Fire and Solar PV Systems – Recommendations for the Fire and Rescue Services

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1 Introduction

1.1 Background

Over the past few years, there have been a number of media reports linking photovoltaic power systems (PV) with fire. With the prevalence of PV systems now in the UK, an increase in incident reports is to be expected.

The National Statistics website[1] shows that, as of the end of November 2016, overall UK solar PV capacity stood at approximately 11 GW. Figure 1 shows the scale of the increase in deployment since 2010, when the feed-in tariff (FIT) was first introduced.

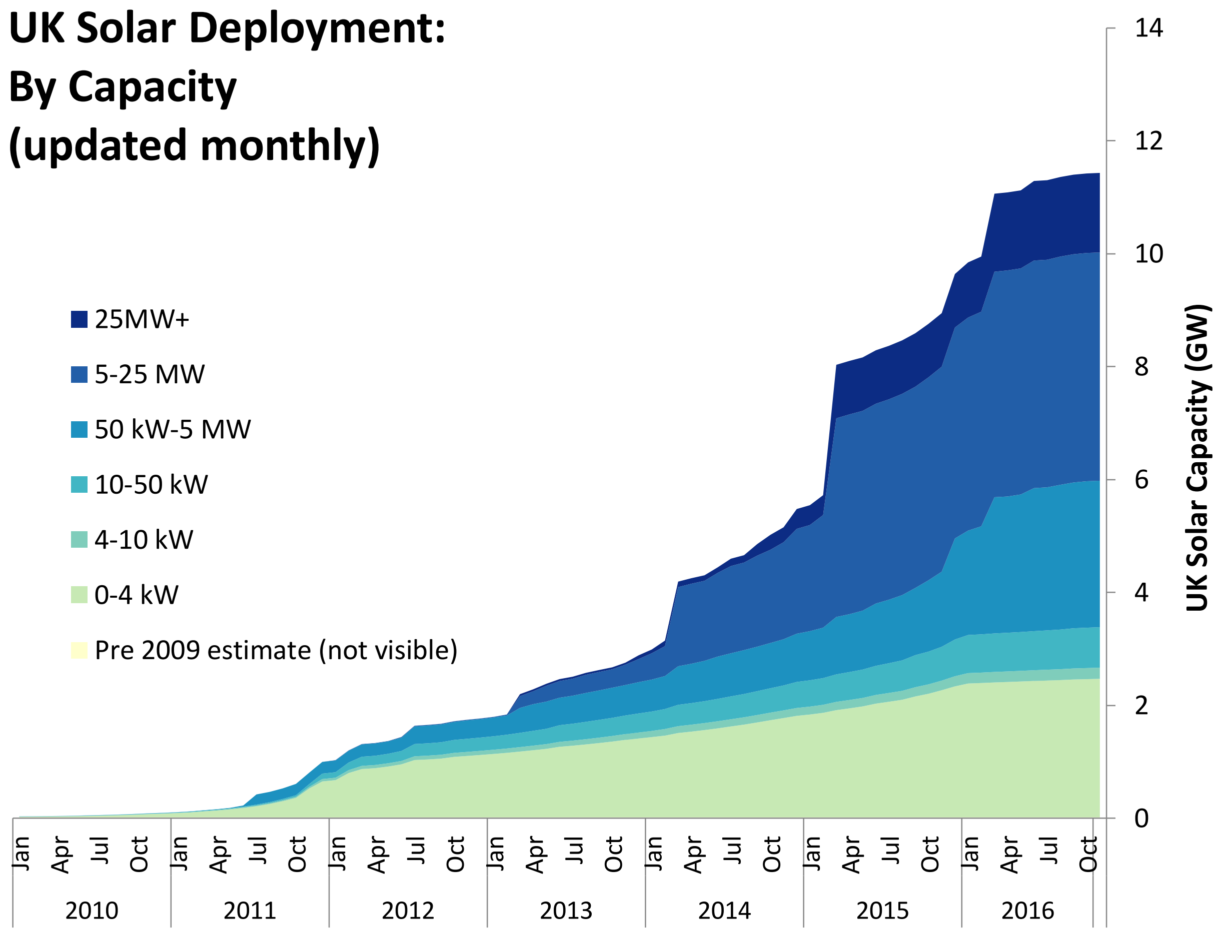

Figure 1: UK PV deployment to November 2016[1]

[1] www.gov.uk/government/statistics/solar-photovoltaics-deployment

At this point in time (November 2016), 48% (5,452 MW) of total installed solar PV capacity came from large scale installations greater than 5 MW, with 21% (2,453 MW) coming from small scale 0 to 4 kW installations, and the overall UK solar PV capacity stood at 11,429 MW across 898,029 installations (provisional figure). This is an increase of 28% (2,484 MW) compared to November 2015.

With this rapid increase in the number of installations, comes an inevitable increase in the number of faults with the potential to cause fires. Whilst some incidents have been reported by the press, others have only become known through word of mouth, and it seems likely that a larger number of fire incidents have not been reported, especially where installers have been able to contain and rectify the fault without intervention from the fire services. Previously, there appears to have been no detailed follow-up investigation in order to properly understand the causes of these fires, or how the presence of PV on a building may have influenced firefighting operations.

Despite the now significant number of PV systems installed in the UK and elsewhere, PV is still a relatively young technology. Consequently, the equipment and installation standards that control the industry are still in a process of evolution. The acquisition of incident data from the field, analysis of root causes and reporting is therefore vital to ensure that standards committees have the latest information to work with, creating the conditions for the standards to remain relevant and effective.

Also, how PV systems can influence firefighting operations may be an essential input during the ongoing development of standards.

Since additional requirements within standards very often result in extra costs to be borne by the industry or consumers, understanding the likelihood of particular faults occurring and the severity of the consequences is essential for ensuring that any changes to standards are measured and properly justified.

This project has therefore been established in order to collate accurate information - both historical and contemporary – on fire incidents involving PV systems in the UK, and on relevant previous research.

To date (January 2017), the project team has completed the following work:

- a literature review
- a review of standards
- a review of training
- established a database of PV fire incidents
- conducted a series of on-site investigations and desk studies of contemporary incidents.

The public project description can be found on the NSC website: http://www.bre.co.uk/nsc/page.jsp?id=3676.

Please note that as far as possible, the authors have avoided reproducing any information of a personal or commercially sensitive nature in this report. The only identifiable references relate to the project team and associated fire investigation professionals.

2 Project outline

The project began in July 2015 and runs to 2018. This report is an output from work package (WP) 8, forming part of deliverable D6. A short outline of the project is presented below.

2.1 Organisation involved

The project team comprises the following organisations and individuals:

- BRE National Solar Centre (NSC)
- BRE Global Fire Safety Group
- Fire Investigations (UK) LLP (FI-UK)
- A representative of the Chief Fire Officer's Association (CFOA)
- A representative of Prometheus Forensic Services Ltd
- Individual PV experts.

The project is owned and funded by the department for Business, Energy and Industrial Strategy (BEIS)

2.2 Programme

Table 1 gives a brief description of the complete three year project, as originally planned, formed from the following work packages:

WP	Description	Status
1	Review of relevant literature. The literature review produced a total of 184 references, mainly from the PV industry, academia and fire services. The full report was submitted to BEIS 25/11/15.	Completed Nov 2015
2	Surveys of standards and training. Standards were mainly international (e.g. IEC), whilst training courses were mainly domestic. The full report was submitted to BEIS 25/11/15 and incorporated into the literature review report.	Completed Nov 2015
3	Survey of historical incidents in the UK – the survey involved contacting installers, building owners, the fire services and DCLGs Incident Reporting System. 37 unique historical incidents of fire involving PV systems in the UK were identified. The output was reported as part of WP5.	Completed Jan 2016
4a	Investigations of live and recent PV fire incidents in the UK. WPs 1 – 3 and 5 laid the foundations for on-going investigations into incidents, as they arise (WP4).	On-going until Feb 2018
4b	Additional Work Package introduced as a variation to the contract to enable laboratory examinations of components suspected of causing fires on PV systems to be undertaken. The data from these examinations feed into WP4 and are stored within the database.	On-going

5	Database development and initial population with historical records.	Completed Dec 2015
6	Fire and Solar PV Systems – *Literature Review, Including Standards and Training** derived from WP1 & 2).	CompletedMarch 2017
7	Fire and Solar PV Systems – *Investigations and Evidence** (derived from WP3, 4 & 5)	Completed March 2017
8	Fire and Solar PV Systems – *Recommendations*:* a) *for PV Industry* (derived from WP6 & 7). b) *for the Fire and Rescue Services* (derived from WP7 & 8). This report.	Completed March 2017
9	Dissemination to BEIS and the solar and fire safety industries	Completion due February 2018

Table 1: Project work packages and status*

***** Note: Following a meeting with BEIS in November 2016, the outputs from work packages 6, 7 and 8 have been recast, as shown in Table 1. The original work packages were as follows:

WP6: Recommendations for improving design and maintenance standards

WP7: Recommendations for improving training

WP8: Recommendations for the safety of fire-fighters in the event of fires involving PV

2.3 Reports

The following reports are the published output from the project to date. The Investigation and Evidence will be revised and re-published in February 2018, following the collection of further data; this aligns with the scheduled end of the project.

- A review of relevant literature, standards and training [1]
- Fire and Solar PV Systems – *Investigations and Evidence* [2]
- Recommendations for the PV industry [3]
- Recommendations for Fire and Rescue Services [4] (this report)

3 Summary of results of investigations

The details of the incident investigations and results can be found in the *Investigations and Evidence* document [2]. The summary of findings presented in this section is reproduced from the *Conclusions* section of that report.

To date (January 2017), a total of 58 unique incidents have been investigated and incorporated into the database:

- 33 are historical incidents, arising before the initiation of the project
- 13 of the incidents were investigated remotely ("desk investigations")
- 12 incidents were investigated on-site shortly after the incident had occurred
- 7 of the investigations include laboratory examinations of fire-damaged components

The severity of the fires varied. 17 of the incidents that were caused by PV systems were classified as 'serious' (i.e. difficult to extinguish and spreading beyond the PV system). 25 incidents were localised fires (affecting only PV components and the immediate area) or 'thermal events' (smoking or smouldering that did not develop into a fire).

In 10 incidents the cause was not thought to be the PV system and in 6 incidents, there was insufficient information to arrive at a reliable conclusion, so classified as 'cause unknown'.

In general, therefore, PV fires have caused damage to PV installations themselves and sometimes to the buildings on which they are mounted. Fortunately, injuries appear to be minor to date: 5 cases of smoke inhalation (treated at scene), 1 minor burn, 1 case of shock and 1 minor knee injury.

There is 1 fatality recorded in the database, but the fire is known to have originated elsewhere in the house and not within the PV system.

The building types involved break down as follows:

- Domestic buildings 27 incidents
- Non-domestic buildings 26 incidents
- Solar farms 5 incidents

However, we strongly suspect a degree of under-reporting, especially amongst solar farms.

The review of international literature conducted under this project in 2015 [5], concluded that:

> *Where PV systems have been the cause of fires, some themes emerge. Much attention is paid to the phenomenon of electrical arcing, where a current flows across an air gap by ionising the air. High voltage arcs are extremely hot and can cause combustion of surrounding materials in less than a second. Arcing can occur where conducting parts become physically separated by mechanical movement or mis-alignment. Also, a build-up of contaminants (e.g. oxide) on electrical contacts can cause resistive heating, resulting in the breakdown of materials and subsequent arcing.*

Certain components, if incorrectly specified, poorly installed or contain manufacturing faults, are typical locations of electrical arcs:

- *DC connectors*
- *DC isolators*
- *Inverters*
- *PV modules, including by-pass diodes and junction boxes*

The experience of investigating 25 recent incidents and 33 historical incidents in the UK has resulted in some very similar findings. Of the 46 incidents that were either known or likely to have been caused by the PV system, our analysis shows that the PV components most likely to develop faults that lead to a fire incident are as follows:

- DC Isolators 16 - 18 incidents
- DC connectors 4 - 10 incidents
- Inverters 6 - 7 incidents
- DC cables 1 - 4 incidents
- PV Modules 1 - 2 incidents

In 4 cases, the origin of the fire was not traced to any particular component.

The majority of incidents (approximately 36%) that were caused by PV systems were attributed to poor installation practices. 12% were attributed to faulty products and 5% to system design errors. The causes of the remainder were unknown.

A summarised, anonymised listing of the database records can be seen in the *Evidence Report* [2].

There are anecdotal reports of power diverters presenting new fire and safety risks. These devices divert excess electricity generated by PV modules to a specific load, such as an immersion heater. However, within this project, we have yet to encounter a fire that appears to have been caused by one of these devices, so the results so far do not support this assertion.

Awareness of the project appears to be gradually building, especially amongst fire and rescue services and with the assistance of CFOA and MCS. This, coupled with seasonal effects are likely to produce further PV fire incidents in the spring and summer.

4 Recommendations for improvement of training for firefighters

As discussed in BRE's literature review on Fire and Solar PV Systems [1], national guidance for firefighters responding to PV-related fires is currently quite general and a number of Fire and Rescue Services (FRSs) have developed their own standard operating procedures (SOPs) to minimise the risk to crew when tackling fires on properties with solar PV systems.

4.1 Incident database evidence

50 of the 58 incidents that are currently logged on the database were attended to by a fire crew. 23 different FRSs are detailed in the incidents. Specific information with respect to the approach that was taken has been provided for some of the incidents by the FRSs and is summarised in Table 2.

No. of reports	Specifically stated FRS approach taken	Supporting incident references
7	Requested third party to isolate solar PV	PVF0001, PVF0028, PVF0040, PVF0042, PVF0044, PVF0049, PVF0053
5	Covered solar modules with tarpaulin or similar	PVF0004, PVF0025, PVF0027, PVF0047, PVF0052
3	FRS isolated DC side of solar PV using DC isolator switch or disconnecting DC connectors	PVF0055, PVF0056
2	Solar cable cut by FRS	PVF0052, PVF0055
2	FRS isolated AC side of solar PV using AC isolator switch or circuit breakers	PVF0051, PVF0054
3	FRS isolated system – unknown if either via DC, AC or both	PVF0004, PVF0007, PVF0015
1	Unable to isolate due to location of isolators	PVF0021
1	Obtained advice on isolation	PVF0002
2	Dynamic Risk Assessment completed	PVF0009, PVF0011

2	Standard Operating Procedures followed	PVF0027, PVF0052
1	Avoided water on panels	PVF0059
26	Unknown action taken	PVF0003, PVF0006, PVF0008, PVF0009, PVF0010, PVF0012, PVF0013, PVF0014, PVF0016, PVF0017, PVF0018, PVF0019, PVF0020, PVF0022, PVF0023, PVF0024, PVF0026, PVF0030, PVF0031, PVF0032, PVF0033, PVF0034, PVF0036, PVF0038, PVF0039, PVF0057

Table 2 Categorisation of FRS approaches to incidents

It can be seen that there seems to be little consistency in the action taken to make a system safe. During the reported incidents a number of third parties were also called in to assist with making systems safe, such as building operators engineers, solar installers, or Distribution Network Operators (DNO), leading to a delay in tackling the fire and potentially increasing risk to the responding FRS crew and third party. It was also noted that in one incident the DNO was unable to assist the FRS as they did not know how to make the solar PV system safe (PVF0002).

Of the 23 FRS included in the database, 17 confirmed that they have SOPs (or other guidance) for dealing with fires on properties with solar PV systems, however this was inconsistently reported across incidents involving the same FRS. Only one FRS specifically advised that they did not have any guidance for this situation (PVF0056).

4.2 Recommendations for FRS training

These findings suggest that there is a need for supplementing nationally accepted guidance [5] and additional training for FRS crew to be able to properly assess the risks that a solar PV system may introduce (whether as a cause to the fire, or being present at a fire incident site) and how to reduce the risks safely, quickly and effectively.

Training should include the following modules:

- Basic understanding and recognition of the PV system components and labels - in order to quickly identify the presence of a PV system, assist with risk assessments and to provide more detailed information to fire investigators and during debriefs.
- Details of the hazards that a PV system may introduce to a fire incident – including associated hazards such as potential to electrify other conductive objects.
- Safe isolation procedures – including an understanding of what parts of the system should still be considered live.
- Other approaches that can be taken to deenergise systems and the risks that these could pose to fire crews.

5 Recommendations for improving the safety of firefighters

The '*Recommendations for PV Industry*' report [3] covers PV system design choices that can enhance firefighter safety.

To date (January 2017), a total of 58 unique incidents have been investigated and incorporated into the database:

- 33 are historical incidents, arising before the initiation of the project
- 13 of the incidents were investigated remotely ("desk investigations")
- 12 incidents were investigated on-site shortly after the incident had occurred
- 7 of the investigations include laboratory examinations of fire-damaged components

Operational information from the relevant FRS has not been available in all cases (see Table 2). In 8 incidents, the local FRS was not called and/or not required. In 50 incidents the FRS was called to the fire and the project team has been able to gather operational information on 25 of these incidents.

It should be noted that 33 incidents recorded in the database are historical. Given the nature of their work firefighters may not have recalled detailed information from an incident unless they had been formally debriefed shortly after the incident and this debrief had been recorded. As such, the information outlined below was not available for all incidents.

Where possible the following questions were posed to the FRS following an incident:

1. Were the crews aware of the presence of the PV system on arrival?
2. Did crews notice a "Solar PV on roof" label near the main electrical intake?
3. If yes, did this change tactics for fighting the fire?
4. If yes, how were the tactics changed?
5. Did crews take any action(s) to make the PV system safe?
6. If yes, please specify:
7. Did the PV system cause any particular hazards for fire crews?
8. If yes, please specify:
9. Does your service have a Standard Operating Procedure or use any other guidance for dealing with fires involving PVs?
10. Did the presence of the PV system exacerbate the fire in any way?

For 17 of the incidents the response to Question 9 was affirmative, i.e. the FRS has a SOP or used other guidance for dealing with fires involving PV. However, this only accounts for eight out of 52 services across the UK. This is not a comment that the remaining FRSs lack a SOP but that we have not received any correspondence to confirm either way.

The *National Operational Guidance* (NOG) for the UK Fire and Rescue Services was updated in 2014; these updates occur in stages. One programme of work is the *Fires in the Built Environment Guidance* which BRE assisted in developing. In August 2014 a set of Knowledge Sheets (technical information for Fire and Rescue Services), was published and this included a sheet on Microgeneration renewable energy technology [9] which incorporates safety information on PV, based upon the best information that was available at the time. This information is available for FRSs to adopt into their local SOPs. The findings of this research may necessitate a revisit of the information and guidance in NOG.

For 6 incidents where the fire had spread, or was more than just a localised event, FRSs reported that, regardless of whether the PV system was involved in the fire or not, the presence of PV slowed down their progress in dealing with the fire. In 3 of those cases this was due to difficulties accessing the isolators or indeed knowing how to isolate the system. Of the 50 incidents attended to by FRS, there were 5 cases of smoke inhalation (treated at scene), 1 minor burn, 1 case of shock, 1 minor knee injury and 1 fatality. In the fatal fire, the cause of the fire was not attributed to the PV system. In all four of these incidents the injuries, whilst related to the fire, were not attributable to a delay in firefighting operations. However, such incidents should be closely monitored as delays in firefighting actions can result in worsening fire conditions.

One factor that has previously arisen (e.g. in reference [6]), is the installation of PV systems on metal roofs. However, this is only likely to be considered during an incident where it is immediately apparent to firefighters that the roof is metal e.g. industrial buildings. 1 incident, investigated as part of the Department for Communities and Local Government (DCLG) "Investigation of Real Fires" project [8], highlighted an example where the presence of a metal roof was not immediately apparent to the fire crews. In this incident the roof tiles of a terraced house were metal, and this fact was only realised when the crews attempted to remove tiles to allow the fire to vent from the property. Once they became aware that the roof covering was metal, their operational tactics changed due to the increased risk of electric shock via the roof covering.

It is clear that early notification to the FRS that a PV system is present at a property could improve safety for both civilians and firefighters, and may also prevent unnecessary delays in dealing with a fire. This will further be of benefit in protection of property as the earlier the FRS can deal with an incident the less potential for damage to property.

Information on the location of PV system safety devices, e.g. isolation switches, is also very important for FRSs to make the system as safe as possible; always with the understanding that hazards cannot be completely eliminated. There are reports of incidents [8] where the DNO has refused to attend or assist where PV systems are present. FRSs tend to contact the system installer, if possible, or a local PV engineer to isolate the system (examples are in database records PVF0001 PVF0007, PVF0011, PVF0016, PVF0018, PVF0020, PVF0032, PVF0058 and PVF0059). It should be noted that this has not prevented the FRS from taking action and extinguishing the fire but it could have a knock-on effect on the severity of a fire.

In 4 cases, FRSs reported covering PV arrays with a tarpaulin (e.g. PVF0027) in an attempt to restrict light available to the system and thus prevent production of electricity. However, one respondent to the project noted that they have no way of testing if this adequately prevented the system from generating electricity. As such, even after attempting to the control the hazard, the FRS was not confident that the risk of electric shock had been eliminated.

The NOG (detailed in Appendix A) highlights the risk to FRS from both falling debris and electrocution. In this research, out of the incidents examined there have not been any reports of PV panels falling from the structure.

Overall, whilst some basic awareness information is currently available for FRSs to use in developing their SOPs, there remains some uncertainty over exactly how systems should be rendered as safe as possible when responding to incidents. Fire-fighters on the ground need to be able to make informed, dynamic assessments of the situation to ensure the safety of the public and fire crews. It is hoped that this project will assist in further developing effective control measures to counter the hazards associated with fires involving PV systems. We anticipate using the existing NOG framework to aid dissemination of the newly acquired information to the fire and rescue services, although separate, more detailed guidance may also be useful.

Feedback from FRSs throughout the project indicates that it would be beneficial to research emergency response methods of making PV systems safe during an incident and this should be the focus of any further guidance.

5.1 Recommendations for improving safety

The research has highlighted a number of ways to improve the safety of firefighters responding to fire incidents on buildings where PV is present; these are summarised in the following recommendations:

- Information on appropriate emergency response methods of making PV systems safe – requires further research.
- Revision of NOG information – in discussion.
- Consistency of SOPs for PV across all UK FRSs – preferably using new NOG information.
- Ability to identify the presence of a PV system early on in firefighting operations – this could be improved through training and through PV installers use of the ‘Solar PV on roof’ label as required by MCS [9].
- Provision of training to fire crews – as detailed in section 4.

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6 Conclusions

The clearest feedback from FRSs so far would appear to be that they need to know how best to make systems safe on arrival and this should be the focus of any further guidance. Feedback from an FRS debrief indicated that there was also concern regarding handing the house back to the householder, once firefighting operations had ceased. Printed guidance for crews to hand to householders could be useful in this regard.

The findings suggest that there is a need for supplementing nationally accepted guidance [5] and additional training for FRS crews to be able to properly assess the risks that a solar PV system may introduce (whether as a cause to the fire, or being present at a fire incident site) and how to reduce the risks safely, quickly and effectively.

Recommendations to improve the safety of firefighters responding to fire incidents on buildings where PV is present are summarised:

- Information on appropriate emergency response methods of making PV systems safe – requires further research.
- Ability to identify the presence of a PV system early on in firefighting operations – this could be improved through training and through PV installers use of the 'Solar PV on roof' label as required by MCS [9].
- Revision of NOG information – in discussion between CFOA and BRE Fire & Safety Team.
- Consistency of SOPs for PV across all UK FRSs – preferably using new NOG information.
- Provision of training to fire crews in the following:
    - Basic understanding and recognition of the PV system components and labels - in order to quickly identify the presence of a PV system, assist with risk assessments and to provide more detailed information to fire investigators and during debriefs.
    - Details of the hazards that a PV system may introduce to a fire incident – including associated hazards such as potential to electrify other conductive objects.
    - Safe isolation procedures – including an understanding of what parts of the system should still be considered live.Other approaches that can be taken to deenergise systems and the risks that these could pose to fire crews.

References

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Appendix A Risks currently identified in the National Occupational Guidance

The NOG document Fires in the Built Environment Knowledge and Information [9] summarises the hazards associated with fires involving PV systems, as follows:

- Risk that the installations e.g. PV modules, glass from the PV modules, may break and fall onto personnel below.
- Installations may not be easily identifiable and may be hidden (flat roof).
- PV arrays which stand off from the roof may cause a channelling effect, thus exacerbating a fire affecting the roof.
- Should the roof of the building be affected by fire, then the additional mechanical loading due to the weight of the PV array, or additional wind-loading caused by the PV array, may cause early collapse of the roof.
- Poorly installed systems may obstruct or restrict use of roof windows as means of escape or hinder firefighting operations.
- There may be restricted access to isolation switches.
- General electric shock risk from PV systems and the production of potentially very high voltage DC electricity.
- Parts of the system are always live while the PV modules are exposed to daylight.
- Risk of electric shock if cables are cut or become damaged by fire.