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Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Inspired PLC

Wythenshawe Hospital

November 2025







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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the potential effects of glint and glare from a rooftop solar photovoltaic development, located atop Wythenshawe Hospital, Manchester, UK. This assessment pertains to the potential impacts upon aviation activity associated with Manchester Airport and Wythenshawe Hospital Helipad.

Overall Conclusions

Overall, a low impact is predicted upon aviation activity associated with Manchester Airport and Wythenshawe Hospital Helipad and mitigation is not recommended. It is recommended that this report is shared with Manchester Airport Group, who safeguard Manchester Airport, and Wythenshawe Hospital to understand their positions.

Guidance and Studies

Guidelines exist in the UK (produced by the Civil Aviation Authority) and in the USA (produced by the Federal Aviation Administration) with respect to solar developments and aviation activity. The UK CAA guidance is relatively high-level and does not prescribe a formal methodology. A specific national guidance policy for determining the impact of glint and glare on aviation activity has also not been produced to date. Therefore, in the absence of this, Pager Power reviewed more general existing planning guidelines and the available studies (discussed below) in the process of defining its own glint and glare assessment guidance and methodology[1]. This methodology 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, consider the screening (existing and/or proposed) between the receptor and the reflecting solar panels. Where appropriate, solar intensity calculations are undertaken in line with the Sandia National Laboratories' FAA methodology[2]. The scenario in which a solar reflection can occur for all receptors is then identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

The available studies have measured the intensity of reflections from solar panels with respect to other naturally occurring and manmade surfaces. The results show that the reflections produced are of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel[3].

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[1] Pager Power Glint and Glare Guidance, Fourth Edition, September 2022.
[2] Formerly mandatory for on-airfield solar developments in the USA under the FAA's interim policy, superseded in 2021 with a policy that effectively requires individual airports to sign off on their on-airfield development as they see fit.
[3] SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

Assessment Conclusions

Manchester Airport

Air Traffic Control (ATC) Tower

Solar reflections are not geometrically possible towards the ATC Tower. No impact is predicted and mitigation is not required.

2 Mile Approach Paths

Solar reflections with an intensity of 'low potential for temporary after-image' from the proposed development are predicted towards the 2-mile approach paths. All glare towards the approach paths is predicted to be below a luminance of 20,000 cd/m². A low impact is predicted in line with FAA 2013 guidance and mitigation is not required.

10NM Approach and Departure Paths

Glare intensities of 'low potential for temporary after-image' are predicted upon sections of the approach and departure paths out to 10 Nautical Miles (NM) for runways 05L/23R and 05R/23L. A low impact is predicted, and no mitigation is recommended.

Runway Ground Receptors

Solar reflections are not geometrically possible towards the Ground Receptors. No impact is predicted and mitigation is not required.

Wythenshawe Hospital Helipad

Solar reflections with an intensity of 'low potential for temporary after-image' are geometrically possible towards sections of the 2-mile helicopter approach paths. This category of glare intensity is acceptable in accordance with the associated guidance (Appendix D) and industry best practice. A low impact is predicted upon pilots on these approaches and mitigation is not recommended.

Solar reflections with an intensity of 'potential for temporary after-image' ('yellow' glare) are geometrically possible towards sections of the helicopter approach paths. These instances of 'yellow' glare could be accommodated subject to consultation with the Helipad. A low impact is predicted and mitigation is not recommended.

It is recommended that this glare scenario is made available to the operator of Wythenshawe Hospital Helipad to understand their position.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 63 countries internationally.

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 potential effects of glint and glare from a rooftop solar photovoltaic development, located atop Wythenshawe Hospital, Manchester, UK. This assessment pertains to the potential impacts upon aviation activity associated with Manchester Airport and Wythenshawe Hospital Helipad.

This report contains the following:

- Solar development details;
- Explanation of glint and glare;
- Manchester Airport details;
- Overview of relevant guidance and relevant studies;
- Assessment methodology;
- Identification of receptors;
- Glint and glare assessment for identified receptors;
- Results discussion.

The relevant technical analysis is presented in each section. Following the assessment, conclusions and recommendations are made.

1.2 Pager Power's Experience

Pager Power has undertaken over 1,700 Glint and Glare assessments in the UK and 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[4]:

- 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.

The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

[4] These definitions are aligned with those presented within the National Policy Statement for Renewable Energy Infrastructure (EN-3) – published by the Department for Energy Security and Net Zero in January 2024 and the Federal Aviation Administration in the USA.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Site Layout

The proposed development[5] is shown in Figure 1 below. The assessed reflector areas are shown in Figure 2 on the following page.

The bounding coordinates for the proposed development have been extrapolated from the site plans. The data can be found in Appendix G.



Figure 1 *Site layout*

[5] Source: MANCHESTER UNIVERSITY -NHS – Wythenshawe REV S3.pdf (cropped).



Figure 2 *Assessed reflector area*

2.2 Solar Panel Technical Information

Table 1 below summarises the technical information of the modelled solar panels used in the assessment.

Panel	Elevation Angle[6] (Tilt)	Azimuth Angle[7]	Assessed centre height[8] above ground level (agl)
1	15°	205°	14.49m
2	25°	26°	
3	22°	206°	
4	25°	26°	
5			
6	20°	206°	
7	25°	116°	
8	25°	28°	
9	26°	26°	
10	25°	206°	
11			
12	21°	116°	
13		296°	
14	22°	116°	
15		296°	
16	17°	296°	

Table 1 *Solar panel technical information*

[6] Pitch above horizontal.
[7] Direction the panels are facing relative to true north.
[8] Relative to the lowest (12.70m) and highest (16.28m) points above ground level.

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 Guidance and Studies

Appendices A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels are possible;
- The measured intensity of a reflection from solar panels can vary from 2% to 30% depending on the angle of incidence;
- Published guidance shows that the intensity of solar reflections from solar panels are equal to or less than those from water. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

3.2 Background

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

3.3 Methodology

3.3.1 Pager Power's Methodology

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 and studies. The methodology for this glint and glare assessment is as follows:

- Identify receptors in the area surrounding the solar development;
- Consider direct solar reflections from the solar development towards the identified receptors by undertaking geometric calculations;
- Consider the visibility of the panels from the receptor's location. If the panels 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 both the solar reflection from the solar 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 - including intensity calculations where appropriate;
- Determine whether a significant detrimental impact is expected in line with the process presented in Appendix D.

3.3.2 Sandia National Laboratories' Methodology

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer freely available however it is now developed by Forge Solar. Pager Power uses this model where required for aviation receptors. Whilst strictly applicable in the USA and to solar photovoltaic developments only, the methodology is widely used by aviation stakeholders internationally.

3.4 Assessment Methodology and Limitations

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

4 IDENTIFICATION OF RECEPTORS

4.1 Manchester Airport Receptors

Manchester Airport has two runways, the details of which are presented below:

- 05L/23R measuring 3,048m by 45m (concrete and asphalt);
- 05R/23L measuring 3,050m by 45m (concrete and asphalt).

Manchester Airport Group (MAG), who safeguard Manchester Airport, require assessment of specific receptors[9], these are as follows:

- Receptor points every nautical mile for approaching / departing aircraft along the extended runway centre line out to 10NM (Figure 3 on page 16);
- Receptor points every 0.1 miles for approaching / departing aircraft along the extended runway centre line out to two miles (Figure 4 on page 17);
- Receptors points along the runways, taken every 160m at a height of 4.04m agl (Figure 5 on page 18).

The details of the runway thresholds are presented in Appendix G, full receptor details can be provided on request.

[9] These receptors have been identified for assessment following consultation with the safeguarding team at Manchester Airport Group (MAG).



Figure 3 *Extended approach path and departure path receptors*



Figure 4 *2-mile approach path and departure path receptors*



Figure 5 *Runway receptors*

4.1.1 ATC Tower Details

Manchester Airport has one ATC Tower, which is 57m tall and located approximately 1.08km north of the runway 23L threshold. The location of the ATC Tower is shown in Figure 6 below, and a ground-based view of the ATC Tower is shown in Figure 7.



Figure 6 *Location of the ATC Tower within Manchester Airport*



Figure 7 *Ground-based view of the ATC Tower at Manchester Airport (visual control room circled)*

4.2 Wythenshawe Hospital Helipad

Wythenshawe Hospital Helipad is a hospital helipad operating emergency service flights, located approximately 50m southeast of the proposed development.

The development's relative location to Wythenshawe Hospital Helipad is shown in Figure 8 below.



Figure 8 *Wythenshawe Hospital Helipad relative to the proposed development*

Figure 9 on the following page shows the helicopter paths. The helicopter approach paths have been placed every 45 degrees within a 360 degree azimuth, using a 10 degree descent gradient. Locations have been selected every 0.1-miles along the helicopter approach paths out to a distance of 2-miles.



Figure 9 *Wythenshawe Hospital Helipad approach paths - aerial image*

5 GLINT AND GLARE ASSESSMENT – TECHNICAL RESULTS

5.1 Aviation Results

5.1.1 Glare Intensity Categorisation

The Pager Power and Forge models have been used to determine whether reflections are possible. Intensity calculations in line with the Sandia National Laboratories methodology have been undertaken for aviation receptors. 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 outside of a pilot's primary field-of-view (50 degrees either side of the direction of travel)'
'Green' glare	'Low potential for temporary after-image'
'Yellow' glare	'Potential for temporary after-image'
'Red' glare	'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. In addition, the intensity model allows for the assessment of a variety of solar panel surface materials. This assessment has considered solar panels with a surface material of 'smooth glass with an anti-reflective coating'. It is understood that this is the most commonly used solar panel surface material. Other surfaces that could be modelled include:

- Smooth glass without an anti-reflective coating;
- Light textured glass without an anti-reflective coating;
- Light textured glass with an anti-reflective coating; or
- Deeply textured glass.

If significant glare is predicted, modelling of less reflective surfaces could be undertaken.

5.1.2 MAG Safeguarding Towards ATC Towers

MAG do not typically accept any solar reflections towards the ATC Tower; however, the key considerations used by Pager Power for determining the impact significance upon an ATC Tower are:

- Whether a reflection is predicted to be experienced in practice;
- The intensity of glare for the solar reflections:
    - Glare with 'low potential for temporary after-image' (green glare);
    - Glare with 'potential for temporary after-image' (yellow glare);
    - Glare with 'potential for permanent eye damage' (red glare).
- Whether a reflection is predicted to be operationally significant in practice or not.

Where no solar reflections are geometrically possible or where solar reflections are predicted to be significantly screened, no impact is predicted, and mitigation is not required.

Glare of any kind towards an ATC tower was formerly not permissible under the interim guidance provided by the Federal Aviation Administration in the USA[10] for on-airfield solar. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach to consider glare towards the ATC Tower in an operational context. As per Pager Power's glint and glare guidance document[11], where solar reflections are of an intensity categorisation of 'low potential for temporary after-image' (green glare), an expert assessment of the following relevant factors is required to determine the impact significance[12]:

- The likely traffic volumes and level of safeguarding at the aerodrome. Licensed aerodromes typically have higher traffic volumes and are formally safeguarded. Unlicensed aerodromes have greater capacity for operational acceptance.
- The time of day at which glare is predicted. Will the ATC Tower be operational at the time of the day at which glare is predicted?;
- The duration of any predicted glare. Glare that is experienced for low durations throughout the year is less significant than longer durations;
- Glare location relative to key operational areas. A solar reflection originating near sensitive areas such as the runway threshold will have a higher impact upon ATC personnel;
- The relative size of the reflecting panel area. Does the reflecting area make up a large percentage of an ATC observer's field-of-view?[13];

[10] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.
[11] Pager Power Glint and Glare Guidance, Fourth Edition, September 2022.
[12] This approach taken is reflective of the changes made in the 2021 FAA guidance; however, it should be noted that this guidance states that it is up to the airport to determine the safety requirements themselves. Therefore, an airport may not accept any glare towards an ATC Tower.
[13] 210 degrees azimuth field of view.

- The location of the source of glare relative to the position of the Sun at the times and dates in which solar reflections are geometrically possible. Effects that coincide with direct sunlight appear less prominent than those that do not;
- The intensity of the predicted glare. Is the intensity of glare close to the green/yellow glare threshold on the intensity chart?;
- The level of predicted effect relative to existing sources of glare. A solar reflection is less noticeable by ATC personnel when there are existing reflective surfaces in the surrounding environment.

Following consideration of these mitigating factors, where the solar reflection is deemed not significant, a low impact is predicted, and mitigation is not recommended; however, consultation with the aerodrome is recommended to understand their position along with any feedback or comments regarding the proposed development. Where the solar reflection is deemed significant or where a glare intensity categorisation of 'potential for temporary after-image' (yellow glare) is predicted, the impact significance is moderate, and mitigation is recommended.

Where solar reflections are of an intensity greater than 'potential for temporary after-image', the impact significance is high, and mitigation is required.

5.1.3 Key Considerations – Runway Approach Paths

MAG has requested that a 'limited' amount of glare with 'low potential for temporary after-image' (green glare) and less than 20,000 cd/m^2 be experienced by pilots; however, the key considerations used by Pager Power for determining the impact significance upon approaching pilots are:

- Whether a reflection is predicted to be experienced in practice;
- The location of glare relative to a pilot's primary field of view (50 degrees either side of the approach bearing).
- The intensity of glare for the solar reflections:
    - Glare with 'low potential for temporary after-image' (green glare);
    - Glare with 'potential for temporary after-image' (yellow glare);
    - Glare with 'potential for permanent eye damage' (red glare).
- Whether a reflection is predicted to be operationally significant in practice or not.

Where no solar reflections are geometrically possible or where solar reflections are predicted to be significantly screened, no impact is predicted, and mitigation is not required.

Where solar reflections are of an intensity no greater than 'low potential for temporary after-image' (green glare) or occur outside of a pilot's primary field-of-view (50 degrees either side of the runway approach relative to the runway threshold), the impact significance is low, and mitigation is not required.

Glare with 'potential for a temporary after-image' (yellow glare) was formerly not permissible under the interim guidance provided by the Federal Aviation Administration in the USA[14] for on-airfield solar. Pager Power recommends a pragmatic approach whereby instances of 'yellow' glare are evaluated in a technical and operational context. Where solar reflections are of an intensity no greater than 'low potential for temporary after-image' expert assessment of the following mitigating factors is required to determine the impact significance[15]:

- The likely traffic volumes and level of safeguarding at the aerodrome – licensed aerodromes typically have higher traffic volumes and are formally safeguarded;
- The time of day at which glare is predicted and whether the aerodrome will be operational such that pilots can be on the approach at these times;
- The duration of any predicted glare – glare that occurs for low durations throughout the year is less likely to be experienced than glare that occurs for longer durations throughout the year;
- The location and size of the reflecting panel area relative to a pilot's primary field-of-view;
- The location of the source of glare relative to the position of the Sun at the times and dates in which solar reflections are geometrically possible – effects that coincide with direct sunlight appear less prominent than those that do not;
- The level of predicted effect relative to existing sources of glare – a solar reflection is less noticeable by pilots when there are existing reflective surfaces in the surrounding environment.

Following consideration of these relevant factors, where the solar reflection is deemed not significant, a low impact is predicted, and mitigation is not recommended; however, consultation with the aerodrome is recommended to understand their position along with any feedback or comments regarding the proposed development. Where the solar reflection is deemed significant, the impact significance is moderate, and mitigation is recommended.

Where solar reflections have an intensity of 'potential for permanent eye damage', the impact significance is high, and mitigation is required.

Tables 3 and 4 on the following pages presents the following for Manchester Airport and Wythenshawe Hospital Helipad:

- Geometric modelling results;
- Glare intensity;
- Predicted impact significance.

[14] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.

[15] This approach taken is reflective of the changes made in the 2021 FAA guidance; however, it should be noted that this guidance states that it is up to the airport to determine the safety requirements themselves. Therefore, an airport may not accept any yellow glare towards approach paths.

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Peak Luminance (cd/m²)	Maximum Glare Duration (mins)	Impact Classification
ATC Tower	Solar reflections are not geometrically possible towards the ATC Tower	N/A	N/A	N/A	N/A	No impact
2-mile Approaches	Solar reflections are geometrically possible towards sections of the approach paths for runway threshold Runway 23 R	**Green**	Solar reflections with a maximum intensity of 'low potential for temporary after-image' are possible Considering the associated guidance (Appendix D) and industry best practice pertaining to 2-mile approach paths, which states that this level of glare	1,650	514	Low Impact
	Solar reflections are geometrically possible towards sections of the approach paths for runway threshold Runway 23 L	'Glare beyond 50°'		654	557	

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Peak Luminance (cd/m^2)	Maximum Glare Duration (mins)	Impact Classification
	Runway 5L	Reflections aren't geometrically possible	N/A	N/A	N/A	No impact
	Runway 5R					
10NM Approaches	Solar reflections are geometrically possible towards sections of the approach paths for runway thresholds 23R, 23L	**'Green'**	Solar reflections with a maximum intensity of 'low potential for temporary after-image' are possible This is considered to be acceptable in accordance with the associated guidance and industry best practice	629	9,229	Low impact
	Solar reflections are not geometrically possible towards the approach paths for runway thresholds 05L, 05R	N/A	N/A	N/A	N/A	No impact

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Peak Luminance (cd/m^2)	Maximum Glare Duration (mins)	Impact Classification
10NM Departures	Solar reflections are geometrically possible towards sections of the departure paths for runway thresholds 23R, 23L	'Glare beyond 50°'	Solar reflections with a maximum intensity of 'low potential for temporary after-image' are possible Solar reflections which occur outside a pilot's primary field-of-view are considered acceptable in accordance with the associated guidance and industry best practice	629	9,229	Low impact
	Solar reflections are not geometrically possible towards the approach paths for runway thresholds 05L, 05R	N/A	N/A	N/A	N/A	No impact

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Peak Luminance (cd/m^2)	Maximum Glare Duration (mins)	Impact Classification
Ground Receptors	Solar reflections not are geometrically possible towards the Ground receptors on runway 05L/23R and 05R/23L	N/A	N/A	N/A	N/A	No impact

Table 3 *Geometric analysis results – Manchester Airport*

Receptor/Runway	Geometric Modelling Result	Maximum Coding	Comment	Impact Classification
Helicopter Approach path 04	Solar reflections are geometrically possible for 0.1 mile of the approach path	'Green'	Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice	Low impact
Helicopter Approach path 09	Solar reflections are geometrically possible for the entire 2-mile approach path	'Yellow'	Solar reflections occur inside a pilot's primary field-of-view for a 1.0 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice Solar reflections occur inside a pilot's primary field-of-view for the entire 2 mile section with glare intensities with 'potential for a temporary after-image' ('yellow' glare). See Section 5.3.2	Low impact (see Section 5.1.4)

Receptor/Runway	Geometric Modelling Result	Maximum Coding	Comment	Impact Classification
Helicopter Approach path 13	Solar reflections are geometrically possible towards a 0.1-mile section of the approach path	'Yellow'	Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities with 'potential for a temporary after-image' ('yellow' glare). See Section 5.3.2	Low impact (see Section 5.1.4
Helicopter Approach path 18	Solar reflections are geometrically possible towards a 0.1-mile section of the approach path	'Yellow'	Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities with 'potential for a temporary after-image' ('yellow' glare). See Section 5.3.2	Low impact (see Section 5.1.4)

Receptor/Runway	Geometric Modelling Result	Maximum Coding	Comment	Impact Classification
Helicopter Approach path 22	Solar reflections are geometrically possible towards a 0.1-mile section of the approach path	'Yellow'	Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities with 'potential for a temporary after-image' ('yellow' glare). See Section 5.3.2	Low impact (see Section 5.1.4)
Helicopter Approach path 27	Solar reflections are geometrically possible for a 0.2-mile section of the approach path	'Green'	Solar reflections occur inside a pilot's primary field-of-view for the 0.2-mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice	Low impact

Receptor/Runway	Geometric Modelling Result	Maximum Coding	Comment	Impact Classification
Helicopter Approach path 31	Solar reflections are geometrically possible for a 0.3-mile section of the approach path	'Green'	Solar reflections occur inside a pilot's primary field-of-view for the 0.3-mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice	Low impact
Helicopter Approach path 36	Solar reflections are geometrically possible for 0.1 mile of the approach path	'Green'	Solar reflections occur inside a pilot's primary field-of-view for a 0.1 mile section with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare), which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice	Low impact

Table 4 *Geometric modelling results – Wythenshawe Helipad receptors*

5.1.4 Helicopter Approach Paths Impact Significance

Glare with 'potential for a temporary after-image' ('yellow' glare) was formerly not permissible under the interim guidance provided by the Federal Aviation Administration in the USA[16] for on-airfield solar toward approach paths. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach whereby instances of 'yellow' glare are evaluated in a technical and operational context. In the case of the proposed development:

[16] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.

Instances of 'yellow' glare (shown in Figure 10 on the following page) are laid out in the table below:

Helicopter Path	Location of 'Yellow' Glare	Maximum Annual Duration (mins)	Percentage of Daylight Hours (%)[17]
9	Entire 2 miles	784	0.02
13	0.1 miles from threshold	335	0.29
18	0.1 miles from threshold	3,692	1.40
22	0.1 miles from threshold	239	0.09

Table 5 *Yellow glare occurrence*

- The instances of 'yellow' glare would occur between:
  - 9, 13, 18, 22 approach paths: early-January to early-May and early-August to late-December;
  - The maximum duration of yellow glare would be less than 60 minutes on the days when the glare is possible[18].
- The 'yellow' glare marginally passes the 'yellow'/'green' threshold on the intensity chart. Green glare (or glare with 'low potential for temporary after-image') is acceptable for approaching aircraft;
- The weather would have to be clear and sunny at the specific times when the glare was possible to be experienced. The modelling considers 100% sunlight during daylight hours which is highly conservative.

The instances of 'yellow' glare could be accommodated subject to consultation with the Helipad. A low impact is predicted and mitigation is not recommended.

It is recommended that the analysis of this yellow glare scenario be made available to the operator of Wythenshawe Hospital Helipad for further discussion.

[17] Based on 12 hours of sunlight per day (262,800 minutes a year).
[18] A conservative estimate based on the annual predicted glare occurrence chart.

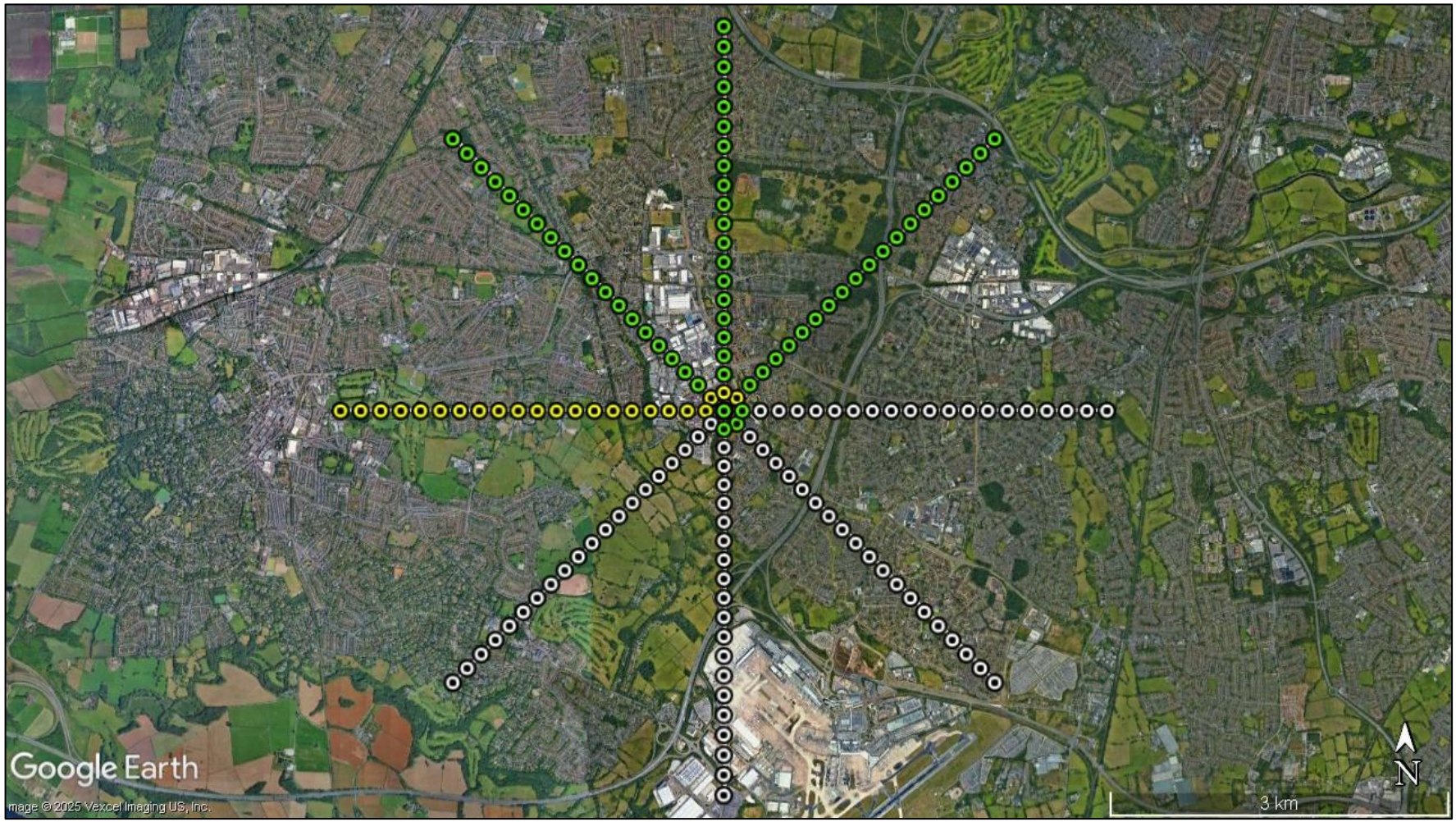


Figure 10 *Yellow glare towards Wythenshawe Hospital Helipad receptors*

6 ASSESSMENT CONCLUSIONS

6.1 Manchester Airport

6.1.1 Air Traffic Control (ATC) Tower

Solar reflections are not geometrically possible towards the ATC Tower. No impact is predicted and mitigation is not required.

6.1.2 2 Mile Approach Paths

Solar reflections with an intensity of 'low potential for temporary after-image' from the proposed development are predicted towards the 2-mile approach paths. All glare towards the approach paths is predicted to be below a luminance of 20,000 cd/m². A low impact is predicted in line with FAA 2013 guidance and mitigation is not required.

6.1.3 10NM Approach and Departure Paths

Glare intensities of 'low potential for temporary after-image' are predicted upon sections of the approach and departure paths out to 10 Nautical Miles (NM) for runways 05L/23R and 05R/23L. A low impact is predicted, and no mitigation is recommended.

6.1.4 Runway Ground Receptors

Solar reflections are not geometrically possible towards the Ground Receptors. No impact is predicted and mitigation is not required.

6.2 Wythenshawe Hospital Helipad

Solar reflections with an intensity of 'low potential for temporary after-image' are geometrically possible towards sections of the 2-mile helicopter approach paths. This category of glare intensity is acceptable in accordance with the associated guidance (Appendix D) and industry best practice. A low impact is predicted upon pilots on these approaches and mitigation is not recommended.

Solar reflections with an intensity of 'potential for temporary after-image' ('yellow' glare) are geometrically possible towards sections of the helicopter approach paths. These instances of 'yellow' glare could be accommodated subject to consultation with the Helipad. A low impact is predicted and mitigation is not recommended.

It is recommended that this glare scenario is made available to the operator of Wythenshawe Hospital Helipad to understand their position.

6.3 Overall Conclusions

Overall, a low impact is predicted upon aviation activity associated with Manchester Airport and Wythenshawe Hospital Helipad and mitigation is not recommended. It is recommended that this report is shared with Manchester Airport Group, who safeguard Manchester Airport, and Wythenshawe Hospital to understand their positions.

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

Renewable and Low Carbon Energy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[19] (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.'

[19] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 14 August 2023, accessed on: 11/12/2023.

National Policy Statement for Renewable Energy Infrastructure

The National Policy Statement for Renewable Energy Infrastructure (EN-3)[20] sets out the primary policy for decisions by the Secretary of State for nationally significant renewable energy infrastructure. Sections 2.10.102-106 state:

'2.10.102 Solar panels are specifically designed to absorb, not reflect, irradiation.[21] However, solar panels may reflect the sun's rays at certain angles, causing glint and glare. Glint is defined as a momentary flash of light that may be produced as a direct reflection of the sun in the solar panel. Glare is a continuous source of excessive brightness experienced by a stationary observer located in the path of reflected sunlight from the face of the panel. The effect occurs when the solar panel is stationed between or at an angle of the sun and the receptor.

2.10.103 Applicants should map receptors to qualitatively identify potential glint and glare issues and determine if a glint and glare assessment is necessary as part of the application.

2.10.104 When a quantitative glint and glare assessment is necessary, applicants are expected to consider the geometric possibility of glint and glare affecting nearby receptors and provide an assessment of potential impact and impairment based on the angle and duration of incidence and the intensity of the reflection.

2.10.105 The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and design. This may need to account for 'tracking' panels if they are proposed as these may cause differential diurnal and/or seasonal impacts.

2.10.106 When a glint and glare assessment is undertaken, the potential for solar PV panels, frames and supports to have a combined reflective quality may need to be assessed, although the glint and glare of the frames and supports is likely to be significantly less than the panels.'

The EN-3 does not state which receptors should be considered as part of a quantitative glint and glare assessment. Based on Pager Power's extensive project experience, typical receptors include residential dwellings, road users, aviation infrastructure, and railway infrastructure.

Sections 2.10.134-136 state:

'2.10.134 Applicants should consider using, and in some cases the Secretary of State may require, solar panels to comprise of (or be covered with) anti-glare/anti-reflective coating with a specified angle of maximum reflection attenuation for the lifetime of the permission.

2.10.135 Applicants may consider using screening between potentially affected receptors and the reflecting panels to mitigate the effects.

2.10.136 Applicants may consider adjusting the azimuth alignment of or changing the elevation tilt angle of a solar panel, within the economically viable range, to alter the angle of incidence

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[20] National Policy Statement for Renewable Energy Infrastructure (EN-3), Department for Energy Security & Net Zero, date: January 2024, accessed on: 17/01/2024.

[21] '*Most commercially available solar panels are designed with anti-reflective glass or are produced with anti-reflective coating and have a reflective capacity that is generally equal to or less hazardous than other objects typically found in the outdoor environment, such as bodies of water or glass buildings.*'

In practice this is unlikely to remove the potential impact altogether but in marginal cases may contribute to a mitigation strategy.'

The mitigation strategies listed within the EN-3 are relevant strategies that are frequently utilised to eliminate or reduce glint and glare effects towards surrounding observers. The most common form of mitigation is the implementation of screening along the site boundary.

Sections 2.10.158-159 state:

2.10.158 Solar PV panels are designed to absorb, not reflect, irradiation. However, the Secretary of State should assess the potential impact of glint and glare on nearby homes, motorists, public rights of way, and aviation infrastructure (including aircraft departure and arrival flight paths).

2.10.159 Whilst there is some evidence that glint and glare from solar farms can be experienced by pilots and air traffic controllers in certain conditions, there is no evidence that glint and glare from solar farms results in significant impairment on aircraft safety. Therefore, unless a significant impairment can be demonstrated, the Secretary of State is unlikely to give any more than limited weight to claims of aviation interference because of glint and glare from solar farms.

The EN-3 goes some way in acknowledging that the issue is more complex than presented in the early draft issues; though, this is still unlikely to be welcomed by aviation stakeholders, who will still request a glint and glare assessment on the basis that glare may lead to a potentially significant impact upon aviation safety.

Finally, the EN-3 relates solely to nationally significant renewable energy infrastructure and therefore does not apply to all planning applications for solar farms.

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, 2012[22] however the advice is still applicable[23] until a formal policy is developed. The relevant aviation guidance from the CAA is presented in the section below.

[22] Archived at Pager Power.
[23] Reference email from the CAA dated 19/05/2014.

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.

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[24], 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.'

[24] Aerodrome Licence Holder.

FAA Guidance

The most comprehensive guidelines available for the assessment of solar developments near aerodromes has been produced by the United States Federal Aviation Administration (FAA). The first guidelines were produced initially in November 2010 and updated in 2013. A final policy was released in 2021, which superseded the interim guidance.

The 2010 document is entitled 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'[25], the 2013 update is entitled 'Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'[26], and the 2021 final policy is entitled 'Federal Aviation Administration Policy: Review of Solar Energy System Projects on Federally-Obligated Airports'[27].

Key excerpts from the final policy are presented below:

Initially, FAA believed that solar energy systems could introduce a novel glint and glare effect to pilots on final approach. FAA has subsequently concluded that in most cases, the glint and glare from solar energy systems to pilots on final approach is similar to glint and glare pilots routinely experience from water bodies, glass-façade buildings, parking lots, and similar features. However, FAA has continued to receive reports of potential glint and glare from on-airport solar energy systems on personnel working in ATCT cabs. Therefore, FAA has determined the scope of agency policy should be focused on the impact of on-airport solar energy systems to federally-obligated towered airports, specifically the airport's ATCT cab.

The policy in this document updates and replaces the previous policy by encouraging airport sponsors to conduct an ocular analysis of potential impacts to ATCT cabs prior to submittal of a Notice of Proposed Construction or Alteration Form 7460-1 (hereinafter Form 7460-1). Airport sponsors are no longer required to submit the results of an ocular analysis to FAA. Instead, to demonstrate compliance with 14 CFR 77.5(c), FAA will rely on the submittal of Form 7460-1 in which the sponsor confirms that it has analyzed the potential for glint and glare and determined there is no potential for ocular impact to the airport's ATCT cab. This process will enable FAA to evaluate the solar energy system project, with assurance that the system will not impact the ATCT cab.

FAA encourages airport sponsors of federally-obligated towered airports to conduct a sufficient analysis to support their assertion that a proposed solar energy system will not result in ocular impacts. There are several tools available on the open market to airport sponsors that can analyze potential glint and glare to an ATCT cab. For proposed systems that will clearly not impact ATCT cabs (e.g., on-airport solar energy systems that are blocked from the ATCT cab's view by another structure), the use of such tools may not be necessary to support the assertion that a proposed solar energy system will not result in ocular impacts.

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[25] Archived at Pager Power.

[26] 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: 08/12/2021.

[27] Federal Aviation Administration Policy: Review of Solar Energy System Projects on Federally-Obligated Airports, Federal Aviation Administration, date: May 2021, accessed on: 08/12/2021.

The excerpt above states where a solar PV development is to be located on a federally obligated aerodrome with an ATC Tower, it will require a glint and glare assessment to accompany its application. It states that pilots on approach are no longer a specific assessment requirement due to effects from solar energy systems being similar to glint and glare pilots routinely experience from water bodies, glass-façade buildings, parking lots, and similar features. Ultimately it comes down to the specific aerodrome to ensure it is adequately safeguarded, and it is on this basis that glint and glare assessments are routinely still requested.

The policy also states that several different tools and methodologies can be used to assess the impacts of glint and glare, which was previously required to be undertaken by the Solar Glare Hazard Analysis Tool (SGHAT) using the Sandia National Laboratories methodology.

In 2018, the FAA released the latest version (Version 1.1) of the 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'[28]. Whilst the 2021 final policy also supersedes this guidance, many of the points are still relevant because aerodromes are still safeguarding against glint and glare irrespective of the FAA guidance. The key points are presented below for reference:

- 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[29].
- 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[30], 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;

[28] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.
[29] Flash 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.
[30] First figure in Appendix B.

    - 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 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 question[31] 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

[31] 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.

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) 2016

In some instances, an aviation stakeholder can refer to the ANO 2016[32] with regard to safeguarding. Key points from the document are presented below.

Lights liable to endanger

224. (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

225. 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.

Endangering safety of an aircraft

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

Endangering safety of any person or property

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[32] The Air Navigation Order 2016. [online] Available at: <https://www.legislation.gov.uk/uksi/2016/765/contents/made> [Accessed 4 February 2022].

241. A person must not recklessly or negligently cause or permit an aircraft to endanger any person or property

Civil Aviation Authority consolidation of UK Regulation 139/2014

The Civil Aviation Authority (CAA) published a consolidating document[33] of UK regulations, (Implementing Rules, Acceptable Means of Compliance and Guidance Material), in 2023. A summary of material relevant to aerodrome safeguarding is presented below:

(a) The aerodrome operator should have procedures to monitor the changes in the obstacle environment, marking and lighting, and in human activities or land use on the aerodrome and the areas around the aerodrome, as defined in coordination with the CAA. The scope, limits, tasks and responsibilities for the monitoring should be defined in coordination with the relevant air traffic services providers, and with the CAA and other relevant authorities.

(b) The limits of the aerodrome surroundings that should be monitored by the aerodrome operator are defined in coordination with the CAA and should include the areas that can be visually monitored during the inspections of the manoeuvring area.

(c) The aerodrome operator should have procedures to mitigate the risks associated with changes on the aerodrome and its surroundings identified with the monitoring procedures. The scope, limits, tasks, and responsibilities for the mitigation of risks associated to obstacles or hazards outside the perimeter fence of the aerodrome should be defined in coordination with the relevant air traffic services providers, and with the CAA and other relevant authorities.

(d) The risks caused by human activities and land use which should be assessed and mitigated should include:

1. obstacles and the possibility of induced turbulence;
2. the use of hazardous, confusing, and misleading lights;
3. the dazzling caused by large and highly reflective surfaces;
4. sources of non-visible radiation, or the presence of moving, or fixed objects which may interfere with, or adversely affect, the performance of aeronautical communications, navigation and surveillance systems; and
5. non-aeronautical ground light near an aerodrome which may endanger the safety of aircraft and which should be extinguished, screened, or otherwise modified so as to eliminate the source of danger.

[33] https://regulatorylibrary.caa.co.uk/139-2014-pdf/PDF.pdf.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

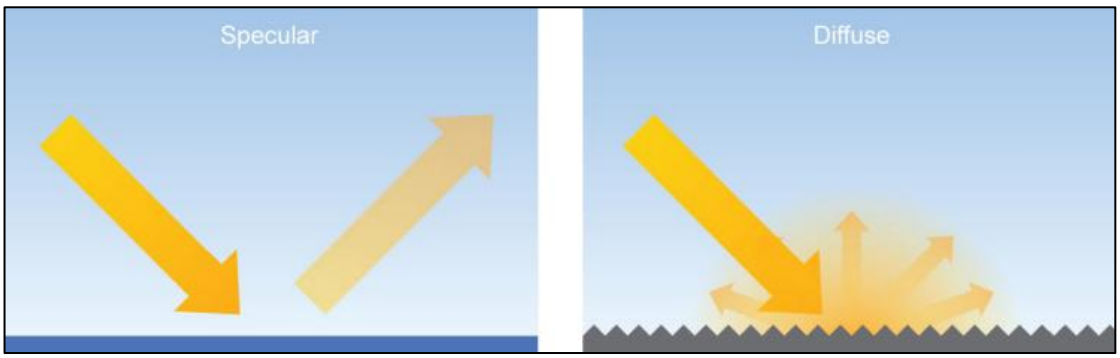
Overview

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 guidance[34], 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

Solar Reflection Studies

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

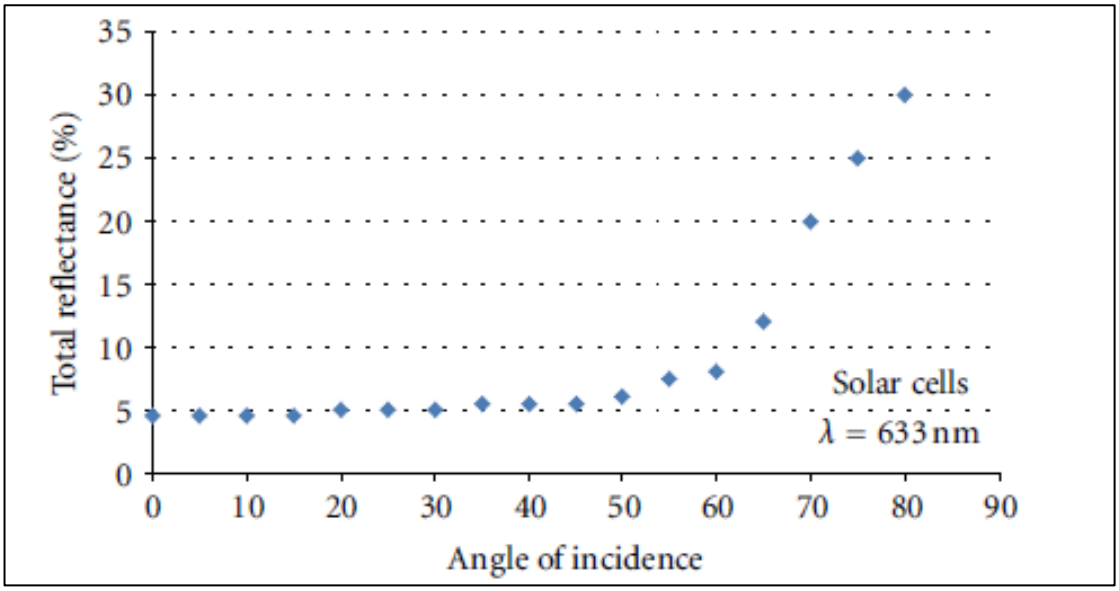
Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems"

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[35]". 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

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

[35] 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:10.5402/2011/65185.7

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.

FAA Guidance – "Technical Guidance for Evaluating Selected Solar Technologies on Airports"[36]

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[37]
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).

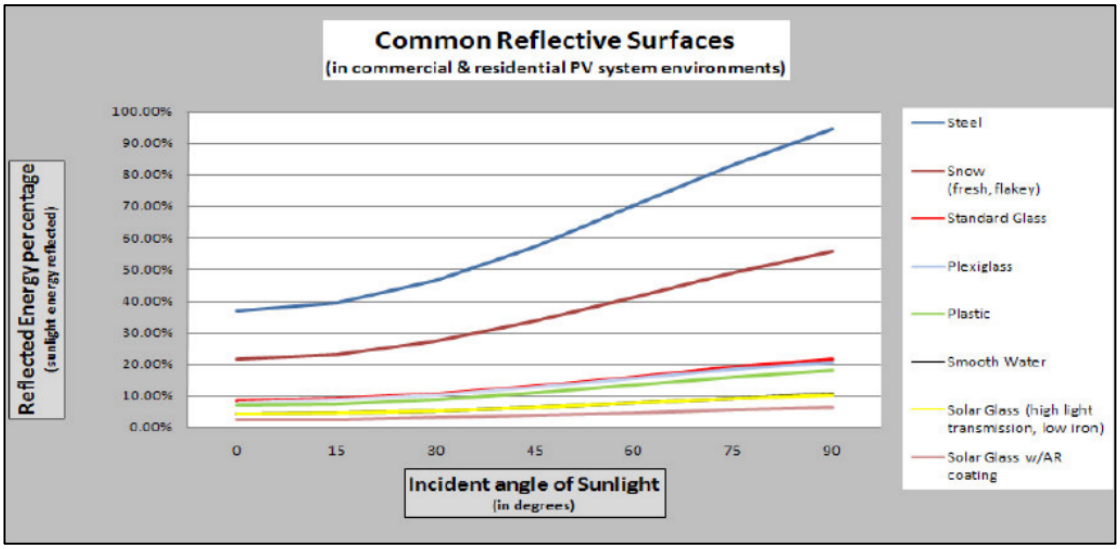
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

[36] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.
[37] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[38] 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.

[38] Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

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).

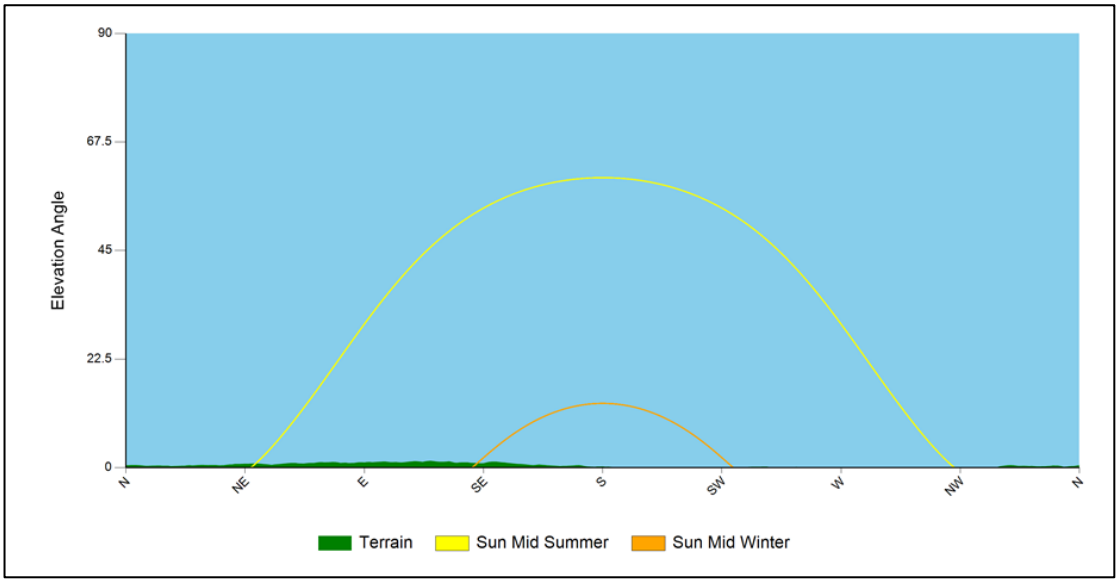
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

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

The following is true at the location of the solar development:

- The Sun is at its highest around midday and is to the south at this time;
- The Sun rises highest on 21 June (longest day);
- On 21 December, the maximum elevation reached by the Sun is at its lowest (shortest day).

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 terrain at the horizon as well as the sunrise and sunset curves throughout the year.



Terrain at the visible horizon and sun paths

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

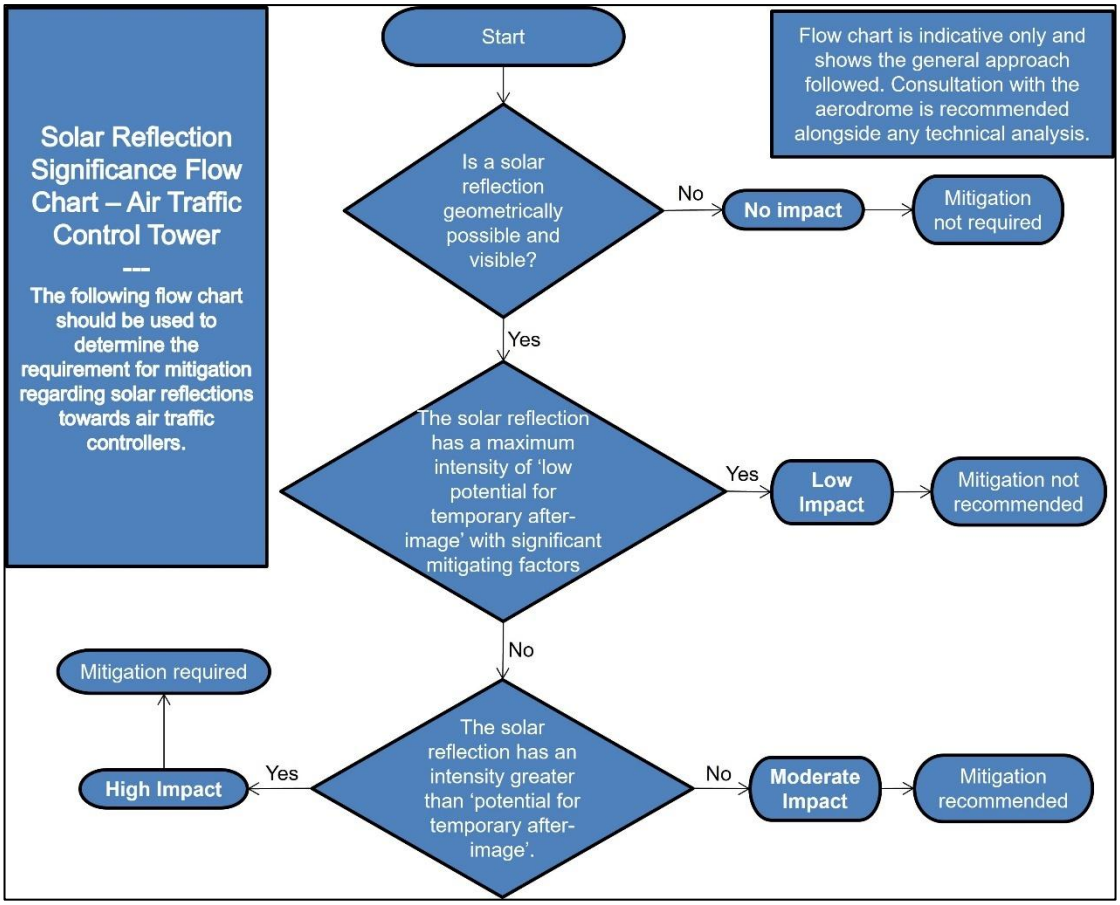
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation
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 recommended.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case given individual receptor criteria.	Mitigation recommended.
High	A solar reflection is geometrically possible and visible under worst-case conditions that will produce a significant impact given individual receptor criteria	Mitigation will be required if the proposed development is to proceed.

Impact significance definition

Impact Significance Determination for ATC Towers

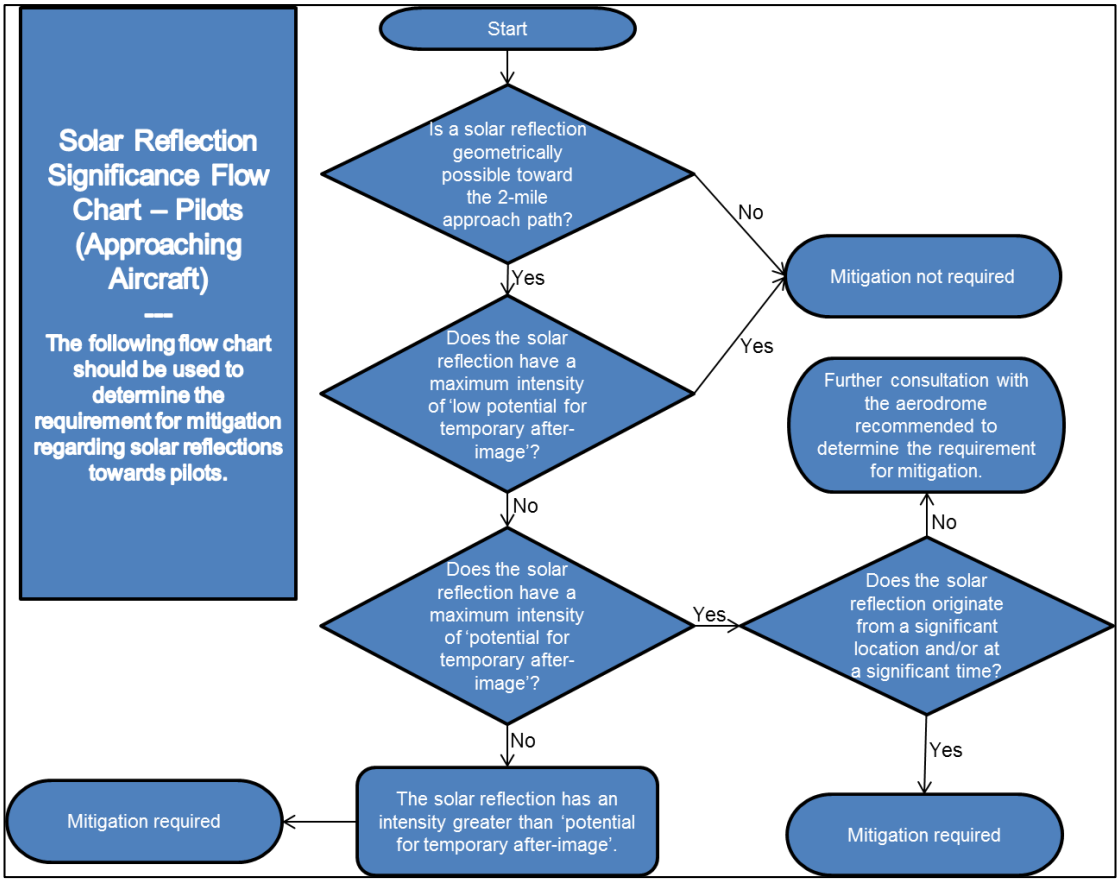
The flow chart presented below has been followed when determining the mitigation requirement for ATC Towers.



ATC Tower receptor 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

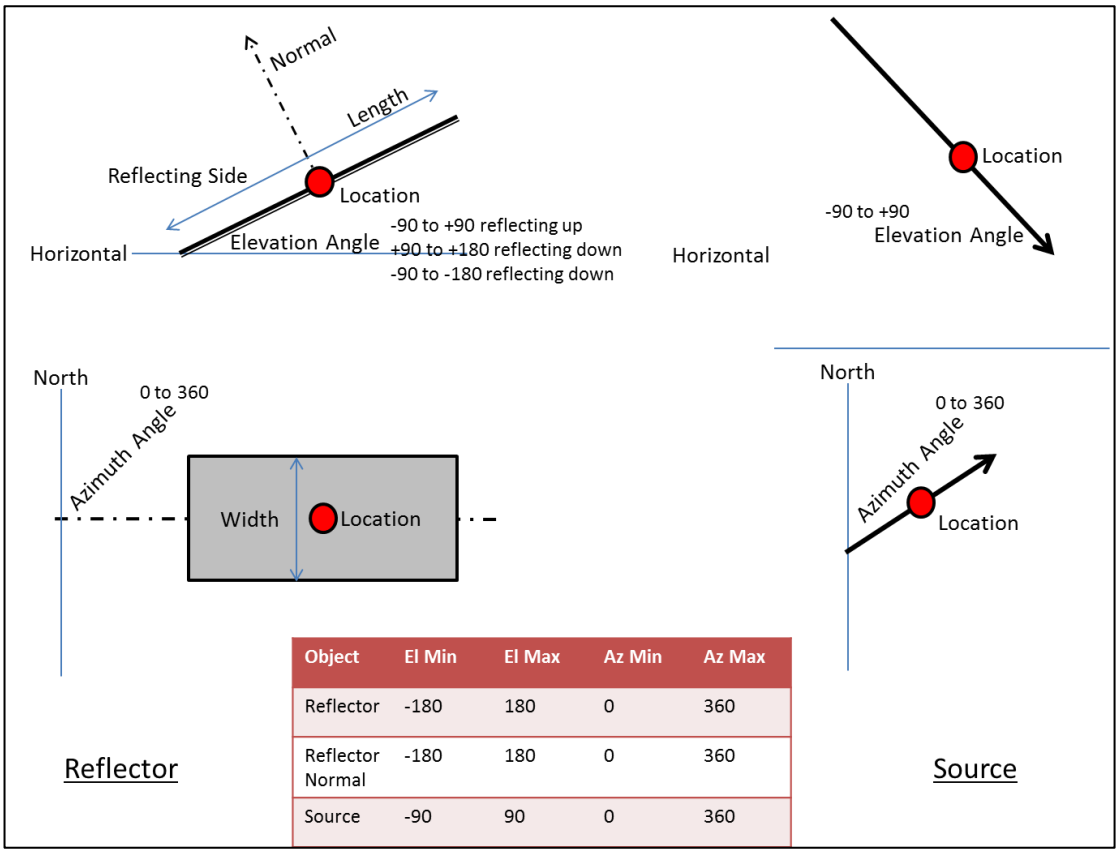
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

Pager Power 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.



Object	El Min	El Max	Az Min	Az Max
Reflector	-180	180	0	360
Reflector Normal	-180	180	0	360
Source	-90	90	0	360

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)[39].

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

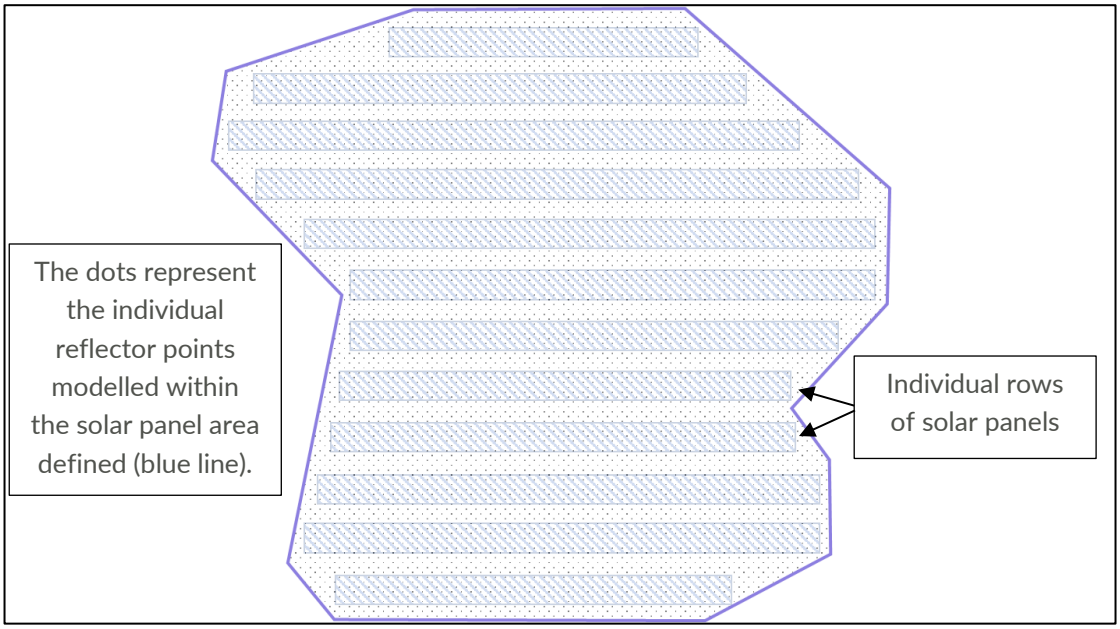
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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 on the following page which illustrates this process.

[39] 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 Forge[40] 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.

[40] Source: https://www.forgesolar.com/help/#assumptions.

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Receptor Details

The co-ordinates and overall altitude of the ATC Tower has been extrapolated from available maps and imagery. The ground height has been taken from Pager Power's database[41] based on the co-ordinates of the ATC Tower. The details are presented in the table below.

Longitude (°)	Latitude (°)	Ground Height Altitude (m) (amsl)	ATC Tower Observer Height[42] (m)	Overall Assessed Height (m)
-2.27963	53.35781	69.90	57	129.90

ATC Tower receptor details

Runway Details

The table below presents the runway details for Manchester Airport.

Runway	Longitude (°)	Latitude (°)	Threshold Altitude (ft) (amsl)
05L/23R	-2.28776	53.34756	211.8
	-2.25928	53.36132	249.1
05R/23L	-2.31066	53.33198	186.3
	-2.27721	53.34815	227.0

Runway details for Manchester Airport

[41] Based on OS Panorama 50m DTM.
[42] https://nats.aero/blog/wp-content/uploads/2015/09/Manchester-Tower-AnatomyV5.pdf.

Wythenshawe Hospital Helipad Receptors

The table below presents the helicopter approach path details for Wythenshawe Hospital Heliport. Full receptor details can be provided upon request.

Runway	Longitude (°)	Latitude (°)	Threshold Elevation (ft) (amsl)
04	-2.28962	53.38841	154.2 ft
09			
13			
18			
22			
27			
31			
36			

Helicopter approach path details for Wythenshawe Hospital Heliport

Modelled Panel Areas

The modelled panel area is presented in the table below.

Panel 1

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29163	53.38873	3	-2.29179	53.38885
2	-2.29149	53.38876	4	-2.29192	53.38882

Panel 1

Panel 2

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29151	53.38879	3	-2.29164	53.38887
2	-2.29148	53.38882	4	-2.29167	53.38884

Panel 2

Panel 3

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29077	53.38844	3	-2.29145	53.38873
2	-2.29081	53.38854	4	-2.29160	53.38869

Panel 3

Panel 4

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29113	53.38866	3	-2.29128	53.38875
2	-2.29110	53.38870	4	-2.29131	53.38871

Panel 4

Panel 5

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29089	53.38863	3	-2.29074	53.38854
2	-2.29093	53.38860	4	-2.29071	53.38858

Panel 5

Panel 6

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29071	53.38844	3	-2.29060	53.38848
2	-2.29055	53.38840	4	-2.29075	53.38852

Panel 6

Panel 7

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29000	53.38904	3	-2.29057	53.38851
2	-2.29016	53.38901	4	-2.29051	53.38839

Panel 7

Panel 8

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29017	53.38911	3	-2.29016	53.38903
2	-2.29031	53.38908	4	-2.29000	53.38906

Panel 8

Panel 9

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29104	53.38938	3	-2.29034	53.38910
2	-2.29100	53.38929	4	-2.29019	53.38913

Panel 9

Panel 10

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29035	53.38902	3	-2.29050	53.38912
2	-2.29031	53.38907	4	-2.29053	53.38908

Panel 10

Panel 11

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29074	53.38914	4	-2.29089	53.38924
2	-2.29071	53.38919	5	-2.29092	53.38919

Panel 11

Panel 12

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29148	53.38910	4	-2.29149	53.38921
2	-2.29137	53.38923	5	-2.29156	53.38912

Panel 12

Panel 13

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29159	53.38913	3	-2.29156	53.38929
2	-2.29152	53.38922	4	-2.29167	53.38916

Panel 13

Panel 14

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29153	53.38905	4	-2.29167	53.38899
2	-2.29155	53.38907	5	-2.29163	53.38892
3	-2.29161	53.38906			

Panel 14

Panel 15

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29181	53.38897	4	-2.29167	53.38911
2	-2.29170	53.38900	5	-2.29171	53.38910
3	-2.29165	53.38906			

Panel 15

Panel 16

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.29193	53.38884	3	-2.29177	53.38892
2	-2.29182	53.38886	4	-2.29184	53.38894

Panel 16

APPENDIX H – DETAILED MODELLING RESULTS

Overview

The Forge chart for the selected receptors is shown on the following page. Each chart shows:

- The annual predicted solar reflections;
- The daily duration of the solar reflections;
- The location of the proposed development where glare will originate;
- The calculated intensity of the predicted solar reflections.

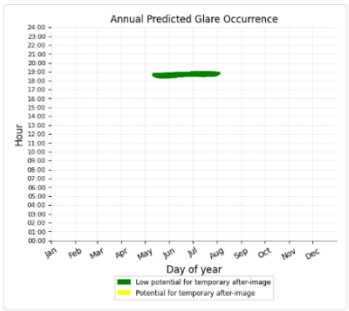
Manchester Airport

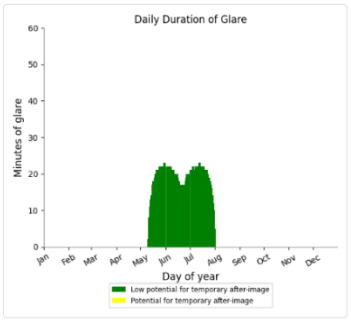
23R Approach

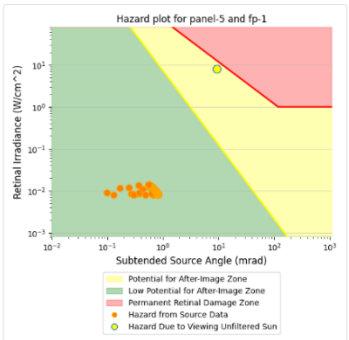
Panel 5: FP 1

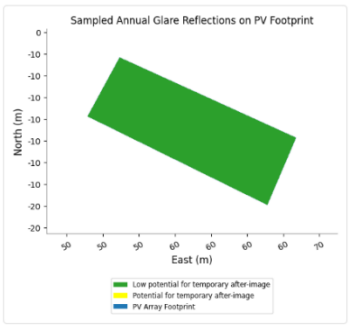
PV array is expected to produce the following glare for this receptor:

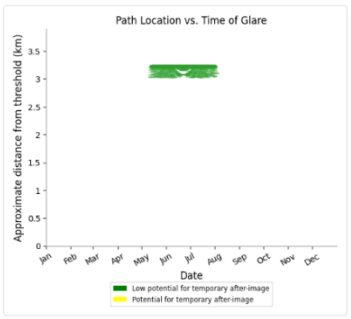
- 1,650 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.

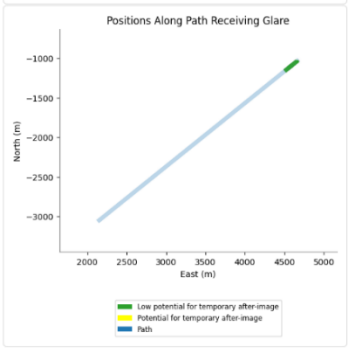


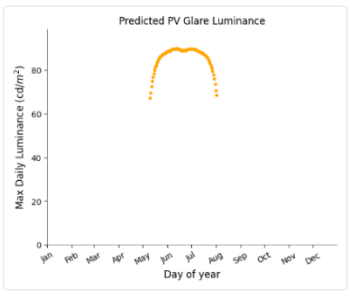




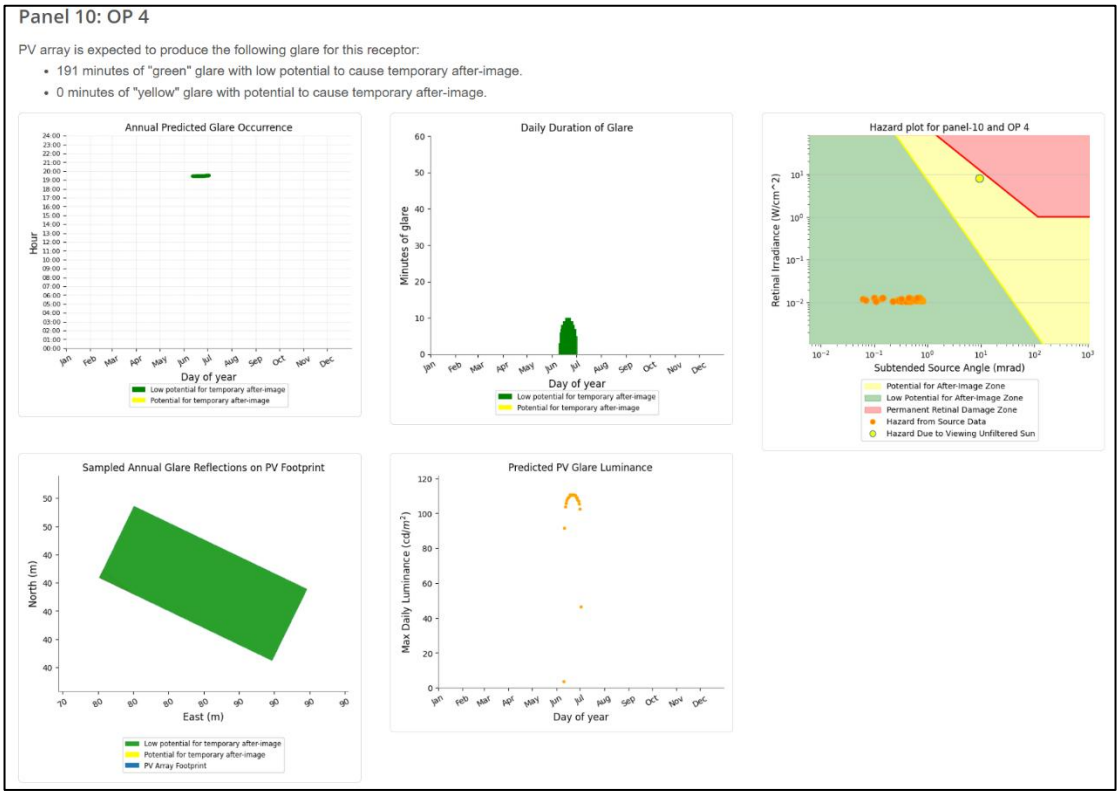








23L Approach



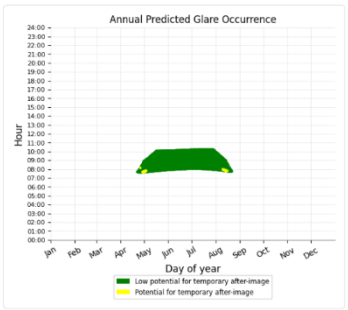
Wythenshawe Hospital Helipad

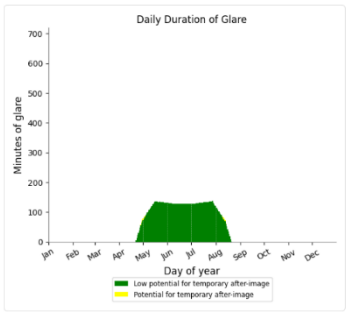
Approach Path 09

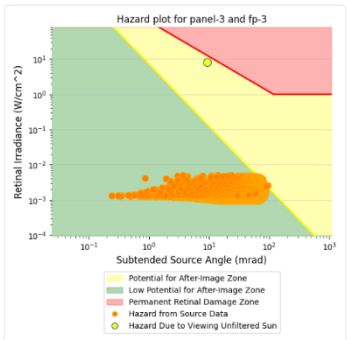
Panel 3: FP 3

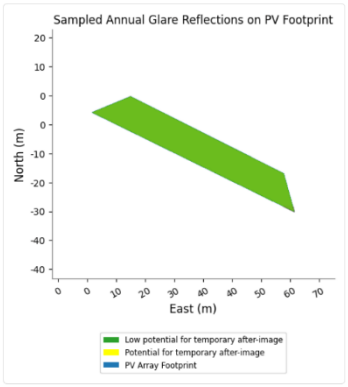
PV array is expected to produce the following glare for this receptor:

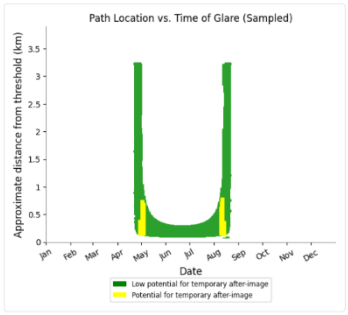
- 13,462 minutes of "green" glare with low potential to cause temporary after-image.
- 49 minutes of "yellow" glare with potential to cause temporary after-image.

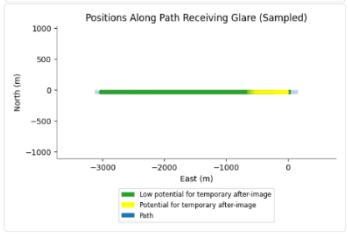










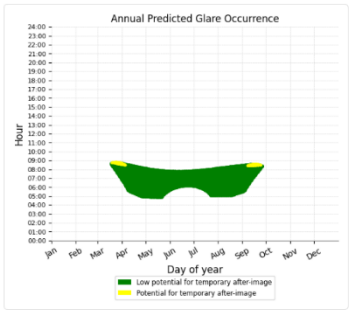


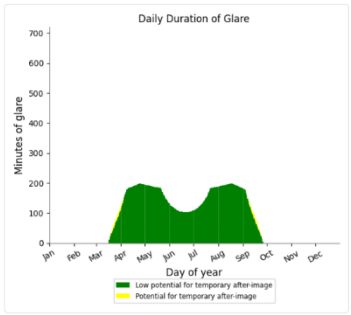
Approach Path 13

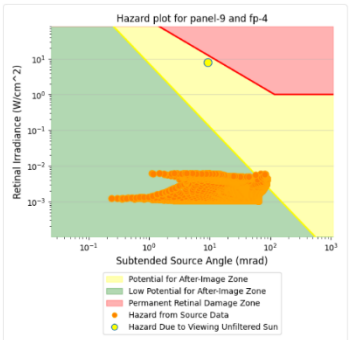
Panel 9: FP 4

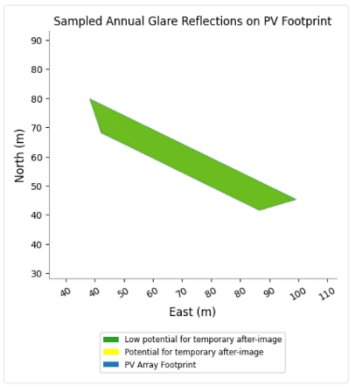
PV array is expected to produce the following glare for this receptor:

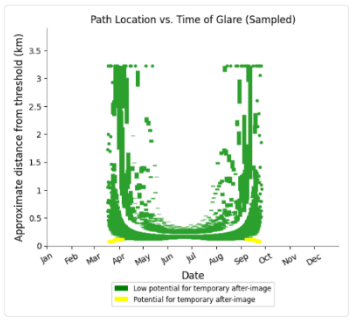
- 28,223 minutes of "green" glare with low potential to cause temporary after-image.
- 335 minutes of "yellow" glare with potential to cause temporary after-image.

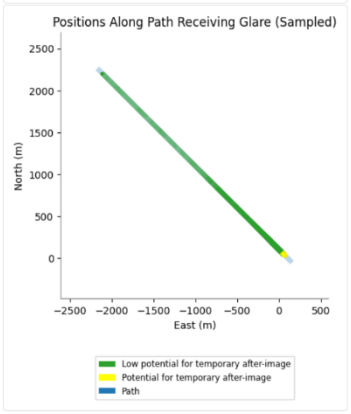




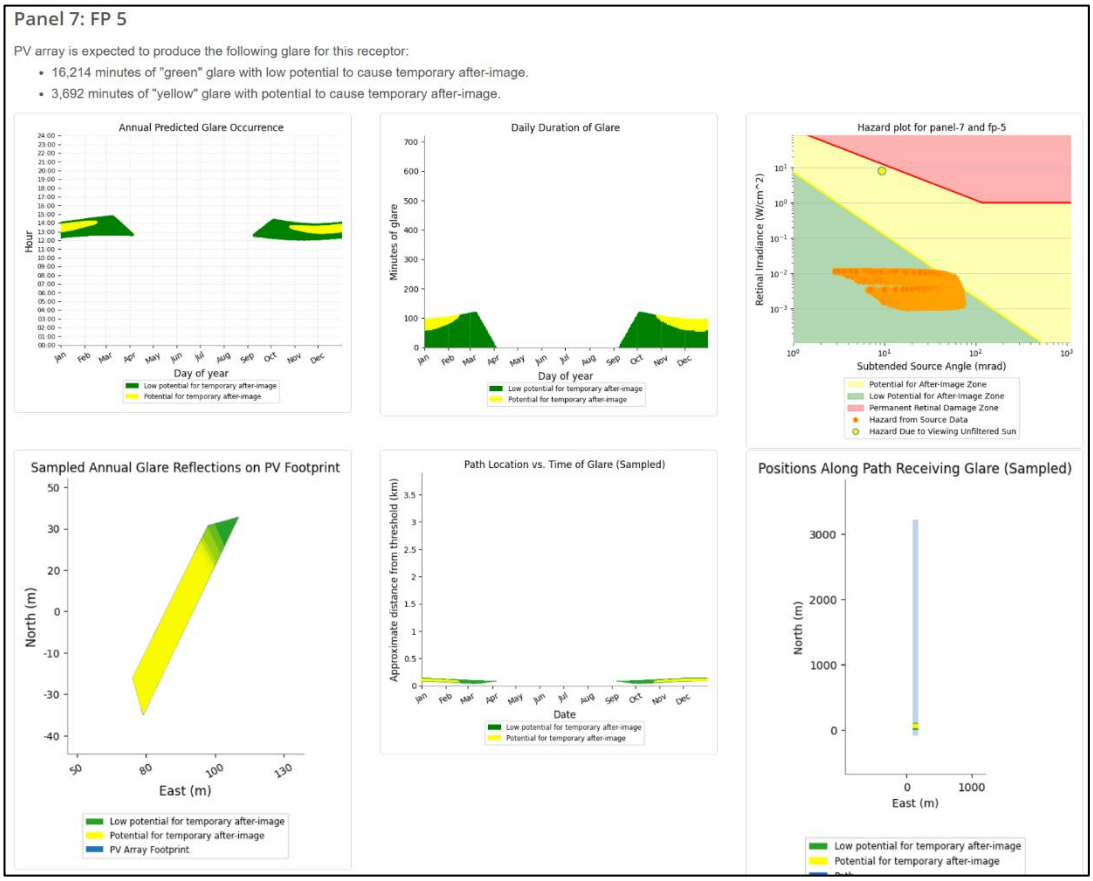




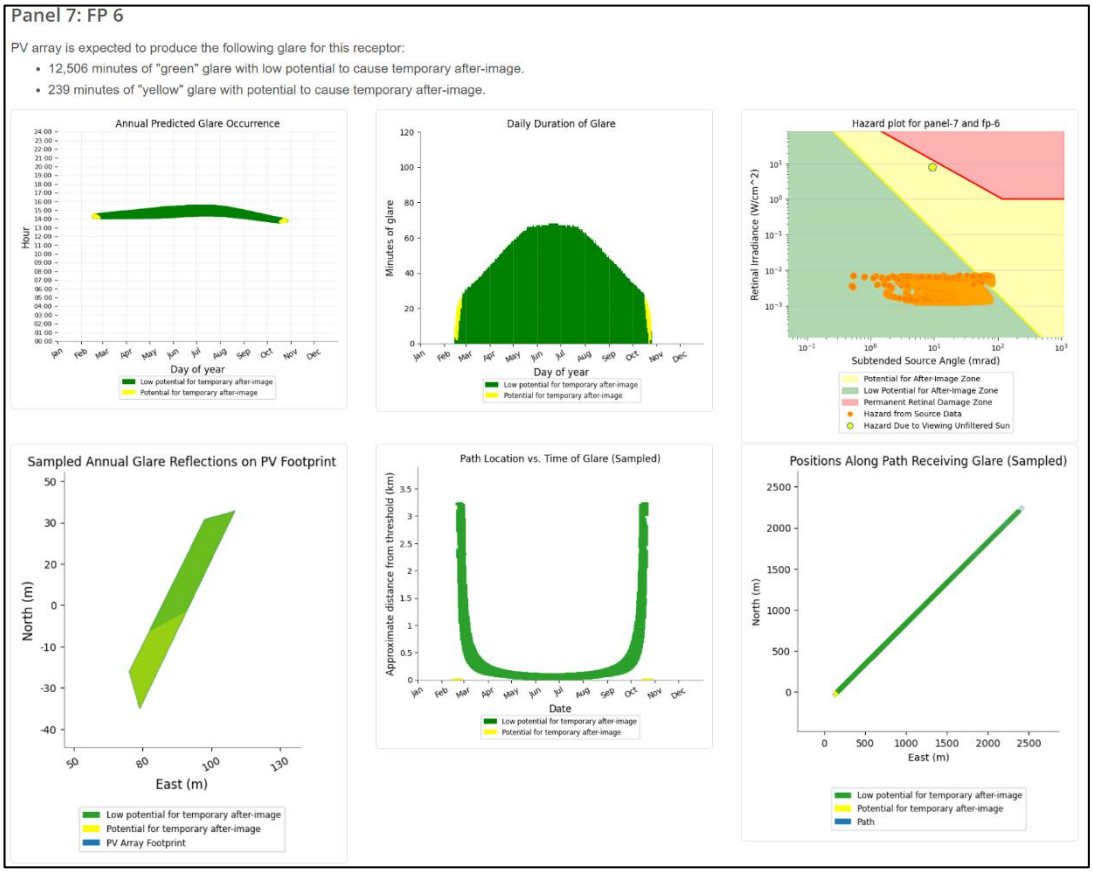




Approach Path 18



Approach Path 22



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