

Glint and Glare Study

THQ Phase 1

Airport City LP Ltd

February, 2022

PLANNING SOLUTIONS FOR:

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

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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	May, 2020	Initial issue – 9270A
2	July, 2020	Updated including solar panels and high-level assessment of car park – 9270B
3	January, 2022	Updated technical modelling – 9270C
4	February, 2022	Visual Circuits considered (High-level) and clarification on MSCP following response from MAG.

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from a proposed building development, consisting of an office building and multi-storey car park, located to the north of Manchester Airport, approximately 1.23km north east of the Air Traffic Control (ATC) Tower. The aviation receptors include the runway approach paths and ATC Tower.

Pager Power

Pager Power has undertaken over 800 glint and glare assessments in the UK, Europe and further afield. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Conclusions

Overall, no significant impact upon aviation activity at Manchester Airport is predicted, and mitigation is not required.

The assessment results are presented on the following page.

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 reviewed existing guidelines and the available studies in the process of defining its own glint and glare assessment guidance document and methodology¹. This methodology defines a comprehensive process for determining the impact upon aviation activity.

Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, consider the screening (existing and/or proposed) between the receptor and the reflecting solar panels. For aviation activity, where a solar reflection is predicted, solar intensity calculations are undertaken in line with the Sandia National Laboratories' FAA methodology². 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

¹ Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021.

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.

produced are of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel³.

Assessment Results

ATC Tower

No solar reflections are geometrically possible towards the ATC Tower.

No impact is predicted, and no mitigation is required.

Approach Paths

Solar reflections have been predicted towards approach paths 23L and 23R only. Intensity calculations were therefore undertaken for the relevant reflectors. The results showed that a solar reflection would have a 'low potential for temporary after-image' which is acceptable considering the associated guidance.

Overall, no significant impact is expected with regard to approaching aircraft, and no mitigation is required.

Visual Circuit Results (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), and Pager Power's previous project experience, no significant impacts upon the visual circuits are anticipated. The solar reflections would either not be visible considering the solar reflection scenario, or the solar reflection would be of acceptable intensity considering the associated guidance and industry best practice. No mitigation is required.

³ SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 countries within South Africa, Europe, America, Asia and Australasia. The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially the company focus was on modelling the impact of wind turbines on radar systems. Over the years, the company has expanded into numerous fields including:

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

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

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

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from a proposed building development, consisting of an office building and multi-storey car park, located to the north of Manchester Airport, approximately 1.23km north east of the Air Traffic Control (ATC) Tower. The aviation receptors include the runway approach paths and ATC Tower.

The analysis contains the following:

- Details of the proposed development;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Identification of aviation concerns and receptors;
- Assessment methodology;
- Glint and glare assessment for:
 - Aircraft approach paths for the relevant runways;
 - ATC tower.
- High-level multi storey car park assessment;
- Results discussion.

1.2 Pager Power's Experience

Pager Power has undertaken over 800 glint and glare assessments internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Glint and Glare Definition

The definition of glint and glare is as follows⁴:

- 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.

⁴These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America.

2 PROPOSED DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Location

The proposed development location and top down plan is marked in Figure 1 below⁵ (Office).



Figure 1 Proposed development location

⁵ Source: BDP. (edited).

2.2 Proposed Development Red Line Boundary

The approximate red line boundary of the proposed development overlaid on aerial imagery is shown in Figure 2 below⁶.



Figure 2 Red line boundary overlaid on aerial imagery

⁶ Copyright © 2022 Google.

2.3 Solar Panels – Office Building

Solar panels are to be located on the southern side of the rooftop façade which surrounds the rooftop infrastructure. Technical drawing showing the side profile and elevation of the solar panels can be seen in Figures 3 and 4 below. The solar panels will be mounted at an elevation angle of 40 degrees above the horizontal and face south westerly as per the orientation of the building.

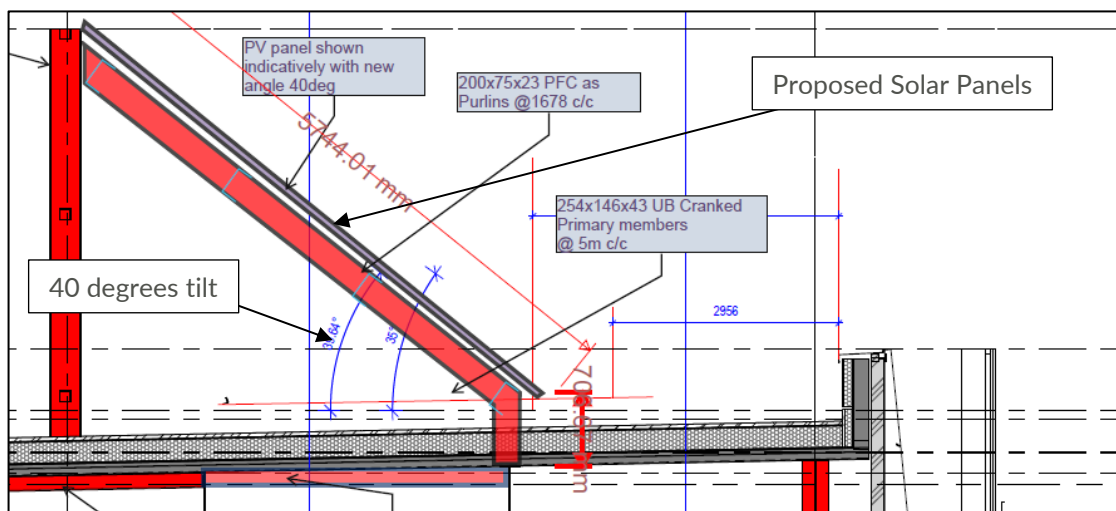


Figure 3 Solar panels 40 degrees tilt angle

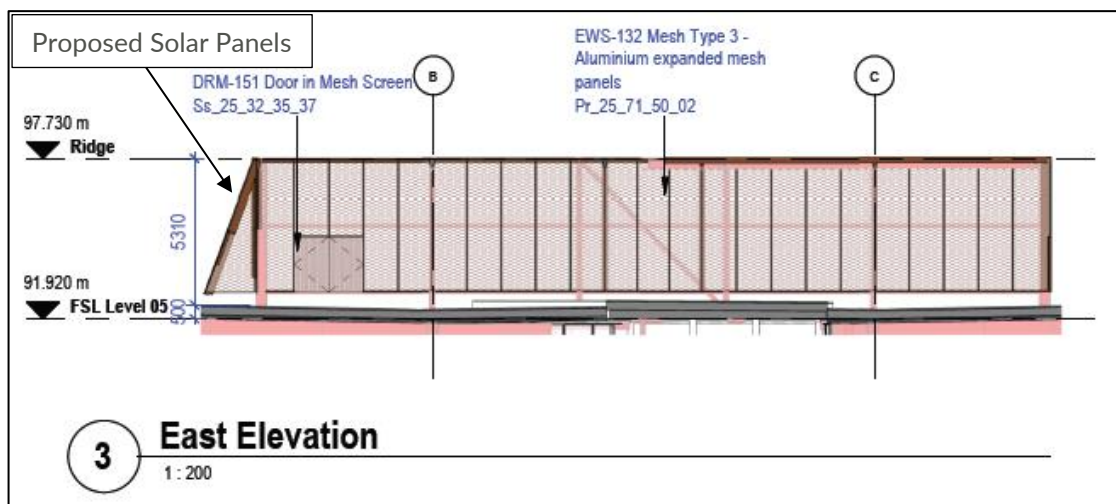
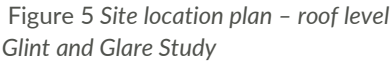


Figure 4 Eastern elevation of solar panels

2.4 Proposed Development Plans

The design plans are presented in the figures⁷ on the following pages. The solar panel area, atrium roof and sky light are highlighted in Figure 5.

⁷ Source: Penson and BDP. (edited).



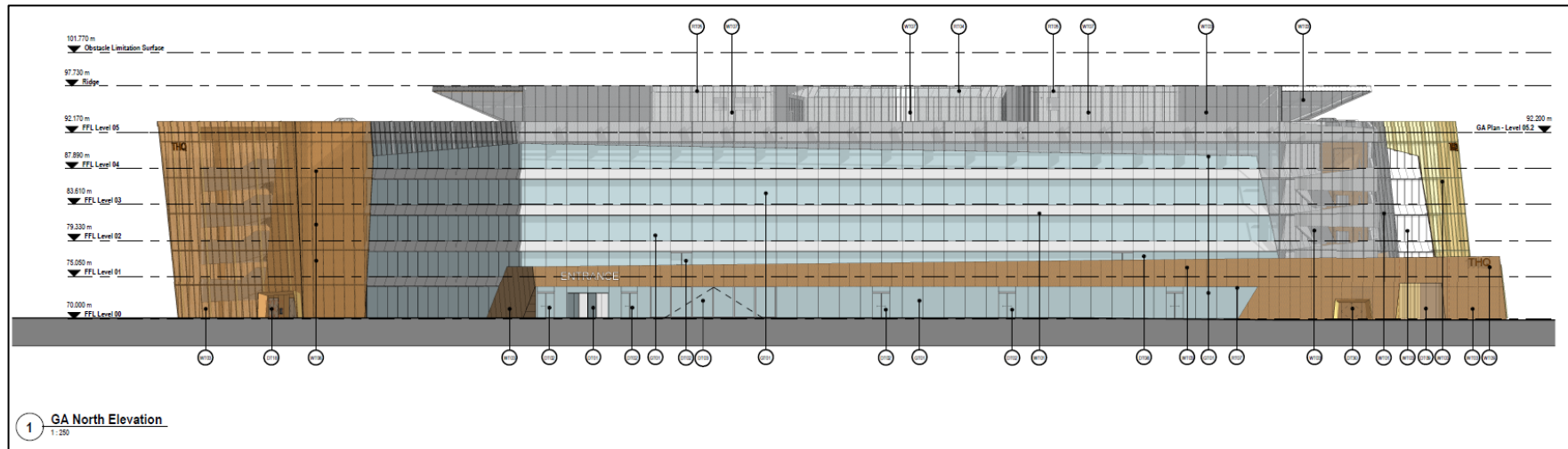


Figure 6 Northern elevation

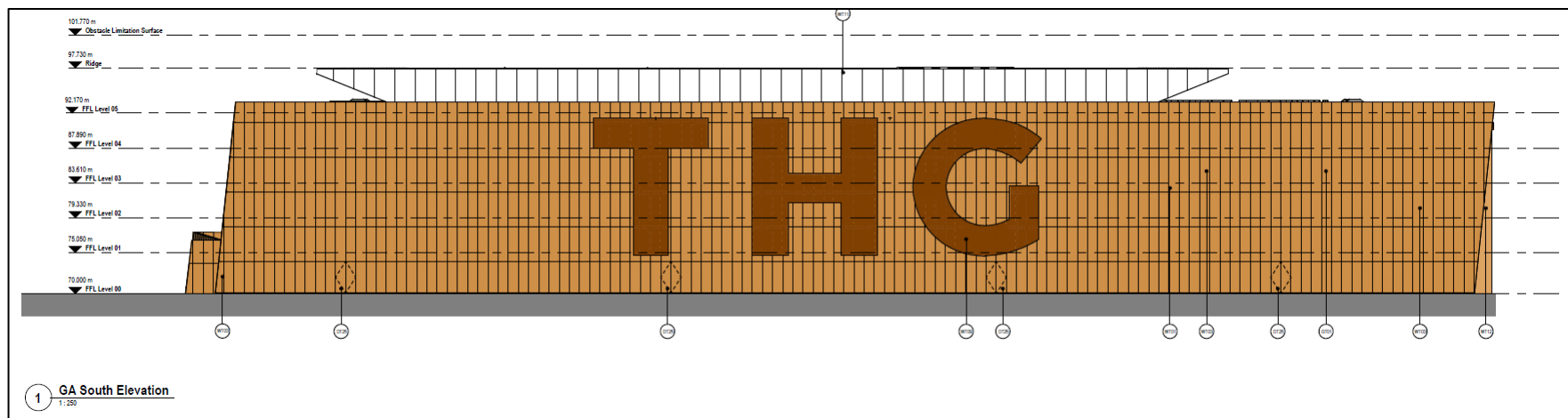


Figure 7 Southern elevation
Glint and Glare Study

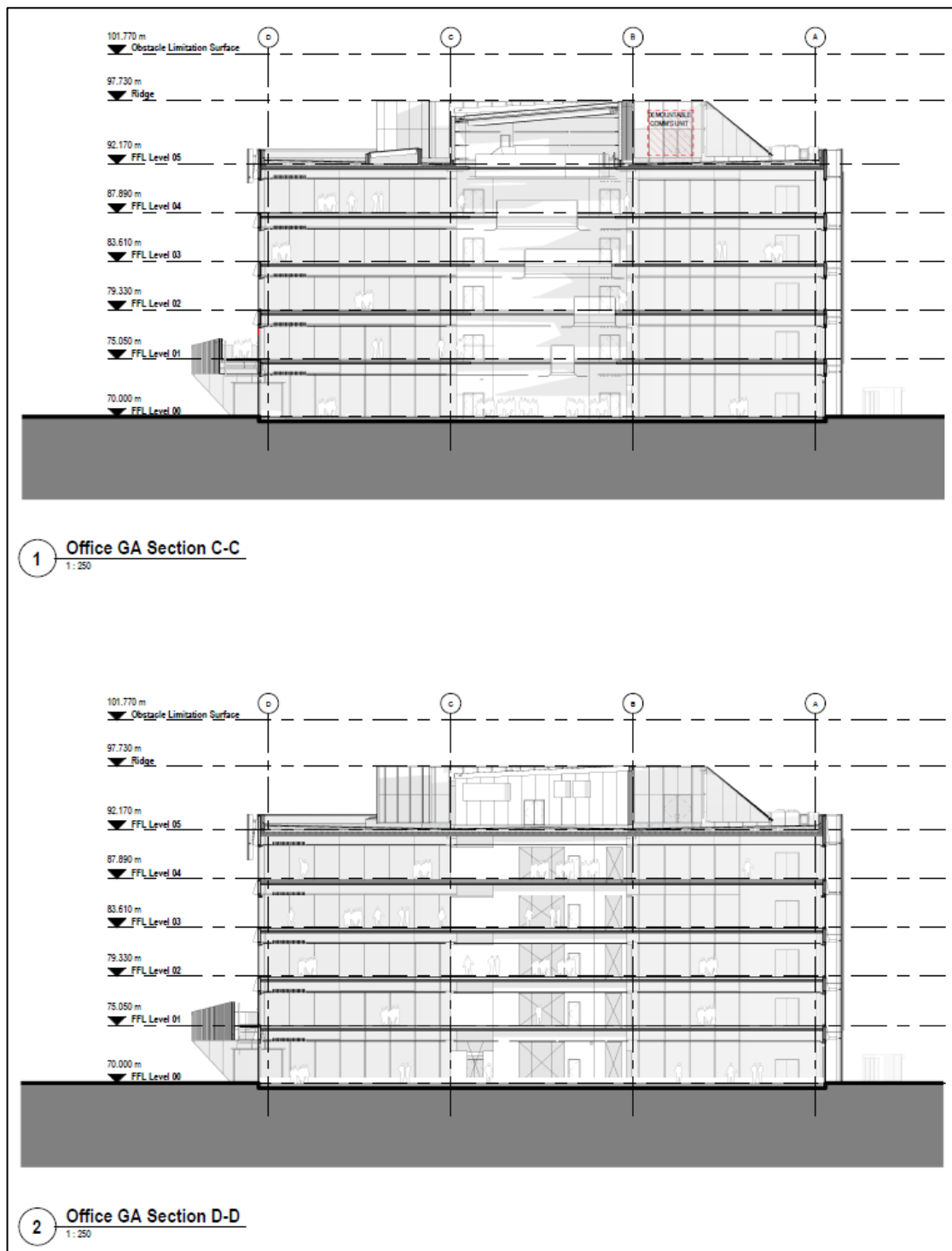


Figure 8 Eastern and western elevations

Solar reflections are most significant when they are specular rather than diffuse i.e. reflections from a smooth mirror-like surface are more noticeable than scattered reflections from rougher surfaces.

Areas of the building which are clad in materials which produce diffuse reflections e.g. non-shiny materials, are not significant in terms of glint and glare.



Glint and Glare Study

3 MANCHESTER AIRPORT DETAILS

3.1 Airport Information

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

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

The runways are shown on the aerodrome chart in Figure 10 below⁸.

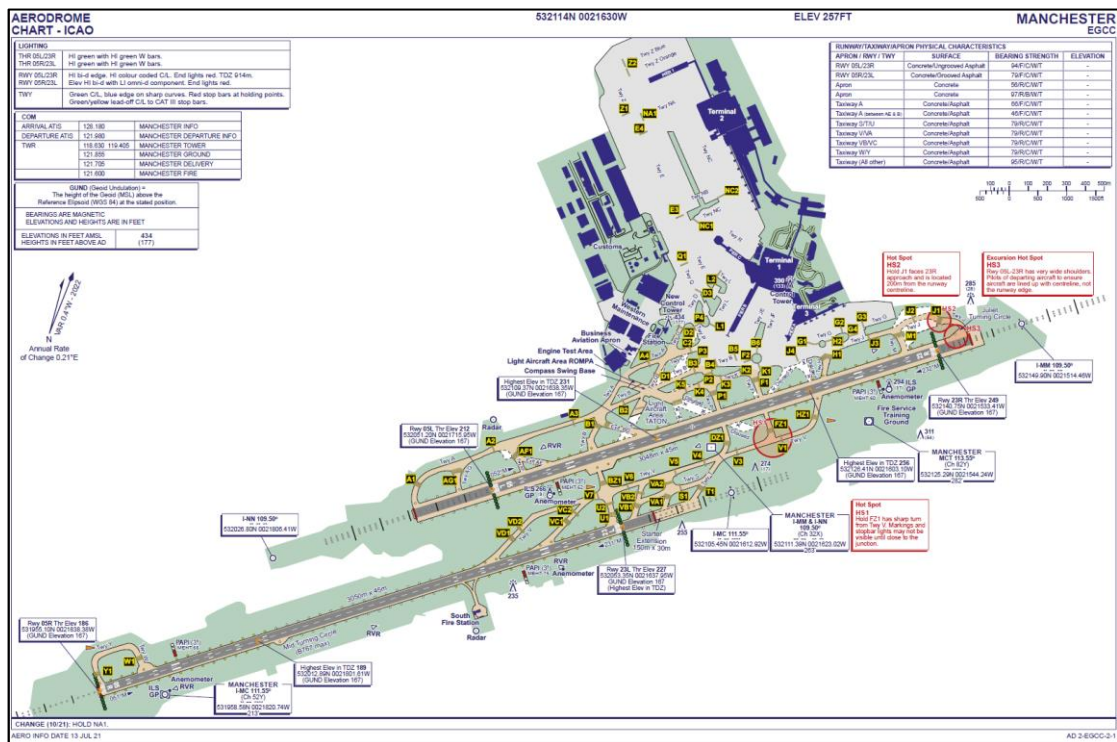


Figure 10 Aerodrome chart – Manchester Airport

⁸ Source: NATS AIP for Manchester Airport (last accessed January, 2022).

The red line boundary of the proposed development relative to Manchester Airport is shown in Figure 11 below⁶.



Figure 11 Location of proposed development relative to the proposed development

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Guidance and Studies

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

4.2 Background

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

4.3 Methodology

4.3.1 Pager Power's Methodology

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

- Identify receptors in the area surrounding the proposed development;
- Consider direct solar reflections from the proposed development towards the identified receptors by undertaking geometric calculations;
- Consider the visibility of the reflectors from the receptor's location. If the reflectors are not visible from the receptor then no reflection can occur;
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur;
- Consider the solar reflection intensity (for reference purposes only for glass);
- 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 the process presented in Appendix D.

4.3.2 Sandia National Laboratories' Methodology

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer available. Whilst strictly applicable in the USA and to solar photovoltaic developments only, the methodology and associated guidance is widely used by UK aviation stakeholders. The following text is taken from the SGHAT model methodology.

'This tool determines when and where solar glare can occur throughout the year from a user-specified PV array as viewed from user-prescribed observation points. The potential ocular impact from the observed glare is also determined, along with a prediction of the annual energy production.'

The result was a chart that states whether a reflection can occur, the duration and predicted intensity for aviation receptors.

Pager Power has undertaken many aviation glint and glare assessments with both models (SGHAT and Pager Power's) producing similar results. Intensity calculations in line with Sandia National Laboratories' methodology has been completed⁹. Where required, cross checks have been completed.

4.4 Assumptions and Limitations

Key assumptions and limitations regarding the analysis in this report are listed below:

- The screening at the site boundary is not included within the modelling output – which considers only the relative heights and geometric relationship between the Sun and the modelled reflectors. The actual predicted visibility is considered when classifying a potential impact following the modelling;
- The assessment assumes that a view of the entire reflector area is possible from the receptor location when in reality this may not occur. A solar reflection can only be experienced by a receptor where the source of the reflection is visible;
- The mesh on the eastern, southern and western façades will reduce the likelihood of specular reflections occurring significantly. Cladding is also present which will produce diffuse reflections. All façades are however modelled as specular reflectors.

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

⁹ Currently using the Forge Solar model, based on the Sandia methodology.

5 IDENTIFICATION OF RECEPTORS

5.1 Air Traffic Control Tower

It is standard practice to determine whether a solar reflection can be experienced by personnel within the ATC Tower. The ATC Tower location is illustrated in Figure 12⁶ below. Coordinate data, taken from the NATS AIP, is presented in Appendix G.



Figure 12 ATC Tower location

5.2 Airborne Receptors – Approaching Aircraft

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

Figure 13⁶ below shows the assessed approach receptor locations and ATC Tower location incorporated into the assessment.

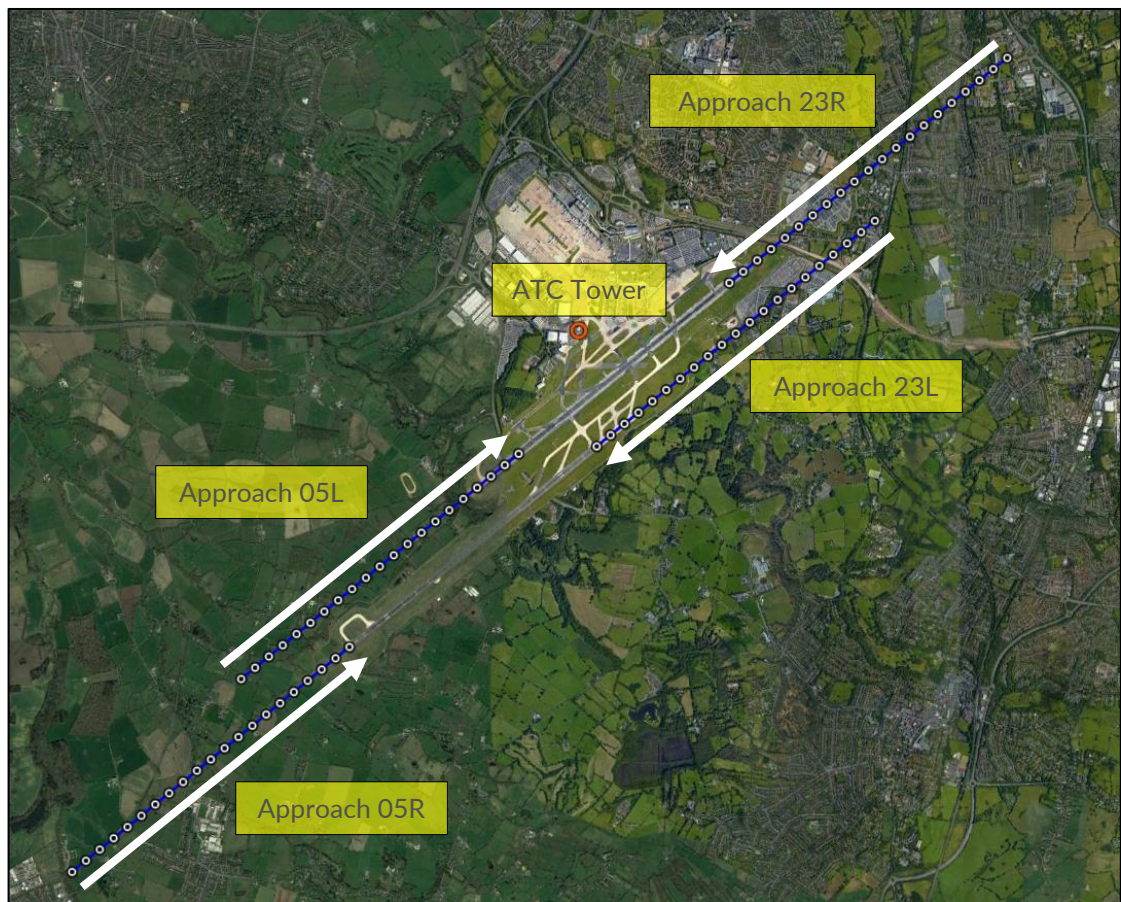


Figure 13 All aviation receptors

The receptor details are presented in Appendix G.

5.3 Airborne Receptors – Aircraft Circuits

Manchester Airport requires consideration (and sometimes geometric modelling) of general aviation aircraft flying both directions in the visual circuits for 05L, 05R, 23R and 23L.

When light aircraft arrive or depart from an aerodrome, they may fly in a standard pattern. A typical circuit is shown in Figure 14 below.

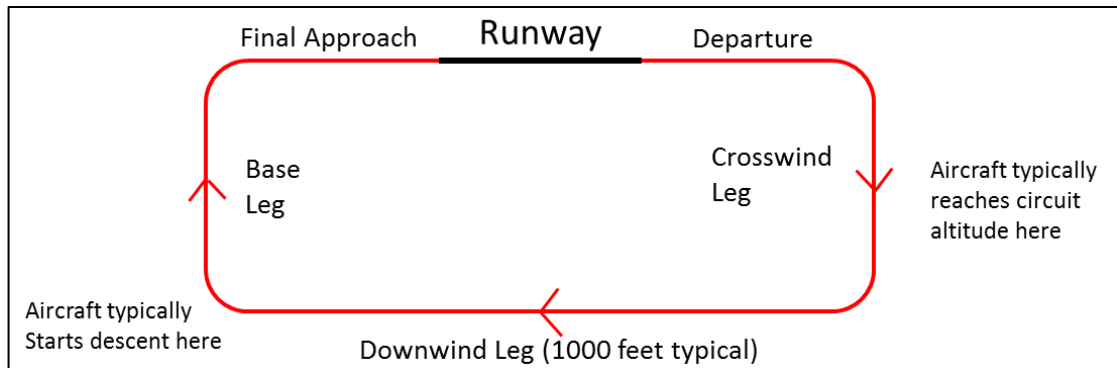


Figure 14 Typical circuit diagram

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

- Circuit altitude 1,000ft (304.8m) above the lowest runway threshold;
- Circuit originates and terminates at the runway ends¹⁰;
- The circuit considers an ascent and descent angle of 5°.

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

A circuit width of 1 nautical mile (nm) has been considered.

Figure 15⁶ on the following page shows the circuits paths for Manchester Airport. The red circle paths belong to Runway 05L-23R while the blue paths belong to Runway 05R-23L. The visual circuits have been considered at a high-level within this report - see Section 7.3.

¹⁰ Runway thresholds.

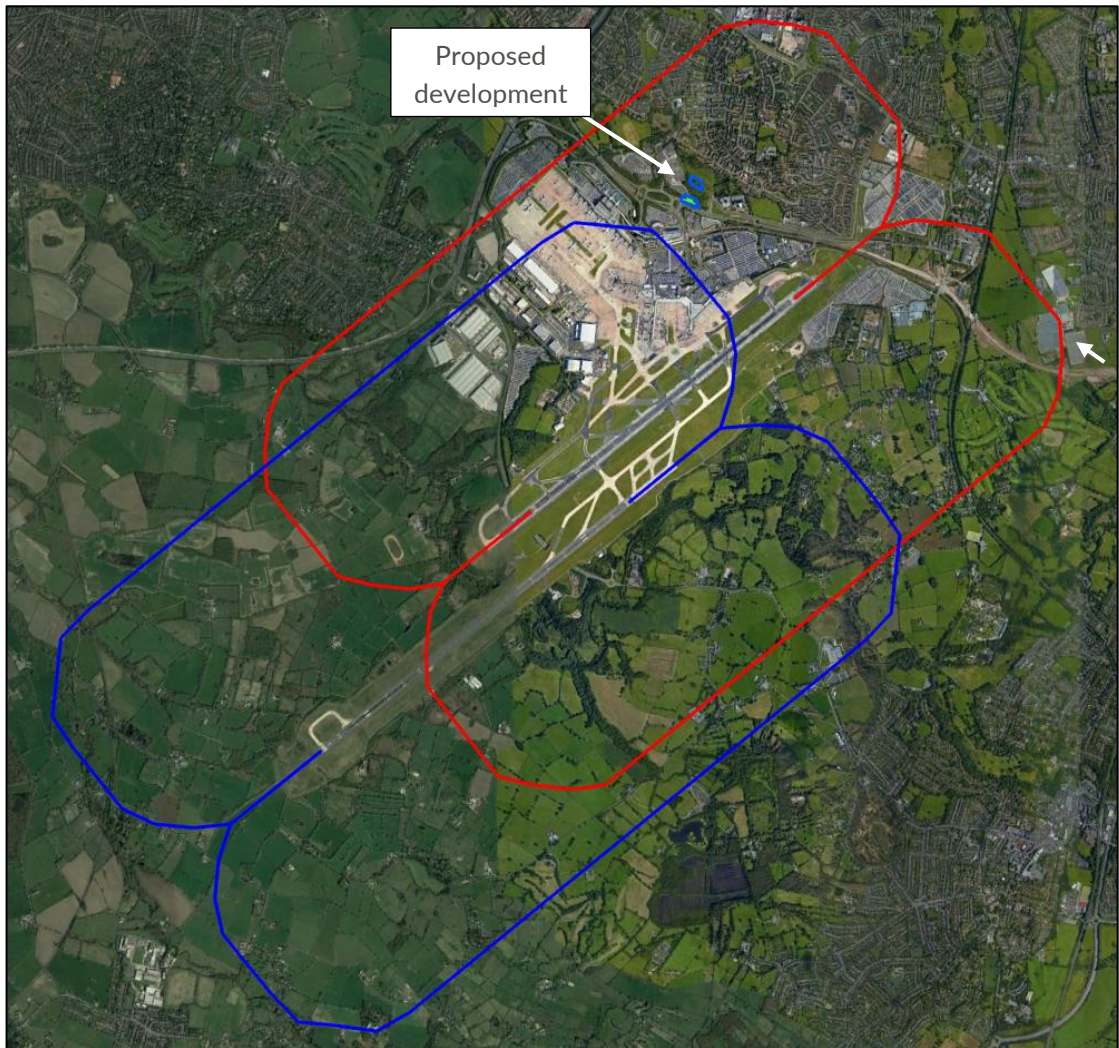


Figure 15 Circuits paths for runways 05L-23R (red line) and 05R-23L (blue line)

6 ASSESSED REFLECTOR AREAS

6.1 Reflector Areas

A number of representative reflector locations are selected within the bounding co-ordinates. The number of modelled reflector points is determined by the size of the reflector area and the assessment resolution. The bounding co-ordinates for the proposed development have been extrapolated from the site images.

A resolution of 2m has been chosen for this assessment for both the façades and roof with various vertical and azimuth angles and heights, as appropriate. This means that a geometric calculation is undertaken for each identified receptor every 2m from within the defined area. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output.

6.2 Proposed Development Reflector Details

Each reflector (façade) has been defined by the floor level up to the proposed development's maximum elevation at an elevation angle of 90 degrees. The atrium roof has been extrapolated to have an elevation angle of 3.5 degrees with an azimuth angle of 21.3 degrees at the proposed development's maximum elevation. The sky light has been assessed as flat at the proposed development's maximum elevation. Because an area has been selected which encompass both areas, both elevation angles have been assessed.

The area extrapolated for the atrium roof and sky light is expected to be larger than the reflector area itself. This method has been selected to allow for any location uncertainties with the extrapolation. The assumptions listed above allows for a conservative approach however it is deemed robust and accurate.

With respect to the proposed rooftop solar panels, the area has modelled at a resolution of 2m and an elevation angle of 40 degrees has been assessed.

Figures 16¹¹ and 17 and on the following pages⁶ illustrate the modelled reflector areas with the boundary points highlighted. The blue line denotes a reflector façade and the green line denotes a reflector area (atrium roof, sky light and solar panels). Further technical parameters are provided in Appendix G.

¹¹ Previous design plans were used to define the façade reflectors. New design plans, which changes only the roof design, were used to define the rooftop reflectors.

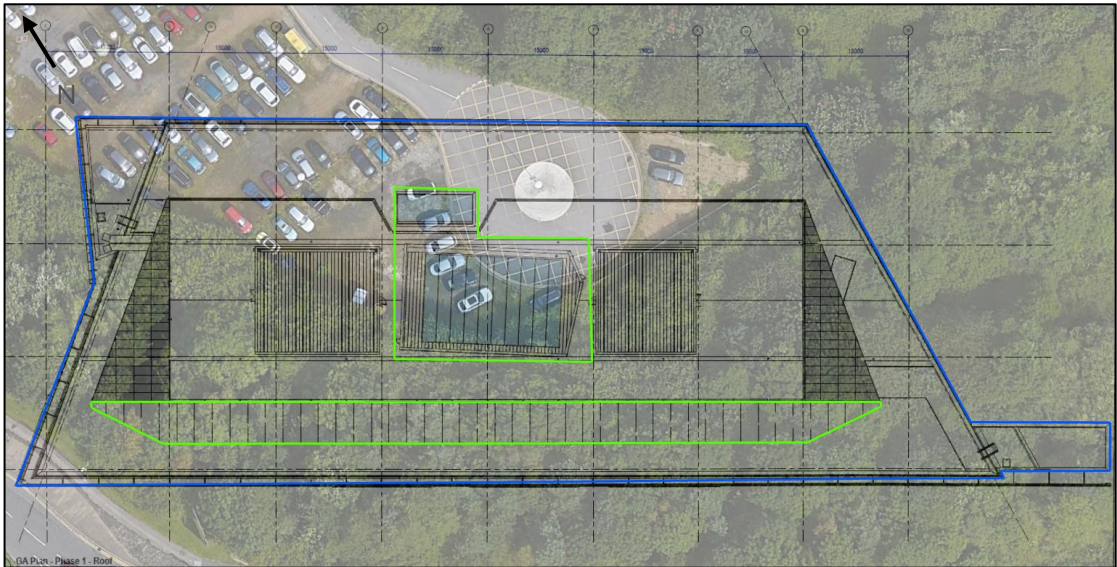


Figure 16 Modelled reflector façades and atrium roof, skylight and solar panels – aerial image with plans overlaid

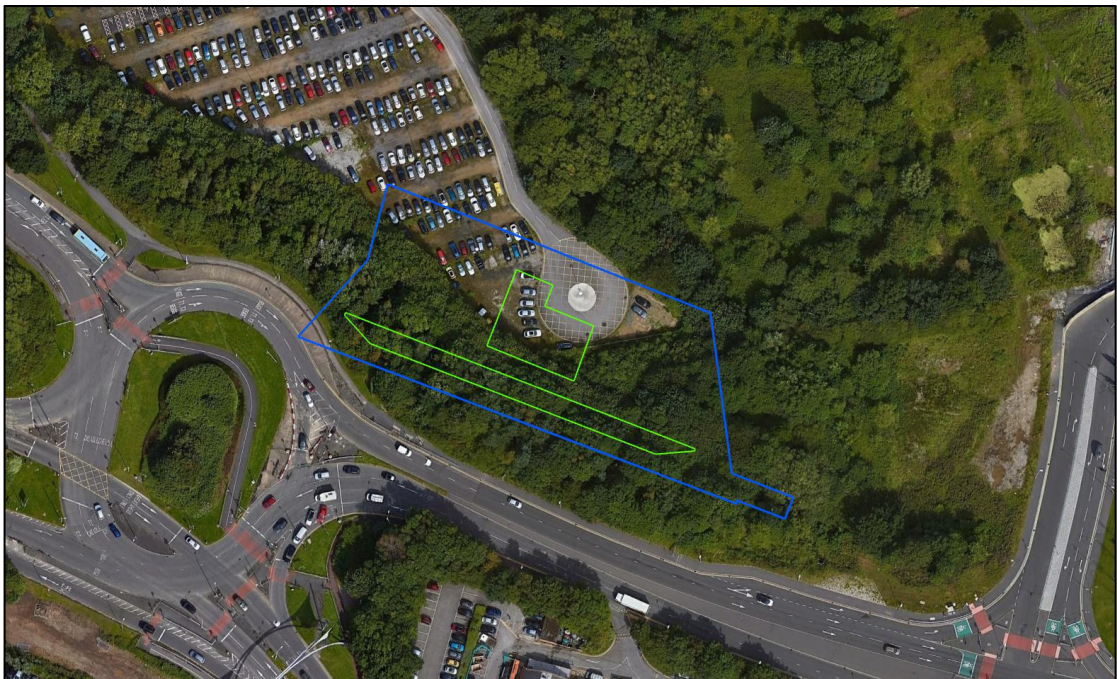


Figure 17 Modelled reflector façades and atrium roof, skylight and solar panels – aerial image

7 GLINT AND GLARE ASSESSMENT RESULTS

7.1 Overview

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

Where glare is predicted, 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.

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

The intensity model allows for assessment of a variety of surface materials. A surface material of 'smooth glass with an anti-reflective coating' has been assessed because this is the most appropriate option for a standard glass window and solar panel. There are however no intensity criteria for glass façades and aviation receptors but it is judged that the results have technical merit for reference purposes. They should not be considered the sole determining factor in judging a project's acceptability in a case such as this one. An external model (Forge) has been used to undertake the intensity calculations.

7.2 Summary of Results

Table 2 on the following page summarises the results of the modelling. Detailed modelling output is shown in the report appendices.

Receptor	Façades	Atrium Roof, Sky Light, and Solar Panels
ATC Tower	No reflections predicted.	No reflections predicted.
Runway 05L Approach	No reflections predicted.	No reflections predicted.

Receptor	Façades	Atrium Roof, Sky Light, and Solar Panels
Runway 23R Approach	Reflections possible from the runway threshold to 2 miles from the runway threshold.	Reflections possible from 0.1 miles from the runway threshold to 2 miles from the runway threshold.
	Glare with low-potential for temporary after-image predicted.	Glare with low-potential for temporary after-image predicted.
Runway 05R Approach	No reflections predicted.	No reflections predicted.
Runway 23L Approach	No reflections predicted.	Reflections possible from 1.3 miles from the runway threshold to 2 miles from the runway threshold.
		Glare with low-potential for temporary after-image predicted.

Table 2 Geometric analysis results (façades, atrium roof, sky light, and solar panels)

7.3 Visual Circuit Results (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), and Pager Power's previous project experience, no significant impacts upon the visual circuits are anticipated. The solar reflections would either not be visible considering the solar reflection scenario, or the solar reflection would be of acceptable intensity considering the associated guidance and industry best practice. No mitigation is required.

8 HIGH-LEVEL CAR PARK ASSESSMENT

8.1 Overview

A high-level assessment of the proposed car park pertaining to parked cars and the building exterior has been completed. The car park is marginally further from the airport and in its shadow with respect to the ATC Tower.

8.2 Proposed Development Plans

A top-down design plan of the carpark rooftop and the side elevations are shown in Figures¹² 18-20 below and on the following pages.

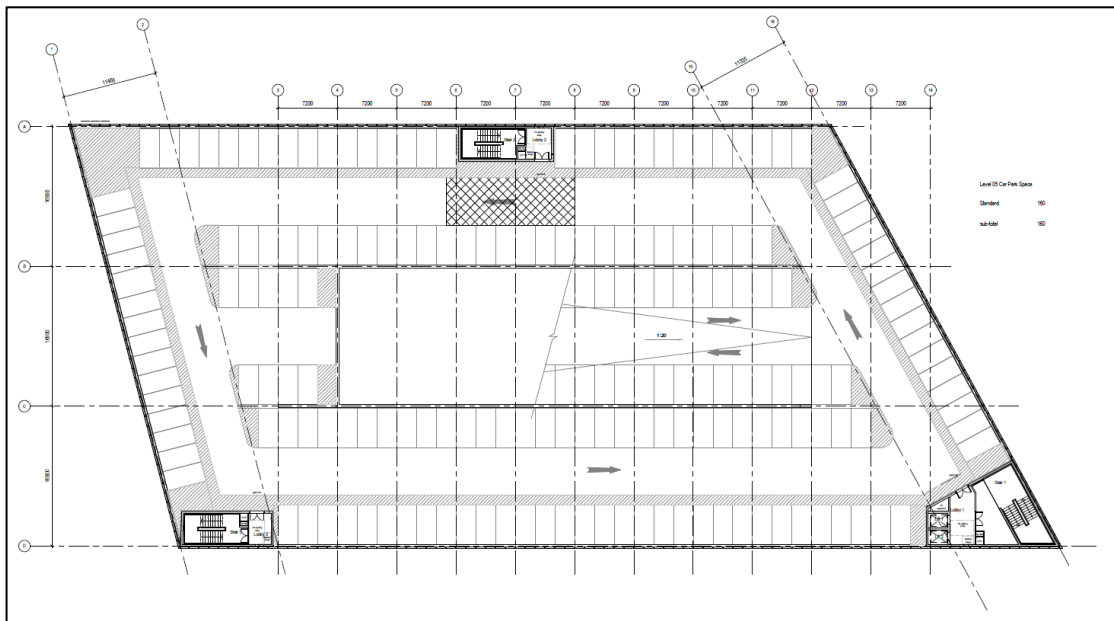


Figure 18 Rooftop level design

¹² Source: BDP. (edited).

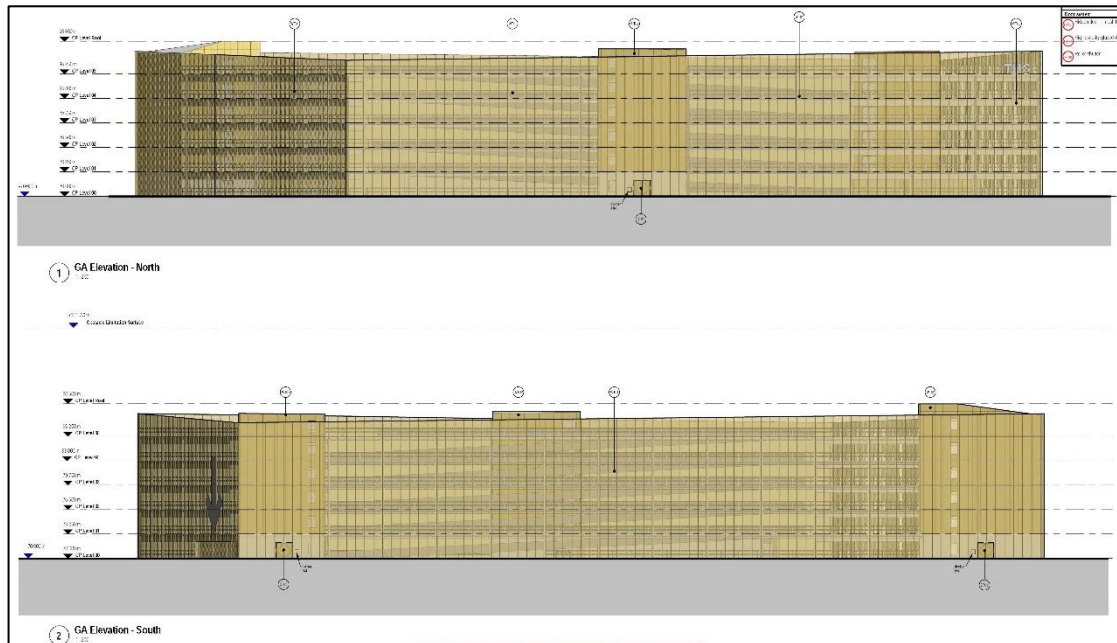


Figure 19 Northern and southern elevations

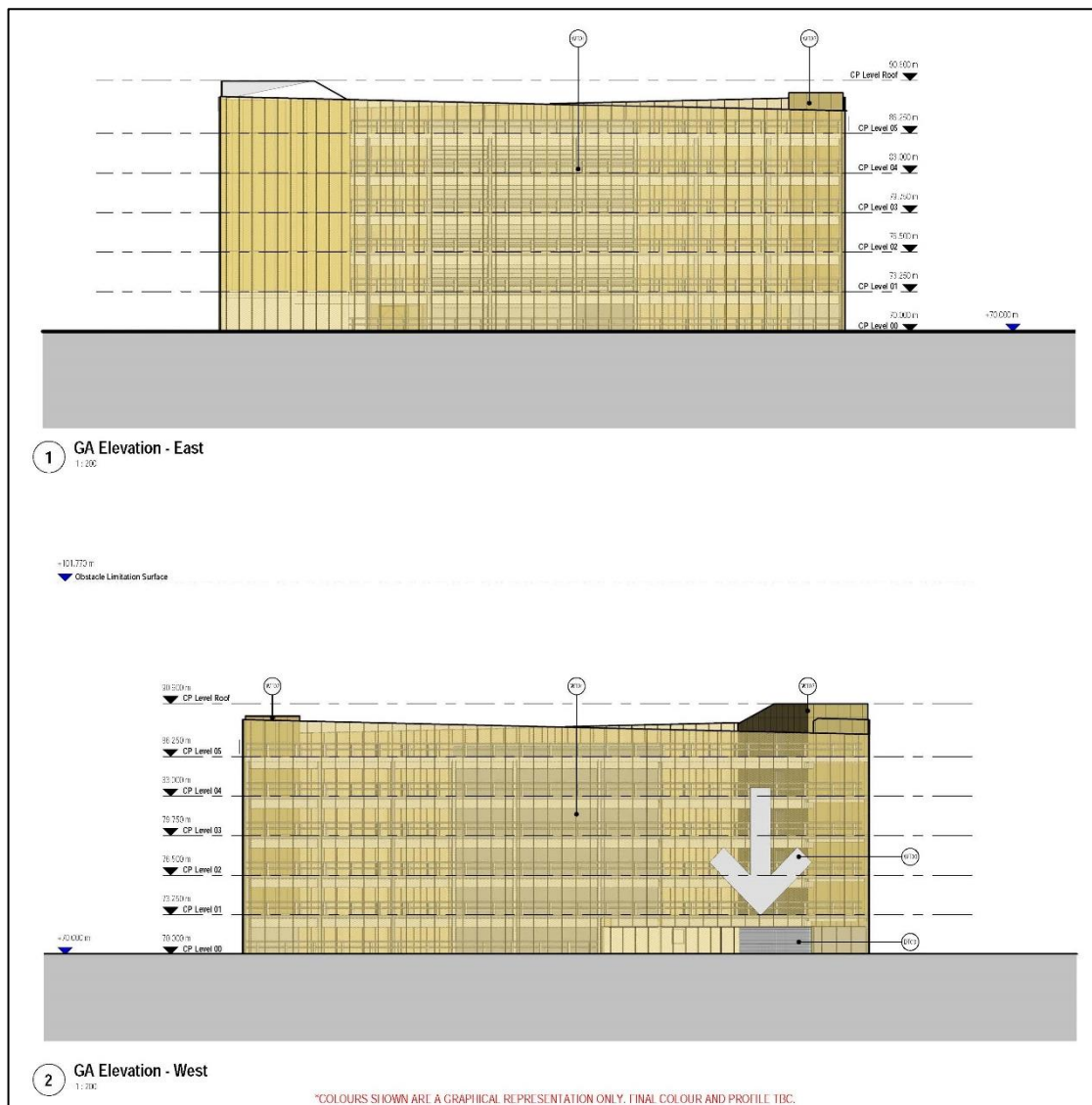


Figure 20 Eastern and western elevations

8.3 High-Level Discussion

The proposed development rooftop, where cars have the potential to produce specular solar reflections, represents an area approximately less than 1% of existing known reflectors in the area, such as existing car parks surrounding the airport. This is illustrated in Figure 21⁶ below where the existing car park areas are shown with orange polygons. Many of these areas are much closer to the ATC Tower which is a key receptor.



Figure 21 Existing reflectors surrounding Manchester Airport

There are no glass facades as part of this design for the MSCP, as illustrated¹³ in Figure 22¹⁴ on the following page. Furthermore, the building exterior will have a mesh material design similar to that mentioned in Section 2.5, which produce diffuse reflections. Non-shiny materials, are not significant in terms of glint and glare.

¹³ This image is simply to illustrate that the car park will not have facades as part of this design. The development plans are shown in the previous section (8.2).

¹⁴ Source: Received via email 31/01/2022.



Figure 22 Indicative visualisation of the proposed car park

For the ATC Tower, the MSCP building will be located behind the proposed office building and the existing 4M office building and therefore expected to be significantly screened. The viewpoint of the ATC Tower towards the proposed development is shown in Figures 23 and 24⁶ on the following pages.

Any reflections from the MSCP building exterior towards the approach paths or visual circuits are expected to be no greater than that for the proposed office building because no glass facades are located on the exterior and any reflections from windscreens from parked cars are expected to be comparable to that of the existing environment.



Figure 23 Proposed office building (blue outlined shape), proposed MSCP (orange shape) and the ATC Tower – aerial image



Figure 24 ATC Tower viewpoint – aerial image

8.4 High-Level Conclusions

Overall, the potential effects caused by the multi-storey carpark are judged to be insignificant with respect to safety and operations. This is predominantly because:

- The car park is over 1.36km from the ATC Tower, a key receptors;
- It is likely to be significantly obscured by the proposed main office building and the existing 4M office building with respect to the ATC Tower;
- It represents a very marginal increase over existing car park areas.
- No significant impacts are predicted for aircraft or visual circuits with respect to reflections from cars or the exterior of the building itself.

9 OVERALL CONCLUSIONS

9.1 Findings

9.1.1 ATC Tower

No solar reflections are geometrically possible towards the ATC Tower.

No impact is predicted, and no mitigation is required.

9.1.2 Approach Paths

Solar reflections have been predicted towards approach paths 23L and 23R only. Intensity calculations were therefore undertaken for the relevant reflectors. The results showed that a solar reflection would have a 'low potential for temporary after-image' which is acceptable considering the associated guidance.

Overall, no significant impact is expected with regard to approaching aircraft, and no mitigation is required.

9.1.3 Visual Circuit Results (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), and Pager Power's previous project experience, no significant impacts upon the visual circuits are anticipated. The solar reflections would either not be visible considering the solar reflection scenario, or the solar reflection would be of acceptable intensity considering the associated guidance and industry best practice. No mitigation is required.

9.2 Conclusions

Overall, no significant impact upon aviation activity at Manchester Airport is predicted, and mitigation is not required.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

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

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

UK Planning Policy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy¹⁵ (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.'

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

¹⁵ Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020

formal policy was cancelled on September 7th, 2012¹⁶ however the advice is still applicable¹⁷ until a formal policy is developed. The relevant aviation guidance from the CAA is presented in the section below.

CAA Interim Guidance

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

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

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

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

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

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 ALH¹⁸, 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.'

¹⁶ Archived at Pager Power

¹⁷ Reference email from the CAA dated 19/05/2014.

¹⁸ Aerodrome Licence Holder.

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*'¹⁹ and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports*'²⁰. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports*'²¹.

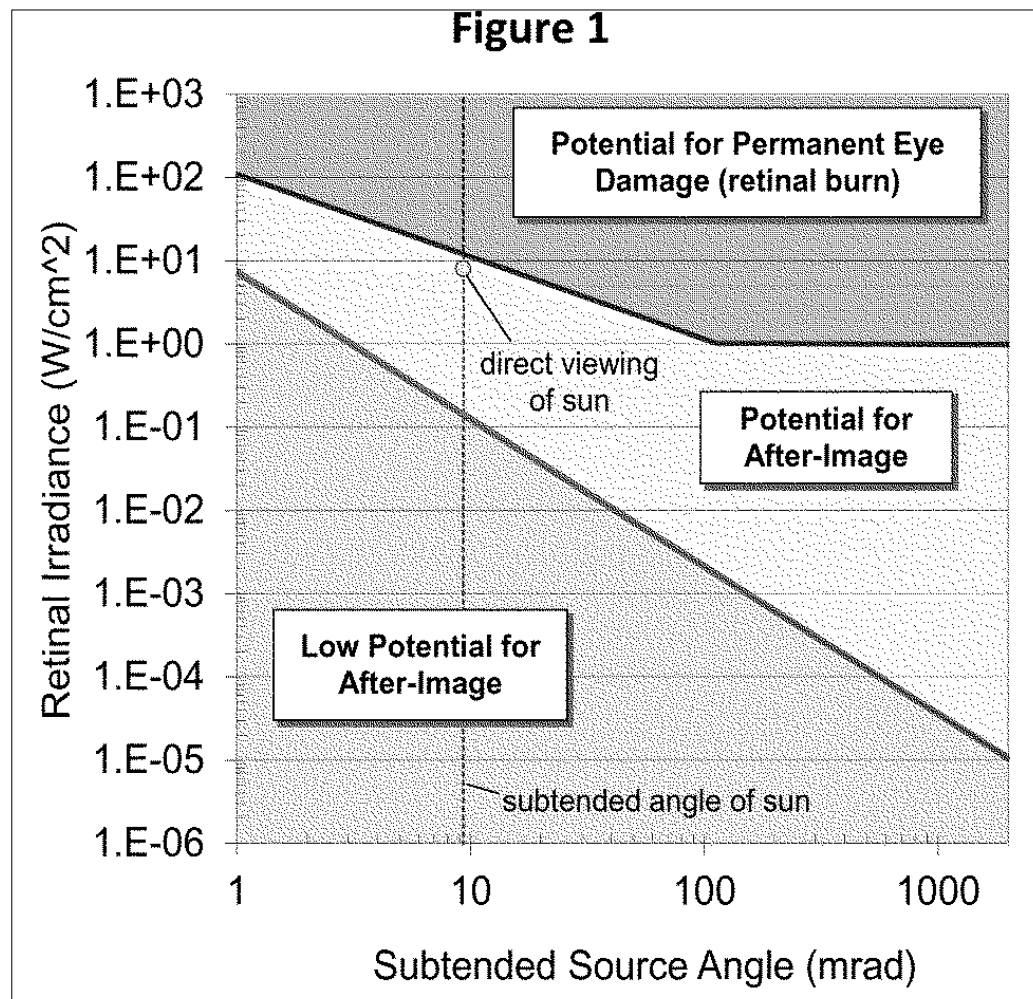
An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *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.*

¹⁹ Archived at Pager Power

²⁰ 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

²¹ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019



Solar Glare Hazard Analysis Plot (FAA)

- To obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a “no objection” ... the airport sponsor will be required to demonstrate that the proposed solar energy system meets the following standards:
- No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATC) cab, and
- No potential for glare or “low potential for after-image” ... along the final approach path for any existing landing threshold or future landing thresholds (including any planned interim phases of the landing thresholds) as shown on the current FAA-approved Airport Layout Plan (ALP). The final approach path is defined as two (2) miles from fifty (50) feet above the landing threshold using a standard three (3) degree glidepath.
- Ocular impact must be analysed over the entire calendar year in one (1) minute intervals from when the sun rises above the horizon until the sun sets below the horizon.

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

Key points from the 2018 FAA guidance are presented below.

- *Reflectivity refers to light that is reflected off surfaces. The potential effects of reflectivity are glint (a momentary flash of bright light) and glare (a continuous source of bright light). These two effects are referred to hereinafter as “glare,” which can cause a brief loss of vision, also known as flash blindness²².*
- *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 16²³, 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*

²² 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.

²³ 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 question²⁴ 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.

²⁴ 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.

Air Navigation Order (ANO) 2009

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

Endangering safety of an aircraft

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

Lights liable to endanger

221.

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

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

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

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

(a) to extinguish or screen the light; and

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

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

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

Lights which dazzle or distract

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

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

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

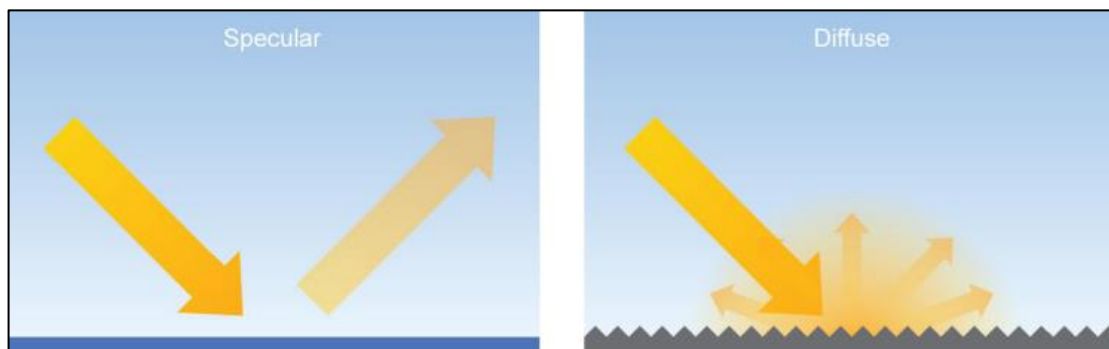
Overview

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

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

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance²⁵, 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

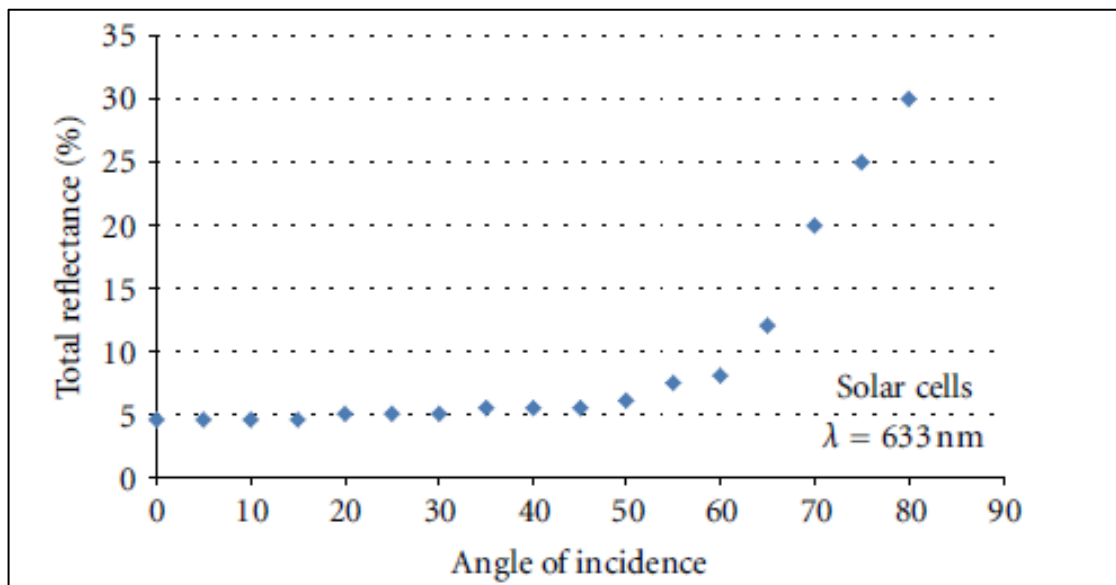
²⁵Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*²⁶. 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.

²⁶ 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”²⁷

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 ²⁸
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.

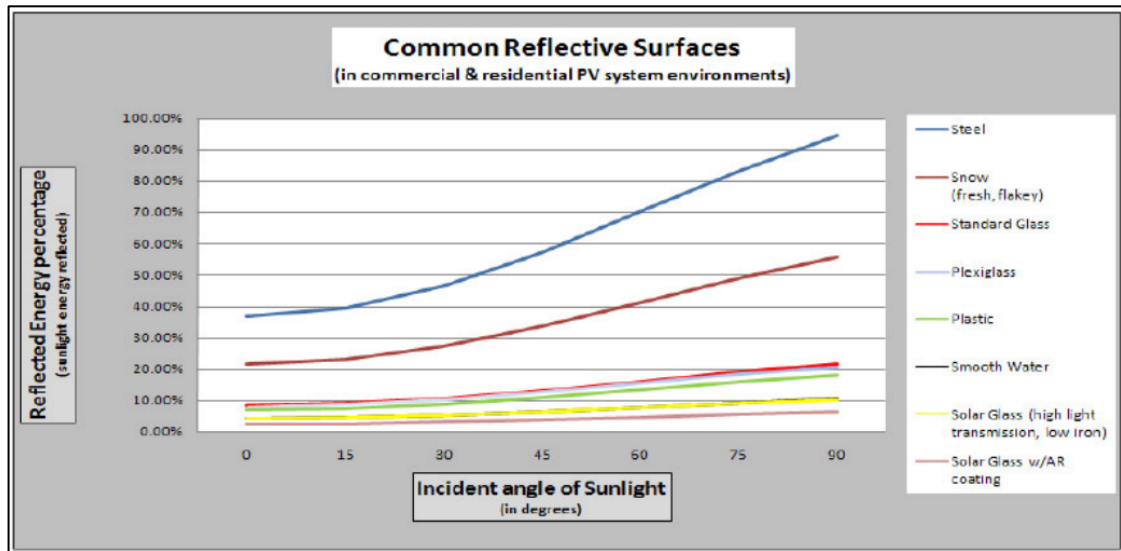
²⁷ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

²⁸ Extrapolated data, baseline of 1,000 W/m² for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification²⁹ 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.

²⁹ Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

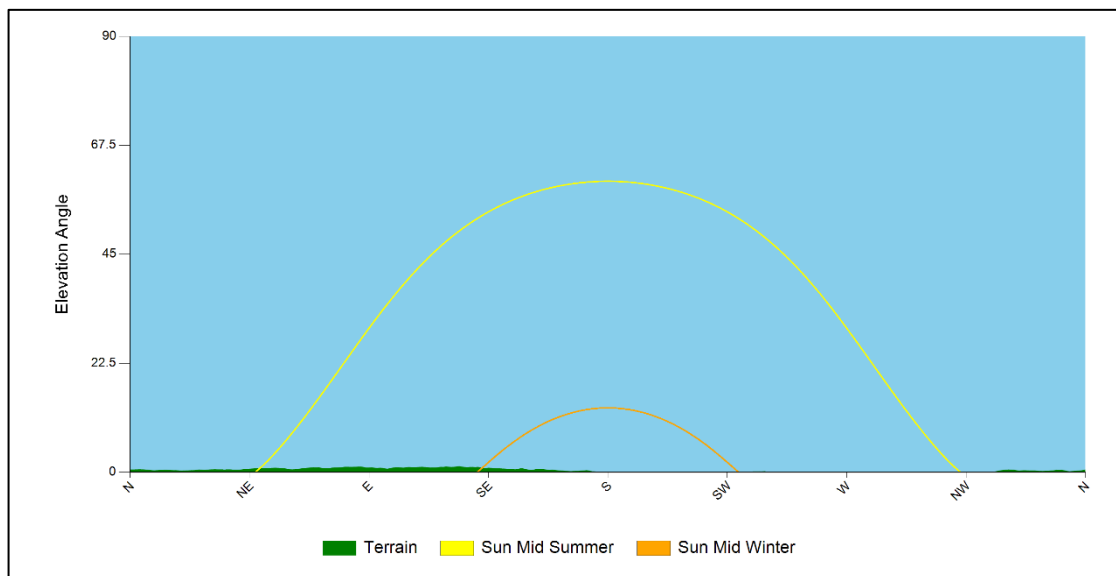
Overview

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

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

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

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector. The terrain and Sun curve from longitude: -2.270686 latitude: 53.367628.



APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

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

Impact Significance Definition

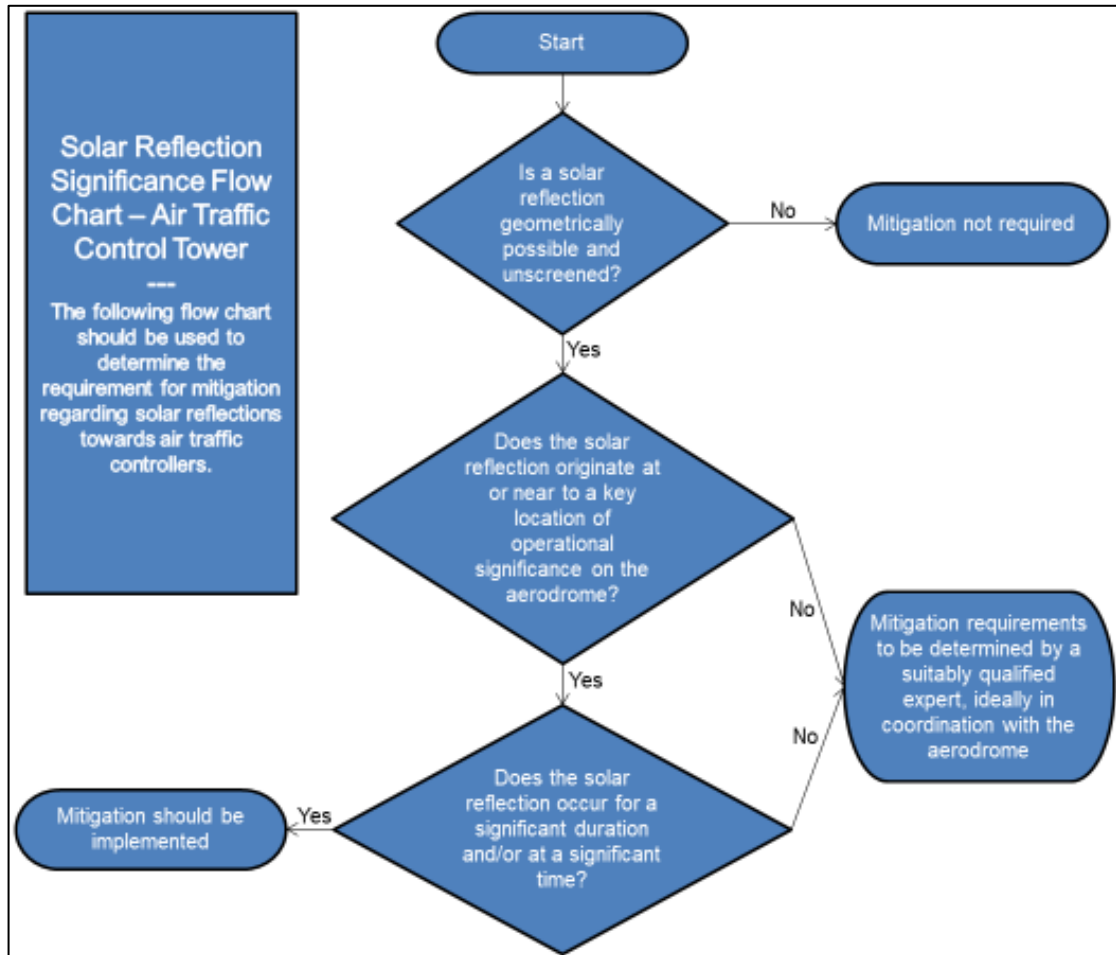
The table below presents the recommended definition of ‘impact significance’ in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation.
Major	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation and consultation is recommended.	Mitigation will be required if the proposed development is to proceed.

Impact significance definition

Assessment Process – ATC Tower

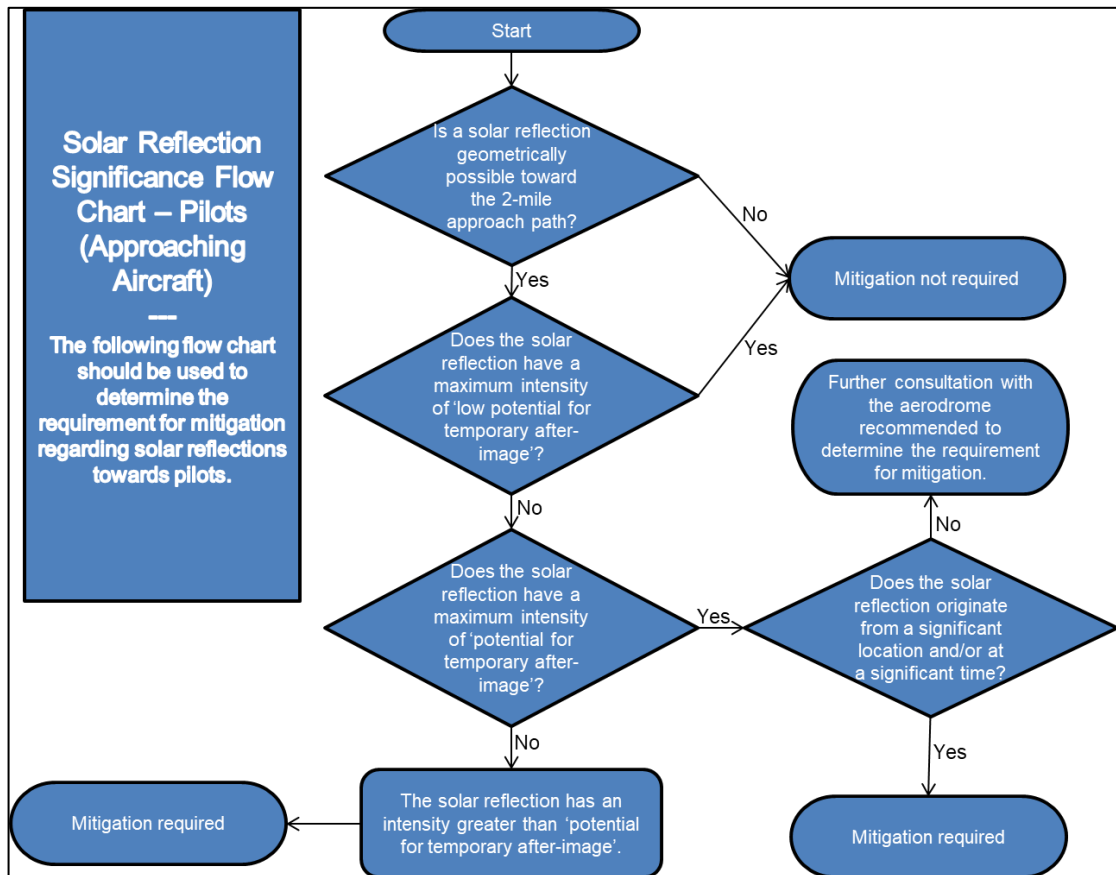
The charts relate to the determining the potential impact upon the ATC Tower.



ATC tower impact significance flow chart

Assessment Process – Approaching Aircraft

The charts relate to the determining the potential impact upon approaching aircraft.



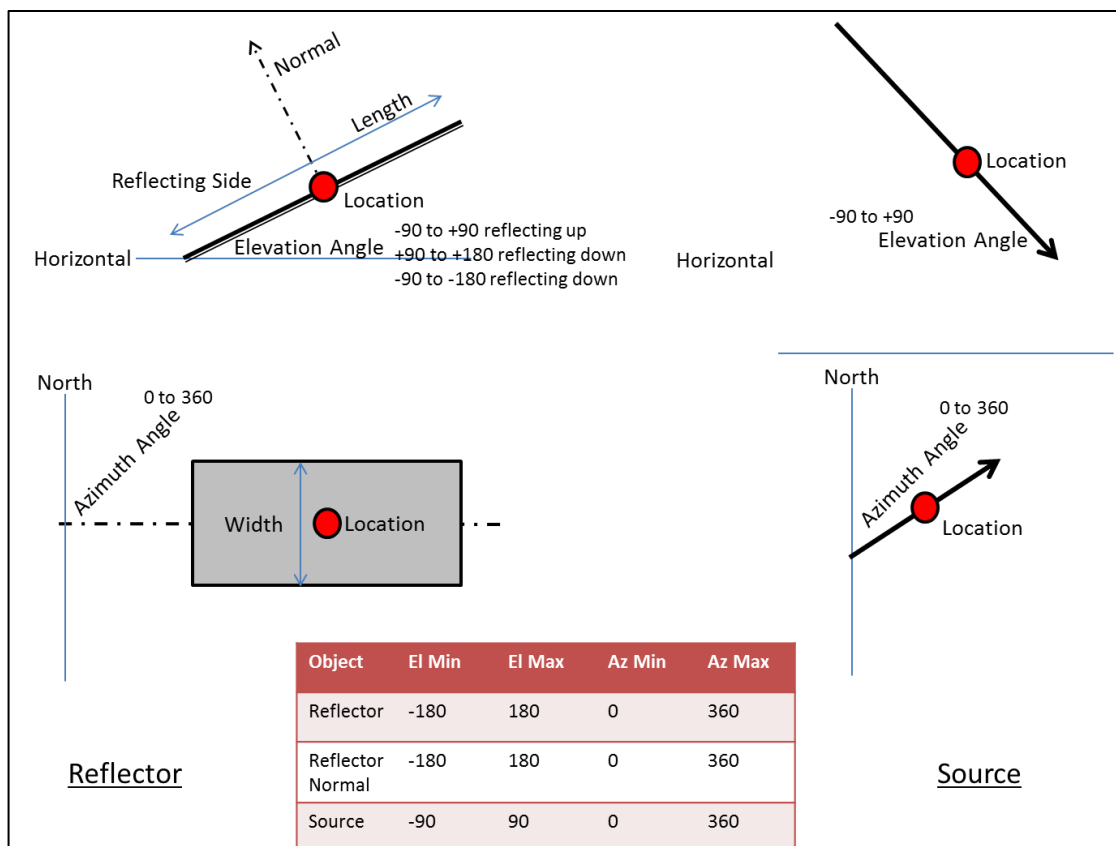
Pilots (approaching aircraft) impact significance flow chart

APPENDIX E – PAGER POWER’S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

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

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



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 reflector areas and the assessed receptor where a solar reflection is geometrically possible.

The model considers terrain between the reflector areas and the visible horizon (where the sun may be obstructed from view of the modelled areas)³⁰.

It is assumed that the elevation angle assessed represents the elevation angle for all reflector points within each area defined.

It is assumed that the azimuth angle assessed represents the azimuth angle for all reflector points within each area defined.

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 reflector area that is not visible to a receptor will not occur in practice.

A finite number of points within each reflector 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 entire face of the area within the development outline, rather a single point is defined every 'x' metres (based on the assessment resolution) with the geometric characteristics of the reflector. A reflector area is however defined to encapsulate all possible reflector locations. See the figure below which illustrates this process.

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 reflector 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.

³⁰ UK only.

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

Forge's Sandia National Laboratories' (SGHAT) Model

The following text is taken from Forge³¹ and is presented for reference.

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

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

³¹ Source: <https://www.forgesolar.com/help/#assumptions>

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Tower Receptor Details

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 Altitude (m) (amsl)	ATC Tower Height (m)	Overall Assessed Height (m)
-2.279717	53.357400	75.22	57.06	132.28

ATC Tower receptor details

Approach 05L Receptor Details

The table below presents the coordinates and overall altitude for aircraft on approach to runway 05L. The altitude of the aircraft is based on a 3-degree descent path referenced to a set threshold point, which is calculated as 50 feet (15.2m) above the runway threshold (212ft amsl).

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold Point	-2.287764	53.347556	79.86
Receptor 2	-2.289651	53.346645	88.29
Receptor 3	-2.291538	53.345735	96.73
Receptor 4	-2.293425	53.344825	105.16
Receptor 5	-2.295312	53.343915	113.59
Receptor 6	-2.297199	53.343004	122.03
Receptor 7	-2.299086	53.342094	130.46
Receptor 8	-2.300973	53.341184	138.90
Receptor 9	-2.302860	53.340273	147.33
Receptor 10	-2.304747	53.339363	155.77
Receptor 11 – 1 mile	-2.306634	53.338453	164.20

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 12	-2.308521	53.337543	172.63
Receptor 13	-2.310408	53.336632	181.07
Receptor 14	-2.312295	53.335722	189.50
Receptor 15	-2.314183	53.334812	197.94
Receptor 16	-2.316070	53.333902	206.37
Receptor 17	-2.317957	53.332991	214.81
Receptor 18	-2.319844	53.332081	223.24
Receptor 19	-2.321731	53.331171	231.67
Receptor 20	-2.323618	53.330261	240.11
2-mile point	-2.325505	53.329350	248.54

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

Approach 23R Receptor Details

The table below presents the coordinates and overall altitude for aircraft on approach to runway 23R. The altitude of the aircraft is based on a 3-degree descent path referenced to a set threshold point, which is calculated as 50 feet (15.2m) above the runway threshold (249ft amsl).

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold Point	-2.259281	53.361319	91.14
Receptor 2	-2.257392	53.362229	99.57
Receptor 3	-2.255504	53.363139	108.00
Receptor 4	-2.253615	53.364048	116.44
Receptor 5	-2.251727	53.364958	124.87
Receptor 6	-2.249838	53.365868	133.31
Receptor 7	-2.247950	53.366777	141.74

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 8	-2.246061	53.367687	150.17
Receptor 9	-2.244173	53.368597	158.61
Receptor 10	-2.242284	53.369506	167.04
Receptor 11 – 1 mile	-2.240396	53.370416	175.48
Receptor 12	-2.238508	53.371326	183.91
Receptor 13	-2.236619	53.372236	192.35
Receptor 14	-2.234731	53.373145	200.78
Receptor 15	-2.232842	53.374055	209.21
Receptor 16	-2.230954	53.374965	217.65
Receptor 17	-2.229065	53.375874	226.08
Receptor 18	-2.227177	53.376784	234.52
Receptor 19	-2.225288	53.377694	242.95
Receptor 20	-2.223400	53.378603	251.39
2-mile point	-2.221511	53.379513	259.82

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

Approach 05R Receptor Details

The table below presents the coordinates and overall altitude for aircraft on approach to runway 05R. The altitude of the aircraft is based on a 3-degree descent path referenced to a set threshold point, which is calculated as 50 feet (15.2m) above the runway threshold (186ft amsl).

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold Point	-2.310661	53.331972	71.93
Receptor 2	-2.312547	53.331062	80.37
Receptor 3	-2.314433	53.330151	88.80

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 4	-2.316319	53.329240	97.24
Receptor 5	-2.318204	53.328330	105.67
Receptor 6	-2.320090	53.327419	114.10
Receptor 7	-2.321976	53.326508	122.54
Receptor 8	-2.323862	53.325598	130.97
Receptor 9	-2.325748	53.324687	139.41
Receptor 10	-2.327634	53.323776	147.84
Receptor 11 – 1 mile	-2.329519	53.322866	156.27
Receptor 12	-2.331405	53.321955	164.71
Receptor 13	-2.333291	53.321044	173.14
Receptor 14	-2.335177	53.320134	181.58
Receptor 15	-2.337063	53.319223	190.01
Receptor 16	-2.338948	53.318312	198.45
Receptor 17	-2.340834	53.317402	206.88
Receptor 18	-2.342720	53.316491	215.31
Receptor 19	-2.344606	53.315580	223.75
Receptor 20	-2.346492	53.314670	232.18
2-mile point	-2.348378	53.313759	240.62

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

Approach 23L Receptor Details

The table below presents the coordinates and overall altitude for aircraft on approach to runway 23L. The altitude of the aircraft is based on a 3-degree descent path referenced to a set threshold point, which is calculated as 50 feet (15.2m) above the runway threshold (227ft amsl).

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold Point	-2.277208	53.348153	84.43
Receptor 2	-2.275321	53.349063	92.86
Receptor 3	-2.273434	53.349973	101.30
Receptor 4	-2.271546	53.350883	109.73
Receptor 5	-2.269659	53.351793	118.17
Receptor 6	-2.267772	53.352703	126.60
Receptor 7	-2.265884	53.353613	135.03
Receptor 8	-2.263997	53.354523	143.47
Receptor 9	-2.262110	53.355433	151.90
Receptor 10	-2.260222	53.356343	160.34
Receptor 11 – 1 mile	-2.258335	53.357253	168.77
Receptor 12	-2.256448	53.358163	177.21
Receptor 13	-2.254560	53.359074	185.64
Receptor 14	-2.252673	53.359984	194.07
Receptor 15	-2.250786	53.360894	202.51
Receptor 16	-2.248898	53.361804	210.94
Receptor 17	-2.247011	53.362714	219.38
Receptor 18	-2.245124	53.363624	227.81
Receptor 19	-2.243236	53.364534	236.25

Location	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 20	-2.241349	53.365444	244.68
2-mile point	-2.239462	53.366354	253.11

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

Modelled Reflector Bounding Points

ID	Longitude (°)	Latitude (°)	Ground Height (m amsl) ³²	Building Height (m agl / m amsl)	Angle Azimuth (°)
1	-2.27131	53.36807	70.00	0-27.73 70.00-97.73	202.1
2	-2.26990	53.36773			
3	-2.26981	53.36731			
4	-2.26954	53.36725			
5	-2.26958	53.36720			
6	-2.26979	53.36724			
7	-2.26979	53.36723			
8	-2.27170	53.36767			
9	-2.27140	53.36787			

Modelled reflector area boundary points – façades

ID	Longitude (°)	Latitude (°)	Ground Height (m amsl) ³³	Building Height (m agl / m amsl)	Elevation Angle/Azimuth Angle (°)
1	-2.27088	53.36765	70.00	27.73 97.73	0 and 3.5 21.3
2	-2.27075	53.36785			
3	-2.27059	53.36781			
4	-2.27063	53.36775			
5	-2.27041	53.36770			
6	-2.27050	53.36756			

Modelled reflector area boundary points – atrium roof and sky light

³² Based on an average height taken from the perimeter co-ordinates and OSGB36 terrain data.

³³ Based on an average height taken from the perimeter co-ordinates and OSGB36 terrain data.

ID	Longitude (°)	Latitude (°)	Ground Height (m amsl) ³⁴	Building Height (m agl / m amsl)	Elevation Angle/Azimuth Angle (°)
1	-2.27136	53.36771	70.00	Modelled at mid-point of panel between 21.92 and 27.73 i.e. 24.57 94.57	40 202.1
2	-2.27010	53.36741			
3	-2.27011	53.36739			
4	-2.27137	53.36769			

Modelled reflector area boundary points – solar panels

³⁴ Based on an average height taken from the perimeter co-ordinates and OSGB36 terrain data.

APPENDIX H – GEOMETRIC CALCULATION RESULTS

The Pager Power charts for the receptors are shown on the following pages. Further modelling charts can be provided upon request. 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 and their intensities – top left;
- The daily duration of the solar reflections – top right;
- The location of the proposed development where glare will originate – bottom left;
- The calculated intensity of the predicted solar reflections – bottom right.

ATC Tower

No glare found.

Runway 05L Approach

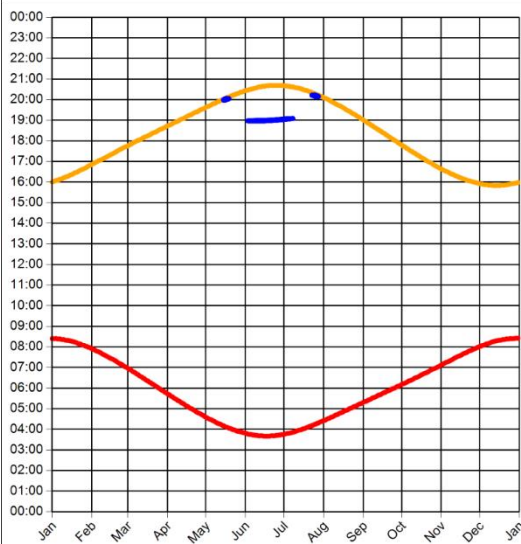
No glare found.

Runway 23R Approach

Pager Power

Observer 23 - Approach 23R- Receptor 02 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.2°
Max observer difference angle: 16°

Observer Location

Sun azimuth ranges (yellow)

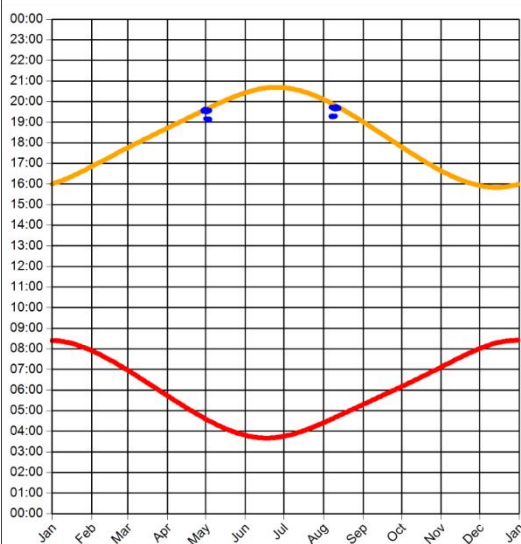


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 24 - Approach 23R- Receptor 03 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.3°
Max observer difference angle: 6.6°

Observer Location

Sun azimuth range is 291.7° - 297.4° (yellow)

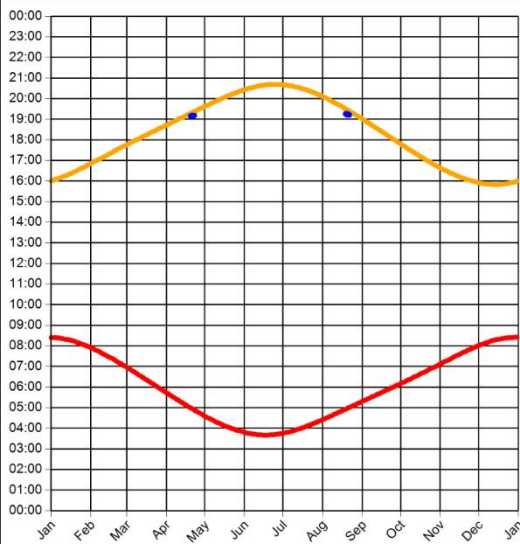


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 25 - Approach 23R- Receptor 04 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 1.7°
Max observer difference angle: 2.4°

Observer Location Sun azimuth range is 288.9° - 290.3° (yellow)

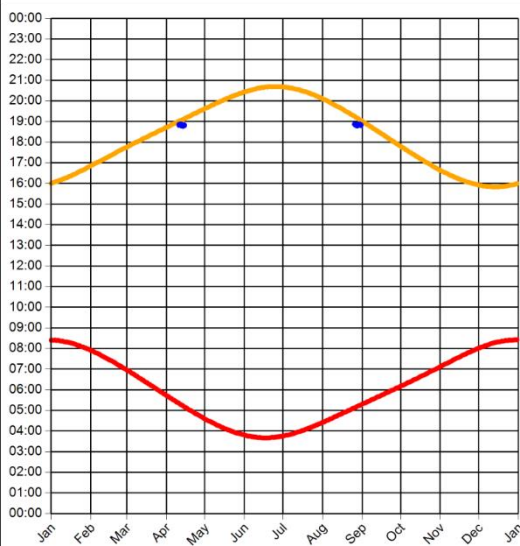


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



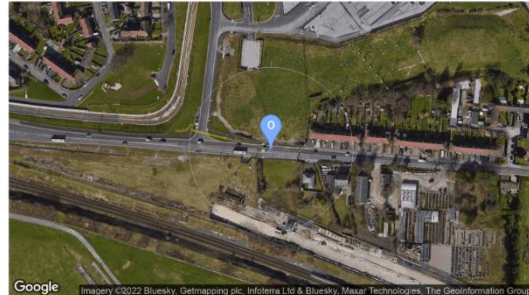
Observer 26 - Approach 23R- Receptor 05 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.3°
Max observer difference angle: 3.8°

Observer Location Sun azimuth range is 282.8° - 284.4° (yellow)

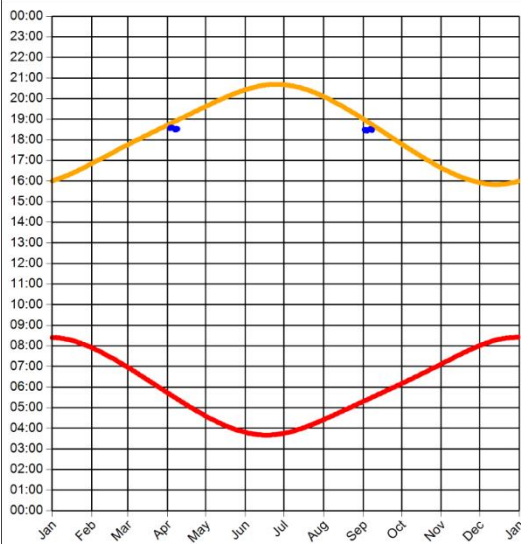


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 27 - Approach 23R- Receptor 06 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.8°
Max observer difference angle: 4.9°

Observer Location Sun azimuth range is 277.5° - 279.1° (yellow)

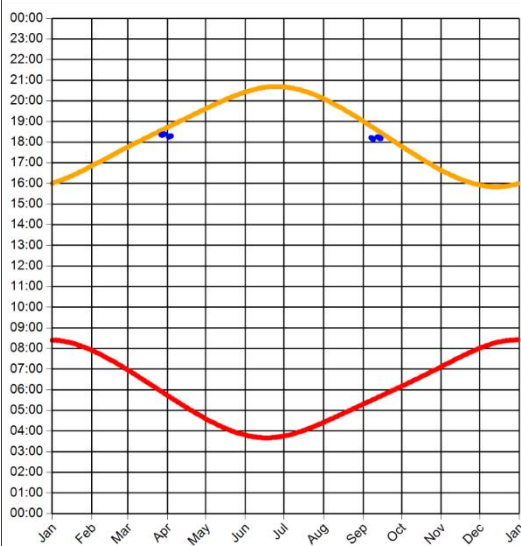


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



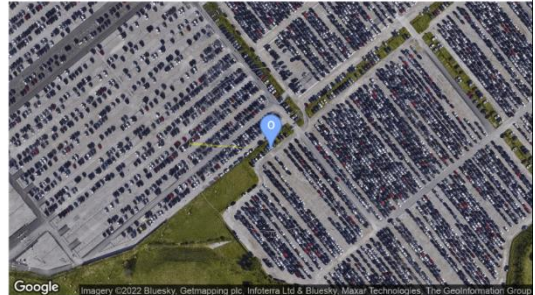
Observer 28 - Approach 23R- Receptor 07 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 3.2°
Max observer difference angle: 5.8°

Observer Location Sun azimuth range is 273.1° - 274.8° (yellow)

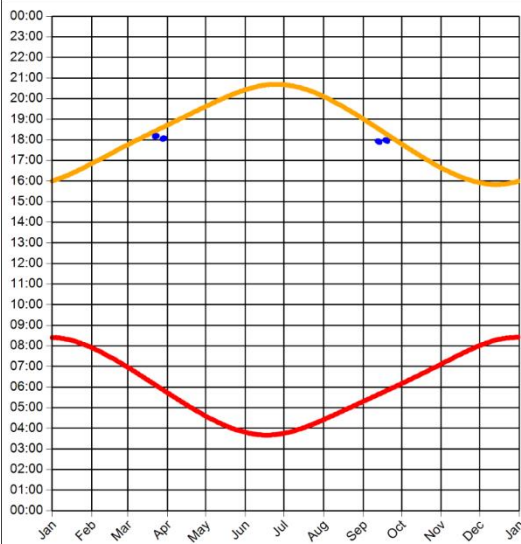


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



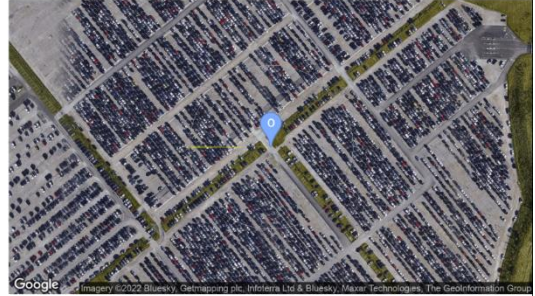
Observer 29 - Approach 23R- Receptor 08 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 3.5°
Max observer difference angle: 6.6°

Observer Location Sun azimuth range is 269.2° - 270.8° (yellow)

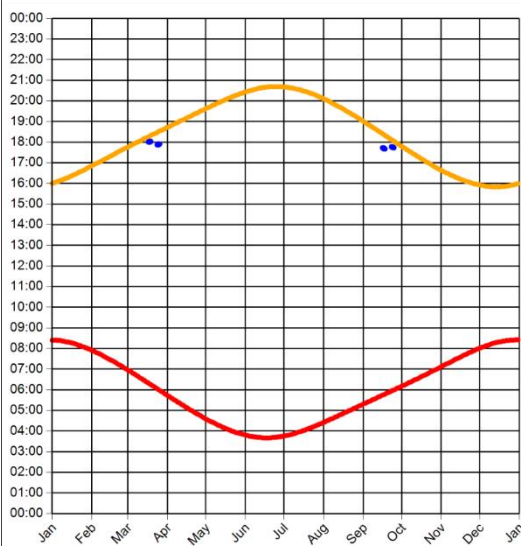


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 30 - Approach 23R- Receptor 09 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 3.9°
Max observer difference angle: 7.3°

Observer Location Sun azimuth range is 265.9° - 267.5° (yellow)

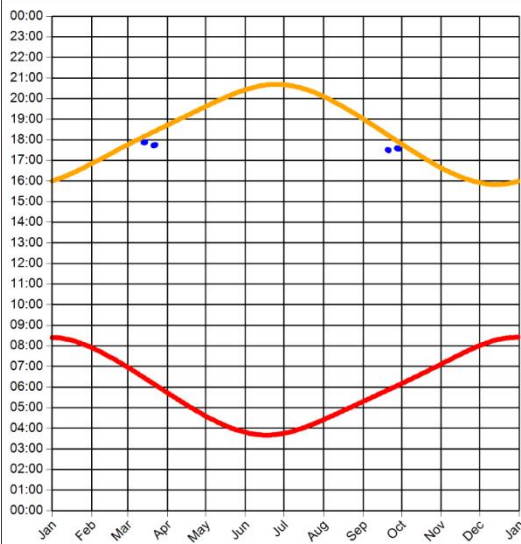


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 31 - Approach 23R- Receptor 10 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4°
Max observer difference angle: 7.8°

Observer Location Sun azimuth range is 263.2° - 264.8° (yellow)

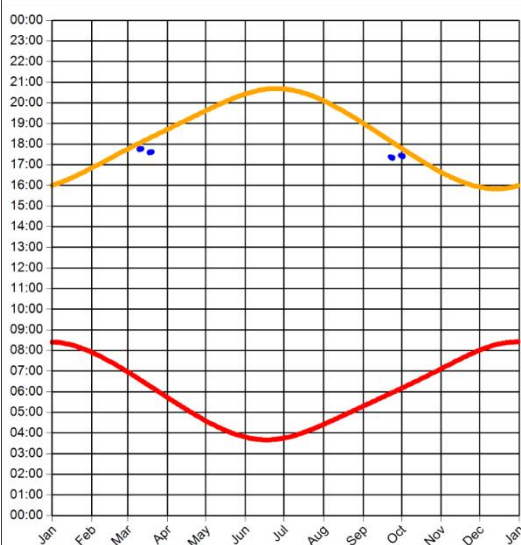


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 32 - Approach 23R- Receptor 11 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.2°
Max observer difference angle: 8.2°

Observer Location Sun azimuth range is 260.7° - 262.5° (yellow)

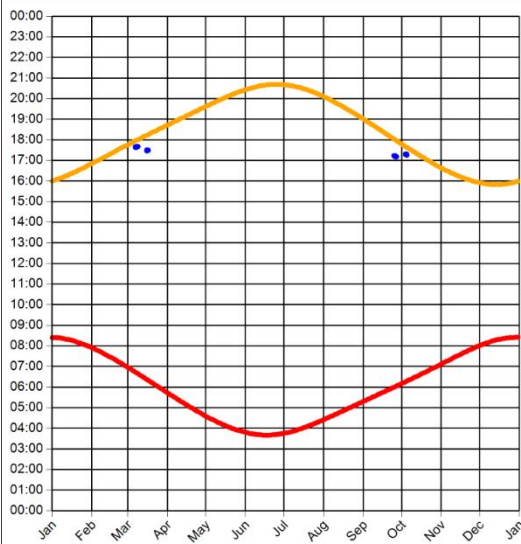


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 33 - Approach 23R- Receptor 12 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.3°
Max observer difference angle: 8.6°

Observer Location Sun azimuth range is 258.6° - 260.1° (yellow)

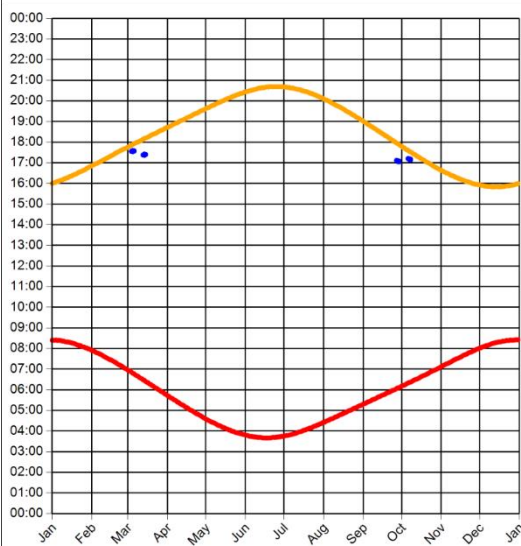


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 34 - Approach 23R- Receptor 13 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.5°
Max observer difference angle: 8.9°

Observer Location Sun azimuth range is 256.7° - 258.3° (yellow)

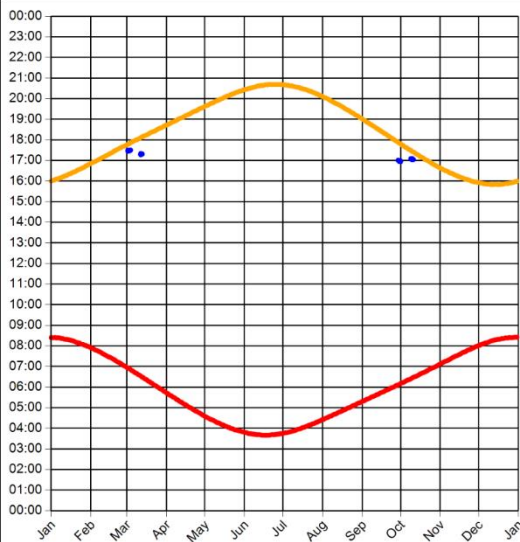


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 35 - Approach 23R- Receptor 14 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.6°
Max observer difference angle: 9.2°

Observer Location Sun azimuth range is 255.1° - 256.7° (yellow)

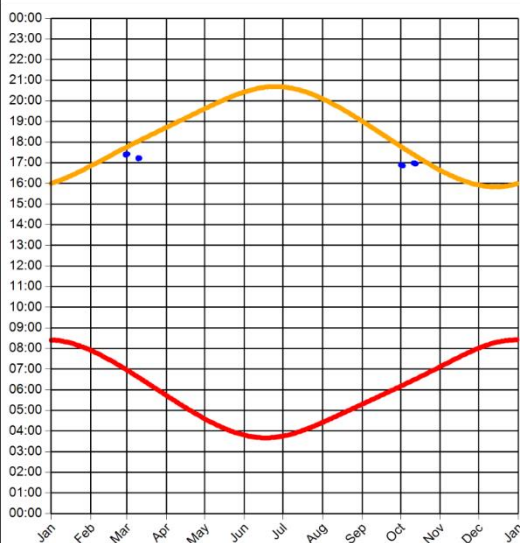


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 36 - Approach 23R- Receptor 15 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.7°
Max observer difference angle: 9.4°

Observer Location Sun azimuth range is 253.6° - 255° (yellow)

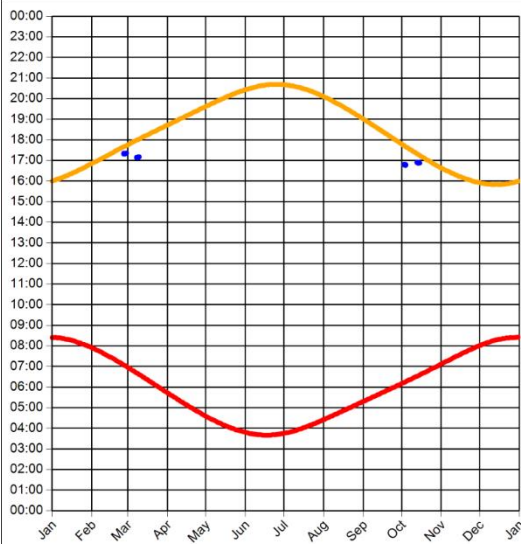


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 37 - Approach 23R- Receptor 16 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.8°
Max observer difference angle: 9.7°

Observer Location Sun azimuth range is 252.3° - 253.8° (yellow)

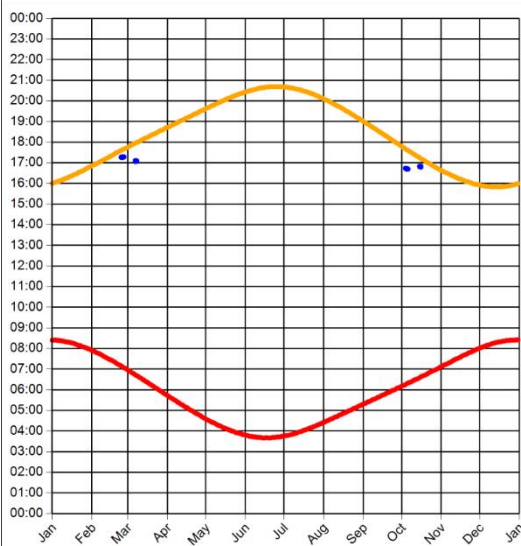


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 38 - Approach 23R- Receptor 17 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.9°
Max observer difference angle: 9.8°

Observer Location Sun azimuth range is 251.2° - 252.5° (yellow)

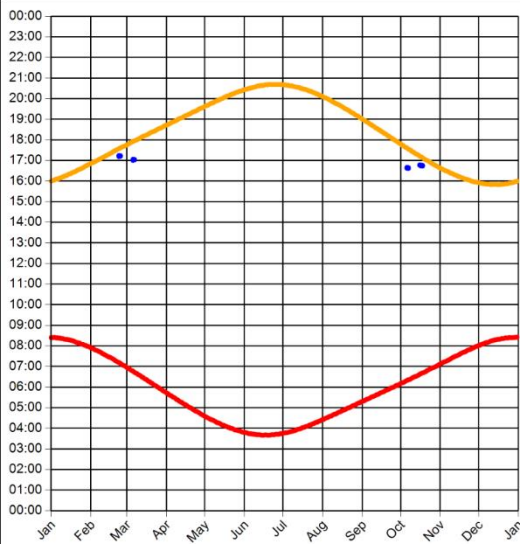


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 39 - Approach 23R- Receptor 18 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.9°
Max observer difference angle: 10°

Observer Location Sun azimuth range is 250.2° - 251.4° (yellow)

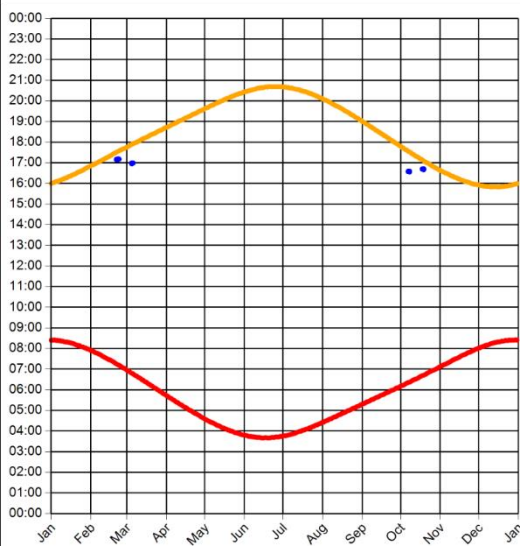


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



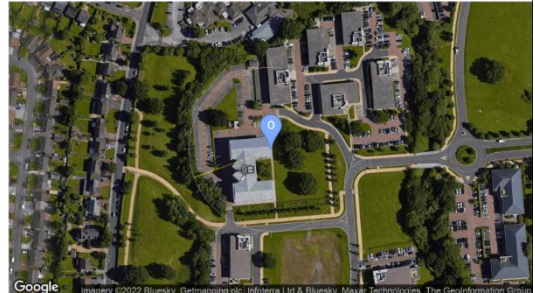
Observer 40 - Approach 23R- Receptor 19 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 5°
Max observer difference angle: 10.1°

Observer Location Sun azimuth range is 249.2° - 250.5° (yellow)

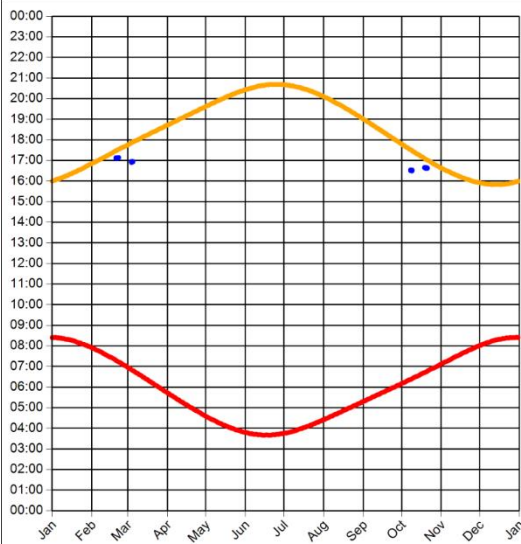


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 41 - Approach 23R- Receptor 20 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 5°
Max observer difference angle: 10.3°

Observer Location Sun azimuth range is 248.3° - 249.6° (yellow)

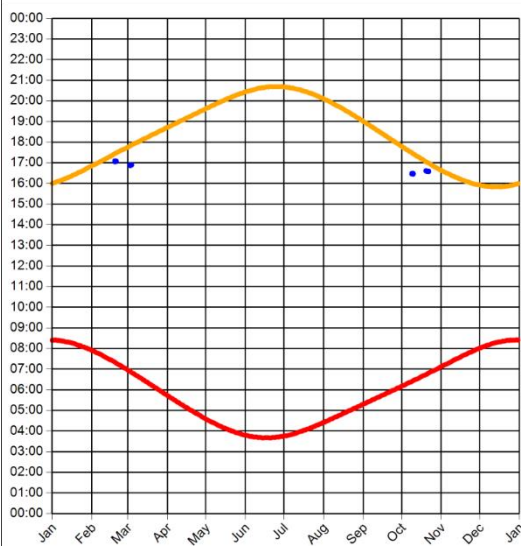


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 42 - Approach 23R- Receptor 21 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 5.1°
Max observer difference angle: 10.4°

Observer Location Sun azimuth range is 247.5° - 248.8° (yellow)



Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

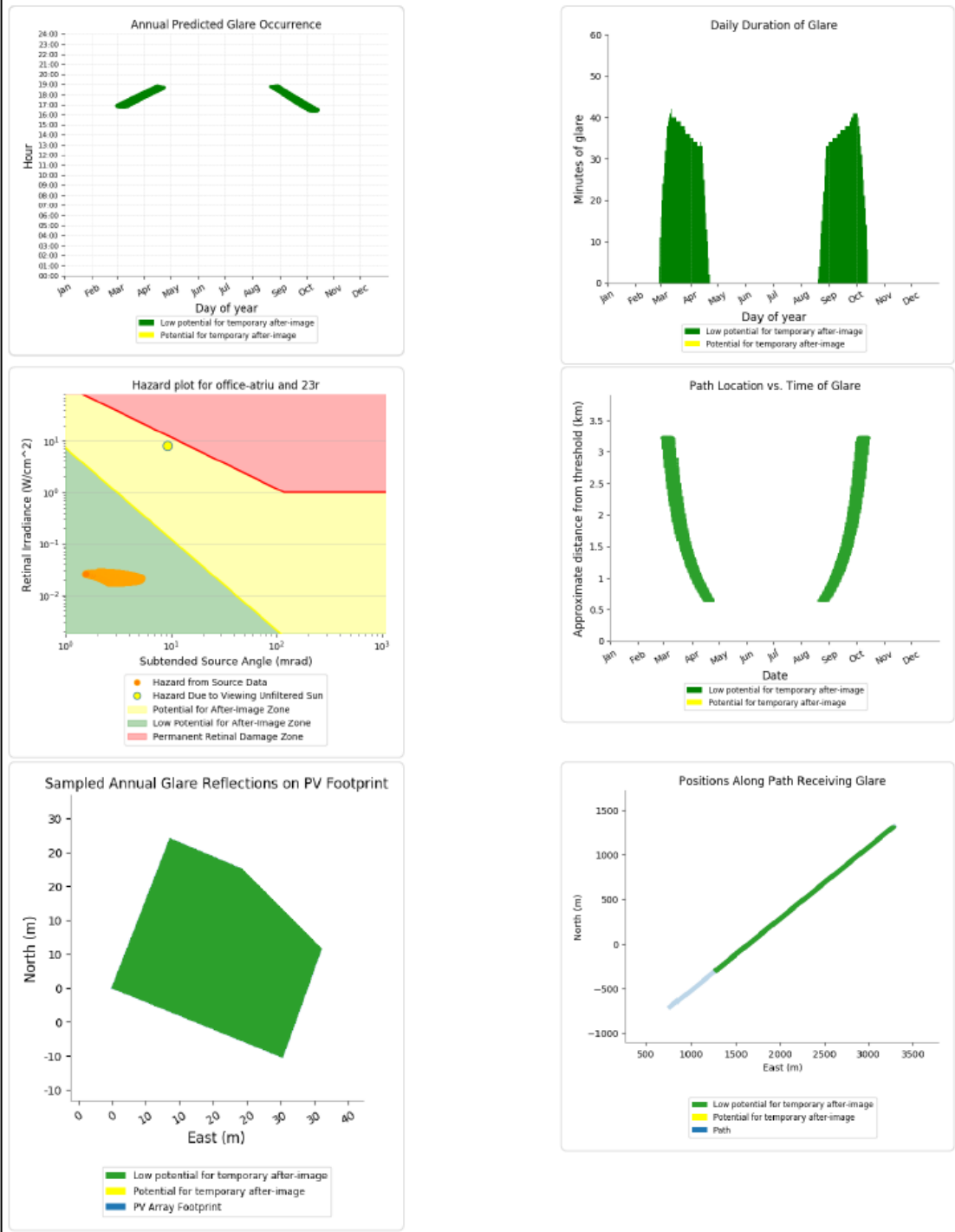


Forge

Office Atrium Roof and Skylight - 3-5 degrees - Receptor (23R)

PV array is expected to produce the following glare for observers on this flight path:

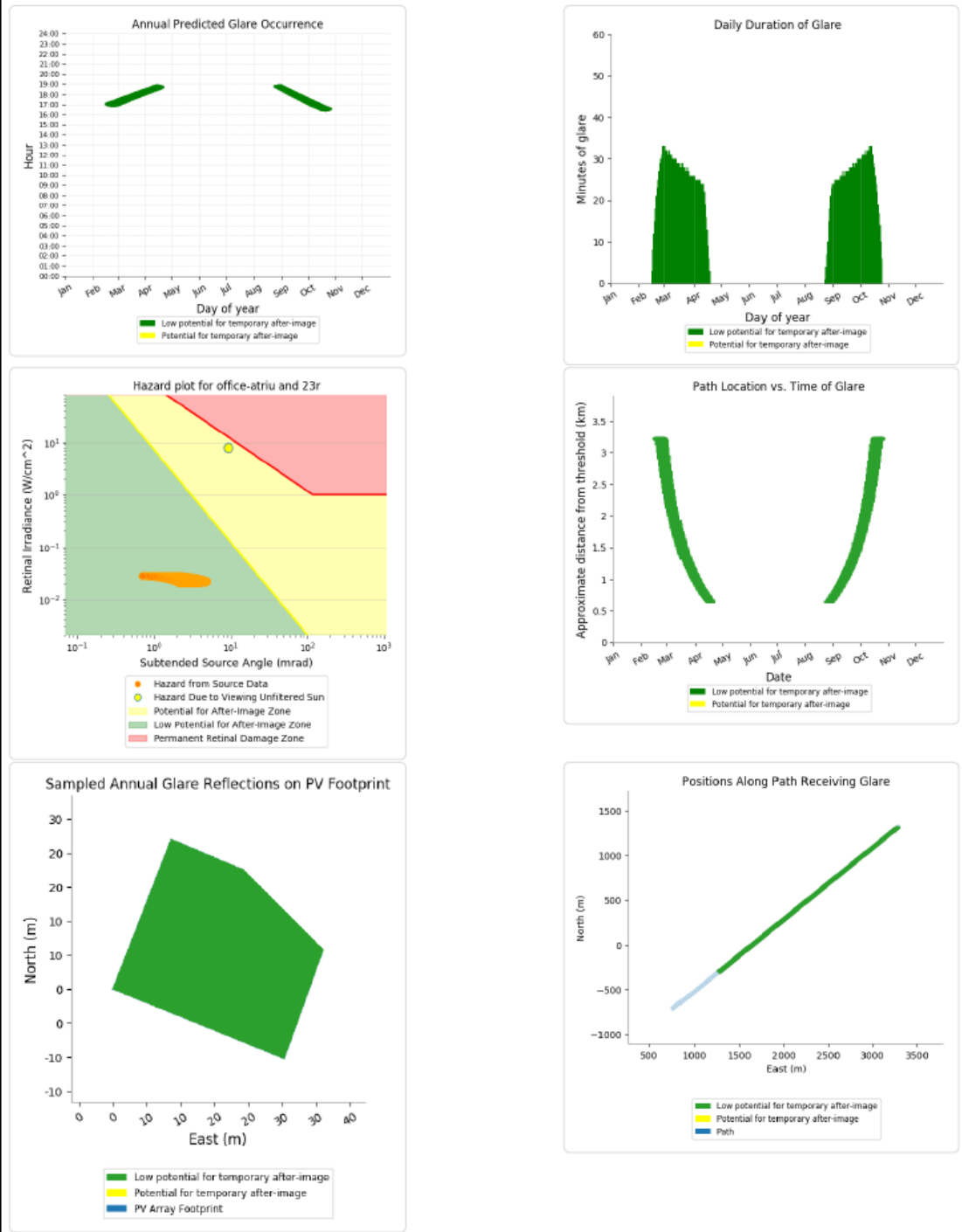
- 3,441 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



Office Atrium Roof and Skylight - Flat - Receptor (23R)

PV array is expected to produce the following glare for observers on this flight path:

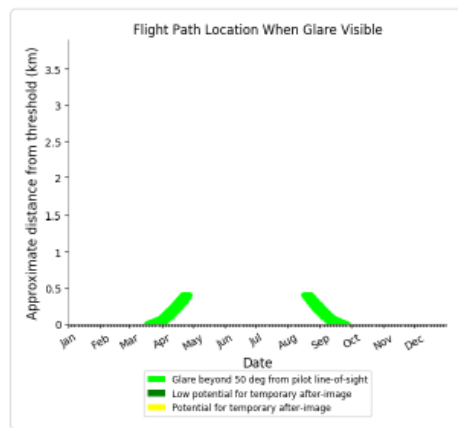
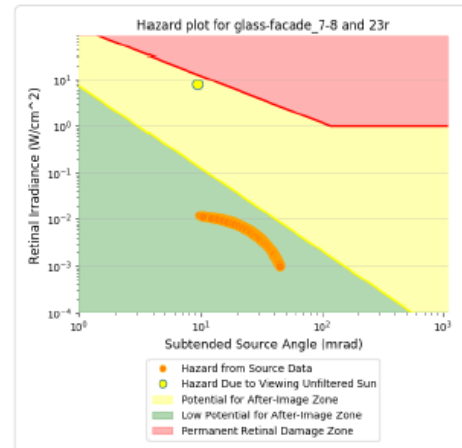
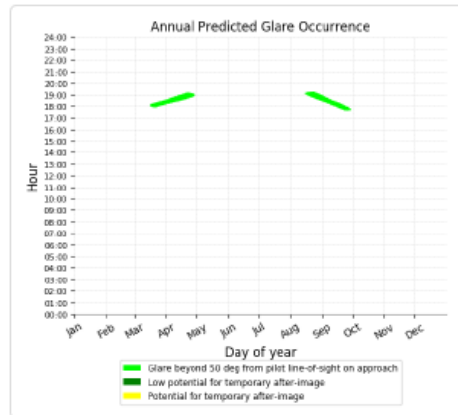
- 3,202 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



Forge - Glass Facades

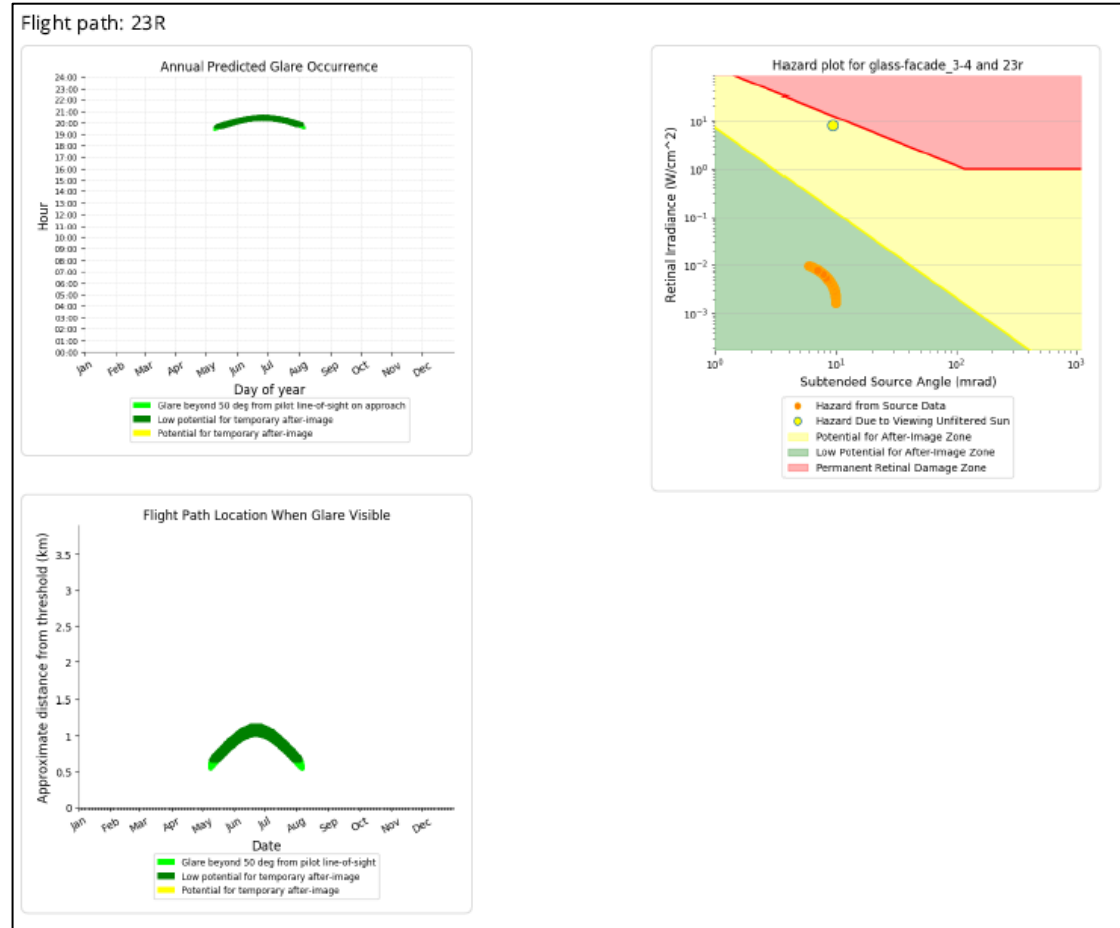
Face 4 to 5, of 10

Flight path: 23R

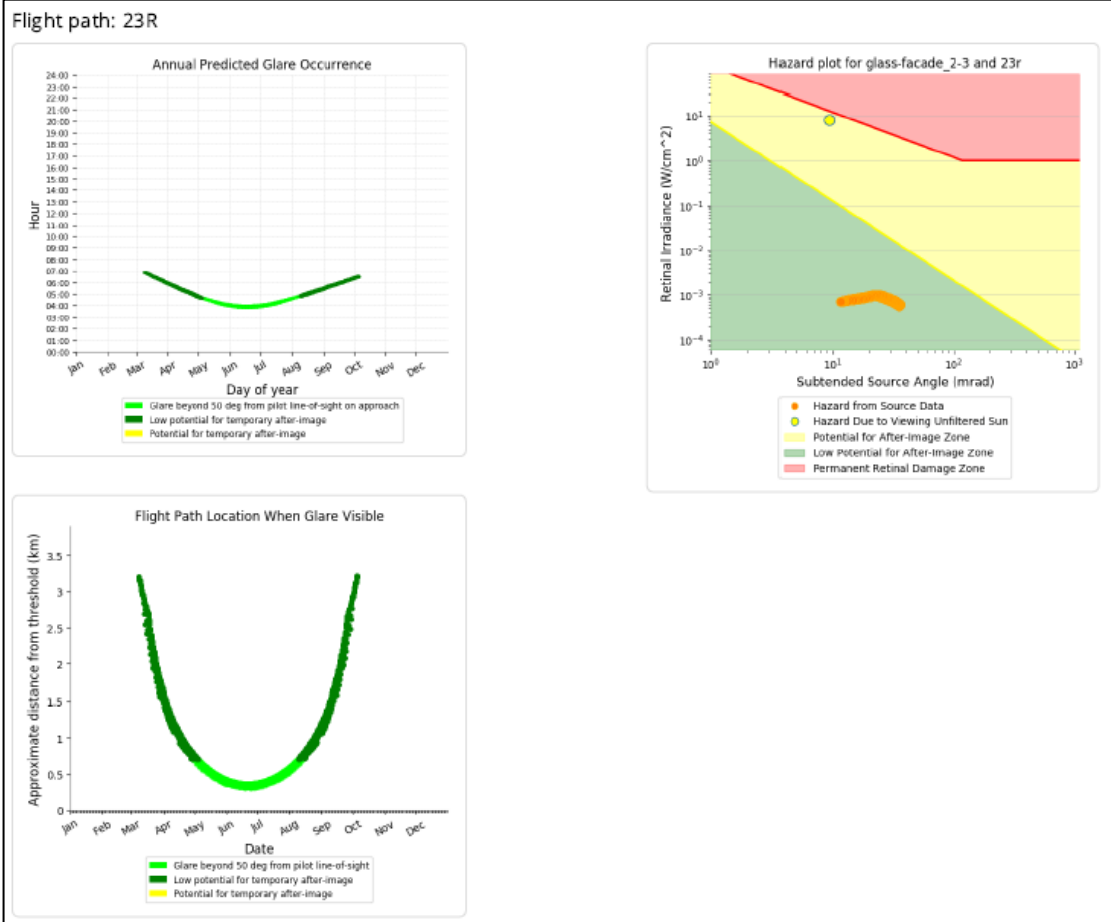


Snipping Tool

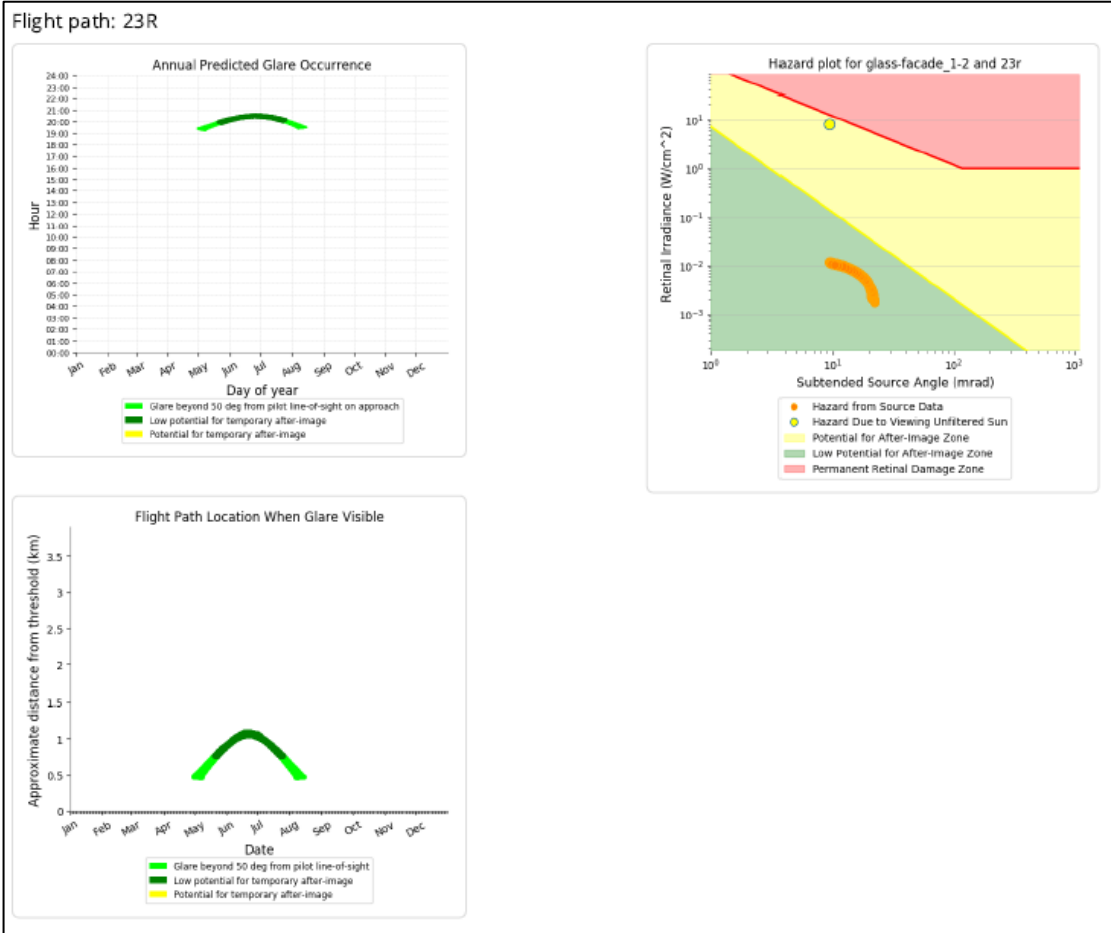
Face 3 to 4, of 10



Face 2 to 3, of 10



Face 1 to 2, of 10

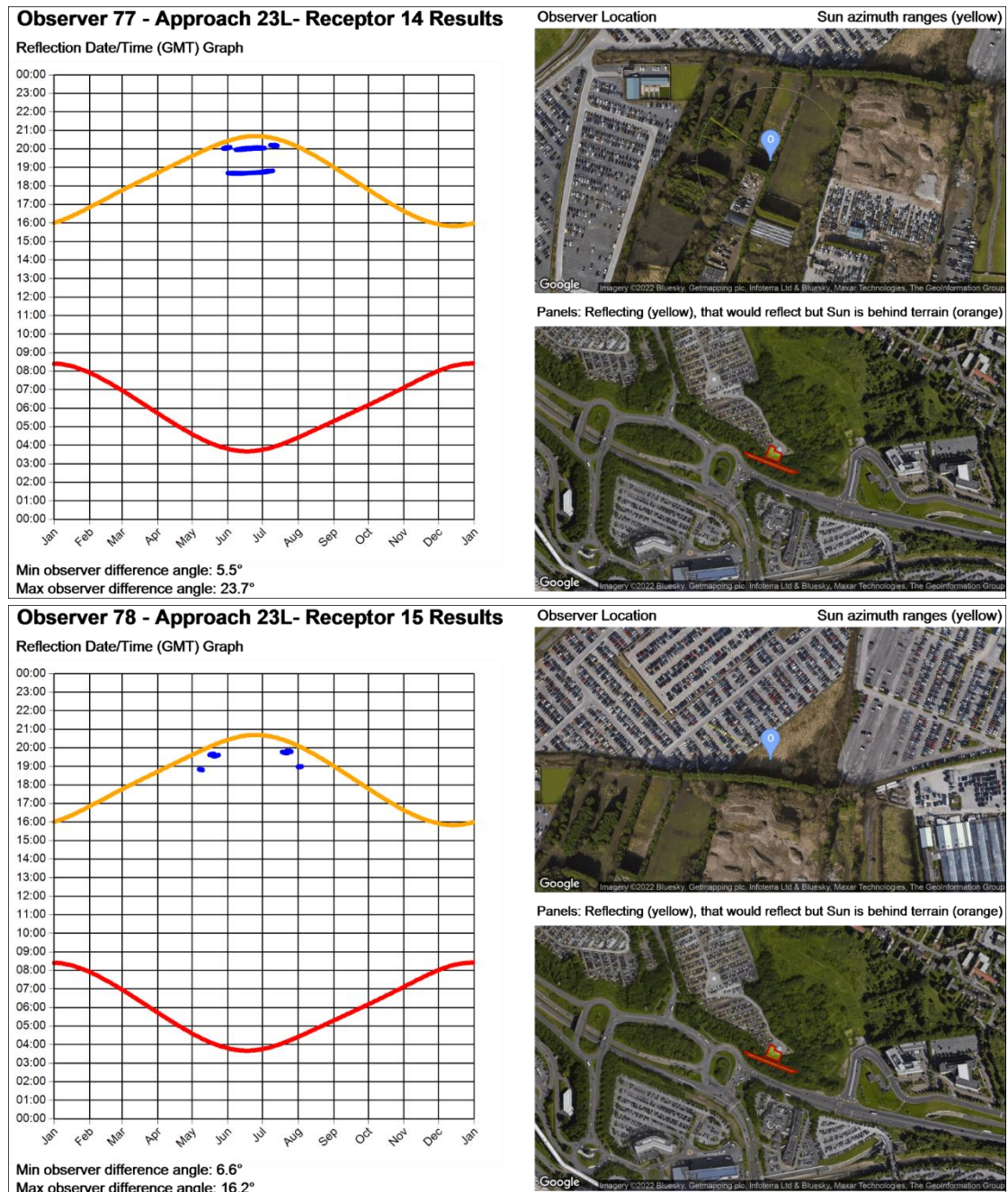


Runway 05R Approach

No glare found.

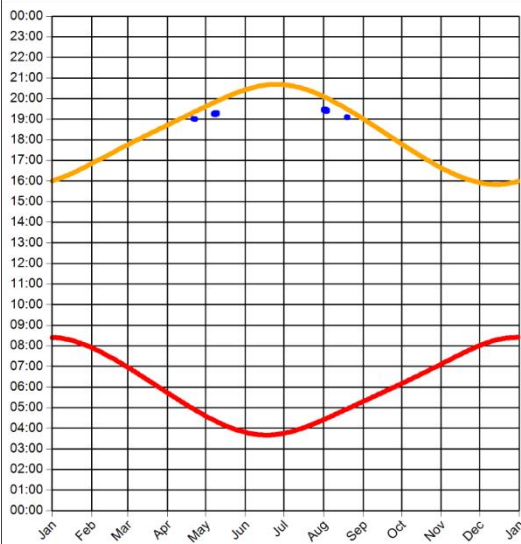
Runway 23L Approach

Pager Power



Observer 79 - Approach 23L- Receptor 16 Results

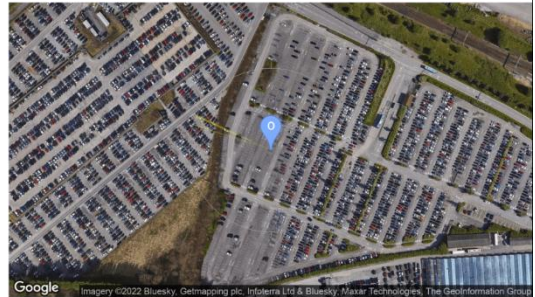
Reflection Date/Time (GMT) Graph



Min observer difference angle: 7.5°
Max observer difference angle: 9.2°

Observer Location

Sun azimuth ranges (yellow)

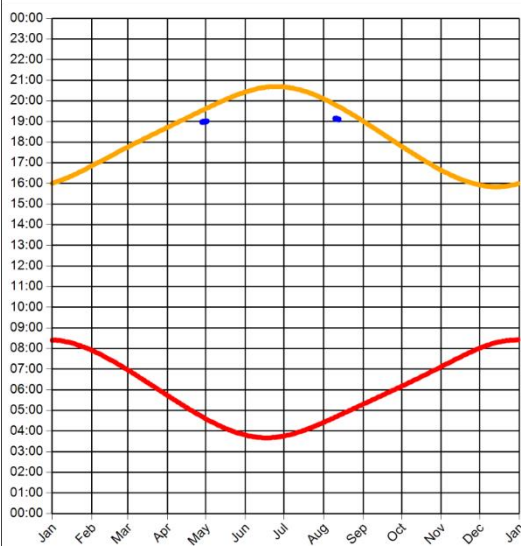


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 80 - Approach 23L- Receptor 17 Results

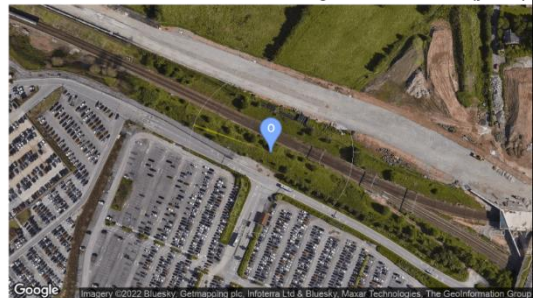
Reflection Date/Time (GMT) Graph



Min observer difference angle: 8.1°
Max observer difference angle: 9°

Observer Location

Sun azimuth range is 288.8° - 290.3° (yellow)

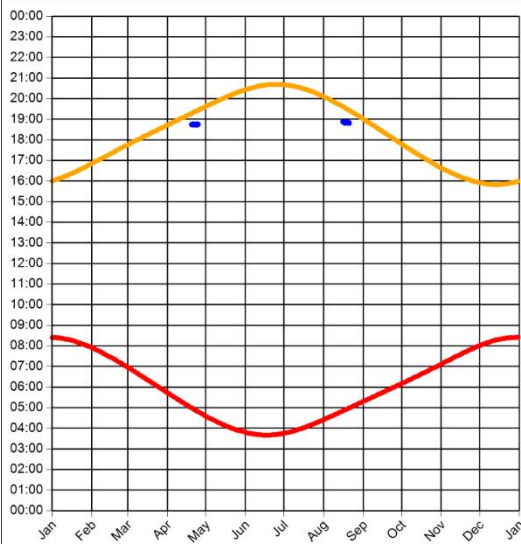


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 81 - Approach 23L- Receptor 18 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 8.3°
Max observer difference angle: 9.6°

Observer Location Sun azimuth range is 284.3° - 286.1° (yellow)

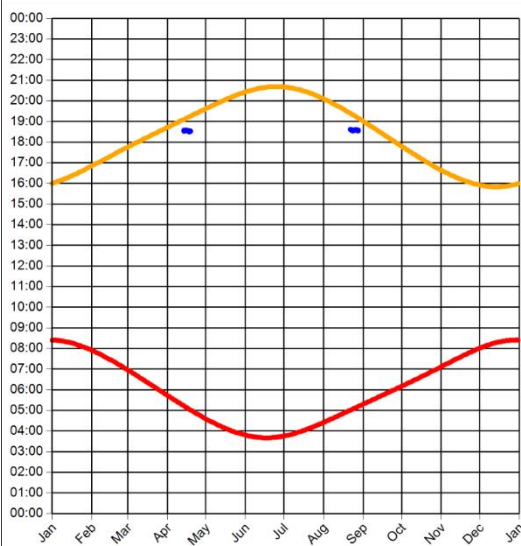


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 82 - Approach 23L- Receptor 19 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 8.4°
Max observer difference angle: 10.2°

Observer Location Sun azimuth range is 280.3° - 282° (yellow)

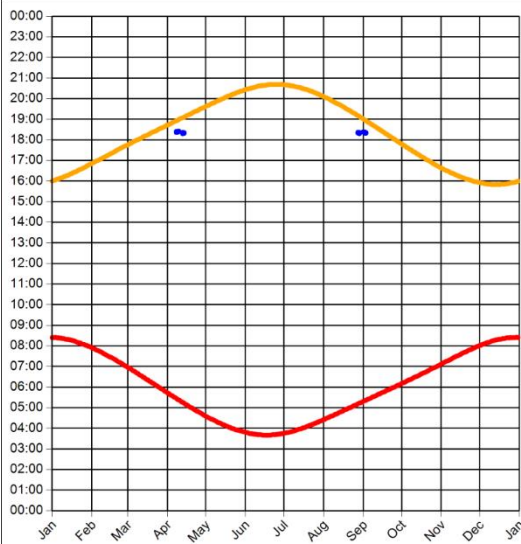


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 83 - Approach 23L- Receptor 20 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 8.4°
Max observer difference angle: 10.6°

Observer Location Sun azimuth range is 276.6° - 278.2° (yellow)

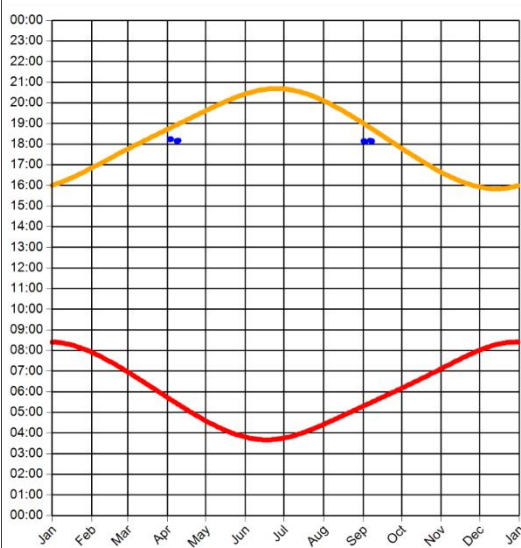


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 84 - Approach 23L- Receptor 21 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 8.4°
Max observer difference angle: 11°

Observer Location Sun azimuth range is 273.5° - 275.1° (yellow)



Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

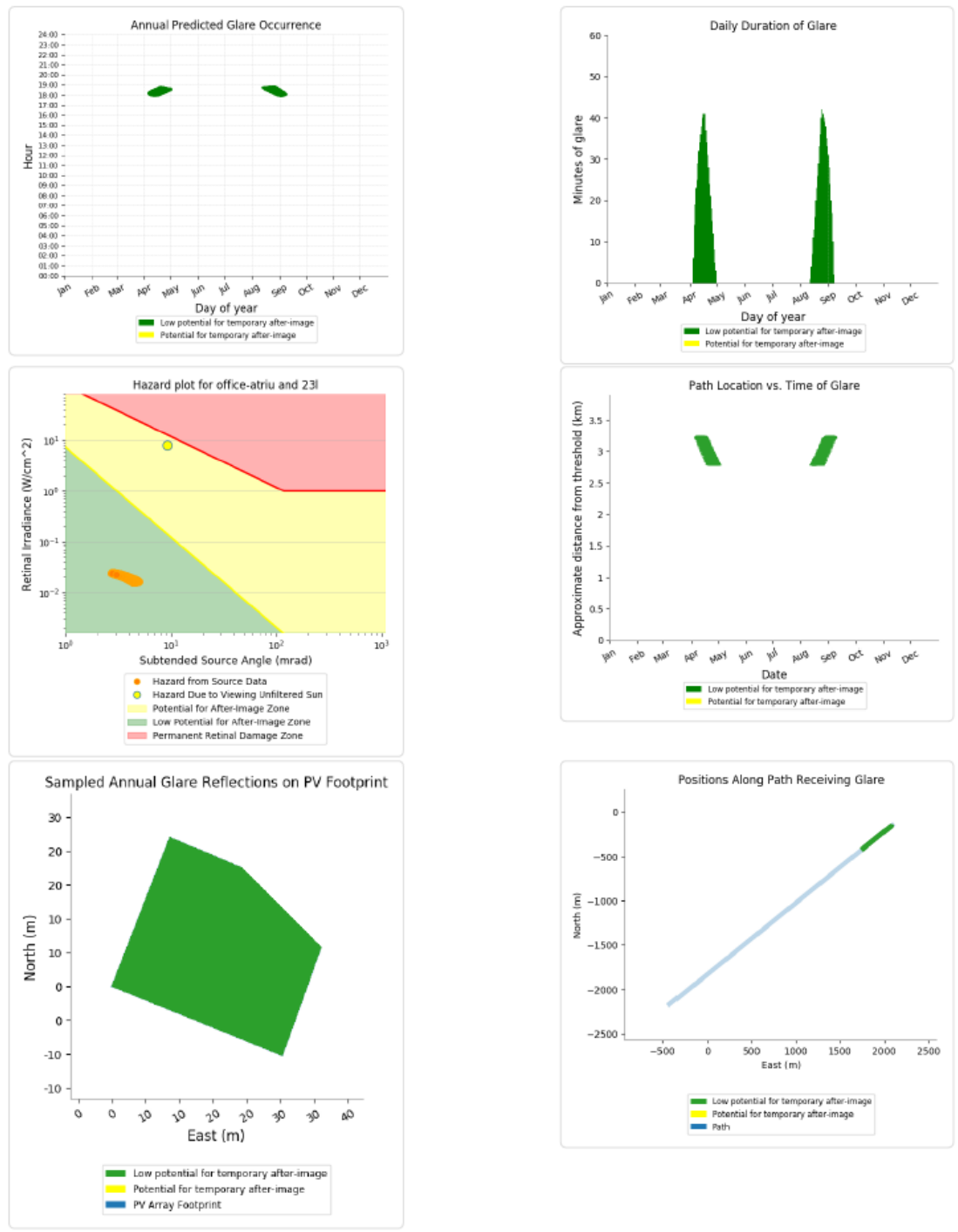


Forge

Office Atrium Roof and Skylight - 3-5 degrees - Receptor (23L)

PV array is expected to produce the following glare for observers on this flight path:

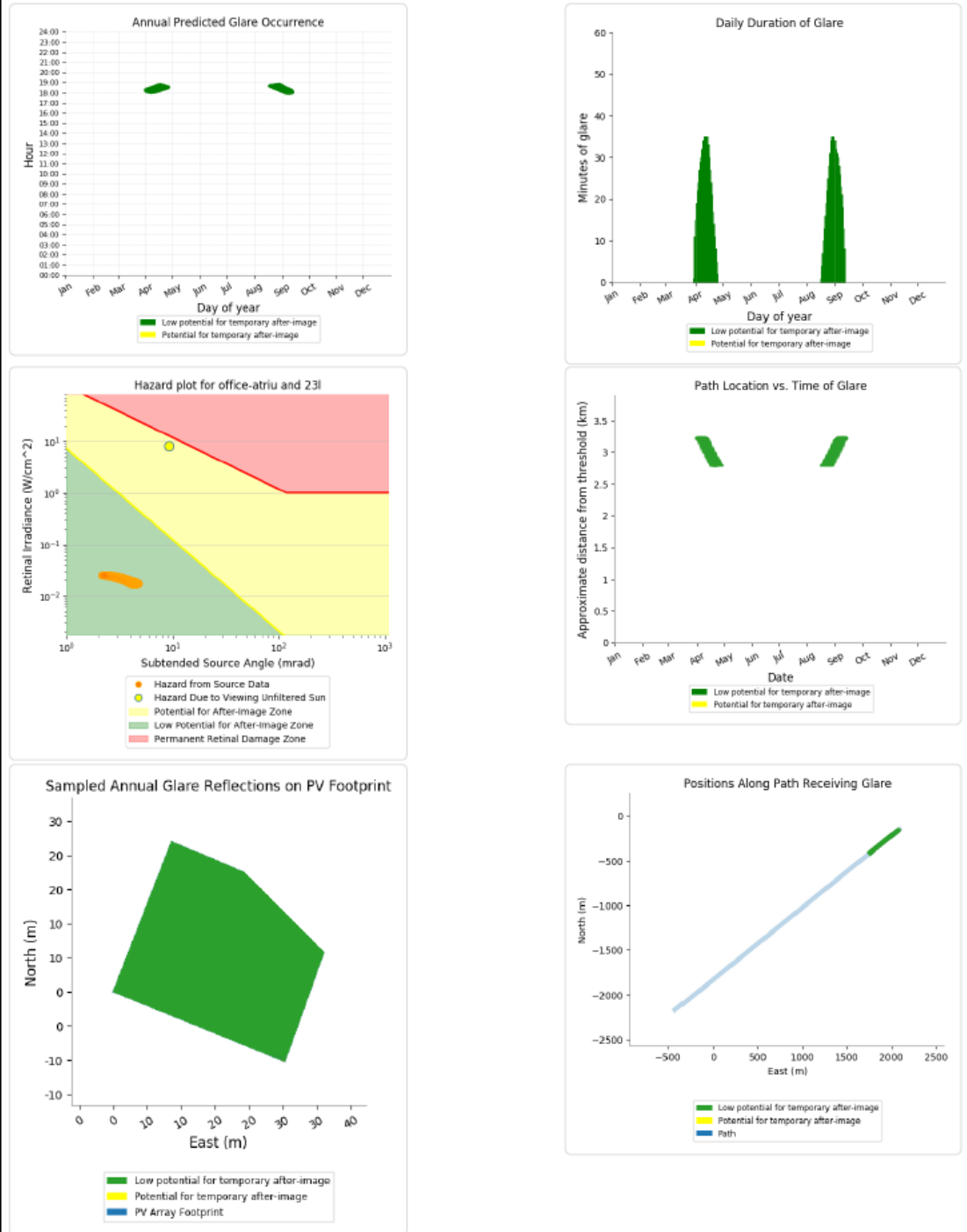
- 1,314 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



Office Atrium Roof and Skylight - Flat - Receptor (23L)

PV array is expected to produce the following glare for observers on this flight path:

- 1,293 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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