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Resilience Solutions

# Risk Insight: Roof Mounted Photovoltaic Panels and Systems

## Design, Installation and Maintenance

# Overview

Photovoltaic (PV) panels and systems are becoming a frequent sight on commercial, industrial and residential premises, representing the largest microgeneration technology that supplies renewable energy to consumers.

It is important that PV systems meet current design, installation, maintenance and operational standards to ensure that the potential for unexpected events, which can result in significant losses, is controlled and the risks associated with these systems are eliminated, controlled or mitigated as far as is reasonably practicable.

The general guidance indicated herein, addresses the design, installation, and maintenance aspects of roof mounted PV systems.

The design and technology of PV panels continues to evolve, meaning that the risks associated, and their appropriate controls, is dynamic and continues to be developed.

This document considers roof mounted PV systems only.

# Discussion

The general guidelines outlined in this document follow the UK Microgeneration Certification Scheme (MCS) and the UK Risk Authority guidelines RC62 (Recommendations for fire safety with photovoltaic panel installations): https://www.riscauthority.co.uk/resource-download/404

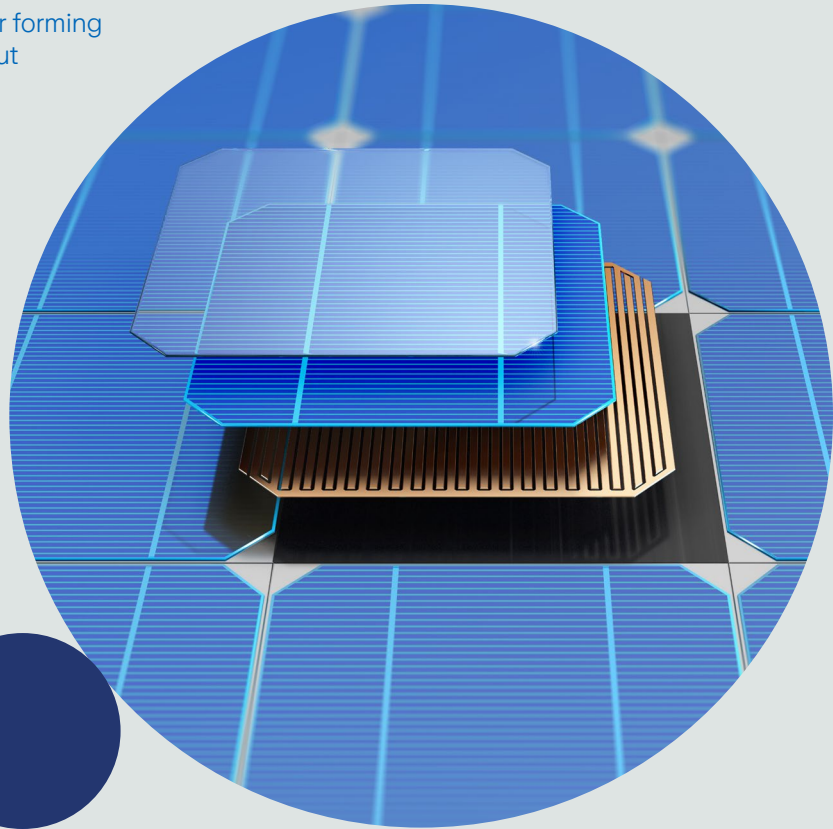
Photovoltaic cells generate Direct Current (DC) electricity from solar irradiance to generate electricity during daylight hours, even without the need for constant sunshine, and overnight via external lighting sources and moonlight. An inverter is utilised to convert the DC to Alternating Current (AC) electricity. PV arrays are constructed using different PV modules/panels, that come in varied sizes and outputs.

PV module/panel technology has been used for over 50 years and has been subject to years of development. The technology is now widely accepted as a common and economical on-site renewable energy source. It significantly supports the global drive towards sustainability, whilst reducing the effects of climate change by lowering carbon emissions.

With the increasing prevalence of PV systems, it is important that the design, installation, and subsequent maintenance elements are fully understood. A lack of understanding relating to these elements can result in subsequent failures and losses.

This document provides guidance relating to roof mounted PV systems, whether retrofitted to an existing building or forming part of a new build project. Other types of PV system can be installed as part of a wall or vertical cladding system, but these are rare.

PV systems can be fitted to flat or pitched roofs on commercial, industrial and residential buildings. Solar PV systems are traditionally designed south facing, on unshaded roof aspects so that optimal operational system efficiencies are apparent. The potential risks of PV systems need to be considered on a case-by-case basis.



## Scope

The guidance provides the steps to consider, in deciding how best to eliminate, control and mitigate the potential risks. It further details good industry practices and standard procedures.

Issues and recommended standards associated with PV systems are covered under the following headings:

- Pre-Installation and Design Stage
- Commissioning
- Operation
- Maintenance

# Pre-Installation and Design Stage

## Risk Assessment

Prior to installation a suitable and sufficient fire risk assessment must be undertaken for all industrial, commercial, and domestic PV installations and be in compliance with the Regulatory Reform (Fire Safety) Order 2005 (or equivalent legislation in Scotland and Northern Ireland) (reference 1).

“The fitting of PV panel installations to combustible roofs should be avoided wherever possible” (source - RC62).

## Solar Energy: Energy Storage Systems (ESS)

For countries such as the UK which have variable weather patterns, the amount of electrical power generated from a solar PV installation will tend to vary. Solar PV panels also generate less electricity in the winter than summer (in the UK, around four times less in December than in June).

Rather than exporting excess power to the grid, Energy Storage Systems (ESS) such as battery storage systems can retain excess power for use in times of lower PV output and, therefore, present an attractive option.

The main battery type used for solar PV installations is Lithium-ion batteries, although Lead-acid batteries can also be used. There are key differences between these, and each have their own advantages and disadvantages. From a risk management perspective, they also introduce a degree of fire/explosion risk which needs to be safely managed.

An important fire hazard to consider with battery storage systems is thermal runaway, where heat is transferred through the battery cells causing further fire spread. Disconnection from the power source does not stop the reaction and damaged batteries can reignite hours or days later due to the thermal runaway.

Zurich is in the process of reviewing and assessing the risks potentially posed by Energy Storage Systems linked to solar PV installations and we plan to publish further guidance for customers in due course. Pending this, please speak to your usual Zurich contact for any specific risk management guidance about proposed new Energy Storage installations.

## Quality of design and installation contractors

Contractors involved with PV system design and installation are to be accredited to a national trade body that has clear and mandatory requirement guidelines covering training, design standards, installation standards and testing / quality standards such as one of the following:

- UK MCS Certification Scheme Requirements (MCS Contractor Certification Scheme)
- UK BS 7671 IET Wiring Regulations 18th edition or later

The wiring and other elements of the electrical installations are to be designed, installed and periodically tested by an electrician competent in working on DC as well as AC installations, in accordance with the standards outlined above. Cabling needs to be correctly specified for life safety reasons as well as prevention of over-loading. The regularity of inspections carried out is to be risk assessed as recommended in a Periodic Inspection Report.

Ground fault detection is to be installed as part of the overall system to prevent and detect short circuits, which is a leading cause of fire.

# Pre-Installation and Design Stage

## Quality of the panels and performance

Electrical connections and control systems within a PV panel system may be a cause of failure and loss.

“Panels should conform to BS EN 61215 (ref 15) or BS EN 61646 (ref 18) in conjunction with BS EN 61730-1 and BS EN 61730-2 (refs 19 and 20) so that they may withstand inclement weather conditions. The panels should be certified by a company with third party accreditation to BS EN 17025 (ref 21).” (RC62)

The effect of shading from sunlight of PV panels needs to be assessed to minimise the potential for backflow of current.

PV panel performance efficiency has a direct correlation with the amount of sunlight falling on the panels and the duration of the exposure to natural light sources. Anything that reduces the PV panel exposure to sunlight will reduce the overall output of the system. In extreme cases, it may result in current backflow from panels exposed to sunlight to panels in shaded areas. This process can increase the panel surface temperatures which can lead to overheating and fire.

Reverse flow diodes are normally fitted to each panel to prevent this occurrence, but these diodes are known to be unreliable over time. The best solution is to ensure the panels are installed where they will not be subjected to shading or partial shading.

Panels also need to be installed away from any aggressive fumes, dust or kitchen extract systems to prevent potential deposits from impacting system efficiencies and a potential reduction in power output. The same consideration needs to be applied where issues with autumn leaves or bird droppings may be relevant.

Shading from trees and other surrounding vegetation will vary according to the angle of the sun and the season.

# Pre-Installation and Design Stage

## Access to the roof

The initial design assessment needs to include safe and reliable access to the roof for the purposes of installation, inspection and maintenance of the system when installed. Access requirements for installation and maintenance engineers and materials including cranes and handling equipment need to be reviewed and identified, which will also minimise the potential for damage to panels and electrical systems during storage and installation.

High Voltage (HV) hazard signage must be clearly displayed.

## Suitability of the roof design and structural integrity of the supporting roof (flammable insulation, flammable roof covering, age of the roof system and strength of the roof support system)

An assessment, review and check of the structural suitability and strength of the roof is a fundamental part of the design process. All factors that may increase roof loadings (weight of panels and fixing systems, snow and ice accumulations or wind effects of PV installation) need to be fully considered. Weather related load considerations should be typical for the area and include an acceptable safety factor to allow for unexpected or extreme events.

This part of the design assessment is to follow good building and civil engineering practice and follow industry accepted codes of practice for example Microgeneration Installation Standard 3002.

Evidence of suitable structural reviews are to be provided for every installation.

“An assessment, review and check of the structural suitability and strength of the roof is a fundamental part of the design process.”

# Pre-Installation and Design Stage

## Damage to roof surfaces caused by panel fixing systems and cables

To secure and prevent movement, PV panel systems need to be fixed to the roof of the building, ensuring the panel weight is securely and properly transferred to the roof supporting structure, this will include the weight of the fixings and associated framework themselves.

There are possible aerodynamic effects that wind and air movement will have on roof mounted panels and the use of non-secured weight retained installations needs to be carefully assessed.

For all pitched roof installations physical fixing with a specific number of brackets and fixings will be required for each panel in the overall array. The physical attachment of these fixings to the roof structure will mean each fixing will breach or pass through the actual roof covering, which creates a potential leakage (water ingress) path in the roof covering, so suitable methods need to be adopted to ensure roof damage is kept to a minimum and minimising potential leakage points. Fixing points will need to be sealed and made water-tight and weatherproof.

Individual panels in the overall array will be connected together and to a power collecting and controlling system. These connections are usually kept short to increase system efficiency and can pass through various conduit, cable trays and connection boxes en-route to the installation control systems. Any such punctures in the roof covering, will also need to be made water-tight and weatherproof.

All weatherproofing measures and steps to guarantee water-tight performance of the roof structure are to be designed to last the whole life span of the PV panel installation.

## Water leaks, causing damage to the roof structure and water ingress into the actual building

Damage to the roof covering of the building or failure of any waterproof membrane will lead to water ingress issues over time that can result in damage to the roof structure or more extensive water damage within the building. The requirements indicated above will help to minimise these risks.

## Impacting existing roof features such as drains, ventilation and the like

Existing roofs may include ventilation or drainage features that are required as part of the building design or to service building services systems such as kitchen extraction ducting, heating, ventilation and air-conditioning systems. PV installations design must ensure these features are not impacted negatively by the PV installation and that safe and suitable access to these features for maintenance purposes is maintained. Inadequate consideration being paid to these facilities can lead to panels being removed or damaged due to unsatisfactory access arrangements.

## Impacting roof inspection and maintenance

The PV panel installation is to be installed to have minimal impact on regular roof inspection and maintenance activities or clearing of accumulated debris operations.

# Pre-Installation and Design Stage

## Quality of fixings and suitability to withstand prevailing weather conditions

PV panel installations may be provided with a manufacturer's guarantee, typically for a 25-year design life. The validity of the manufacturer's guarantee may be dependent on the use of approved fixing systems. The choice of fixing system needs to consider the local installation requirements and associated weather-related conditions including snow load, wind, hail, rain, and ice. The specified fixings are to ensure a life cycle exceeding the panel design life and require minimal maintenance and are to also allow for potential panel expansion under thermal stress.

## Radiant heat transfer to the roof from the panels in use (Thermal Expansion)

PV panels will get hot due to solar radiation. The panel heat will be radiated to the roof structure, where it can cause overheating and rapid deterioration due to a lack of ventilation between panels and the roof surface. In extreme cases panels have been known to fail due to overheating or in combination with other contributory factors.
A suitable gap should be provided between individual panels depending on the roof system in use.

PV roof tiles are a physical part of the roof structure and so must be designed and installed in accordance with manufacturer's specification and need to comply with the relevant national approved documents/building regulations.

## Quality of the electrical installation on the roof and in the building

Electrical faults routinely and regularly cause fires. There are national and international standards for electrical installations covering cable sizes, cable routing, fittings (fixings) and connectors (for the purpose of this document, we refer to UK standards only). Any contractor involved in the installation of a PV system should be trained and certified to comply with the local / UK standards. The installation specification is to include a quality inspection and commissioning test of the system, prior to hand over.

All electrical work is to be certified as compliant with the relevant local / UK standards.

# Pre-Installation and Design Stage

## Isolation potential

PV panels generate electrical current when exposed to daylight and even some external lighting sources overnight or moonlight. Even on cloudy and overcast days, PV panels will still be generating electrical current. Array strings and individual panels cannot be safely isolated and will still produce electrical charge if disconnected from the rest of the overall system. This means the system is considered “live” constantly and introduces safety issues for contractors engaged in installation and maintenance of the PV system.

PV systems need to be fitted with isolators to disconnect the array / string from the outgoing electrical supply. Additional isolation devices are to be included on inverter and control equipment where DC is converted to AC prior to use in the building or diversion to the national grid.

“Provide a switch in a prominent location readily accessible to fire-fighters to isolate the DC side of the PV system near the panels to ensure the safety of fire-fighting personnel” (RC62).

This switch should be at ground level, easily accessible and ideally external to the building. Failure to do this could result in the Fire and Rescue Service (FRS) resorting to defensive fire-fighting tactics only, ensuring that the fire does not spread to neighbouring structures.

As PV panels cannot be made electrically safe, additional care is required to ensure that the design and installation is properly earthed and protected.

The local fire brigade should also be advised of the proposed system and design to enable them to assess their ability to isolate the system before it is installed. In addition, the fire brigade should be invited to visit the premises following installation so they can familiarise themselves with the layout and assess how best to tackle any fire.

# Commissioning

A comprehensive commissioning process is to be in place for all PV systems prior to hand-over. This process is to be in line with recommendations made by the MCS (Microgeneration Certification Scheme) installer guidance.

The PV System installation and commissioning contractor is to ensure that the building occupier / owner is fully trained and understands the operational risks and safety features of the system. Full documentation is to be provided including details of recommended inspection and maintenance requirements.

# Operation

## Damage to panels due to weather (mainly wind and hail impact damage)

PV panels may be subject to damage from weather conditions such as snow, hail, wind or lightning. The potential for damage will depend on the local prevailing weather conditions and the quality of the installation design. Installed panels on a flat roof, set at a low angle will be more exposed to snow load damage than similar panels on a pitched roof set at a steeper angle.

String arrangements of panels can also create an increased risk of damage to the panels (and roof structure) from high winds or during turbulent air flow.

## Damage to roof due to structural failure (overload)

In addition to the load imposed on the roof by the PV system, associated fixings, cabling and junction boxes, the roof will also be subject to additional loads due to potential accumulations of snow, ice or rainwater. Flat roofs are particularly at risk of failure from these weather conditions with PV installations making the risk increased.
“Where PV panels are to be installed on an existing roof, consideration should be given to the additional weight presented by the panels” (RC62).

## Water leaks caused by the fixing systems (resulting in roof damage or building damage)

Failure or deterioration of panel fixings, an insufficient allowance for thermal expansion or failure of cable entry seals and weatherproofing can lead to water ingress issues and subsequent damage to the roof structure. Rectification of these faults can mean panels will need to be removed to ensure effective repairs are completed.

## Thermal movement of panels under use causing damage or disturbance to the fixing system with potential damage to the roof integrity

Lack of allowance for thermal expansion is a potential design problem. Rectification may require removal and subsequent refitting of panels to ensure effective repairs are completed.

## Panel security to the building structure

Panels may become detached or fall off or be torn away by gusts of wind if not securely attached and fixed to the roof structure. Loose panels can be difficult to identify and may require the entire panel system to be removed so it can be refitted correctly.

Loosely fitted panels may be subject to movements, which can lead to electrical faults due to strains exerted on wiring and connection systems, any subsequent damage to cabling can lead to electrical short circuits which can start a fire.

Panels falling from the roof can lead to a serious risk of injury, therefore panels need to be properly secured to the roof structure.
The use of ballast to retain panels needs to be fully assessed for potential aerodynamic effects and instability.

# Operation

## Possible non-weather-related damage (Vermin, Insects, Birds and People)

Vegetation and other debris may accumulate under PV panels providing an ideal environment for vermin, insects or birds. These can cause damage to panels and/or wiring systems and associated connections leading to electrical short circuiting and fire. The debris accumulations beneath the panels will provide a fuel source, which can be ignited by radiant heat from the operating panels and by electrical short circuiting. The PV installation needs to be inspected regularly to ensure any such accumulations of vegetation or other debris are removed promptly and any damage promptly maintained.

Roof mounted PV panels are usually much less exposed to acts of vandalism, petty theft or damage by people than ground mounted PV installations. Unauthorised and/or easy access to roof mounted installations needs to be deterred as much as possible and access to roof space is to be restricted as far as is practical. Damage and theft can occur when roof space is accessible, which will leave the system unsafe with subsequent fire a real possibility. Overall site security needs to be reviewed for all large-scale PV installations.

## Ventilation and cooling for the electrical control and inverter equipment

Heat is generated under normal operating conditions of the electrical control system and inverter. These pieces of equipment can also be subject to thermal gain due to their location (roof void or partitioned off compartment). Dust accumulations on and around these pieces of equipment may also lead to localised overheating and component failure. These types of equipment are not usually tolerant of high operating temperatures and may fail leading to reduced operating life or efficiency, unexpected failure, electrical faults and the risk of fire.

Cool locations for siting of this equipment is preferable and consideration needs to be given to ventilation systems including fans and ducted natural ventilation to ensure operating temperatures are controlled. Warning systems and automatic shutdown (or trip) systems should be included to shut down electrical equipment that suffers from overheating.

Regular inspection and maintenance are required to keep this equipment in good condition and working order.

## Failure of panels during operation

Manufacturers will typically specify a 25-year life cycle for PV panels. The design of the installation should allow for panel replacement with the minimum need for removal of other operating panels. Cables may suffer deterioration, fretting, insulation failure or mechanical stress. Control equipment and inverters may suffer age related failure, overheating, electrical surge damage or lightning strike.

## Overheating of panels or cabling

As indicated above, PV panels may overheat due to poor cooling and ventilation, surface contamination and backflow currents. Cables can suffer from electrical overload, although this is rare. Electrical control systems and inverters can suffer overheating due to poor or failed ventilation or inadequacy of cooling systems or from dust contamination and the like. Fire is a direct possibility resulting from overheating of equipment and associated cabling, electrical faults and short circuiting.

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“...debris accumulations beneath the panels will provide a fuel source, which can be ignited...”

# Operation

## Failure of Inverter

Inverters will not typically last as long as the panels supplying them with electrical energy, usually having a life cycle of 10/12 years, depending upon the operating conditions. Inverters need to be fully monitored to indicate any issues and should shut down safely in case of component failure. Any installation may suffer sudden and unexpected failure.

## Battery operation / charging and gas ventilation

If the panel installation is designed to supply “off grid” power, then it will need to include DC storage batteries, to store any excess power generated during the day. These batteries can come in a variety of forms and whatever batteries are sourced as part of the overall installation need to be specified to operate with PV systems.

Any storage battery represents a risk of high energy electrical discharge from the energy stored therein. Lead acid batteries (liquid or gel type) present a potential explosion risk due to hydrogen liberated during the charging process. Battery installation should be designed to minimise gas build up with adequate ventilation provided. They should also be enclosed in a secure and insulated container or compartment to protect the batteries from damage and to prevent accidental contact with the battery terminals.

The use of lithium-ion batteries will introduce additional safety and fire risks.

# Maintenance

All maintenance operations must be undertaken strictly in accordance with the manufacturers and installers instructions annually by competent electrical engineers (such as those recognised in the UK by the NICEIC, the Electrical Contractors Association (ECA) or Select in Scotland) who are familiar with the form of installation and the appropriate forms of access equipment.

It is essential that provision of safe access to the roof and all system equipment and components is addressed at the design stage. “While ease of maintenance involves access being gained to the roof, the economics of PV installations demand that as great an area of the roof as possible be covered in panels. It must therefore be ensured at the design stage that a sufficient area of roof remains free of panels to allow access and maintenance work to be carried out safely” (source - RC62).

Serious consideration needs to be given to the carrying out of thermographic examinations of the PV panels and associated wiring and connection boxes to identify any “hot spots” associated with the installation, at the time of any routine service and maintenance visit. Thermographic examination should also be made of the inverter and control equipment.

## Inspection and testing of panels and electrical cabling and connectors

All PV system equipment requires routine inspection and maintenance, including visual inspection, physical inspection and testing. The inspection and maintenance regime is to be documented and recorded and should follow manufacturers and installer guidelines to ensure compliance with the system warranty.

Electrical inspection and testing is to be conducted by qualified electrical contractors, competent in both AC and DC installations, and meet the requirements (scope and frequency) of BS EN 62446-1 PV systems – requirements for testing, documentation and maintenance and BS 7671 – Requirements for electrical installations (IET Wiring Regulations).

Periodic visual inspections are to be made to ensure the system remains in good condition, for signs of damage to cables, or overload and arcing, build-up of dirt or debris on PV panels, vermin or insect infestation and attachment security of fixings and the like. Additional visual and physical inspections need to be undertaken following extreme weather events, such as high winds, snow or lightning. Build-up of leaves, litter or other debris is to be removed as soon as practicable, to maintain adequate ventilation and cooling of the PV panels.

## Panel cleaning

PV panels will become dirty and contaminated over time leading to operational inefficiencies and a potential increase in operational temperatures, which can lead to long term deterioration and failure. Periodic cleaning of PV panel surfaces (frequency to be stipulated by the installer) will need to be undertaken to maintain efficiency of the PV panel system and access to the panels is to be maintained for this purpose, with appropriate anchor points provided to ensure the safety of servicing and cleaning engineers.

Pressure washing is a permitted technique for cleaning of panels; but to prevent damage, only specially trained contractors should be allowed to utilise this type of cleaning.
The inverter equipment is to be kept clean and free from debris, dust or other rubbish build up and compartments containing inverter equipment are not to be used for storage.

## Panel replacement

Provision is to be made for the replacement of damaged or faulty panels, allowing the work to be undertaken with the minimum disturbance to the remaining panels. Cables need to be routed to minimise damage potential during maintenance or replacement operations to PV panels.

# Zurich Resilience Solutions

For further information about any of the topics mentioned in this guidance, or to discuss a specific photovoltaic panel installation project, please speak to your local Zurich contact, or email Zurich Resilience Solutions at zrs.property.uk@uk.zurich.com.

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ZRSTM60 (12/21) ZUR

# References


1. Relevant UK national fire safety regulations e.g.
   - The Regulatory Reform (Fire Safety) Order 2005,
   - The Fire (Scotland) Act 2005,
   - Fire Safety (Scotland) Regulations 2006,
   - Fire and Rescue Services (Northern Ireland) Order 2006
   - Fire Safety Regulations (Northern Ireland) 2010
2. Microgeneration Certification Scheme (MCS)
   - Guide to Installation of Photovoltaic Systems
   - MCS 001 Installation Standard
   - MCS 025 Installer Certification Scheme Competency Criteria Guidance
   - MCS 3002 Requirements for MCS Contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar photovoltaic microgeneration systems
3. RISC Authority
   - RC62 Recommendations for fire safety with photovoltaic panel installations.
4. BS EN 62446-1 PV systems – requirements for testing, documentation and maintenance.
5. BS 7671 – Requirements for electrical installations (IET Wiring Regulations).