

Glint and Glare Assessment

Workman LLP

Unit 1, Building 401

September 2021

PLANNING SOLUTIONS FOR:

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

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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	September 2021	Initial issue

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from the proposed Unit 1, Building 401 located approximately 550m northwest of the Air Traffic Control (ATC) Tower at Manchester Airport. The building roof will consist of glass rooflights and solar panels, which require a glint and glare assessment with respect to aviation activity associated with Manchester Airport.

A specific layout for the rooflights and solar panels has not yet been determined and therefore this assessment has provided guidance to develop a layout which is acceptable in accordance with the appropriate safeguarding criteria.

Pager Power

Pager Power has undertaken over 700 glint and glare assessments in the UK, Europe and further afield. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Overall Conclusions and Recommendations

A layout of the rooflights and solar panels which ensures no glare is predicted towards the ATC Tower is expected to be available. The primary constraint is ensuring rooflights, or solar panels that follow the pitch of the roof, are not located within two small areas of the southeast facing sections of the roof (see Section 8.1). Solar panels that are mounted on 5- and 10-degree frames can be located in these areas as they will not produce glare towards the ATC Tower.

No significant impacts upon approaching aircraft or aircraft using the visual circuits are predicted for any potential rooflight and solar panel layout.

Guidance and Studies

Guidelines exist in the UK (produced by the Civil Aviation Authority) and in the USA (produced by the Federal Aviation Authority) with respect to solar developments and aviation activity, however a specific methodology for aviation assessments has not been produced to date. Therefore, Pager Power has reviewed existing guidelines and the available studies (discussed below) in the process of defining its own glint and glare assessment guidance¹.

This guidance document defines the process for determining the impact upon aviation activity. Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, undertake solar intensity calculations in line with the Sandia National Laboratories' FAA methodology. The scenario in which a solar reflection can occur is identified

¹ Solar Photovoltaic Development – Glint and Glare Guidance, November 2020.

and discussed, and a comparison is made against the available reflection studies to determine the overall impact.

Assessment Results

ATC Tower Results

The analysis has shown that solar reflections are predicted towards the ATC Tower from two small sections of the southeast facing sections of the roof if the rooflights and solar panels both follow the 9-degree pitch of the rooftop. Any predicted glare towards an ATC tower is not acceptable in accordance with the associated guidance and industry best practice, and is therefore likely to cause an objection to be raised by Manchester Airport.

However, the analysis has shown that solar reflections are not geometrically possible towards the ATC Tower from any section of the rooftop if the elevation angle is increased to 14 and 19 degrees. This means that solar panels on a 5- or 10-degree mounting frame located within the 'reflecting areas' will no longer produce solar reflections towards the ATC Tower.

Therefore, ensuring the layout of the rooflights and solar panels is developed in accordance with the above will guarantee that no impacts are predicted upon the ATC Tower.

Runway 05L/05R Results

The modelling has shown that solar reflections are not geometrically possible towards aircraft along the 2-mile approach paths for runways 05L and 05R.

No impacts are therefore predicted upon aircraft approaching runways 05L and 05R for any potential rooflight and solar panel layout.

Runway 23R/23L Results

The modelling has shown that solar reflections predicted towards pilots along the 2-mile approach paths for runway 23R and 23L will have a maximum of 'low potential for temporary after-image'. This level of glare is acceptable considering the associated guidance and industry best practice.

A low impact is therefore predicted upon aircraft approaching runways 23R and 23L for any potential rooflight and solar panel layout.

Visual Circuit Results (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), no significant impact upon the visual circuits is anticipated as any visible solar reflection would be of acceptable intensity under the associated guidance and industry best practice.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 countries within South Africa, Europe, America, Asia and Australasia.

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.

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from the proposed Unit 1, Building 401 located approximately 550m northwest of the Air Traffic Control (ATC) Tower at Manchester Airport. The building roof will consist of glass rooflights and solar panels, which require a glint and glare assessment with respect to aviation activity associated with Manchester Airport.

A specific layout for the rooflights and solar panels has not yet been determined and therefore this assessment has provided guidance to develop a layout which is acceptable in accordance with the appropriate safeguarding criteria.

The specific receptors requiring assessment are the approach paths, the ATC Tower, and aircraft in the visual circuits. The analysis contains the following:

- Details of the proposed development;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Identification of aviation concerns and receptors;
- Assessment methodology;
- Glint and glare assessment for:
 - Aircraft approach paths for the relevant runways;
 - ATC Tower;
 - Visual circuit paths (high-level).
- Results discussion;
- High-level overview of mitigation.

Following this, a summary of findings and overall conclusions and recommendations from the desk-based analysis is presented. No site survey has taken place at this stage.

1.2 Pager Power's Experience

Pager Power has undertaken over 700 glint and glare assessments internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Glint and Glare Definition

The definition of glint and glare is as follows:

- Glint – a momentary flash of bright light typically received by moving receptors or from moving reflectors.
- Glare – a continuous source of bright light typically received by static receptors or from large reflective surfaces.

These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America. The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

2 PROPOSED DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Masterplan

The proposed development masterplan is presented in Figure 1² below. This assessment concerns Units 1a, 1b, and 1c only.



Figure 1 Masterplan

2.2 Assessment Parameters

Solar reflections are most significant when they are specular rather than diffuse i.e. reflections from a smooth mirror-like surface are more noticeable than scattered reflections from rougher surfaces. The rooftop of the proposed development will consist of multiple rooflights, covering approximately 20% of the roof surface area, and solar panels that will be installed on other parts of the rooftop.

² Source: A 100 000-T2-Proposed site Block Plan (cropped).

The rooflights and solar panels have the potential to produce specular reflections and could be located over any parts of the roof. As such, the assessment has considered the entire rooftop to contain reflective surfaces, which would be considered the worst-case with respect to glint and glare.

The reflector areas and technical details used in this assessment are presented in Section 6.

2.3 Building Elevations

The building elevations are shown in Figures 2 to 5³ below and on the following page.

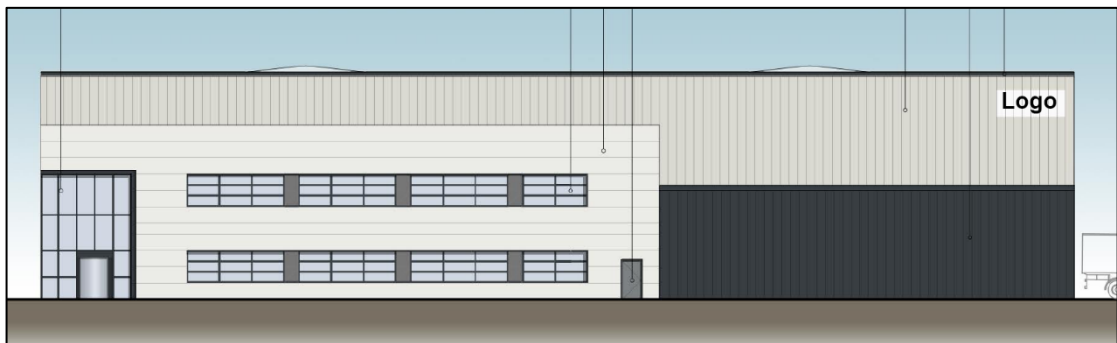


Figure 2 Northeast elevation



Figure 3 Southeast elevation

³ Source: 020598-RPS-SI-XX-DR-A-0111 (Proposed Elevations).

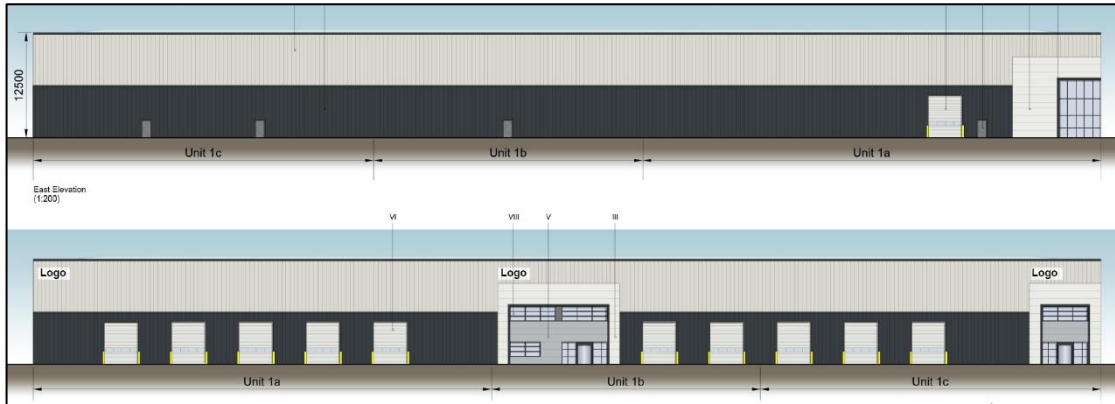


Figure 4 Southwest elevation

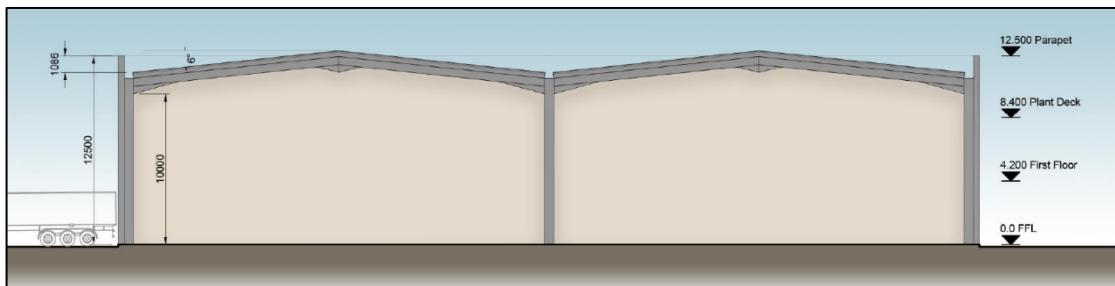


Figure 5 Indicative section

3 MANCHESTER AIRPORT DETAILS

3.1 Airport Information

Manchester Airport is a Civil Aviation Authority (CAA) licensed aerodrome with two runways. The runway details are presented below:

1. 05L/23R measuring 3,048m by 45m (asphalt);
2. 05R/23L measuring 3,050m by 45m (asphalt).

The runways are shown on the aerodrome chart in Figure 6⁴ below.

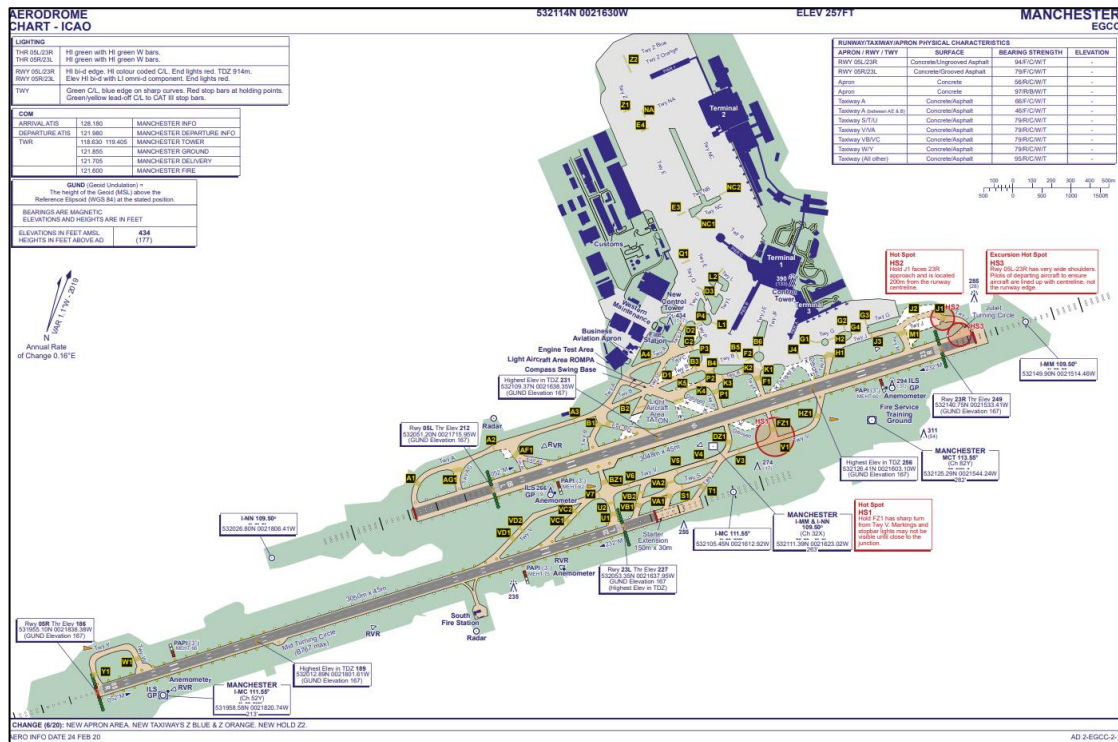


Figure 6 Aerodrome chart – Manchester Airport

⁴ Source: NATS AIP for Manchester Airport (last accessed September, 2021).

The proposed development building footprint relative to Manchester Airport is shown in Figure 7⁵ below.



Figure 7 Location of proposed development relative to the proposed development

⁵ Copyright © 2021 Google.

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Guidance and Studies

Appendix A and B present a review of relevant guidance and independent studies with regard to glint and glare issues. Much of the information on this topic is in relation to solar photovoltaic developments, however many of the technical principles are applicable to other smooth reflectors such as glass.

4.2 Background

Details of the Sun's movements and solar reflections are presented in Appendix C.

4.3 Methodology

The assessment methodology is based on guidance, studies, previous discussions with stakeholders and Pager Power's practical experience.

The glint and glare assessment methodology has been derived from the information provided to Pager Power through consultation with stakeholders and by reviewing the available guidance. The methodology for the aviation glint and glare assessment is as follows:

- Identify receptors in the area surrounding the proposed development;
- Consider direct solar reflections from the proposed development towards the identified receptors by undertaking geometric calculations;
- Consider the visibility of the reflectors from the receptor's location. If the reflectors are not visible from the receptor then no reflection can occur;
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur;
- Consider the solar reflection intensity;
- Consider both the solar reflection from the proposed development and the location of the direct sunlight with respect to the receptor's position;
- Consider the solar reflection with respect to the published studies and guidance;
- Determine whether a significant detrimental impact is predicted.

Within the Pager Power modelling, the reflector area is defined, as well as the relevant receptor locations. The result is a chart that states whether a reflection can occur, the duration and location from which a solar reflection can occur. Intensity calculations are also completed in line with the Sandia National Laboratories methodology⁶.

⁶ The model used to determine intensity is external (Forge Solar).

This model was primarily designed for the assessment of solar photovoltaic developments at airports. This methodology was not designed for metal or glass façades however it is useful for technical context.

Further technical details regarding the methodology of the geometric calculations and limitations are presented in Appendix E and Appendix F.

5 IDENTIFICATION OF RECEPTORS

5.1 Air Traffic Control Tower

It is standard practice to determine whether a solar reflection can be experienced by personnel within the ATC Tower. The ATC Tower location is illustrated in Figure 8⁷ below.

Coordinate data, taken from the NATS AIP, is presented in Appendix G.



Figure 8 ATC Tower location

⁷ Copyright © 2021 Google.

5.2 Airborne Receptors – Approaching Aircraft

A geometric glint and glare assessment has been undertaken for aircraft on the final approach towards the runways. This is considered to be the most critical stage of the flight. The Pager Power approach for determining receptor (aircraft) locations on the approach path is to select locations along the extended runway centre line from 50ft above the runway threshold out to a distance of 2 miles. The height of the aircraft is determined by using a 3-degree descent path relative to the runway threshold height.

Figure 9⁸ below shows the assessed approach receptor locations and ATC Tower location incorporated into the assessment.

The detailed information for approach path receptors is presented in Appendix G.

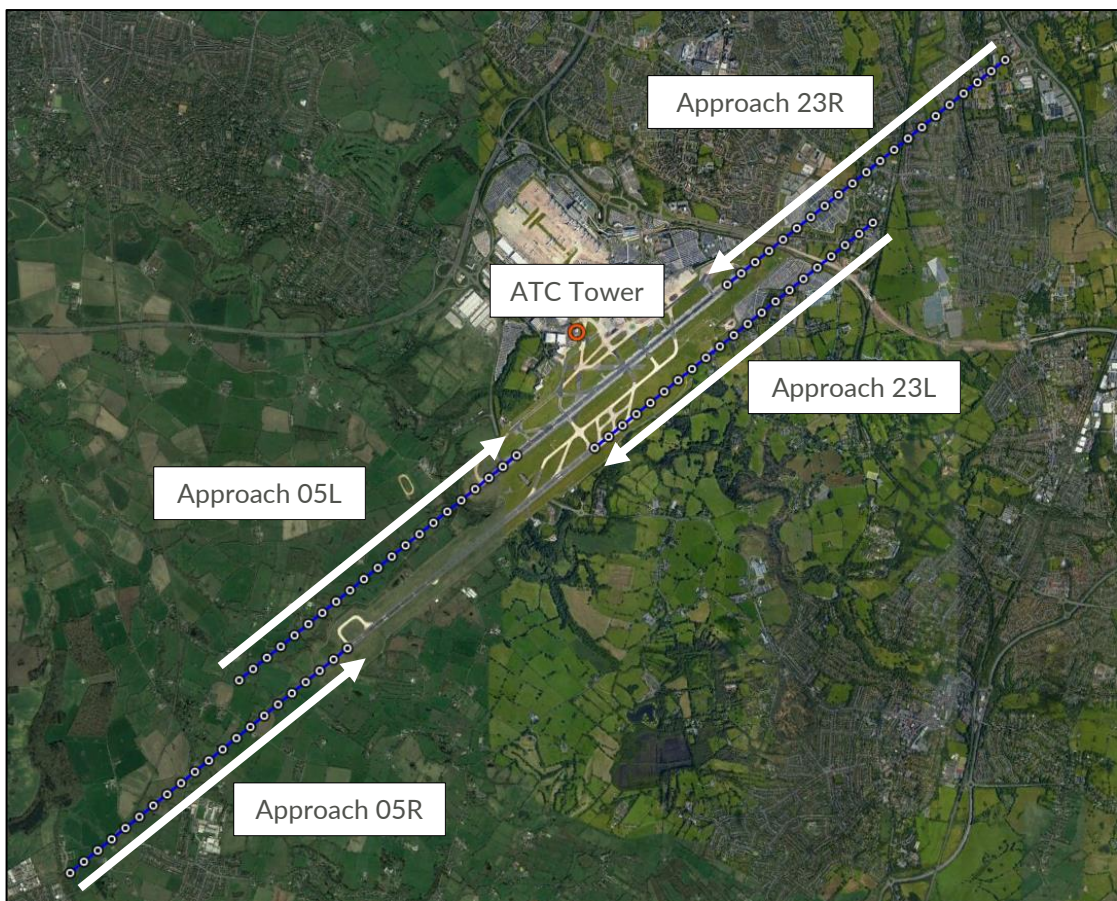


Figure 9 All aviation receptors

⁸ Copyright © 2021 Google.

5.3 Airborne Receptors – Aircraft Circuits

Manchester Airport requires assessment of general aviation aircraft flying both directions in the visual circuits for 05L, 05R, 23L and 23R.

When light aircraft arrive or depart from an aerodrome, they may fly in a standard pattern. A typical circuit is shown in Figure 10 below.

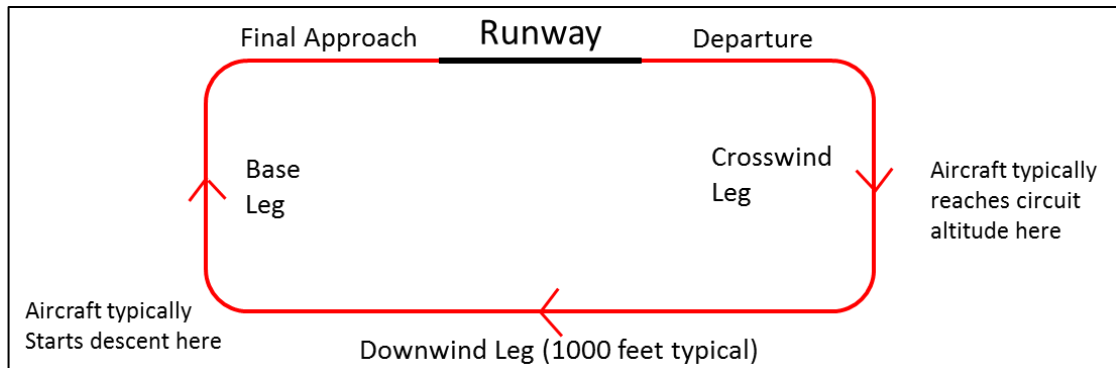


Figure 10 Typical circuit diagram

The way circuits are flown varies from airport to airport, pilot to pilot and aircraft to aircraft. The assessed circuit has the following characteristics:

- Circuit altitude 1,000ft (304.8m) above the lowest runway threshold;
- Circuit originates and terminates at the runway ends⁹;
- The circuit considers an ascent and descent angle of 5°.

It is assumed that aircraft will be at 1,000ft above mean sea level on the base leg.

A circuit width of 1 nautical mile (nm) has been modelled for the 1,000ft circuit.

Figure 11¹⁰ on the following page shows the circuits paths for Manchester Airport. The red circle paths belong to Runway 05L-23R while the blue paths belong to Runway 05R-23L. The visual circuits have been considered at a high-level within this report.

⁹ Runway thresholds.

¹⁰ Source: Copyright © 2020 Google, Landsat/Copernicus.



Figure 11 Circuits paths for runways 05L-23R (red line) and 05R-23L (blue line)

6 ASSESSED REFLECTOR AREAS

6.1 Reflector Areas

The entire rooftop has been considered as a reflective area to remain conservative. The unit is split into four distinctive reflector areas, which are shown in Figure 12 below.

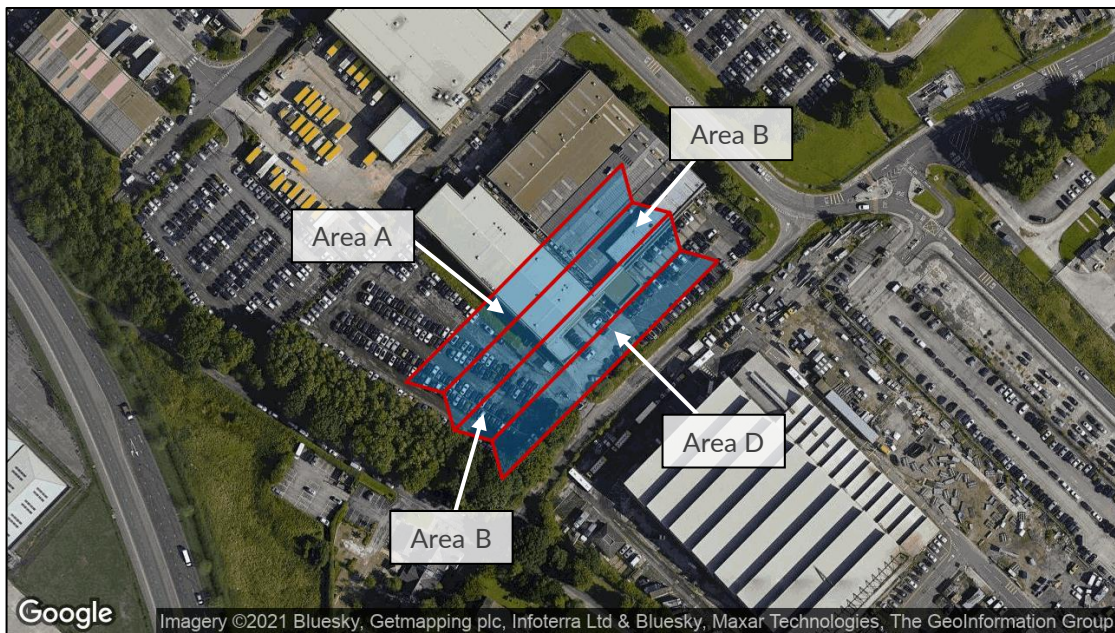


Figure 12 Modelled reflector areas

Although the rooflights will follow the roof pitch, the solar panels have the potential to be mounted on frames that do not follow the roof pitch. Each area has therefore been assessed at varying elevation angles to reflect typical mounting systems for rooftop solar panels.

The technical details used in this assessment are presented in Table 1 below.

Technical Details		
Areas	A / C	B / D
Roof azimuth angles (°)	315	135
Assessed height (m amsl ¹¹)	80	
Elevation angle (°)	9 / 14 / 19	

Table 1 Technical details

¹¹ Above mean sea level

A number of representative locations are selected within the rooftop areas. The number of modelled reflector points is determined by the size of the reflector area and the assessment resolution. The bounding coordinates for the rooftop areas have been extrapolated from the site plans and can be found in Appendix G. All ground heights have been based on OSGB36 Panorama terrain data.

A resolution of 2m has been chosen for Pager Power model in this assessment. This means that a geometric calculation is undertaken for each identified receptor every 2m from within the defined area. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output.

7 GLINT AND GLARE ASSESSMENT RESULTS

7.1 Overview

The Pager Power and Forge model have been used to determine whether reflections are possible. Where solar reflections have been predicted, intensity calculations in line with the Sandia National Laboratories methodology have been undertaken for reference purposes. These calculations are routinely required for solar photovoltaic developments on or near aerodromes.

The intensity model calculates the expected intensity of a reflection with respect to the potential for an after-image (or worse) occurring. The designation used by the model is presented in Table 2 below along with the associated colour coding.

Coding Used	Intensity Key
Glare beyond 50°	 Glare beyond 50 deg from pilot line-of-sight
Low potential	 Low potential for temporary after-image
Potential	 Potential for temporary after-image
Potential for permanent eye damage	 Potential for permanent eye damage

Table 2 Glare intensity designation

This coding has been used in the table where a reflection has been calculated and is in accordance with Sandia National Laboratories' methodology.

The intensity model allows for assessment of a variety of surface materials. A surface material of 'smooth glass without an anti-reflective coating' has been assessed because this is the most conservative option. Whilst the criteria is applicable to solar panels, there are however no intensity criteria for glass or metal façades and aviation receptors, but it is judged that the results have technical merit for reference purposes. They should not be considered the sole determining factor in judging a project's acceptability in a case such as this one.

7.2 Summary of Results

Table 3 on the following page summarises the results for each assessed elevation angle. The predicted glare times are based solely on bare-earth terrain i.e. without consideration of screening from buildings and vegetation. The final column summarises the predicted impact considering the level of predicted screening based on a desk-based review of the available imagery. The significance of any predicted impact is discussed in the subsequent report sections.

The modelling output showing the precise predicted times for the 9-degree elevation angle and the reflecting panel areas are shown in Appendix H. The other modelling outputs can be provided upon request.

Receptor	9 degrees	14 degrees	19 degrees
ATC Tower	Solar reflections with 'low potential for temporary after-image' are predicted to originate from parts of Areas B and D. Discussed further in Section 8.1.	No solar reflections geometrically possible. No impacts predicted.	No solar reflections geometrically possible. No impacts predicted.
Runway 05L Approach	No solar reflections geometrically possible. No impacts predicted.		
Runway 05R Approach			
Runway 23R Approach	Solar reflections with 'low potential for temporary after-image' are predicted towards the entire 2-mile approach. Low impact is predicted.		
Runway 23L Approach	Solar reflections with 'low potential for temporary after-image' are predicted towards part of the 2-mile approach. Low impact is predicted.		
Visual Circuits	Solar reflections may be possible towards pilots along the visual circuit paths. Glare intensities are predicted to be no worse than those predicted towards pilots on approach. Low impact predicted.		

Table 3 Summary of geometric analysis results

8 RESULTS DISCUSSION

8.1 ATC Tower Results

The analysis has shown that solar reflections are predicted towards the ATC Tower from two small sections of Areas B and D if the rooflights and solar panels both follow the 9-degree pitch of the rooftop. Any predicted glare towards an ATC tower is not acceptable in accordance with the associated guidance and industry best practice and is therefore likely to cause an objection to be raised by Manchester Airport. The reflecting areas are shown in Figure 13¹² below.

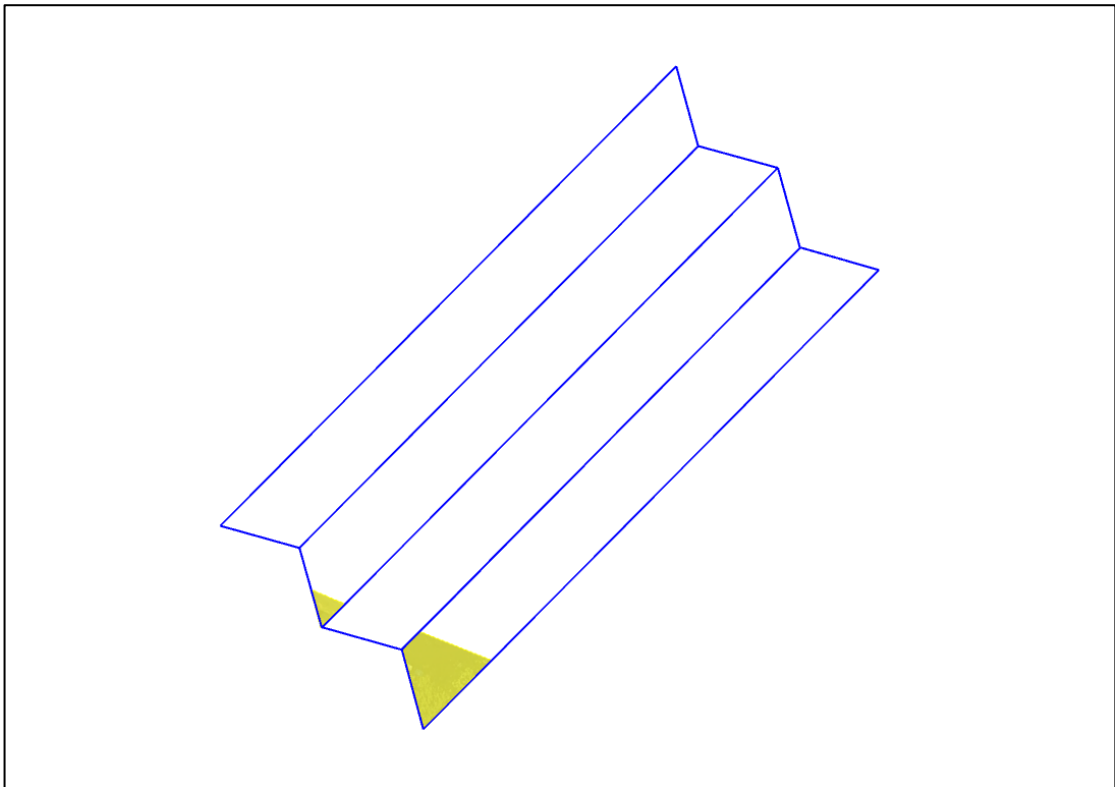


Figure 13 *Reflecting areas*

However, the analysis has shown that solar reflections are not geometrically possible towards the ATC Tower from any section of the rooftop if the elevation angle is increased to 14 and 19 degrees. This means that solar panels on a 5- or 10-degree mounting frame located within the 'reflecting areas' will no longer produce solar reflections towards the ATC Tower.

Therefore, ensuring the layout of the rooflights and solar panels is developed in accordance with the above will guarantee that no impacts are predicted upon the ATC Tower.

¹² Copyright © 2021 Google.

8.2 Runway 05L/05R Results

The modelling has shown that solar reflections are not geometrically possible towards aircraft along the 2-mile approach paths for runways 05L and 05R.

No impacts are therefore predicted upon aircraft approaching runways 05L and 05R for any potential rooflight and solar panel layout.

8.3 Runway 23R/23L Results

The modelling has shown that solar reflections predicted towards pilots along the 2-mile approach paths for runway 23R and 23L will have a maximum of 'low potential for temporary after-image'. This level of glare is acceptable considering the associated guidance and industry best practice.

A low impact is therefore predicted upon aircraft approaching runways 23R and 23L for any potential rooflight and solar panel layout.

8.4 Visual Circuit Results (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), no significant impact upon the visual circuits is anticipated as any visible solar reflection would be of acceptable intensity under the associated guidance and industry best practice.

9 OVERALL CONCLUSIONS

9.1 Overall Conclusions and Recommendations

A layout of the rooflights and solar panels which ensures no glare is predicted towards the ATC Tower is expected to be available. The primary constraint is ensuring rooflights, or solar panels that follow the pitch of the roof, are not located within two small areas of the southeast facing sections of the roof (see Section 8.1). Solar panels that are mounted on 5- and 10-degree frames can be located in these areas as they will not produce glare towards the ATC Tower.

No significant impacts upon approaching aircraft or aircraft using the visual circuits are predicted for any potential rooflight and solar panel layout.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

This section presents details regarding the relevant guidance and studies with respect to the considerations and effects of solar reflections from solar panels, known as 'Glint and Glare'.

This is not a comprehensive review of the data sources, rather it is intended to give an overview of the important parameters and considerations that have informed this assessment.

UK Planning Policy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy¹³ (specifically regarding the consideration of solar farms, paragraph 013) states:

'What are the particular planning considerations that relate to large scale ground-mounted solar photovoltaic Farms?

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;*

...

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.'

¹³ [Renewable and low carbon energy](#), Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare are, however, provided for assessing the impact of solar reflections upon surrounding roads and dwellings. Therefore, the Pager Power approach is to determine whether a reflection from the proposed solar development is geometrically possible and then to compare the results against the relevant guidance/studies to determine whether the reflection is significant.

The Pager Power approach has been informed by the policy presented above, current studies (presented in Appendix B) and stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document¹⁴ which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

Aviation Assessment Guidance

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, 2012¹⁵ however the advice is still applicable¹⁶ until a formal policy is developed. The relevant aviation guidance from the CAA is presented in the section below.

CAA Interim Guidance

This interim guidance makes the following recommendations (p.2-3):

'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.

¹⁴ Solar Photovoltaic Development – Glint and Glare Guidance, Second Edition 2, October 2018. Pager Power.

¹⁵ Archived at Pager Power

¹⁶ Reference email from the CAA dated 19/05/2014.

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 ALH¹⁷, 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.

FAA Guidance

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

The 2010 document is entitled 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'¹⁸ and the 2013 update is entitled 'Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'¹⁹. In April 2018 the FAA released a new version (Version 1.1) of the 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'²⁰.

An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

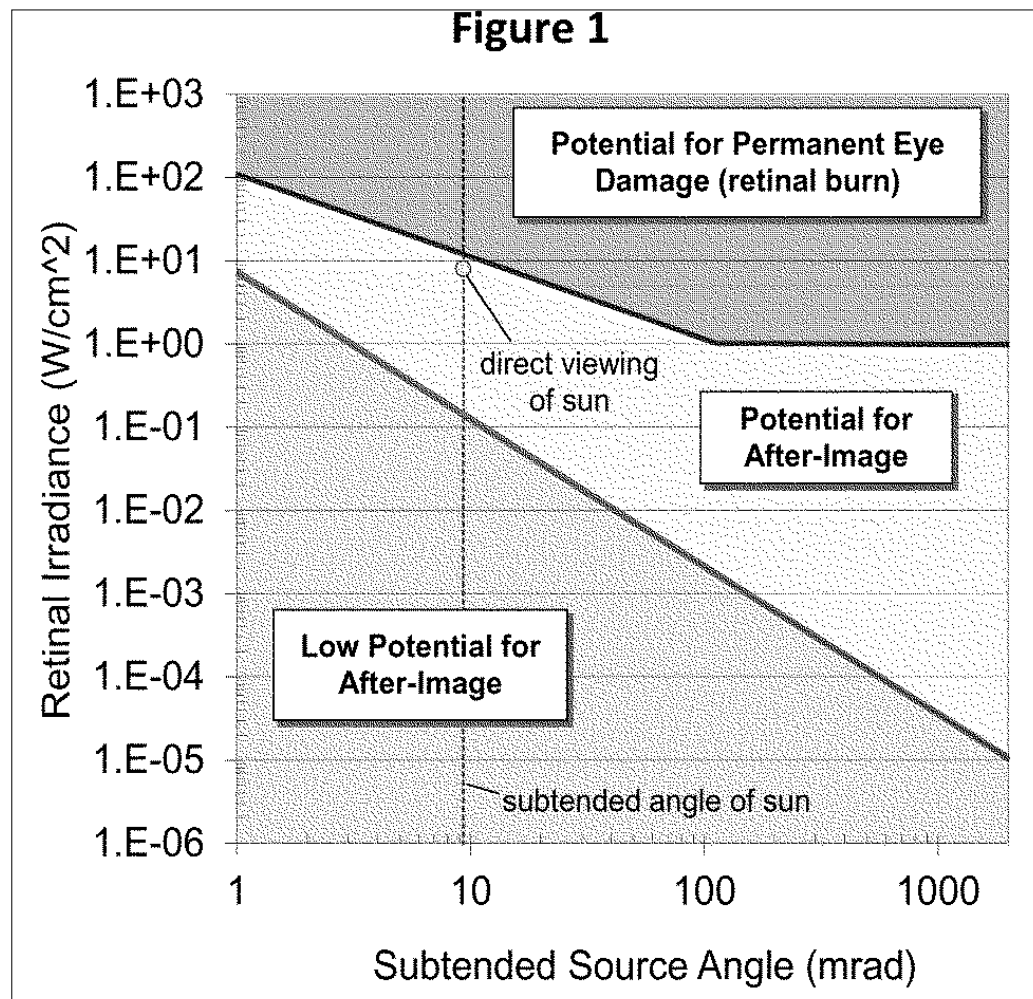
- Solar energy systems located on an airport that is not federally-obligated or located outside the property of a federally-obligated airport are not subject to this policy.
- Proponents of solar energy systems located off-airport property or on non-federally-obligated airports are strongly encouraged to consider the requirements of this policy when siting such system.
- FAA adopts the Solar Glare Hazard Analysis Plot.... as the standard for measuring the ocular impact of any proposed solar energy system on a federally-obligated airport. This is shown in the figure below.

¹⁷ Aerodrome Licence Holder.

¹⁸ Archived at Pager Power

¹⁹ Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports, Department of Transportation, Federal Aviation Administration (FAA), date: 10/2013, accessed on: 20/03/2019

²⁰ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019



Solar Glare Hazard Analysis Plot (FAA)

- To obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a “no objection” ... the airport sponsor will be required to demonstrate that the proposed solar energy system meets the following standards:
- No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATC) cab, and
- No potential for glare or “low potential for after-image” ... 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 glidepath.
- Ocular impact must be analysed over the entire calendar year in one (1) minute intervals from when the sun rises above the horizon until the sun sets below the horizon.

The bullets highlighted above state there should be ‘no potential for glare’ at that ATC Tower and ‘no’ or ‘low potential for glare’ on the approach paths.

Key points from the 2018 FAA guidance are presented below.

- *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 blindness²¹.*
- *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 16²², 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.*
- *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:*
 - *A qualitative analysis of potential impact in consultation with the Control Tower, pilots and airport officials;*
 - *A demonstration field test with solar panels at the proposed site in coordination with FAA Tower personnel;*
 - *A geometric analysis to determine days and times when an impact is predicted.*
- *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*

²¹Flash Blindness, as described in the FAA guidelines, can be described as a temporary visual interference effect that persists after the source of illumination has ceased. This occurs from many reflective materials in the ambient environment.

²² First figure in Appendix B.

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.
- 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.
- **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.

Air Navigation Order (ANO) 2009

In some instances, an aviation stakeholder can refer to the ANO 2009 with regard to safeguarding. Key points from the document are presented below.

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—

²³ Ho, Clifford, Cheryl Ghanbari, and Richard Diver. 2009. Hazard Analysis of Glint and Glare From Concentrating Solar Power Plants. SolarPACES 2009, Berlin Germany. Sandia National Laboratories.

(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.'

The document states that no 'light', 'dazzle' or 'glare' should be produced which will create a detrimental impact upon aircraft safety.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

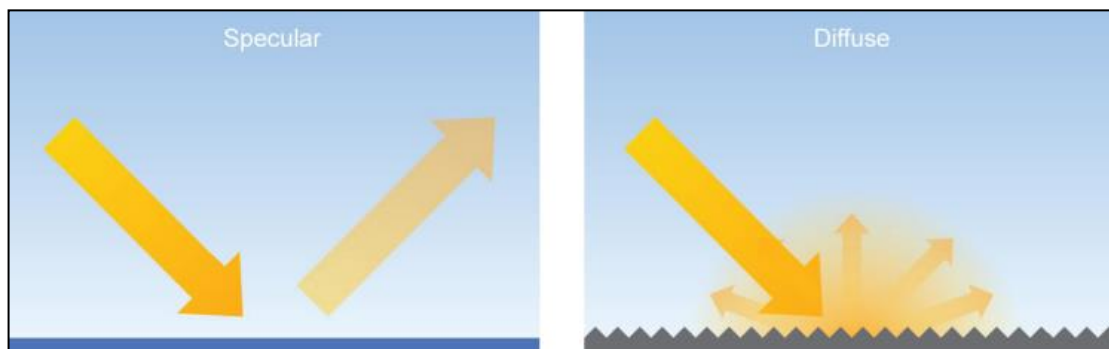
Overview

Studies have been undertaken assessing the type and intensity of solar reflections from various surfaces including solar panels and glass. An overview of these studies is presented below.

The guidelines presented are related to aviation safety. The results are applicable for the purpose of this analysis.

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance²⁴, illustrates the difference between the two types of reflections. Because solar panels are flat and have a smooth surface most of the light reflected is specular, which means that incident light from a specific direction is reradiated in a specific direction.



Specular and diffuse reflections

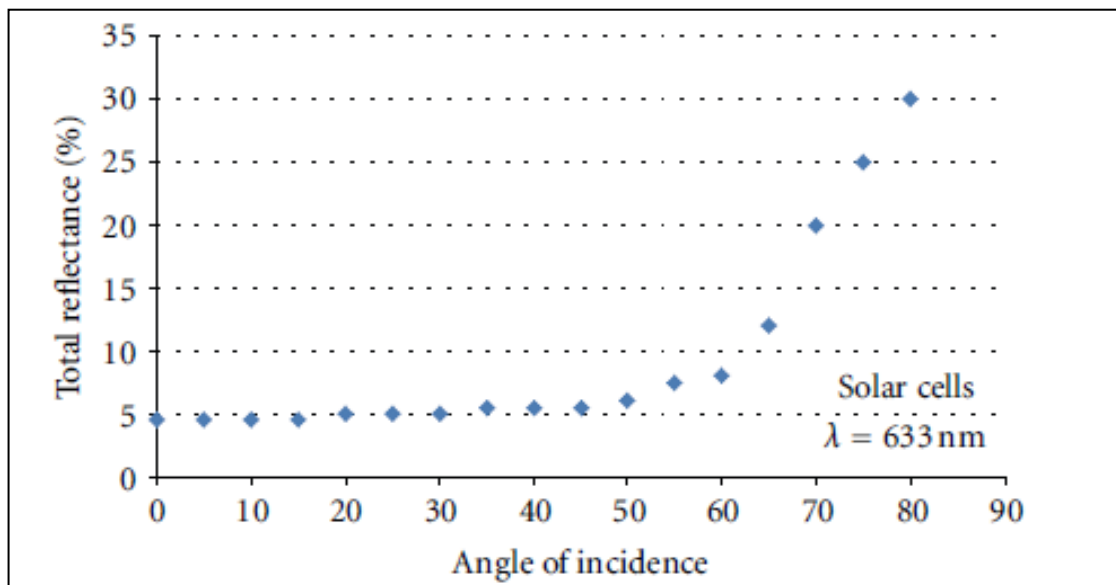
²⁴Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

Solar Reflection Studies

An overview of content from identified solar panel reflectivity studies is presented in the subsections below.

Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems"

Evan Riley and Scott Olson published in 2011 their study titled: *A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems*²⁵. They researched the potential glare that a pilot could experience from a 25 degree fixed tilt PV system located outside of Las Vegas, Nevada. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image caused by smooth water. The study demonstrated that the reflectance of the solar cell varied with angle of incidence, with maximum values occurring at angles close to 90 degrees. The reflectance values varied from approximately 5% to 30%. This is shown on the figure below.



Total reflectance % when compared to angle of incidence

The conclusions of the research study were:

- The potential for hazardous glare from flat-plate PV systems is similar to that of smooth water;
- Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have a reflectivity greater than water and flat plate PV modules.

²⁵ Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems," ISRN Renewable Energy, vol. 2011, Article ID 651857, 6 pages, 2011. doi:10.5402/2011/651857

FAA Guidance – “Technical Guidance for Evaluating Selected Solar Technologies on Airports”²⁶

The 2010 FAA Guidance included a diagram which illustrates the relative reflectance of solar panels compared to other surfaces. The figure shows the relative reflectance of solar panels compared to other surfaces. Surfaces in this figure produce reflections which are specular and diffuse. A specular reflection (those made by most solar panels) has a reflection characteristic similar to that of a mirror. A diffuse reflection will reflect the incoming light and scatter it in many directions. A table of reflectivity values, sourced from the figure within the FAA guidance, is presented below.

Surface	Approximate Percentage of Light Reflected ²⁷
Snow	80
White Concrete	77
Bare Aluminium	74
Vegetation	50
Bare Soil	30
Wood Shingle	17
Water	5
Solar Panels	5
Black Asphalt	2

Relative reflectivity of various surfaces

Note that the data above does not appear to consider the reflection type (specular or diffuse).

An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

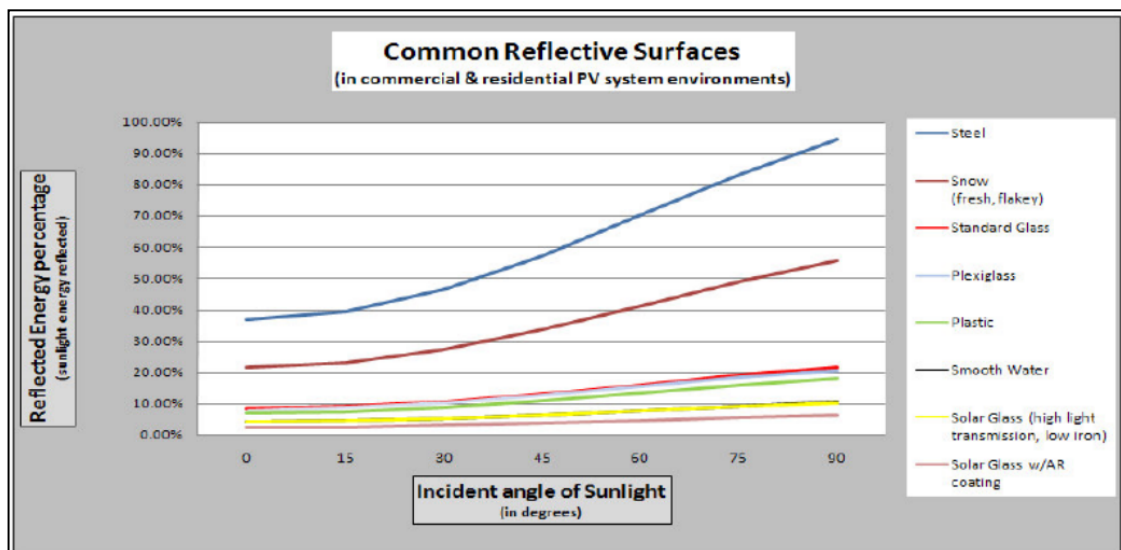
²⁶ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

²⁷ Extrapolated data, baseline of 1,000 W/m² for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification²⁸ to 'increase awareness concerning the possible glare and reflectance impact of PV Systems on their surrounding environment'.

The figure presented below shows the relative reflectivity of solar panels compared to other natural and manmade materials including smooth water, standard glass and steel.



Common reflective surfaces

The results, similarly to those from Riley and Olsen study (2011) and the FAA (2010), show that solar panels produce a reflection that is less intense than those of 'standard glass and other common reflective surfaces'.

With respect to aviation and solar reflections observed from the air, SunPower has developed several large installations near airports or on Air Force bases. It is stated that these developments have all passed FAA or Air Force standards with all developments considered "No Hazard to Air Navigation". The note suggests that developers discuss any possible concerns with stakeholders near proposed solar farms.

²⁸ Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

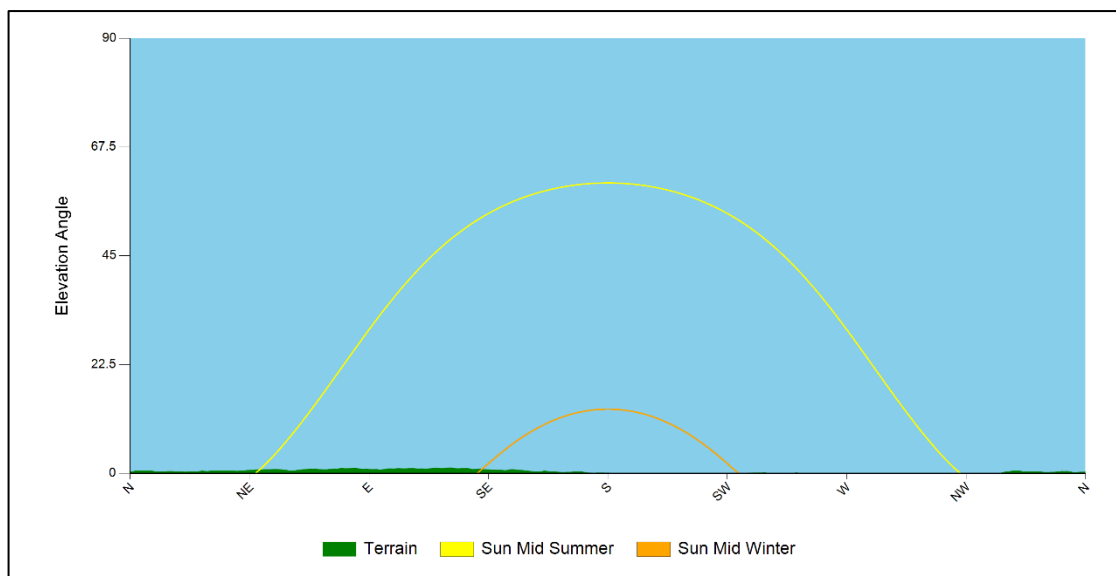
Overview

The Sun's position in the sky can be accurately described by its azimuth and elevation. Azimuth is a direction relative to true north (horizontal angle i.e. from left to right) and elevation describes the Sun's angle relative to the horizon (vertical angle i.e. up and down).

The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- Time;
- Date;
- Latitude;
- Longitude.

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector. The figure below shows the Sun's movement across the sky at the development location. It shows the Sun's azimuth angle from true north. The high line illustrates the summer solstice (the longest day) and the lower line illustrates the winter solstice (the shortest day). For all other days in the year, the Sun would be between this maximum and minimum.



Sun movement graph

APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

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

Impact Significance Definition

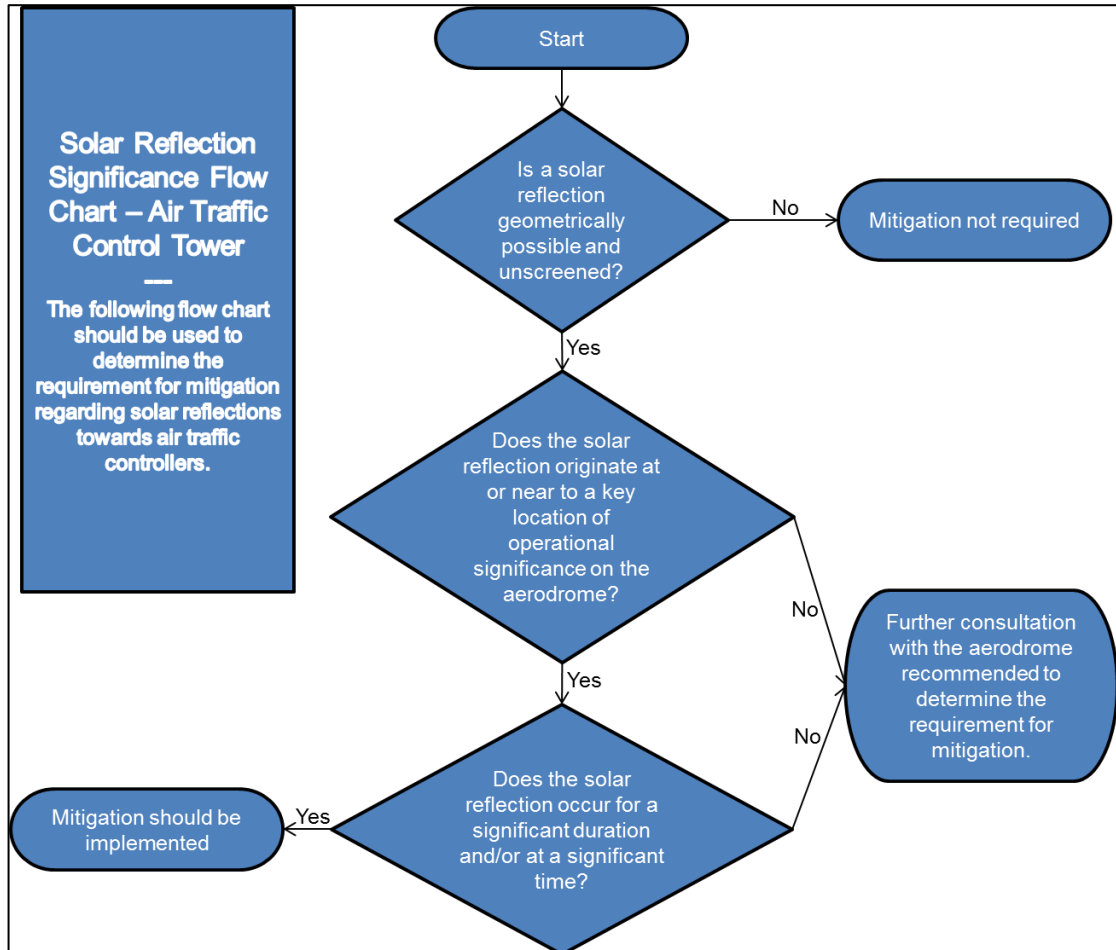
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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.	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.
Major	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.

Impact significance definition

Impact Significance Determination for an ATC Tower

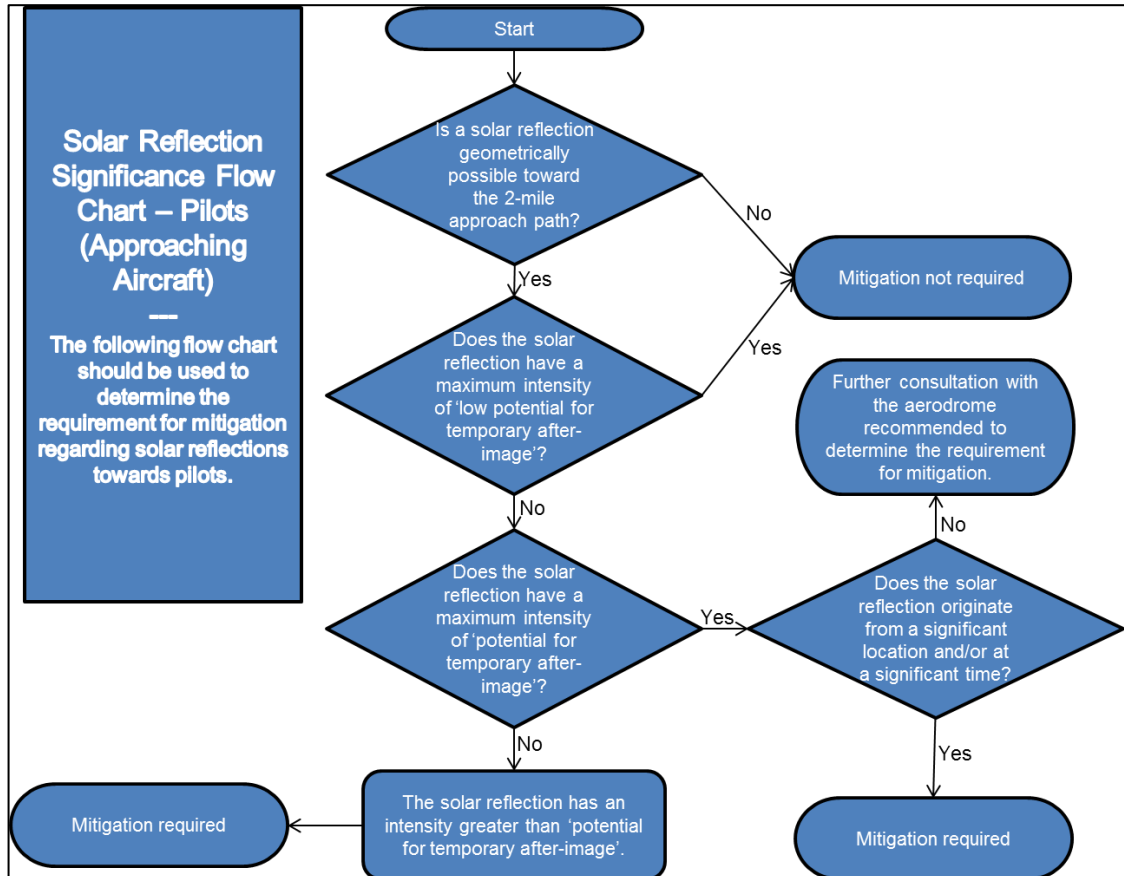
The flow chart presented below has been followed when determining the mitigation requirement for an ATC Tower.



ATC Tower mitigation requirement flow chart

Impact Significance Determination for Approaching Aircraft

The flow chart presented below has been followed when determining the mitigation requirement for approaching aircraft.



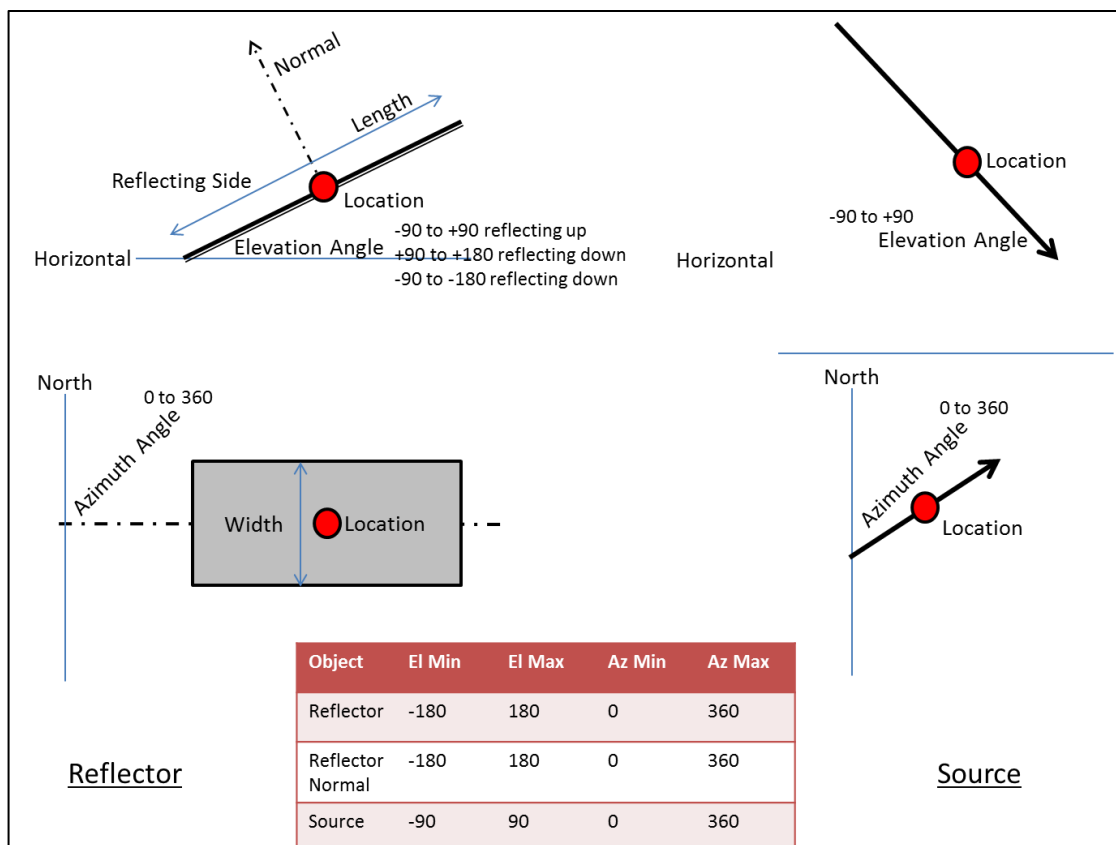
Approaching aircraft receptor mitigation requirement flow chart

APPENDIX E – PAGER POWER’S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

- The Earth’s orbit around the Sun;
- The Earth’s rotation;
- The Earth’s orientation;
- The reflector’s location;
- The reflector’s 3D Orientation.

Reflections from a flat reflector are calculated by considering the normal which is an imaginary line that is perpendicular to the reflective surface and originates from it. The diagram below may be used to aid understanding of the reflection calculation process.



Reflection calculation process

The following process is used to determine the 3D azimuth and elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;
- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
 - The angle between source and normal is equal to angle between normal and reflection;
 - Source, Normal and Reflection are in the same plane.

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

The model considers 100% sunlight during daylight hours which is highly conservative.

The model does not account for terrain between the reflecting solar panels and the assessed receptor where a solar reflection is geometrically possible.

The model considers terrain between the reflecting solar panels and the visible horizon (where the sun may be obstructed from view of the panels)²⁹.

It is assumed that the panel elevation angle assessed represents the elevation angle for all of the panels within each solar panel area defined.

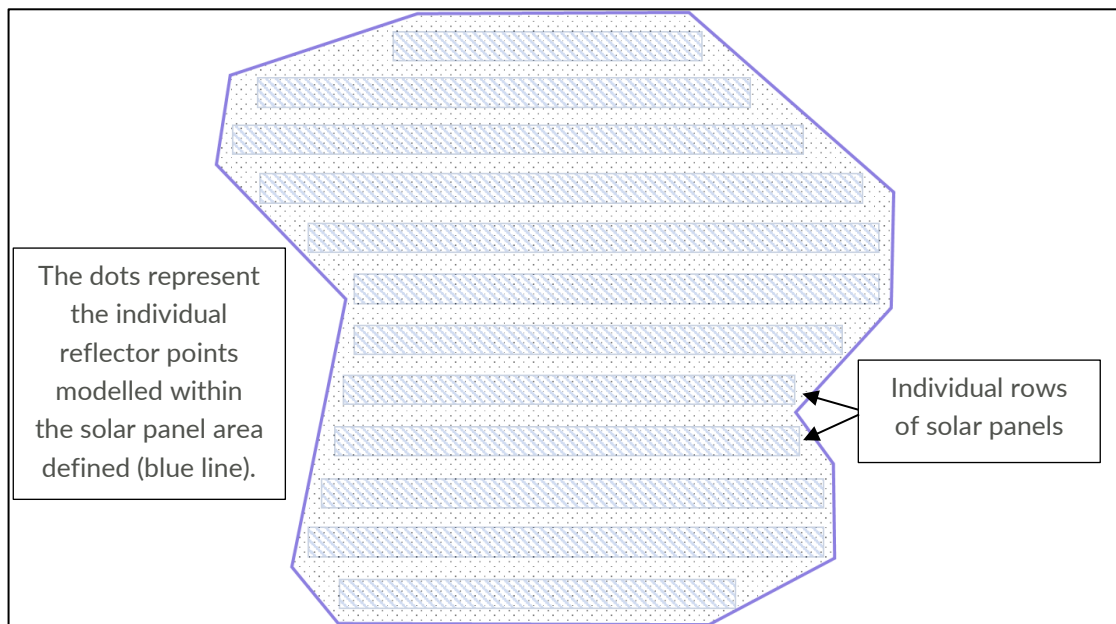
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

Only a reflection from the face of the panel has been considered. The frame or the reverse or frame of the solar panel has not been considered.

The model assumes that a receptor can view the face of every panel (point, defined in the following paragraph) within the development area whilst in reality this, in the majority of cases, will not occur. Therefore any predicted solar reflection from the face of a solar panel that is not visible to a receptor will not occur in practice.

A finite number of points within each solar panel area defined is chosen based on an assessment resolution so that a comprehensive understanding of the entire development can be formed. This determines whether a solar reflection could ever occur at a chosen receptor. The model does not consider the specific panel rows or the entire face of the solar panel within the development outline, rather a single point is defined every 'x' metres (based on the assessment resolution) with the geometric characteristics of the panel. A panel area is however defined to encapsulate all possible panel locations. See the figure below which illustrates this process.

²⁹ UK only.



Solar panel area modelling overview

A single reflection point is chosen for the geometric calculations. This suitably determines whether a solar reflection can be experienced at a receptor location and the time of year and duration of the solar reflection. Increased accuracy could be achieved by increasing the number of heights assessed however this would only marginally change the results and is not considered significant.

The available street view imagery, satellite mapping, terrain and any site imagery provided by the developer has been used to assess line of sight from the assessed receptors to the modelled solar panel area, unless stated otherwise. In some cases, this imagery may not be up to date and may not give the full perspective of the installation from the location of the assessed receptor.

Any screening in the form of trees, buildings etc. that may obstruct the Sun from view of the solar panels is not within the modelling unless stated otherwise. The terrain profile at the horizon is considered if stated.

Forge's Sandia National Laboratories' (SGHAT) Model

The following text is taken from Forge³⁰ and is presented for reference.

Summary of assumptions and abstractions required by the SGHAT/ForgeSolar analysis methodology

1. Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
2. Result data files and plots are now retained for two years after analysis completion. Files should be downloaded and saved if additional persistence is required.
3. The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
4. Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects analyses of path receptors.
5. Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including ATCTs. Note that the SGHAT/ForgeSolar methodology has always relied on an analytical, qualitative approach to accurately determine the overall hazard (i.e. green vs. yellow) of expected glare on an annual basis.
6. The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
7. The algorithm assumes that the PV array is aligned with a plane defined by the total heights of the coordinates outlined in the Google map. For more accuracy, the user should perform runs using minimum and maximum values for the vertex heights to bound the height of the plane containing the solar array. Doing so will expand the range of observed solar glare when compared to results using a single height value.
8. The algorithm does not consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
9. The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
10. The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.
11. The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.
12. Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
13. Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
14. Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
15. PV array tracking assumes the modules move instantly when tracking the sun, and when reverting to the rest position.

³⁰ Source: <https://www.forgesolar.com/help/#assumptions>

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Tower

Longitude (°)	Latitude (°)	Assessed Altitude (m amsl ³¹)
-2.2797167	53.3574000	126.91

ATC Tower receptor details

Runway 05L Approach

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
1	-2.2877640	53.3475560	79.86
2	-2.2896436	53.3466471	88.29
3	-2.2915230	53.3457382	96.73
4	-2.2934024	53.3448293	105.16
5	-2.2952818	53.3439204	113.59
6	-2.2971610	53.3430114	122.03
7	-2.2990402	53.3421024	130.46
8	-2.3009193	53.3411933	138.90
9	-2.3027983	53.3402843	147.33
10	-2.3046772	53.3393752	155.77
11	-2.3065560	53.3384660	164.20
12	-2.3084348	53.3375569	172.63
13	-2.3103135	53.3366477	181.07
14	-2.3121921	53.3357385	189.50

³¹ Metres above mean sea level.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
15	-2.3140706	53.3348292	197.94
16	-2.3159490	53.3339199	206.37
17	-2.3178274	53.3330106	214.81
18	-2.3197057	53.3321013	223.24
19	-2.3215839	53.3311919	231.67
20	-2.3234620	53.3302825	240.11
21	-2.3253401	53.3293731	248.54

Assessed receptor (aircraft) locations on the approach path for runway 05L

Runway 23R Approach

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
1	-2.2592806	53.3613194	91.14
2	-2.2573996	53.3622276	99.57
3	-2.2555184	53.3631359	108.00
4	-2.2536372	53.3640440	116.44
5	-2.2517559	53.3649522	124.87
6	-2.2498746	53.3658603	133.31
7	-2.2479931	53.3667684	141.74
8	-2.2461116	53.3676765	150.17
9	-2.2442300	53.3685845	158.61
10	-2.2423483	53.3694925	167.04
11	-2.2404666	53.3704005	175.48
12	-2.2385847	53.3713084	183.91
13	-2.2367028	53.3722163	192.35

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
14	-2.2348208	53.3731242	200.78
15	-2.2329387	53.3740321	209.21
16	-2.2310566	53.3749399	217.65
17	-2.2291743	53.3758477	226.08
18	-2.2272920	53.3767555	234.52
19	-2.2254096	53.3776632	242.95
20	-2.2235271	53.3785709	251.39
21	-2.2216445	53.3794786	259.82

Assessed receptor (aircraft) locations on the approach path for runway 23R

Runway 05R Approach

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
1	-2.3106611	53.3319722	71.93
2	-2.3125394	53.3310629	80.37
3	-2.3144177	53.3301537	88.80
4	-2.3162959	53.3292443	97.24
5	-2.3181740	53.3283350	105.67
6	-2.3200520	53.3274256	114.10
7	-2.3219300	53.3265162	122.54
8	-2.3238079	53.3256068	130.97
9	-2.3256856	53.3246973	139.41
10	-2.3275633	53.3237878	147.84
11	-2.3294410	53.3228783	156.27
12	-2.3313185	53.3219687	164.71

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
13	-2.3331960	53.3210591	173.14
14	-2.3350734	53.3201495	181.58
15	-2.3369507	53.3192399	190.01
16	-2.3388279	53.3183302	198.45
17	-2.3407051	53.3174205	206.88
18	-2.3425821	53.3165108	215.31
19	-2.3444591	53.3156010	223.75
20	-2.3463360	53.3146912	232.18
21	-2.3482129	53.3137814	240.62

Assessed receptor (aircraft) locations on the approach path for runway 05R

Runway 23L Approach

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
1	-2.2772083	53.3481528	84.43
2	-2.2753284	53.3490614	92.86
3	-2.2734484	53.3499700	101.30
4	-2.2715683	53.3508786	109.73
5	-2.2696881	53.3517872	118.17
6	-2.2678078	53.3526957	126.60
7	-2.2659275	53.3536042	135.03
8	-2.2640471	53.3545126	143.47
9	-2.2621666	53.3554211	151.90
10	-2.2602860	53.3563295	160.34
11	-2.2584054	53.3572378	168.77

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
12	-2.2565246	53.3581462	177.21
13	-2.2546438	53.3590545	185.64
14	-2.2527629	53.3599628	194.07
15	-2.2508820	53.3608710	202.51
16	-2.2490009	53.3617792	210.94
17	-2.2471198	53.3626874	219.38
18	-2.2452386	53.3635956	227.81
19	-2.2433573	53.3645037	236.25
20	-2.2414759	53.3654118	244.68
21	-2.2395944	53.3663199	253.11

Assessed receptor (aircraft) locations on the approach path for runway 23L

Modelled Reflector Areas

Area A

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-2.289019	53.359614	3	-2.287621	53.360277
2	-2.288788	53.359575	4	-2.287685	53.360417

Modelled reflector area A

Area B

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-2.288722	53.359436	3	-2.287621	53.360277
2	-2.287388	53.360239	4	-2.288788	53.359576

Modelled reflector area B

Area C

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-2.288489	53.359398	3	-2.287388	53.360240
2	-2.287323	53.360099	4	-2.288721	53.359437

Modelled reflector area C

Area D

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-2.287322	53.360100	3	-2.288425	53.359259
2	-2.288488	53.359398	4	-2.287092	53.360061

Modelled reflector area D

APPENDIX H – GEOMETRIC CALCULATION RESULTS – PAGER POWER RESULTS

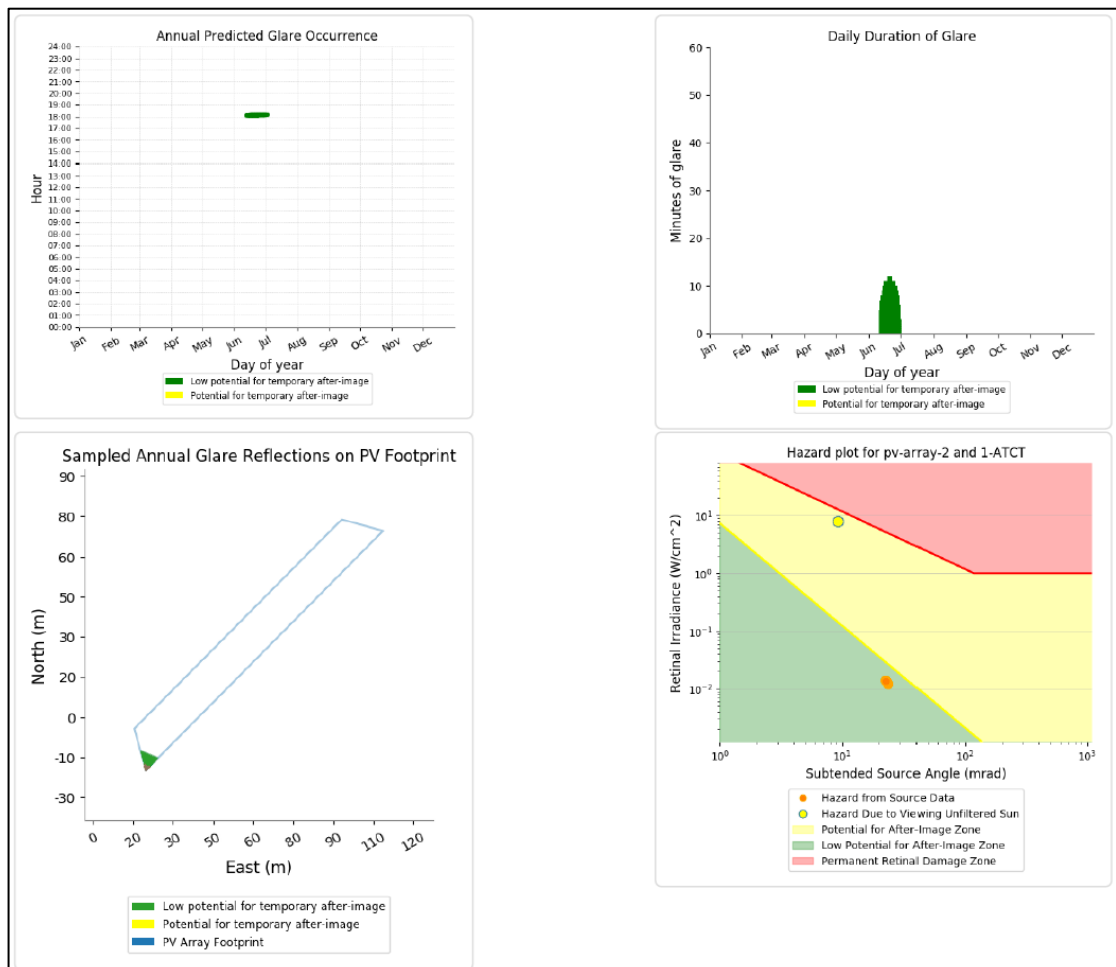
Overview

The charts for the receptors are shown on the following pages. In detail, each chart shows:

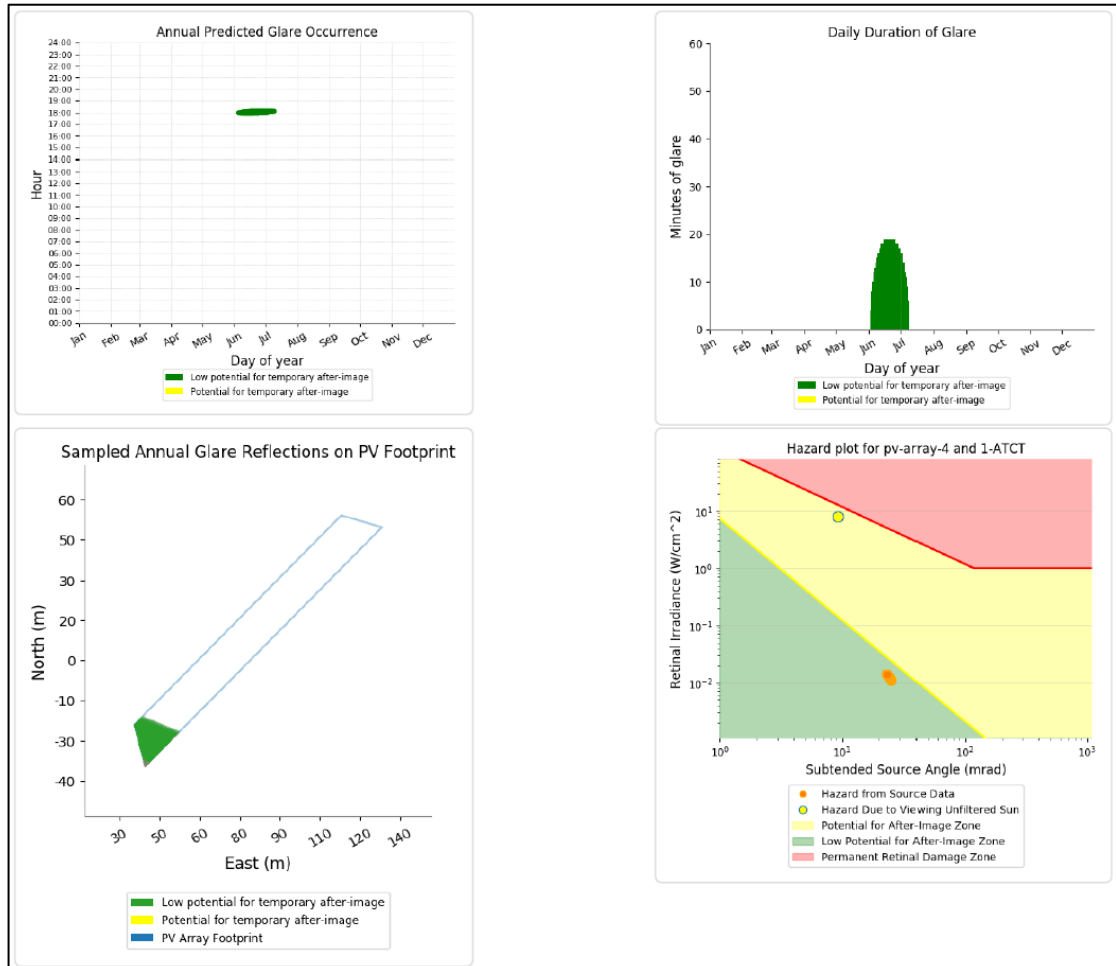
- The reflection date/time graph – top left image. The chart shows the time at which glare at the corresponding intensities can occur;
- Duration of glare – top right image. The chart shows the duration for the corresponding glare intensities;
- The reflecting areas – bottom left image. Indicative only;
- Glare intensity graph – bottom right image. Shows you the intensity of glare produced and the categorisation it falls within.

ATC Tower

Area B

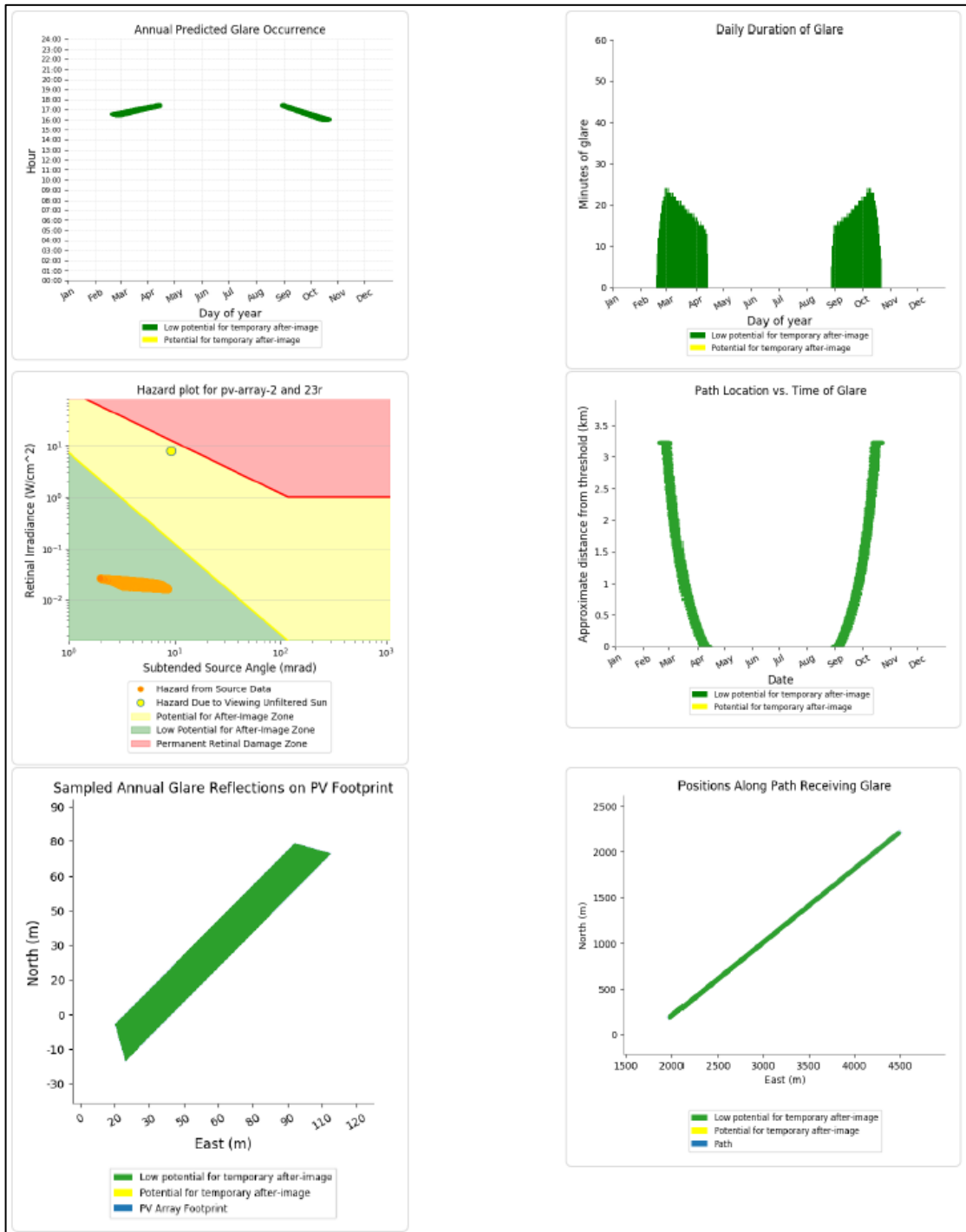


Area D

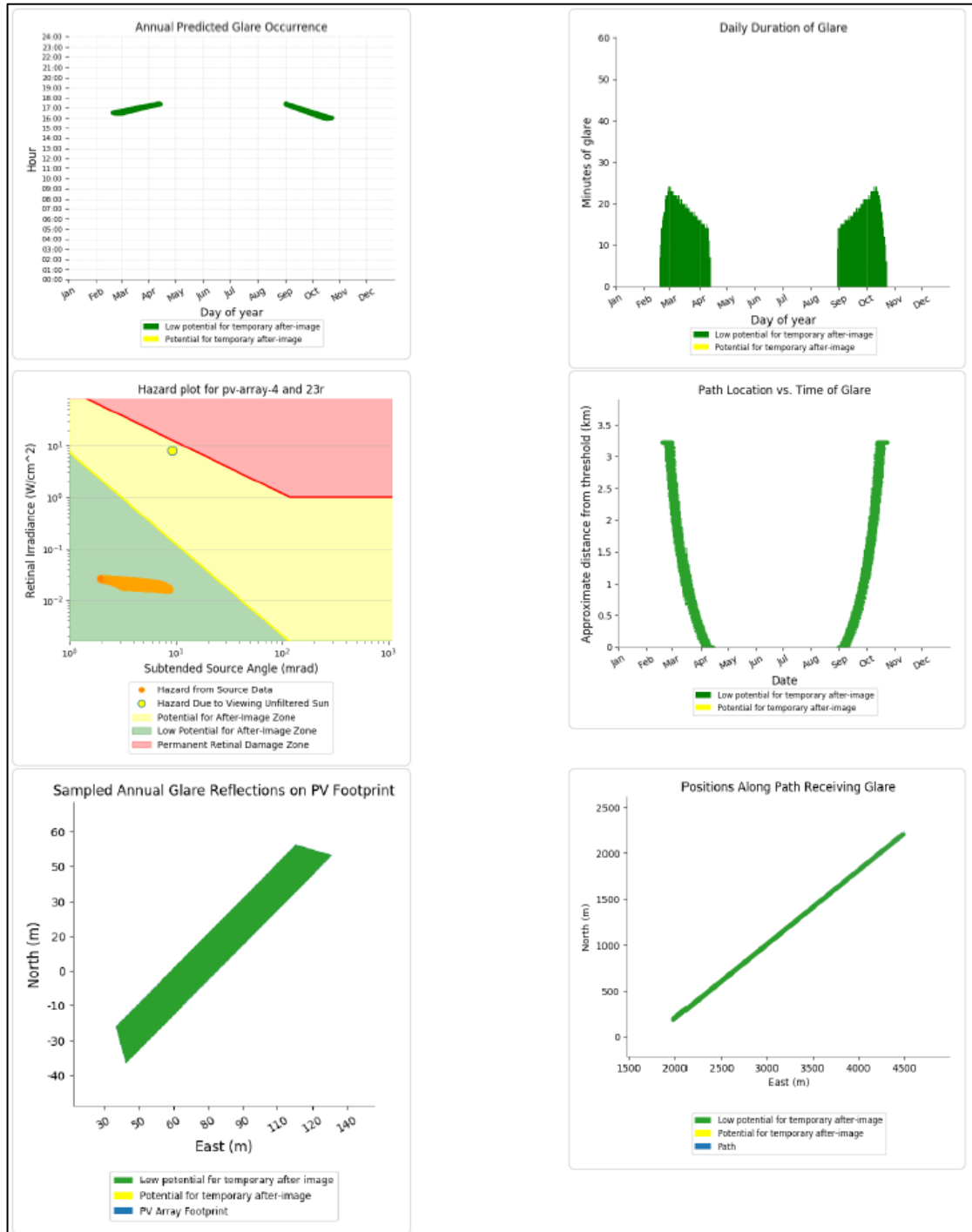


Runway 23R

Area B

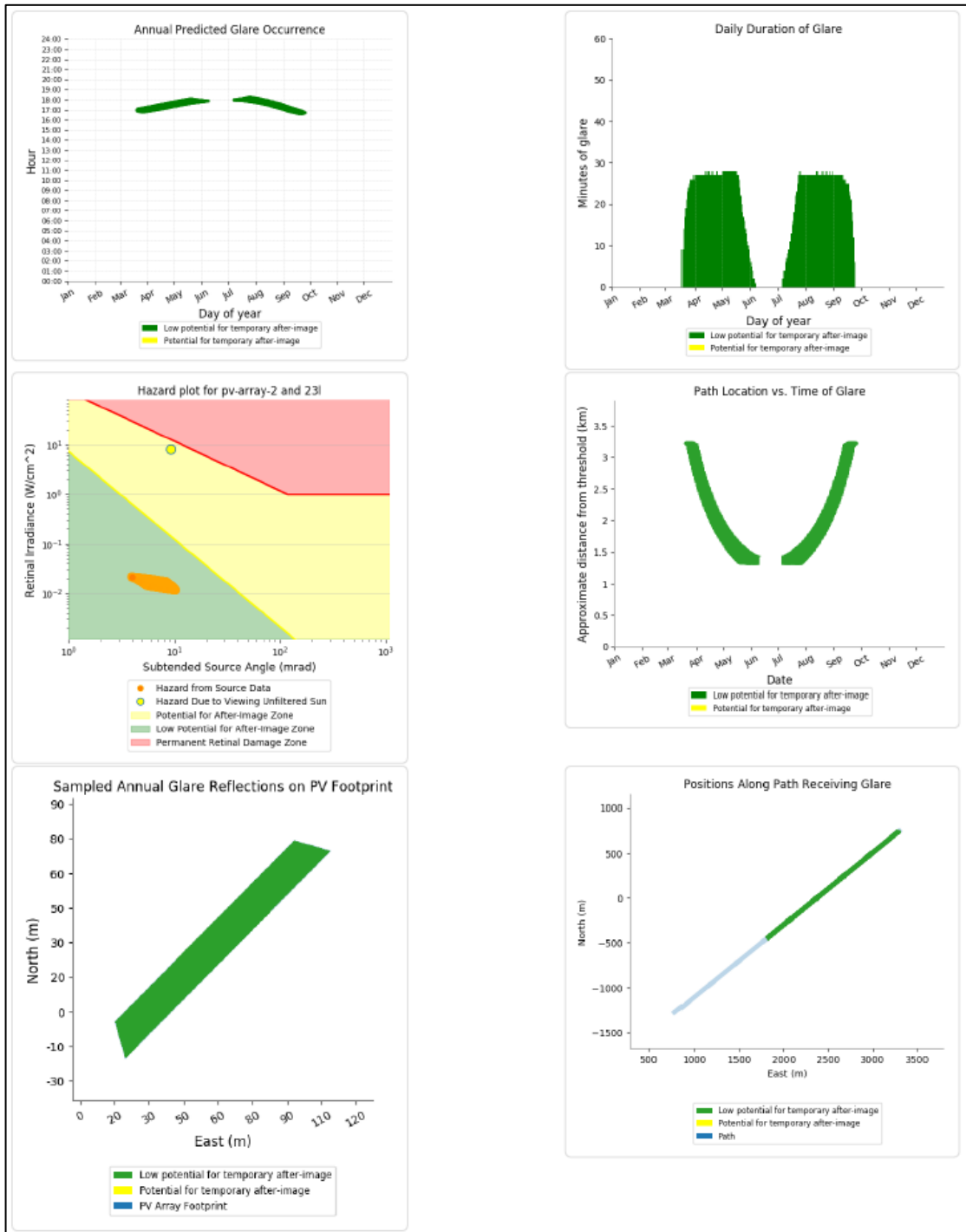


Area D

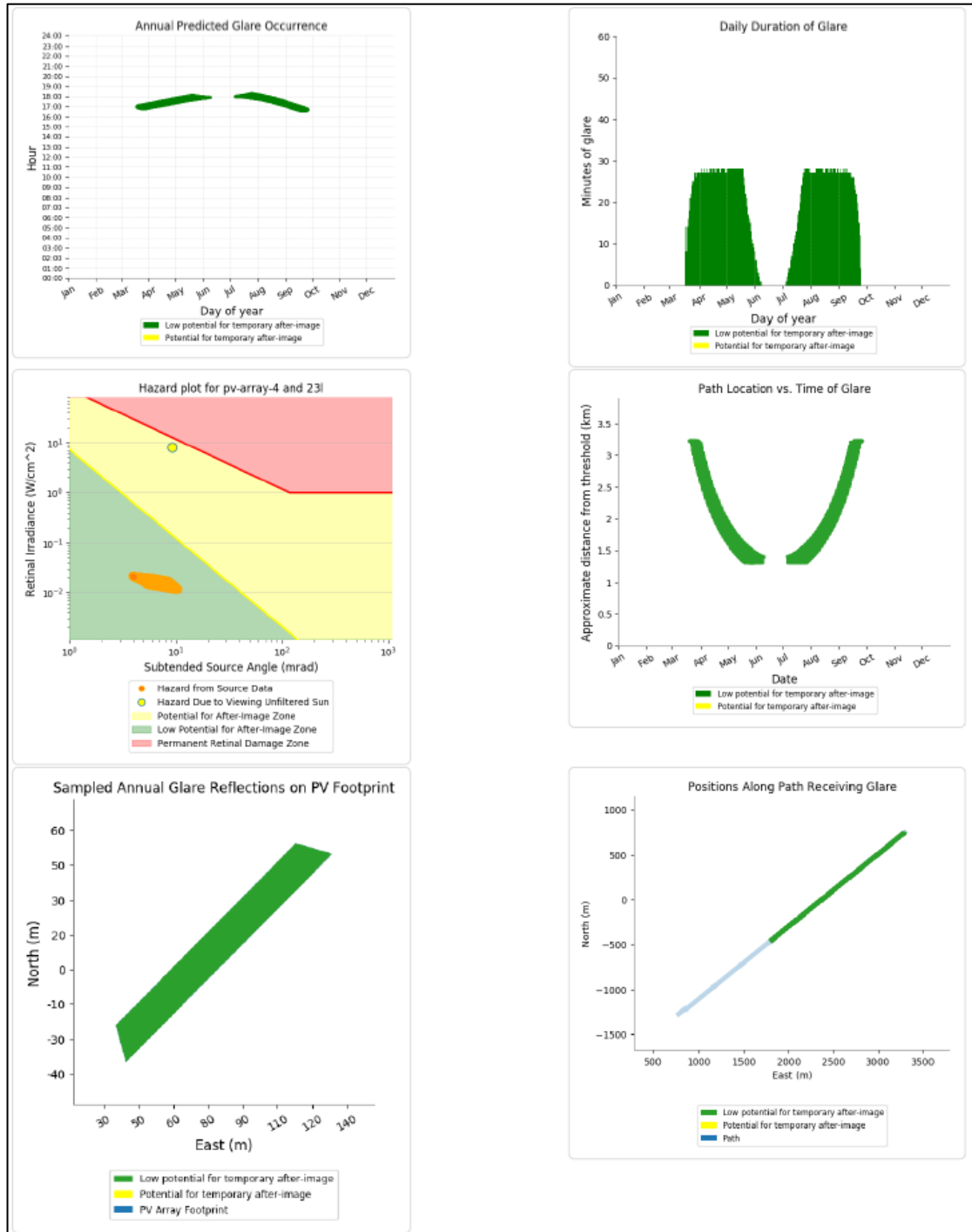


Runway 23L

Area B



Area D





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