PAGERPOWER
Urban & Renewables

Solar Photovoltaic (PV) Glint and Glare Study

RPS Group PLC

Houston Solar Farm and Energy Storage Facility

May 2023





PLANNING SOLUTIONS FOR:

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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	December 2022	Initial issue
2	May 2023	Administrative reviews

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from the proposed development: a ground-mounted solar photovoltaic (PV) and energy storage development located in Renfrewshire, Scotland. This assessment pertains to the possible impact upon road safety, residential amenity and aviation activity associated with Glasgow Airport.

Overall Conclusions

Mitigation is recommended for a 200m section of the B790 and for two dwellings.

Solar reflections with a maximum glare intensity of having a 'low potential for temporary after-image' are predicted towards the ATC Tower at Glasgow Airport. This is the lowest intensity category within industry-standard modelling methodology for glare effects and is consistent with glare commonly encountered from outdoor surfaces.

Furthermore, there are mitigating factors (Section 5.2.3) that reduce the overall impact. Overall, it is assessed that the potential effects upon the ATC Tower could be operationally accommodated.

This report should be made available to the safeguarding team at Glasgow 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. There is no formal planning guidance for the assessment of solar reflections from solar panels towards roads and nearby dwellings. 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]. The guidance document sets out the methodology for assessing road safety, residential amenity and aviation activity with respect to solar reflections from solar panels.

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 where appropriate in line with the Sandia National Laboratories' FAA methodology[2]. The scenario in which a solar reflection can occur for all

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

[2] Formerly mandatory for on-airfield solar developments in the USA under the FAA's interim policy, superseded in 2021 with a policy that effectively requires individual airports to sign off on their on-airfield development as they see fit.

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 – Glasgow Airport

ATC Tower

Solar reflections with a maximum glare intensity of having a 'low potential for temporary after-image' are geometrically possible towards the ATC Tower at Glasgow Airport. This is the lowest intensity category within industry-standard modelling methodology for glare effects and is consistent with glare commonly encountered from outdoor surfaces.

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[4] for on-airfield solar. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach to consider glare towards the ATC Tower in an operational context.

There are mitigating factors (Section 5.2.3) that reduce the overall impact. In particular, solar reflections are predicted to occur for a short duration of time throughout the year, and intervening vegetation and terrain is predicted to decrease the impact significance.

Overall, it is assessed that the potential effects upon the ATC Tower could be operationally accommodated. This report should be made available to the safeguarding team at Glasgow Airport to understand their position along with any feedback or comments regarding the proposed development.

Runway 05 2-Mile Approach

Solar reflections are geometrically possible towards a 0.9-section of the 2-mile approach path towards runway 05. Solar reflections occur outside a pilot's primary field-of-view (50 degrees either side of the runway approach relative to the runway threshold) which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice.

Runway 23 2-Mile Approach

Solar reflections with intensities no greater than having a 'low potential for temporary after-image' are geometrically possible towards a 0.2-section of the 2-mile approach path towards runway 23, which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice.

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

[4] This guidance (FAA, 2013) has since been superseded (FAA, 2021) and airports are tasked with determining safety requirements themselves

Assessment Conclusions - Roads

Solar reflections are geometrically possible towards the following sections of road:

- 800m section of Houston Road;
- 980m section of Bridge of Weir Road;
- 3.3km section of the B790.

For all 800m and 980m sections of Houston Road and Bridge of Weir Road respectively, screening in the form of existing vegetation and buildings will significantly obstruct views of reflecting panels. Therefore, road users along these roads will not experience solar reflections in practice. **No impact is predicted, and mitigation is not required.**

For a 300m section of the B790, partial views of reflecting panels considered possible despite partial screening in the form of existing terrain. A low impact is predicted and mitigation is not required due to the following:

- Any effects would be fleeting in nature due to smalls gaps in the existing vegetation screening and therefore would not be considered a sustained reflection;
- The separation distance between a road user and closest reflecting panel is at least 200m;
- Any visible effects are likely to be limited to elevated road users, there are less HGV drivers using this road type than a dual carriageway.

For a separate 200m section of the B790, mitigation is recommended due to solar reflections occurring within a road user's primary field of view (50 degrees either side of the direction of travel) and a lack of sufficient mitigating factors.

Assessment Conclusions - Dwellings

Solar reflections are geometrically possible towards all 82 of the assessed dwellings. Significant screening of reflecting panels in the form of existing vegetation has been identified for 72 dwellings, for which no impact is predicted.

For eight dwellings, views of the reflecting panels are considered possible. A low impact is predicted and mitigation is not required due to the following:

- The duration of predicted effects is not significant;
- The separation distance between the dwelling and closest reflecting panel is sufficiently large;
- Any visible effects are likely to be limited to observers above the ground floor only.

For two dwellings, screening as per the landscape mitigation plan predicted to significantly obstruct views of reflecting panels, for which no impact is predicted. Mitigation is not required.

Mitigation Strategy

The strategy will overlap with other areas of the development process, including landscape and visual impacts. The reflecting areas that should be obscured from view, based on the proposed configuration, have therefore been defined in Sections 6.2 for roads. The mitigation strategy should address this accordingly.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 58 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 the proposed development: a ground-mounted solar photovoltaic (PV) and energy storage development located in Renfrewshire, Scotland. This assessment pertains to the possible impact upon road safety, residential amenity and aviation activity associated with Glasgow Airport.

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 and conclusions.

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[5] 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.

[5] These definitions are aligned with those presented within the Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) – published by the Department for Energy Security and Net Zero in March 2023 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 site layout[6] for the proposed development. The areas of solar photovoltaic panels are indicated by areas of blue.

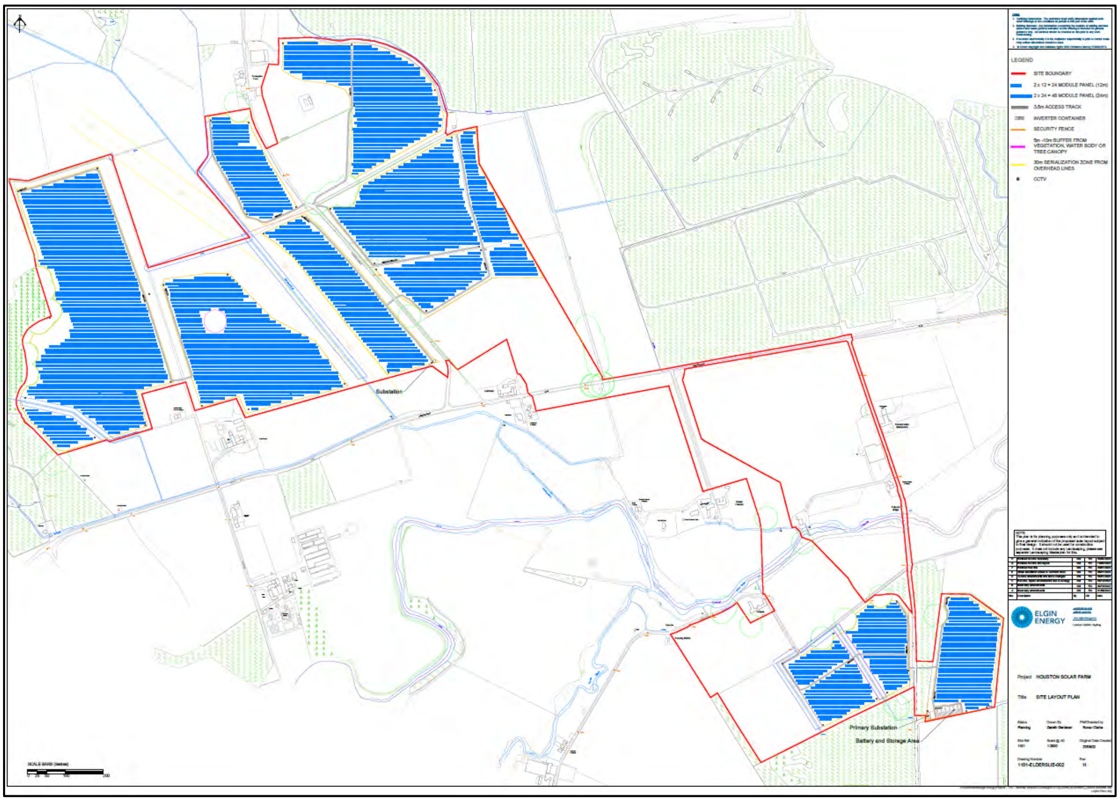

Figure 1 *Site layout*

[6] Source: 1101-ELDERSLIE-002RevH_230403-(Elderslie Site Layout Plan)

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 2 below shows the assessed reflector areas onto aerial imagery that have been used for modelling purposes.

Figure 2 *Assessed reflector areas*

The assessed reflector areas consider a 'worst-case scenario', which assumed total panel coverage of the entire site. In reality, panel arrays are separated by a distance of 2-8 meters.

2.4 Resolution

A resolution of 20m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 20m 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. 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

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

Panel Information	
Azimuth angle[7]	180°
Elevation tilt	25°
Assessed centre height[8] agl[9]	2.0m

Table 1 *Solar panel technical information*

2.6 Energy Storage Facility

The proposed energy storage facility will comprise 12 storage units, each of which look similar in appearance to a shipping container. No solar panels are to be implemented on the storage units or other reflective elements associated with this part of the project, and therefore have been excluded from further assessment.

[7] Orientation of the panels relative to True North (0°)

[8] The midpoint between the frame height above ground (0.8m) and the frame at the highest point (3.2m) bas been used as the assessed centre height

[9] 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

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. There is no formal planning guidance for the assessment of solar reflections from solar panels towards roads and nearby dwellings. 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[10]. The guidance document sets out the methodology for assessing road safety, residential amenity and aviation activity with respect to solar reflections from solar panels.

The Pager Power approach is to identify receptors, undertake geometric reflection calculations and review the scenario under which a solar reflection can occur, whilst comparing the results against available solar reflection studies.

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

- Specular[11] reflections of the Sun from solar panels and glass 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 still water and similar to those from glass. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment, including steel[12].

3.3 Background

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

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

[11] A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse reflection will reflect the incoming light and scatter it in many directions.

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

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. The method for identifying relevant receptors is explained in Section 4 of this report;
- 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 available. Pager Power has since reviewed the Sandia National Laboratories model and is developing its own intensity calculation model in line with Sandia National Laboratories' methodology. 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. Therefore, where the Pager Power geometrical analysis indicates that a solar reflection is geometrically possible, an intensity calculation in line with Sandia National Laboratories' methodology has also been completed[13].

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.

[13] Currently using the Forge Solar model, based on the Sandia methodology.

4 IDENTIFICATION OF RECEPTORS

4.1 Overview

The following section presents the relevant receptors assessed within this report. 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 Glasgow Airport. Information and the aerodrome chart can be found via the National Air Traffic Services (NATS) Aeronautical Information Publication (AIP).

4.2.1 Glasgow Airport Information

Glasgow Airport is a Civil Aviation Authority (CAA) licensed aerodrome, with one Air Traffic Control (ATC) Tower. The runway details are presented below:

- 05/23 measuring 2,661m by 45m (asphalt).

The aerodrome chart is shown on the following page. The location of the ATC Tower is indicated with a yellow circle.

Glasgow Airport is approximately 3.6km from the closest panel area pertaining to the proposed development. The location relative to the proposed development is illustrated in Figure 3 below.

Figure 3 *Glasgow Airport relative to the proposed development*

Figure 4 *Glasgow Airport 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. An estimated[14] height of 12m is used to model the eye-level of air traffic controllers within the ATC Tower. The ATC Tower is shown in Figure 5 below.

Figure 5 *ATC Tower at Glasgow Airport*

4.2.3 Runway Receptors

It is Pager Power's methodology to assess whether a solar reflection can be experienced on the approach paths for the associated runways. This is considered to be the most critical stage of the flight.

A geometric glint and glare assessment has been undertaken for all aircraft approach paths at Glasgow Airport. 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.

Runway receptors Runway Threshold to Receptor 2.0 denote the receptors along the 2-mile approach paths for each runway at 0.1-mile intervals.

The runway receptors, as well as the ATC Tower is illustrated in Figure 6 on the following page.

[14] Following a review of the 3D aerial imagery

Figure 6 *Aviation receptors for Glasgow Airport*

4.3 Ground-Based Receptors

4.3.1 Overview

There is no formal guidance with regard to the maximum distance at which glint and glare should be assessed. From a technical perspective, there is no maximum distance for potential reflections. The significance of a reflection however decreases with distance because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases. Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances.

Potential receptors within the associated assessment area are identified based on mapping and aerial photography of the region. The initial judgement is made based on high-level consideration of aerial photography and mapping i.e. receptors are excluded if it is clear from the outset that no visibility would be possible. A more detailed assessment is made if the modelling reveals a reflection would be geometrically possible.

4.3.2 Assessment Area

The above parameters and industry experience over a significant number of glint and glare assessments undertaken, shows that a 1km assessment area from the proposed development is considered appropriate for glint and glare effects on road users and dwellings. Reflections towards ground-based receptors located further north than any proposed panel are highly unlikely[15]. Therefore, receptors north of the most northern panel areas have not been modelled. The assessment area (white outlined area in the proceeding Figure 7) has been designed accordingly as 1km from the proposed development, disregarding the area to the north of the north-most solar panels.

[15] For fixed, south-facing panels at this latitude.

Figure 7 *Assessment Area*

4.4 Road Receptors

4.4.1 Road Receptors Overview

Road types can generally be categorised as:

- Major National – Typically a road with a minimum of two carriageways with a maximum speed limit of up to 70mph. These roads typically have fast moving vehicles with busy traffic;
- National – Typically a road with a one or more carriageways with a maximum speed limit 60mph or 70mph. These roads typically have fast moving vehicles with moderate to busy traffic density;
- Regional – Typically a single carriageway with a maximum speed limit of up to 60mph. The speed of vehicles will vary with a typical traffic density of low to moderate;
- Local – Typically roads and lanes with the lowest traffic densities. Speed limits vary.

Technical modelling is not recommended for local roads, where traffic densities are likely to be relatively low. Any solar reflections from the proposed development that are experienced by a road user along a local road would be considered low impact in the worst-case in accordance with the guidance presented in Appendix D. The analysis has also considered major national, national, and regional roads that:

- Are within the one-kilometre assessment area;
- Have a potential view of the panels.

4.4.2 Identified Road Receptors

The following sections of regional and national road have been identified within the assessment area with potential views of the panel area:

- 802m section of Houston Road – receptors 1 to 9;
- 981m section of Bridge of Weir Road – receptors 10 to 20;
- 3.28km section of the B790 – receptors 20 to 53.

Receptors 1 to 53 are placed approximately 100m apart along the identified road sections. An additional height of 1.5m is added to the assessed height to account for the eye-level of a typical road user[16].

Figure 8 on the following page shows the road receptors.

[16] This fixed height for the road receptors is for modelling purposes. Changes to the modelling height by a few metres is not expected to significantly change the modelling results. Views for elevated drivers are also considered in the results discussion, where appropriate.

Figure 8 *Road receptors*

4.5 Dwelling Receptors

4.5.1 Dwelling Receptors Overview

The analysis has considered dwellings that:

- Are within the one-kilometre assessment area; and
- Have a potential view of the panels.

In residential areas with multiple layers of dwellings, only the outer dwellings have been considered for assessment. This is because they will mostly obscure views of the solar panels to the dwellings behind them, which will therefore not be impacted by the proposed development because line of sight will be removed, or they will experience comparable effects to the closest assessed dwelling.

Additionally, in some cases, a single receptor point may be used to represent a small number of separate addresses. In such cases, the results for the receptor will be representative of the adjacent observer locations, such that the overall level of effect in each area is captured reliably.

4.5.2 Identified Dwelling Receptors

The assessed dwelling receptors are shown in Figure 9 on the following page. In total, 82 dwellings have been assessed. An additional 1.8m height above ground is used in the modelling to simulate the typical viewing height of an observer on the ground floor[17].

[17] Changes to this height are not significant, and views above the ground floor considered are considered where appropriate

Figure 9 *Dwelling receptors*

5 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

5.1 Overview

The following sub-section presents 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 Aviation Results

5.2.1 Overview

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 2 below along with the associated colour coding.

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

Table 2 *Glare intensity designation*

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

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.

5.2.2 Geometric Results and Discussion

The table on the following page present the following:

- Geometric modelling results;
- Glare intensity;
- Comment and predicted impact significance.

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.

Runway/Receptor	Geometric Modelling Result	Glare Intensity	Comment
ATC Tower	Solar reflections are geometrically possible towards the ATC Tower		Solar reflections with intensities no greater than having a 'low potential for temporary after-image' ('green' glare) towards the ATC Tower are not acceptable. Further analysis is carried out in Section 5.2.3
Runway 05	Solar reflections occur along a 0.9-mile section, between the threshold and 0.9 miles from the threshold		Solar reflections occur outside a pilot's primary field-of-view, which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice No further analysis required
Runway 23	Solar reflections occur along a 0.2-mile section, between the threshold and 0.2 miles from the threshold inside a pilot's primary field-of-view		Glare intensities are 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 No further analysis required

Table 3 *Geometric Modelling Results and Discussion for Glasgow Airport receptors*

5.2.3 ATC Tower Results Discussion

Solar reflections with a maximum glare intensity of having a 'low potential for temporary after-image' are geometrically possible towards the ATC Tower at Glasgow Airport. This is the lowest intensity category within industry-standard modelling methodology for glare effects and is consistent with glare commonly encountered from outdoor surfaces.

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 for on-airfield solar. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach to consider glare towards the ATC Tower in an operational context.

Figure 10 *Distance between ATC Tower and reflecting panel area*

Figure 11 *Viewpoint of reflecting panel area from ATC Tower*

The following can be concluded:

- The glare intensity is categorised as 'green' glare which is the lowest intensity;
- Solar reflections are possible for a total of 1,677 minute per year. This represents a small portion of time compared to average daylight hours[18] in any one year (approximately 0.63%);
- Solar reflections originate 3.8km away at its closest point which decreases the impact significance;
- Intervening vegetation and terrain exists in between the ATC Tower and reflecting panel area decreases the impact significance;
- This assessment has considered a worst-case scenario and modelled panels with a surface material of 'smooth glass without an anti-reflective coating'. In reality, solar panels will have an anti-reflective coating;
- The weather would have to be clear and sunny at the specific times when glare is possible.

5.2.4 ATC Tower Results Conclusion

It is assessed that reflections towards the ATC Tower can be operationally accommodated for based on factors such as the glare intensities being categorised as 'green', the total time duration of 'green' glare, and mitigating factors such as the separation distance and intervening vegetation and terrain. The findings of this report should be made available to the safeguarding

[18] Assuming an average of 12 hours of daylight per day (262,800 minutes per year).

team at Glasgow Airport as they have the deepest familiarity with their own operations, and consultation should be undertaken to better understand their position.

5.3 Road Results

5.3.1 Overview

The key considerations for road users along major national, national, and regional roads are:

- Whether a reflection is predicted to be experienced in practice; and
- The location of the reflecting panel relative to a road user's direction of travel.

Where solar reflections are not geometrically possible, or the reflecting panels are predicted to be significantly obstructed from view, no impact is predicted, and mitigation is not required.

Where solar reflections originate from outside of a road user's primary horizontal field of view (50 degrees either side relative to the direction of travel), or the closest reflecting panel is over 1km from the road user, the impact significance is low, and mitigation is not recommended.

Where solar reflections are predicted to be experienced from inside of a road user's primary field of view, expert assessment of the following factors is required to determine the impact significance and mitigation requirement:

- Whether the solar reflection originates from directly in front of a road user – a solar reflection that is directly in front of a road user is more hazardous than a solar reflection to one side;
- Whether visibility is likely for elevated drivers (relevant to dual carriageways and motorways[19]);
- The separation distance to the panel area. Larger separation distances reduce the proportion of an observer's field of view that is affected by glare;
- Whether a solar reflection is fleeting in nature. Small gap/s in screening, e.g. an access point to the site, may not result in a sustained reflection for a road user;
- The position of the Sun. Effects that coincide with direct sunlight appear less prominent than those that do not. The Sun is a far more significant source of light.

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, the impact significance is moderate, and mitigation is recommended.

Where solar reflections originate from directly in front of a road user and there are no mitigating factors, the impact significance is high, and mitigation is required.

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[19] There is typically a higher density of elevated drivers (such as HGVs) along dual carriageways and motorways compared to other types of road.

5.3.2 Geometric Results and Discussion

The table on the following page present the following:

- Geometric modelling results (bare earth terrain i.e. without consideration of screening);
- Desk-based review of identified screening;
- Consideration of relevant mitigating factors where appropriate;
- Predicted impact significance.

Road Receptor	Geometric Modelling Results (screening not considered)	Identified Screening	Relevant Factors	Predicted Impact Classification
1 – 16	Solar reflections geometrically possible **inside** a road user's primary field-of-view[20]	Screening in the form of existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact
17 – 20	Solar reflections geometrically possible **outside** a road user's primary field-of-view	Screening in the form of existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact
21 – 30	Solar reflections geometrically possible **inside** a road user's primary field-of-view	Screening in the form of existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact
31 – 33	Solar reflections geometrically possible **inside** a road user's primary field-of-view	Screening deemed not sufficient to significantly obstruct views of reflecting panels Mitigation recommended (Section 6.2)	Effects would be sustained for this section of road	Moderate

[20] 50 degrees either side relative to the direction of travel

Road Receptor	Geometric Modelling Results (screening not considered)	Identified Screening	Relevant Factors	Predicted Impact Classification
34 – 37	Solar reflections geometrically possible **inside** a road user's primary field-of-view	Screening in the form of existing vegetation predicted to decrease visibility of reflecting panels	Effects would be fleeting and more visible to elevated drivers Separation distance of at least 200m	Low
38 – 53	Solar reflections geometrically possible **inside** a road user's primary field-of-view	Screening in the form of existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact

Table 4 *Geometric Modelling Results and Predicted Impact Classification for road receptors*

5.3.3 Review of Available Imagery

A review of available imagery is presented in the following figures on the following pages. The cumulative reflecting panel areas are indicated by regions of yellow. The identified screening in the form of existing vegetation and buildings is outlined in orange and pink respectively. Streetview images are used to show the point-of-view of a road user at specific locations.

Figure 12 *Screening for road receptors 1 to 12*

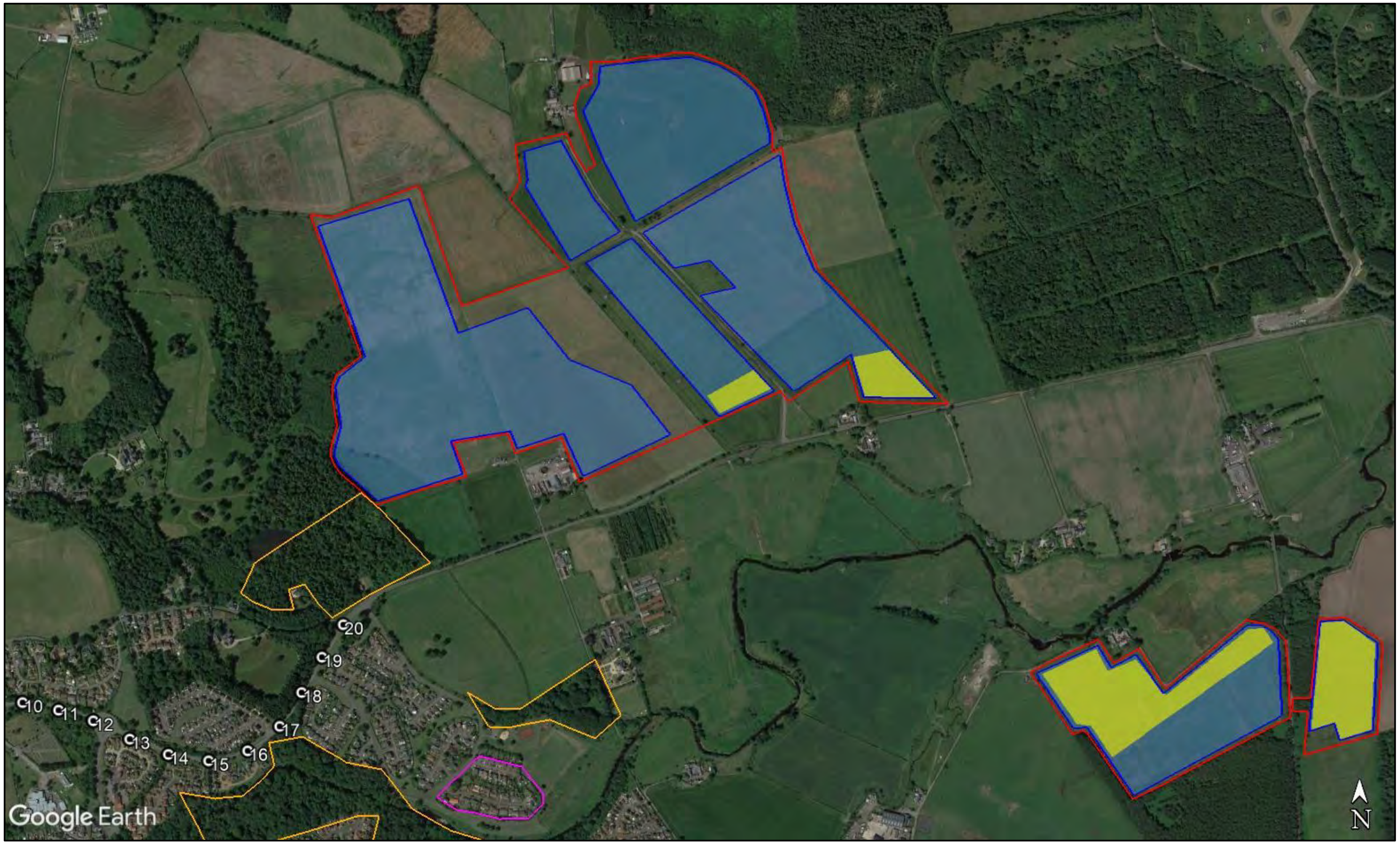

Figure 13 *Screening for road receptors 10 to 20*

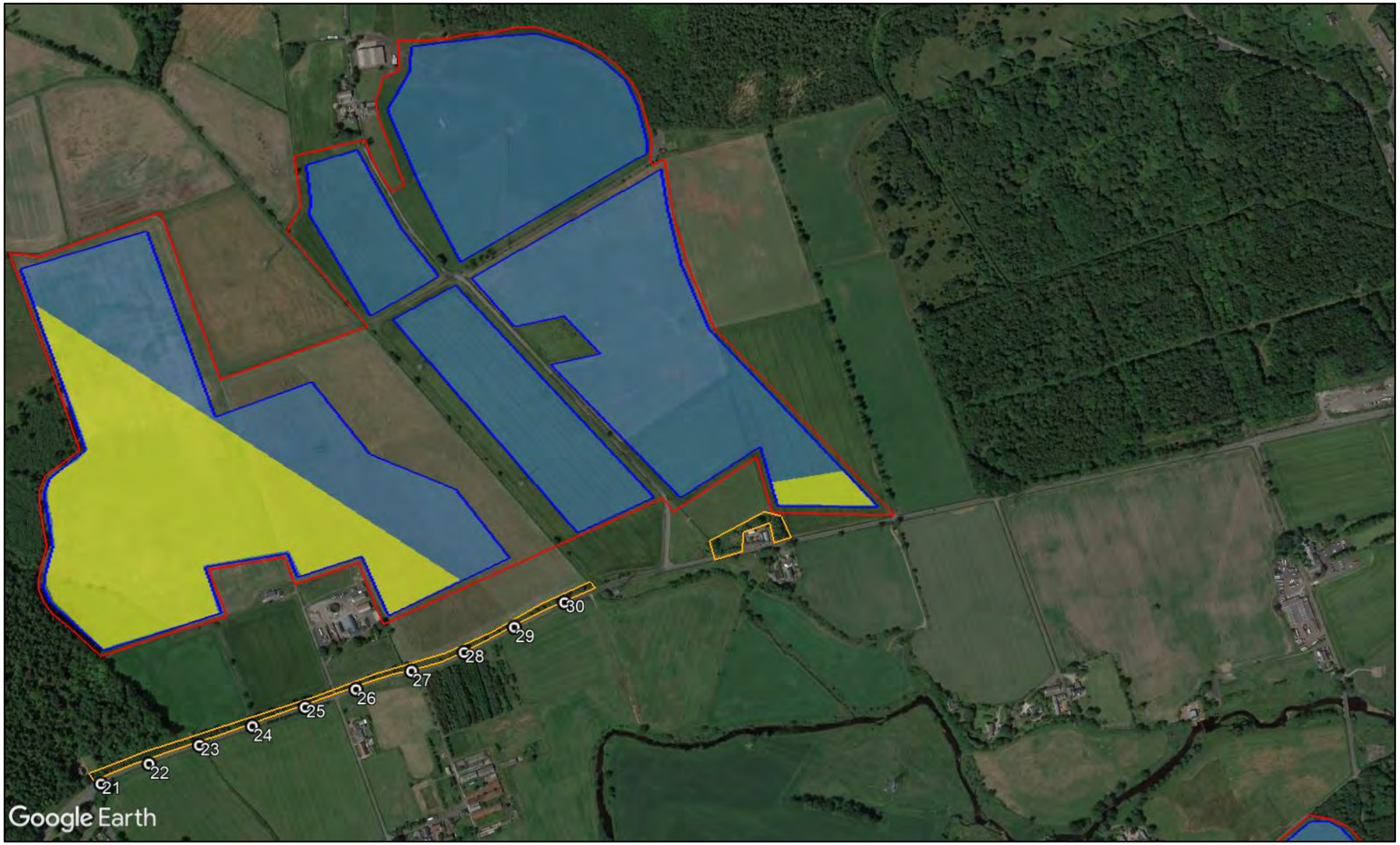

Figure 14 *Screening for dwellings 21 to 30*

Figure 15 *East point-of-view from road receptor 30*

Figure 16 *West point-of-view from road receptor 30*

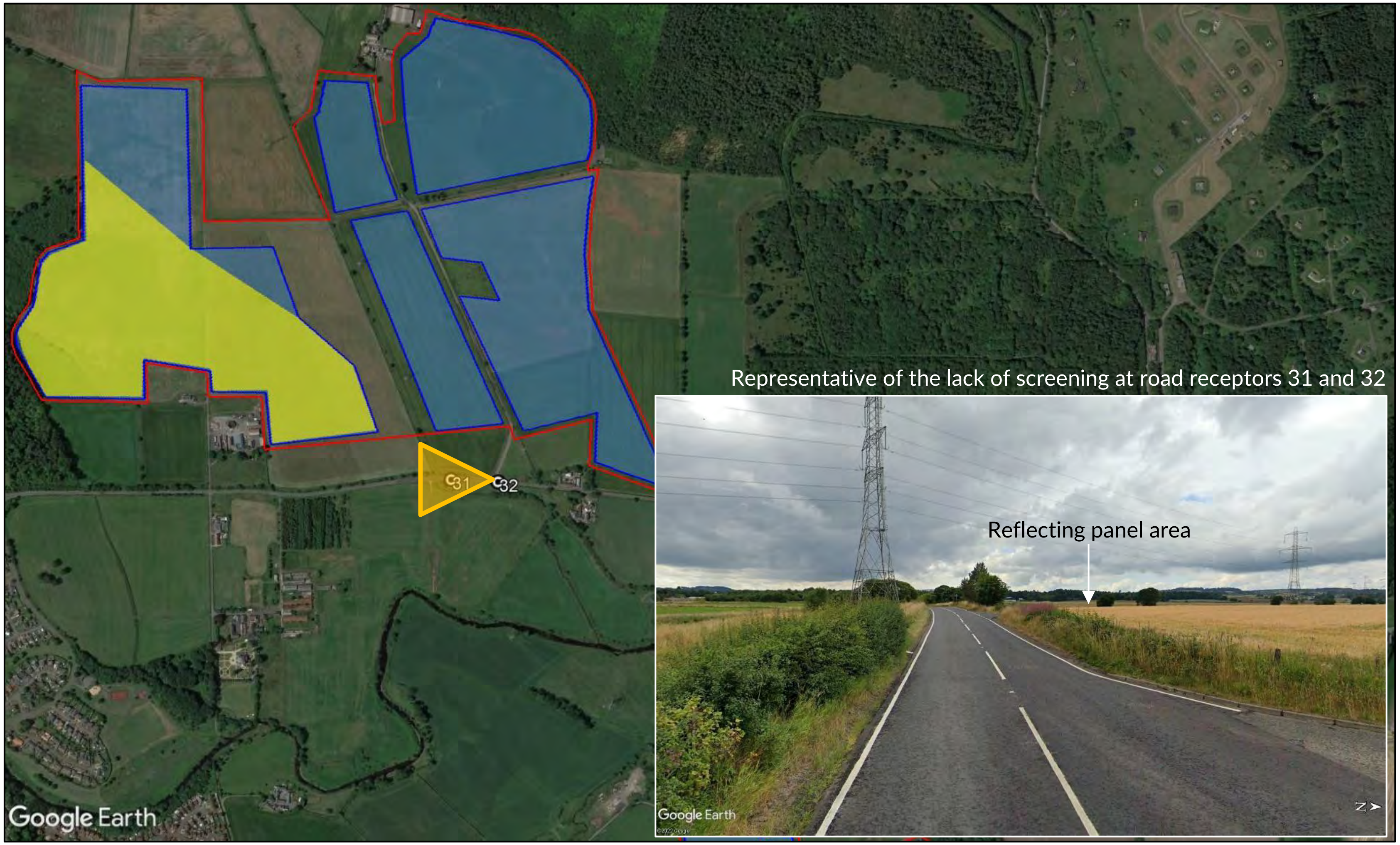

Figure 17 *Point-of-view from road receptor 31 and 32*

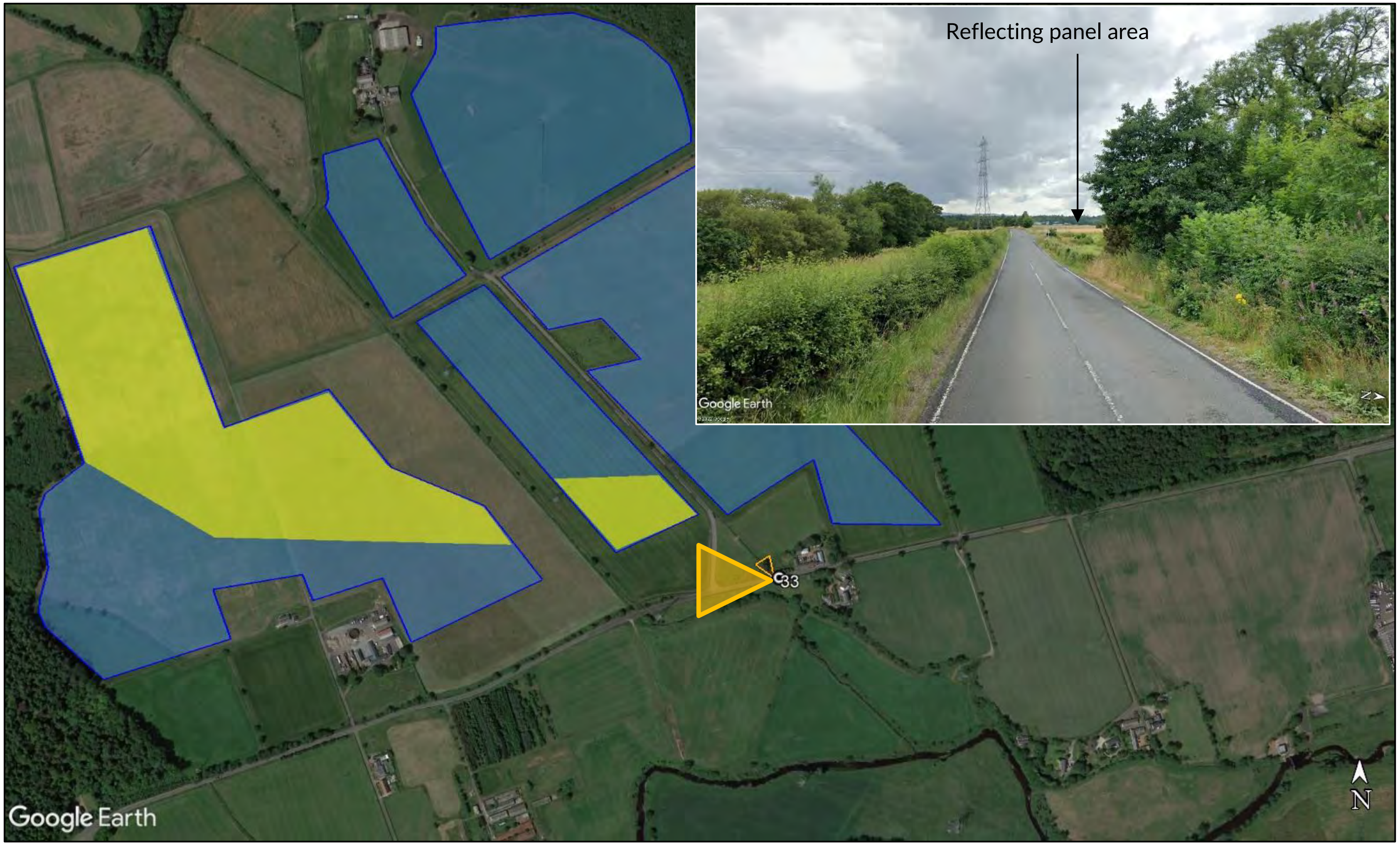

Figure 18 *Point-of-view from road receptor 33*

Figure 19 *Points-of-view for road receptors 34 and 37*

Figure 20 *Screening for road receptors 38 to 53*

5.4 Dwelling Results

5.4.1 Overview

The key considerations for residential dwellings are:

- Whether a reflection is predicted to be experienced in practice;
- The duration of the predicted effects, relative to thresholds of:
    - 3 months per year;
    - 60 minutes on any given day.

Where solar reflections are not geometrically possible, or the reflecting panels are predicted to be significantly obstructed from view, no impact is predicted, and mitigation is not required.

Where effects occur for **less** than three months per year and less than 60 minutes on any given day, or the closest reflecting panel is over 1km from the dwelling, the impact significance is low, and mitigation is not recommended.

Where reflections are predicted to be experienced for **more** than three months per year and/or for more than 60 minutes on any given day, expert assessment of the following mitigating factors is required to determine the impact significance and mitigation requirement:

- The separation distance to the panel area – larger separation distances reduce the proportion of an observer's field of view that is affected by glare;
- The position of the Sun – effects that coincide with direct sunlight appear less prominent than those that do not;
- Whether visibility is likely from all storeys – the ground floor is typically considered the main living space and has a greater significance with respect to residential amenity;
- Whether the dwelling appears to have windows facing the reflecting area – factors that restrict potential views of a reflecting area reduce the level of impact.

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, the impact significance is moderate, and mitigation is recommended.

If effects last for more than 3 months per year and for more than 60 minutes on any given day, and there are no mitigating factors, the impact significance is high, and mitigation is required.

5.4.2 Geometric Results and Discussion

The table on the following page present the following:

- Geometric modelling results (bare earth terrain i.e. without consideration of screening);
- Desk-based review of identified screening;
- Consideration of relevant mitigating factors where appropriate;
- Predicted impact significance.

Dwelling Receptor	Geometric Modelling Results (screening not considered)	Identified Screening	Relevant Factors	Predicted Impact Classification
1 – 21	Solar reflections geometrically possible for **more** than 3 months per year but **less** than 60 minutes per day	Existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact
22 – 46	Solar reflections geometrically possible for **less** than 3 months per year and **less** than 60 minutes per day	Existing vegetation and intervening terrain predicted to significantly obstruct views of reflecting panels	N/A	No impact
47 – 48	Solar reflections geometrically possible for **more** than 3 months per year but **less** than 60 minutes per day	Screening as per landscape mitigation plan predicted to significantly obstruct views of reflecting panels	N/A	No impact
49 – 54	Solar reflections geometrically possible for **less** than 3 months per year and **less** than 60 minutes per day	Existing vegetation predicted to significantly obstruct views of reflecting panels	N/A	No impact
55 – 63	Solar reflections geometrically possible for **more** than 3 months per year but **less** than 60 minutes per day	Existing vegetation and intervening terrain predicted to reduce impact significance	N/A	Low

Dwelling Receptor	Geometric Modelling Results (screening not considered)	Identified Screening	Relevant Factors	Predicted Impact Classification
64 – 82	Solar reflections geometrically possible for **more** than 3 months per year but **less** than 60 minutes per day	Existing vegetation and intervening terrain predicted to significantly obstruct views of reflecting panels	N/A	No impact

Table 5 *Geometric Modelling Results and Predicted Impact Classification for dwelling receptors*

5.4.3 Review of Available Imagery

A review of available imagery is presented in the following figures. The cumulative reflecting panel areas are indicated by regions of yellow. The identified screening in the form of existing vegetation and buildings is outlined in orange and pink respectively. Visible terrain[21] from a receptor is shown by regions shaded in green.

[21]High-level zones of theoretical visibility (ZTC Viewshed) generated by Google Earth. The green highlighted areas denote sections that are potentially visible to the observer at a height of 5.0m agl to account for views from ground and above ground levels.

Figure 21 *Screening for dwellings 1 to 2*

Figure 22 *Screening for dwellings 3 to 25*

Figure 23 *Screening for dwellings 26 to 46*

Figure 24 *Screening for dwellings 47 to 48*

Figure 25 *Screening for dwellings 49 to 54*

Figure 26 *Screening for dwellings 55 to 63*

Figure 27 *Screening for dwellings 64 to 67*

Figure 28 *Screening for dwellings 68 to 70*

Figure 29 *Screening for dwellings 71 to 75*

Figure 30 *Screening for dwelling 76*

Figure 31 *Screening for dwelling 77*

Figure 32 *Screening for dwellings 78 to 82*

6 MITIGATION STRATEGY

6.1 Overview

Ordinarily, mitigation for ground-based receptors is achieved where necessary via screening in the form of planting to obstruct views. The optimal strategy may therefore include:

- Site surveys to inform visibility more accurately;
- Provision of screening (planting or opaque fence) at the site boundary, or between the observer and reflecting area;
- Changes to site configuration or panel details such as back track angle or site layout.

Screening is likely to be possible for the proposed development and possible locations for screening are shown on the following pages (red lines). Reflecting panels should be screened from at least the ground floor of the dwellings and for a typical road user.

The strategy will overlap with other areas of the development process, including landscape and visual impacts. The reflecting areas that should be obscured from view, based on the proposed configuration, have therefore been defined in Sections 6.2 for roads. The mitigation strategy should address this accordingly.

The tailored planting (landscape mitigation plan) addresses the predicted impacts. The planting plan is provided within the Landscape and Visual Impact Assessment provided as part of the application for consent. The landscape mitigation plan is shown in Figure 33 on the following page.

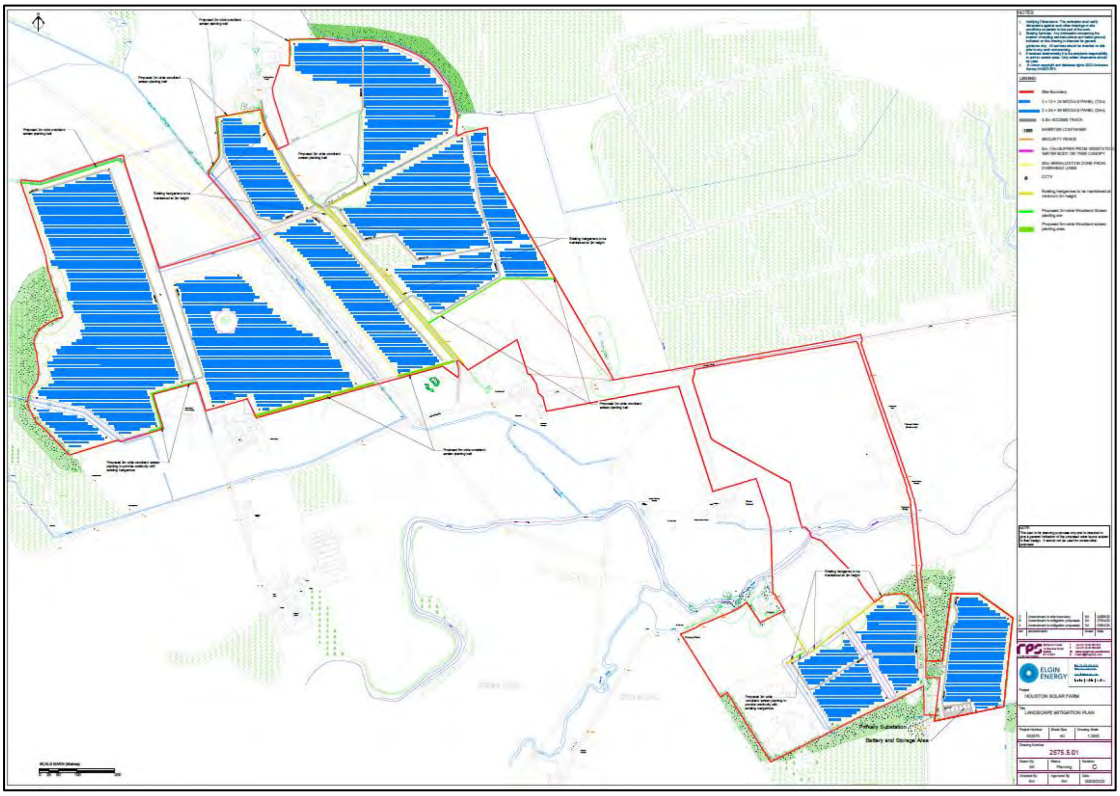

Figure 33 *Landscape mitigation plan*

6.2 Mitigation for Road Receptors

Mitigation is recommended for a 200m section of the B790, namely between road receptors 31 to 33. The reflecting panel areas which should be obstructed to sufficiently reduce the level of impact. The recommended screening locations are shown as the red areas in Figure 34 on the following page.

Figure 34 *Mitigation recommendation for road receptors 31 to 33*

7 OVERALL CONCLUSIONS

7.1 Assessment Conclusions – Glasgow Airport

7.1.1 ATC Tower

Solar reflections with a maximum glare intensity of having a 'low potential for temporary after-image' are geometrically possible towards the ATC Tower at Glasgow Airport. This is the lowest intensity category within industry-standard modelling methodology for glare effects and is consistent with glare commonly encountered from outdoor surfaces.

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[22] for on-airfield solar. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach to consider glare towards the ATC Tower in an operational context.

There are mitigating factors (Section 5.2.3) that reduce the overall impact. In particular, solar reflections are predicted to occur for a short duration of time throughout the year, and intervening vegetation and terrain is predicted to decrease the impact significance.

Overall, it is assessed that the potential effects upon the ATC Tower could be operationally accommodated. This report should be made available to the safeguarding team at Glasgow Airport to understand their position along with any feedback or comments regarding the proposed development.

7.1.2 Runway 05 2-Mile Approach

Solar reflections are geometrically possible towards a 0.9-section of the 2-mile approach path towards runway 05. Solar reflections occur outside a pilot's primary field-of-view which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice.

7.1.3 Runway 23 2-Mile Approach

Solar reflections with intensities no greater than having a 'low potential for temporary after-image' are geometrically possible towards a 0.2-section of the 2-mile approach path towards runway 23, which is acceptable in accordance with the associated guidance (Appendix D) and industry best practice.

7.2 Assessment Conclusions - Roads

Solar reflections are geometrically possible towards the following sections of road:

- 800m section of Houston Road;
- 980m section of Bridge of Weir Road;

[22] This guidance (FAA, 2013) has since been superseded (FAA, 2021) and airports are tasked with determining safety requirements themselves

- 3.3km section of the B790.

For all 800m and 980m sections of Houston Road and Bridge of Weir Road respectively, screening in the form of existing vegetation and buildings will significantly obstruct views of reflecting panels. Therefore, road users along these roads will not experience solar reflections in practice. **No impact is predicted, and mitigation is not required.**

For a 300m section of the B790, partial views of reflecting panels considered possible despite partial screening in the form of existing terrain. A low impact is predicted and mitigation is not required because:

- Any effects would be fleeting in nature due to smalls gaps in the existing vegetation screening and therefore would not be considered a sustained reflection;
- The separation distance between a road user and closest reflecting panel is at least 200m;
- Any visible effects are likely to be limited to elevated road users, there are less HGV drivers using this road type than a dual carriageway.

For a separate 200m section of the B790, mitigation is recommended due to solar reflections occurring within a road user's primary field of view (50 degrees either side of the direction of travel) and a lack of sufficient mitigating factors.

7.3 Assessment Conclusions - Dwellings

Solar reflections are geometrically possible towards all 82 of the assessed dwellings. Significant screening of reflecting panels in the form of existing vegetation has been identified for 72 dwellings, for which no impact is predicted.

For eight dwellings, views of the reflecting panels are considered possible. A low impact is predicted and mitigation is not required due to the following:

- The duration of predicted effects is not significant;
- The separation distance between the dwelling and closest reflecting panel is sufficiently large;
- Any visible effects are likely to be limited to observers above the ground floor only.

For two dwellings, screening as per the landscape mitigation plan predicted to significantly obstruct views of reflecting panels, for which no impact is predicted. Mitigation is not required.

7.4 Overall Conclusions

Mitigation is recommended for a 200m section of the B790 and for two dwellings.

Solar reflections with a maximum glare intensity of having a ‘low potential for temporary after-image’ are predicted towards the ATC Tower at Glasgow Airport. This is the lowest intensity category within industry-standard modelling methodology for glare effects and is consistent with glare commonly encountered from outdoor surfaces.

Furthermore, there are mitigating factors (Section 5.2.3) that reduce the overall impact. Overall, it is assessed that the potential effects upon the ATC Tower could be operationally accommodated.

This report should be made available to the safeguarding team at Glasgow 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, rather it is intended to give an overview of the important parameters and considerations that have informed this assessment.

UK Planning Policy

Renewable and Low Carbon Energy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[23] (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.'

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

Draft National Policy Statement for Renewable Energy Infrastructure

The Draft National Policy Statement for Renewable Energy Infrastructure (EN-3)[24] sets out the primary policy for decisions by the Secretary of State for nationally significant renewable energy infrastructure. Section 2.52 states:

'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*[25] *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.

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare has been determined when assessing the impact of solar reflections upon surrounding roads and dwellings. Therefore, the Pager Power approach is to determine whether a reflection from the proposed

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

[25] 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.

solar development is geometrically possible and then to compare the results against the relevant guidance/studies to determine whether the reflection is significant.

The Pager Power approach has been informed by the policy presented above, current studies (presented in Appendix B) and stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document[26] which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

Aviation Assessment Guidance

The UK Civil Aviation Authority (CAA) issued interim guidance relating to Solar Photovoltaic Systems (SPV) on 17 December 2010 and was subject to a CAA information alert 2010/53. The formal policy was cancelled on September 7th, 2012[27] however the advice is still applicable[28] 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 ALH[29], 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

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[26] Solar Photovoltaic Development Glint and Glare Guidance, Fourth Edition, September 2022. Pager Power.

[27] Archived at Pager Power

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

[29] Aerodrome Licence Holder.

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

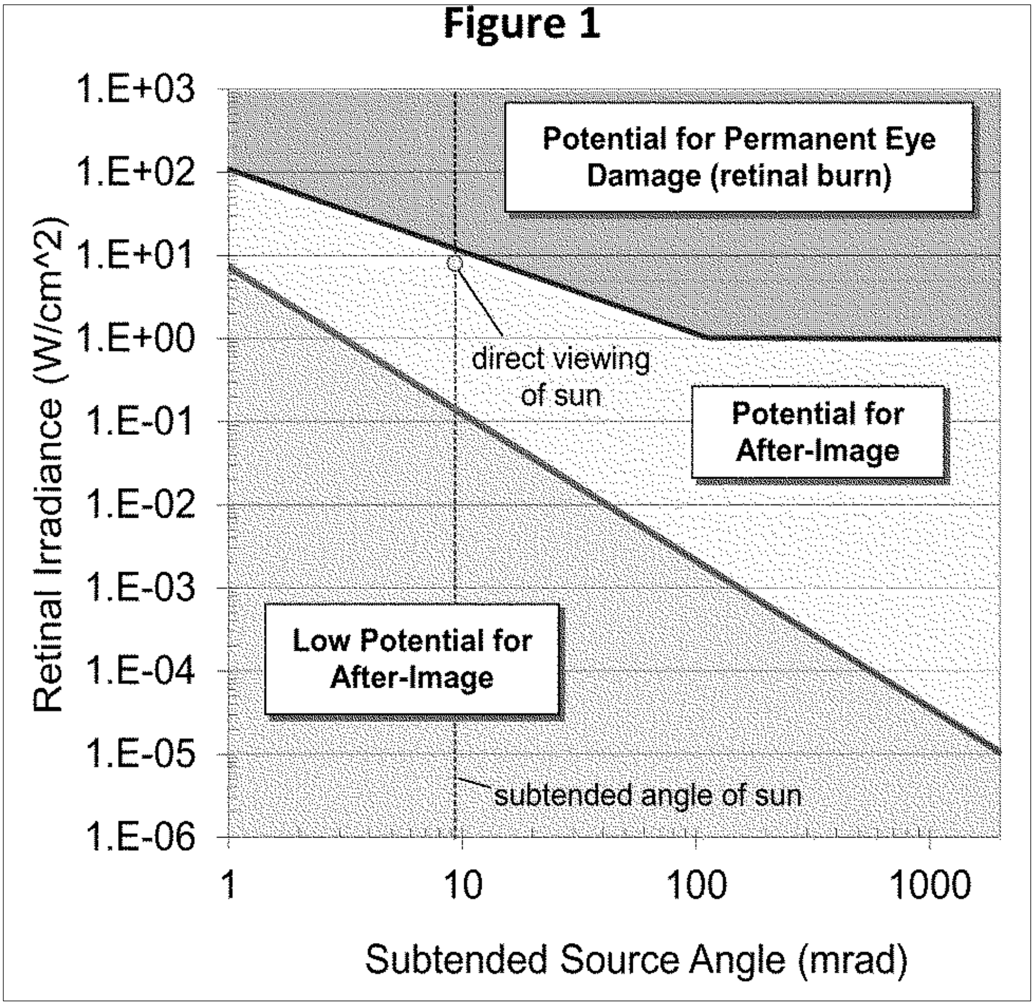
The most comprehensive guidelines available for the assessment of solar developments near aerodromes were produced initially in November 2010 by the United States Federal Aviation Administration (FAA) and updated in 2013.

The 2010 document is entitled '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[30] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'*[31]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[32].

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.*

[30] Archived at Pager Power
[31] 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
[32] 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 blindness*[33].
- *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*[34]*, flat, smooth surfaces reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces reflect light in a diffused or scattered manner and, therefore, the light will not be received as bright.*
- *Because the FAA has no specific standards for airport solar facilities and potential glare, the type of glare analysis may vary. Depending on site specifics (e.g., existing land uses, location and size of the project) an acceptable evaluation could involve one or more of the following levels of assessment:*
    - *A qualitative analysis of potential impact in consultation with the Control Tower, pilots and airport officials;*
    - *A demonstration field test with solar panels at the proposed site in coordination with FAA Tower personnel;*
    - *A geometric analysis to determine days and times when an impact is predicted.*
- *The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and system design.*
- ***1. Assessing Baseline Reflectivity Conditions** – Reflection in the form of glare is present in current aviation operations. The existing sources of glare come from glass windows, auto surface parking, rooftops, and water bodies. At airports, existing reflecting surfaces may include hangar roofs, surface parking, and glassy office buildings. To minimize unexpected glare, windows of air traffic control towers and airplane cockpits are coated with anti-reflective glazing. Operators also wear polarized eye wear. Potential glare from solar panels should be viewed in this context. Any airport considering a solar PV project should first review existing sources of glare at the airport and the effectiveness of measures used to mitigate that glare.*
- ***2. Tests in the Field** – Potential glare from solar panels can easily be viewed at the airport through a field test. A few airports have coordinated these tests with FAA Air Traffic*

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[33] 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.

[34] First figure in Appendix B.

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 question35 but still requires further research to definitively answer.*
- ***Experiences of Existing Airport Solar Projects*** *– Solar installations are presently operating at a number of airports, including megawatt-sized solar facilities covering multiple acres. Air traffic control towers have expressed concern about glint and glare from a small number of solar installations. These were often instances when solar installations were sited between the tower and airfield, or for installations with inadequate or no reflectivity analysis. Adequate reflectivity analysis and alternative siting addressed initial issues at those installations.*

Air Navigation Order (ANO) 2009

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

Endangering safety of an aircraft

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

Lights liable to endanger

221.

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[35] 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.

(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

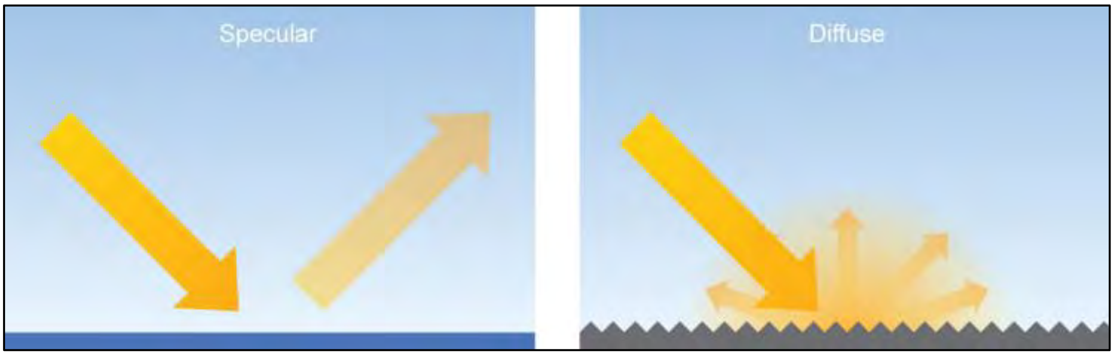
Overview

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 reflection will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance[36], 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

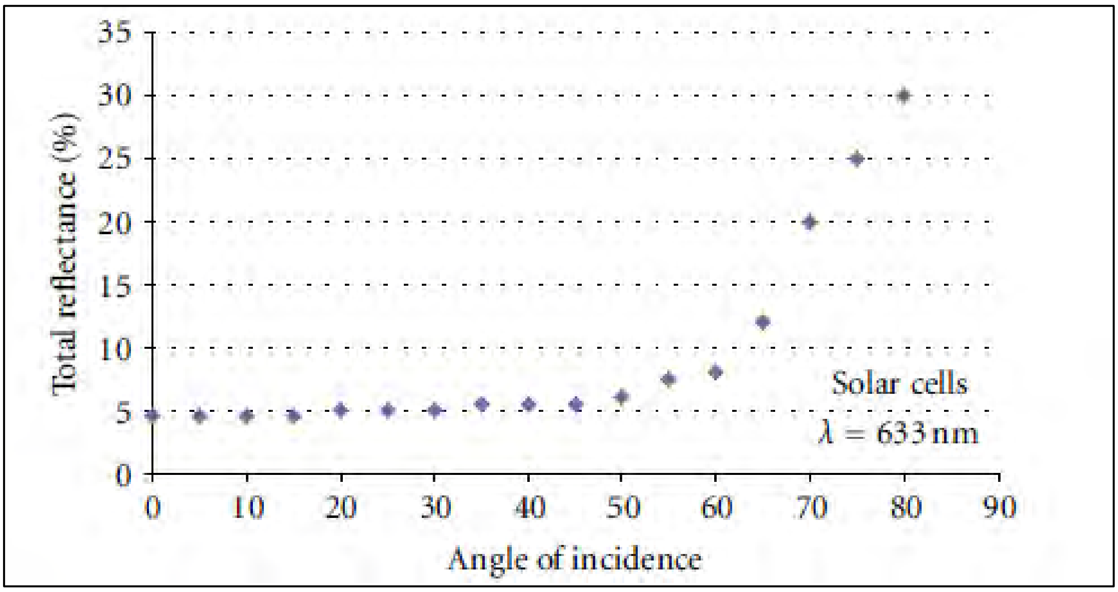
[36] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.

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*[37]". 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.

[37] 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"[38]

The 2018 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[39]
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.

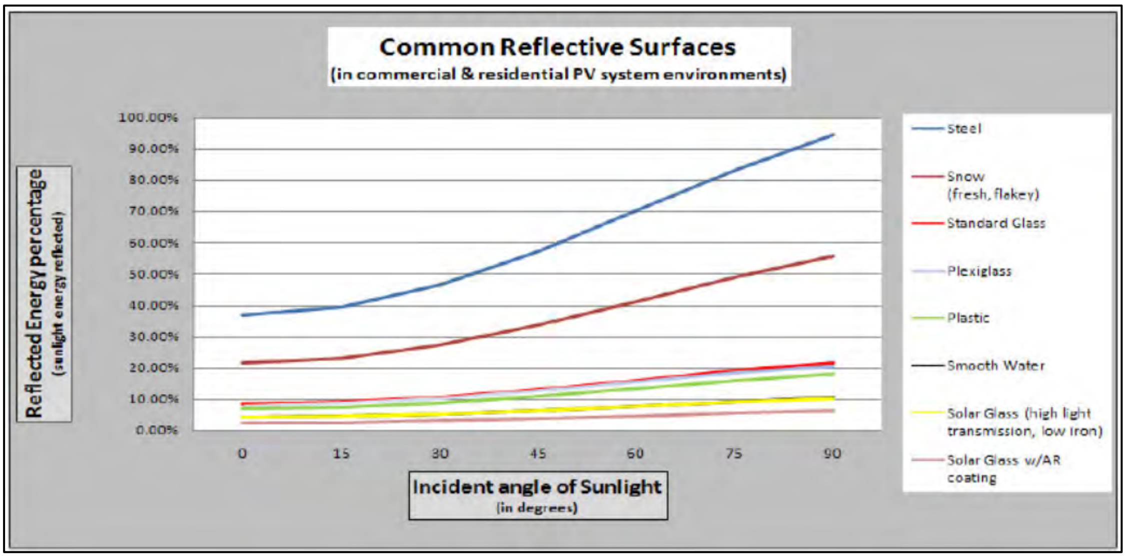
[38] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.

[39] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[40] 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.

[40] 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).

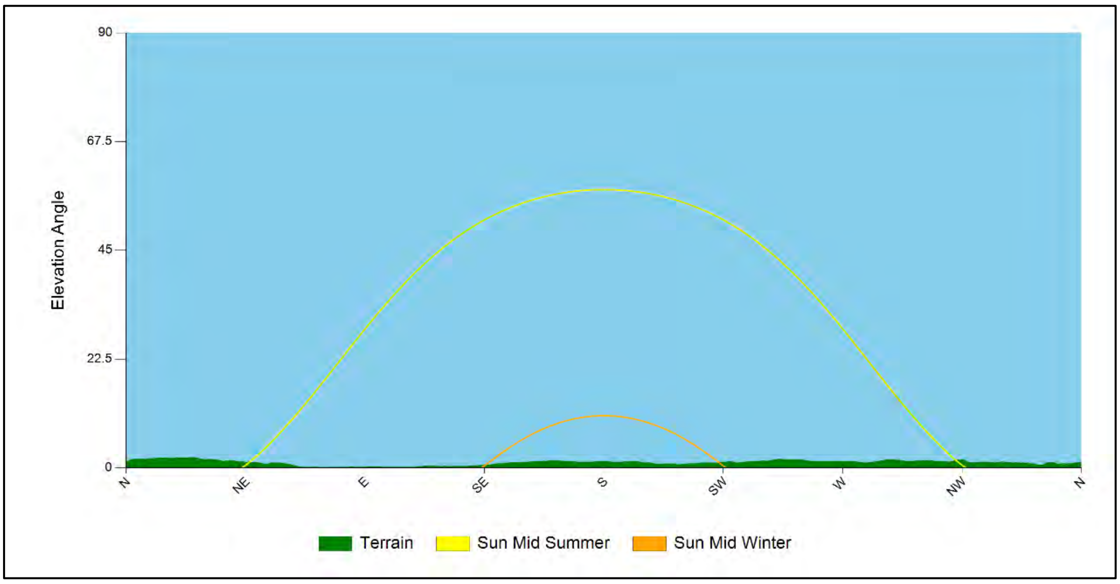
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- 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 paths

APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

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

Impact Significance Definition

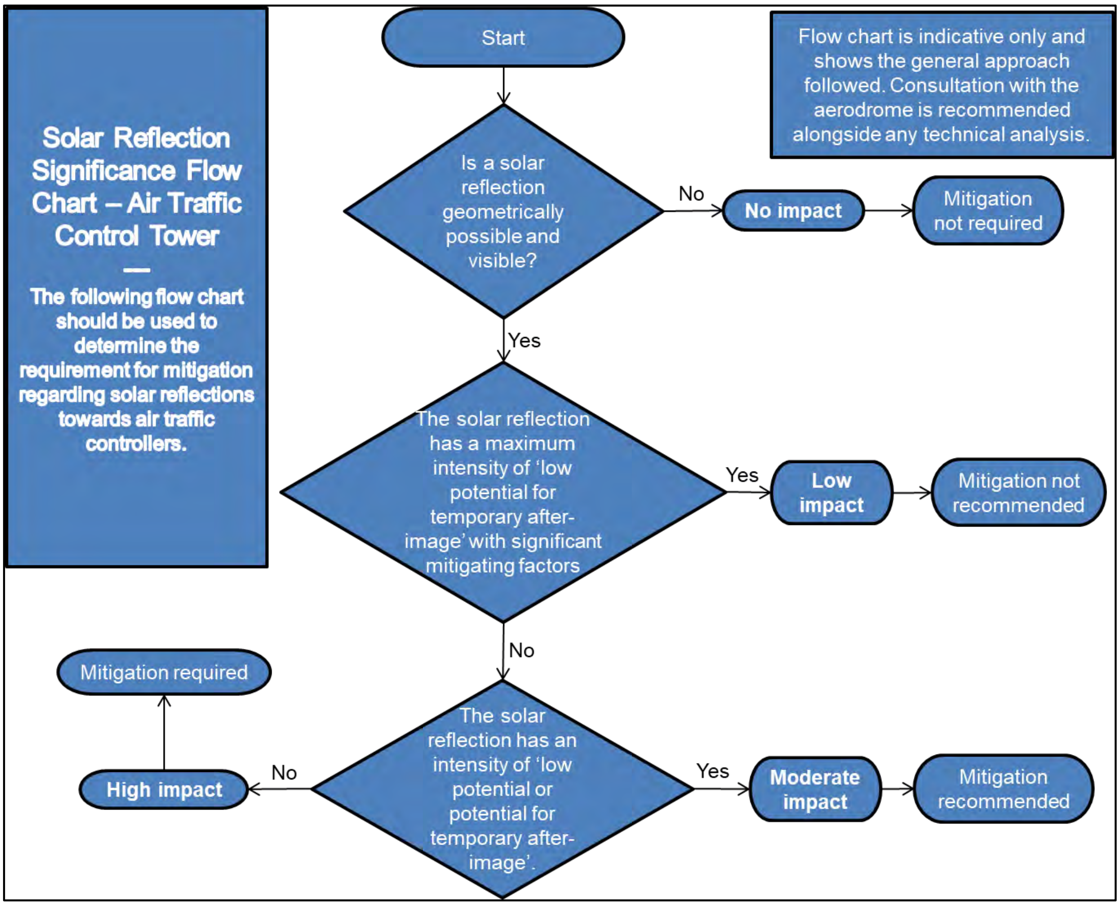
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation 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 Towers

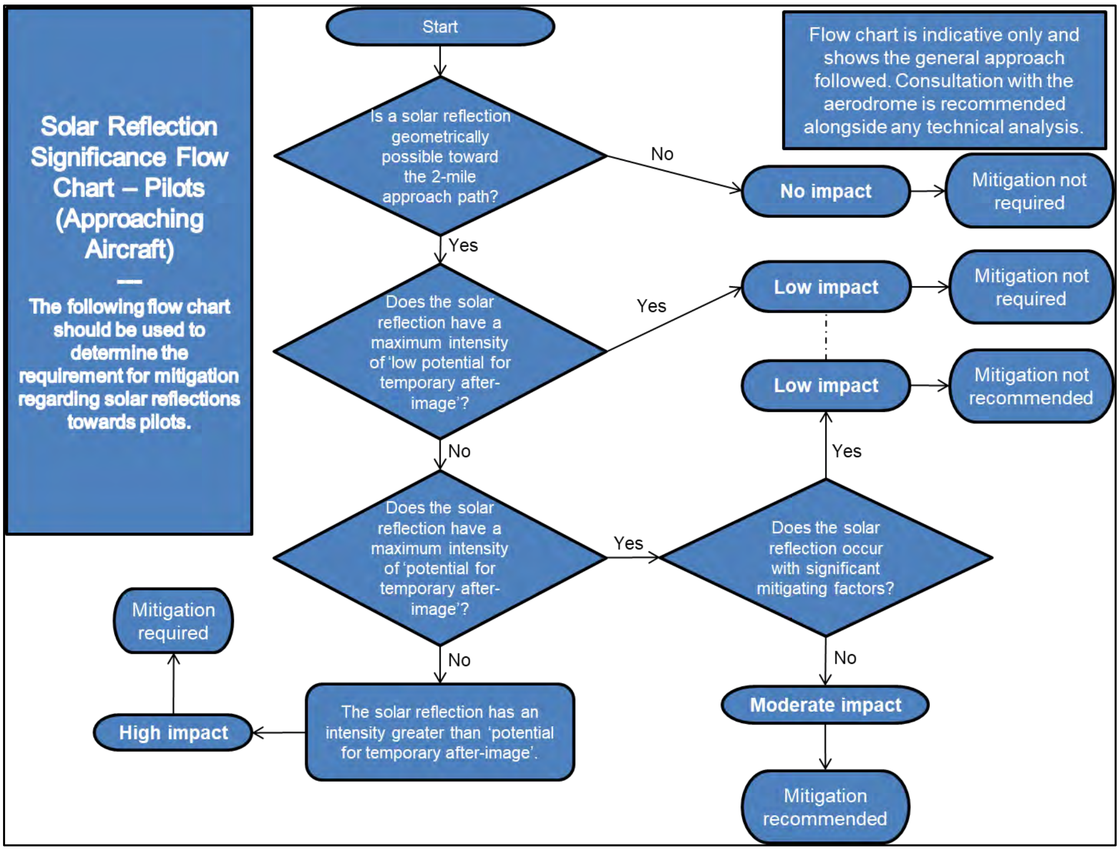
The flow chart presented below has been followed when determining the mitigation requirement for the ATC Tower.



ATC Tower receptor mitigation requirement flow chart

Impact Significance Determination for Approaching Aircraft

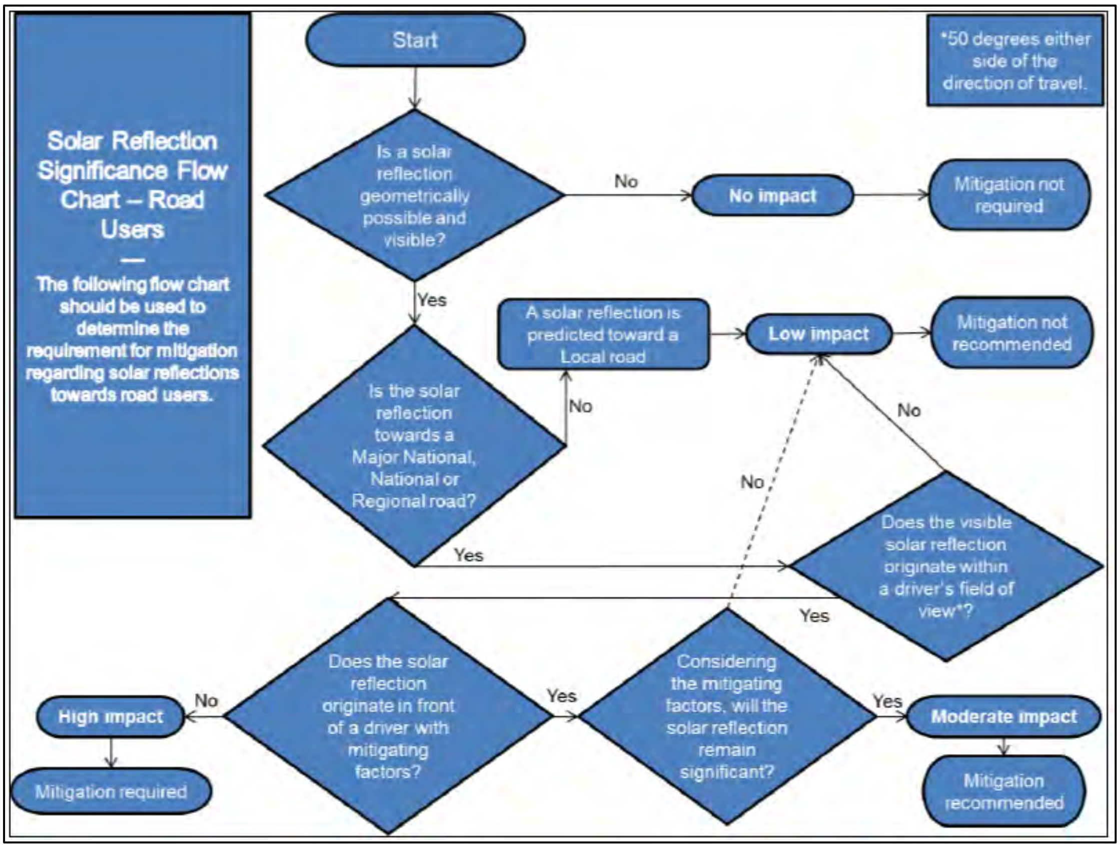
The flow chart presented below has been followed when determining the mitigation requirement for approaching aircraft.



Approaching aircraft receptor mitigation requirement flow chart

Impact Significance Determination for Road Receptors

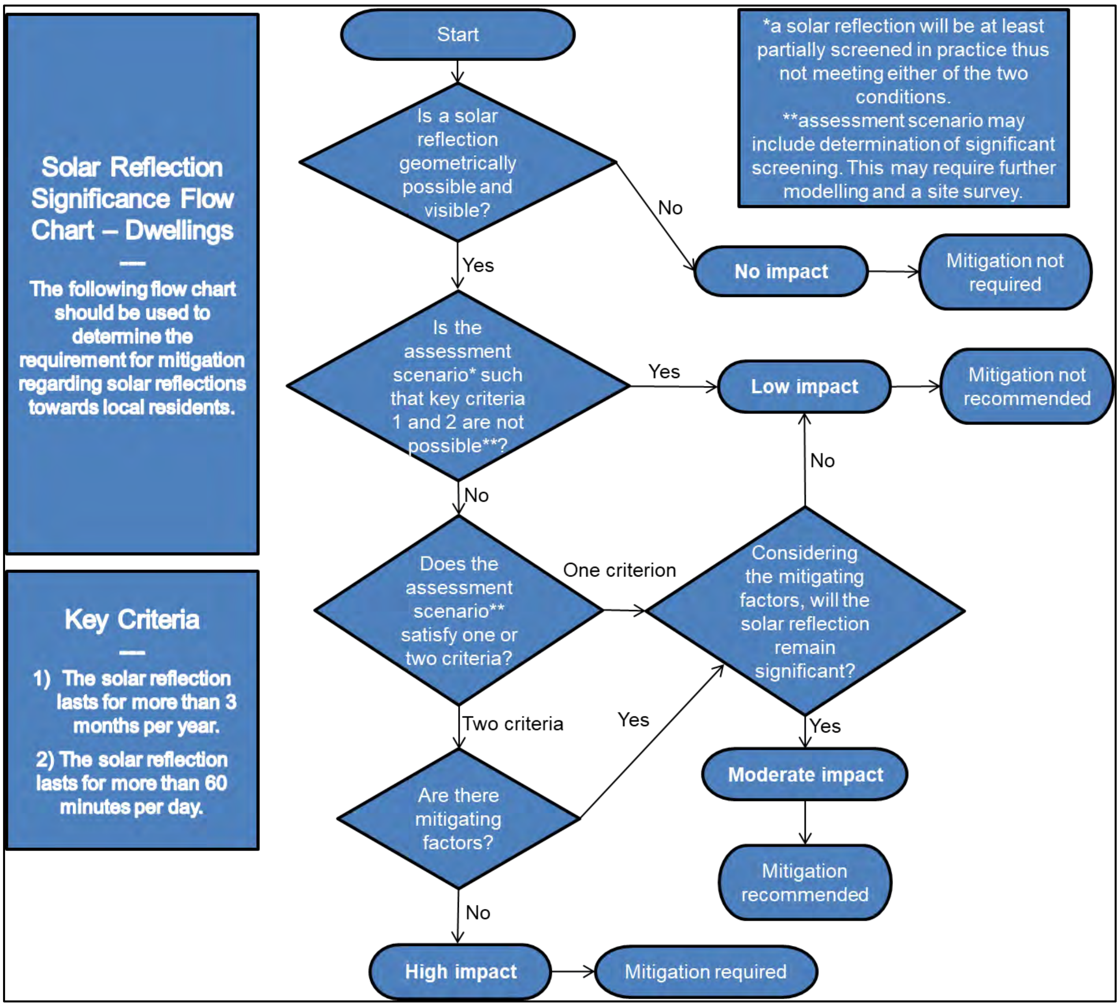
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Impact Significance Determination for Dwelling Receptors

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



Dwelling receptor mitigation requirement flow chart

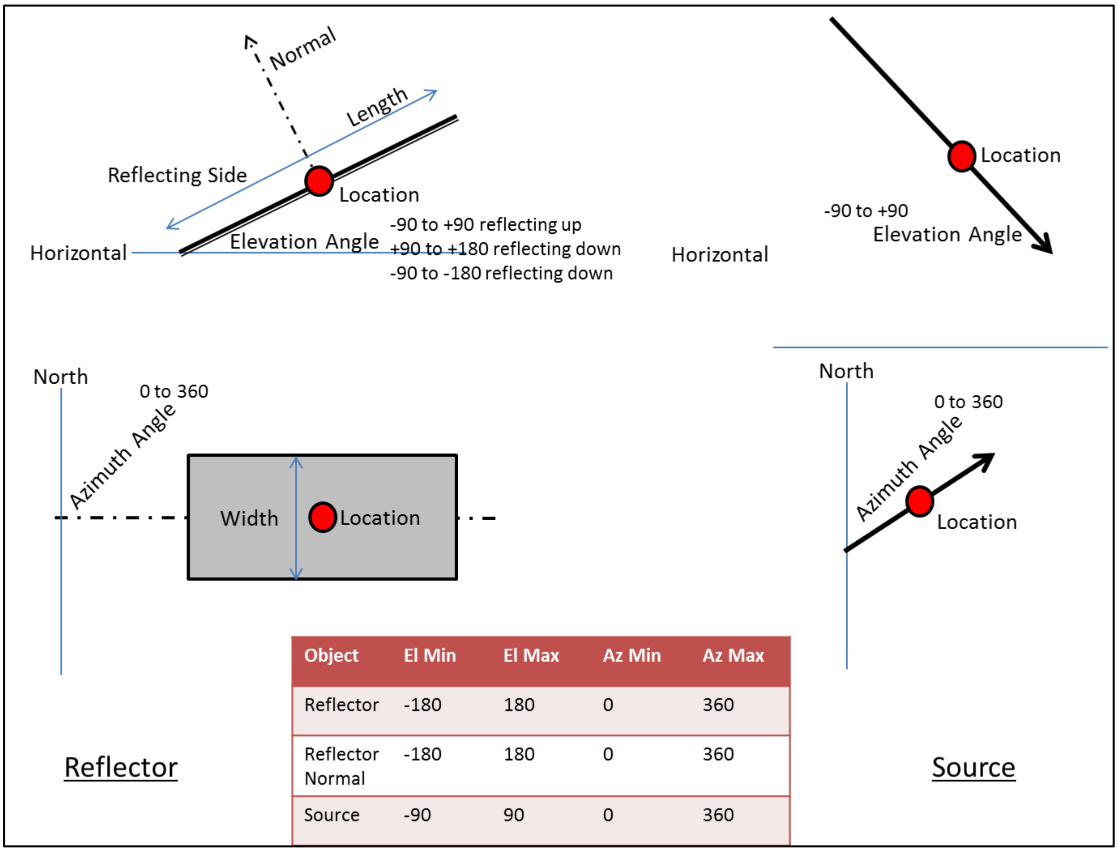
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

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)[41].

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

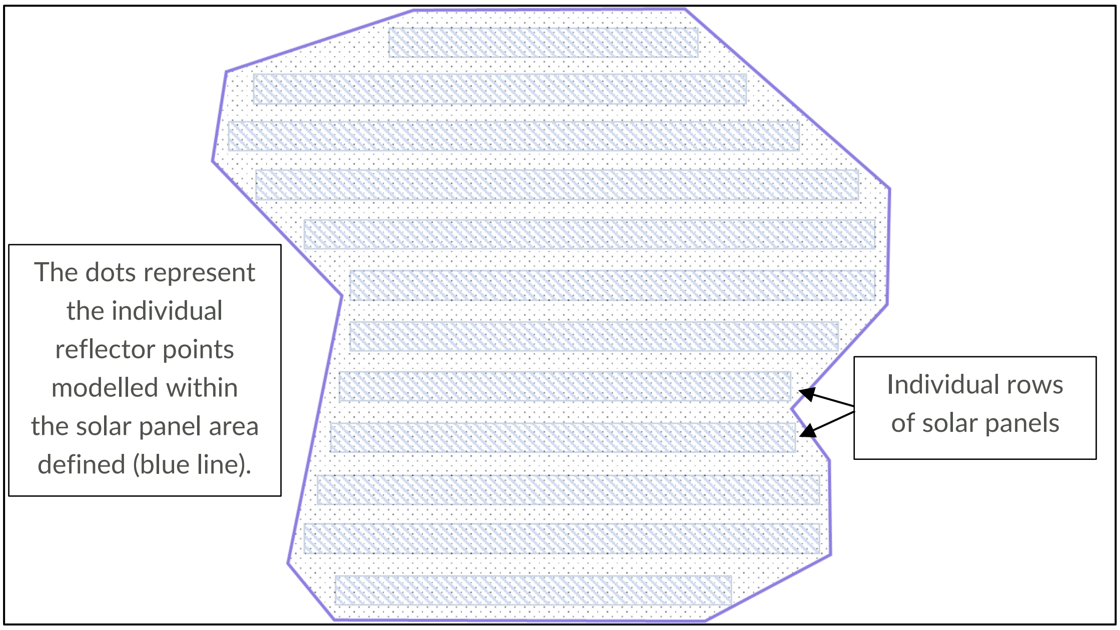
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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.

[41] 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[42]

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.

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

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Overview

Data and terrain heights are ascertained from OS Terrain 50 DTM data.

The ATC Tower at Glasgow Airport

An additional height of 12m is added to the ground elevation to model the eye-level of an air traffic controller.

Longitude (°)	Latitude (°)	Ground Height (m)	Assessed Height (m)
-4.43077	55.86950	6.00	18.00

ATC Tower

The Approach Paths for Glasgow Airport Runways

The tables in this section present the data for the assessed locations for aircraft on approach to runways. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway thresholds.

Runway 05

Receptor	Longitude (°)	Latitude (°)	Assessed Height (m) (amsl)
Threshold	-4.44905	55.86348	23.20
1	-4.45092	55.86248	31.63
2	-4.45279	55.86148	40.06
3	-4.45466	55.86048	48.50
4	-4.45653	55.85949	56.93
5	-4.45840	55.85849	65.37
6	-4.46027	55.85749	73.80
7	-4.46214	55.85649	82.23
8	-4.46400	55.85549	90.67
9	-4.46587	55.85449	99.10

Receptor	Longitude (°)	Latitude (°)	Assessed Height (m) (amsl)
10	-4.46774	55.85349	107.54
11	-4.46961	55.85249	115.97
12	-4.47148	55.85150	124.41
13	-4.47335	55.85050	132.84
14	-4.47522	55.84950	141.27
15	-4.47709	55.84850	149.71
16	-4.47896	55.84750	158.14
17	-4.48083	55.84650	166.58
18	-4.48269	55.84550	175.01
19	-4.48456	55.84450	183.45
20	-4.48643	55.84351	191.88

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

Runway 23

Receptor	Longitude (°)	Latitude (°)	Assessed Height (m) (amsl)
Threshold	-4.42179	55.87808	21.58
1	-4.41992	55.87907	30.01
2	-4.41805	55.88007	38.45
3	-4.41618	55.88107	46.88
4	-4.41430	55.88207	55.32
5	-4.41243	55.88307	63.75
6	-4.41056	55.88407	72.19
7	-4.40869	55.88506	80.62

Receptor	Longitude (°)	Latitude (°)	Assessed Height (m) (amsl)
8	-4.40682	55.88606	89.05
9	-4.40495	55.88706	97.49
10	-4.40308	55.88806	105.92
11	-4.40121	55.88906	114.36
12	-4.39934	55.89006	122.79
13	-4.39747	55.89105	131.22
14	-4.39560	55.89205	139.66
15	-4.39373	55.89305	148.09
16	-4.39186	55.89405	156.53
17	-4.38999	55.89505	164.96
18	-4.38812	55.89605	173.40
19	-4.38625	55.89704	181.83
20	-4.38438	55.89804	190.26

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

Road Receptor Data

The road receptor data is presented in the table below. An additional 1.5m height has been added to the elevation to account for the eye-level of an observer at these receptors.

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
1	-4.54580	55.86723	39.69	28	-4.52047	55.87038	9.50
2	-4.54422	55.86736	38.59	29	-4.51903	55.87078	8.50
3	-4.54263	55.86724	33.74	30	-4.51759	55.87118	8.31
4	-4.54130	55.86772	30.96	31	-4.51615	55.87148	8.50
5	-4.53979	55.86796	28.02	32	-4.51454	55.87174	7.50
6	-4.53820	55.86810	24.33	33	-4.51290	55.87193	7.50
7	-4.53662	55.86797	22.11	34	-4.51126	55.87213	7.50
8	-4.53513	55.86762	21.50	35	-4.50982	55.87230	7.50
9	-4.53357	55.86759	20.96	36	-4.50825	55.87249	6.50
10	-4.54474	55.86596	35.99	37	-4.50674	55.87267	6.50
11	-4.54319	55.86582	30.43	38	-4.50504	55.87288	5.50
12	-4.54197	55.86555	24.27	39	-4.50360	55.87305	5.50
13	-4.54045	55.86516	21.50	40	-4.50203	55.87324	5.50
14	-4.53896	55.86481	21.50	41	-4.50053	55.87342	4.50
15	-4.53740	55.86466	20.31	42	-4.49882	55.87363	4.50
16	-4.53588	55.86487	16.30	43	-4.49738	55.87380	3.50
17	-4.53461	55.86542	15.84	44	-4.49581	55.87398	3.50
18	-4.53375	55.86617	18.50	45	-4.49404	55.87419	2.50
19	-4.53296	55.86695	18.46	46	-4.49266	55.87436	2.50

20	-4.53212	55.86767	20.50	47	-4.49102	55.87453	2.50
21	-4.53085	55.86828	17.72	48	-4.48951	55.87405	2.59
22	-4.52949	55.86860	16.30	49	-4.48821	55.87393	2.50
23	-4.52805	55.86889	11.50	50	-4.48644	55.87413	2.50
24	-4.52653	55.86920	10.50	51	-4.48506	55.87429	2.50
25	-4.52502	55.86950	10.50	52	-4.48350	55.87450	2.50
26	-4.52357	55.86979	10.36	53	-4.48233	55.87478	2.50
27	-4.52198	55.87008	9.50				

Road Receptor Data

Dwelling Receptor Data

The dwelling receptor data is presented in the table below. An additional 1.8m height has been added to the elevation to account for the eye-level of an observer at these receptors.

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
1	-4.52387	55.87946	13.80	42	-4.52569	55.86445	11.73
2	-4.52366	55.87892	14.27	43	-4.52530	55.86440	11.62
3	-4.54339	55.87639	31.80	44	-4.52513	55.86411	10.97
4	-4.54333	55.87598	29.71	45	-4.52485	55.86387	10.80
5	-4.54432	55.87203	35.96	46	-4.52465	55.86361	10.80
6	-4.54400	55.87165	35.98	47	-4.52601	55.87127	10.80
7	-4.54485	55.87112	37.46	48	-4.52335	55.87074	11.80
8	-4.54468	55.87082	34.46	49	-4.52349	55.86904	9.80
9	-4.54423	55.87077	33.82	50	-4.52338	55.86880	9.80
10	-4.54405	55.87069	33.00	51	-4.52185	55.86720	9.80

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
11	-4.54316	55.87061	31.36	52	-4.52115	55.86732	9.59
12	-4.54065	55.86776	31.09	53	-4.52206	55.86674	10.27
13	-4.54009	55.86773	28.80	54	-4.52114	55.86666	9.80
14	-4.53955	55.86775	26.80	55	-4.52150	55.86331	10.62
15	-4.53917	55.86780	26.98	56	-4.52136	55.86347	10.10
16	-4.53888	55.86832	24.80	57	-4.52115	55.86364	10.35
17	-4.53867	55.86787	24.80	58	-4.52096	55.86375	10.80
18	-4.53827	55.86786	24.59	59	-4.52057	55.86382	10.80
19	-4.53794	55.86788	25.45	60	-4.52041	55.86369	10.80
20	-4.53750	55.86792	25.15	61	-4.51856	55.86408	12.80
21	-4.53654	55.86802	22.22	62	-4.51844	55.86435	12.29
22	-4.53667	55.86731	22.80	63	-4.51812	55.86415	12.67
23	-4.53416	55.86815	21.80	64	-4.51200	55.87211	7.80
24	-4.53392	55.86835	21.80	65	-4.51117	55.87182	7.57
25	-4.53142	55.86843	18.62	66	-4.51159	55.87157	7.80
26	-4.53093	55.86725	19.00	67	-4.51115	55.87161	7.13
27	-4.53065	55.86705	19.80	68	-4.50917	55.86388	8.17
28	-4.53029	55.86691	19.55	69	-4.50931	55.86372	8.27
29	-4.52992	55.86649	19.41	70	-4.50971	55.86286	10.96
30	-4.52965	55.86652	19.62	71	-4.50645	55.86946	6.80
31	-4.52945	55.86625	18.34	72	-4.50536	55.86911	5.80

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
32	-4.52925	55.86611	17.18	73	-4.50409	55.86945	5.80
33	-4.52905	55.86601	17.16	74	-4.50312	55.86974	5.80
34	-4.52882	55.86595	16.78	75	-4.50121	55.86726	7.60
35	-4.52831	55.86580	12.86	76	-4.49609	55.87173	3.80
36	-4.52812	55.86588	13.33	77	-4.49021	55.86256	11.56
37	-4.52757	55.86535	11.62	78	-4.49025	55.87322	3.80
38	-4.52732	55.86538	11.67	79	-4.48953	55.87378	3.64
39	-4.52706	55.86529	11.70	80	-4.48949	55.87044	3.80
40	-4.52661	55.86462	11.80	81	-4.48929	55.87008	3.80
41	-4.52616	55.86454	11.80	82	-4.48312	55.87261	2.80

Dwelling receptor data

Modelled Reflector Areas

The modelled reflector areas are presented in the tables below.

Panel Area 1

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.53234	55.87317	12	-4.52344	55.87191
2	-4.53251	55.87293	13	-4.52267	55.87095
3	-4.53230	55.87206	14	-4.51920	55.87188
4	-4.53254	55.87160	15	-4.52075	55.87299
5	-4.53257	55.87139	16	-4.52322	55.87355
6	-4.53239	55.87118	17	-4.52488	55.87472
7	-4.53085	55.87040	18	-4.52765	55.87415
8	-4.52748	55.87100	19	-4.52962	55.87715

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
9	-4.52795	55.87174	20	-4.53322	55.87653
10	-4.52557	55.87196	21	-4.53133	55.87362
11	-4.52529	55.87157			

Panel Area 1

Panel Area 2

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.52503	55.87821	5	-4.52122	55.87641
2	-4.52488	55.87757	6	-4.52227	55.87717
3	-4.52497	55.87743	7	-4.52355	55.87844
4	-4.52319	55.87578			

Panel Area 2

Panel Area 3

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.51505	55.87286	3	-4.52255	55.87572
2	-4.52074	55.87627	4	-4.51724	55.87229

Panel Area 3

Panel Area 4

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.51526	55.87839	8	-4.51973	55.88026
2	-4.51525	55.87860	9	-4.52200	55.88010
3	-4.51550	55.87914	10	-4.52203	55.87972
4	-4.51584	55.87955	11	-4.52266	55.87909
5	-4.51650	55.87988	12	-4.52182	55.87797
6	-4.51731	55.88013	13	-4.52059	55.87664
7	-4.51840	55.88031			

Panel Area 4

Panel Area 5

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.51762	55.87577	8	-4.51347	55.87556
2	-4.51658	55.87517	9	-4.51426	55.87661
3	-4.51801	55.87499	10	-4.51465	55.87749
4	-4.51428	55.87285	11	-4.51484	55.87813
5	-4.51199	55.87367	12	-4.52028	55.87639
6	-4.51150	55.87272	13	-4.51905	55.87561
7	-4.50860	55.87270			

Panel Area 5

Panel Area 6

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.50257	55.86533	8	-4.49786	55.86685
2	-4.50073	55.86382	9	-4.49954	55.86609
3	-4.49483	55.86560	10	-4.50062	55.86696
4	-4.49496	55.86731	11	-4.50162	55.86667
5	-4.49530	55.86752	12	-4.50215	55.86717
6	-4.49567	55.86763	13	-4.50460	55.86654
7	-4.49619	55.86763	14	-4.50313	55.86532

Panel Area 6

Panel Area 7

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-4.49272	55.86543	5	-4.49235	55.86773
2	-4.49251	55.86505	6	-4.49329	55.86770
3	-4.49119	55.86527	7	-4.49374	55.86525
4	-4.49099	55.86722			

Panel Area 7

APPENDIX H – DETAILLED MODELLING RESULTS

Overview

Each Pager Power 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 image. 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 aviation receptors are shown on the following pages. Each chart shows:

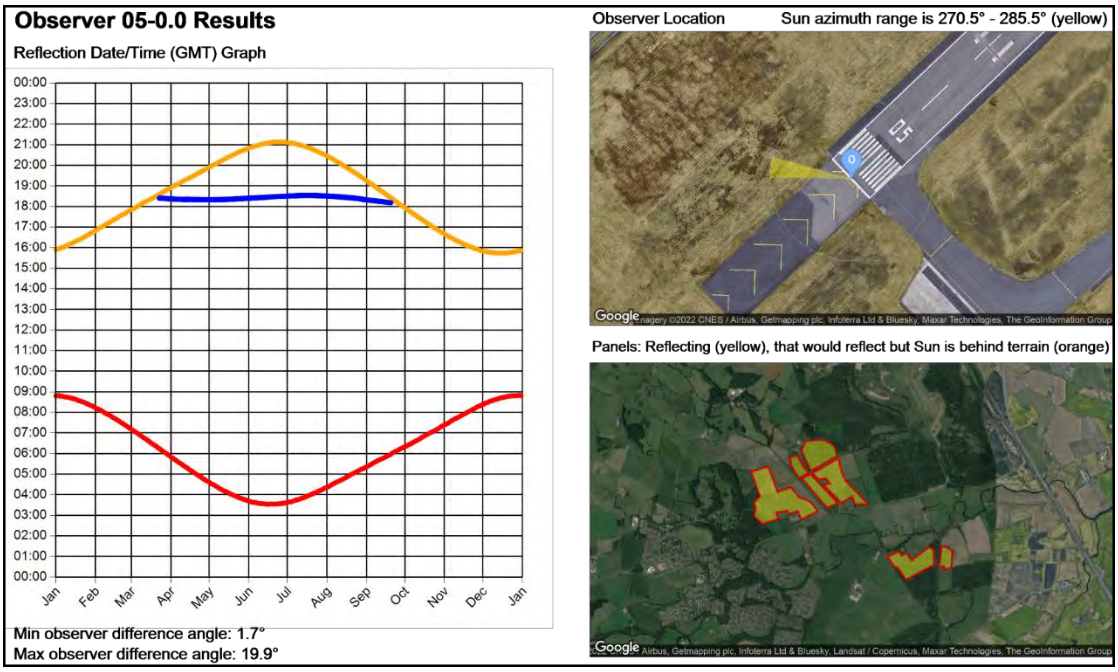
- The annual predicted solar reflections.
- The daily duration of the solar reflections.
- The location of the proposed development where glare will originate.
- The calculated intensity of the predicted solar reflections.

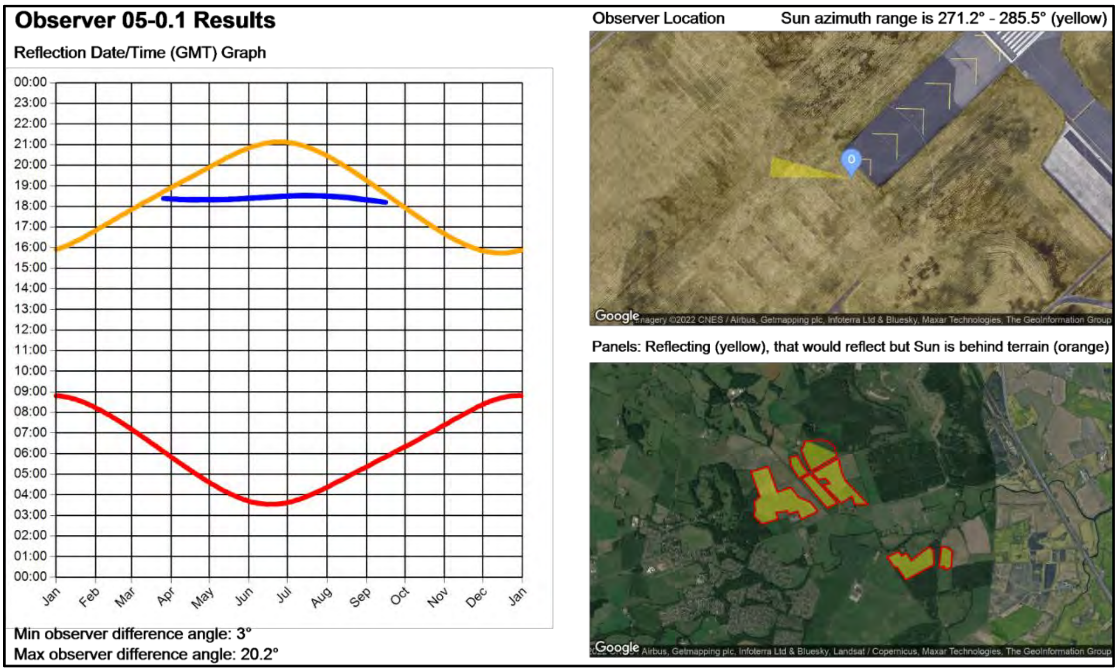
For approach paths, two further charts are shown within the Forge modelling results:

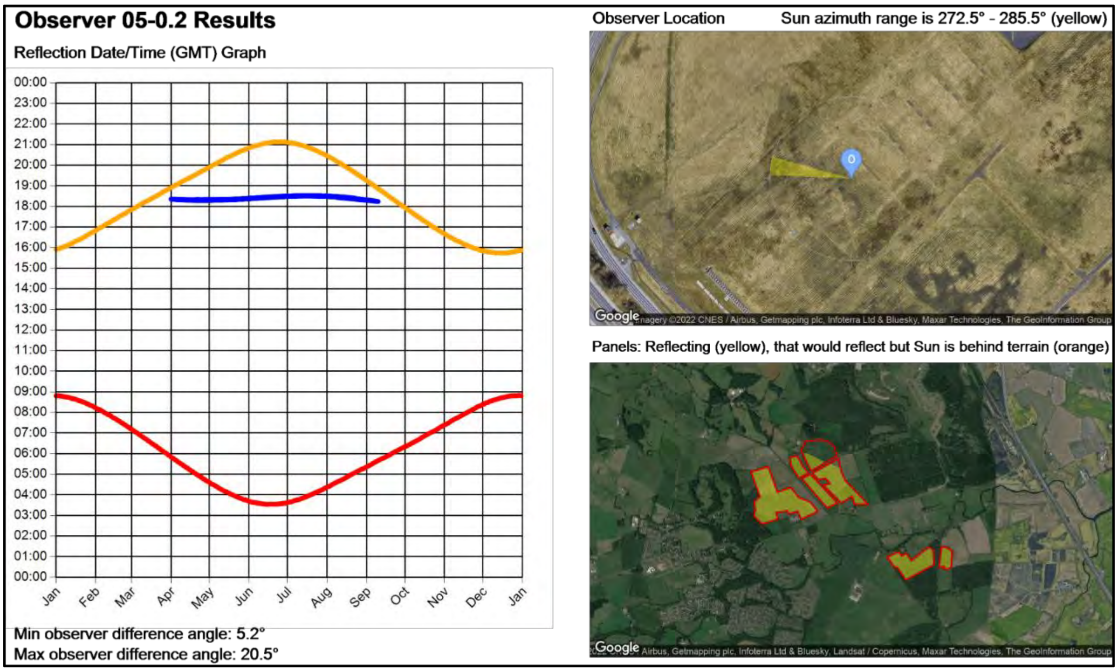
- Locations along the approach path receiving glare.
- The dates when glare would occur at each location along the approach.

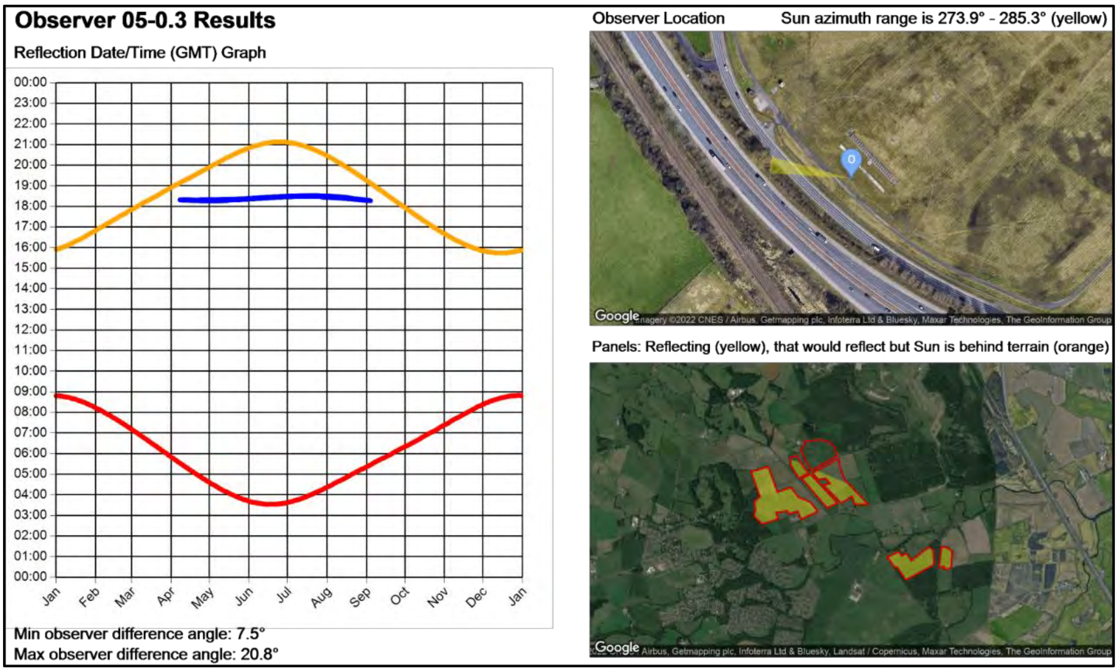
Full Pager Power and Forge modelling results are available upon request.

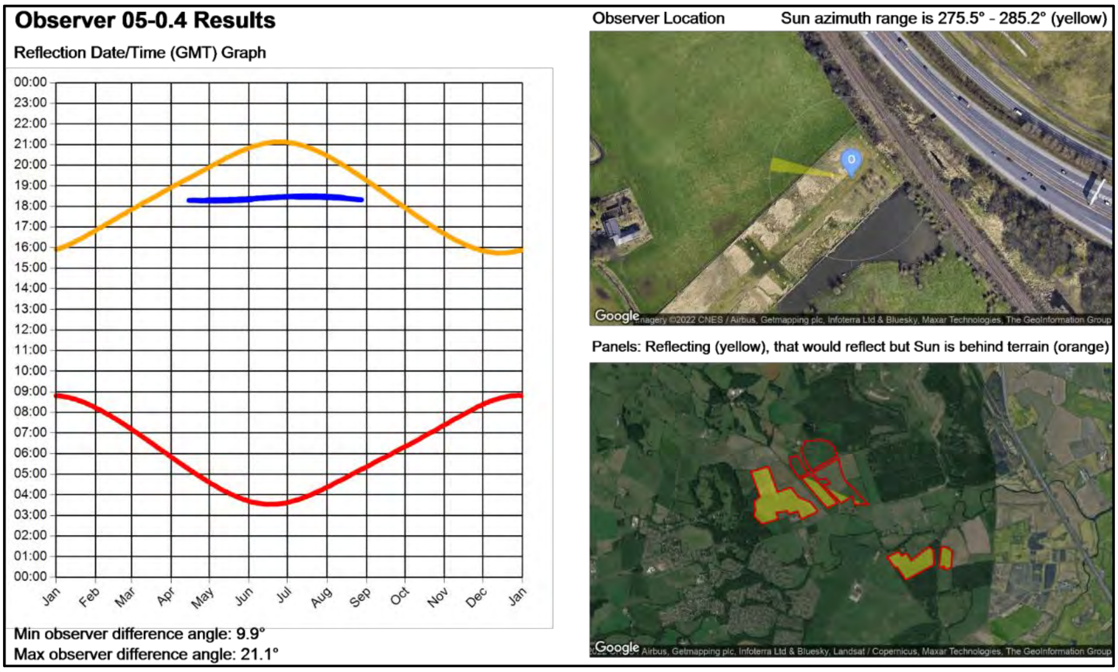
Aviation Modelling Results

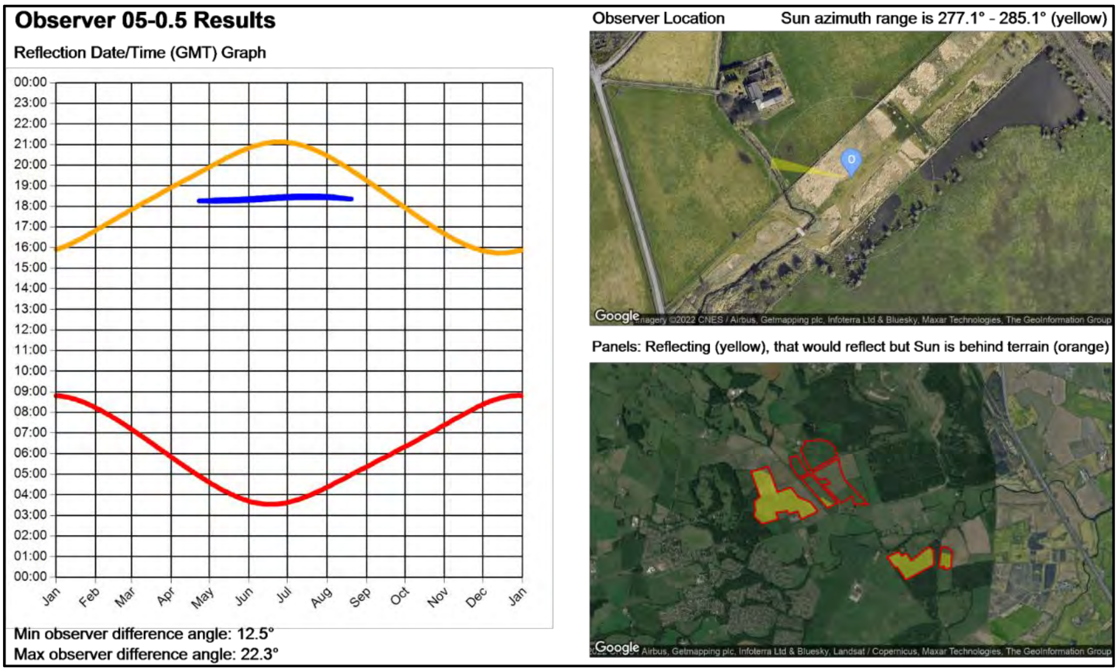


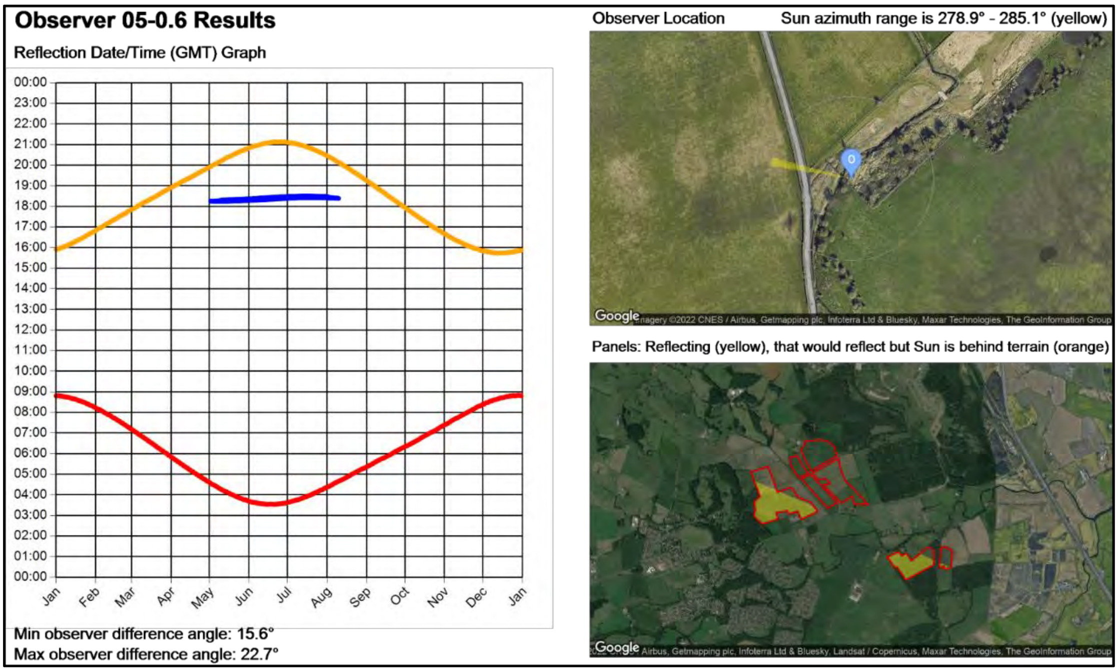


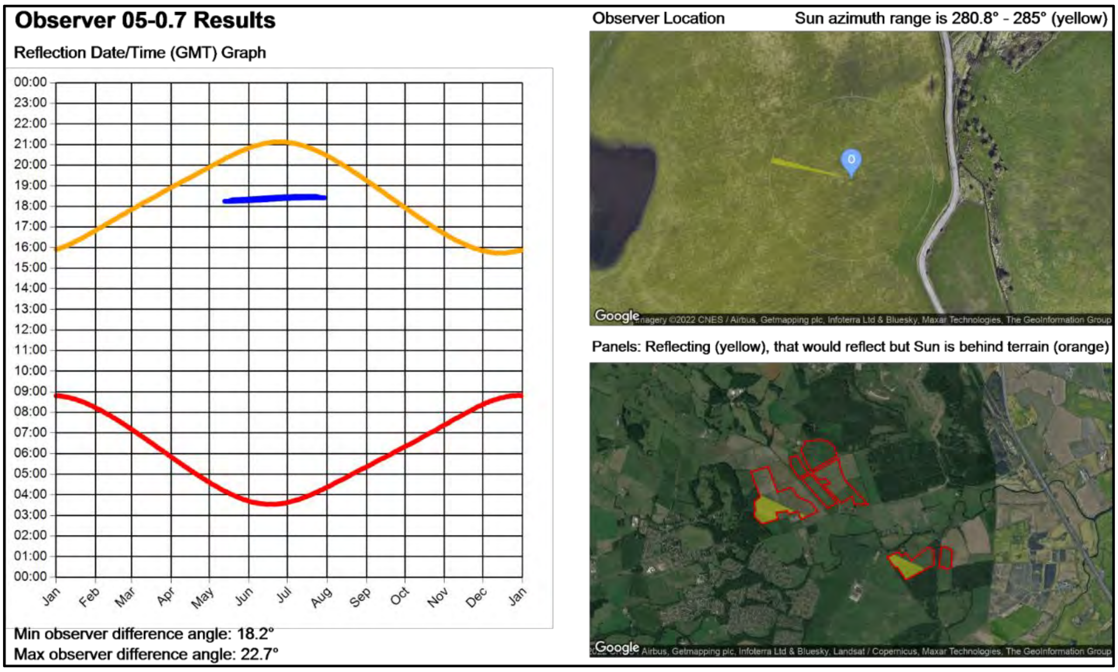

Observer 05-0.2 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 5.2°
Max observer difference angle: 20.5°
Observer Location
Sun azimuth range is 272.5° - 285.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

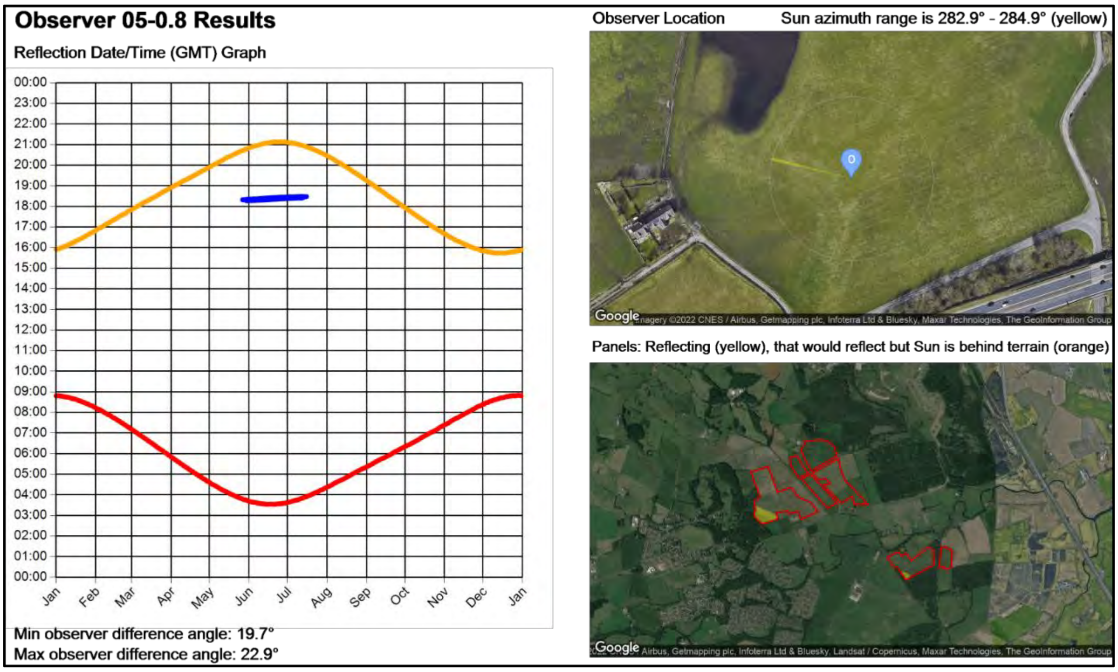

Observer 05-0.3 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 7.5°
Max observer difference angle: 20.8°
Observer Location
Sun azimuth range is 273.9° - 285.3° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

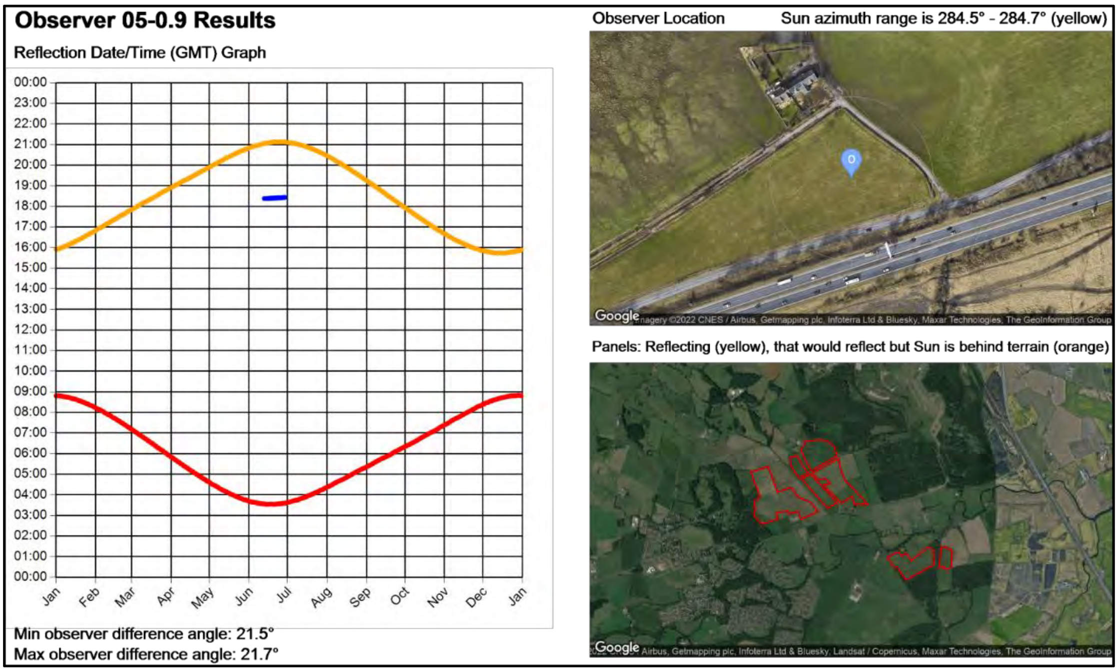

Observer 05-0.4 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 9.9°
Max observer difference angle: 21.1°
Observer Location
Sun azimuth range is 275.5° - 285.2° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

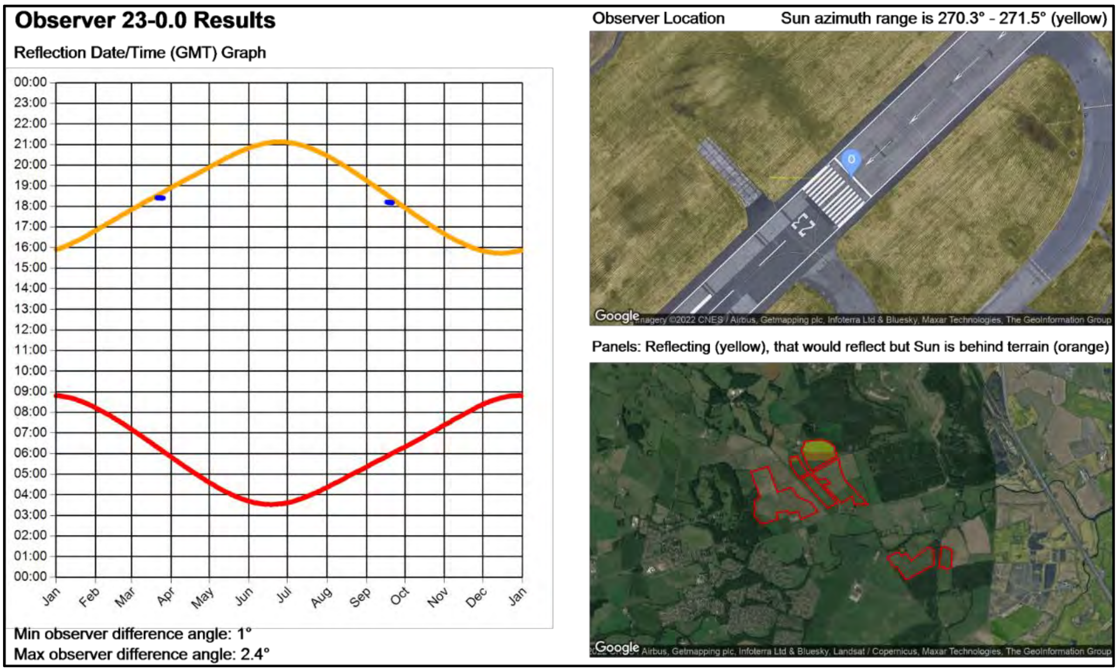

Observer 05-0.5 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 12.5°
Max observer difference angle: 22.3°
Observer Location
Sun azimuth range is 277.1° - 285.1° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

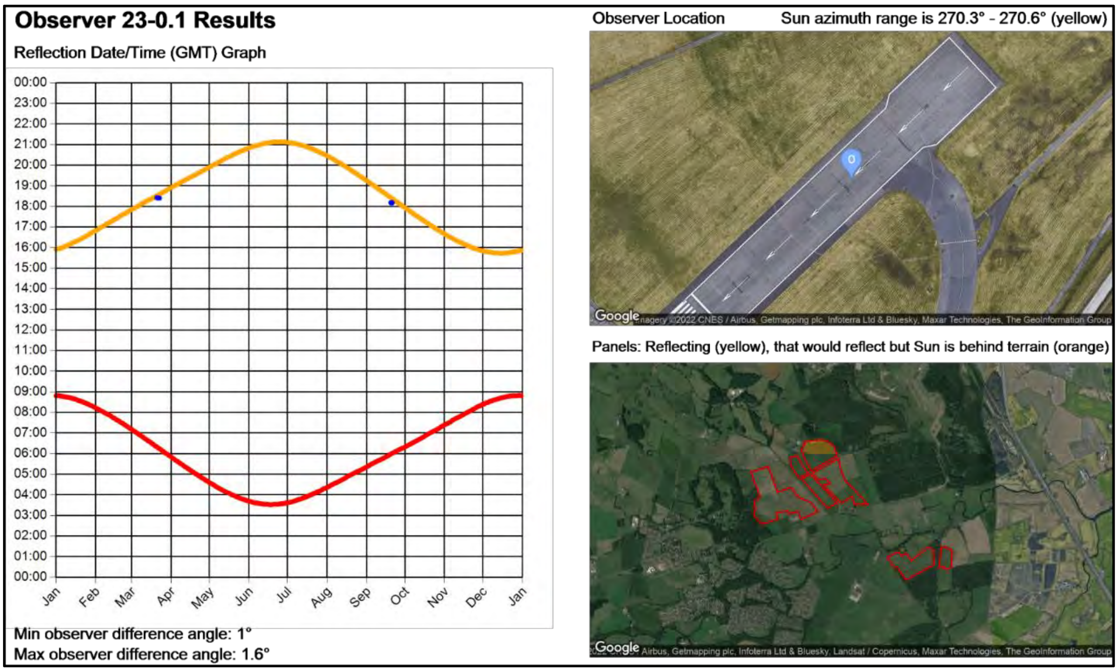

Observer 05-0.6 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 15.6°
Max observer difference angle: 22.7°
Observer Location
Sun azimuth range is 278.9° - 285.1° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

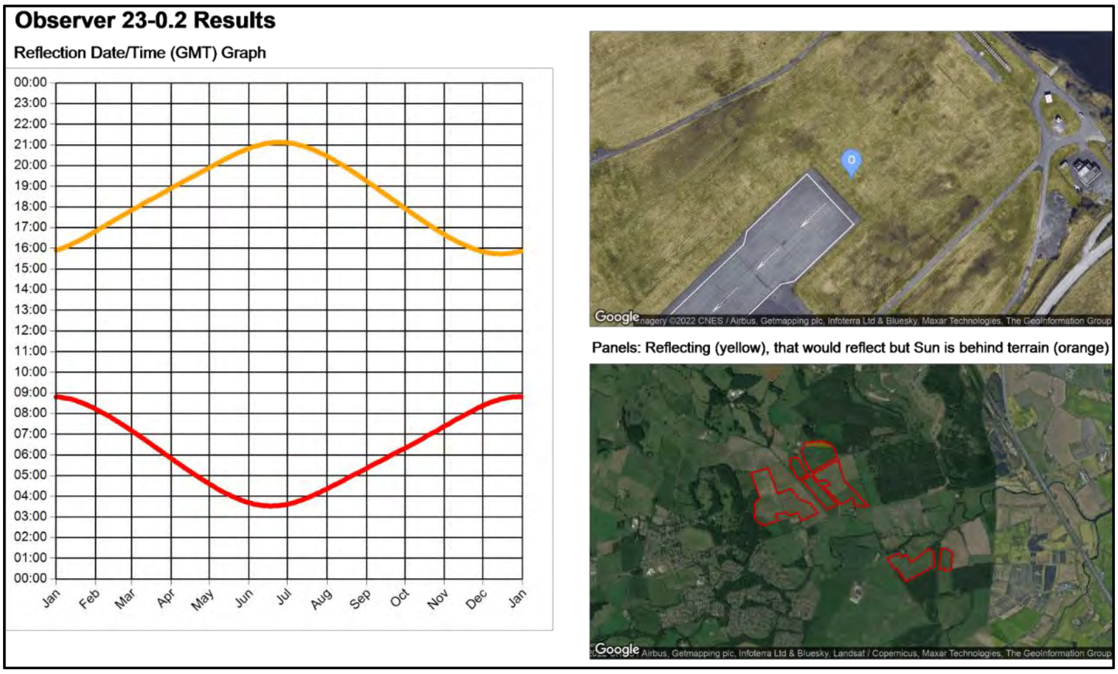

Observer 05-0.7 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 18.2°
Max observer difference angle: 22.7°
Observer Location
Sun azimuth range is 280.8° - 285° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)


Observer 05-0.8 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: 19.7°
Max observer difference angle: 22.9°
Observer Location
Sun azimuth range is 282.9° - 284.9° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Google


Observer 05-0.9 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: 21.5°
Max observer difference angle: 21.7°
Observer Location
Sun azimuth range is 284.5° - 284.7° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Google


Observer 23-0.0 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 270.3° - 271.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 1°
Max observer difference angle: 2.4°

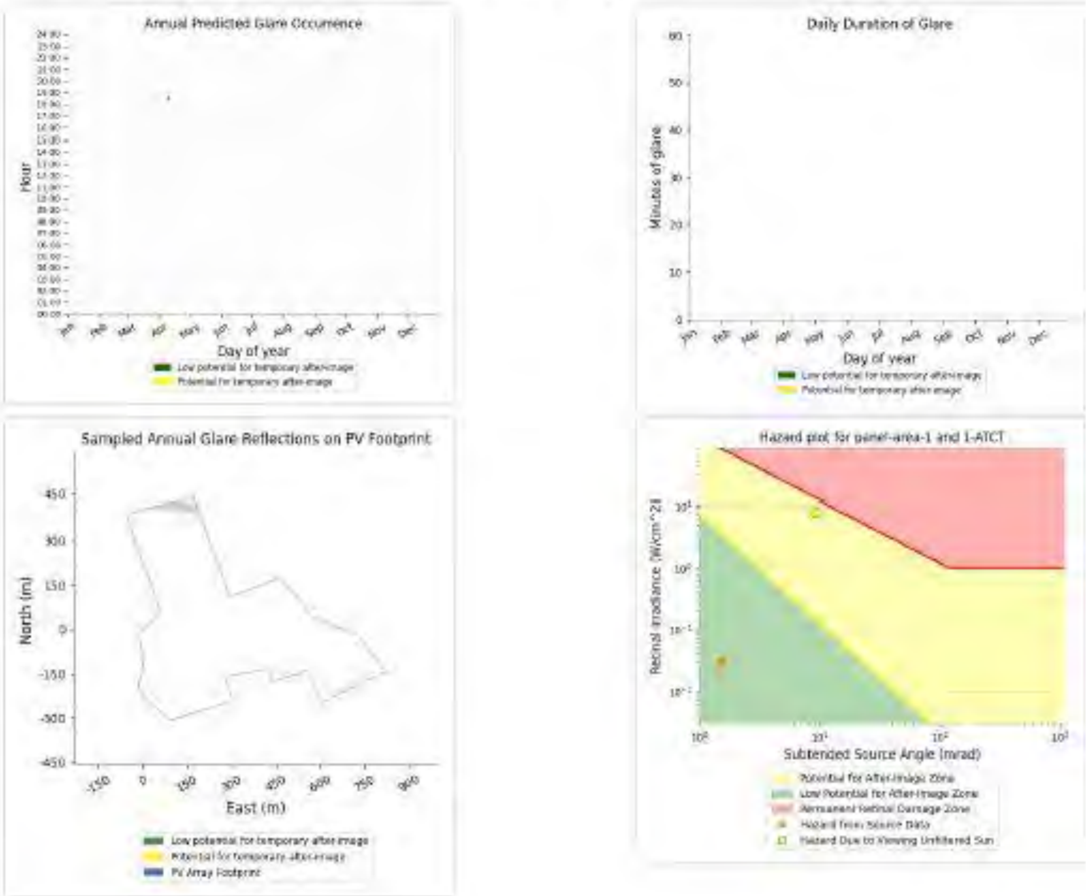

Observer 23-0.1 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 270.3° - 270.6° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 1°
Max observer difference angle: 1.6°


Observer 23-0.2 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
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

Panel Area 1 - OP Receptor (1-ATCT)

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

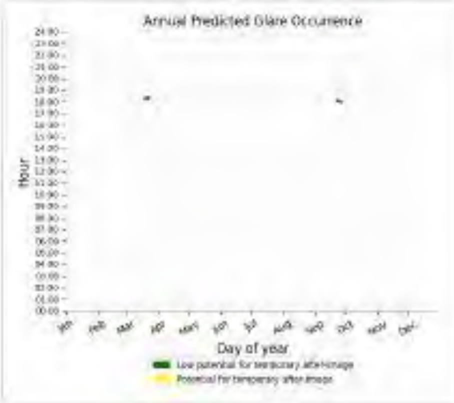
- 1 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.

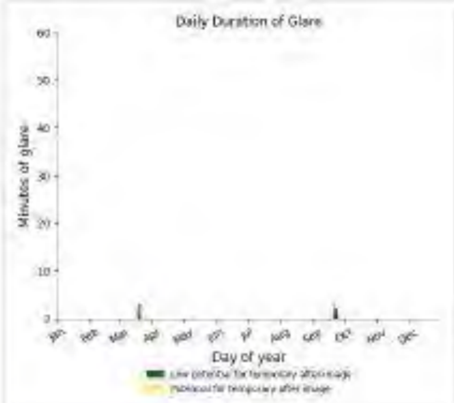


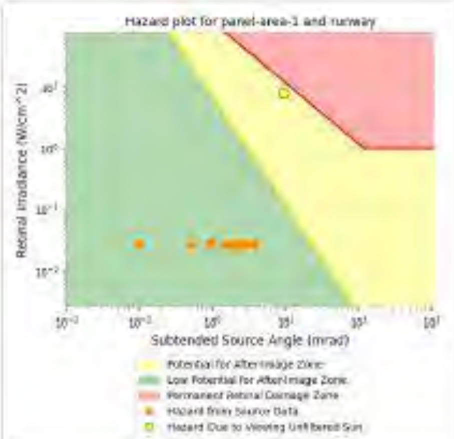
Panel Area 1 - Receptor (Runway 23 Approach)

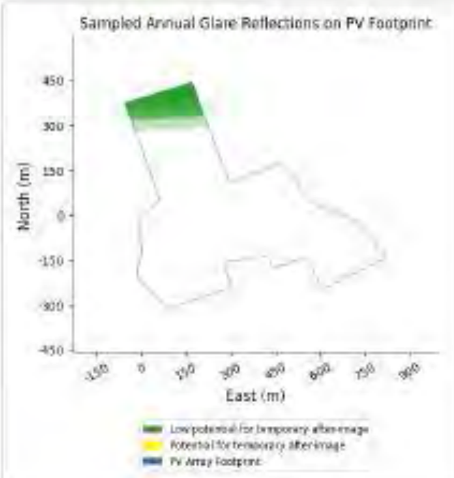
PV array is expected to produce the following glare for observers on this flight path:

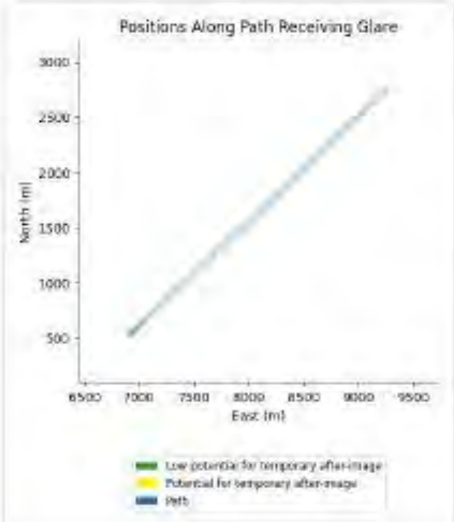
- 18 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.





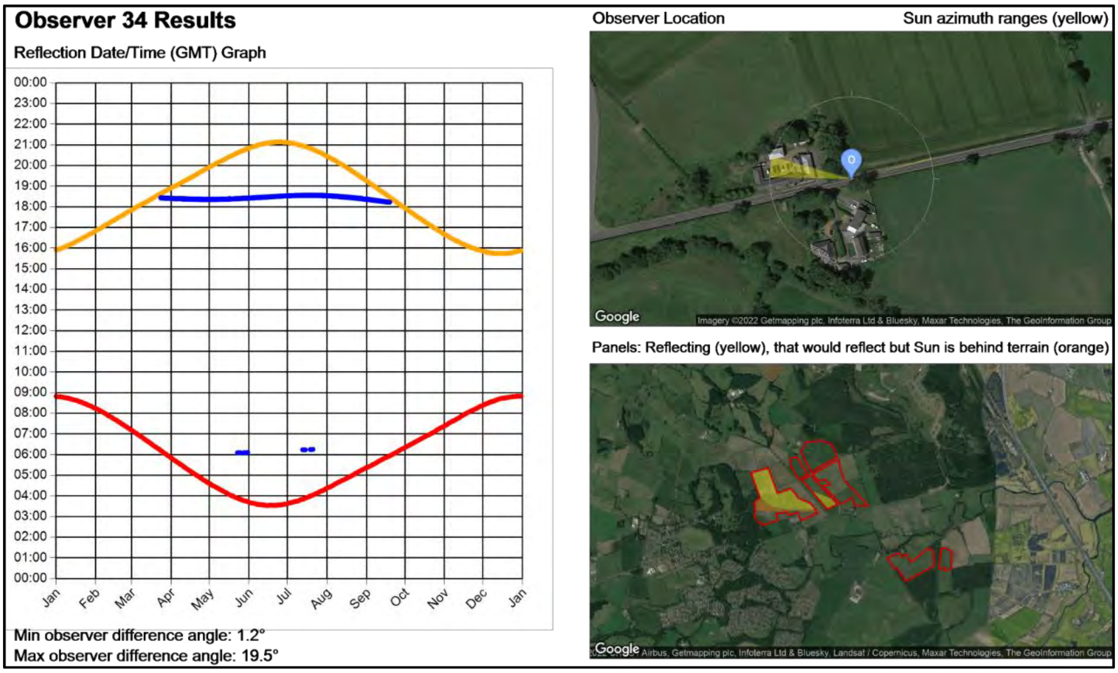


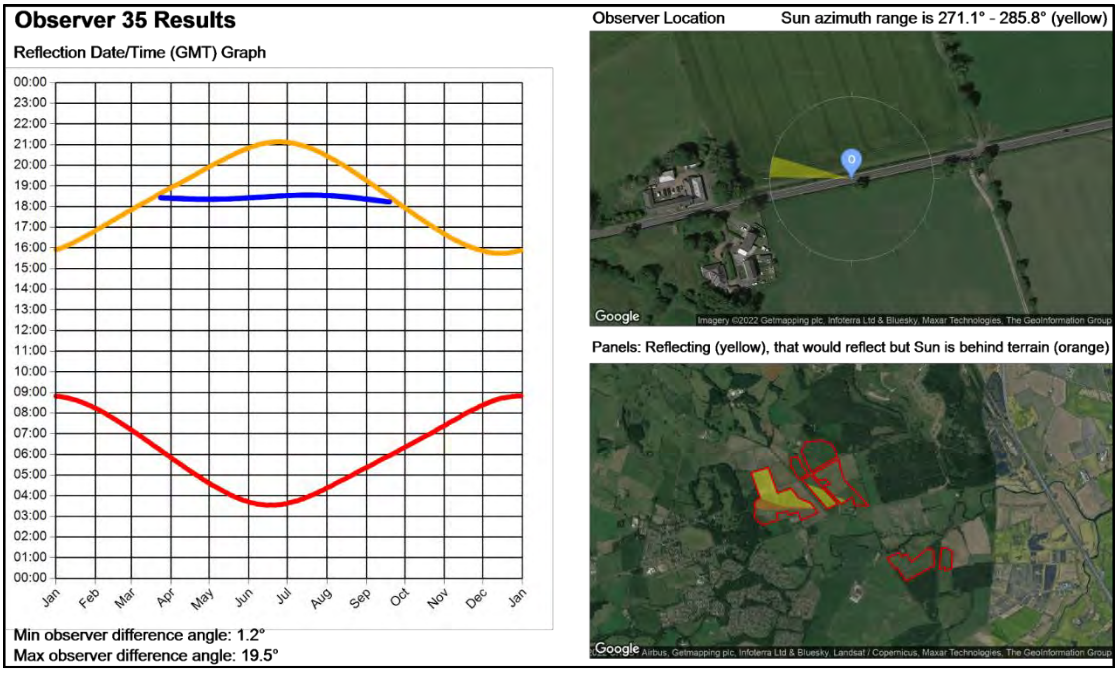




Road Modelling Results

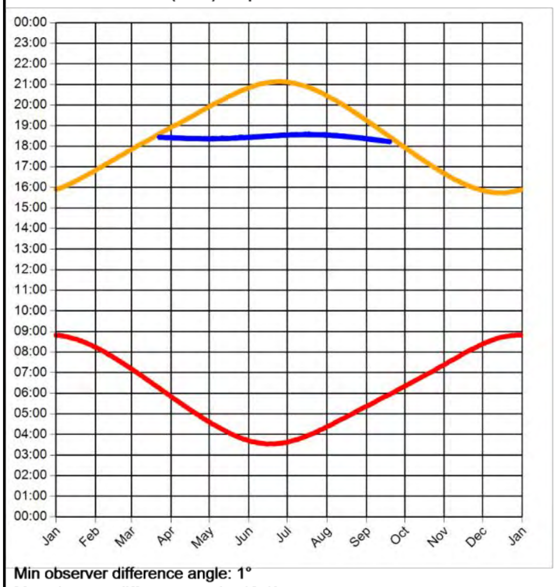
The modelling results have been presented for receptors where mitigation has been recommended.





Observer 36 Results

Reflection Date/Time (GMT) Graph



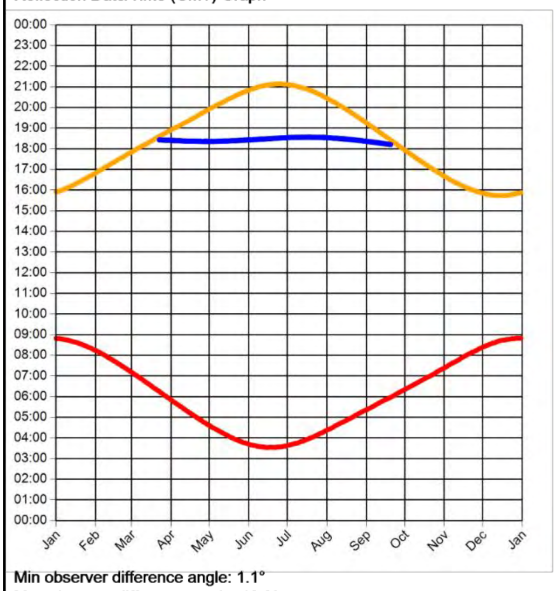
Min observer difference angle: 1°
Max observer difference angle: 19.4°

Observer Location — Sun azimuth range is 271° - 285.9° (yellow)

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

Observer 37 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 1.1°
Max observer difference angle: 19.3°

Observer Location — Sun azimuth range is 270.8° - 285.9° (yellow)

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

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