PAGERPOWER
Urban & Renewables

Solar Photovoltaic and Building Development – Glint and Glare Guidance





PLANNING SOLUTIONS FOR:

- Solar
- Telecoms
- Railways
- Defence
- Buildings
- Wind
- Airports
- Radar
- Mitigation

www.pagerpower.com

April 2021 – Third edition

ADMINISTRATION PAGE

Reference:	Solar Photovoltaic Glint and Glare Guidance
Author and Reviewers:	Danny Scrivener, Kai Frolic and Mike Watson
Telephone:	+44 (0)1787 319001
Email:	danny@pagerpower.com, kai@pagerpower.com, mike@pagerpower.com

PAGERPOWER
Urban & Renewables

Revision History		
Issue	**Date**	**Detail of Changes**
1	April, 2017	First edition
2	October, 2018	Second edition This revision adds a methodology for the assessment of helipad operations whilst adding clarity to the previously presented methodologies through the experience gained in the time between edition 1 and 2. The methodologies have not changed significantly. High-level comments regarding the impact of building developments, particularly façades capable of producing specular reflections, is included within the foreword, which is also a new addition.
3	December, 2020	Third edition Updated Pager Power details. Updated Literature Review section Updated significance flow charts for determining the impact of solar reflections for road and dwelling receptors. Further comments on common considerations from railway stakeholders for glint and glare assessments including building and solar photovoltaic developments. Additional details regarding aviation assessments for building developments and the safeguarding of non-typical aviation receptors.
3.1	April, 2021	Update to the impact significance flow charts for road and dwelling receptors.

Stour Valley Business Centre, Sudbury, CO10 7GB

T:+44 (0)1787 319001 *E:*info@pagerpower.com *W:*www.pagerpower.com

FOREWORD

Introduction and Background

The number, size and scale of solar photovoltaic (PV) developments continues to rise, with glint and glare assessments often required within the UK, South Africa, Australia, India and elsewhere in the world. The requirement for a glint and glare assessment now extends to building developments with reflective façades. Rapid deployment of PV in the UK between 2010-2015 lead to a knowledge gap in the area of glint and glare, with assessments often required without definition of what constitutes a significant impact. Pager Power has been at the forefront of this planning issue, having now completed over 600 glint and glare assessments to date.

The original aim of the first edition of the glint and glare guidance was to produce a standardised methodology for PV developers, planners and stakeholders to follow. This was well received, adding clarity to a previously unfamiliar planning issue. The second edition, produced over a year and a half later, did not reinvent the assessment methodology for PV, it merely refined and added detail where required based on the experience gained subsequently. The requirement for glint and glare assessments of building developments, specifically those with large reflective façades, had also grown between the first and second edition and therefore further additional information regarding the methodology for assessment was provided.

The third edition now further refines the guidance and adds additional guidance for building developments, specifically in the vicinity of airports and railway infrastructure. The focus remains on the guidance for PV panels, however where required, additional information in presented for building developments.

The guidance presents the methodology recommended by Pager Power through assessment experience. It should be used for reference and ideally, the methodology should be agreed with the relevant stakeholder where an assessment is required. There may be cases where the assessment scenario does not match the guidance criteria, in this situation, a pragmatic approach is recommended.

It is understood that this guidance document has now been referred to internationally.

Guidance Basis

Prepared for:

Developers, planners and stakeholders.

Aim:

To provide guidance for assessing the impact of glint and glare from solar photovoltaic (PV) panels and building developments with large reflective façades upon surrounding receptors.

Receptors:

Dwellings (residential amenity), Roads (safety), Rail (safety) and Aviation (safety).

EXECUTIVE SUMMARY

Overview and Purpose

The purpose of this guidance document is to provide solar photovoltaic (PV) and building developers, planners and stakeholders with an assessment process for determining the effects of glint and glare (solar reflections) upon receptors surrounding a proposed solar PV and building development.

Throughout the document, the focus remains on the guidance for PV panels, however where required, additional information in presented for building developments. If a building development is not specifically mentioned, then assume the guidance is not applicable or relevant.

Formal guidance around glint and glare remains somewhat lacking in many cases. This guidance document has therefore been produced to bridge this knowledge gap pertaining to the assessment of glint and glare. The aim is to produce a standardised assessment process for developers, planners and stakeholders to reduce the element of risk associated with glint and glare.

The guidance presented is based on the following:

- Reviews of existing guidance in a variety of areas;
- Glint and glare assessment experience and industry knowledge;
- An overview of available solar reflection studies.

This guidance document is based on knowledge initially gained through analysis within the UK and Irish markets however the methodologies are deemed applicable, and have been used, for worldwide solar PV development and building development.

Key Receptors

Glint and glare can significantly affect nearby receptors under particular conditions. The key receptors with respect to glint and glare are residents in surrounding dwellings, road users, train infrastructure (including train drivers), and aviation infrastructure (including pilots and air traffic controllers). Other receptors do exist, however this guidance considers the four most common receptor types unless otherwise stated.

Modelling Requirements

A geometric glint and glare assessment model must include the following:

- The Earth's orbit around the Sun;
- The Earth's rotation;
- The Earth's orientation;

- The location of the solar PV development or building development including the reflector (solar panel or façade) area;
- The reflector's 3D orientation including azimuth angle of the solar panel or façade (the orientation of the reflectors relative to north and the reflector elevation angle;
- Local topography including receptor and panel or façade heights above mean sea level.

For increased accuracy, the model could account for the following:

- Terrain at the visible horizon;
- Local time zone and daylight savings times;
- Consideration of sunrise and sunset times;
- Determine which solar panels create the solar reflection within the solar PV development;
- Determine what area of the façade create the solar reflection from the building development;
- Azimuth range of the Sun[1] when a solar reflection is geometrically possible;
- Vertical elevation range of the Sun when a solar reflection is geometrically possible;
- High-resolution analysis i.e. undertaking multiple geometric calculations within the given solar PV development or façade area. For example, at intervals of between 1 and 20 metres;
- Consideration of the effect of non-specular reflective surfaces e.g. masonry between glass façades;
- The intensity[2] of any solar reflection produced.

Assessment Inputs – Receptors

The following paragraphs set out the key distances for identifying receptors and the height data which should be included.

Dwellings within approximately 1km of a proposed solar PV development that may have a view of the PV panels should be assessed. Terrain heights and an additional height to account for the solar panel and eye level within the relevant floor of the dwelling should also be considered. Dwellings are not typically assessed for building developments.

National roads, or those with greater significance, within approximately 1km of a proposed solar PV development that may have a view of the PV panels should be assessed. Terrain heights and

[1] The azimuth range is the angle between the Sun and North, measured clockwise around the receptor's horizon. The Sun azimuth range shows the location of the Sun when a geometric solar reflection is possible. Therefore, it is possible to determine whether the Sun and the solar reflection are both likely to be visible to a receptor.
[2] In W/cm^2 at the retina, for example.

an additional height to account for the solar panel and eye level of a road user should also be considered. Roads are not typically assessed for building developments.

Where railway infrastructure is located within approximately 100m of a proposed solar PV or building development that may have a view of the PV panels, an assessment should be undertaken. Train drivers out to 500m should be assessed. Any signals, crossings or vital railway infrastructure within 500m that could be affected by glare should be assessed especially where railway signal utilises incandescent bulb[3] technology and/or where no hood is attached. Terrain heights and an additional height to account for the solar panel/façade and eye level of a train driver or the height of a railway signal should also be considered.

Aviation receptors out to 30km[4] from a proposed PV development should be considered to determine the requirement for assessment, if any. A full technical assessment is usually undertaken for those developments located within 10km of an aerodrome or if specifically requested by the aerodrome safeguarding team. The typical receptors include the Air Traffic Control (ATC) tower and a 2-mile approach path for the relevant runway approaches. Additional receptors may be included where a solar reflection may be deemed a hazard to safety e.g. helipad approaches and the visual manoeuvring area (VMA). Aviation receptors for building developments are the same.

Assessment Significance

Determining the significance of a solar reflection varies for each receptor type. In general, the significance criteria for glint and glare effects are as follows:

- No Impact – A solar reflection is not geometrically possible or will not be visible from the assessed receptor. No mitigation required.
- Low – A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels significantly or the glare time per year is considered negligible. No mitigation required.
- Moderate – A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case scenario e.g. a solar reflection originates from a less sensitive location. Mitigation may be required.
- High – A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation will be required if the proposed development is to proceed. Mitigation and consultation is recommended.

There may be instances where the solar reflection scenario does not fall accurately within the significance categories. Where this occurs, detailed consideration of the receptors and the modelling results should be undertaken.

[3] Non-LED.
[4] Aviation stakeholders can and have requested a glint and glare assessment beyond 30km.

See the following sections where the process for determining the significance of a solar reflection is described for each receptor type:

- Section 6 – Dwellings;
- Section 7 – Road infrastructure;
- Section 8 – Railway infrastructure;
- Section 9 – Aviation infrastructure.

In each section, the process for determining the significance of a solar reflection is described comprehensively.

Guidance Conclusions

This guidance should be followed to ensure comprehensive assessment of solar PV and building developments with respect to glint and glare. This guidance is applicable for solar PV and building development anywhere in the world.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Term	Definition
Aerodrome	A defined area on land or water (including any buildings, installations, and equipment) intended to be used either wholly or in part for the arrival, departure, and surface movement of aircraft[5].
Approach Path	The descent path of an aircraft as it comes in for landing.
ATC Tower	Air Traffic Control tower – used by air traffic controllers to observe and direct aviation activity at or near to an aerodrome.
Azimuth Angle	The angle the solar panel faces relative to north (0/360 degrees).
CAA	Civil Aviation Authority.
Diffuse Reflection	The reflection of light from a surface such that the incident light is reflected at many angles rather than at just one angle.
Elevation Angle	The angle of the solar panel relative to 0 degrees (the horizontal or flat).
FAA	Federal Aviation Administration.
Façade	The reflective surface of a building development
Glare	A continuous source of bright light.
Glint	A momentary flash of bright light.
Glint and Glare	As above. Interchangeably used with the term 'solar reflection' where the specific type of reflection is not necessary.
IAA	Irish Aviation Authority.
Incandescent Light Bulb	An incandescent light bulb is an electric light with a wire filament heated to a high temperature. An electric current is passed through it until it glows with visible light.

[5] International Civil Aviation Organization (ICAO) Documents, Aerodrome Standards, Aerodrome Design and Operations. Annex 14 to The Convention on International Civil Aviation (Chicago Convention), Volume I- Aerodrome Design and Operations under Definitions.

Term	Definition
Incident Solar Reflection	The solar reflection from the solar panel appears visible and close to the location of the Sun, such that both the solar reflection and the Sun originate and are visible from a receptor's viewpoint simultaneously. The angle between the reflected light and the perpendicular (or normal) to the surface (solar panel) is the angle of incidence.
LED	A light-emitting diode (LED). It is a semiconductor diode, which glows when a voltage is applied. LED signals are brighter and more efficient than incandescent bulbs and normally do not have a reflective mirror.
Level Crossing	A crossing where (typically) a road passes over a railway line.
Level Crossing Warning Lights (LCWL)	The system of lights located next to a level crossing on a railway line, used to warn road users from crossing.
National Roads: Typically A Roads (UK) or N Roads (Ireland)	Typically a road with a one or more carriageways with a maximum speed limit of up to 60mph or 70mph (UK A Road) or 100kph (Ireland N Road). These roads typically have fast moving vehicles with moderate to busy traffic density. Other road designations or maximum speed limits may apply internationally.
Major National Roads: Typically a motorway	Typically a road with a minimum of two carriageways with a maximum speed limit of up to 70mph (UK) or 120kph (Ireland). These roads typically have fast moving vehicles with busy traffic. Other road designation or maximum speed limits may apply internationally.
Local Roads	Typically roads and lanes with the lowest traffic densities. Speed limits vary.
Normal	The mathematical term used to define the line at right angles to a reflector i.e. a solar panel.
Potential for temporary after-image	The likelihood of a solar reflection continuing to appear in one's vision after the exposure to the original image has ceased.
Railway Signal	A light or physical signalling system located beside a railway line. Used to indicate to a train driver a particular order.

Term	Definition
Receptor	A potential viewer of glint and glare effects. They may be located in a dwelling, as a pilot in a plane, as a road user, train operator etc..
Regional Roads B Roads (UK) or R Roads (Ireland)	Typically a single carriageway with a maximum speed limit of up to 60mph (UK B Road) or 80kph (Ireland R Road). The speed of vehicles will vary with a typical traffic density of low to moderate. Other road designations or maximum speed limits may apply internationally.
Runway Threshold	The beginning of the physical runway surface.
SGHAT	Solar Glare Hazard Analysis Tool - solar glint and glare model designed by Sandia National Laboratory, specifically for aviation and recommended by the FAA.
Signal Hood	A signal hood is located on a lit railway signal to screen the light from direct sunlight.
Shadow Flicker	Refers to the sunlight flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties through small openings such as windows.
Solar Reflection	Also referred to as glint or glare. Used interchangeably to describe glint or glare where the type of solar reflection is not necessary.
Specular Reflection	The mirror-like reflection of light from a surface, in which light from a single incoming direction is reflected into a single outgoing direction.

Glossary

PAGERPOWER
Urban & Renewables

PAGER POWER COMPANY PROFILE

Company Background

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 48 countries within Europe, Africa, America, Asia and Australia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially the company focus was on modelling the impact of wind turbines on radar systems.

Over the years, the company has expanded into numerous fields including:

- Renewable energy projects.
- Building developments.
- Aviation and telecommunication systems.

Pager Power prides itself on providing comprehensive, understandable and accurate assessments of complex issues in line with national and international standards. This is underpinned by its custom software, longstanding relationships with stakeholders and active role in conferences and research efforts around the world.

Pager Power's assessments withstand legal scrutiny and the company can provide support for a project at any stage.

Pager Power's Experience

Pager Power has undertaken over 600 Glint and Glare Assessments in the United Kingdom and internationally.

The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1 OVERVIEW

Introduction

1.1 Glint and glare is a planning consideration brought about through the rise and rapid deployment of solar photovoltaic (PV) development. There has been a lack of official guidance documents for developers, planners or stakeholders to follow and therefore Pager Power has produced this document to assist with this planning consideration.

1.2 The requirement for a glint and glare assessment has now extended to new building developments, or indeed any project which has the potential to produce significant glare through a specular solar reflection.

1.3 Whilst general planning guidance for solar PV development has been established, there is no specific planning guidance, in the UK and Ireland, for assessing the effects of glint and glare on surrounding receptors. There also remains no standardised guidance in regard to glare from building developments.

1.4 This guidance document has specific focus on the UK and Irish markets however the methodologies are deemed applicable for worldwide solar PV or building development.

Purpose

1.5 This guidance has been produced for developers, planners and stakeholders.

1.6 The aims of this guidance are as follows:

- To bridge the knowledge gap for all stakeholders regarding glint and glare (solar reflections) from solar PV and building developments;
- To produce a standardised and universally agreed methodology for assessing the impact of glint and glare upon receptors surrounding a proposed solar PV and building development;
- To ensure the proper and safe development of renewable energy schemes and building projects in the UK, Ireland and internationally with respect to glint and glare.

1.7 A standardised process will reduce risk for all stakeholders of a proposed solar PV or building development.

1.8 The guidance is based on industry knowledge, consultation and experience.

Scope

1.9 Glint and glare is referenced within guidance documents[6] throughout the UK and Ireland, however a specific methodology for assessing, contextualising and determining the impact of solar glint and glare are not provided for many receptor types. Aviation is covered within FAA guidance from the USA, however this is not strictly applicable within the UK and Ireland, nor is it currently endorsed by the CAA or IAA in the UK or Republic of Ireland respectively.

1.10 This guidance document aims to present a standardised methodology for assessing glint and glare for surrounding receptors, this includes:

- Residents in surrounding dwellings;
- Road users on surrounding roads;
- Railway infrastructure (including train drivers);
- Aviation infrastructure (including pilots and air traffic controllers).

Glint and Glare Definition

1.11 The reflective properties of solar PV panels vary from different manufacturers. Whilst solar panels vary in their reflectivity with some claiming 'anti-glare' properties, no solar panel absorbs 100% of the incoming light. Therefore, any solar PV panel has the potential to produce a solar reflection. The relative absorptive properties of a solar panel should be considered on a case-by-case basis.

1.12 The reflective properties of glass are similar to PV panels, with both producing reflections of similar intensities.

1.13 The definition of glint and glare can vary, however, the definition used for the purpose of this guidance is as follows:

- Glint – a momentary flash of bright light;
- Glare – a continuous source of bright light.

1.14 In context, glint will be witnessed by moderate to fast moving receptors whilst glare would be encountered by static or slow moving receptors with respect to a solar farm. The term 'solar reflection' is used to refer to both reflection types i.e. glint and glare.

[6] Overview of the associated guidance is presented in Section 3.

2 CONSULTATION

Consultation Overview

Consultation with key stakeholders is essential to ensure any concerns are suitably addressed. A list of some of the key stakeholders pertaining to safety related glint and glare issues is presented in Table 1 below.

Party	Comment
UK Civil Aviation Authority (CAA)	Key stakeholders pertaining to safety.
UK Ministry of Defence (MOD)	
Irish Department of Defence (DOD)	
Irish Aviation Authority (IAA)	
Network Rail	
Irish Rail	
Relevant Highways Agencies	

Table 1 *Stakeholder consultation*

3 LITERATURE REVIEW

3.1 A review of the available guidance and studies pertaining to solar PV developments and glint and glare is presented in this section.

Planning Guidance

UK Planning Practice Guidance

3.2 UK Planning Practice Guidance dictates that a glint and glare assessment is required in some instances. The guidance for 'Renewable and low carbon energy'[7] dictates the following with respect to glint and glare. Note only the relevant information is presented.

The deployment of large-scale solar farms can have a negative impact on the rural environment, particularly in undulating landscapes. However, the visual impact of a well-planned and well-screened solar farm can be properly addressed within the landscape if planned sensitively.

Particular factors a local planning authority will need to consider include:

- *the proposal's visual impact, the effect on landscape of glint and glare (see guidance on landscape assessment) and on neighbouring uses and aircraft safety;*
- *the extent to which there may be additional impacts if solar arrays follow the daily movement of the sun;*
- *great care should be taken to ensure heritage assets are conserved in a manner appropriate to their significance, including the impact of proposals on views important to their setting. As the significance of a heritage asset derives not only from its physical presence, but also from its setting, careful consideration should be given to the impact of large scale solar farms on such assets. Depending on their scale, design and prominence, a large scale solar farm within the setting of a heritage asset may cause substantial harm to the significance of the asset;*
- *the potential to mitigate landscape and visual impacts through, for example, screening with native hedges.*
- *The approach to assessing cumulative landscape and visual impact of large scale solar farms is likely to be the same as assessing the impact of wind turbines. However, in the case of ground-mounted solar panels it should be noted that with effective screening and appropriate land topography the area of a zone of visual influence could be zero.*

---

[7] UK Planning Practice Guidance, 2015. Renewable and low carbon energy - What are the particular planning considerations that relate to large scale ground-mounted solar photovoltaic Farms? Last accessed 01.07.2020.

3.3 The UK planning guidance does not provide a specific methodology for assessing the impact of glint and glare.

Road Safety Guidance

UK Highway Code

3.4 Information relating to solar glare and general guidelines for safer driving is presented in the UK's Highway Code8. Each country will have their own guidance with respect to road safety. The relevant information is presented below for reference. Note only the relevant information is presented.

93 Slow down, and if necessary stop, if you are dazzled by bright sunlight.

125 The speed limit is the absolute maximum and does not mean it is safe to drive at that speed irrespective of conditions. Driving at speeds too fast for the road and traffic conditions is dangerous. You should always reduce your speed when:

- *the road layout or condition presents hazards, such as bends;*
- *sharing the road with pedestrians, cyclists and horse riders, particularly children, and motorcyclists;*
- *weather conditions make it safer to do so;*
- *driving at night as it is more difficult to see other road users.*

146 Adapt your driving to the appropriate type and condition of road you are on. In particular:

- *do not treat speed limits as a target. It is often not appropriate or safe to drive at the maximum speed limit;*
- *take the road and traffic conditions into account. Be prepared for unexpected or difficult situations, for example, the road being blocked beyond a blind bend. Be prepared to adjust your speed as a precaution;*
- *where there are junctions, be prepared for road users emerging;*
- *in side roads and country lanes look out for unmarked junctions where nobody has priority;*
- *be prepared to stop at traffic control systems, road works, pedestrian crossings or traffic lights as necessary;*
- *try to anticipate what pedestrians and cyclists might do. If pedestrians, particularly children, are looking the other way, they may step out into the road without seeing you.*

[8] The Highway Code, 2016. Department of Transport, UK Government. Last accessed 01.07.2020.

3.5 Different countries have various highway standards that must be followed. The UK Highway Code states that a driver should be aware of particular hazards such as glare from the Sun, and should adjust their driving style appropriately. Solar panels reflect sunlight producing solar reflections under specific conditions, therefore it is advised that this guidance is considered.

Railway Guidance

3.6 It is understood that that railway guidance with respect to signalling has changed[9]. The following historical guidance is therefore presented for reference only.

UK Network Rail Guidance

3.7 This section provides an overview of the relevant railway guidance with respect to the siting of signals on railway lines. Network Rail is the stakeholder of the UK's railway infrastructure[10]. Generally, a railway operator's concerns would likely to relate to the following:

- The development producing a solar reflection that affects train drivers;
- The development producing a solar reflection towards level crossing warning lights (LCWL) or level crossings; and
- The development producing a solar reflection that affects railway signals.

3.8 The railway guidelines are presented below. The extract is taken from section 3.2 of the 'Guidance on Signal Positioning and Visibility' which details the visibility of signals, train drivers' field of vision and the implications with regard to signal positioning. Note only the relevant information is presented.

> ***3.2 The visibility of signals***
>
> ***3.2.1 Overview***
>
> *The effectiveness of an observer's visual system in detecting the existence of a target will depend upon the object's position in the observer's visual field, its contrast with its background, its luminance properties, and the observer's adaptation to the illumination level of the environment. It is also influenced by the processes relating to colour vision, visual accommodation, and visual acuity. Each of these issues is described below.*
>
> ***3.2.2 Field of vision***
>
> *The field of vision, or visual field, is the area of the visual environment that is registered by the eyes when both eyes and head are held still. The normal extent of the visual field is approximately 135 degrees in the vertical plane and 200 degrees in the horizontal plane.*
> *The visual field is normally divided into central and peripheral regions: the central field being the area that provides detailed information. This extends from the central point (0 degrees) to approximately 30 degrees at each eye. The peripheral field extends from 30 degrees out to the edge of the visual field.*

---

[9] Known to Pager Power as of August 2020.

[10] Guidance on Signal Positioning and Visibility, December 2003. Railway Group Guidance Note. Last accessed 28.03.2017.

Objects are seen more quickly and identified more accurately if they are positioned towards the centre of the observer's field of vision, as this is where our sensitivity to contrast is highest. Peripheral vision is particularly sensitive to movement and light.

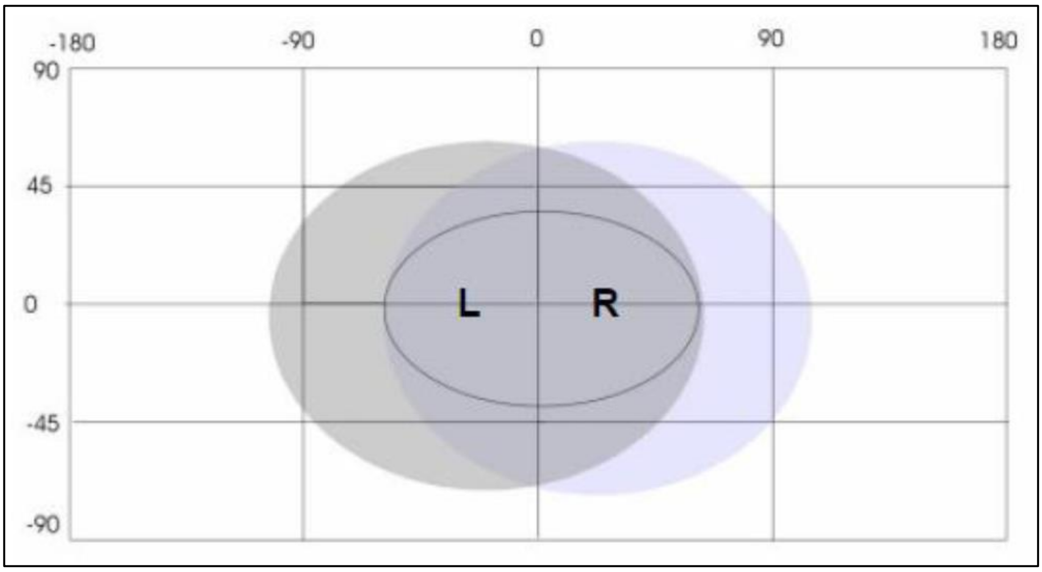

Figure 1 *Field of view*

In the diagram above, the two shaded regions represent the view from the left eye (L) and the right eye (R) respectively. The darker shaded region represents the region of binocular overlap. The oval in the centre represents the central field of vision.

Research has shown that vehicle drivers search for signs/signals towards the centre of the field of vision. As approach speed increases, drivers demonstrate a tunnel vision effect and focus only on objects in a field of + 8° from the direction of travel

3.2.2.1 Field of vision

*Drivers become increasingly dependent on central vision for signal detection at increasing train speeds, and even minor distractions can reduce the visibility of the signal if it is viewed towards the peripheral field of vision. (**D I**)*

*Because of our sensitivity to movement in the peripheral field, the presence of clutter to the sides of the running line, for example, fence posts, lamp-posts, traffic, or non-signal lights, such as house, factory or security lights, can be highly distracting. (**D I**)*

3.2.2.2 Implications

*Signals should be at a height and distance from the running line that permits them to be viewed towards the centre of the field of vision. (**D**)*

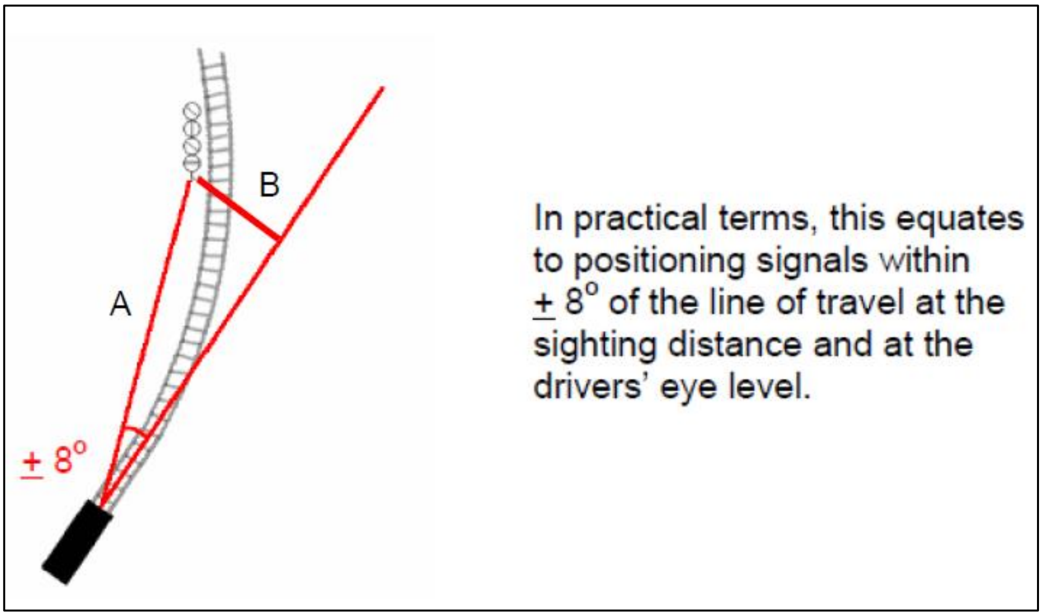

Figure 2 *Signal positioning*

*'Car stop' signs should be positioned such that, if practicable, platform starting signals and 'OFF' indicators can be seen in the driver's central field of vision. (**D**)*

*If possible, clutter and non-signal lights in a driver's field of view should be screened off or removed so that they do not cause distraction. (**D I**)*

The distance at which the 8° cone along the track is initiated is dependent on the minimum reading time and distance which is associated to the speed of trains along the track. The extract below is taken from section B5 (pages 8-9) of the guidance which details the required minimum reading time for a train driver when approaching a signal. Note only the relevant information is presented.

'B5.2.2 Determining the assessed minimum reading time

GE/RT8037

The assessed minimum reading time shall be no less than eight seconds travelling time before the signal.

The assessed minimum reading time shall be greater than eight seconds where there is an increased likelihood of misread or failure to observe. Circumstances where this applies include, but are not necessarily limited to, the following:

a) the time taken to identify the signal is longer (for example, because the signal being viewed is one of a number of signals on a gantry, or because the signal is viewed against a complex background)

b) the time taken to interpret the information presented by the signal is longer (for example, because the signal is capable of presenting route information for a complex layout ahead) *c) there is a risk that the need to perform other duties could cause distraction from viewing the signal correctly (for example, the observance of lineside signs, a station stop between the caution and stop signals, or DOO (P) duties)*

d) the control of the train speed is influenced by other factors (for example, anticipation of the signal aspect changing).

The assessed minimum reading time shall be determined using a structured format approved by the infrastructure controller.

3.9 Network Rail guidance does not specifically reference the effect of glint and glare from solar PV developments on railway infrastructure. Nonetheless, the guidance references the importance of signal visibility and driver awareness, hence the guidance has merit when determining whether glint and glare will have a significant impact on railway safety.

Aviation Guidance

UK CAA Guidance

3.10 The UK Civil Aviation Authority (CAA) issued interim guidance relating to Solar Photovoltaic Systems (SPV) on 17 December 2010 and was subject to a CAA information alert 2010/53. The formal policy was cancelled on September 7th, 2012[11] however it remains the most recent and comprehensive CAA guidance produced to date. The CAA guidance is presented in the section below. Note only the relevant information is presented.

> **Interim CAA Guidance - Solar Photovoltaic Systems**
>
> *BACKGROUND*
>
> *1 Airport interest in solar energy is growing rapidly as a way to reduce operating costs and to demonstrate a commitment to renewable energy and sustainable development. In response, the CAA is seeking to develop its policy on the installation of Solar Photovoltaic (SPV) Systems and their impact on aviation. In doing so, it is reviewing the results of research having been carried out in the United States by the Federal Aviation Administration (FAA) culminating in the publication of Technical Guidance for Evaluating Solar Technologies on Airports[12] and also reviewing guidance issued by other National Aviation Safety Administrations and Authorities on this subject.*
>
> *2 On completion of the review, the CAA, together with the assistance of other aviation stakeholders, will develop a policy and provide formal guidance material on the installation of SPV, principally on or in the vicinity[13] of licensed aerodromes but will also include guidance on installations away from aerodromes (or 'en-route'[14]). This document therefore constitutes interim CAA guidance until a formal policy has been developed.*
>
> *DISCUSSION*
>
> *3 At present the key safety issue is perceived to be the potential for reflection from SPV to cause glare, dazzling pilots or leading them to confuse reflections with aeronautical lights. Whilst permission is not required from the CAA for any individual or group to shine or reflect a light or lights into the sky, SPV developers should be aware of the requirements to comply with the Air Navigation Order (ANO) 2009. In particular, developers and Local Planning Authorities (LPA) should be cognisant of the following articles of the ANO with respect to any SPV development regardless of location:*
>
> - *Article 137 – Endangering safety of an aircraft.*

[11] CAA, 2010. Interim CAA Guidance - Solar Photovoltaic Systems. Last accessed 28.03.2017.
[12] Discussed in the following section.
[13] *'In this context, the term "in the vicinity" refers to officially safeguarded aerodromes noted in the Planning Circulars (see Paragraph 10) and a distance of up to 15km from the 'Aerodrome Reference Point' or the centre of the longest runway.'*
[14] *'SPV installations proposed further than 15km from an aerodrome are considered "en-route" developments, and may still require consultation with the CAA for an assessment on the impact, if any, to CNS equipment.'*

- *Article 221 – Lights liable to endanger.*
- *Article 222 – Lights which dazzle or distract.*

4 The potential for SPV installations to cause electromagnetic or other interference with aeronautical Communications Navigational and Surveillance equipment (CNS) must be considered by the SPV developer, in coordination with the CAA, the aerodrome Air Traffic Service provider (ATS), the Air Navigation Service Provider (ANSP) and/or NATS and the MoD, as required.

5 Where SPV systems are installed on structures that, for example, extend above the roofline of tall buildings (either on, or 'off-aerodrome'), or where they are installed in the vertical plane (on plinths or towers), then there may be the potential for creating an obstacle hazard to aircraft and - in addition to the potential for creating turbulence hazard to aircraft - any infringement of the aerodrome Obstacle Limitation Surfaces (OLS) shall also need to be considered by the Aerodrome Licence Holder (ALH).

6 For all planned SPV installations it is best practice for the developer to consult with the operators of nearby aerodromes before any construction is initiated.

7 An ALH, in agreement with their LPA, may wish to initiate procedures so that it is only consulted on SPV planning applications at shorter distances from the aerodrome (for example within a 5 km radius), or at distances that would limit SPV development from within the aircraft operating visual circuit; however, this is at the discretion of the ALH and no CAA approval or endorsement of this decision is necessary.

RECOMMENDATIONS

8. It is recommended that, as part of a planning application, the SPV developer provide safety assurance documentation (including risk assessment) regarding the full potential impact of the SPV installation on aviation interests.

9. Guidance on safeguarding procedures at CAA licensed aerodromes is published within CAP 738 Safeguarding of Aerodromes and advice for unlicensed aerodromes is contained within CAP 793 Safe Operating Practices at Unlicensed Aerodromes.

10. Where proposed developments in the vicinity of aerodromes require an application for planning permission the relevant LPA normally consults aerodrome operators or NATS when aeronautical interests might be affected. This consultation procedure is a statutory obligation in the case of certain major airports, and may include military establishments and certain air traffic surveillance technical sites. These arrangements are explained in Department for Transport Circular 1/2003 and for Scotland, Scottish Government Circular 2/2003.

11. In the event of SPV developments proposed under the Electricity Act, the relevant government department should routinely consult with the CAA. There is therefore no requirement for the CAA to be separately consulted for such proposed SPV installations or developments.

12. If an installation of SPV systems is planned on-aerodrome (i.e. within its licensed boundary) then it is recommended that data on the reflectivity of the solar panel material should be included in any assessment before installation approval can be granted. Although approval for installation is the responsibility of the ALH, as part of a condition of a CAA Aerodrome Licence, the ALH is required to obtain prior consent from CAA Aerodrome Standards Department before any work is begun or approval to the developer or LPA is granted, in accordance with the procedures set out in CAP 791 Procedures for Changes to Aerodrome Infrastructure.

13. During the installation and associated construction of SPV systems there may also be a need to liaise with nearby aerodromes if cranes are to be used; CAA notification and permission is not required.

14. The CAA aims to replace this informal guidance with formal policy in due course and reserves the right to cancel, amend or alter the guidance provided in this document at its discretion upon receipt of new information.

15. Further guidance may be obtained from CAA's Aerodrome Standards Department via aerodromes@caa.co.uk.

3.11 The CAA Guidance does not provide a methodology for assessing the effects of glint and glare on aviation infrastructure. Many aviation stakeholders under the umbrella of the CAA in the UK utilise the US FAA guidance presented on the following page. It is known that other countries internationally recommend the FAA guidance and it remains the most detailed methodology for assessing glint and glare internationally. The FAA guidance is presented in the following subsection.

US FAA Guidance

3.12 The most comprehensive guidelines available for the assessment of solar PV developments near aerodromes were produced initially in November 2010 by the United States Federal Aviation Administration (FAA) and updated in 2013.

3.13 The 2010 document is entitled 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'[15].

3.14 The 2013 version is entitled 'Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'[16].

3.15 The 2018 version is entitled 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'[17] and is version 1.1 of the 2013 edition. The key changes are as follows:

Version 1.1 (April 2018):

o Updated Section 3.1.2, Reflectivity, to incorporate the latest information about evaluating solar glint and glare.

o Updated corresponding references to glare throughout the document.

o Clarified the relationship between solar energy and the FAA's Voluntary Airport Low Emissions (VALE) program in Section 5.3.2.

o Added information about the FAA's Airport Energy Efficiency Program to Section 5.3.3.

o Updated FAA Contact information on Appendix A (where appropriate).

3.16 Key points[18] from the latest FAA guidance produced in 2018 are presented in the following section.

16. Abstract

Airport interest in solar energy is growing rapidly as a way to reduce airport operating costs and to demonstrate a commitment to sustainable development. In response, the Federal Aviation Administration (FAA) has prepared Technical Guidance for Evaluating Selected Solar Technologies on Airports to meet the regulatory and informational needs of the FAA Airports organization and airport sponsors.

For airports with favorable solar access and economics, this report provides a checklist of FAA procedures to ensure that proposed photovoltaic or solar thermal hot water systems are safe and pose no risk to pilots, air traffic controllers, or airport operations. Case studies of operating

---

[15] FAA, 2010. Technical Guidance for Evaluating Selected Solar Technologies on Airports. Last accessed 28.03.2017.
[16] FAA, 2013. Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports. Last accessed 28.03.2017.
[17] FAA, 2018. Technical Guidance for Evaluating Selected Solar Technologies on Airports. Last accessed 06.07.2020.
[18] Edited to include only key information with respect to assessing glint and glare from solar PV developments.

airport solar facilities are provided, including Denver International, Fresno Yosemite International, and Albuquerque International Sunport.

…

Preface

Over 15 airports around the country are operating solar facilities and airport interest in solar energy is growing rapidly. In response, the Federal Aviation Administration (FAA) has prepared this report, Technical Guidance for Evaluating Selected Solar Technologies on Airports, to meet the regulatory and information needs of FAA personnel and airport sponsors in evaluating airport solar projects.

The guidance is intended to provide a readily usable reference for FAA technical staff who review proposed airport solar projects and for airport sponsors that may be considering a solar installation. It addresses a wide range of topics including solar technology, electric grid infrastructure, FAA safety regulations, financing alternatives, and incentives.

Airport sponsors are interested in solar energy for many reasons. Solar technology has matured and is now a reliable way to reduce airport operating costs. Environmentally, solar energy shows a commitment to environmental stewardship, especially when the panels are visible to the traveling public. Among the environmental benefits are cleaner air and fewer greenhouse gases that contribute to climate change. Solar use also facilitates small business development and U.S. energy independence.

While offering benefits, solar energy introduces some new and unforeseen issues, like possible reflectivity and communication systems interference. The guidance discusses these issues and offers new information that can facilitate FAA project reviews, including a flow chart of FAA procedures to ensure that proposed systems are safe and pose no risks to pilots, air traffic controllers, or airport operations.

The guidance includes case studies of operating solar projects at Denver International, Fresno Yosemite International, Metropolitan Oakland International, Meadows Field (Bakersfield), and Albuquerque International Sunport. Each case study highlights a particular area of interest such as the selected technology, siting considerations, financing, and regulatory requirements.

…

1 AIRPORTS AND SOLAR ENERGY: CHARTING A COURSE

Though solar energy has been evolving since the early 1990's as a mainstream form of renewable energy generation, the expansion in the industry over the past 10 years and corresponding decrease in prices has only recently made it a practical consideration for airports. Solar energy presents itself as an opportunity for FAA and airports to produce on-site electricity and to reduce long-term electricity use and energy costs. While solar energy has many benefits, it does introduce some new and unforeseen issues, like possible glare (also referred to as reflectivity) and communication systems interference, which have complicated FAA review and *approval of this technology. This guide discusses such issues and how FAA reviews for solar projects can be streamlined and standardized to a greater extent.*

…

3.1.2 Reflectivity

Reflectivity refers to light that is reflected off surfaces. The potential effects of reflectivity are glint (a momentary flash of bright light) and glare (a continuous source of bright light). These two effects are referred to hereinafter as "glare," which can cause a brief loss of vision, also known as flash blindness.

FAA Order 7400.2, Procedures for Handling Airspace Matters, defines flash blindness as "generally, a temporary visual interference effect that persists after the source of illumination has ceased."

The amount of light reflected off a solar panel surface depends on the amount of sunlight hitting the surface, its surface reflectivity, geographic location, time of year, cloud cover, and solar panel orientation. As illustrated on Figure 16[19]*, flat, smooth surfaces reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces reflect light in a diffused or scattered manner and, therefore, the light will not be received as bright.*

CSP systems use mirrors to maximize reflection and focus the reflected sunlight and associated heat on a design point to produce steam, which generates electricity. About 90 percent of sunlight is reflected. However, because the reflected sunlight is controlled and focused on the heat collecting element (HCE) of the system, it generally does not reflect back to other sensitive receptors. Another source of reflection in a CSP system is the light that contacts the back of the HCE and never reaches the mirror. Parts of the metal frame can also reflect sunlight. In central receiver (or power tower) applications, the receiver can receive concentrated sunlight that is up to a thousand times the sun's normal irradiance. Reflections from a central receiver, although approximately 90% absorptive, can still reflect a great deal of sunlight.

Solar PV and SHW panels are constructed of dark, light-absorbing materials and covered with an anti-reflective coating designed to maximize absorption and minimize reflection. However, the glass surfaces of solar PV and SHW systems also reflect sunlight to varying degrees throughout the day and year. The amount of reflected sunlight is based on the incidence angle of the sun relative to the light-sensitive receptor (e.g., a pilot or air traffic tower controller). The amount of reflection increases with lower incidence angles. In some situations, 100% of the sun's energy can be reflected from solar PV and SHW panels.

Because solar energy systems introduce new visual surfaces to an airport setting where reflectivity could result in glare that can cause flash blindness to those that require clear,

[19] Shown as figure 3 in this report.

unobstructed vision, project proponents should evaluate reflectivity during project siting and design.

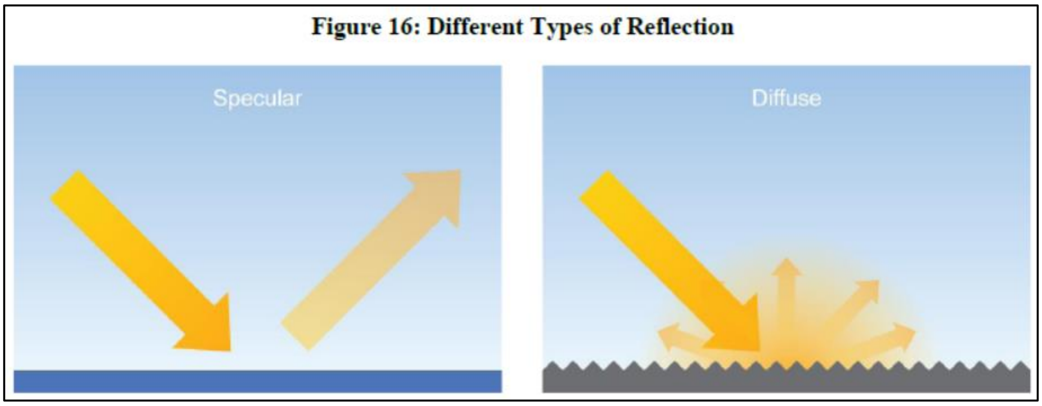

Figure 3 *Specular versus diffuse reflections*

Completing an Individual Glare Analysis

Evaluating glare for a specific project should be an iterative process that looks at one or more of the methodologies described below. Airport sponsors should coordinate closely with the FAA's Office of Airports to evaluate the potential for glint and glare for solar projects on airport property. These data should include a review of existing airport conditions and a comparison with existing sources of glare, as well as related information obtained from other airports with experience operating solar projects.

Because the FAA has no specific standards for airport solar facilities and potential glare, the type of glare analysis may vary. Depending on site specifics (e.g., existing land uses, location and size of the project) an acceptable evaluation could involve one or more of the following levels of assessment:

(1) A qualitative analysis of potential impact in consultation with the Air Traffic Control Tower, pilots, and airport officials

(2) A demonstration field test with solar panels at the proposed site in coordination with Air Traffic Control Tower personnel

(3) A geometric analysis to determine days and times when there may be an ocular impact.

The FAA should be consulted after completing each of the following steps to determine if potential reflectivity issues have been adequately considered and addressed.

The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and system design.

1. Assessing Baseline Reflectivity Conditions

Reflection in the form of glare is present in current aviation operations. The existing sources of glare come from glass windows, auto surface parking, rooftops, and water bodies. At airports, existing reflecting surfaces may include hangar roofs, surface parking, and glassy office buildings. To minimize unexpected glare, windows of air traffic control towers and airplane *cockpits are coated with anti-reflective glazing. Operators also wear polarized eye wear. Potential glare from solar panels should be viewed in this context. Any airport considering a solar PV project should first review existing sources of glare at the airport and the effectiveness of measures used to mitigate that glare.*

2. Tests in the Field

Potential glare from solar panels can easily be viewed at the airport through a field test. A few airports have coordinated these tests with FAA Air Traffic Controllers to assess the significance of glare impacts. To conduct such a test, a sponsor can take a solar panel out to proposed location of the solar project, and tilt the panel in different directions to evaluate the potential for glare onto the air traffic control tower. For the two known cases where a field test was conducted, tower personnel determined the glare was not significant. If there is a significant glare impact, the project can be modified by ensuring panels are not directed in that direction.

3. Geometric Analysis

Geometric studies are the most technical approach for reflectivity issues. They are conducted when glare is difficult to assess through other methods. Studies of glare can employ geometry and the known path of the sun to predict when sunlight will reflect off of a fixed surface (like a solar panel) and contact a fixed receptor (e.g., control tower). At any given site, the sun moves across the sky every day and its path in the sky changes throughout year. This in turn alters the destination of the resultant reflections since the angle of reflection for the solar panels will be the same as the angle at which the sun hits the panels. The larger the reflective surface, the greater the likelihood of glare impacts. Figure 17 provides an example of such a geometric analysis (not shown).

Facilities placed in remote locations, like the desert, will be far from receptors and therefore potential impacts are limited to passing aircraft. Because the intensity of the light reflected from the solar panel decreases with increasing distance, an appropriate question is how far you need to be from a solar reflected surface to avoid flash blindness. It is known that this distance is directly proportional to the size of the array in question23 but still requires further research to definitively answer.

The FAA Airport Facilities Terminal Integration Laboratory (AFTIL), located at the William J. Hughes Technical Center at Atlantic City International Airport, provides system capabilities to evaluate control tower interior design and layout, site selection and orientation, height determination studies, and the transition of equipment into the airport traffic control tower environment. AFTIL regularly conducts computer assessments of potential penetrations of airspace for proposed airport design projects and has modeled the potential characteristics of glare sources, though not for solar projects. AFTIL may be a resource for regional FAA officials and sponsors who seek to evaluate the potential effects of glare from proposed solar projects.

Experiences of Existing Airport Solar Projects

Solar installations are presently operating at a number of airports, including megawatt-sized solar facilities covering multiple acres. Air traffic control towers have expressed concern about *glint and glare from a small number of solar installations. These were often instances when solar installations were sited between the tower and airfield, or for installations with inadequate or no reflectivity analysis. Adequate reflectivity analysis and alternative siting addressed initial issues at those installations*

3.17 The previous 2013 guidance stated that any proposed solar PV development should not produce glint and glare towards the ATC Tower (existing or proposed). ‘No glint and glare’ or glare with a ‘low potential for temporary after-image’ is acceptable towards any existing or proposed 2-mile runway approach path[20]. Glare of greater intensity is not acceptable towards a 2-mile runway approach. Most aerodromes[21] still apply the 2013 guidance. The 2018 update offers three assessment options however where a proposed solar development is located where a risk to aviation safety is possible, geometric analysis, as per the 2013 guidance, will likely be the only option available to alleviate concerns.

---

[20] As per the Solar Glare Hazard Analysis Tool (SGHAT), developed by Sandia National Laboratories – discussed in the 2013 guidance.

[21] Based on Pager Power’s assessment experience.

The Air Navigation Order

3.18 The Air Navigation Order (ANO) from 2009[22] contains general aviation legislation with respect to aviation safety. Key points relating to general safety and light as a hazard are presented below. Note only the relevant information is presented.

The Air Navigation Order 2009

'Endangering safety of an aircraft

137. A person must not recklessly or negligently act in a manner likely to endanger an aircraft, or any person in an aircraft.

Lights liable to endanger

221.—(1) A person must not exhibit in the United Kingdom any light which—

(a) by reason of its glare is liable to endanger aircraft taking off from or landing at an aerodrome; or

(b) by reason of its liability to be mistaken for an aeronautical ground light is liable to endanger aircraft.

(2) If any light which appears to the CAA to be a light described in paragraph (1) is exhibited, the CAA may direct the person who is the occupier of the place where the light is exhibited or who has charge of the light, to take such steps within a reasonable time as are specified in the direction—

(a) to extinguish or screen the light; and

(b) to prevent in the future the exhibition of any other light which may similarly endanger aircraft.

(3) The direction may be served either personally or by post, or by affixing it in some conspicuous place near to the light to which it relates.

(4) In the case of a light which is or may be visible from any waters within the area of a general lighthouse authority, the power of the CAA under this article must not be exercised except with the consent of that authority.

Lights which dazzle or distract

222. A person must not in the United Kingdom direct or shine any light at any aircraft in flight so as to dazzle or distract the pilot of the aircraft.'

[22] The Air Navigation Order, 2009. No. 3015. Last accessed 01.07.2020.

3.19 The document states that no ‘light’, ‘dazzle’ or ‘glare’ should be produced which would produce a detrimental impact to aircraft safety. This guidance is referenced within the CAA guidance.

4 MODELLING PARAMETER REQUIREMENTS

4.1 A glint and glare assessment requires a geometric model to accurately predict whether a solar reflection is geometrically possible towards a receptor.

Geometric Modelling Requirements

4.2 The requirements for a geometric model are presented below. Failure to include the parameters below is likely to result an over-simplified output that would not be considered reliable in the context of predicted impact. The calculations are three dimensional and complex, and must account for the following:

- The Earth's orbit around the Sun;
- The Earth's rotation;
- The Earth's orientation;
- The location of the solar PV development or building development including the reflector (solar panel or façade) area;
- The reflector's 3D orientation including azimuth angle of the solar panel or façade (the orientation of the reflectors relative to north and the reflector elevation angle;
- Local topography including receptor and reflector (panel or façade) heights above mean sea level.

For increased accuracy, the model could account for the following:

- Terrain at the visible horizon;
- Local time zone and daylight savings times;
- Consideration of sunrise and sunset times;
- Determine which solar panels create the solar reflection within the solar PV development;
- Determine what area of the façade create the solar reflection from the building development;
- Azimuth range of the Sun[23] when a solar reflection is geometrically possible;
- Vertical elevation range of the Sun when a solar reflection is geometrically possible;
- High-resolution analysis i.e. undertaking multiple geometric calculations within the given solar PV development or façade area. For example, at intervals of between 1 and 20 metres;

[23] The azimuth range is the angle between the Sun and North, measured clockwise around the receptor's horizon. The Sun azimuth range shows the location of the Sun when a geometric solar reflection is possible. Therefore, it is possible to determine whether the Sun and the solar reflection are both likely to be visible to a receptor.

- Consideration of the effect of non-specular reflective surfaces e.g. masonry between glass façades;
- The intensity[24] of any solar reflection produced.

Geometric Modelling Overview

4.3 Solar reflections from a solar panel or a façade made of glass are specular meaning that a high percentage of incoming light is reflected in a particular direction. The direction of a specular solar reflection from a flat reflector is calculated by considering the normal. The normal is an imaginary line perpendicular to the reflective surface and originates from the point the incoming light intercepts the face of the reflector. Figure 4 and Figure 5 below may be used to aid understanding of the reflection calculation process.

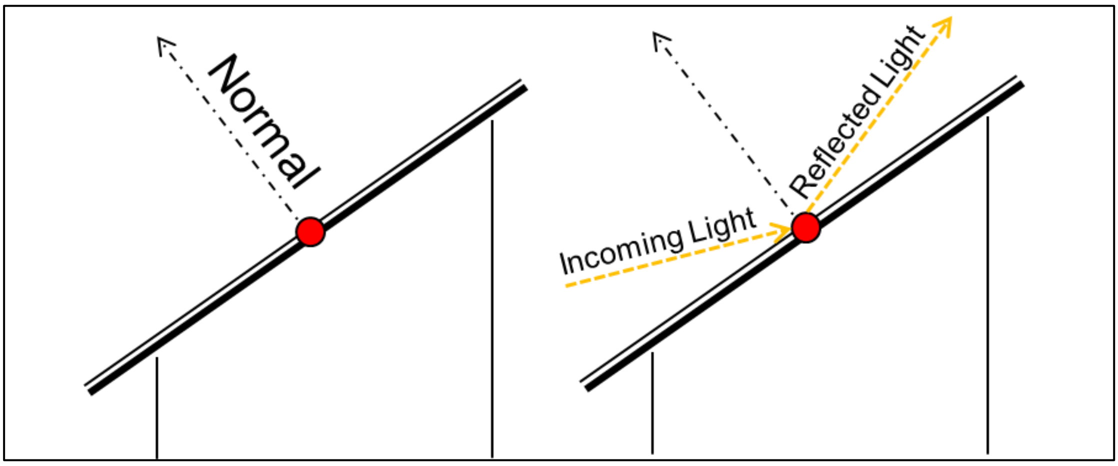

Figure 4 *Illustration showing normal and solar reflection from a solar panel (side on).*

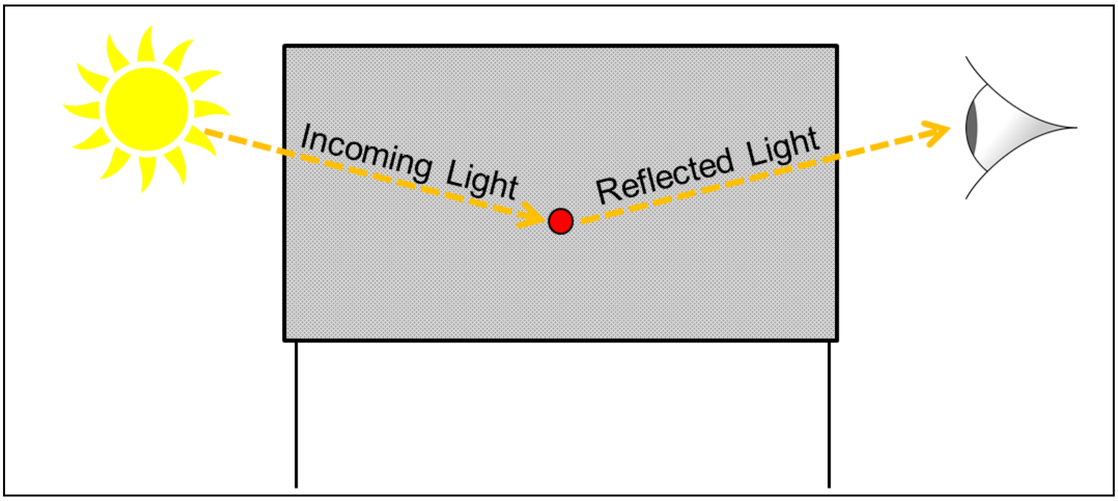

Figure 5 *Illustration showing solar reflection from a solar panel (top down).*

[24] In W/cm^2 at the retina, for example.

4.4 The direction of a solar reflection is also dependent on the elevation angle and the azimuth angle of a solar panel. The solar panel elevation angle and azimuth angle are illustrated in Figure 6 below.

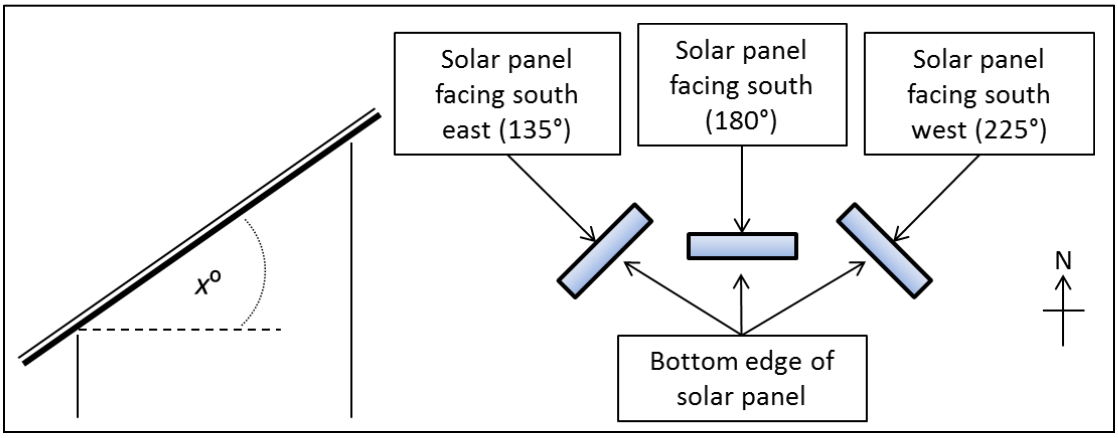

Figure 6 *Illustration showing panel elevation angle (side-on) and panel azimuth angle (top down)*

4.5 The left image in Figure 6 shows the panel elevation angle. A typical panel elevation angle value for x in the UK and Ireland is 15°-35°. The right image shows the panel azimuth angle viewed from a top down perspective. A typical panel azimuth angle in the UK and Ireland is 180° (facing south towards the equator). Building façades are typically at 90 degrees to the horizontal, however some buildings, such as the Shard in London (UK), do not have façades that are perpendicular to the ground.

Geometric Modelling Methodology Overview

4.6 A geometric solar reflection model needs to consider a number of factors when determining whether a solar refection is geometrically possible towards a surrounding receptors, and if so, the duration throughout the year. The following information is required for a complete geometric solar reflection model:

- A model of the Sun's path throughout the sky for an entire selected year;
- For calculating a solar reflection:
  - The 3D angle between the source and the normal;
  - The azimuth and elevation of the solar reflection, by verifying the following:
    - That the angle between source (the Sun) and normal (relative to ther reflector, considering its elevation and azimuth angle) is equal to the angle between the normal and solar reflection;
    - That the source, normal and solar reflection are in the same plane;
    - A model of the path of the Sun relative to the reflector area based on the reflector's latitude and longitude;
    - The assessed receptor location's latitude and longitude relative to the above.

- The model must then be run to determine whether the Sun is ever in a position within the sky to create a solar reflection from the reflectors towards the assessed receptor. This must consider the relative heights of the reflectors and receptors. Where a solar reflection is geometrically possible, a date time graph is a suitable representational format.

4.7 The process outlined above does not describe the full methodology for undertaking a detailed geometric glint and glare assessment however, it presents the key criteria that must be considered within a model.

Modelling Parameter Requirement Conclusions

4.8 Various modelling methodologies can be used to model solar reflections from the Sun. The process outlined provides general guidance for the parameters that should be built into a geometric solar reflection model.

5 GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

5.1 The significance of glint and glare will vary for different receptors. This section presents a general overview of the significance criteria with respect to experiencing a solar reflection.

Impact Significance Definition

5.2 For each glint and glare assessment, an overall conclusion should be made with reference to the requirement for mitigation for each assessed receptor. Table 2 below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels significantly.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation and/or recommendations for or against mitigation should be made by an expert on a case by case basis with suitable reasoning.

Impact Significance	Definition	Mitigation Requirement
High	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation and consultation is recommended.	Mitigation will be required if the proposed development is to proceed.

Table 2 *Impact significance definition*

5.3 Figure 7 on the following page highlights the general conditions under which a solar reflection may be possible. These are key considerations when determining whether a solar reflection is to be considered significant and whether mitigation should be implemented.

General Overview – Determining Significant Glint and Glare Effects

5.4 The following six conditions should be considered when determining whether a predicted solar reflection will produce an impact (low to high) for the assessed receptors. These conditions are illustrated in Figure 7 to the right. Each one is explained further below.

1. The reflector can be seen by the receptor i.e. there is line of sight between the observer (receptor) and the reflector;
2. The location of the receptor relative to the solar reflection. The significance of a solar reflection may be dependent on its location of origin relative to the location of the receptor;
3. The time of day when the Sun is in the position to produce a solar reflection from a reflector towards an assessed receptor[25]. Some times of day may be more significant than others for some receptors;
4. The path between the Sun and reflector is clear of obstruction i.e. there is a line of sight between the Sun and the reflector when the Sun is at a location in the sky where it can produce a solar reflection;
5. The solar reflection is not coming from the same direction as the Sun. A solar reflection is less significant when a receptor is already facing directly at the Sun;
6. A momentary exposure is less significant than a prolonged one. Therefore, the duration of the solar reflection should be considered for static receptors i.e. dwellings or ATC Towers.

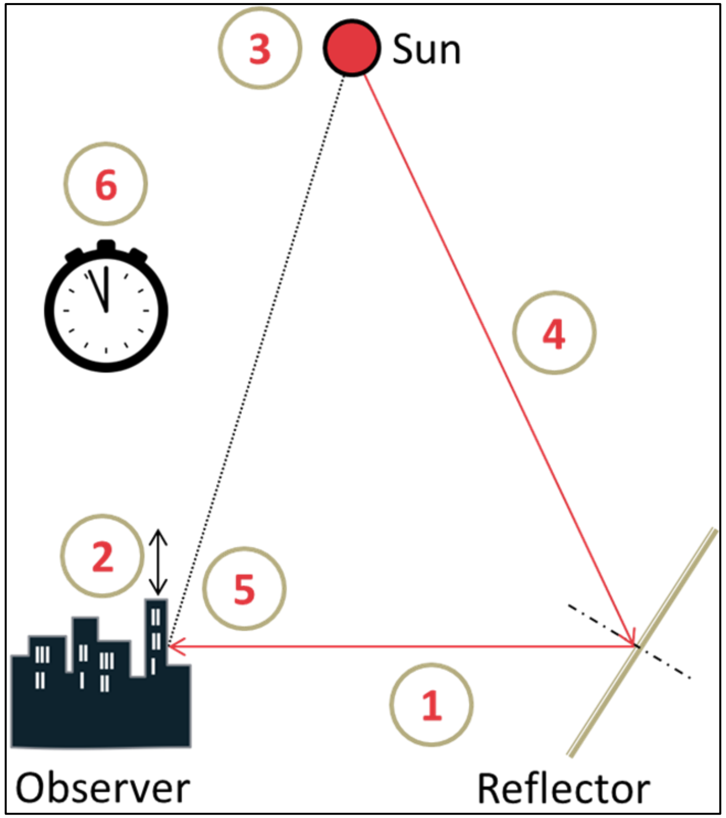

Figure 7 *Conditions for determining significant glint and glare*

[25] Not specifically referenced within the significance criteria for each assessed receptor (dwellings, road, rail and aviation) however in some instance the time of day may warrant consideration.

5.5 Figure 8 below shows the general process for determining the significance of glint and glare.

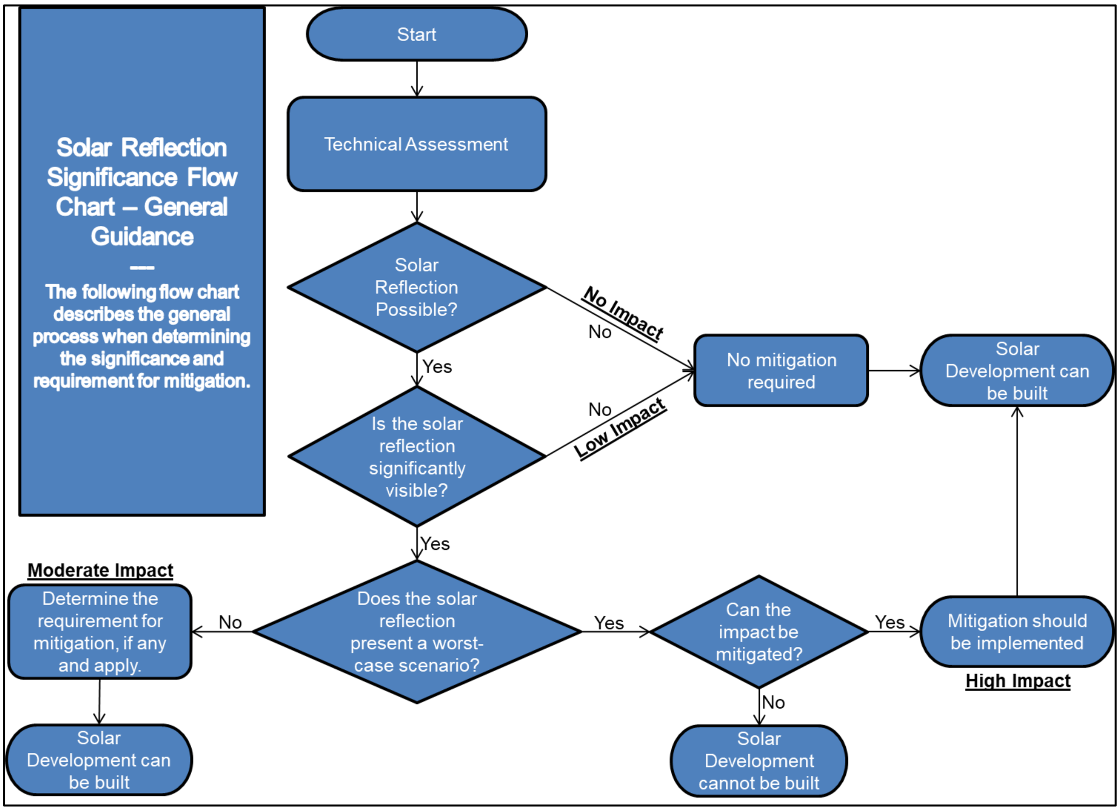

Figure 8 *General process for determining the significance of glint and glare*

5.6 The specific methodologies for each receptor (dwellings, road, railway and aviation) are presented in Sections 6-9.

6 ASSESSING THE IMPACT UPON SURROUNDING DWELLINGS

Overview

6.1 Local residents are a key stakeholder within the local environment when proposing a solar PV development. This is because residents will be living in close proximity to the solar PV development whilst also potentially having views of the solar panels for its lifetime. Where a view of the solar panel exists, a solar reflection may be possible which may impact upon residential amenity. The following guidance has therefore been produced to determine in what instances, a solar reflection becomes significant and mitigation should be implemented. The effects of glint and glare from building developments is not typically considered however, if required, the general methodology can be applied.

Key Considerations

6.2 A list of key considerations for assessing glint and glare with respect to surrounding dwellings and residential amenity is presented below:

- Surrounding dwellings may have views of a solar PV development. Where a view of the solar panel exists, a solar reflection may be possible;
- A view of a solar panel however does not guarantee that a solar reflection is possible;
- There is no technical limit (distance) within which solar reflections is possible for a surrounding dwelling receptor however, the significance of a reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases;
- Seasonal variations or additional developments may change the view from a dwelling towards the solar panels over time;
- Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances;
- In general, the geometry of the relationship between typical ground mounted solar panels and the movement of the Sun in the northern hemisphere means that dwellings due east and west of the panels are most likely to view a solar reflection for south facing arrays panels. Dwellings that are north or south of the panels are unlikely to experience a solar reflection in this instance;
- For solar PV developments that have solar panels orientated at an azimuth angle other than south, solar reflections may be directed in alternate directions.

6.3 The following subsections present the recommended methodology for assessing the impact upon residential amenity.

Identifying Receptors

6.4 The following process should be used for identifying dwelling receptors:

1. Identify dwellings in the immediate surrounding area (out to approximately 1km from the solar PV development boundary) that may have visual line of sight to the solar panels. Figure 9 below shows the receptor identification process;
2. If visual line of sight exists between the proposed solar PV development and a dwelling, then a solar reflection could be experienced if it is geometrically possible. If there is no line of sight, then a reflection cannot be experienced;
3. An additional height should be added to the ground level at a dwelling to represent a viewing height;
4. For dwellings, a recommended additional height of 1.8 metres above ground level should be added to account for eye level on the ground floor. A height of 3.8 metres is recommended for a first floor. Additional heights should be considered where a receptor is higher than a first floor. Modelling is recommended for ground floor receptors because it is typically occupied during daylight hours;
5. Use the height and location data within the geometric solar reflection model.

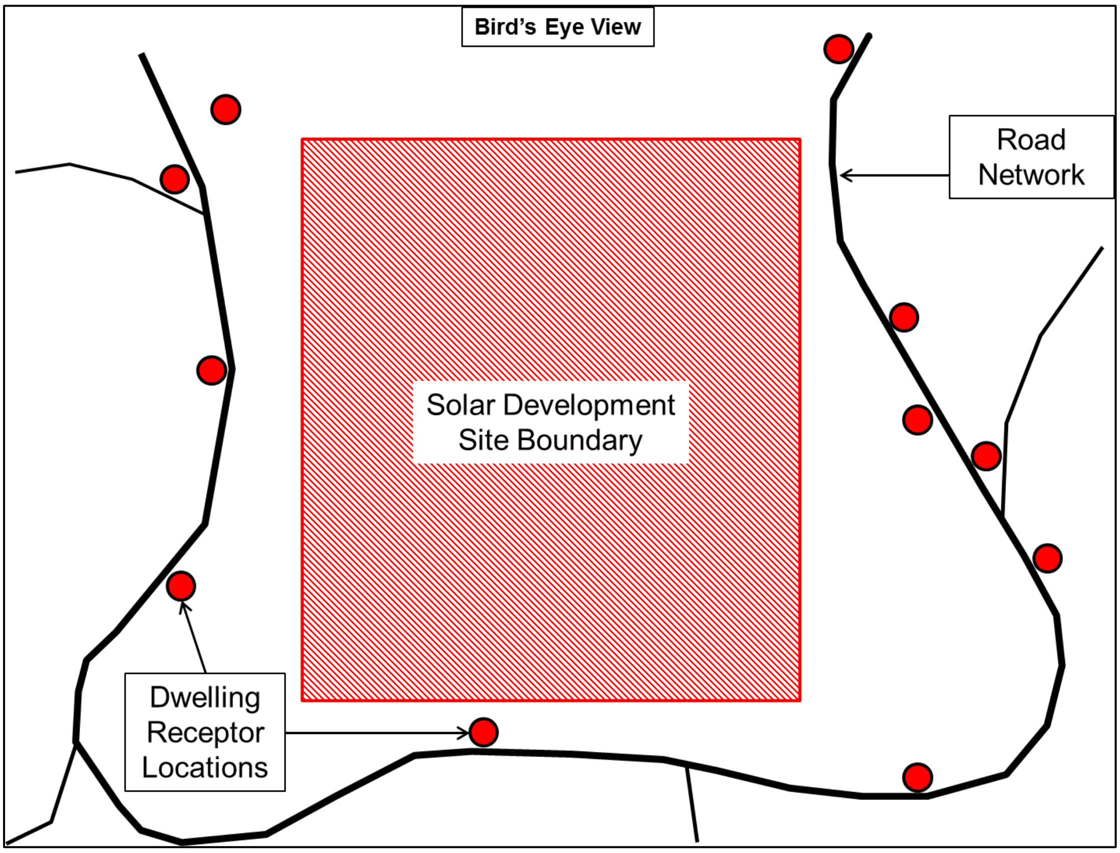

Figure 9 *Illustration showing receptor identification process – dwellings*

Assessment Process

6.5 The following process should be used for modelling glint and glare for the identified dwelling receptors:

1. Define the solar PV development panel area;
2. Undertake geometric calculations, as outlined within Section 4 of this guidance;
3. Produce a solar reflection chart to determine whether a solar reflection is geometrically possible, and if so at what time/duration;
4. Assess the results of the geometric glint and glare assessment in the context of the following:
    a. Sun location relative to the solar panels;
    b. Location of the reflecting solar panels relative to the dwelling;
    c. Existing screening;
    d. Proposed screening;
5. Determine whether a solar reflection is significant;
6. Consider mitigation, if required.

Discussion of Significant Effects

6.6 There are many solar PV developments where solar reflections are geometrically possible and visible from surrounding dwellings. Experiencing a solar reflection does not, however, guarantee a significant effect requiring mitigation will occur. Assuming the solar PV development is visible from a window of a room occupied during daylight hours, the duration of time for which a solar reflection could last is the most significant characteristic.

6.7 Other factors that could be considered when determining whether a solar reflection is significant include:

- Whether the solar reflection is incident to direct sunlight and the location;
- Whether the dwelling has a window facing the solar PV development;
- The room within the dwellings from which a solar reflection may be visible i.e. is it occupied for a long period during daylight hours e.g. a living room;
- The time of day/year when a solar reflection is geometrically possible.

6.8 The duration of time for which a solar reflection is possible is the main defining characteristic when determining whether mitigation is required. Defining a minimum duration for effects to become significant is, however, subjective. For static receptors, the length of time for which a solar reflection is geometrically possible and visible will determine its significance upon residential amenity. Therefore, it is appropriate to choose a duration beyond which solar reflections become significant and where mitigation is required. Applying a strictly scientific approach is difficult however because:

- Most models generally show a worst-case scenario of glint and glare, often predicting solar reflections for a much greater length of time than will be experienced in reality;
- The scenario in which glint and glare occurs will vary for each dwelling;
- The effects of glint and glare are subjective and the significance will vary from person to person.

6.9 To quantify and determine where a significant impact is expected, previous glint and glare assessment experience has been drawn upon as well as a review of existing guidance with respect to light based environmental impacts, these include:

- Previous glint and glare assessment experience;
- Shadow flicker guidance for wind turbines[26]. Guidance has been produced which sets durations beyond which a significant impact on residential amenity is expected and mitigation is required.

Previous Experience of Glint and Glare Dwelling Assessments

6.10 It is common for dwellings to be located within 1km of a proposed solar PV development. Assessment experience means that typical results for proposed ground mounted solar PV developments[27] are known. It is common for solar reflections to be possible in the mid-morning (~06:00-08:00 GMT) and again in the early evening (~17:00-19:00 GMT). There are many examples of dwellings located where a solar reflection is geometrically possible however, a solar reflection could only ever be significant where the solar reflection is visible from the dwelling. Assuming a solar reflection is geometrically possible, and the reflecting solar panels are visible, a solar reflection would be experienced when the following conditions are met:

1. An observer is located at a point within the dwelling where a solar reflection is possible e.g. located at a kitchen window at the time of the day when a solar reflection is geometrically possible;
2. The weather at the particular time of the day when a solar reflection is geometrically possible is clear and sunny;
3. There are clear unobstructed views from this window towards the reflecting solar panel area

6.11 The likelihood of these conditions being met varies both person to person and geographically based on local climate conditions. However, it illustrates that a predicted geometric solar reflection does not guarantee a visible solar reflection when considering real world conditions.

---

[26] Shadow flicker, like glint and glare, is considered a detrimental effect created through the manipulation of sunlight. Therefore the guidance has been used for comparative purposes.

[27] At typical solar panel azimuth and inclinations. Defined as panel elevation angle 15-30 degrees and south facing in the UK and Ireland.

Shadow Flicker Guidance

6.12 "Shadow flicker" refers to the sunlight flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring dwellings through small openings such as windows. This can cause a significant detrimental impact upon residential amenity under certain conditions.

6.13 A review of the shadow flicker guidance has been undertaken, with specific reference to the guidance where time limits have been stated for the maximum acceptable duration of shadow flicker, beyond which mitigation is required. The guidance states the following:

1. Shadow flicker is possible at dwellings within 10 rotor diameters[28]. A typical rotor diameter for a large-scale wind turbine is 90m, making the potential shadow flicker zone out to 900m from the wind turbine location[29];
2. The following must all apply:
    a. Shadow flicker is only possible when the wind turbine is rotating; and
    b. Shadow flicker is only possible where the Sun passes behind the rotating wind turbine relative to the assessed dwelling; and
    c. Shadow flicker is possible within rooms where windows have a clear view of the rotating wind turbine.
3. Shadow flicker is deemed significant where it lasts for longer than 30 minutes per day and for more than 30 hours of the year within 500m of the turbine[30] in some European countries. Beyond this distance no maximum acceptable time is stated;
4. Mitigation is required if all of the above are satisfied.

Determination of Significant Effects

6.14 The effects of glint and glare differ to shadow flicker for a number of reasons, and could be considered less significant because:

- A solar panel produces a solar reflection and therefore the light reflected is less intense than direct sunlight because a percentage of the light is absorbed by the solar panel. Shadow flicker is the effect of the varying light levels directly from the Sun;
- Shadow flicker produces significant variations to light levels within a room. An observer does not have to be looking at the wind turbine directly to observe the

[28] Onshore Wind Energy Planning Conditions Guidance Note, Renewables Advisory Board and BERR (2007). Last accessed 02/11/2016.
[29] The search radius for dwellings is within 1km from a proposed solar development for glint and glare effects. This search area is for glint and glare effects is therefore expected to be larger than the area for shadow flicker for the majority of large-scale onshore wind turbines.
[30] Draft PPS18: Renewable Energy Annex 1 Wind Energy Planning Issues: Shadow Flicker and Reflected Light, Planning Portal Northern Ireland (the shadow flicker recommendations are based on research by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany). Last accessed 02/11/2016.

effect. For glint and glare effects to be experienced, an observer has to view the solar panels directly;

- A solar reflection from a solar panel will appear static, whereas the effect of shadow flicker will inherently flicker in time with 1/3 the frequency of the rotating blades (assuming three blades);
- The presence of shadow flicker would be a new effect experienced at a dwelling. Solar panels produce solar reflections of similar intensity to those from still water or glass for example, both common reflective sources next to dwellings.

6.15 Shadow flicker guidance states that effects for more than 30 minutes per day, over 30 hours of the year, is significant and requires mitigation. Considering the information presented within Section 6.5 and the above, it is deemed appropriate to consider the effects of glint and glare less significant than shadow flicker. Therefore, the duration beyond which mitigation should be required for glint and glare is longer than for shadow flicker.

6.16 Therefore the recommendation within this guidance is:

- If visible glint and glare is predicted for a surrounding dwelling for longer than 60 minutes per day, for three or more months of the year, then the impact should be considered significant with respect to residential amenity. In this scenario, mitigation should be implemented.

6.17 The process outlined in the following flow chart (Figure 10 below) is recommended when determining whether a solar reflection should be deemed significant and mitigation implemented.

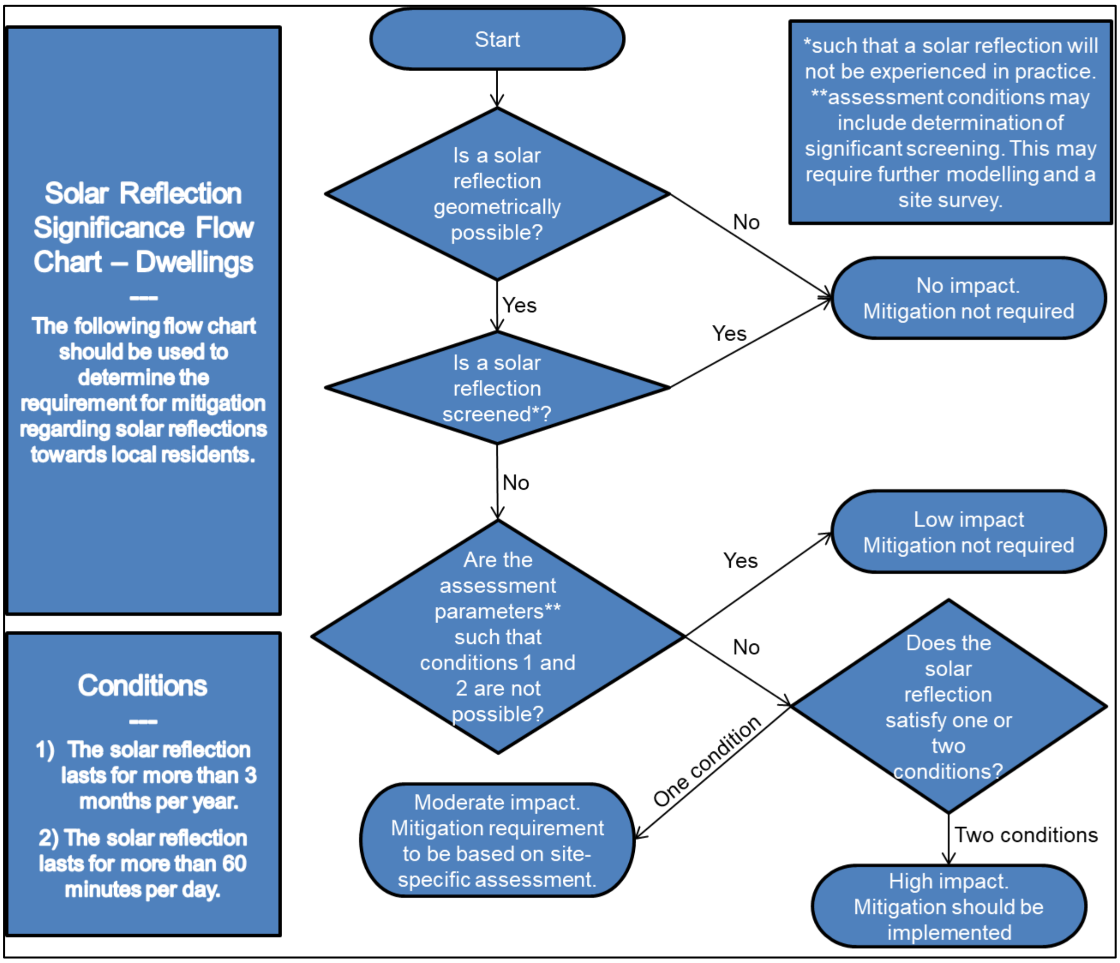

Figure 10 *Dwelling impact significance flow chart*

6.18 'Significant screening' with respect to visibility of reflecting solar panels implies that the observer's view is impeded to the extent that the presence of the solar panels cannot be easily discerned at first glance. For example, a hedgerow that contains small gaps that facilitate partial visibility of the panel face(s) would provide 'significant screening'. Figure 11 on the following page illustrates this.

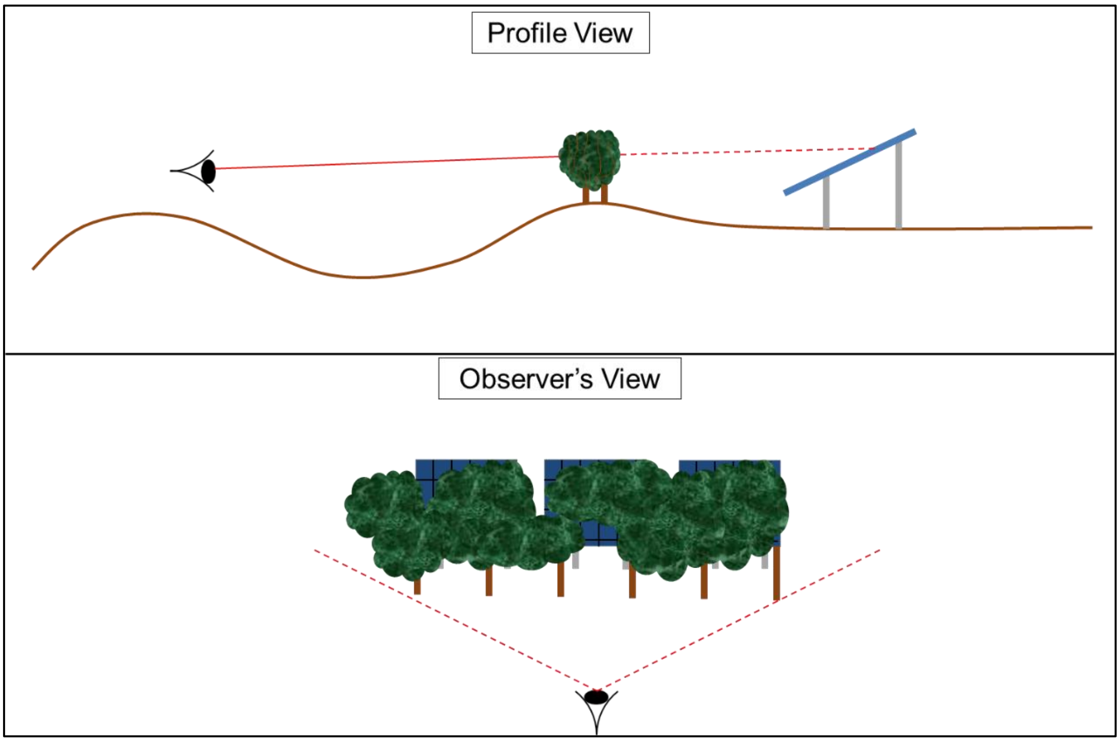

Figure 11 *Illustration of 'significant screening'*

Conclusions

6.19 The size of the solar panel area and visibility of the reflecting solar panels relative to the assessed dwelling will determine the duration of the solar reflection. Where solar reflections persist beyond 60 minutes per day for three or more months per year, solar reflections are considered significant and mitigation should be implemented. Consultation is recommended where there is a requirement for mitigation.

7 ASSESSING THE IMPACT UPON ROAD USERS

Overview

7.1 Locating a solar PV development next to a road is often essential due to access requirements. The possibility of glint and glare effects from the proposed solar PV development can however lead to concerns with respect to the possible impact upon road safety especially if the solar PV development is to be located next to a road with fast moving and/ or busy traffic. Therefore, a glint and glare assessment may be requested by the relevant stakeholders so that the possible effects can be understood. The effects of glint and glare from building developments is not typically considered however, if required, the general methodology can be applied.

Key Considerations

7.2 A list of key considerations for assessing glint and glare with respect to road safety is presented below:

- A road user may have views of a solar PV development. Where a view of the solar panel exists, a solar reflection may be possible;
- A view of a solar panel does not however guarantee that a solar reflection is possible;
- There is no technical limit (distance) within which a solar reflection is possible for a surrounding road user however, the significance of a reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases;
- Seasonal variations to vegetation or new additional development may change the view from a road user towards the solar panels over time;
- Terrain and shielding by vegetation are also more likely to obstruct an observer's view over longer distances;
- In general, the geometry of the relationship between typical ground mounted solar panels and the movement of the Sun in the northern hemisphere means that roads due east and west of the panels are most likely to view a solar reflection for south facing arrays panels. Roads that are north or south of the panels are very unlikely to experience a solar reflection;
- For solar PV developments that have solar panels orientated at an azimuth angle other than south, solar reflections may be directed in alternate directions.

7.3 The following subsections present the recommended methodology for assessing the impact upon road safety.

Identifying Receptors

7.4 The following process should be used for identifying road receptors:

1. Identify roads in the immediate surrounding area (out to approximately 1km from the solar PV development boundary) that may have visual line of sight to the solar panels;
2. If visual line of sight exists between the proposed solar PV development and the road, then a solar reflection could be experienced if it is geometrically possible;
3. If there is no line of sight, then a reflection cannot be experienced;
4. Assess a length of road, choosing individual receptor locations no more than 200 metres apart. This is shown in Figure 12 on the following page;
5. An additional height should be added to the ground level height to represent the typical viewing height from a road user. For road users, a height of 1.5 metres is recommended;
6. Use the height and location data within the geometric solar reflection model.

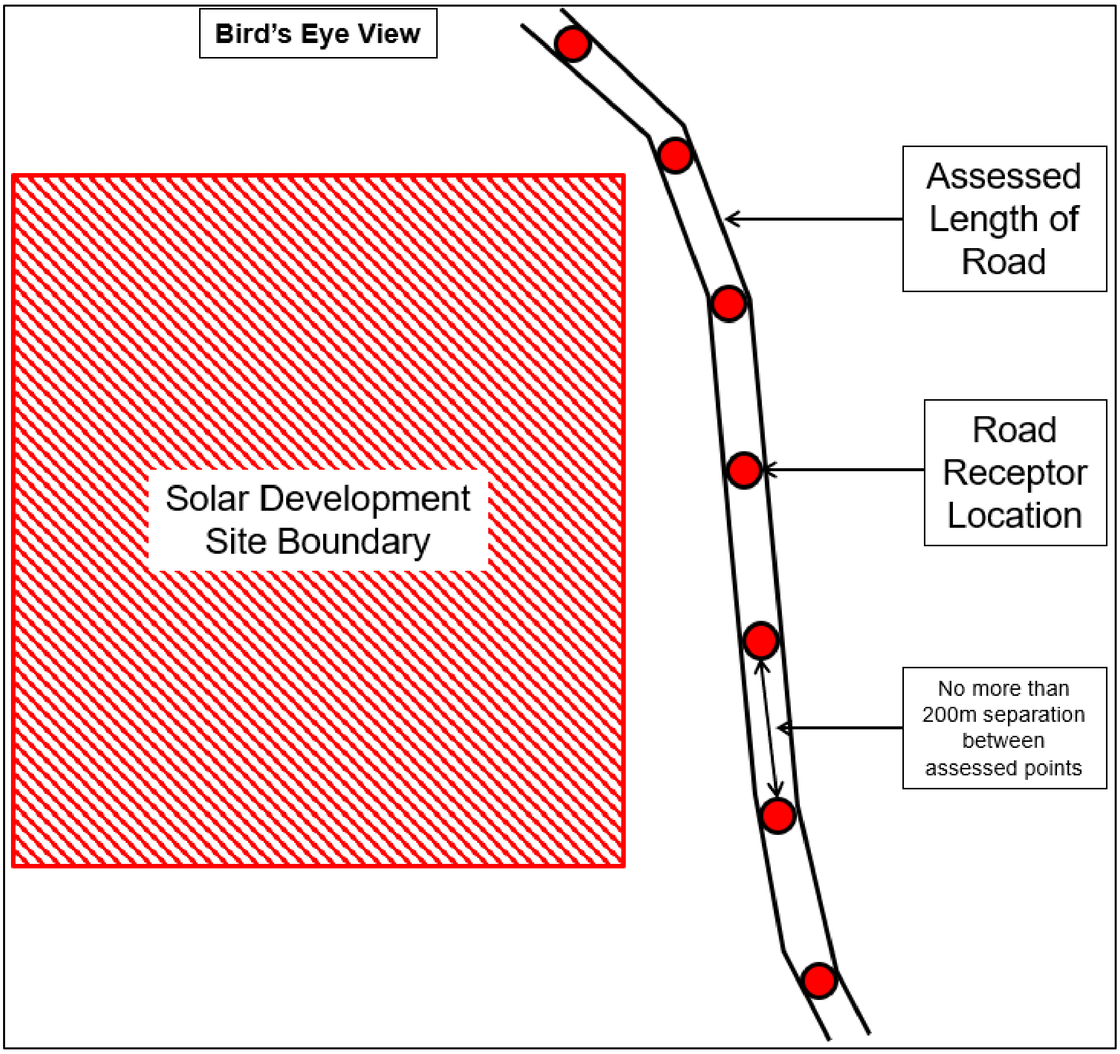

Figure 12 Illustration showing receptor identification process – roads

Assessment Process

7.5 The following process should be used for modelling glint and glare for the identified road user receptors:

1. Define the solar PV development solar panel area;
2. Undertake geometric calculations, as outlined within Section 4 of this guidance;
3. Produce a solar reflection chart to determine whether a solar reflection is geometrically possible;
4. Assess the results of the geometric glint and glare assessment in the context of the following:
   a. Sun location relative to the solar panels;
   b. Location of the reflecting solar panels relative to the road and direction of traffic;

c. Consideration of existing screening;

d. Consideration of proposed screening;

5. Determine whether a solar reflection is significant;

6. Consider mitigation, if required.

Determination of Significant Effects

7.6 A road user travelling on surrounding roads where a solar reflection is geometrically possible would experience a solar reflection that is fleeting in nature. This is because the road user is typically moving at speeds anywhere up to 70mph or 120kph. This means that the duration of a predicted solar reflection is mostly dependent on the speed of the road user travelling past the solar farm at the time when a solar reflection is geometrically possible. Therefore, the location of origin of the solar reflection is more significant than its duration because the receptor is moving.

7.7 There are many solar PV developments where solar reflections are geometrically possible towards roads. Experiencing a solar reflection does not guarantee a significant effect requiring mitigation and there are criteria that should be considered when determining the significance of a solar reflection, these are:

- Is the solar reflection incident to direct sunlight?
- What type of road is affected? Major National, National, Regional or Local roads?
- Does the solar reflection appear in-line with, or close to, the direction of travel?
- What is the length of road that may experience a solar reflection?

7.8 For south facing solar panels at standard inclinations[31] it is likely that the Sun will be incident to the solar reflections in the UK and Ireland. Whether the solar reflection appears in-line with, or close to, the direction of travel depends on the geographic location of the surrounding road relative to the solar PV development. This, along with the size of the proposed solar PV development, determines the length of road that may be affected.

7.9 Because the length of time a solar reflection can last is mostly dependent on the road user's speed rather than the solar PV development, the length of time that a solar reflection is not considered when determining its significance. Instead, the location of origination of the solar reflection and road type are considered.

7.10 The process outlined in the flow chart on the following page (Figure 13) is recommended when determining whether a solar reflection should be deemed significant and mitigation implemented.

[31] Defined as 15-35 degrees in the UK and Ireland.

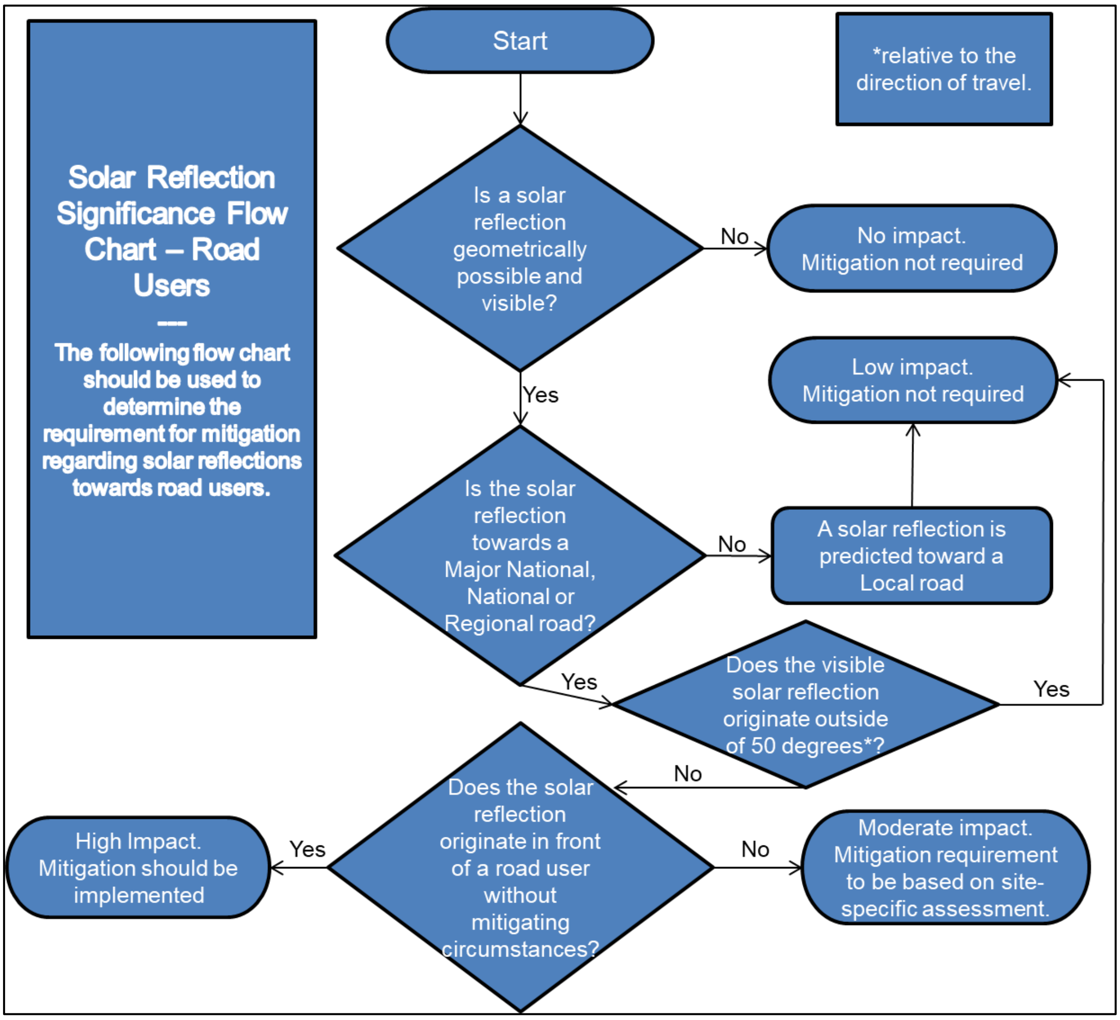

Figure 13 *Road user impact significance flow chart*

7.11 Regional, National and Major National roads are the most important in the majority of instances. Local roads may, under particular conditions, prove to be vital to the surrounding road network. Therefore, consultation with the local highways authority is recommended to ascertain the significance of a surrounding road where it is unknown.

7.12 The road classifications are based on typical UK roads, however what constitutes a regional road (for example) may vary in different countries. Therefore, alongside road classification, the road size, speed limit, surface, traffic volume and traffic speed should also be considered when applying impact significance with road classification.

Conclusions

7.13 The visibility and size of the reflecting solar panel area from an assessed road will in part, determine the duration of a solar reflection. In most scenarios, the speed of the vehicle will be the overall determining factor which determines the duration of the solar reflection. The type of road affected and location of origin of the solar reflection with respect to the direction of road travel will determine the requirement for mitigation. Consultation with the local highway authority is recommended where mitigation is required.

8 ASSESSING THE IMPACT UPON RAILWAY OPERATIONS

Overview

8.1 Solar PV and building developments can be located adjacent to railway lines. Indeed there are already a number of operational solar PV developments in these locations present in the UK[32,33]. A consideration of a railway stakeholder may be the safety implications of glint and glare effects from a proposed solar PV or building development. It is therefore important to set a specific and standardised assessment methodology so that all proposals are assessed in the same way.

Key Considerations

8.2 A list of key considerations for assessing glint and glare with respect to rail safety is presented below:

- A train driver may have views of a solar PV or building development. Where a view of the solar panel or façade exists, a solar reflection may be possible;
- A view of the reflector does not however guarantee that a solar reflection is possible;
- There is no technical limit (distance) to which a solar reflection is possible towards a surrounding railway line however, the significance of a reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases;
- Seasonal variations or additional development may change the view from a receptor location towards the solar panels or building development over time;
- Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances;
- In general, the geometry of the relationship between typical ground mounted solar panels and the movement of the Sun in the northern hemisphere means that railways due east and west of the panels are most likely to view a solar reflection for traditional south facing arrays panels. Railways that are north or south of the panels are very unlikely to experience a solar reflection;
- For building developments and for solar developments that have solar panels orientated at azimuth angles other than south, solar reflections may be directed in alternate directions

.

[32] Hadlow Solar Farm, Off Sherenden Road, Tudeley, Kent, England.
[33] Tower Hayes Solar Farm, near Stanton under Bardon, Leicestershire, England.

8.3 The following subsections present the recommended methodology for assessing the impact upon railway safety.

Identifying Receptors – Railway Infrastructure

8.4 The following process should be used for identifying receptors[34]:

1. Identify whether a railway line or railway infrastructure is present within 100m of the solar or building development ;
2. If visual line of sight exists between the proposed solar or building development and the railway line, then a solar reflection could be experienced if it is geometrically possible. If there is no line of sight, then a reflection cannot be experienced;
3. Assess a length of railway line, choosing individual receptor locations no more than 200 metres apart out to up to 500m from the development location. This is shown in Figure 14 on the following page with reference to a solar development;
4. An additional height should be added to the ground level height to represent the typical viewing height of a train driver. For train drivers, a height of 2.75 metres is recommended;
5. Identify any other railway infrastructure that may be present within 500m of the proposed development. This includes railway signals and crossings;
6. Use the height and location data for feeding into the geometric solar reflection model.

[34] Railway signals are discussed separately, beginning paragraph 8.11.

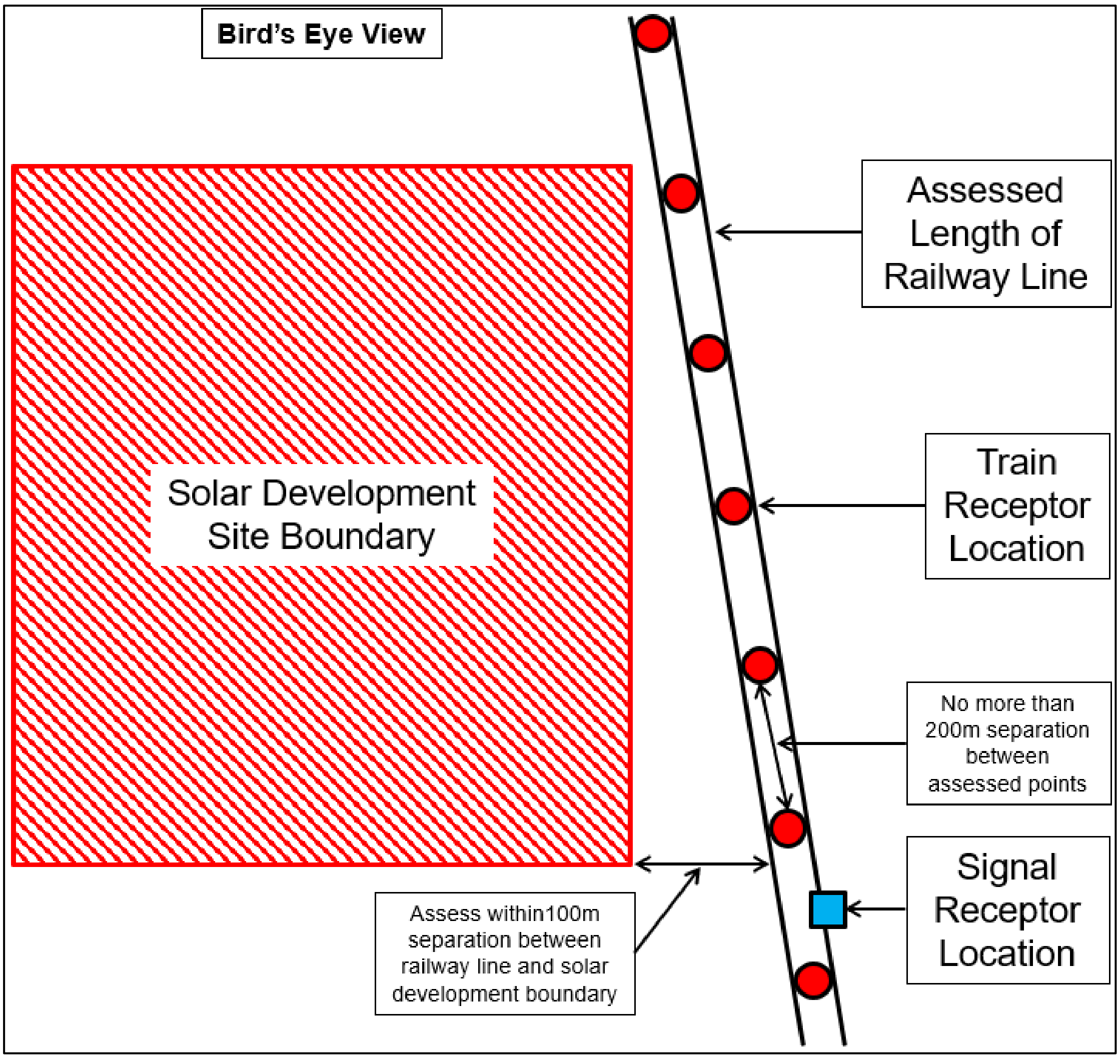

Figure 14 *Illustration showing receptor identification process – train drivers and signals*

Assessment Process

8.5 The following process should be used for modelling glint and glare for a railway line:

1. Define the solar PV development solar panel area or building façade;
2. Undertake geometric calculations for train drivers and any other railway infrastructure, as outlined within Section 4 of this guidance;
3. Produce a solar reflection chart to determine whether a solar reflection is geometrically possible;
4. Assess the results of the geometric glint and glare assessment in the context of the following:
    a. Sun location relative to the solar panels or façade;
    b. Location of the reflecting solar panels or façade relative to the railway line, direction of trains and key infrastructure, such as railway signals;

    c. Existing screening;
    d. Proposed screening;

5. Consider train driver workload;
6. Assess the intensity of the solar reflection, if appropriate;
7. Determine whether a solar reflection is significant;
8. Consider mitigation, if required.

Determination of Significant Effects

8.6 A train driver travelling on a section of railway line where a solar reflection is geometrically possible would experience a solar reflection that is fleeting in nature. This is because a train will typically be moving at speeds anywhere up to 120mph (~190kph). This means that the duration of a predicted solar reflection is mostly dependent on the speed of the train travelling past the solar PV or building development at the time when a solar reflection is geometrically possible. Therefore, the location of origin of the solar reflection is more significant than its duration because the receptor is moving.

8.7 There are examples of solar PV and building developments where solar reflections are geometrically possible towards an adjacent railway line. Experiencing a solar reflection does not necessarily mean there is a significant effect requiring mitigation. The following criteria should be considered when determining the significance of a solar reflection towards a train driver or train infrastructure:

- Is the solar reflection incident to direct sunlight?
- Does the affected length of railway have a signal, crossing or switch/set of points?
- Does the solar reflection appear in line with, or close to, the direction of travel?
- What is the length of railway that may experience a solar reflection?
- What is the intensity of the solar reflection?[35]

8.8 For south facing solar panels at standard inclinations[36] it is likely that the Sun will be incident to the solar reflections in the UK and Ireland. Whether the solar reflection appears in line with, or close to, the direction of travel depends on the geographic location of the surrounding railway relative to the solar PV development. This, along with the size of the proposed solar PV development, determines the length of railway line that may be affected.

8.9 For building developments, the scenarios in which solar reflections can occur can vary significantly.

---

[35] The intensity of any calculated solar reflection may be requested by the railway stakeholder. An assessment methodology aligned with the methodology produced for aviation receptors can be utilised (Section 9).
[36] Typically 15-35 degrees in the UK and Ireland

8.10 Because the length of time a solar reflection can last is mostly dependent on a train's speed rather than the solar PV or building development, the length of time that a solar reflection can last is not considered when determining its significance. Instead, the location of origination of the solar reflection, length of railway and infrastructure present on the assessed railway line are considered.

8.11 The process outlined in the flow chart below (Figure 15) is recommended when determining whether a solar reflection should be deemed significant and mitigation implemented.

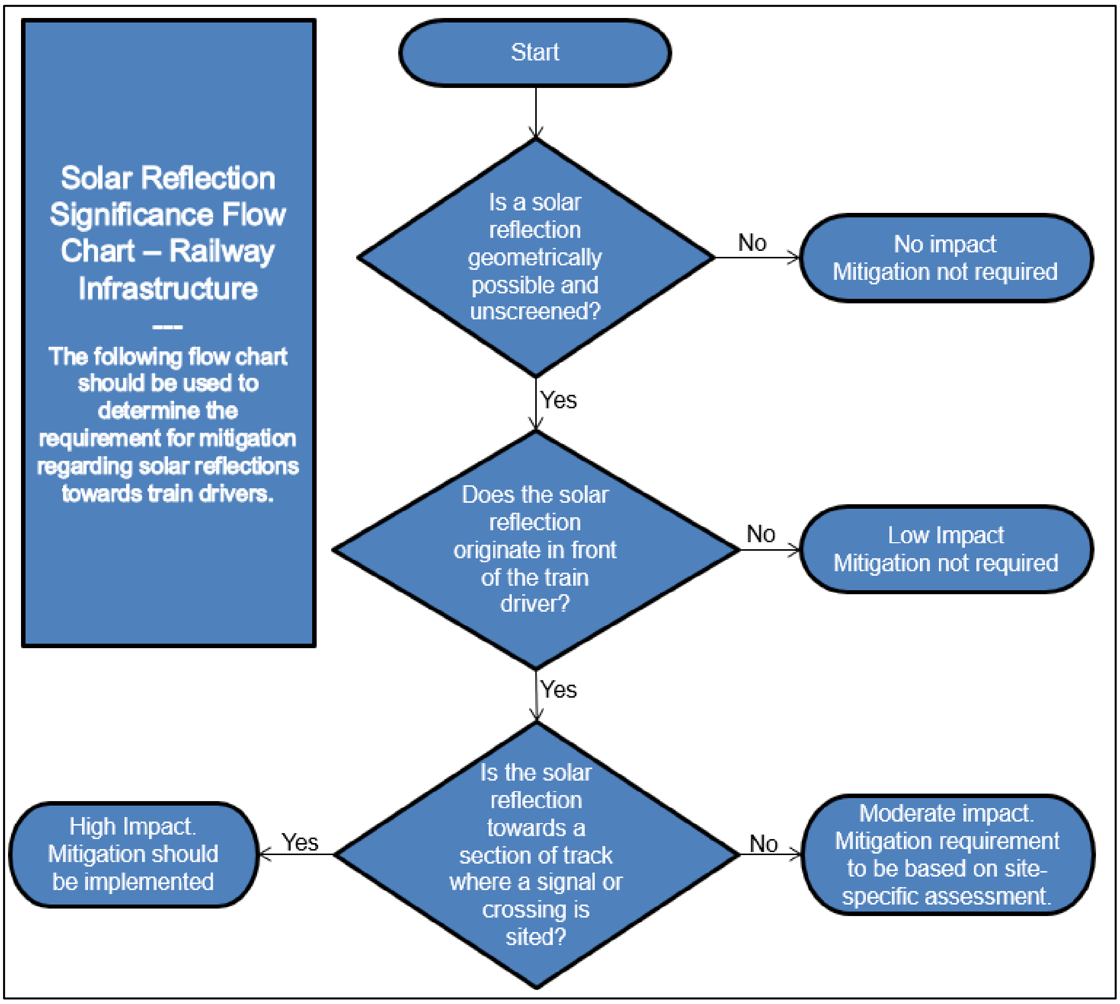

Figure 15 *Train driver impact significance flow chart*

Other considerations

Railway Signals

8.12 Railway signal lights are located immediately adjacent to or above a railway line and are used to direct trains on the lines. In some instances, signals may be difficult to identify and therefore consultation with the railway stakeholder may be beneficial to identify their location and specification. An assessment may be required because of the potential for a phantom aspect illusion occurring. The definition of phantom aspect is presented below.

8.13 'Light emitted from a Signal lens assembly that has originated from an external source (usually the Sun) and has been internally reflected within the Signal Head in such a way that the lens assembly gives the appearance of being lit[37].'

8.14 A phantom aspect is caused when the incoming light is of an intensity which causes a light signal to appear illuminated when it is not switched on. This is a particular problem for filament bulbs with a reflective mirror incorporated into the bulb design.

8.15 No known studies have shown that a phantom aspect illusion is possible due to a solar reflection from a solar panel or glass. Furthermore, modern LED signals are designed to reduce or completely eliminate the likelihood of a phantom aspect illusion occurring and many have hoods attached to reduce the risk of incoming direct light illuminating the signal lens directly. Nevertheless, following consultation with railway operators, it is recommended that an assessment of all signal lights be undertaken. A railway signal location should also be considered where there may be solar reflections towards a train driver on the railway line where the signal is present. This is because a train driver's workload may be higher where signals are present, increasing the potential impact as a result of the solar reflection. If the assessed reflectors are not in line of sight to the signal lens, then no phantom aspect illusion is possible.

Level Crossings and Level Crossing Warning Lights (LCWL)

8.16 For determining the impact of glint and glare upon level crossings with respect to road users, follow the 'road users' assessment methodology presented in Section 7. For LCWLs, follow the assessment of railway signals as presented in Section 8.11. In both instances, consultation with the railway and/or road stakeholder is advised.

Switches/Set of Points

8.17 Switches and sets of points are present on sections of track where a train may cross from one section of a railway line to another. Where this occurs, a train driver's workload may be increased, and the effect of a solar reflection may increase the significance of a solar reflection.

---

[37] Glossary of Signalling Terms, Railway Group Guidance Note GK/GN0802. Issue One. Date April 2004.

Conclusions

8.18 The size of the reflector area and visibility of the reflectors relative to static infrastructure (such as signals) will determine the duration of the solar reflection. For moving trains, their speed will be the overall determining factor with regard to the duration of the solar reflection. Consultation with the railway stakeholder is recommended to determine the requirement for assessment, identify particular receptors and determine whether mitigation is required.

9 ASSESSING THE IMPACT UPON AVIATION OPERATIONS

Overview

9.1 Solar PV developments and aviation activity can safely co-exist. There are many examples of solar PV developments being sited on or near to an aerodrome[38]. Safeguarding an aerodrome and its aviation activity is essential, and glint and glare effects may cause a safety concern under certain conditions. Therefore a glint and glare assessment of a proposed solar PV development is essential when it is to be sited in the vicinity of an aerodrome.

9.2 More recently, the effect of solar reflections from building developments with surfaces capable of producing specular solar reflections has been raised as a potential concern at a number of UK airports.

9.3 This section presents a recommended assessment approach, based on previous guidance and experience within the UK, Ireland and internationally.

Key Considerations

9.4 The two main receptors that require consideration within an aviation glint and glare assessment are pilots in aircraft and air traffic controllers in the Air Traffic Control (ATC) Tower. Helipads and alternate aviation receptors are considered separately within this sector.

9.5 Whilst a proposed solar PV development may be located such that air traffic controllers have no view of the solar panels, pilots navigating the airspace above will almost certainly have a view of the solar panels. Where a view of the solar panel exists, a solar reflection may be possible. A view of a solar panel does not however guarantee that a solar reflection is possible.

9.6 There is no technical limit (distance) within which a solar reflection is possible towards the ATC Tower or pilots, however the significance of a reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases.

9.7 Seasonal variations or additional development may change the view from the ATC tower towards the solar panels over time.

9.8 Terrain and shielding by vegetation are also more likely to obstruct an air traffic controller's view at longer distances.

9.9 In general, the geometry of the relationship between typical ground mounted solar panels and the movement of the Sun in the northern hemisphere means that ATC towers due east and west of the panels are most likely to view a solar reflection for south facing arrays panels. ATC

[38] Gatwick Airport and Athens Airport for example.

towers north or south of the panels are very unlikely to experience a solar reflection unless the solar PV development and ATC Tower are in close proximity i.e. an on-aerodrome development. Pilots may experience solar reflection from a greater number of locations because of the changing location and altitude of the aircraft.

9.10 For building developments and for solar developments that have solar panels orientated at azimuth angles other than south, solar reflections may be directed in alternate directions.

9.11 The key considerations listed in the sections above are broadly the same for both solar and building developments.

Identifying Receptors – Aerodromes

9.12 The following process should be used for identifying the requirement for assessment:

1. Identify aerodromes within 30km of the proposed solar PV development. Complete the following depending on proximity;
    a. Within 5km: consult with the aerodrome, complete a glint and glare assessment;
    b. Within 5-10km: consult with the aerodrome, the aerodrome is likely to request a glint and glare assessment;
    c. 10km-30km: consider consultation with certified and licensed aerodromes, the aerodrome may request a glint and glare assessment;
    d. 30km+: consultation and assessment not considered a requirement, however requests for assessment have been requested beyond 30km.

9.13 If a glint and glare assessment is to be completed, follow the process outlined below for identifying receptors:

1. Identify any existing or proposed ATC Towers (if there is one) and approach routes for all existing or proposed runways;
2. If visual line of sight exists between the proposed solar PV development and the ATC Tower, then a solar reflection could be experienced if it is geometrically possible;
3. If there is no line of sight, then a reflection cannot be experienced;
4. Assess a 2-mile[39] approach path towards the runways using the following criteria;
    a. Starting point taken at 50 feet (15.2m) above the runway threshold;
    b. Measure out to 2 miles from the runway threshold using a 3 degree descent path (unless requested otherwise or as per the published aeronautical approach procedures);

[39] A statute mile (1.61km).

c. Take reference aircraft locations at no more than ¼ mile intervals (minimum of nine points over 2-miles);

5. An additional height should be added to the ground level height to represent the viewing height of an air traffic controller within the ATC Tower;

6. Use the height and location data for feeding into the geometric solar reflection model. Figure 16 below shows the process for identifying aviation receptors.

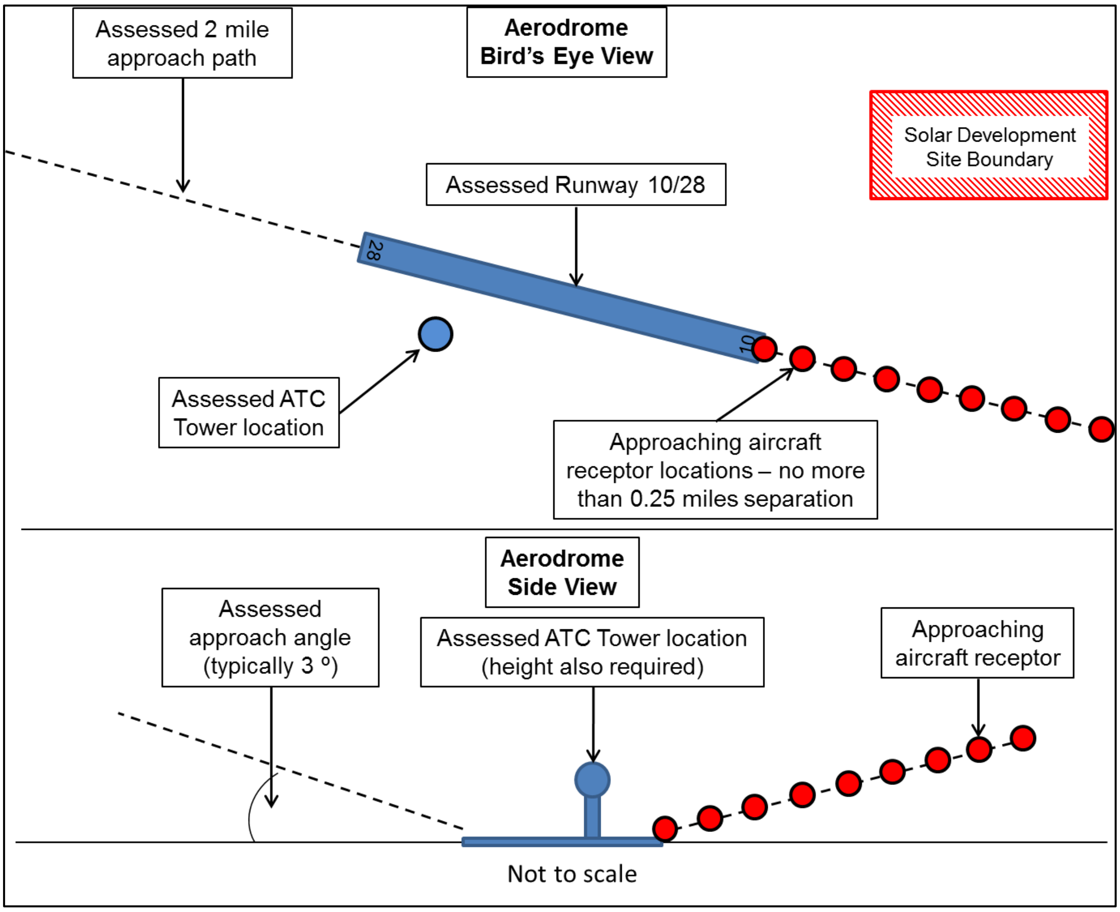

Figure 16 *Illustration showing receptor identification process – aviation*

Assessment Process

9.14 The following process should be used for modelling glint and glare effect for aviation activity:

1. Define the solar PV development solar panel area;
2. Undertake geometric calculations, as outlined within Section 4 of this guidance;
3. Produce a solar reflection chart to determine whether a solar reflection is geometrically possible;
4. Assess the results of the geometric glint and glare assessment in the context of the following:

a. Sun location relative to the solar panels;
b. Location of the reflecting solar panels relative to the ATC Tower and/or aircraft location;
c. Consideration of existing screening (ATC Tower only);
d. Consideration of proposed screening (ATC Tower only);

5. Determine whether a solar reflection is significant;
6. Consider mitigation, if required.

Building Developments

9.15 The process for assessing reflective façades on building developments is similar to those for solar panels however the FAA guidance does not apply to reflective surfaces other than solar panels and therefore the significance of a reflection, as per the sections below, can be considered for reference from a technical perspective but should not be the sole determining factor in assigning an impact significance.

Determination of significant effects

Air Traffic Control

9.16 An air traffic controller uses the visual control room to monitor and direct aircraft on the ground, approaching and departing the aerodrome. It is essential that air traffic controllers have a clear unobstructed view of the aviation activity. The key areas on an aerodrome are the views toward the runway thresholds, taxiways and aircraft bays.

9.17 The FAA guidance states that no solar reflection towards the ATC tower should be produced by a proposed solar PV development:

> '*1. No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATCT) cab…*'

9.18 However, it is recommended that any predicted solar reflection should be assessed pragmatically. Therefore, the following should be considered when determining whether a solar reflection is significant:

1. The predicted intensity of the solar reflection;
2. Location of origin of the solar reflection relative to the ATC Tower;
3. Solar reflection duration per day;
4. Number of days a solar reflection is geometrically possible per year;
5. The time of day when a solar reflection is geometrically possible.

9.19 Determining a period of time and location from which a predicted solar reflection is considered significant will depend on the operations at a particular aerodrome.

9.20 The process outlined within the flow chart on the following page (Figure *17*) is recommended when determining whether a solar reflection should be deemed significant and mitigation implemented.

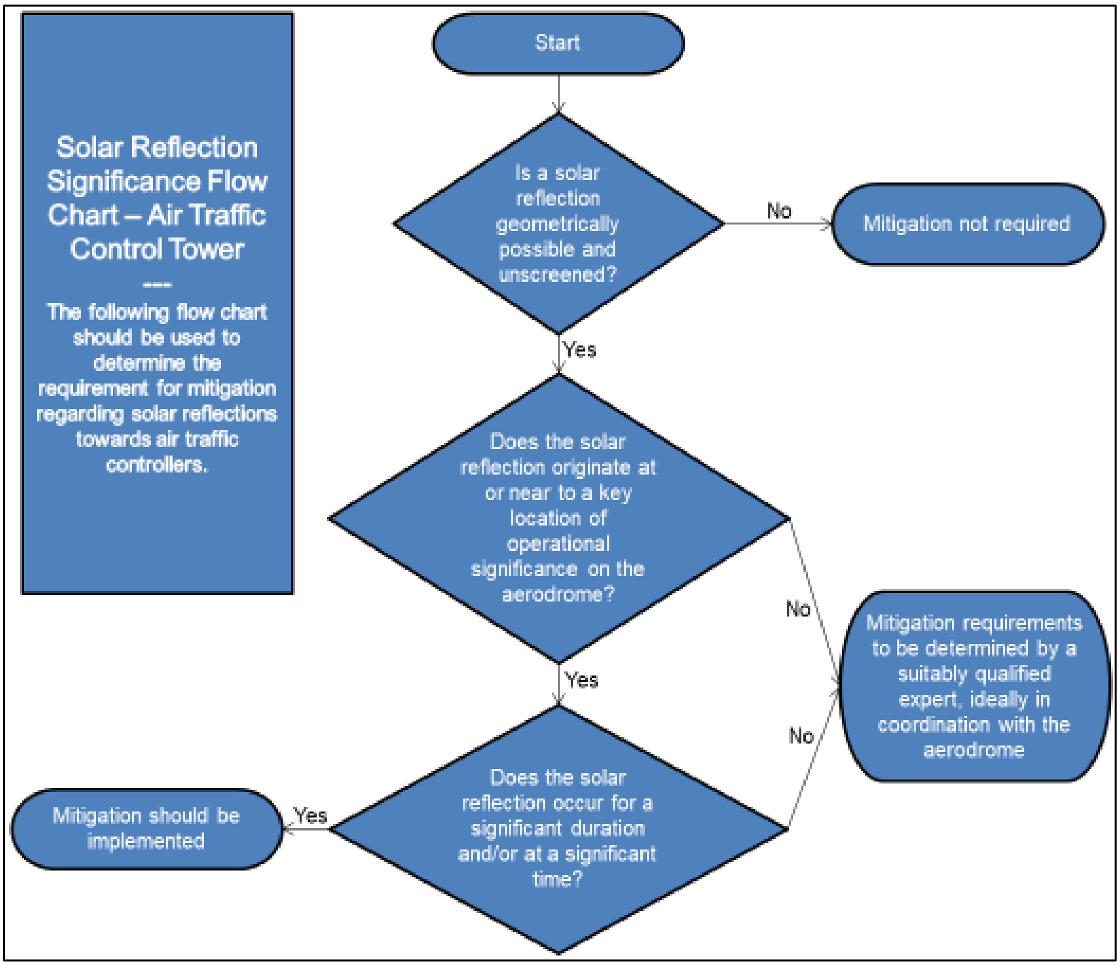

Figure 17 *ATC tower impact significance flow chart*

Approaching Aircraft

9.21 A pilot flying a 2-mile final approach path where a solar reflection is geometrically possible would experience a fleeting solar reflection as the aircraft travels through the solar reflection zone. This means that the duration of a predicted solar reflection is dependent on the speed of the aircraft above the solar PV development at the time when a solar reflection is geometrically possible. Therefore, the location of origin of the solar reflection is more significant than its duration because it is a fast-moving receptor. The time at which the solar reflection may occur should however be considered.

9.22 There are examples of solar PV developments where solar reflections are geometrically possible towards approaching aircraft. Experiencing a solar reflection does not guarantee a significant effect requiring mitigation, however there are criteria that should be considered when determining the significance of a solar reflection and mitigation requirements, these are:

- Is the solar reflection incident to direct sunlight?
- Does the solar reflection originate from near to a runway threshold?
- What is the length of approach path that can experience a solar reflection?
- Does the solar reflection occur at a significant time?
- Does the solar reflection occur for a significant period of time?
- What is the intensity of the solar reflection?

9.23 Further comments regarding the solar reflection intensity and its effect on the significance is presented in the following sub-section.

Solar Reflection Intensity

9.24 Many UK and Irish aviation stakeholders have adopted the FAA guidance with respect to glint glare. Along with the guidance, the Sandia Solar Glare Hazard Analysis Tool (SGHAT) model was also created. This model can be used to determine the intensity of a solar reflection which is significant when determining the impact upon approaching aircraft.

9.25 The FAA guidance states:

> *2. No potential for glare or "low potential for after-image" (shown in green in Figure 1) along the final approach path for any existing landing threshold or future landing thresholds (including any planned interim phases of the landing thresholds) as shown on the current FAA-approved Airport Layout Plan (ALP). The final approach path is defined as two (2) miles from fifty (50) feet above the landing threshold using a standard three (3) degree glide path.*

9.26 It is recommended that the FAA guidance is used as a basis for assessment, however it is advised that a pragmatic approach is followed when determining whether a predicted solar reflection may indeed by a hazard to aviation safety.

9.27 The process outlined within the flow chart (Figure 18) on the following page is recommended when determining whether a solar reflection should be deemed significant and mitigation implemented.

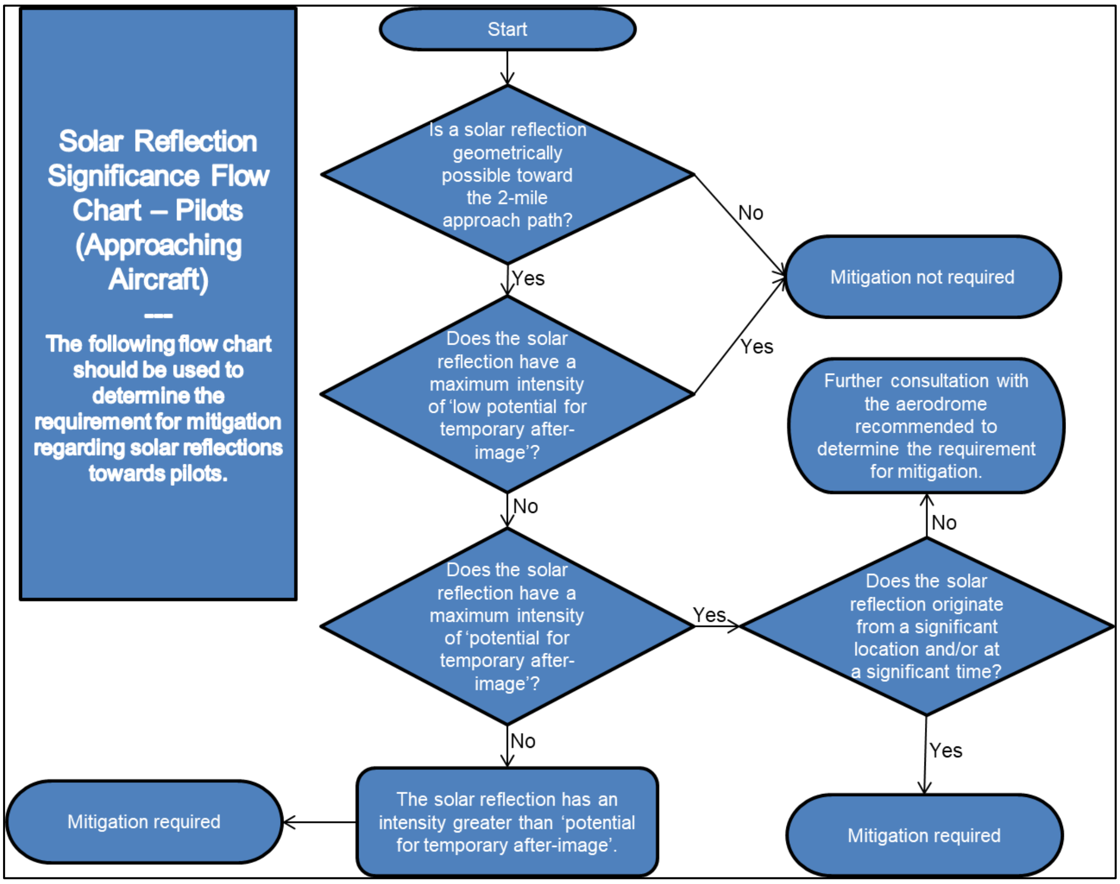

Figure 18 *Pilots (approaching aircraft) impact significance flow chart*

Helipads

9.28 Where helipads are present, a glint and glare assessment may be required. Therefore, Pager Power's has developed a standard methodology to determine the significance of a solar reflection towards a helicopter pilot on approach towards a helipad. The approach paths are assessed within the glint and glare assessment because they are considered to be the most critical stage of the flight.

9.29 The approach for determining receptor (helicopter) locations on the approach paths is to select locations along each bearing (spaced at maximum of 10 degrees) based on the centre point of the helipad out to a distance of 2 miles, spaced every ¼ mile. All possible approach paths are assessed unless specified or requested otherwise. The altitude of the aircraft is based on a 10 degree descent[40] path referenced to 2m above the helipad centre point (approximate eye level of a helicopter pilot).

[40] Normal helicopter descent angle on approach.

9.30 Similarly, to the assessment for fixed wing aircraft on approach, the location, duration, time and intensity of the solar reflection are considered to determine whether an impact may be significant. The flow chart presented in Figure 17 can therefore be followed to determine the impact significance. Results should be considered on a case-by-case basis.

Other Considerations

Circling Aircraft, Visual Manoeuvring Areas, Visual Circuits and En-Route Aircraft

9.31 Some aerodromes may request that circling aircraft, visual manoeuvring areas, visual circuits and en-route aircraft be assessed. If requested, the requirements of the assessment should be considered on a case-by-case basis and through consultation with the aerodrome. A typical assessment for aircraft in the Visual Manoeuvring Area (VMA) is as follows:

- Glint and glare calculations are undertaken for points spaced at regular intervals across a 10km radius circle centred above the airport at an altitude of 1500 feet above mean sea level[41];
- For each point where glint and glare is possible, the glare is classified in accordance with FAA standards;
- Where glint and glare is predicted to have 'potential for temporary after-image' or greater, the following should be completed:
    - The results will be overlaid on the published ICAO[42] Visual Approach Chart for the airport or similar;
    - An operational assessment should be undertaken using the overlaid Visual Approach Chart, considering the following:
        - Visual Holding Patterns;
        - Visual Reporting Points;
        - Aircraft joining approach from Visual Hold;
        - Other Visual Approach Chart features.
- Considering all of the above, it should be determined whether a significant impact is expected;
- Where glint and glare is not predicted or predicted to have a 'low-potential for temporary after-image', there will be no significant impact.

[41] Specific request may vary from an aerodrome depending on its operations.
[42] International Civil Aviation Organisation – ICAO. Chart usually available from the relevant national aviation stakeholder or aerodrome.

Conclusions

9.32 The size of the solar panel area and visibility of the reflecting solar panels relative to static infrastructure (such as the ATC Tower) will determine the duration of the solar reflection. The same is true for a reflective façade on a building development. For moving aircraft, its speed will be the overall determining factor with regard to the duration of the solar reflection. Consultation with the aviation stakeholder is essential to determine the requirement for assessment. It is recommended to consider aerodromes within 30km, though a detailed assessment may not be required.

10 OVERALL CONCLUSIONS

Overview

10.1 The purpose of this guidance document is to provide solar PV and building developers, planners and stakeholders with an assessment process for determining the effect of glint and glare (solar reflections) upon receptors surrounding a proposed solar PV or building development.

10.2 Formal guidance around glint and glare remains somewhat lacking in many cases. This guidance document has been produced to bridge this knowledge gap pertaining to the assessment of glint and glare from solar PV panels and reflective façades on building developments. The aim is to standardise an assessment process for developers, planners or stakeholders to follow.

10.3 The guidance presented within this document is based on the following:

- Reviews of existing guidance in a variety of areas;
- Glint and glare assessment experience and industry knowledge;
- Overview of available solar reflection studies.

10.4 The methodologies presented are deemed applicable for worldwide solar PV and building development.

Modelling Requirements

10.5 A geometric glint and glare assessment model must include the following:

- The Earth's orbit around the Sun;
- The Earth's rotation;
- The Earth's orientation;
- The location of the solar PV development or building development including the reflector (solar panel or façade) area;
- The reflector's 3D orientation including azimuth angle of the solar panel or façade (the orientation of the reflectors relative to north and the reflector elevation angle;
- Local topography including receptor and panel or façade heights above mean sea level.

10.6 For increased accuracy, the model could account for the following:

- Terrain at the visible horizon;
- Local time zone and daylight savings times;
- Consideration of sunrise and sunset times;
- Determine which solar panels create the solar reflection within the solar PV development;

- Determine what area of the façade create the solar reflection from the building development;
- Azimuth range of the Sun[43] when a solar reflection is geometrically possible;
- Vertical elevation range of the Sun when a solar reflection is geometrically possible;
- High-resolution analysis i.e. undertaking multiple geometric calculations within the given solar PV development or façade area. For example, at intervals of between 1 and 20 metres;
- Consideration of the effect of non-specular reflective surfaces e.g. masonry between glass façades;
- The intensity[44] of any solar reflection produced.

Assessment Inputs – Receptors

10.7 The following paragraphs set out the key distances for identifying receptors and the height data which should be included.

10.8 Dwellings within approximately 1km of a proposed solar PV development that may have a view of the PV panels should be assessed. Terrain heights and an additional height to account for the solar panel and eye level within the relevant floor of the dwelling should also be considered. Dwellings are not typically assessed for building developments.

10.9 Roads within approximately 1km of a proposed solar PV development that may have a view of the PV panels should be assessed. Terrain heights and an additional height to account for the solar panel and eye level of a road user should also be considered. Roads are not typically assessed for building developments.

10.10 Where railway infrastructure is located within approximately 100m of a proposed solar PV or building development that may have a view of the PV panels, an assessment should be undertaken. Train drivers out to 500m should be assessed. Any signals, crossings or vital railway infrastructure within 500m that could be affected by glare should be assessed especially where railway signal utilises incandescent bulb[45] technology and/or where no hood is attached. Terrain heights and an additional height to account for the solar panel/façade and eye level of a train driver or the height of a railway signal should also be considered.

[43] The azimuth range is the angle between the Sun and North, measured clockwise around the receptor's horizon. The Sun azimuth range shows the location of the Sun when a geometric solar reflection is possible. Therefore, it is possible to determine whether the Sun and the solar reflection are both likely to be visible to a receptor.
[44] In W/cm^2 at the retina, for example.
[45] Non-LED.

10.11 Aviation receptors out to 30km[46] from a proposed PV development should be considered to determine the requirement for assessment, if any. The typical receptors include the Air Traffic Control (ATC) tower and a 2-mile approach path for the relevant runway approaches. Additional receptors may be included where a solar reflection may be deemed a hazard to safety e.g. helipad approaches and the visual manoeuvring area (VMA). Aviation infrastructure is similarly assessed for building developments.

Assessment Significance

10.12 Determining the significance of a solar reflection varies for each receptor type. In general, the significance criteria for glint and glare effects are as follows:

- No Impact – A solar reflection is not geometrically possible or will not be visible from the assessed receptor. No mitigation required.
- Low – A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels significantly or the glare time per year is considered negligible. No mitigation required.
- Moderate – A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case scenario e.g. a solar reflection originates from a less sensitive location . Mitigation may be required.
- High – A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation will be required if the proposed development is to proceed. Mitigation and consultation is recommended.

10.13 There may be instances where the solar reflection scenario does not fall accurately within the significance categories. Where this occurs, detailed consideration of the receptors and the modelling results should be undertaken.

10.14 See the following sections where the process for determining the significance of a solar reflection is described for each receptor type:

- Section 6 – Dwellings;
- Section 7 – Road infrastructure;
- Section 8 – Railway infrastructure;
- Section 9 – Aviation infrastructure.

10.15 In each section, the process for determining the significance of a solar reflection is described comprehensively.

[46] Aviation stakeholders can and have requested a glint and glare assessment beyond 30km.

Guidance Conclusions

10.16 This guidance should be followed to ensure comprehensive assessment of solar PV and building developments with respect to glint and glare. This guidance is applicable for solar PV and building development anywhere in the world.

PAGERPOWER
Urban & Renewables

Pager Power Limited
Stour Valley Business Centre
Sudbury
Suffolk
CO10 7GB

Tel: +44 1787 319001 **Email:** info@pagerpower.com **Web:** www.pagerpower.com