PAGERPOWER
Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Quartz Project Services

Hangar 4 at Manchester Airport

March 2023

PLANNING SOLUTIONS FOR:

- Solar
- Telecoms
- Railways
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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	March 2023	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 rooftop mounted solar photovoltaic (PV) panels pertaining to the proposed Hangar 4 development located at Manchester Airport. This assessment pertains to the possible impact upon aviation activity associated with Manchester Airport.

This report considers a worst-case panel layout, where solar panels are located on all rooftop areas. This report has been produced to inform the design of the panel areas.

Overall Conclusions

Solar reflections towards the ATC Tower are judged to be of a low impact when considered in an operational context (Section 5.5.1.). However, it is understood that Manchester Airport Group (MAG) have a zero-tolerance policy in place for solar reflections towards the ATC Tower. Therefore the results of the analysis should be used to inform the design of the panel areas either by re-orientating the offending panel areas or by omitting panels in particular areas altogether.

For the 10-nautical mile (NM) approach and departure paths associated with runways 05L/23R and 05R/23L, general aviation (GA) and commercial aircraft (CA) circuits, and the overhead 5km x 5km area, solar reflections with a maximum intensity of 'low potential for temporary after-image' are predicted. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these aviation receptors. Mitigation is not required for aircraft activity.

This report should be made available to MAG, who safeguard Manchester Airport, to understand their position along with any feedback or comments regarding the proposed development.

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. Pager Power has however produced guidance for glint and glare and solar photovoltaic developments, which was published in early 2017, with the fourth edition originally published in 2022[1]. This methodology defines a comprehensive process for determining the impact upon aviation activity.

For aviation activity, Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted where a solar reflection is predicted, solar intensity

[1] Pager Power Glint and Glare Guidance, Fourth Edition, September 2022.

calculations are undertaken where appropriate 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].

Assessment Conclusions – Manchester Airport

ATC Tower

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted towards the ATC Tower. The effects have been considered in an operational context (Section 5.5.1) and in particular:

- Solar reflections occur for a short period of time in comparison to annual daylight hours;
- Solar reflections do not originate near to taxiways and runway thresholds;
- The reflecting panel areas take up a small percentage of the lateral field-of-view for air traffic controllers.

In an operational context, a low impact is predicted upon air traffic controllers and mitigation is not required.

MAG, however, have a zero-tolerance policy in place for solar reflections towards the ATC Tower. The results of the analysis should be used to inform the design of the panel areas either by re-orientating the offending panel areas or by omitting panels in particular areas altogether.

10NM Approach Paths for Runways 05L23R and 05R/23L

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted along the entire 10NM approach path associated with runway 23R, and a 9NM section of the 10NM approach path associated with runway 23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to 2-mile approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these approach paths. A low impact is predicted, and mitigation is not required.

Solar reflections are not geometrically possible towards the 10NM approach paths associated with runways 05L and 05R. No impact is predicted, and mitigation is not required.

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[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).

10NM Departure Paths for 05L/23R and 05R/23L

Solar reflections occur outside a pilot's field-of-view along the 10NM departure path associated with runways 23R and 23L, which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice. A low impact is predicted, and mitigation is not required.

Solar reflections are not geometrically possible towards the 10NM departure paths for runways 05L and 05R. No impact is predicted, and mitigation is not required.

General Aviation Circuits

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted along sections of the GA circuits associated with runways 05L/23R and 05R/23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths. A low impact is predicted, and mitigation is not required.

Commercial Aviation Circuits

Solar reflections originating from the rooftop-mounted panels with glare intensities no greater than 'low potential for temporary after-image' are predicted along sections of the CA circuits associated with runways 05L/23R and 05R/23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths. A low impact is predicted, and mitigation is not required.

Overhead 5km x 5km Area

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted within a 5km x 5km area of airspace above the proposed development. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for these receptors. A low impact is predicted, and mitigation is not required.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 56 countries within Europe, Africa, 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 rooftop mounted solar photovoltaic (PV) panels pertaining to the proposed Hangar 4 development located at Manchester Airport. This assessment pertains to the possible impact upon aviation activity associated with Manchester Airport.

This report considers a worst-case panel layout, where solar panels are located on all rooftop areas. This report has been produced to inform the design of the panel areas.

This report contains the following:

- Solar development details;
- Explanation of glint and glare;
- Overview of relevant guidance and studies;
- Overview of Sun movement;
- Assessment methodology;
- Identification of receptors;
- Glint and glare assessment for identified receptors;
- Results discussion;
- Overall conclusions and recommendations.

1.2 Pager Power's Experience

Pager Power has undertaken over 1,000 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[4] 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.

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 Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) – published by the Department for Business, Energy & Industrial Strategy in September 2021 and the Federal Aviation Administration in the USA.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Overview

The following sections present key details pertaining to the proposed development and this assessment.

2.2 Proposed Development Site Layout

Figure 1 below shows the redline boundary[5] for the proposed development.

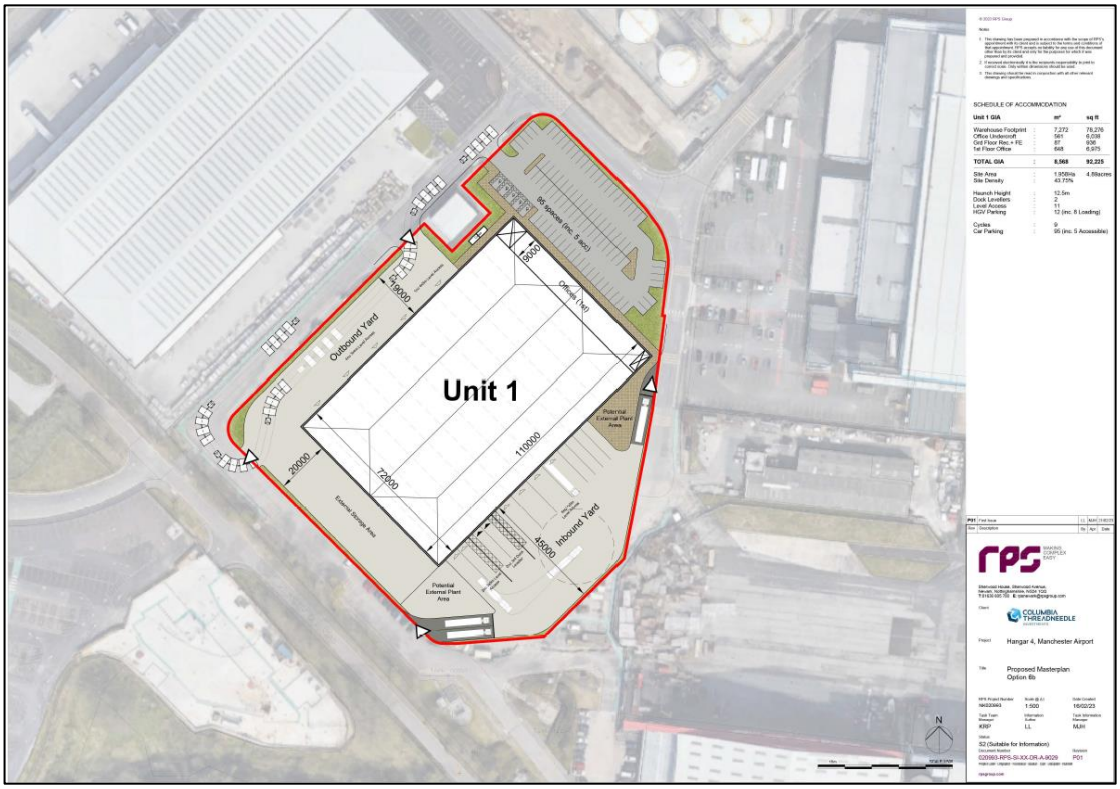

Figure 1 *Redline boundary*

The proposed elevation profile[6] and proposed roof plan[7] are shown in Figures 2 and 3 respectively on the following pages.

The roof layout plan and that the panel layout design has not yet been confirmed. Therefore, the rooftop has been assessed as if each areas will have solar panels located on it (Section 2.3). The results of the analysis should be used to inform the design of the panel areas.

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[5] Source: 020993-RPS-SI-XX-DR-A-9029-P01-Proposed Masterplan Option 6b
[6] Source: 020993-RPS-SI-XX-DR-A-0111 (Proposed Elevations)
[7] Source: 020993-RPS-SI-XX-DR-A-9023-P01-Proposed Roof Plan

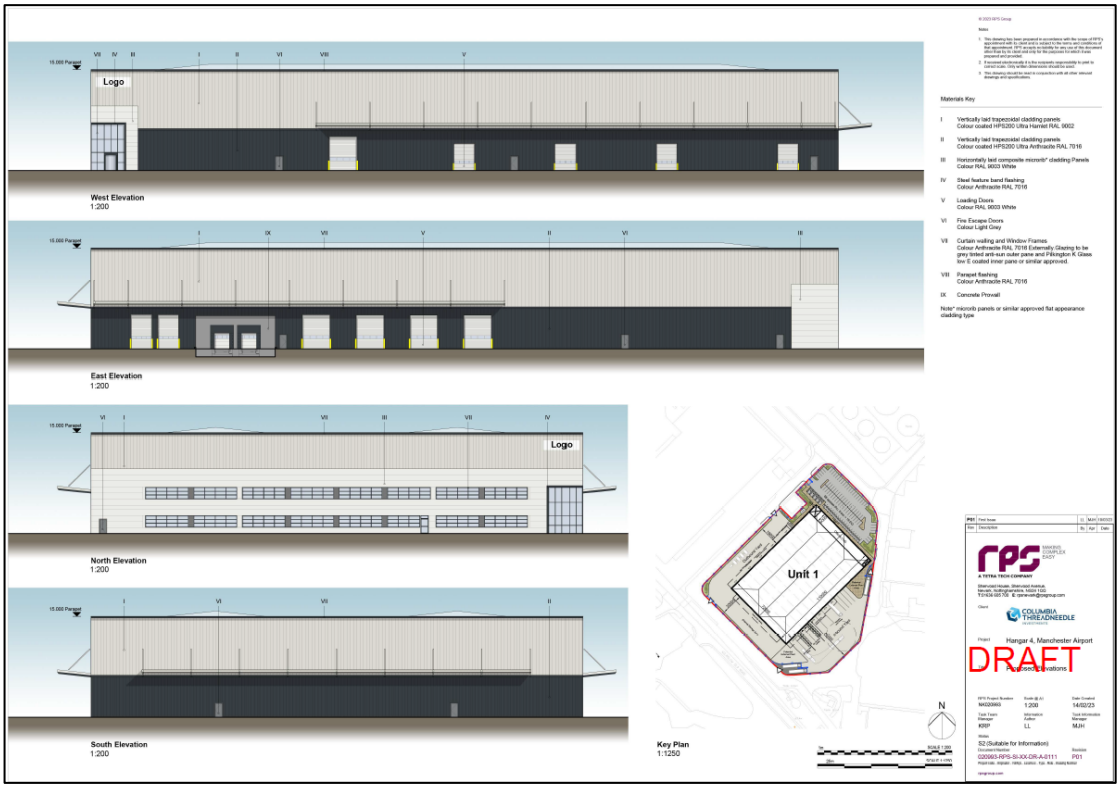

Figure 2 *Proposed elevations*

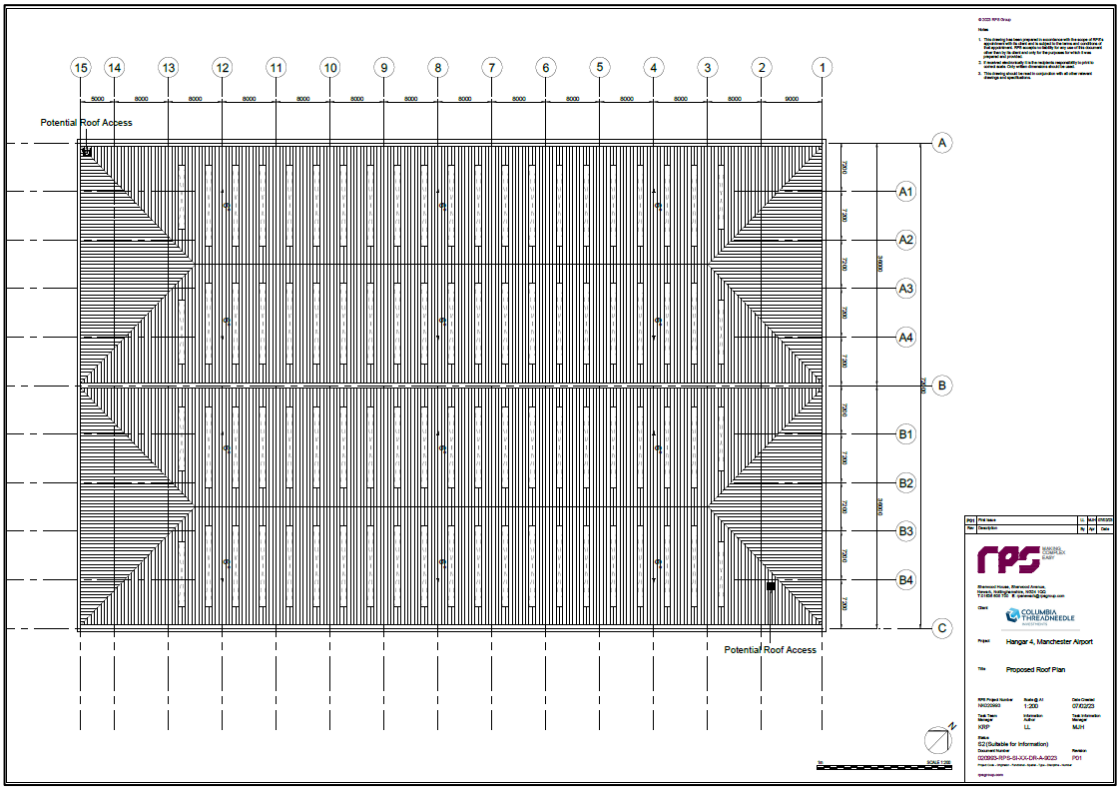

Figure 3 *Proposed rooftop layout*

2.3 Reflector Areas

The bounding coordinates for the proposed development have been extrapolated from the site plans. The data can be found in Appendix G. Figure 4 on the following page shows the assessed reflector areas that have been used for modelling purposes.

The reflector areas consider a worst-case panel layout, where solar panels are located on all rooftop areas. This report has been produced to inform the design of the panel areas.

Figure 4 *Assessed reflector areas*

2.4 Resolution

The Pager Power model has used a resolution of 1m for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 1m from within the defined areas. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output. If a reflection is experienced from an assessed panel location, then it is likely that a reflection will be viewable from similarly located panels within the proposed solar development.

2.5 Solar Panel Technical Information

The technical information of the modelled solar panels used in the assessment. summarises below:

- Azimuth angles[8]: 135°/315° (south-east facing / north-west facing)
  The ends of each roof have not been assessed (north-east facing / south-west facing), as it not usual for solar panels to be located here, and therefore are not expected to be located here as part of any design;
- Elevation angle[9]: 6°;
- Assessed centre height agl[10]: 16m.

[8] Orientation the panels are facing relative to True North (0°)
[9] Tilt above horizontal
[10] above ground level

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 Overview

The following sub-sections provide a general overview with respect to the guidance studies and methodology which informs this report. Pager Power has also produced its own Glint and Glare Guidance which draws on assessment experience, consultation and industry expertise.

3.2 Guidance and Studies

Appendix A 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.

3.3 Background

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

3.4 Methodology

Information regarding Pager Power's and Sandia National Laboratories' methodology is presented in the following sub-sections 3.4.1 and 3.4.2 respectively.

3.4.1 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, studies and Pager Power's practical experience. The methodology for this 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, if appropriate;

- 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 expected in line with Appendix D.

Within the Pager Power model, 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 the panels that can produce the solar reflection towards the receptor.

Where a solar reflection is identified for an aviation approach path receptor, intensity calculations are completed in line with the Sandia National Laboratories methodology (section 3.4.2).

3.4.2 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.

3.5 Assessment Methodology and Limitations

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

4 IDENTIFICATION OF RECEPTORS

4.1 Overview

The following sections present the relevant receptors assessed within this report. Terrain data has been interpolated based on Ordnance Survey of Great Britain (OSGB) 50 Digital Terrain Model (DTM) data. The receptor details for all receptors are presented in Appendix G.

4.2 Aviation Receptors

The following subsections present the relevant data and receptors associated with Manchester Airport. The aerodrome details and the aerodrome chart can be found via the NATS Aeronautical Information Publication (AIP).

4.2.1 Manchester Airport Information

Manchester Airport is a Civil Aviation Authority (CAA) licensed aerodrome, with an Air Traffic Control (ATC) Tower and two operational runways, the details of which are presented below:

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

The aerodrome chart is shown in Figure 5 on the following page.

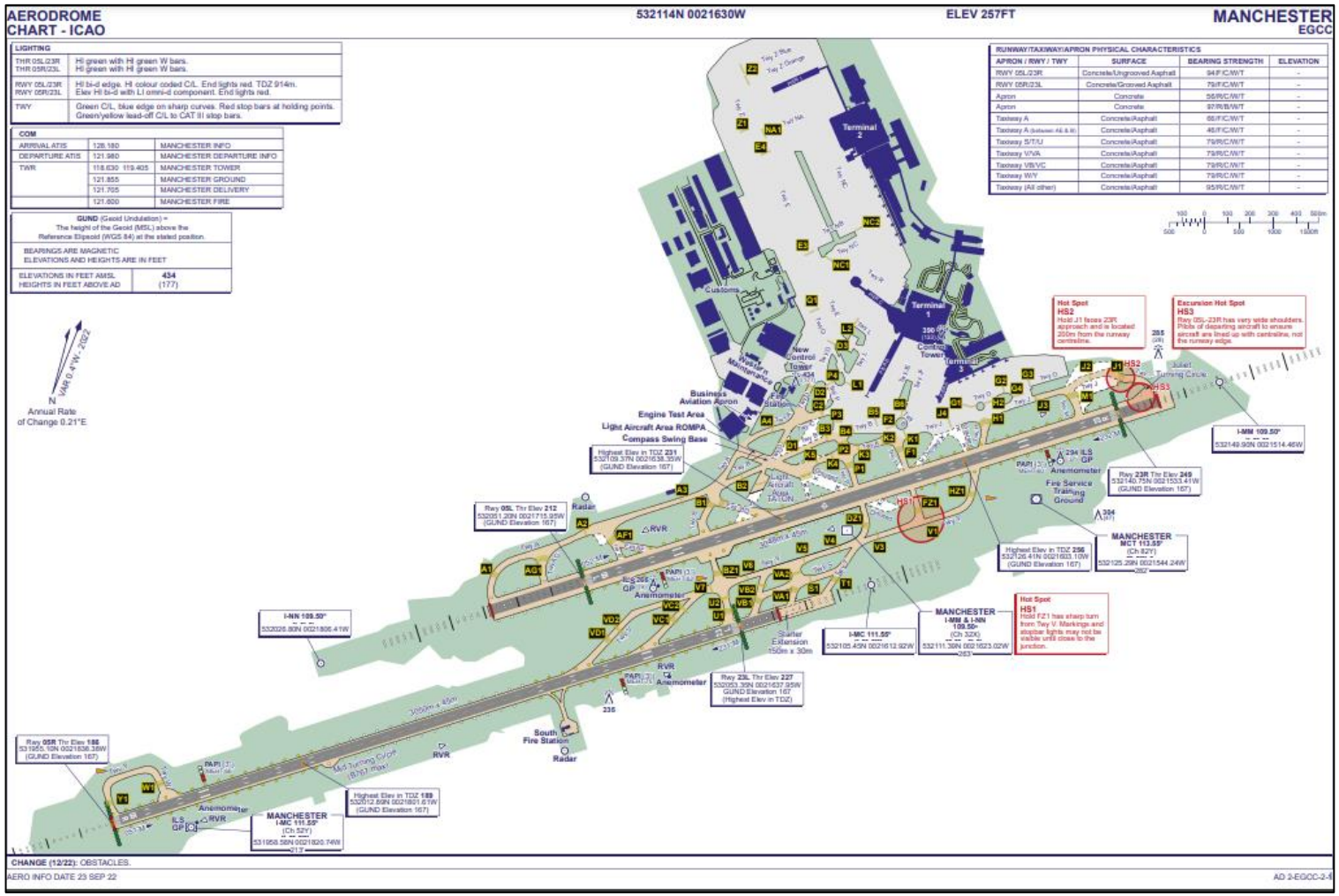

Figure 5 *Aerodrome chart*

4.2.2 ATC Tower

It is standard practice to determine whether a solar reflection can be experienced by personnel within the ATC Tower. A height of 57.06m above ground level has been used to model the eye-level of air traffic controllers[11].

The location of the ATC Tower receptor is shown in Figure 6 on the following page.

4.2.3 Aviation Receptors

Manchester Airport Group (MAG), who safeguard Manchester Airport, require assessment of specific receptors. The specific receptors are as follows:

- Receptor points every nautical mile on all final approaches, from 10NM on the final approach centre line starting at 3000 feet AMSL with the altitude decreasing with the glide slope (normal radar approach by ATC) to 50 feet above the runway threshold;
- Receptor points every nautical mile for departing aircraft, maintaining the runway centre line out to 10NM climbing to 1500 feet AMSL for emergency planning (GA and Performance A certified aircraft);
- Receptor points every nautical mile in a general aviation (GA) circuit at 1000 feet AMSL and 1NM downwind leg (standard GA circuit pattern);
- Receptor points every nautical mile in a commercial aviation (CA) circuit at 1500 feet and 2NM downwind leg (standard CA circuit pattern);
- An overhead 5km x 5km area above the proposed development, set to a minimum of 2500 feet AGL (standard Radio Altitude (RA) activation point for all aircraft).

These receptors shown in Figures 7 to 10 on pages 22 to 25.

[11] Confirmed by Manchester Airport Group Safeguarding Team

Figure 6 *ATC Tower at Manchester Airport*

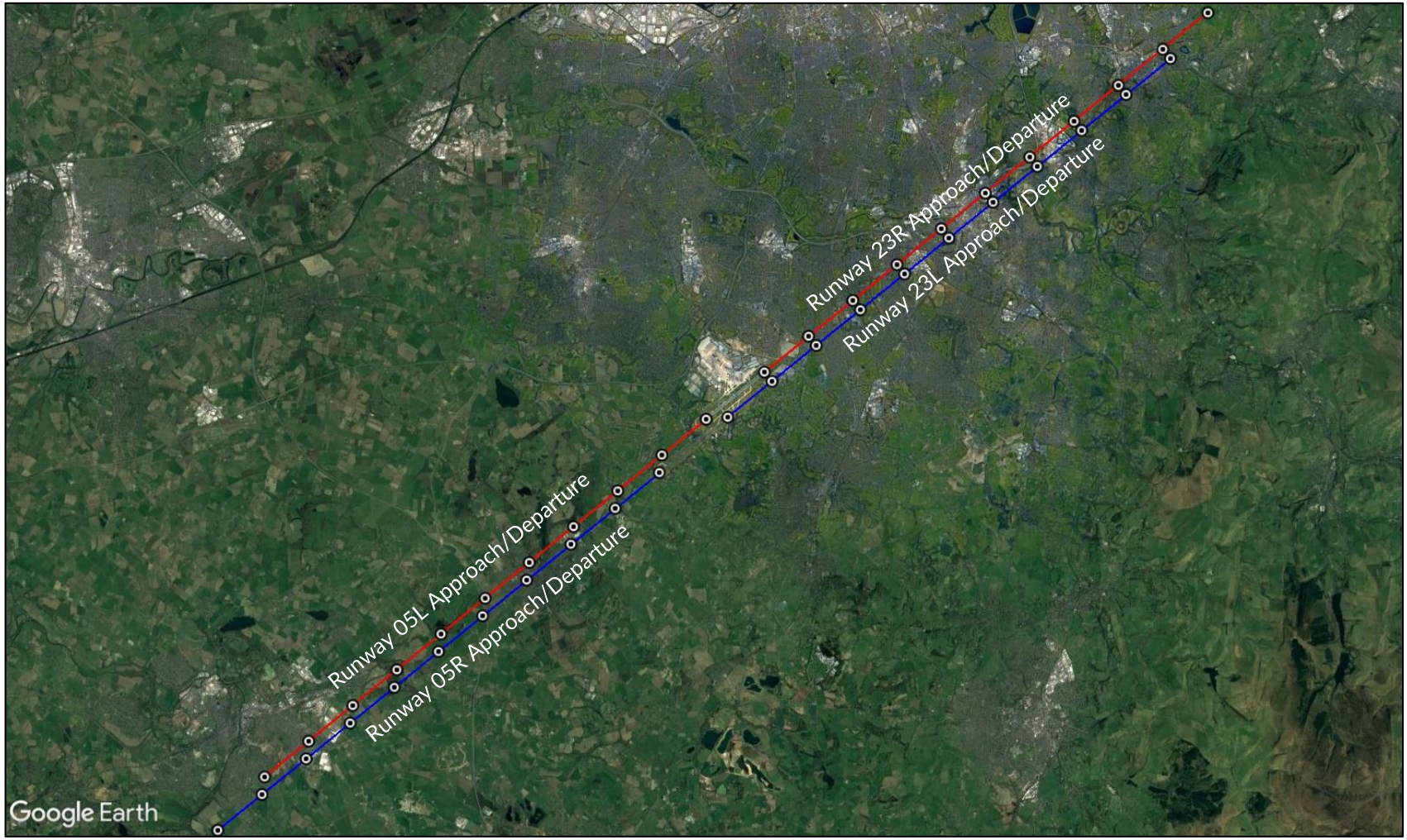

Figure 7 *Extended approach path and departure path receptors*

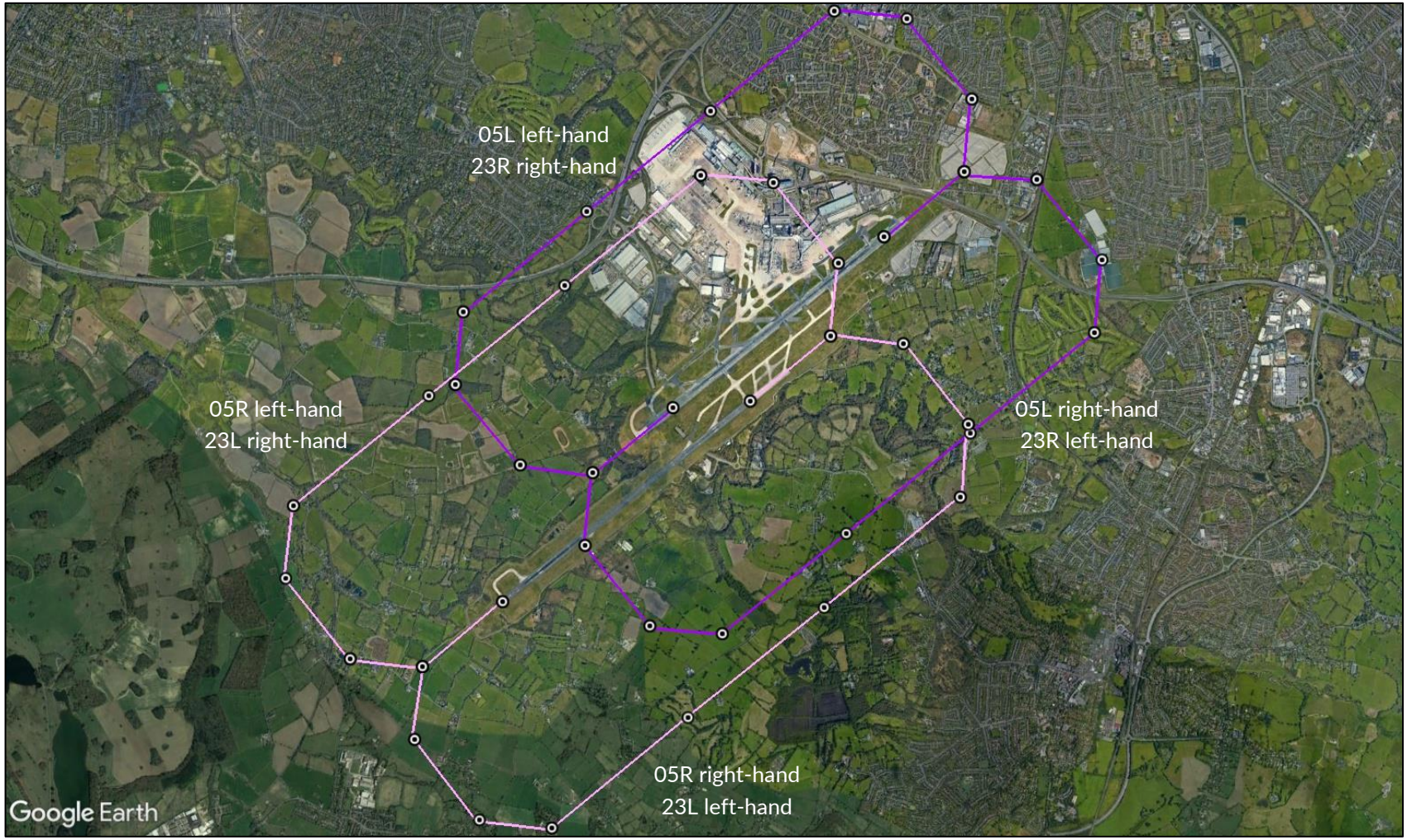

Figure 8 *GA visual circuits*

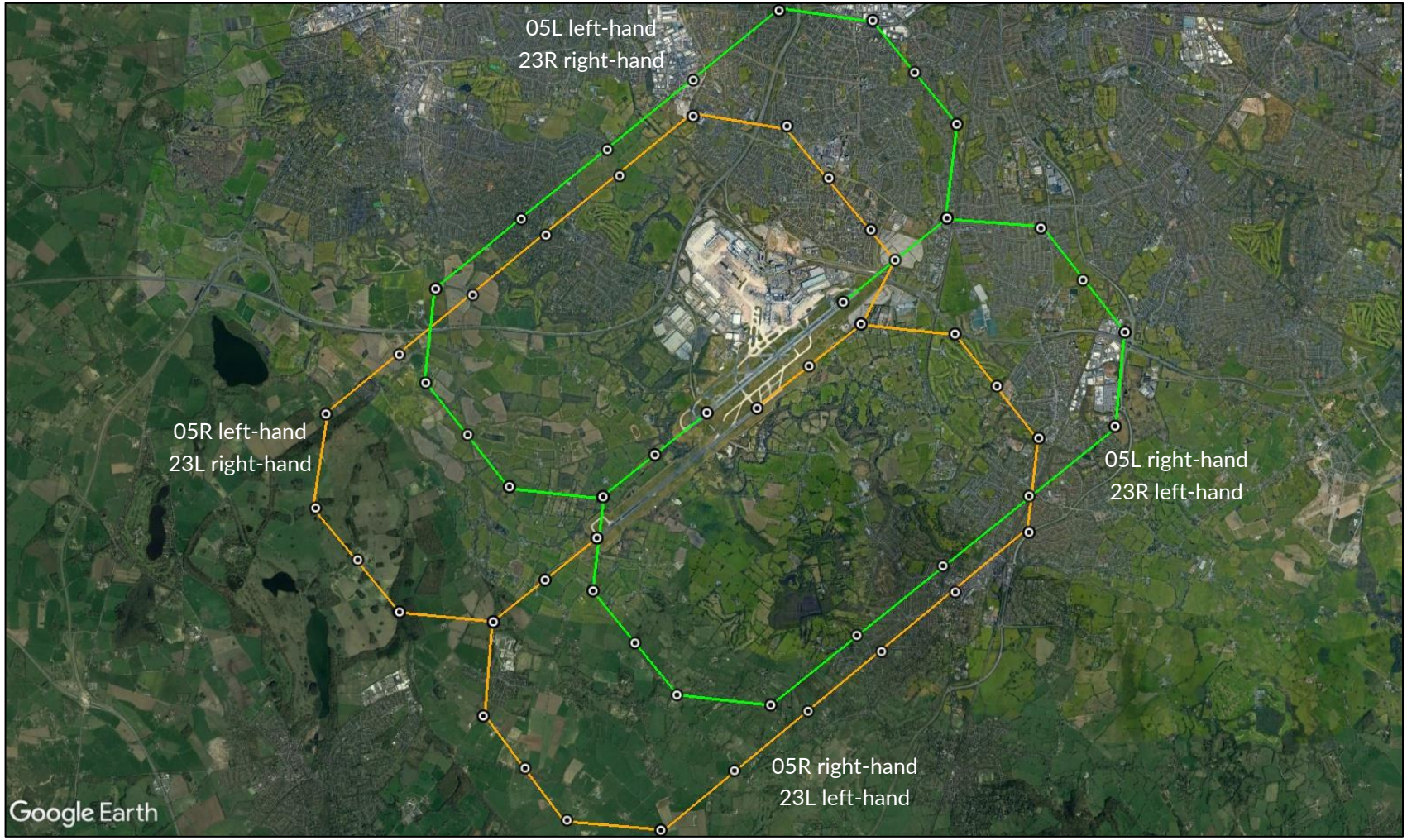

Figure 9 *CA visual circuits*

Figure 10 *Overhead receptors*

5 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

5.1 Overview

The following subsections present the significance of any predicted impact in the context of existing screening and the relevant criteria set out in each sub-section. The criteria are determined by the assessment process for each receptor, which are set out in Appendix D.

When determining the visibility of the reflecting panels for an observer, a conservative review of the available imagery has been undertaken, whereby it is assumed views of the panels are possible if it cannot be reliably determined that existing screening will remove effects.

5.2 Glare Intensity Categorisation

The Pager Power and Forge models have been used to determine whether reflections are possible for aviation receptors. Intensity calculations (Forge Model) in line with the Sandia National Laboratories methodology have been undertaken. 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 1 below along with the associated colour coding.

Category	Intensity Key
Glare beyond 50°	Glare beyond 50 deg from pilot line-of-sight
Low potential ('green')	Low potential for temporary after-image
Potential ('yellow')	Potential for temporary after-image
Potential for permanent eye damage ('red')	Potential for permanent eye damage

Table 1 *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. In the first instance, a surface material of 'smooth glass without an anti-reflective coating' is assessed. This is the most reflective surface and allows for a 'worst case' assessment. Other surfaces that could be modelled include:

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

Appendix H presents the results charts showing specific times and dates.

5.3 Key Considerations – ATC Tower

5.3.1 MAG Safeguarding Towards ATC Towers

MAG have a zero-tolerance policy in place for solar reflections towards the ATC Tower. Therefore the results of the analysis should be used to inform the design of the panel areas either by re-orientating the offending panel areas or by omitting panels in particular areas altogether.

The following section has been included for determining the impact significance of solar reflections towards an ATC Tower in an operational context.

5.3.2 Glare Towards ATC Tower – Operational Context

The process for determining the impact significance is defined in Appendix D. For an ATC Tower, the key considerations are:

- Whether a reflection is predicted to be experienced in practice;
- 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[12] for on-airfield solar. Pager Power recommends a pragmatic approach to consider glare towards the ATC Tower in an operational context. Where solar reflections are of an intensity no greater than 'low potential for temporary after-image' (green glare) expert assessment of the following factors is required to determine the impact significance[13]:

- 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 ATC Tower be operational at these times;
- The duration of any predicted glare; as glare that is experienced for low durations throughout the year is less significant than longer durations;
- Glare location relative to key operational areas;
- The relative size of the reflecting panel area and whether the reflecting area takes up a large percentage of an ATC controller's field-of-view[14];
- 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;

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[12] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.
[13] 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.
[14] 210 degrees azimuth field of view.

- The level of predicted effect relative to existing sources of glare – a solar reflection is less noticeable by ATC controllers when there are existing reflective surfaces in the surrounding environment.

Following consideration of these mitigating factors, where the solar reflection does not remain significant, a low impact is predicted, and mitigation is not recommended. Where the solar reflection remains significant or where glare with no greater than '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.

5.4 Key Considerations – Runway Approach Paths

The process for determining impact significance is defined in Appendix D. For the runway approach paths, the key considerations 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[15] for on-airfield solar towards 2-mile approach paths for runway thresholds[16]. 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

[15] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.
[16] This technical context is applicable towards the 10NM approach and departure paths as per MAG requirements

temporary after-image' expert assessment of the following mitigating factors is required to determine the impact significance[17]:

- 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 mitigating factors, where the solar reflection does not remain 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 remains significant, 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.

In all cases, however, consultation with the aerodrome is recommended to understand their position pertaining to solar reflections towards the ATC Tower or approach paths, along with any feedback or comments regarding the proposed development.

5.5 Assessment Results – Aviation Receptors: Manchester Airport

Table 2 on the following page presents the following:

- Geometric modelling results;
- Glare intensity;
- Relevant factors, visibility and predicted impact significance.

[17] 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.

Reference to a pilot's primary field-of-view is made when analysing the geometric results. A pilot's primary field-of-view is defined as 50 degrees either side of the runway approach relative to the runway threshold.

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
ATC Tower	Solar reflections originating from panel areas orientated 135° are geometrically possible towards the ATC Tower	'Green'	MAG are not tolerant of solar reflections towards the ATC Tower. The offending panel areas should be re-orientated or omitted altogether Analysis of the solar reflections in an operation context is presented in Section 5.5.1
10NM Approach Path Runway 05L	Solar reflections are not geometrically possible from the panel areas	N/A	No impact predicted
10NM Approach Path Runway 23R	Solar reflections originating from the panel areas occur along the entire 10NM approach	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to 2-mile approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these approach paths Low impact predicted and mitigation is not required

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
10NM Approach Path Runway 05R	Solar reflections are not geometrically possible from the panel areas	N/A	No impact predicted
10NM Approach Path Runway 23L	Solar reflections originating from the panel areas occur along a 9NM-section, between 1NM and 10NM from the threshold	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to 2-mile approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these approach paths Low impact predicted and mitigation is not required
10NM Departure Path Runway 05L	Solar reflections are not geometrically possible from the panel areas	N/A	No impact predicted

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
10NM Departure Path Runway 23R	Solar reflections originating from the panel areas occur along the entire 10NM departure	Glare beyond field-of-view	Solar reflections occur outside a pilot's primary field-of-view 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 predicted and mitigation is not required
10NM Departure Path Runway 05R	Solar reflections are not geometrically possible from the panel areas	N/A	No impact predicted
10NM Departure Path Runway 23L	Solar reflections originating from the panel area occur along a 9NM-section, between 1NM and 10NM from the threshold	Glare beyond field-of-view	Solar reflections occur outside a pilot's primary field-of-view 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 predicted and mitigation is not required

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
GA Circuit 05L/23R	Solar reflections originating from the panel area occur along separate points along the circuit	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths Low impact predicted and mitigation is not required
GA Circuit 05R/23L	Solar reflections originating from the panel area occur along separate points along the circuit	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths Low impact predicted and mitigation is not required

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
CA Circuit 05L/23R	Solar reflections originating from the panel area occur along separate points along the circuit	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths Low impact predicted and mitigation is not required
CA Circuit 05R/23L	Solar reflections originating from the panel area occur along separate points along the circuit	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths Low impact predicted and mitigation is not required

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment
Overhead 5km x 5km	Solar reflections are geometrically possible at specific points of the overhead area	'Green'	Solar reflections occur inside a pilot's primary field-of-view with glare intensities no greater than having a 'low potential for temporary after-image' ('green' glare) Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for these receptors Low impact and mitigation is not required

Table 2 *Geometric modelling results – Manchester Airport receptors*

Figures 11 to 16 on the following pages show where solar reflections with 'green' glare intensities are geometrically possible.

Figure 11 *Solar reflections towards 10NM approaches and departures*

Figure 12 *Solar reflections towards GA circuits associated with runways 05L/23R*

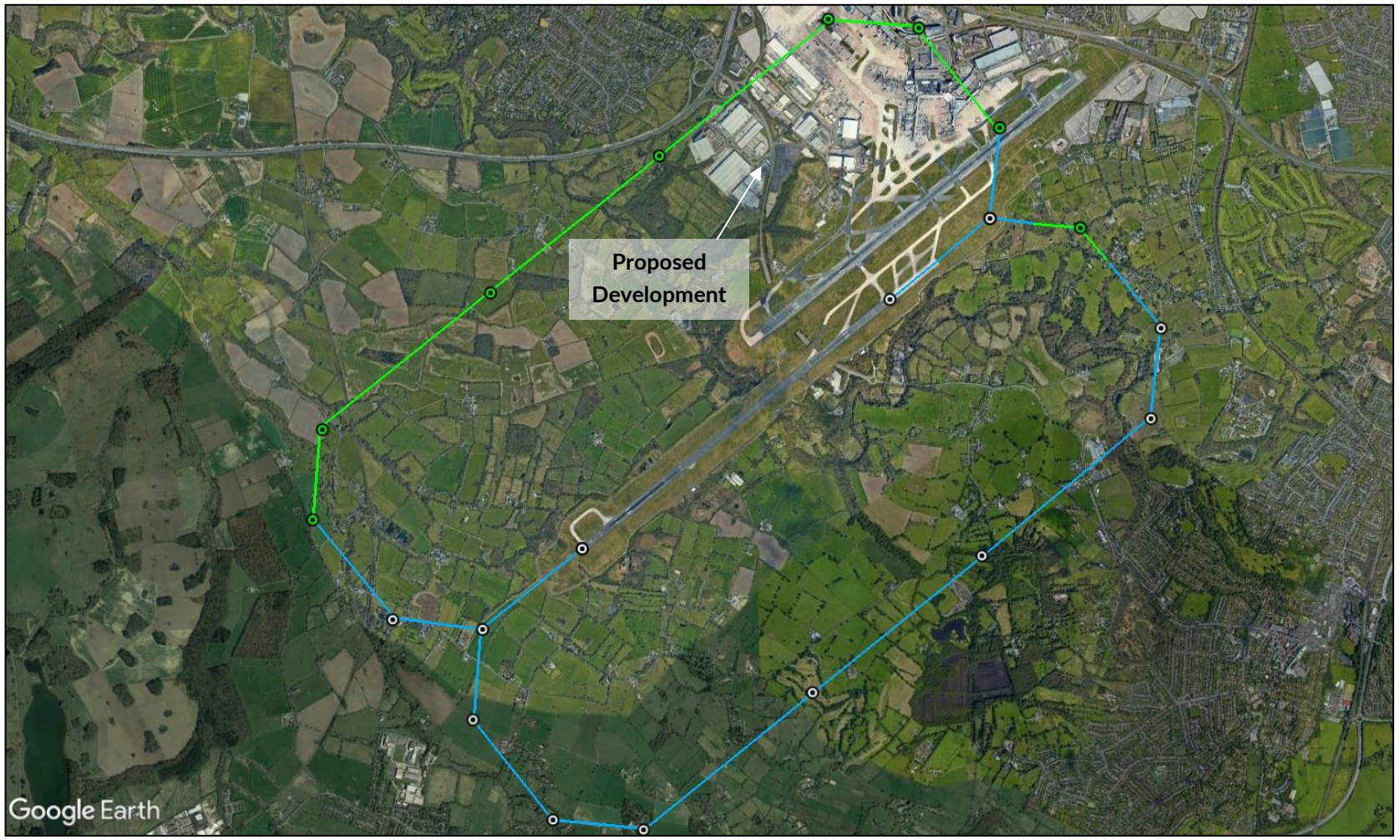

Figure 13 *Solar reflections towards GA circuits associated with runways 05R/23L*

Figure 14 *Solar reflections towards CA circuits associated with runways 05L/23R*

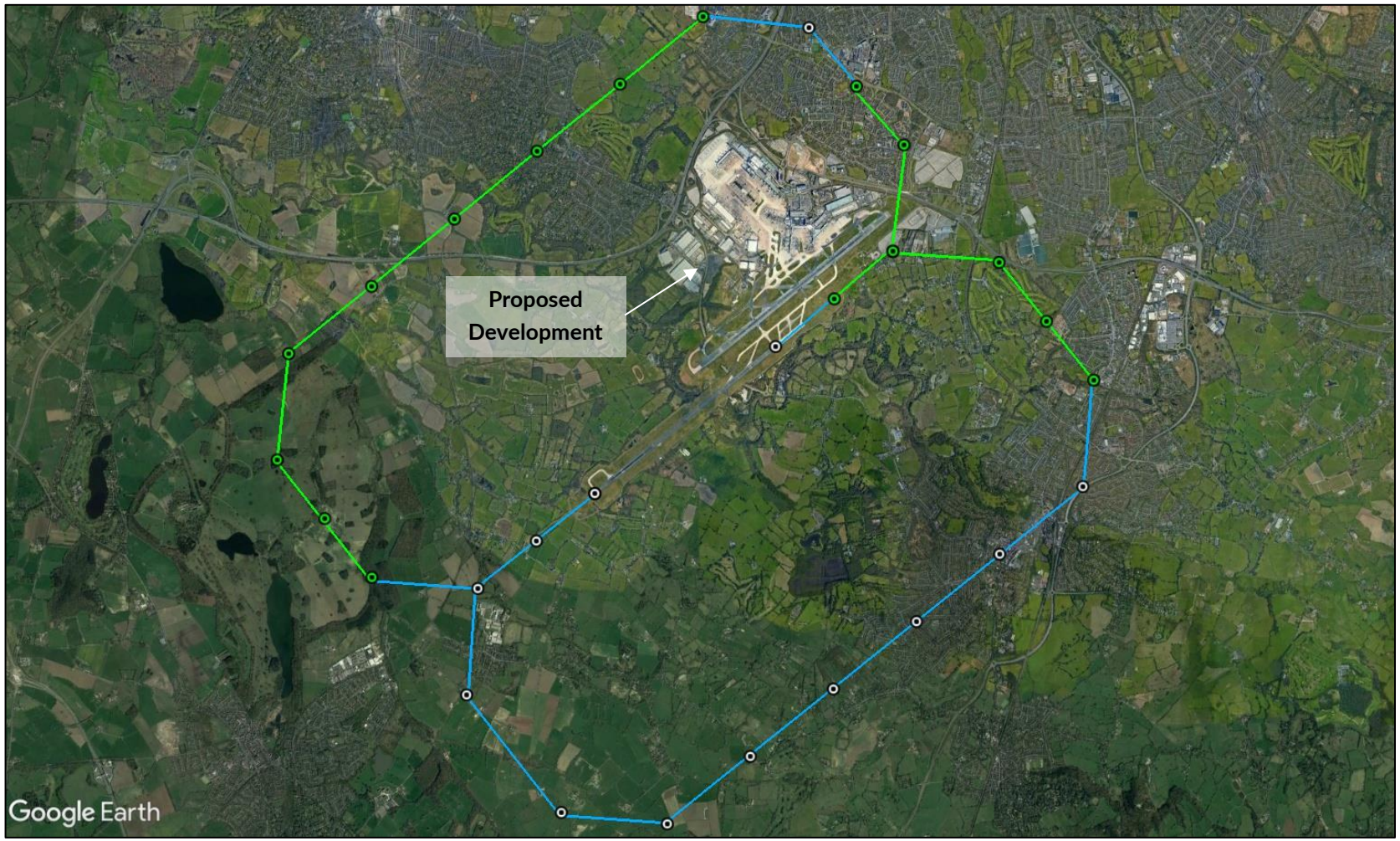

Figure 15 *Solar reflections towards CA circuits associated with runways 05R/23L*

Figure 16 *Solar reflections towards 5km x 5km overhead area*

5.5.1 Glare Towards ATC Tower

MAG are not tolerant of solar reflections towards the ATC Tower. The offending panel areas should be re-orientated or omitted altogether.

The solar reflections towards the ATC Tower (from the assessed panels in this report) are considered in an operational context is required to determine the impact significance upon personnel in the ATC Tower.

The following can be concluded:

- Solar reflections of 'green' glare are predicted from two of the four panel areas (2 and 4), with 2,815 minutes per year originating from panel area 2 and 2,678 minutes per year from panel area 4. This represents 1.07% and 1.02% of average daylight hours[18] in any one year, and 2.09% cumulatively;
- Glare intensities are of a maximum of 'green' category and do not border onto the next significant category 'yellow', i.e. solar reflections do not border on having 'potential for temporary after-image';
- Solar reflections are predicted for approximately 110 days (late April to mid-August), lasting less than 30 minutes on any given day. Glare can also only occur when the weather is clear and sunny;
- Although air traffic controllers will have a 360-degree field-of-view within the ATC Tower, solar reflections do not originate close to taxiways or runway thresholds. This is illustrated in Figure 17 on the following page 45;
- Solar reflections originating from the reflecting panel areas will occupy 10.45% of the lateral field-of-view (when looking in the direction of the reflecting panels). This is illustrated in Figure 18 on page 46;
- The separation distance between the closest reflecting panel area and the ATC Tower is approximately 310 metres. This is illustrated in Figure 19 on page 47;

Overall, a low impact is predicted upon air traffic controllers and mitigation is not recommended.

[18] Based on 12 hours of sunlight a year

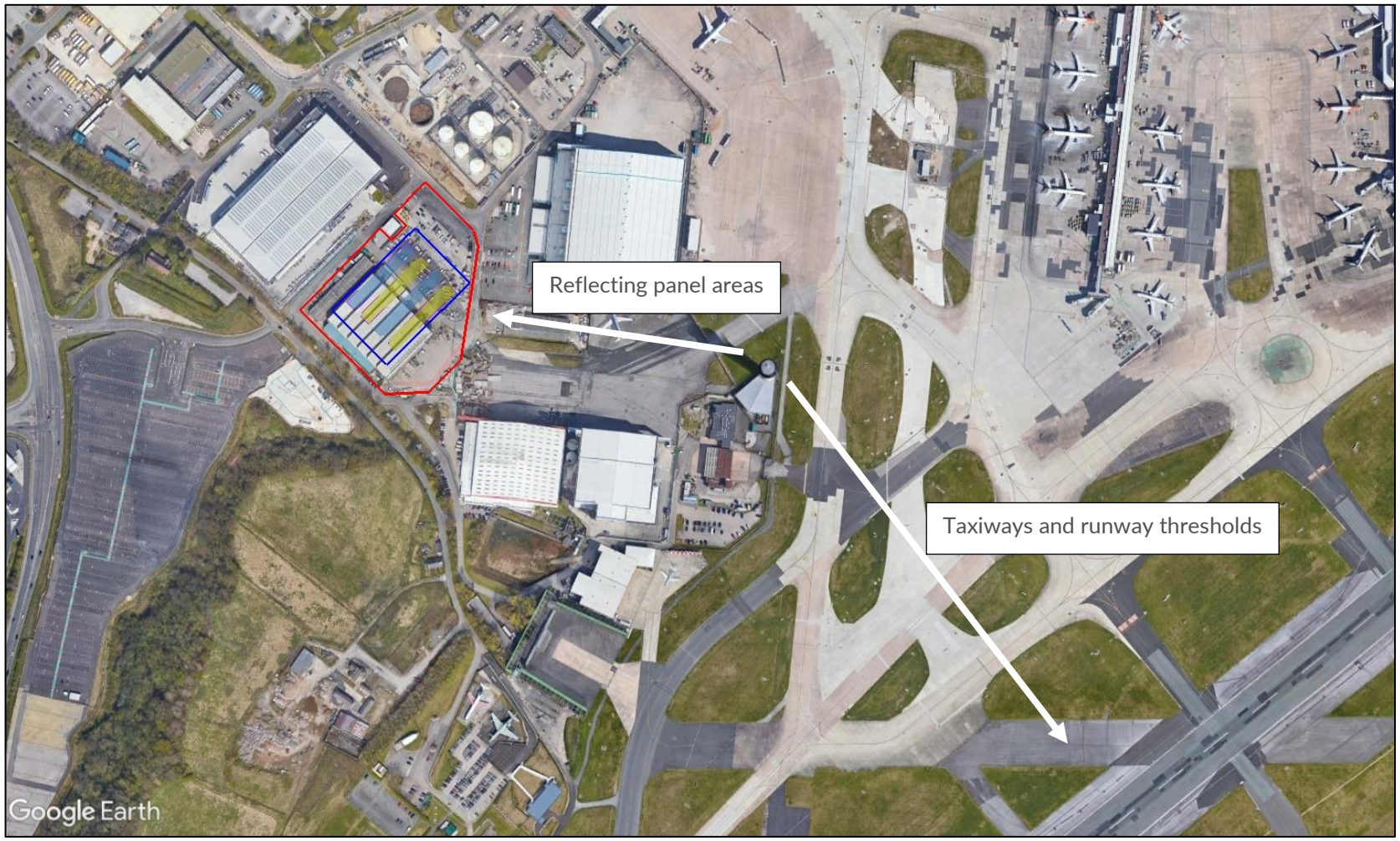

Figure 17 *Solar reflections originating away from operational areas*

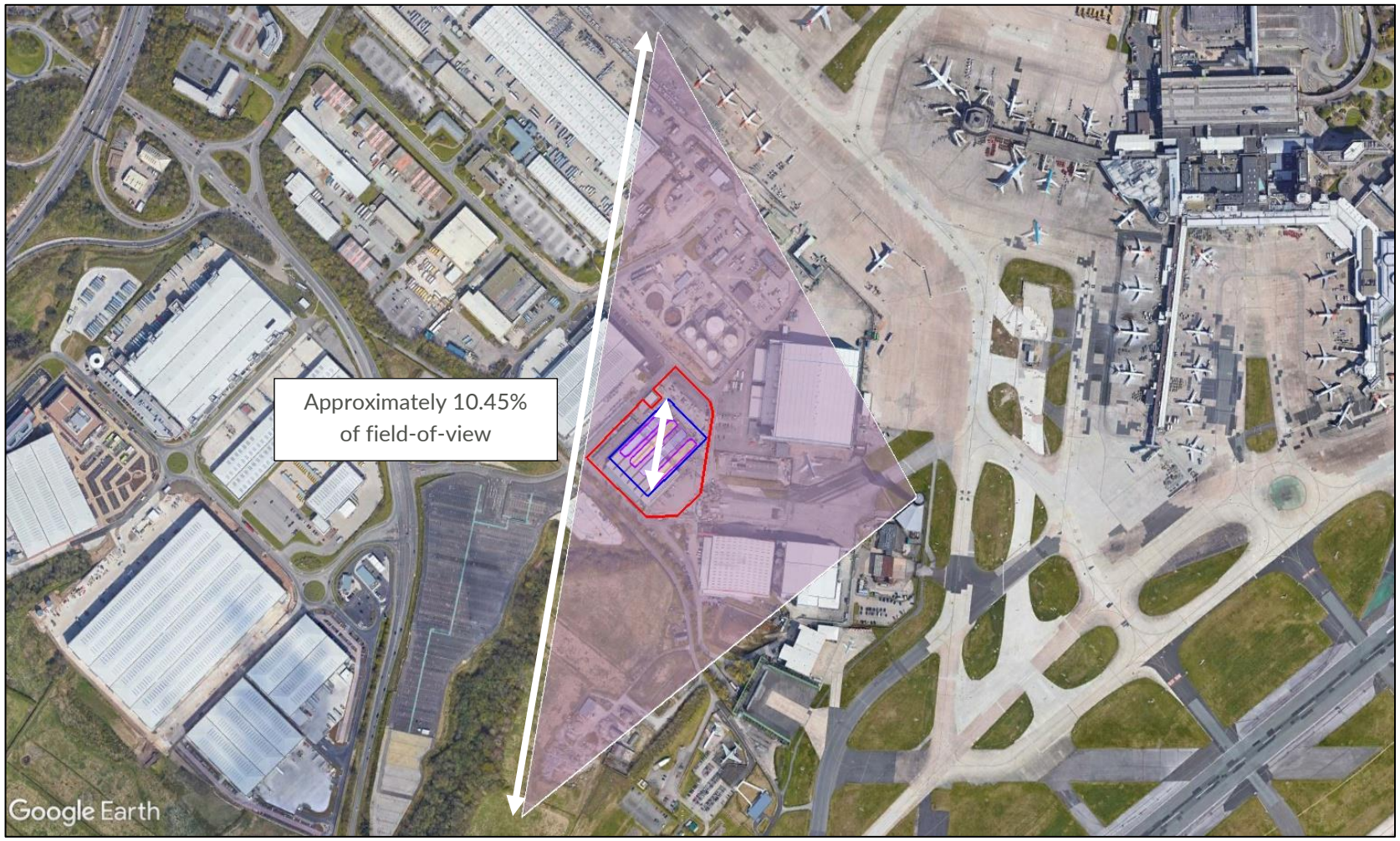

Figure 18 *Percentage of lateral field-of-view*

Figure 19 *Separation distance between reflecting panels and ATC Tower*

6 OVERALL CONCLUSIONS

6.1 Conclusions – Manchester Airport

ATC Tower

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted towards the ATC Tower. The effects have been considered in an operational context (Section 5.5.1) and in particular:

- Solar reflections occur for a short period of time in comparison to annual daylight hours;
- Solar reflections do not originate near to taxiways and runway thresholds;
- The reflecting panel areas take up a small percentage of the lateral field-of-view for air traffic controllers.

In an operational context, a low impact is predicted upon air traffic controllers and mitigation is not required.

MAG, however, have a zero-tolerance policy in place for solar reflections towards the ATC Tower. The results of the analysis should be used to inform the design of the panel areas either by re-orientating the offending panel areas or by omitting panels in particular areas altogether.

10NM Approach Paths for Runways 05L23R and 05R/23L

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted along the entire 10NM approach path associated with runway 23R, and a 9NM section of the 10NM approach path associated with runway 23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to 2-mile approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these approach paths. A low impact is predicted, and mitigation is not required.

Solar reflections are not geometrically possible towards the 10NM approach paths associated with runways 05L and 05R. No impact is predicted, and mitigation is not required.

10NM Departure Paths for 05L/23R and 05R/23L

Solar reflections occur outside a pilot's field-of-view along the 10NM departure path associated with runways 23R and 23L, which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice. A low impact is predicted, and mitigation is not required.

Solar reflections are not geometrically possible towards the 10NM departure paths for runways 05L and 05R. No impact is predicted, and mitigation is not required.

General Aviation Circuits

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted along sections of the GA circuits associated with runways 05L/23R and 05R/23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this

level of glare is also acceptable for the circuit paths. A low impact is predicted, and mitigation is not required.

Commercial Aviation Circuits

Solar reflections originating from the rooftop-mounted panels with glare intensities no greater than 'low potential for temporary after-image' are predicted along sections of the CA circuits associated with runways 05L/23R and 05R/23L. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for the circuit paths. A low impact is predicted, and mitigation is not required.

Overhead 5km x 5km Area

Solar reflections with glare intensities no greater than 'low potential for temporary after-image' are predicted within a 5km x 5km area of airspace above the proposed development. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for these receptors. A low impact is predicted, and mitigation is not required.

6.2 Overall Conclusions

Solar reflections towards the ATC Tower are judged to be of a low impact when considered in an operational context (Section 5.5.1.). However, it is understood that Manchester Airport Group (MAG) have a zero-tolerance policy in place for solar reflections towards the ATC Tower. Therefore the results of the analysis should be used to inform the design of the panel areas either by re-orientating the offending panel areas or by omitting panels in particular areas altogether.

For the 10-nautical mile (NM) approach and departure paths associated with runways 05L/23R and 05R/23L, general aviation (GA) and commercial aircraft (CA) circuits, and the overhead 5km x 5km area, solar reflections with a maximum intensity of 'low potential for temporary after-image' are predicted. Considering the associated guidance (Appendix D) and industry best practice pertaining to approach paths, which states that this level of glare intensity is acceptable, it can be concluded that this level of glare is also acceptable for these aviation receptors. Mitigation is not required for aircraft activity.

This report should be made available to MAG, who safeguard Manchester Airport, to understand their position along with any feedback or comments regarding the proposed development.

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 and is limited to the UK; however, it is relevant from a technical and planning perspective. The section 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 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.'

Draft National Policy Statement for Renewable Energy Infrastructure

The Draft 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. Section 2.52 states:

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[19] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 01/11/2021

[20] Draft National Policy Statement for Renewable Energy Infrastructure (EN-3), Department for Business, Energy & Industrial Strategy, date: September 2021, accessed on: 01/11/2021.

'2.52.1 Solar panels may reflect the sun's rays, 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.

2.52.2 In some instances, it may be necessary to seek a glint and glare assessment as part of the application. This may need to account for 'tracking' panels if they are proposed as these may cause differential diurnal and/or seasonal impacts. The potential for solar PV panels, frames and supports to have a combined reflective quality should be assessed. This assessment needs to consider the likely reflective capacity of all of the materials used[21] in the construction of the solar PV farm.

2.52.3 Applicants should consider using, and in some cases the Secretary of State may require, solar panels to be of a non-glare/ non-reflective type and the front face of the panels to comprise of (or be covered) with a non-reflective coating for the lifetime of the permission.

2.52.4 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 and motorists.

2.52.5 There is no evidence that glint and glare from solar farms interferes in any way with aviation navigation or pilot and aircraft visibility or safety. Therefore, the Secretary of State is unlikely to have to give any weight to claims of aviation interference as a result of glint and glare from solar farms.'

Consultation to determine whether EN-3 provides a suitable framework to support decision making for nationally significant energy infrastructure ended in November 2021. Pager Power is aware that aviation stakeholders were not consulted prior to the publication of the draft policy and understands that they will still request a glint and glare assessment on the basis that glare may lead to impact upon aviation safety. It is possible that the draft policy will change in light of the consultation responses from aviation stakeholders.

Finally, it should be noted that 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.

CAA Interim Guidance

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

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[21] In Pager Power's experience, the solar panels themselves are the overriding source of specular reflections which have the potential to cause significant impacts upon safety or amenity.

[22] Archived at Pager Power

[23] Reference email from the CAA dated 19/05/2014.

'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.'

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.

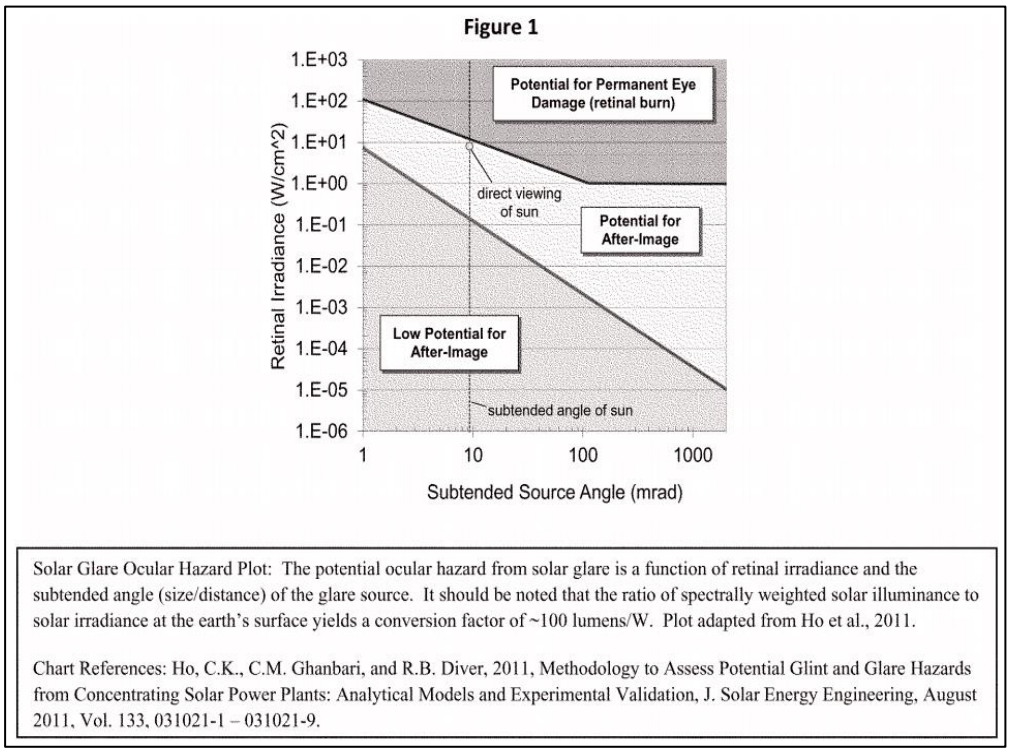
The 2010 document is entitled '*Technical Guidance for Evaluating Selected Solar Technologies on Airports*'[25] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System*

[24] Aerodrome Licence Holder.
[25] Archived at Pager Power

Projects on Federally Obligated Airports'[26]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[27].

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.*



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*

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[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: 20/03/2019

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

- *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 blindness*[28].
- *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*[29]*, 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*

[28] 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.
[29] First figure in Appendix B.

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 question30 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) 2016

In some instances, an aviation stakeholder can refer to the ANO 2016[31] 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

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[30] 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.

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

(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

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

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

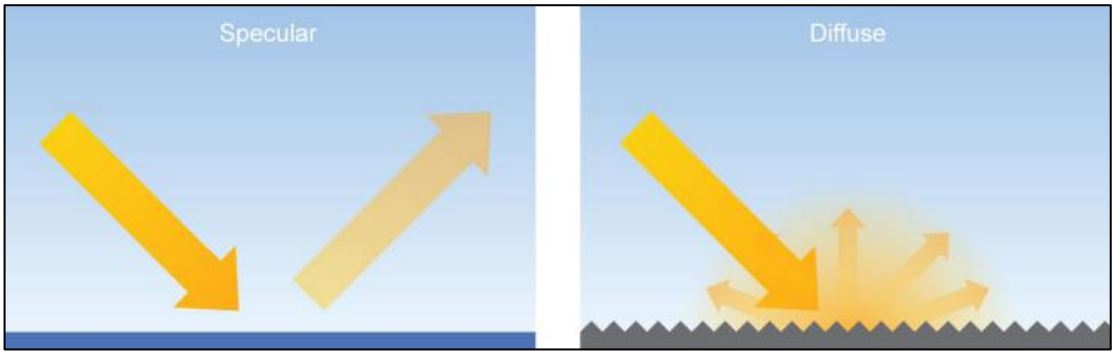
Overview

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[32], 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

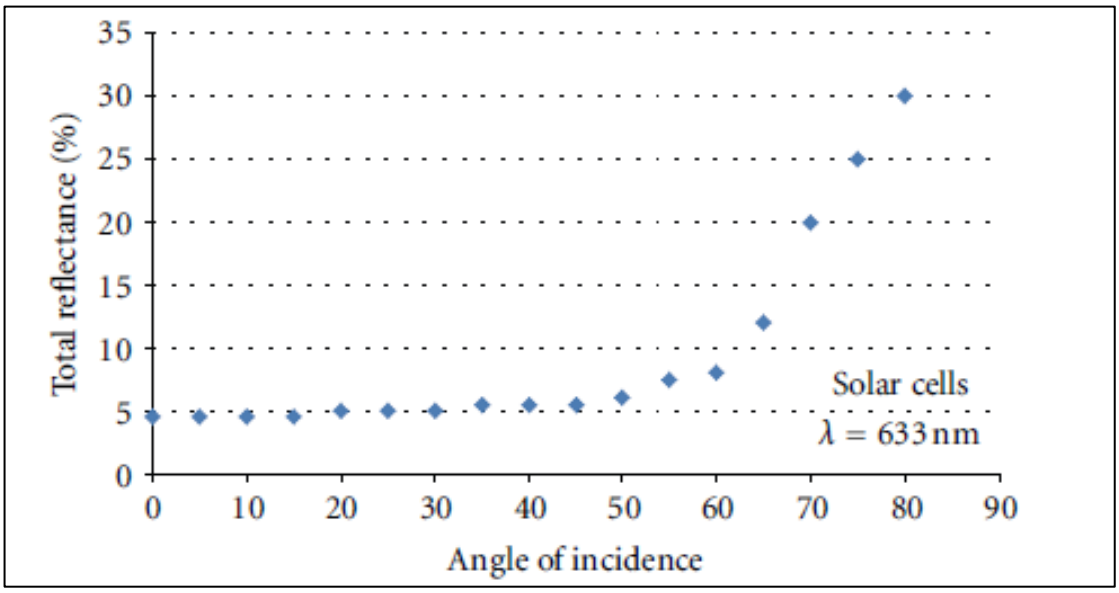
[32] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*[33]". 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.

[33] 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"[34]

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[35]
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).

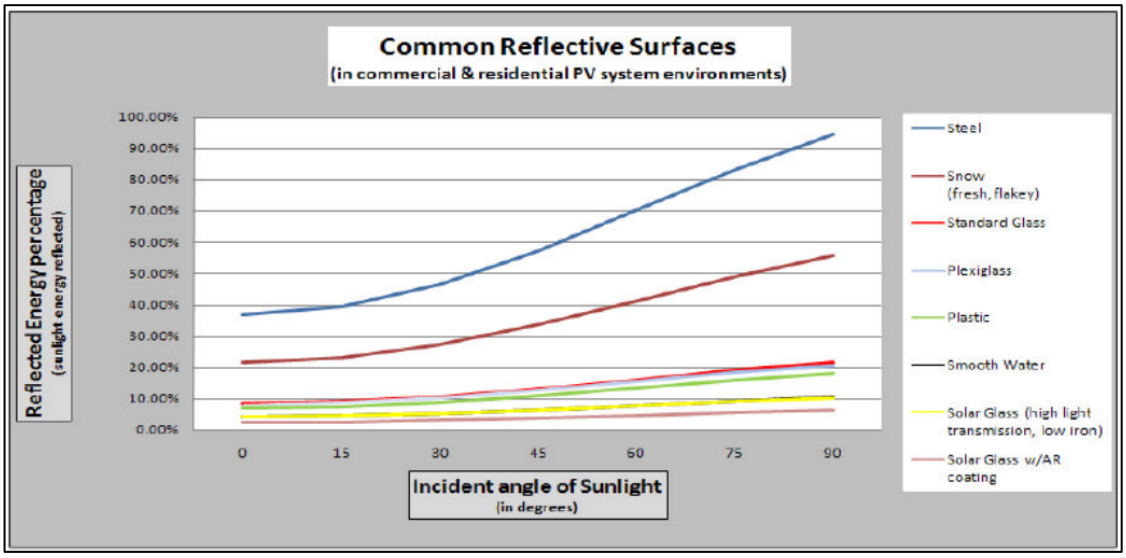
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

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

SunPower Technical Notification (2009)

SunPower published a technical notification[36] 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.

[36] 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).

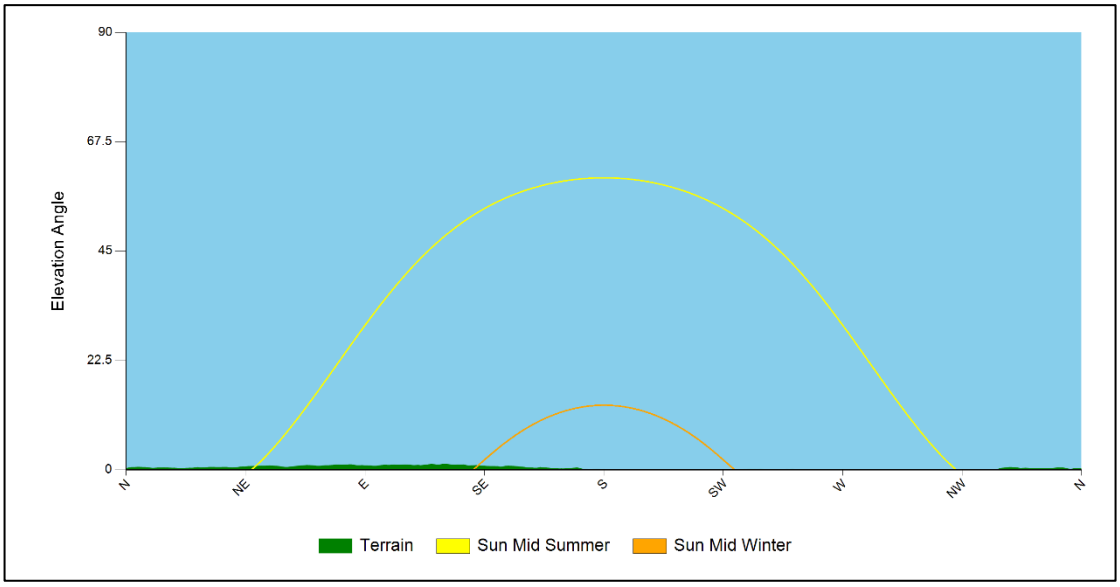
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- 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 from the proposed development location as well as the sunrise and sunset curves throughout the year.



Terrain at the visible horizon and sun path

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

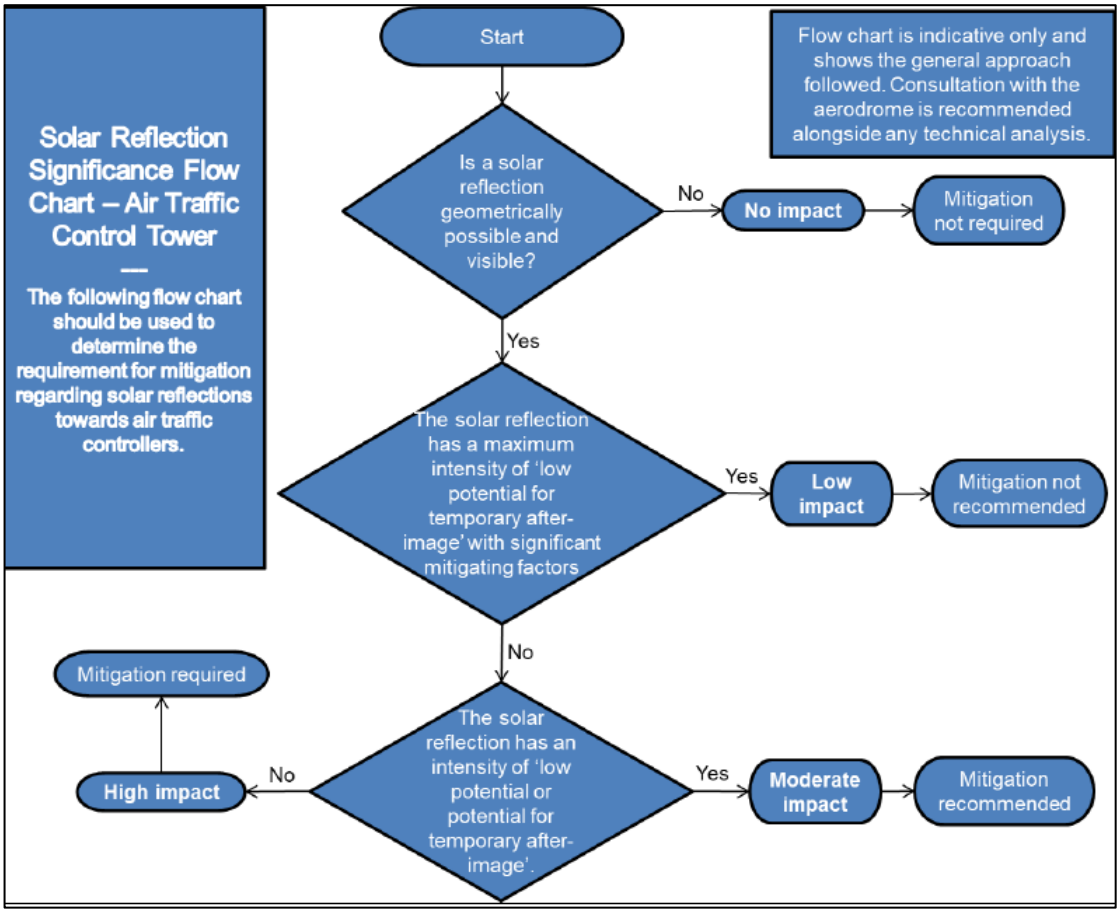
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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 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.
Major	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 Tower

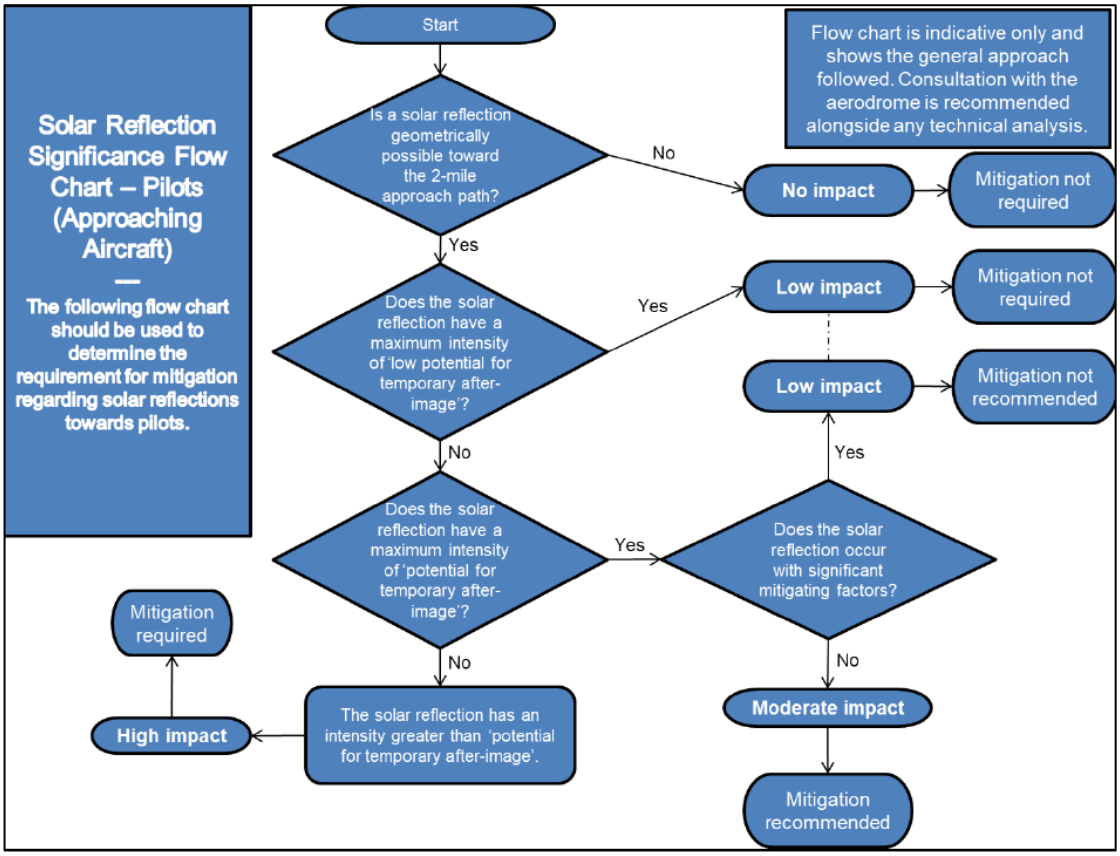
The flow chart presented below has been followed when determining the mitigation requirement for ATC Tower receptors.



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.



Approach path receptor mitigation requirement flow chart

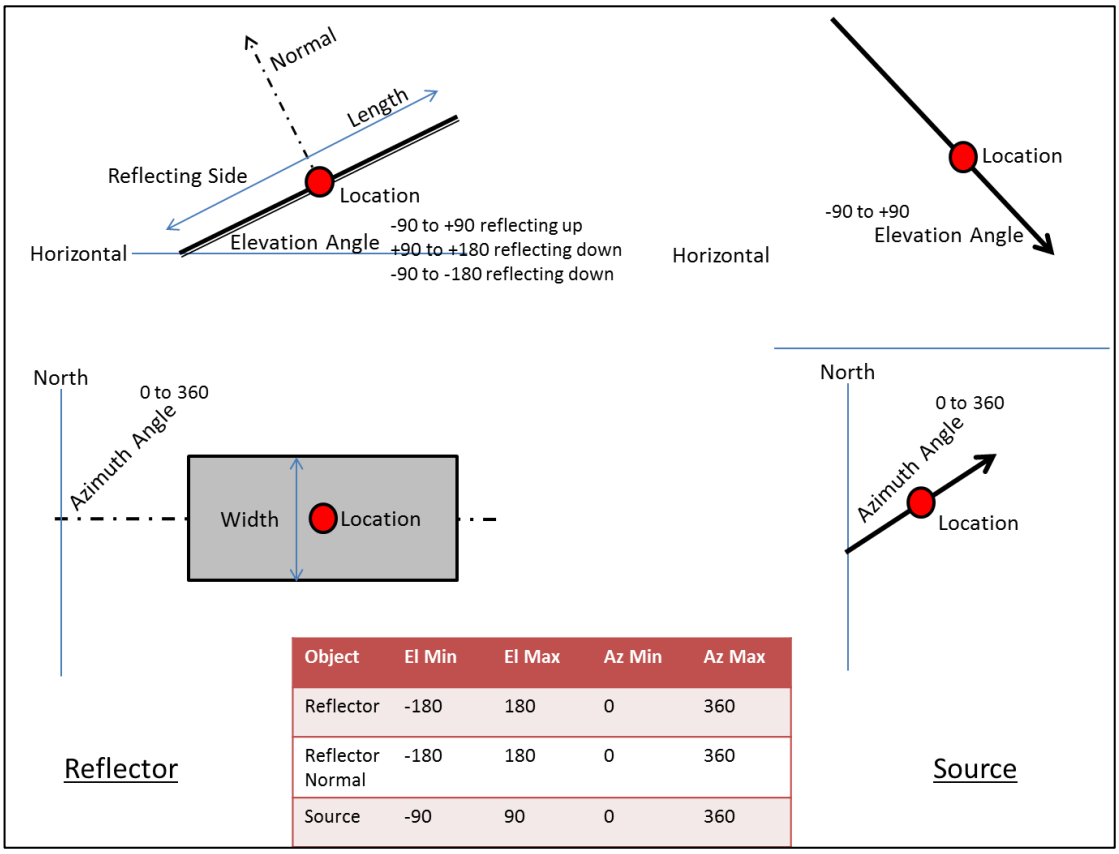
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

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)[37].

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

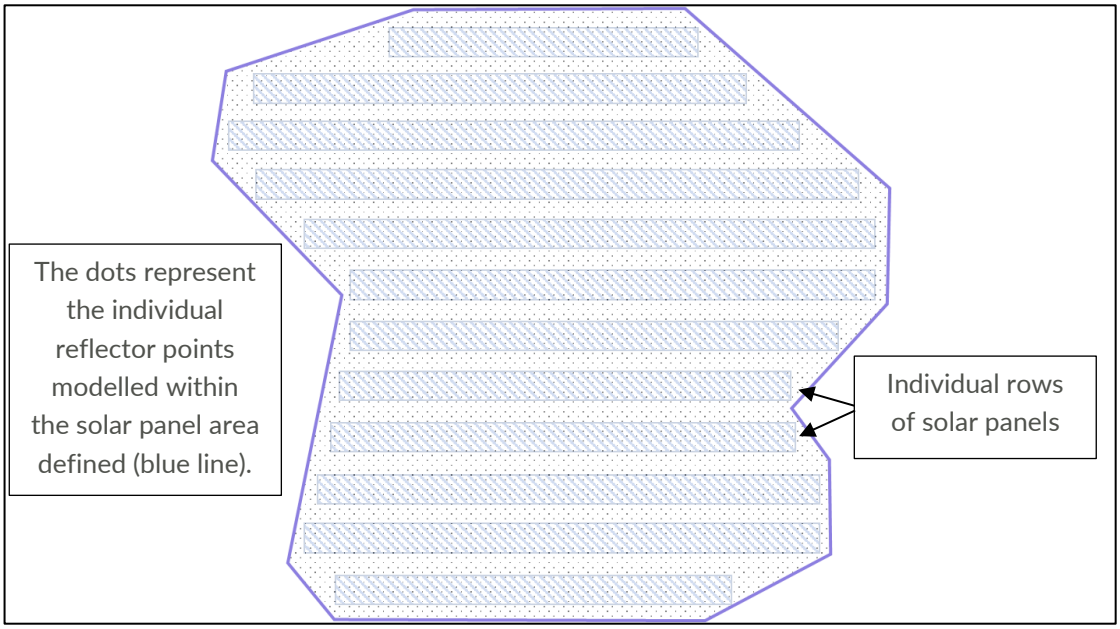
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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.

[37] 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[38]

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.

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

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Overview

Data and terrain heights are ascertained from OSGB 50 DTM data.

ATC Tower at Manchester Airport

ATC Tower

The table below presents the coordinates and overall altitude for the ATC Tower. The coordinates have been taken from the NATS AIP and the tower height has been confirmed by Manchester Airport safeguarding team.

Longitude (°)	Latitude (°)	Ground Height (m amsl)	ATC Tower Height (m agl)	Overall Assessed Height (m amsl)
-2.27962	53.35783	75.22	57.06	132.28

ATC Tower

Aviation Receptors

The specific receptors as per MAG requirements can be provided upon request.

Modelled Reflector Areas

Panel Area 1

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.28553	53.35834	4	-2.28482	53.35890
2	-2.28474	53.35880	5	-2.28570	53.35839
3	-2.28472	53.35884	6	-2.28560	53.35833

Panel Area 1

Panel Area 2

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.28451	53.35871	4	-2.28547	53.35830
2	-2.28461	53.35877	5	-2.28549	53.35826
3	-2.28468	53.35876	6	-2.28539	53.35820

Panel Area 2

Panel Area 3

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.28514	53.35810	4	-2.28444	53.35867
2	-2.28435	53.35857	5	-2.28532	53.35815
3	-2.28434	53.35861	6	-2.28521	53.35809

Panel Area 3

Panel Area 4

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-2.28412	53.35847	4	-2.28508	53.35806
2	-2.28422	53.35854	5	-2.28510	53.35802
3	-2.28429	53.35853	6	-2.28500	53.35796

Panel Area 4

APPENDIX H – DETAILLED MODELLING RESULTS

Overview

The Pager Power charts for the receptors are shown below and on the following pages. Each chart shows:

- The receptor (observer) location – top right image. This also shows the azimuth range of the Sun itself at times when reflections are possible. If sunlight is experienced from the same direction as the reflecting panels, the overall impact of the reflection is reduced as discussed within the body of the report;
- The reflecting panels – bottom right image. The reflecting area is shown in yellow. If the yellow panels are not visible from the observer location, no issues will occur in practice. Additional obstructions which may obscure the panels from view are considered separately within the analysis;
- The reflection date/time graph – left hand side of the page. The blue line indicates the dates and times at which geometric reflections are possible. This relates to reflections from the yellow areas.
- The sunrise and sunset curves throughout the year (red and yellow lines).

The Forge charts for the receptors are shown on the following pages. Each chart shows:

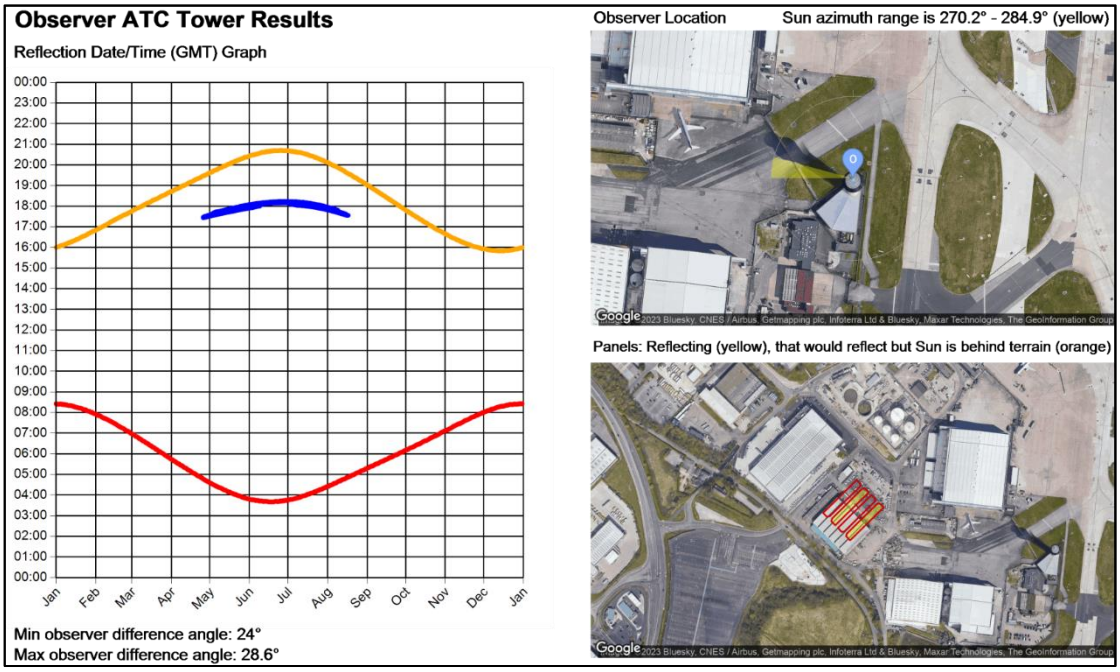
- The annual predicted solar reflections.
- The daily duration of the solar reflections.
- The location of the proposed development where glare will originate.
- The calculated intensity of the predicted solar reflections.

For approach paths, two further charts are shown within the Forge modelling results:

- Locations along the approach path receiving glare.
- The dates when glare would occur at each location along the approach.

Selected results have been shown for completeness. Full modelling results are available upon request.

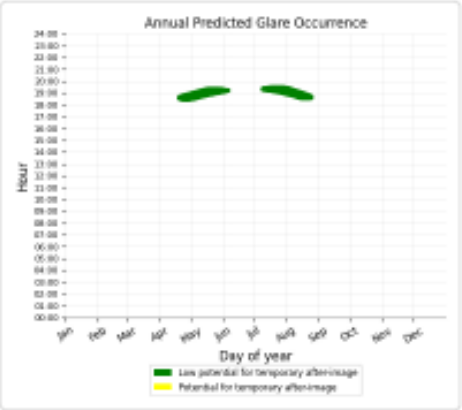
ATC Tower

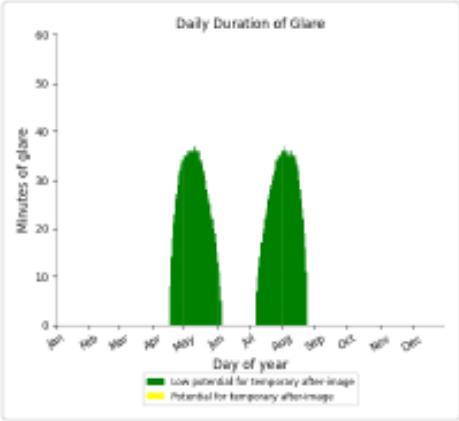

Observer ATC Tower Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 24°
Max observer difference angle: 28.6°
Observer Location
Sun azimuth range is 270.2° - 284.9° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

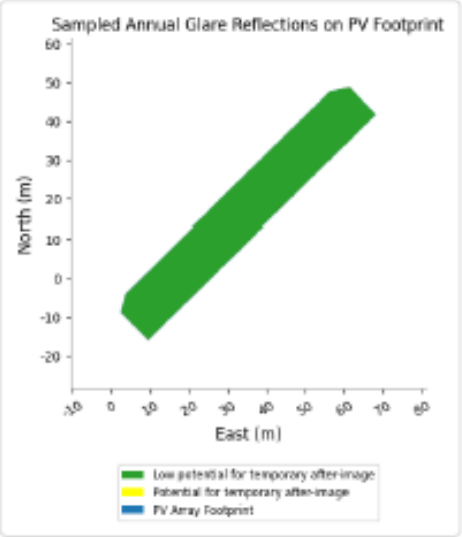
Panel Area 2 - OP Receptor (1-ATCT)

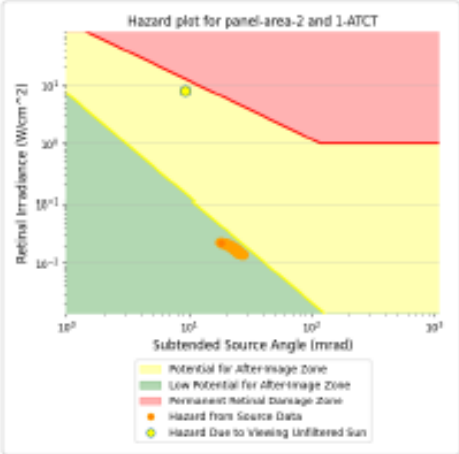
PV array is expected to produce the following glare for receptors at this location:

- 2,678 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.





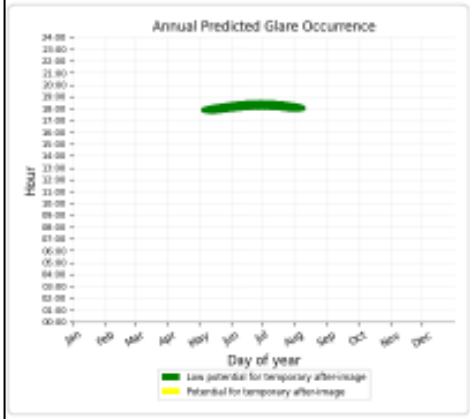


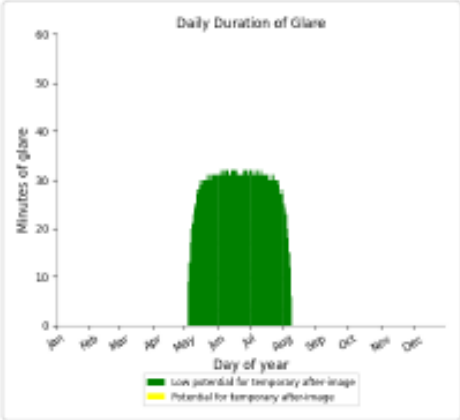


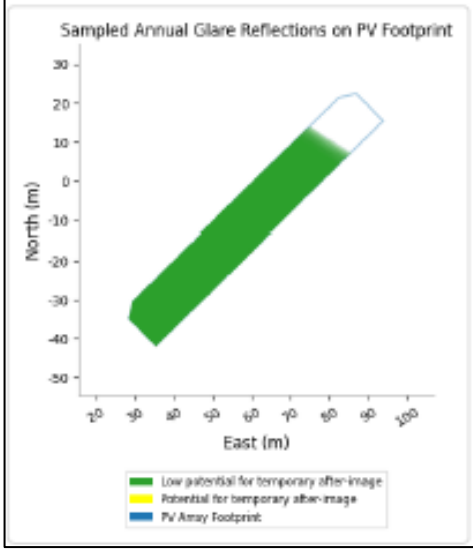
Panel Area 4 - OP Receptor (1-ATCT)

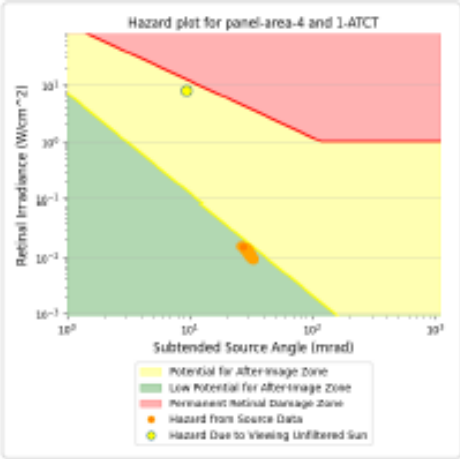
PV array is expected to produce the following glare for receptors at this location:

- 2,815 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.









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