lead to erroneous conclusions. Rather, it has been established that it is necessary to treat the PV-installation as a system composed of several parts namely the panels, mounting equipment, and the roof buildup to assess the fire risk correctly. To this end, systems approvals are now being developed by the insurance industry.

The addition of a PV installation transforms the situation in the case of a fire because a flame can get deflected below the panels, returning a significant amount of heat back into the roofing surface, thus allowing the flame spread to occur where there otherwise would be close to none (assuming the roofing membrane used has the appropriate fire classification). Figures 5 and 6 (adapted from Kristensen, 2022) schematically show the scenarios without and with panels installed (which also applies for panels installed with a flat configuration).

Without overlying panel: No (or negligible) flame spread beyond the ignition source (here a wood crib, which was used in the experiments that confirmed this fire development).



a) Radiative heat transfer from ignited wood crib (fading red cloud).

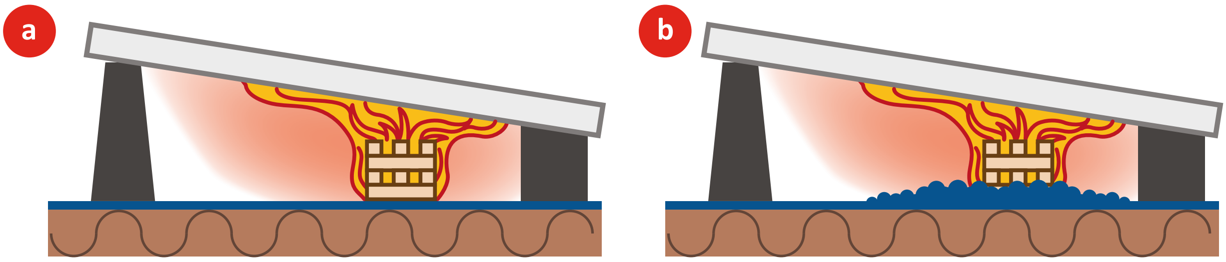
b) Heating of nearby roofing membrane.

c) Release of combustible pyrolysis gases (fading blue cloud).

d) Ignition of pyrolysis gases, additional radiative heat transfer, but no self-sustained flame spread.

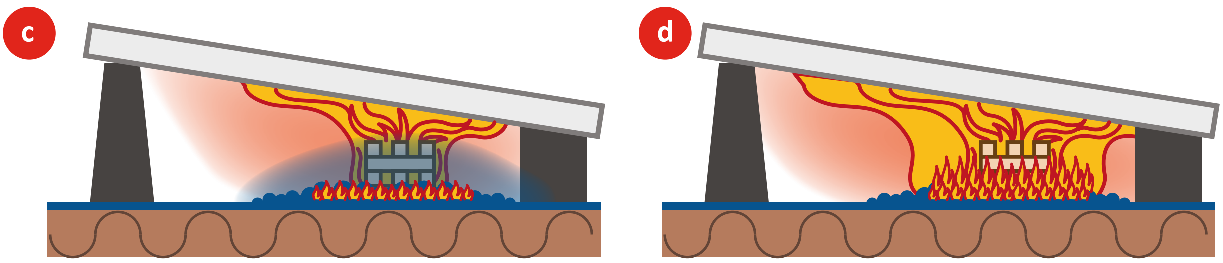
Figure 5: Illustration of the ignition process for a wood crib on a roof construction (blue roofing membrane, brown insulation).

With overlying panel: Significant flame spread underneath the PV panel. Note that the roofing membrane and the insulation material below were the same in both cases (Figures 5 and 6).



a) Radiative heat transfer from deflected flame (fading red cloud).

b) Heating of nearby roofing membrane.



c) Release of combustible pyrolysis gases and initial ignition (fading blue cloud).

d) Increased heat release rate due to higher mass flux of pyrolysis gases, heating of nearby materials and self-sustained flame spread.

Figure 6: Illustration of the ignition and flame spread process for a wood crib below a PV module (inclined grey rectangle) on a roof construction (blue roofing membrane, brown insulation).

Figures 5 and 6 have been reproduced based on artwork by Jens Steemann Kristensen, 2022.

All configurations have proven to increase the extent of fire spread beyond the expected spread on a roof that is otherwise similar, and this has been evidenced both in real fires and in experiments. Once outside of the area covered by panels, the fire spread normally stops after a relatively short distance. The figure below (adapted from Kristensen and Jomaas, 2018) shows the aftermath from experiments that were performed outside with the real wind affecting the test. The grey area in the figure is indicating the extent of the fire spread.

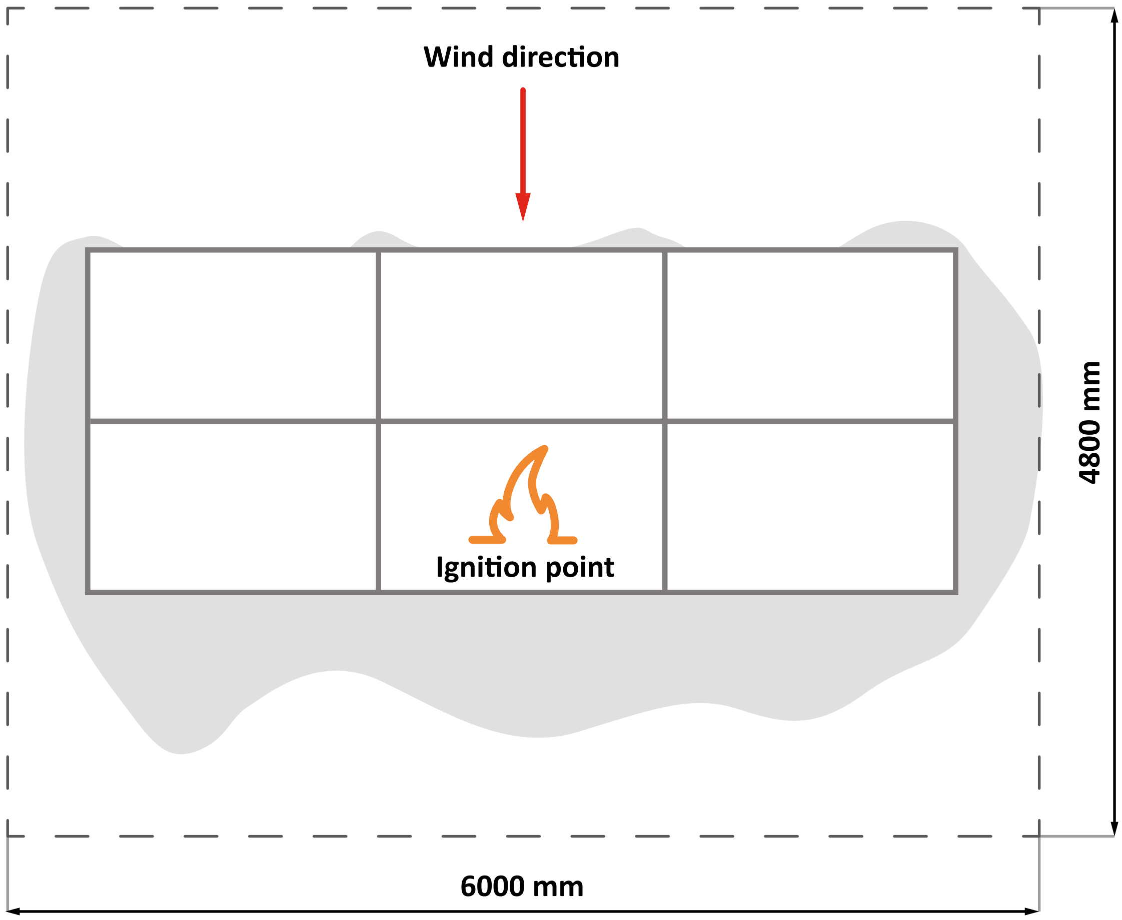


Figure 7: Fire experiments on roofs with PV systems have shown that the fires typically do not spread much beyond the area of the PV array (adapted from Kristensen and Jomaas, 2018). These findings are generally supported by actual fires on roofs.

3. Flat Roof Constructions with PV Systems

For rooftop fires involving PV systems, it becomes even more important to have a careful consideration for the firewall attributes (as evidenced by the ASKO fire in Norway), the placement of roof vents, the distancing between PV arrays (c) and the size of the PV arrays (a*b).

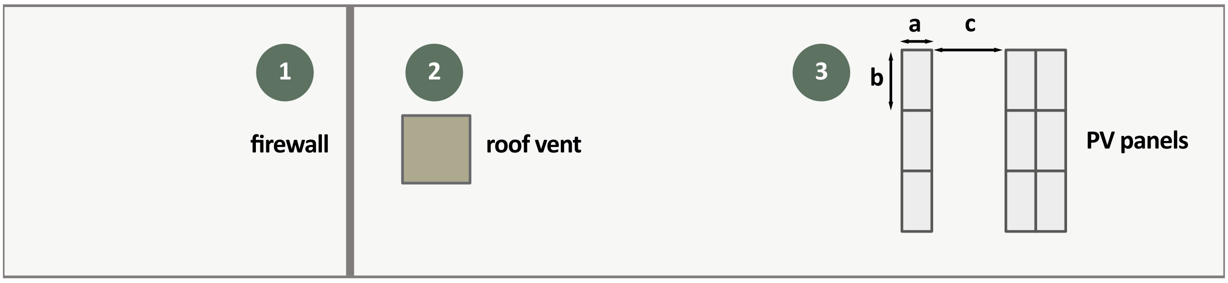
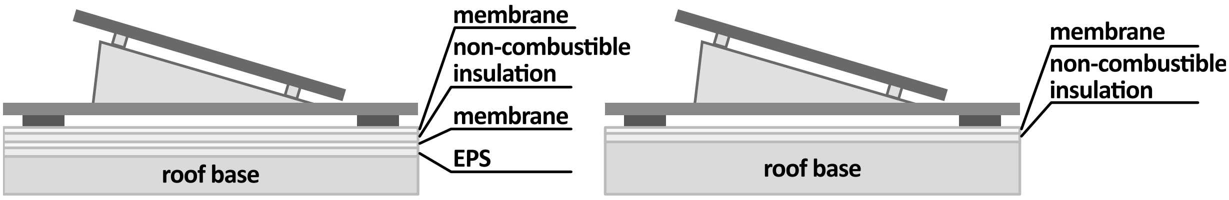


Figure 8: Top view of a roof construction with (1) firewall, (2) roof vent and (3) PV panels. The roof vent should also follow national standards for distance to the firewall.

In terms of the roof buildup for buildings with PV installations, a major distinction should be made between retrofits and new buildups. Retrofitting an existing roof to accommodate rooftop solar is by far the most used practice, in part because it is generally acknowledged that it is more sustainable to utilise existing roofs/buildings than to build new ones.

The figure below shows two typical compositions for the two main categories of roof buildups.

- For retrofitted roofs, research has shown that a typical buildup with EPS and membrane on top of the roof base requires a mitigation layer to prevent involvement of the EPS, which is strictly necessary to avoid a very large fire. Following most insurance standards, this mitigation layer typically consists of a layer of non-combustible insulation with a new roofing membrane on top. As the system behaviour is key for PV fire safety, it is recommend that the performance of the mitigation layer is confirmed via reference to sound data from experiments or statistics.
- For a new roof, one should avoid the use of highly combustible insulation like EPS on top of the roof base. Rather, it is recommended to use a more fire-safe alternative, such as a non-combustible insulation, with a roof membrane on top. The recommendation for non-combustible insulation is based on publicly available test results, which show that the spread across membranes that the PV modules facilitate is independent of the type of membrane, and that the ensuing fires are significant enough to involve combustible insulation materials in the fire.



Typical roof buildup for RETROFITTING **Typical roof buildup for NEW BUILDING**

Membrane

The table below shows the typical membranes used for roofing. Before they are introduced into the European market, they have to be tested according to EN 13501-5 (EN 13501-5 Fire Classification of Construction Products and Building Elements - Part 5: Classification Using Data from External Fire Exposure to Roofs Tests, 2016). For example, the table shows that PVC was classified as Broof by three different test methods, since different countries prefer different test methods. It should be noted that Broof classifications are obtained for the roof system, not just for the membrane itself.

Experiments have shown that the classification can be compromised when a PV panel is placed above a membrane, regardless of the type. This is more critical for smaller gap heights.

Table 1: Typical roof membranes and the test method used to obtain their B_{roof} classification.

Type of membrane	Test method
TPO (Thermoplastic Poly Olefin)	B_{roof}(t1)
TPO/FPA (Flexible Polypropylene Alloy)	B_{roof}(t1)
FPO (Flexible Poly Olefin)	B_{roof}(t2)
PVC (Poly Vinyl Chloride)	B_{roof}(t2)
PVC	B_{roof}(t3)
Bitumen	B_{roof}(t3)
PVC	B_{roof}(t4)

Insulation

If the EPS cannot be removed from an existing roof, there is a need for a carefully selected mitigation layer. The solution with the mitigation layer should be tested as built, and the ignition source should be large enough to create a challenging fire development under the PV panel.

The insulation plays an important role in retaining or dissipating the heat produced by the fire. If the insulation enables more heat to penetrate the roof buildup faster, then less is conserved at the level of combustion and the fire spread rate is lowered. Conversely, if the insulation allows less heat to penetrate the roof buildup, more will be preserved at the location of combustion and the fire spread rate will increase. Note that a faster fire spread rate might be desired, as this can protect, for example, an underlying EPS layer. This, however, is under the assumption that the fire will stop at the edge of the PV array, which might not be the case for membrane types with dripping/melting behaviour (e.g., bitumen).

Furthermore, if the thermal transmittance (U-value) of different underlying insulating solutions is equivalent, the heat transfer contributions to the fire dynamics from different insulation materials are expected to be the same. However, even for the same U-value of the insulation materials, a different behaviour is observed when the duration of the fire is considered. Experiments by Kristensen and Jomaas have shown that longer-lasting fires demonstrate the ability to compromise combustible insulating materials, thus potentially enabling the fire to progress from the building envelope to the interior of the building.

Hence, great importance and distinction between the roof buildups is associated with retrofitting of existing roofs and that of new roofs. The material selection can lead to significant differences when it comes to fire safety. When changes are made to an existing building, the fire safety implications of these changes are often not considered on the same level as they would be for a new building.

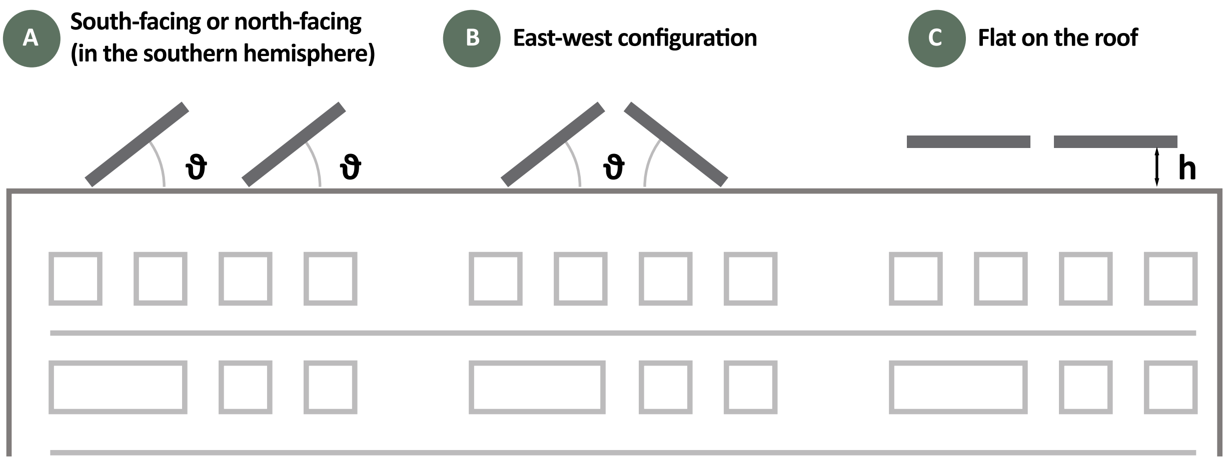
In the end, it is about risk mitigation, and when there is combustible insulation materials on the roof, there is a higher fuel load which can be ignited and contribute to a fire in case of an unpredicted fire event.

Type of PV Module

There are multiple types of PV modules, for example glass-foil (UL 790 Class C), glass-glass (UL 790 Class C), glass-glass (UL 790 Class A). Although there may be some differences in terms of fire spread related to the different types of modules, all types of modules will impact the fire spread. In fact, experiments have shown that even a steel plate resulted in similar spread as a PV module. Thus, a risk reduction should not be based on the selection of PV module alone.

The PV modules play an essential role in the fire spread of PV-related rooftop fires. They can either be one of the sources of ignition or just become involved in a fire originating outside of the PV installation. Their presence is the crucial contribution to the worsened consequences of a PV-related fire compared to roofing fire without a PV system. The following points explain in more detail how the choosing and placement of solar panels and elements around them on a roof affects the building's fire risk.

PV systems are generally installed in three different orientations, as shown below in a simplified side-view of a building with PV panels on a flat roof. Recently, vertical panels have also gained increased attention, and initial testing has shown that this orientation does not result in the fire spread scenario shown in Figure 6 (Jomaas, Simakovs and Rus, 2024; Bellini, 2024).



Side view

Panel geometry

Crucial parameters here are the gap height and the inclination of the panels. The lower the gap height, the higher the amount of heat transfer back to the roofing material, thus resulting in a faster increase of the fire size and flame spread rate. Research by Kristensen et al. (2020) has shown that a critical gap height exists, which means that at a certain height, the fire behaviour on the roof is close to equivalent of one where panels are not present. Given that the roofing membranes are correctly chosen, installing panels with a gap height that exceeds this value (which must be established for the entire buildup) will therefore lead to a significantly reduced fire risk.

Inclination of panels introduces a form of a chimney effect, which brings larger amounts of oxygen to the fire and increasing the flame spread rate even more. Just as for the faster spread rate discussed in the insulation section, the consequences are not so straightforward. The faster flame spread will also typically result in a shorter overall fire duration, and thus exposing the roof buildup to heat for lesser amount of time, potentially leading to smaller consequences (as the risk of spread into the roof buildup is reduced).

Array configuration

Several national guidelines have requirements for the distances between the PV arrays and for the maximum size of the PV arrays. As such, it is recognized that these types of distances are of importance, and they acknowledge that the PV panels influence the fire spread on roofs. An example from Italy (Cancelliere et al., 2016) is shown in the figure below, where the distances between arrays and distances to firewalls, skylights and smoke and heat vents are shown. These numbers vary somewhat from country to country, and it would therefore be a very useful development if these installation requirements were made uniform. Note that this type of uniformity should be based on research, and that the distances are expected to be different for PV installations with variation in roof buildup and PV panel geometry.

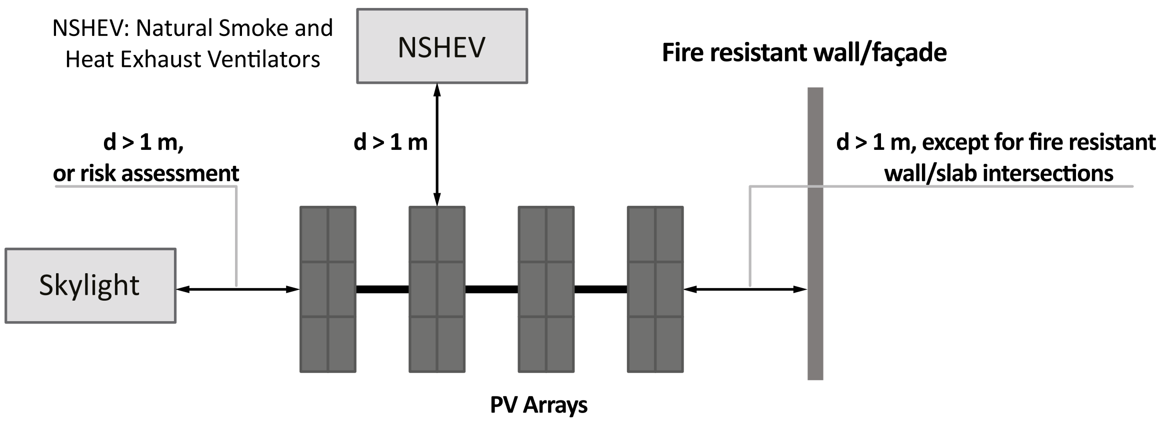


Figure 9: Recommended distance between arrays and distance to firewalls, skylights and smoke and heat vents. Reproduced from Cancelliere, 2016.

Two measures were noticed in most of the documents from insurance companies and safety consultancies, as shown in the table below, namely area of the array and the spacing between them. The area of the array is prescribed ranging from 40 m x 40 m to 45 m x 45 m and the spacing between the arrays should be from 1 m to 2 m, depending on some additional requirements specified in individual guidelines.

Table 2: Recommended array size and distancing around arrays as given in various guidelines.

Publisher	Size of the array	Distancing between arrays and other elements on the roof
Allianz	45 m x 45 m	1.2 m
AXA XL	45 m x 45 m	1.2 m or 1.8 m [1]
RSA Insurance	46 m x 46 m	1.2 m
SZPV	40 m x 40 m	1.0 m or 2.0 m [2]
BVS[3]	up to 1,800 m^2 (approx. 42 m x 42 m)	1.0 m or 2.0 m [4]
VdS 2234	40 m x 40 m	> 5 m

1. For the distance from the edge of the roof to the PV installation the requirement is 4 ft (1.2 m) for roofs with a length or width of less than 250 ft (75 m) and 6 ft (1.8 m) for over 250 ft (75 m) in length or width.
2. For flat roofs larger than 40 m x 40 m, the arrays shall be limited to a maximum of 40 m x 40 m. There shall be a minimum 1.0 m wide access strip between the roof's edge and such a field. There shall be a clear passageway of at least 2.0 m in width between two such arrays.
3. Document is only aimed at roofs with an area larger than 1800 m^2.
4. 1.0 m for cases with non-combustible roof surface (e.g., 5 cm thick gravel surface) and if the roof cladding is combustible (also classification Broof(t1) without protection by a 5 cm thick gravel surface), a horizontal distance of 2 m must be maintained.

The ASKO fire in Norway ("Brannen i ASKO-bygget," 2017) had its origin in a charging forklift. This fire is a very good example of a fire starting inside a building that later on influenced by PV installations. The fire within one compartment broke through the roof, whereupon it propagated along a PV-equipped roof and then into another compartment. The PV system (panels and roof composition) and the lack of an extension of the firewall above the roof level were both significant aspects with respect to the fire becoming as large as it did. The fire resulted in the loss of 9,000 m^2 out of a total of 100,000 m^2 and approximately 200 million NOK in value (with recent updates doubling that number due to business and logistics interruption). Through extensive firefighting efforts, the fire was contained within a fire section containing the freezer storage of the warehouse facility.

The ASKO fire in Norway spread across many arrays, and also across the internal fire wall, thus compromising the intended compartmentation.

Photo credit: ASKO warehouse fire in Vestby, Norway in 2017, copyright Tor Aage Hansen/ROCKWOOL Group

Photo credit: CambsNews/Terry Harris

The fire at the Lidl distribution center in Peterborough, UK in February 2024 also spread across many aisle separations. In addition, the direction of spread indicates that in a south-facing configuration, the spread across an aisle separation is easier on the ‘higher end’ of the inclined panel (towards the left in the photo). Still, the wind direction at the moment of the picture is also favouring the same direction. In this fire, the polypropylene (i.e., combustible) footings appear to have contributed to the fire spread, which is in line with findings by Kristensen and Jomaas (2018).

KEY TAKEAWAYS:

- **The fire risk with PV panels on roofs is larger than without panels.**
- **Assessing the fire safety of a PV installation must be done on the system level because individual elements do not necessarily present the risk comprehensively. However, the true risk emerges when the different elements are combined and must be assessed as a system.**
- **Parameters that crucially govern the fire dynamics in a PV-related fire are:**
  - **gap height**
  - **inclination of the panels**
  - **roof buildup (membrane and insulation materials…)**
  - **array configuration (size of the array and distancing between arrays)**
- **The type of panel is not as significant a factor as the parameters above.**
- **All membranes get involved in the fire and leads to spread beyond the origin when they are placed below PV panels (that are sufficiently close to the roof surface).**
- **Based on the above, non-combustible insulation materials and mountings are recommended to achieve significant risk reduction.**

4. Firefighting

The challenges related to achieving successful and safe firefighting for fires with PV installations on roofs are for the most part the same whether the fire starts inside the building or on the roof. In general, the firefighting requires:

1. **Safe rooftop access**
2. **Safe operations while on roof**
3. **Successful applications of extinguishing medium (water, foam, ...)**

A picture from the rooftop fire in Robbinsville, New Jersey, USA with firefighters in action.

Photo credit: Edmund Haemmerle

The installation of rooftop solar can interfere with all these aspects. Therefore, it is essential that the following aspects are ensured.

1 No PV panels next to the edge of the roof on any side, and aisles free of PV panels to enable uninterrupted walking path from any access point on the roof.

2 Extension of firewalls to avoid unexpected fire development, sufficiently strong roof construction, and main system shut-off to reduce electrocution concerns.

3 The successful application of extinguishing medium requires proximity, as the PV panels will otherwise block the application stream and are thus linked to the two previous requisites. If environmental concerns are of particular importance, this becomes even more crucial, as the amount of water used should be limited.

PV panels produce potentially lethal amounts of DC electricity whenever they are exposed to light, which is the power source. All solar PV systems include isolation switches, most inverters have arc fault detection equipment and some solar PV systems have additional power electronics designed to monitor and “shutdown” the PV system if a fault arises. However, all this electro-mechanical equipment operates “downstream” of the solar panels themselves. The PV panels and the wiring leading to the first point of electro-mechanical isolation remains live as long as the PV panels are receiving light. Whether the PV system is directly the source of ignition or indirectly involved (ignition source external to PV system) the DC risks apply for first responders tasked with resolving the issue at source. Therefore, fires involving PV panels should not be tackled by untrained personnel. The panels must be de-energised during first responder operations as they pose an electrical hazard. All PV systems when compromised present a live DC electrical risk to life that can escalate to becoming a fire if the risk is left unattended. As firefighters cannot be expected to understand the various solar PV system technologies in detail arriving at a fire, they require a simple and effective method to safely de-energise a solar PV system at the source of power production.

A major fire that occurred at a warehouse in Noardburgum, Netherlands on May 20, 2021, serves as an example of additional environmental concerns that can arise from fires involving PV systems (Bellini, 2021). The municipality said in a press release that it had received around 73 notifications from concerned residents in the surrounding area who were alarmed by the presence of PV module fragments on their properties. According to Urs Muntwyler, an expert on fire incidents in PV installations and CEO of Swiss engineering company Ingenieurbüro Muntwyler, the particles found by the residents, which are also seen in a picture published in the municipality press statement, are similar to those that he found after a fire occurred at a PV system located in Lanzenhäusern, Switzerland.

The fire in Noardburgum, Netherlands resulted in environmental concerns several kilometres away from the fire location.

Photo credit: NoorderNieuws/de Vries Media

As for fires with origin inside the building, they more often result in very large fires, and environmental concerns are thus of more importance for these fires. The plumes become very large and can carry parts of the PV panels very far (as evidenced by the fire in the Netherlands), thus causing environmental concerns in a large surrounding area. In addition, as the fires are large, more water will be used by the firefighters, thus creating a greater probability for ground and groundwater contamination around the fire location. In areas where the nearby environment is particularly sensitive, these aspects should therefore be considered with significant care.

KEY TAKEAWAYS:

- **Fires with origin in the building typically requires non-combustible roof construction if spread to the outside is to be prevented.**

- **Firewalls must be extended sufficiently above the roof level to prevent spread between compartments.**

- **Installed PV systems affect the fire brigade's ability to successfully extinguish a fire.**
  - **Ensure access and safe operations.**
  - **Ensure ability to apply extinguishing medium directly to the fire, rather than on the panels themselves.**

A firefighter in the smoke from the PV fire on a roof in Robbinsville, NJ, USA. Ramali et al. (2023) suggested that firefighters should follow a list of safety practices before, during and after fires involving PV systems. Wearing appropriate PPE at all times was one of the recommendations.

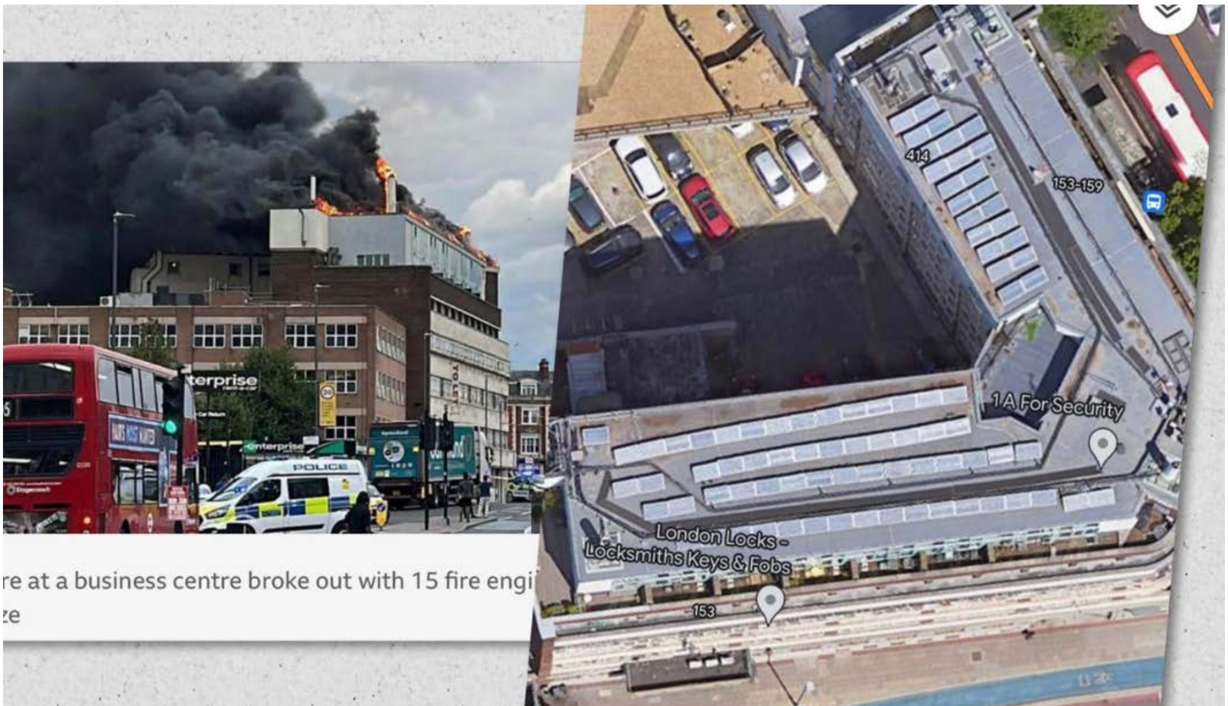
Photo credit: Edmund Haemmerle

5. General Concerns

There are some general fire safety concerns related to the installation of PV systems on roofs, and these will be discussed in the following. For example, it is not (yet) common to have detection systems installed on roofs, thus a roof fire can develop into a large fire before it is detected because it is relying on visual observations by people. Other general concerns are related to poor installation practice and lack of maintenance.

An example of a significant fire related to the general concerns occurred in August 2023 when a fire started on a roof in London, UK. It is assumed that the origin was in the rooftop PV system that was installed. The fire eventually spread through the roof and forced residents to evacuate very rapidly, as by the time alarms went off inside the building, the fire was already rather large. As seen from the photos below, the system appears not to follow conventional installation practice, and it also suffered from poor maintenance. The PV arrays were either installed very unevenly, or wind or other forces have moved them, which is a well-known cause of strain on the electrical cables associated with such system, which in turn can cause arcing and ignition of rooftop material.

As we know that movement of PV arrays under severe wind conditions or storms can lead to malfunction and ignition risks, ballast is oftentimes added to line load systems. It is worth noting that such ballast can result in other problems, both in terms damage from the ballast itself, and the possible influence on the underlying insulation material.



Excerpt from news story about the rooftop fire in London, along with a Google maps screenshot of the PV system on the roof.

https://www.bbc.com/news/uk-england-london-66622684

Personnel qualifications

A great number of PV-related fires (over 55 %) result from causes that are directly or at least indirectly connected to the installation process. The number includes causes for ignition related to the panel, isolator, inverter, and connector. With a better focus on the installation process, the number of fires occurring because of these failures could be significantly reduced.

An installer's certification review performed by BRE (BRE, 2011) found that in many European member states there is no certification scheme in operation that enables PV installers to demonstrate their competence and quality of work to potential clients. This represents a barrier to the uptake of PV within Europe since the complexity of PV systems and their high cost means customers are reluctant to make the required financial commitment without the reassurance that a certified installer would bring. According to the findings (BRE, 2011), the key areas that should be included in the PV certification trainings are: applicable regulations and directives; installation and maintenance requirements; site specific issues; system performance; technical competences; quality management and customer care.

Further to the work by BRE, the current work reviewed other guidelines to capture how many of these included explicit requests for the installers to be adequately certified/qualified/trained. The results can be seen in the Table 3.

Table 3: Review of guidelines requiring certification of installers

Country	Organization	Required certification
Germany	Allianz (Allianz Risk Consulting, 2019)	YES
Germany	VdS (VdS, 2023)	YES
France	AxaXL (AXA XL Risk Consulting, 2021)	YES
UK	RSA (RSA Insurance Group, 2020)	NO
Slovenia	SZPV (SZPV, 2016)	YES
Austria	BVS (BVS - Brandverhütungsstelle, 2022)	NO
Canada	Canadian solar (Canadian Solar Inc., 2020)	YES
China	Longi (LONGi Solar Technology Co., Ltd., 2023)	YES
China	JA solar (Shanghai JA Solar Technology Co., Ltd., 2019)	YES
South Korea	LG (LG Electronics Deutschland GmbH, 2019)	YES

Operation and maintenance

Data identify some specific areas where maintenance standards can be improved (Pester et al., 2017):

- Inspection of the internals of DC isolators (sampling if there are a large number), checking for signs of overheating, moisture and loose terminals.
- Methodology for sampling inspections of any site-assembled DC connectors (connectors assembled under factory conditions are less likely to be an issue).

It is necessary to establish a flexible inspection and cleaning mechanism or use a data collection system to decide whether unplanned maintenance is necessary to reduce the risk of fire in different environments (Wu et al., 2020).

PV maintenance should include the following four types of maintenance procedures (NREL, 2018):

Administration of maintenance: Being aware of the responsibilities for each of the consequent parts of maintenance and clearly establishing them.

Preventive maintenance: Scheduled maintenance is often carried out at intervals to conform to the manufacturer's recommendations, as required by the equipment warranties.

Corrective maintenance: Required to repair damage or replace failed components. It is possible to perform some corrective maintenance, such as inverter resets or communications resets remotely. Also, less urgent corrective maintenance tasks can be combined with scheduled preventive maintenance tasks.

Condition-based maintenance: Uses real-time information from data loggers to schedule preventive measures or corrective maintenance problems by anticipating failures or catching them early.

Although not regulated, typical maintenance actions that PV installations may require include:

- Inspecting wiring connections and terminations for looseness and corrosion.
- Inspecting wiring harnesses to ensure they are neatly bundled and protected.
- Inspecting the PV array for cleanliness, absence of damage, and structural integrity.
- Inspecting roof penetrations and weather sealing.
- Maintaining batteries, which may include cleaning, adding electrolytes, charge equalization, and replacement, if necessary.

Maintenance of solar PV systems is defined in the IEC 62446-1 and 2 standards. The IEC 62446-1 is an international standard for testing, documenting, and maintaining grid-connected photovoltaic systems. It sets standards for how system designers and installers of grid-connected PV systems must provide information and documentation to customers.

Lack of statistics

Risk assessment always includes the probability of the reviewed event and its consequences. To perform a proper risk assessment of the PV-related fires reliable data would need to exist for the number of PV-related fires and the extent of damages they inflicted. Data-gathering approaches vary greatly among the countries and before relevant measures to improve and unify the gathering processes are put in place, comprehensive risk assessments will be scarce.

Lack of updated building data

There is a lack of updated building data for firefighters to access on their way to a fire scene. They should ideally be able to have information of the following nature:

1. Installation
    a. PV system layout ☑
    b. PV system specifics ☑
        I. Type ☑
        II. Age ☑
        III. Presence of safety devices (e.g., micro-inverters) ☑
2. Roof construction
    a. Membrane type ☑
    b. Insulation material used (combustible vs. non-combustible) ☑
    c. Type of footing used (combustible vs. non-combustible) ☑

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