PAGERPOWER
Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Hatton Cross, Underground Station

TfL

March, 2020





ADMINISTRATION PAGE

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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 rooftop solar photovoltaic (PV) panel area to be situated on Hatton Cross Underground Station's roof, located to the west of London Heathrow Airport.

This assessment pertains to the possible effects upon aviation activity at London Heathrow Airport. In particular, the runway approach paths for runways 09R/27L, 09L/27R, the proposed 09/27 runway and the Air Traffic Control (ATC) Tower.

Pager Power

Pager Power has undertaken over 450 glint and glare assessments in the UK, Europe and further afield. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Assessment Results –ATC Tower

The results of the analysis have shown that the reflections from the proposed development towards the existing ATC Tower are not possible. Therefore, no impact is expected and mitigation is not required.

Assessment Results – Runway Approach

Runway Approach 09L

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09L are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the runway 09L approach are predicted.

Runway Approach 27R

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27R are geometrically possible and they will be experienced by pilots approaching the runway between 1.3 and 2 miles from the threshold.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green").

Such level of glare is acceptable and will not pose a threat to pilots' safety. Therefore, no significant impacts on pilots on the runway 27R approach are predicted.

Runway Approach 09R

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09R are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the runway 09R approach are predicted.

Runway Approach 27L

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27L are geometrically possible and they will be experienced by pilots approaching the runway between 0.2 and 0.3 miles and between 0.9 and 2 miles from the threshold.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green").

Such level of glare is acceptable and will not pose a threat to pilots' safety. Therefore, no impacts on pilots on the runway 27L approach are predicted.

Proposed Runway Approach 09

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on the proposed runway approach 09 are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the proposed runway 09 approach are predicted.

Proposed Runway Approach 27

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on the proposed runway approach 27 are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the proposed runway 27 approach are predicted.

Recommendation

Results should be made available to the airport safeguarding team at London Heathrow Airport.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 48 countries within South Africa, Europe, America, Asia and Australasia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

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

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

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

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

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from the proposed rooftop solar photovoltaic (PV) panel area to be situated on Hatton Cross, Underground Station's roof, located to the west of London Heathrow Airport.

This assessment pertains to the possible effects upon aviation activity at London Heathrow Airport. In particular, the runway approach paths for runways 09R/27L, 09L/27R, the proposed 09/27 runway and the Air Traffic Control (ATC) Tower. A report has therefore been produced that contains the following:

- Details of the proposed solar development layouts;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Identification of aviation concerns and receptors;
- Assessment methodology;
- Glint and glare assessment for:
    - Aircraft approach paths;
    - ATC Tower.
- Results discussion.

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

1.2 Pager Power's Experience

Pager Power has undertaken over 450 Glint and Glare assessments internationally. The studies have included assessment civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Guidance and Studies

Guidelines exist in the UK (produced by the CAA[1]) and in the USA (produced by the FAA[2]) with respect to solar developments and aviation activity, however a specific methodology for aviation assessments in Ireland has not been produced to date. Therefore, Pager Power has reviewed existing guidelines and the available studies (discussed below) in the process of defining its own glint and glare assessment guidance. This guidance document, now in its second edition, defines the process for determining the impact upon aviation activity. Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, undertake solar intensity calculations in line with the Sandia National Laboratories' FAA methodology. The scenario in which a solar reflection can occur is identified 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].

1.4 Glint and Glare Definition

The definition of glint and glare can vary, however, the definition used by Pager Power is as follows:

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

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

[1] Civil Aviation Authority.
[2] Federal Aviation Administration.
[3] SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

2 PROPOSED DEVELOPMENT DETAILS

2.1 Proposed Development – Location

Figure 1[4] below shows the red line boundary where development is located.

Figure 1 - Proposed development location

[4] Copyright © 2020 Google.

2.2 Proposed Development – Layout

The arrangement of the solar panels has been provided by Duncan Brewer (Figure 2[5] below). The area considered for the assessment is shown in Figure 3[6] on page 15.

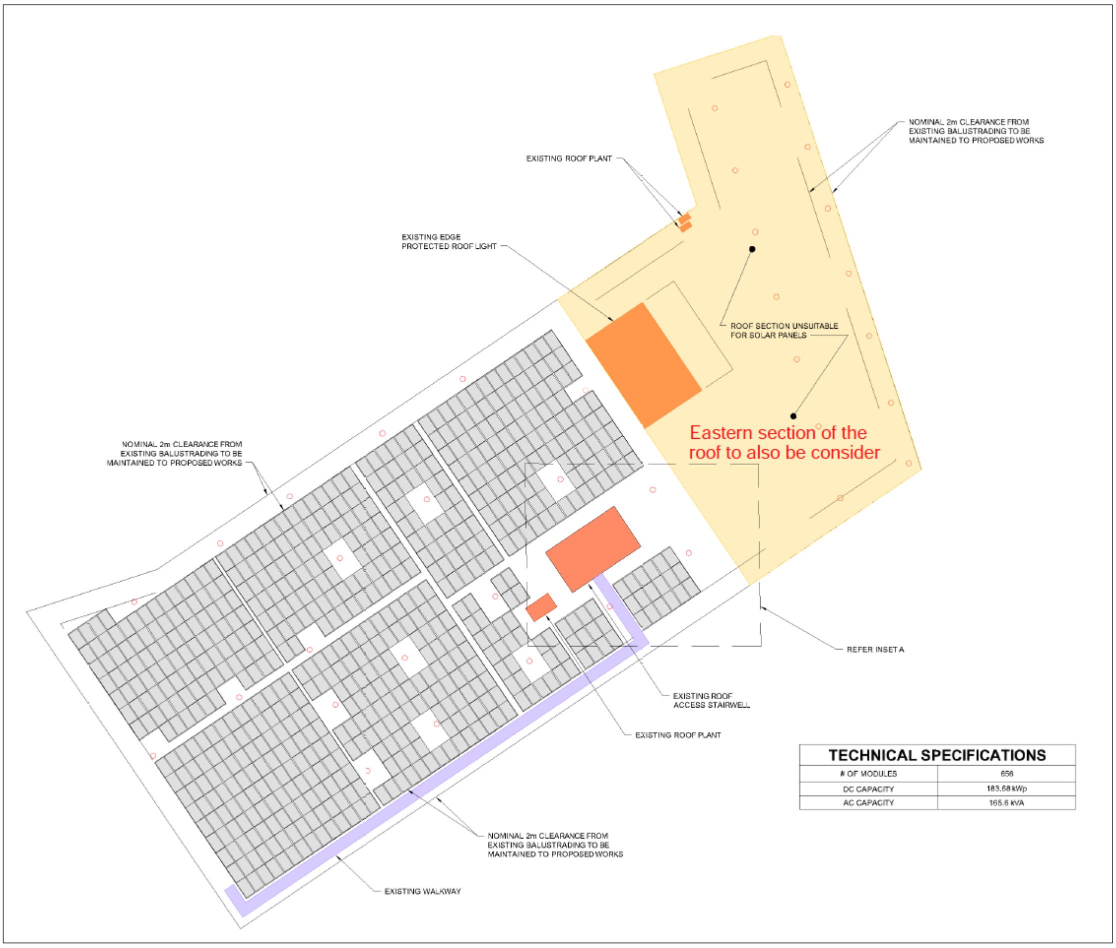

Figure 2 – Rooftop PV development layout

[5] Transport for London Rooftop Solar Feasibility, AECOM, Project No. 60617618, date: 06/03/2020 (modified).
[6] Copyright © 2020 Google.

The photovoltaic area is located on the station roof (Figure 3). The details are as follows:

- Panels tilt: 10°;
- Elevation: 7m (agl);
- Orientation: 143°.

Figure 3 – Rooftop PV layout location

3 LONDON HEATHROW AIRPORT DETAILS

3.1 Overview

The following section presents general details regarding London Heathrow Airport.

3.2 Airport Information

London Heathrow Airport is a Civil Aviation Authority (CAA) licensed aerodrome used predominately by jet and fixed wing propeller aircraft for private and commercial use.

3.3 Runway Details

London Heathrow Airport has two existing runways and one proposed runway. The runways details are presented below:

1. 09R/27L measuring 3,660m by 50m (asphalt, grooved);
2. 09L/27R measuring 3,902m by 50m (asphalt, grooved);
3. 09/27 measuring 3,500m (proposed).

The runways (09R/27L and 09L/27R) are shown in Figure 4[7] (aerodrome chart) on the following page.

3.4 Air Traffic Control Tower

London Heathrow Airport has an ATC Tower located between the two runways. Further details are presented in Section 5.2 of this report.

[7] Civil Aviation Authority AIP. Last accessed 19.03.20.

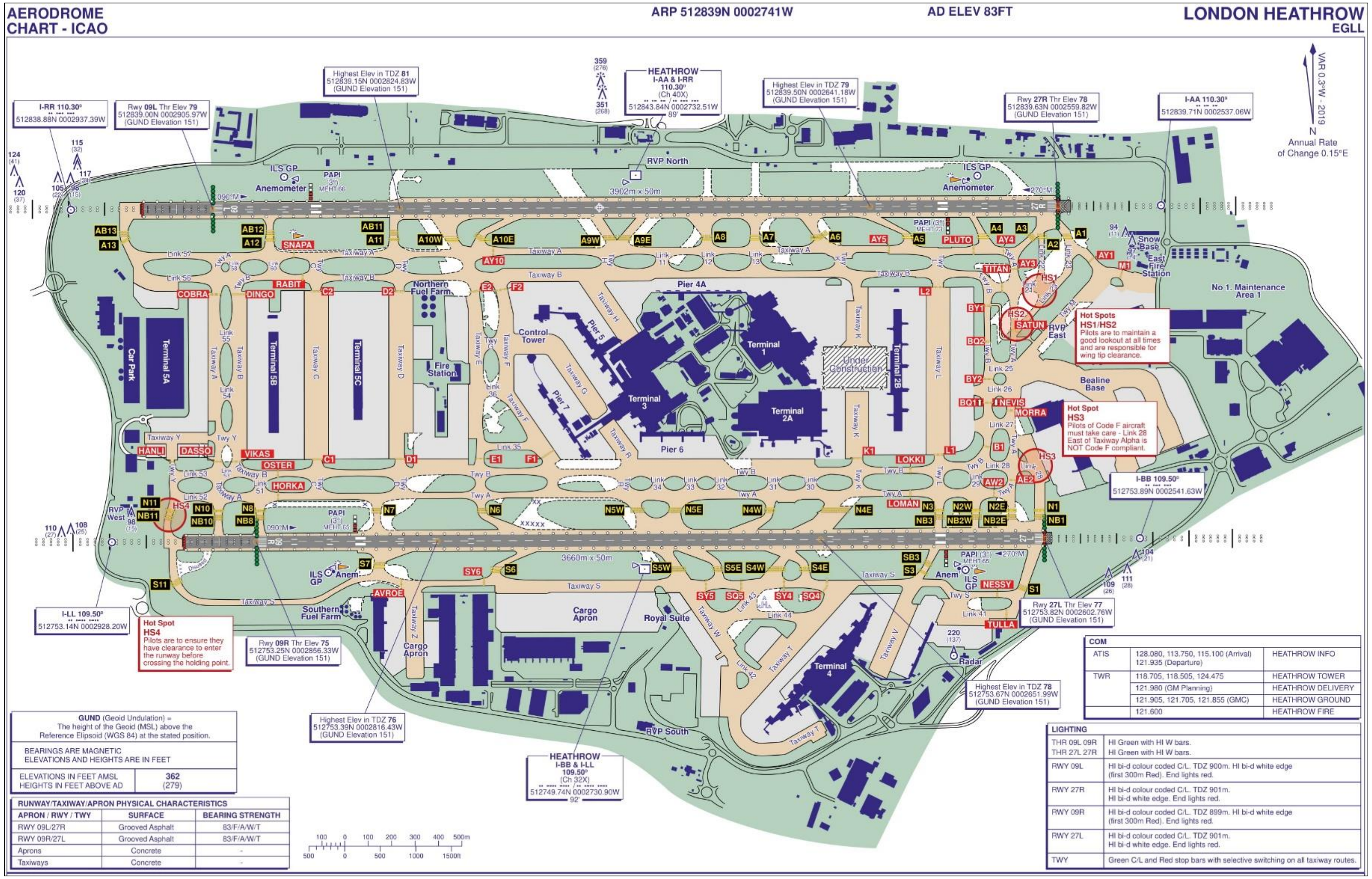

Figure 4 – London Heathrow Airport aerodrome chart

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Overview

The following sub-sections provide a general overview with respect to the guidance studies and methodology which informs this report.

Glint and glare from surfaces capable of producing specular reflections are a significant consideration for aviation operations. Rules exist produced by the UK Civil Aviation Authority (CAA) and the Federal Aviation Administration (FAA). Whilst the UK CAA guidance[8] is applicable to the UK, it lacks any details of the assessment requirement. Therefore, the guidance produced by the FAA[9] is widely accepted by UK airports as the defining standard. Pager Power has also produced its own Glint and Glare Guidance which draws on assessment experience, consultation and industry expertise.

The guidance addresses the effect of solar reflections from solar photovoltaic panels near aerodromes, but the requirement for assessment can also be extended to glass façades and other reflective surfaces.

4.2 Guidance and 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 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 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.

4.3 Background

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

[8] http://www.caa.co.uk/docs/697/srg_asd_solarphotovoltaicsystguidance.pdf.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 however the advice is still applicable until a formal policy is developed.

[9] http://www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf

4.4 Methodology

The assessment methodology is based on guidance, studies, previous discussions with stakeholders and Pager Power's practical experience. Information regarding the methodology of Pager Power's and Sandia National Laboratories' methodology is presented below.

4.4.1 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. The methodology for the aviation glint and glare assessment is as follows:

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

4.4.2 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[10].

4.5 Assessment Methodology and Limitations

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

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

5 IDENTIFICATION OF RECEPTORS

5.1 Overview

The following section presents the relevant receptors assessed within this report.

5.2 Air Traffic Control Tower

It is important to determine whether a solar reflection can be experienced by personnel monitoring flights within the ATC Tower.

The co-ordinates and maximum altitude of the existing ATC Tower have been taken from the NATS AIP for London Heathrow Airport.

Figure 5[11] below shows the location of the ATC Tower. The altitude of the ATC tower considered for the analysis is 109m (amsl) (Figure 6[12]).

Figure 5 – ATC Tower location

[11] Copyright © 2020 Google.
[12] Copyright © 2020 Google.

Figure 6 – ATC Tower 3D view

5.3 Approaching Aircraft

It is Pager Power's methodology to assess whether a solar reflection can be experienced on the approach paths for the associated runways. London Heathrow Airport has two operational runway approach paths per each runway and a proposed runway. The runway designation is 09R/27L and 09R/27L. Both approaches of the proposed third runway have been also considered.

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

Figure 7[13] on the following page shows the assessed aircraft receptor locations.

[13] Copyright © 2020 Google.

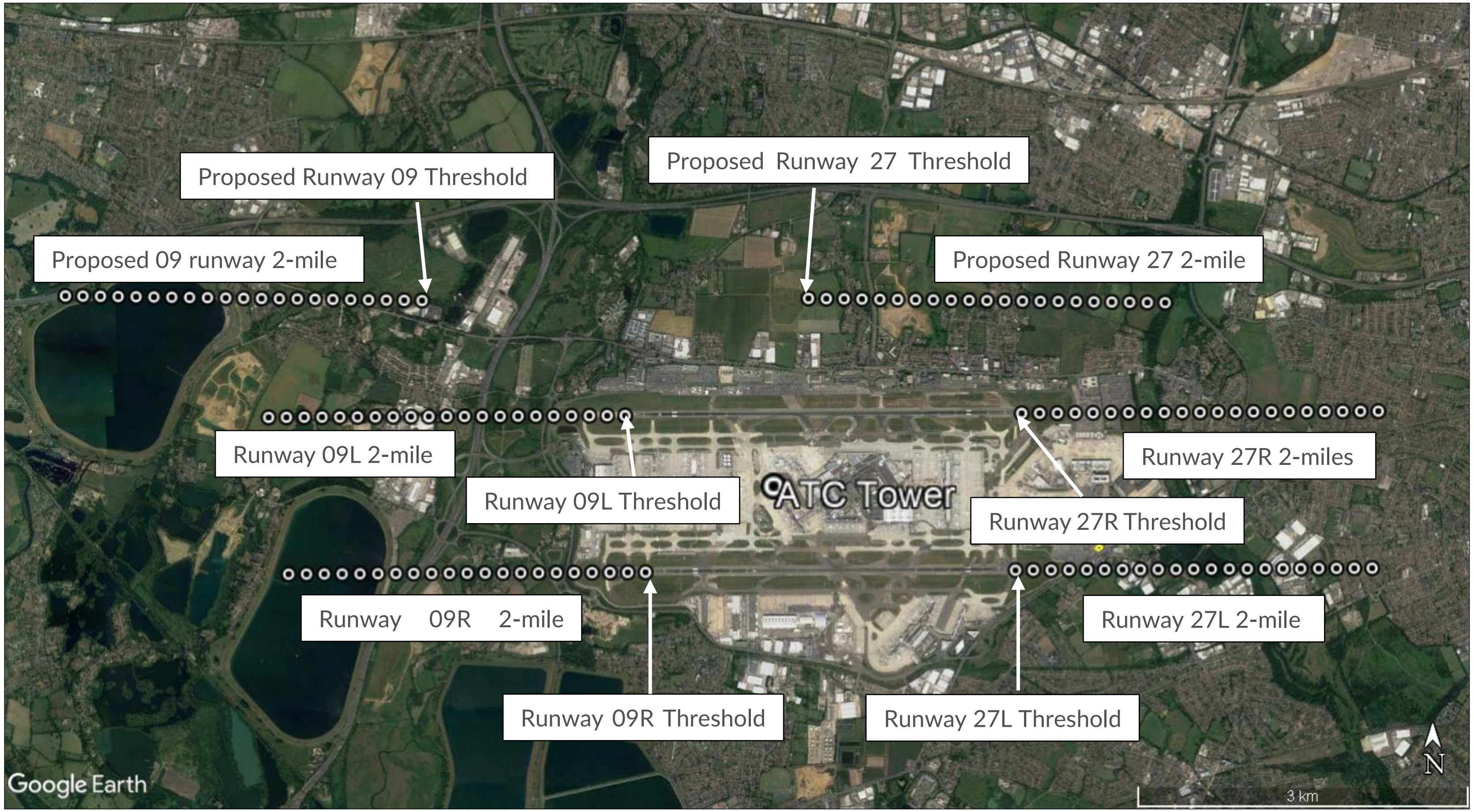

Figure 7 – Approach receptor locations

6 ASSESSED REFLECTOR AREA

6.1 Overview

The following section presents the modelled reflector area.

6.2 Reflector Area

Resolutions of 1m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 1m 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. The number of modelled reflector points are determined by the size of the reflector area and the assessment resolution. The bounding co-ordinates for each area have been extrapolated from the site maps. All rooftop altitudes and panel elevation data have been provided by the developer.

Figure 8[14] below presents the locations of the proposed solar panels area.

The full assessment data can be found in Appendix G.

Figure 8 – Assessed rooftop solar development area details

[14] Aerial image copyright © 2020 Google.

7 GLINT AND GLARE ASSESSMENT RESULTS

7.1 Overview

The following section presents an overview of the glare for the identified receptors.

The Pager Power model has been used initially. Where solar reflections have been predicted, intensity calculations in line with Sandia National Laboratories' methodology have been undertaken.

Where glare is predicted, the intensity model calculates the expected intensity of a reflection with respect to the potential for an after-image (or worse) occurring. The designation used by the model is presented in Table 1 below along with the associated colour coding.

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

Table 1 – Glare intensity designation

This coding has been used in the table where a reflection has been calculated and is in accordance with Sandia National Laboratories' methodology. The relative width of the colour band is related to the estimated percentage of each type of glare[15].

In addition, the intensity model allows for 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[16].

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

[15] Where two or more glare intensities are predicted for a particular receptor throughout the year.

[16] Not believed to be commercially viable for solar panels currently.

The tables in the following subsections summarise the months and times during which a solar reflection could be experienced by a receptor.

<u>This does not mean that reflections would occur continuously between the times shown</u>.

The range of times at which reflections are geometrically possible is generally greater than the length of time for any particular day. This is because the times of day at which reflections could start and stop vary throughout the days/months.

The results of the analysis are presented in the following sections. Appendix H presents the results charts and is provided separately.

Where glare is predicted by the Pager Power model but not by Forge, it is likely because the glare occurs outside of 50 degrees relative to the pilot's field of view and is therefore not automatically recorded by Forge.

7.2 ATC Tower

The results of the geometric calculation for the ground-based aviation receptors is presented in Table 2 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the ground-based aviation receptors? (GMT)			
	am	pm		
ATC Tower	None.	None.	None.	None.

Table 2 – Geometric analysis results for the ground-based aviation receptors

7.3 Geometric Calculation Results Overview – Approach for Runway 09L

The results of the geometric calculations for the approach towards runway 09L are presented in Table 3 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 09L Approach? (GMT)			
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	None.

Table 3 – Geometric analysis results for the Runway 09R Approach

7.4 Geometric Calculation Results Overview – Approach for Runway 27R

The results of the geometric calculations for the approach towards runway 27R are presented in Table 4 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
Threshold – 1.2 miles	None.	None.	None.	None.
1.3 miles	None.	Between 15:40 and 15:43 during the beginning of January. Between 15:29 and 15:40 from early December to the end of December.	"Green" glare with low potential for after image.	Discussion in Section 8.4
1.4 miles	None.	Between 15:52 and 15:56 during mid- January. Between 15:30 and 15:33 during late November.	"Green" glare with low potential for after image.	Discussion in Section 8.4
1.5 miles	None.	Between 16:02 and 16:05 during late January. Between 15:34 and 15:37 during mid- November.	"Green" glare with low potential for after image.	Discussion in Section 8.4
1.6 miles	None.	Between 16:09 and 16:12 during the end of January. Between 15:40 and 15:42 during early November.	"Green" glare with low potential for after image.	Discussion in Section 8.4

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
1.7 miles	None.	Between 16:15 and 16:18 during early February. Between 15:45 and 15:47 during the beginning of November.	"Green" glare with low potential for after image.	Discussion in Section 8.4
1.8 miles	None.	Between 16:20 and 16:22 during mid- February. Between 15:50 and 15:52 during the end of October.	"Green" glare with low potential for after image.	Discussion in Section 8.4
1.9 miles	None.	Between 16:24 and 16:27 during mid- February. Between 15:54 and 15:56 during late October.	"Green" glare with low potential for after image.	Discussion in Section 8.4
2.0 miles	None.	Between 16:28 and 16:30 during mid- February. Between 15:58 and 16:00 during late October.	"Green" glare with low potential for after image.	Discussion in Section 8.4

Table 4 – Geometric analysis results for the Runway 27R Approach

7.5 Geometric Calculation Results Overview – Approach for Runway 09R

The results of the geometric calculations for the approach towards runway 09R are presented in Table 5 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 09R Approach? (GMT)			
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	None.

Table 5 – Geometric analysis results for the Runway 09R Approach

7.6 Geometric Calculation Results Overview – Approach for Runway 27L

The results of the geometric calculations for the approach towards runway 27L are presented in Table 6 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
Threshold	None.	None.	None.	None.
0.1 miles	None.	None.	None.	None.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
0.2 miles	Between 04:32 and 04:37 during late April. Between 04:39 and 04:43 during mid- August.	None.	“Green” glare with low potential for after image.	Discussion in Section 8.6
0.3 miles	Between 04:24 and 04:37 from the end of May to mid- July.	None.	“Green” glare with low potential for after image.	Discussion in Section 8.6
0.4 miles	None.	None.	None.	None.
0.5 miles	None.	None.	None.	None.
0.6 miles	None.	None.	None.	None.
0.7 miles	None.	None.	None.	None.
0.8 miles	None.	None.	None.	None.
0.9 miles	None.	Between 17:31 and 17:42 from the end of May to mid- July.	“Green” glare with low potential for after image.	Discussion in Section 8.6

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
1 mile	None.	Between 17:26 and 17:38 from mid- May to early June. Between 17:36 and 17:43 from the beginning of July to late July.	“Green” glare with low potential for after image.	Discussion in Section 8.6
1.1 miles	None.	Between 17:24 and 17:32 from mid- May to late May. Between 17:34 and 17:41 from mid- July to the end of July.	“Green” glare with low potential for after image.	Discussion in Section 8.6
1.2 miles	None.	Between 17:22 and 17:29 during mid- May. Between 17:32 and 17:39 during the end of July.	“Green” glare with low potential for after image.	Discussion in Section 8.6
1.3 miles	None.	Between 17:21 and 17:26 during early May. Between 17:30 and 17:36 during the beginning of August.	“Green” glare with low potential for after image.	Discussion in Section 8.6

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
1.4 miles	None.	Between 17:21 and 17:25 during the beginning of May. Between 17:29 and 17:35 during early August.	"Green" glare with low potential for after image.	Discussion in Section 8.6
1.5 miles	None.	Between 17:20 and 17:24 during the beginning of May. Between 17:28 and 17:33 during early August.	"Green" glare with low potential for after image.	Discussion in Section 8.6
1.6 miles	None.	Between 17:20 and 17:23 during the end of April. Between 17:27 and 17:32 during early August.	"Green" glare with low potential for after image.	Discussion in Section 8.6
1.7 miles	None.	Between 17:19 and 17:22 during the end of April. Between 17:26 and 17:31 during mid- August.	"Green" glare with low potential for after image.	Discussion in Section 8.6

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Runway 27L Approach? (GMT)			
	am	pm		
1.8 miles	None.	Between 17:19 and 17:22 during late April. Between 17:26 and 17:30 during mid- August.	“Green” glare with low potential for after image.	Discussion in Section 8.6
1.9 miles	None.	Between 17:19 and 17:21 during late April. Between 17:25 and 17:29 during mid- August.	“Green” glare with low potential for after image.	Discussion in Section 8.6
2.0 miles	None.	Between 17:18 and 17:21 during late April. Between 17:24 and 17:28 during mid- August.	“Green” glare with low potential for after image.	Discussion in Section 8.6

Table 6 – Geometric analysis results for the Runway 27L Approach

7.7 Geometric Calculation Results Overview – Approach for the Proposed Runway 09

The results of the geometric calculations for the approach towards the proposed runway 09 are presented in Table 3 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Proposed Runway 09 Approach? (GMT)			
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	None.

Table 7 – Geometric analysis results for the Proposed Runway 09 Approach

7.8 Geometric Calculation Results Overview – Approach for the Proposed Runway 27

The results of the geometric calculations for the approach towards the proposed runway 27 are presented in Table 4 below.

Receptor	Pager Power Results		Glare Type	Reflection Expected
	Reflection possible toward the Proposed Runway 27 Approach? (GMT)			
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	None.

Table 8 – Geometric analysis results for the Proposed Runway 27 Approach

8 GEOMETRIC ASSESSMENT RESULTS, DISCUSSION AND CONCLUSIONS

8.1 Overview

The results of the aviation glint and glare calculations are presented in the following sub-sections.

8.2 ATC Tower

The results of the analysis have shown that the reflections from the proposed development towards the existing ATC Tower are not possible. Therefore, no impact is expected and mitigation is not required.

8.3 Approach 09L

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09R are not geometrically possible for the entire 2-miles approach. Therefore, no impacts on pilots on the runway 09R approach are predicted.

8.4 Approach 27R

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27R are geometrically possible and they will be experienced by pilots approaching the runway between 2 and 1.3 miles from the threshold.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green") as shown in Figure 9 on the following page.

Such level of glare is acceptable and will not pose a threat to pilots' safety. Therefore, no impacts on pilots on the runway 27R approach are predicted.

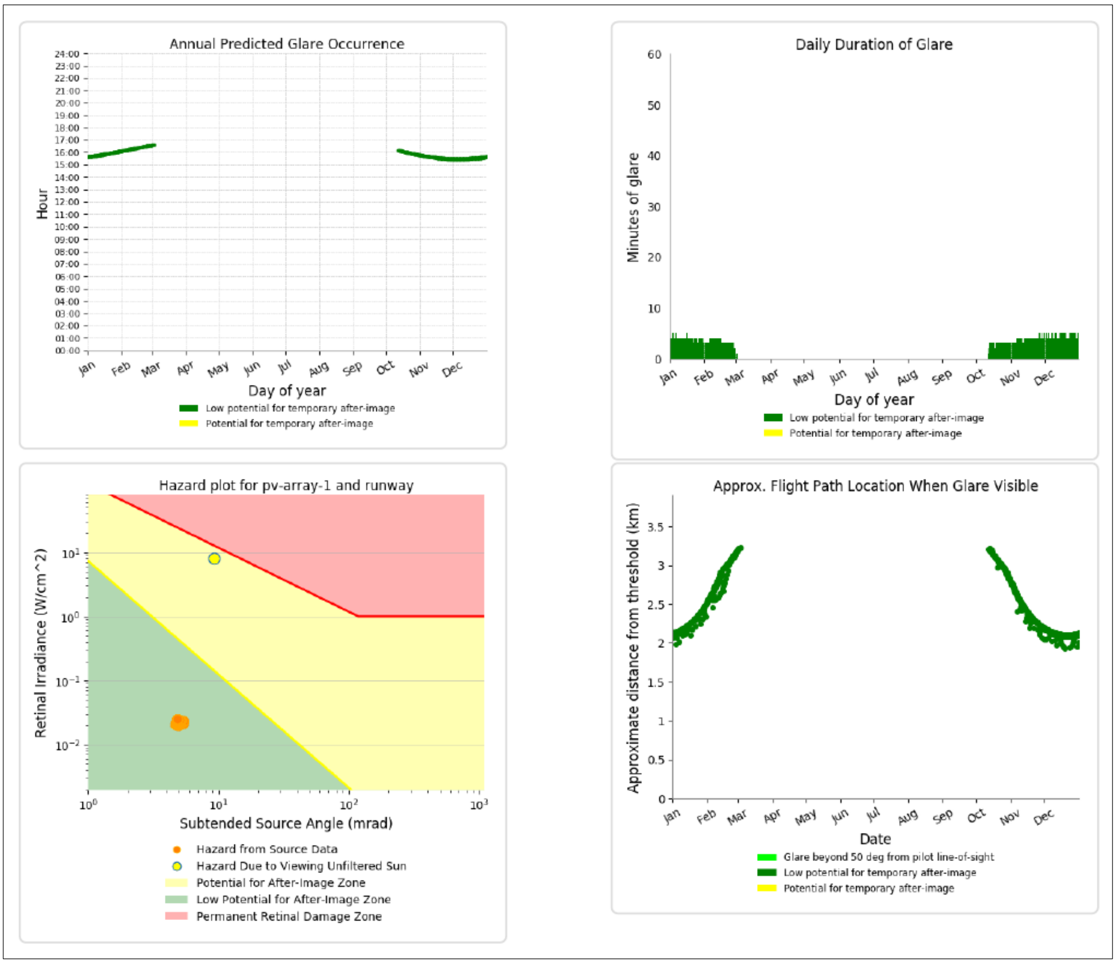

Figure 9 – Forge analysis: Approach 27R

8.5 Approach 09R

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09L are not geometrically possible for the entire 2-miles approach. Therefore, no impacts on pilots on the runway 09L approach are predicted.

8.6 Approach 27L

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27L are geometrically possible and they will be experienced by pilots approaching the runway between 0.2 and 0.3[17] miles and between 0.9 and 2 miles from the threshold.

[17] The analysis carried out with Forge sowed in Figure 10 shows no reflection at 0.2 and 0.3 miles from the approach. This is because the reflective area is outside the pilot's field of view.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green") as shown in Figure 10 below.

Such level of glare is acceptable and will not pose a threat to pilots' safety.

Therefore, no impacts on pilots on the runway 27L approach are predicted.

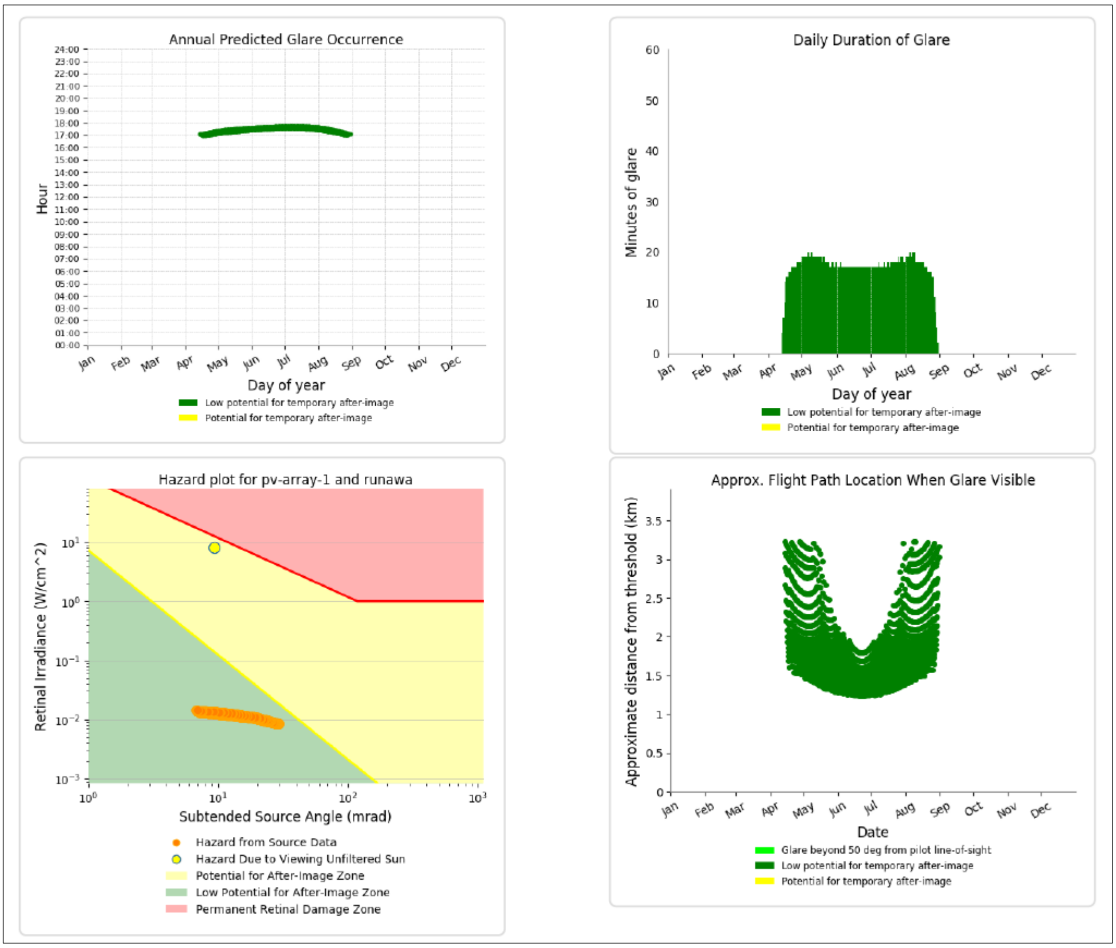

Figure 10 – Forge analysis: Approach 27L

8.7 Proposed Approach 09

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on the proposed runway approach 09 are not geometrically possible for the entire 2-miles approach. Therefore, no impacts on pilots on the proposed runway approach 09 are predicted.

8.8 Proposed Approach 27

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on the proposed runway approach 27 are geometrically not possible for the entire 2-miles approach[18]. Therefore, no impacts on pilots on the proposed runway approach 27 are predicted.

[18] The analysis carried out with Forge predicts glare with low potential for after image for a negligible amount of minutes per year. This is because Forge considers the diffraction of light when reflected by solar panels. When the assessment is carried out without diffraction factor Forge results are equivalent to the results produced by the Pager Power tool.

9 OVERALL CONCLUSIONS

9.1 Assessment Results –ATC Tower

The results of the analysis have shown that the reflections from the proposed development towards the existing ATC Tower are not possible. Therefore, no impact is expected and mitigation is not required.

9.2 Assessment Results – Runway Approach

9.2.1 Runway Approach 09L

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09L are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the runway 09L approach are predicted.

9.2.2 Runway Approach 27R

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27R are geometrically possible and they will be experienced by pilots approaching the runway between 1.3 and 2 miles from the threshold.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green").

Such level of glare is acceptable and will not pose a threat to pilots' safety. Therefore, no significant impacts on pilots on the runway 27R approach are predicted.

9.2.3 Runway Approach 09R

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on approach 09R are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the runway 09R approach are predicted.

9.2.4 Runway Approach 27L

The results of the analysis have shown that the reflections from the proposed development towards pilots landing on approach 27L are geometrically possible and they will be experienced by pilots approaching the runway between 0.2 and 0.3 miles and between 0.9 and 2 miles from the threshold.

However, the analysis shows that reflections will produce glare with low potential to cause temporary after-image ("green").

Such level of glare is acceptable and will not pose a threat to pilots' safety. Therefore, no impacts on pilots on the runway 27L approach are predicted.

9.2.5 Proposed Runway Approach 09

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on the proposed runway approach 09 are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the proposed runway 09 approach are predicted.

9.2.6 Proposed Runway Approach 27

The results of the analysis have shown that solar reflections from the proposed development towards pilots landing on the proposed runway approach 27 are not geometrically possible for the entire 2-mile approach. Therefore, no impacts on pilots on the proposed runway 27 approach are predicted.

9.3 Recommendation

Results should be made available to the airport safeguarding team at London Heathrow Airport.

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

UK National Planning Practice Guidance dictates that in some instances a glint and glare assessment is required however, there is no specific guidance with respect to the methodology for assessing the impact of glint and glare.

The planning policy from the Department for Communities and Local Government (paragraph 27[19]) states:

'Particular factors a local planning authority will need to consider include… the effect on landscape of glint and glare and on ***neighbouring uses and aircraft safety***.'

The National Planning Policy Framework for Renewable and Low Carbon Energy[20] (specifically regarding the consideration of solar farms, paragraph 26 and 27) 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;*

[19] Planning practice guidance for renewable and low carbon energy, Department for Communities and Local Government, date: 06/2013, accessed on: 20/03/2019
[20] Planning practice guidance for renewable and low carbon energy, Department for Communities and Local Government, date: 06/2013, accessed on: 20/03/2019

The approach to assessing cumulative landscape and visual impact of large scale solar farms is likely to be the same as assessing the impact of wind turbines. However, in the case of ground-mounted solar panels it should be noted that with effective screening and appropriate land topography the area of a zone of visual influence could be zero.'

Aviation Assessment Guidance

The UK Civil Aviation Authority (CAA) issued interim guidance relating to Solar Photovoltaic Systems (SPV) on 17 December 2010 and was subject to a CAA information alert 2010/53. The formal policy was cancelled on September 7th, 2012[21] however the advice is still applicable[22] 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[23], as part of a condition of a CAA Aerodrome Licence, the ALH is required to obtain prior consent from CAA Aerodrome Standards Department before any work is begun or approval to the developer or LPA is granted, in accordance with the procedures set out in CAP 791 Procedures for Changes to Aerodrome Infrastructure.

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

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*'[24] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports*'[25]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports*'[26].

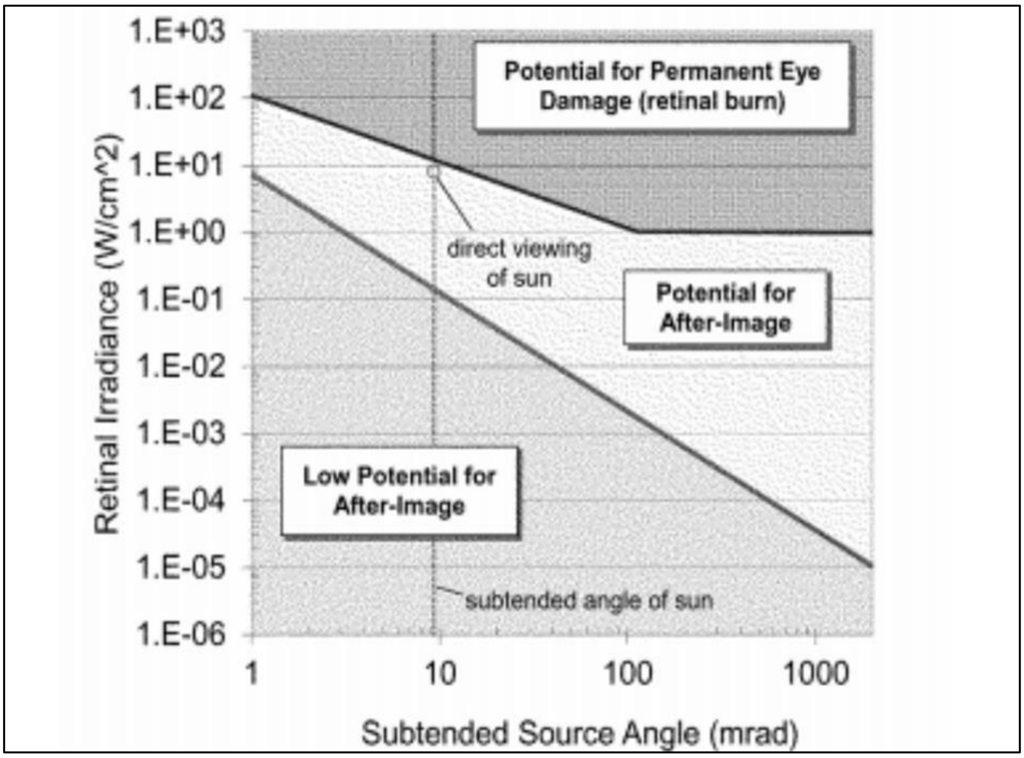
An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *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.*

[24] Archived at Pager Power

[25] 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

[8] 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*[27]*.*
- *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*[28]*, 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*

[27]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.

[28] 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 question*[29] *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.*

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

Air Navigation Order (ANO) 2009

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

Endangering safety of an aircraft

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

Lights liable to endanger

221.

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

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

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

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

(a) to extinguish or screen the light; and

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

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

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

Lights which dazzle or distract

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

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

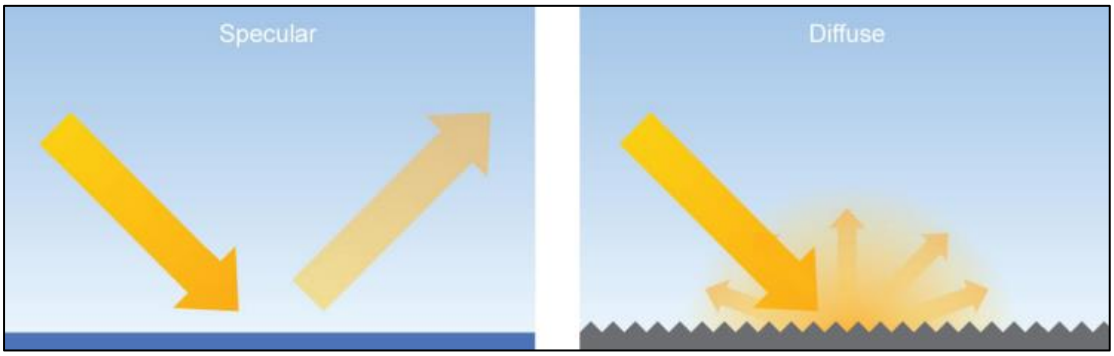
APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

Overview

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

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance[30], 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

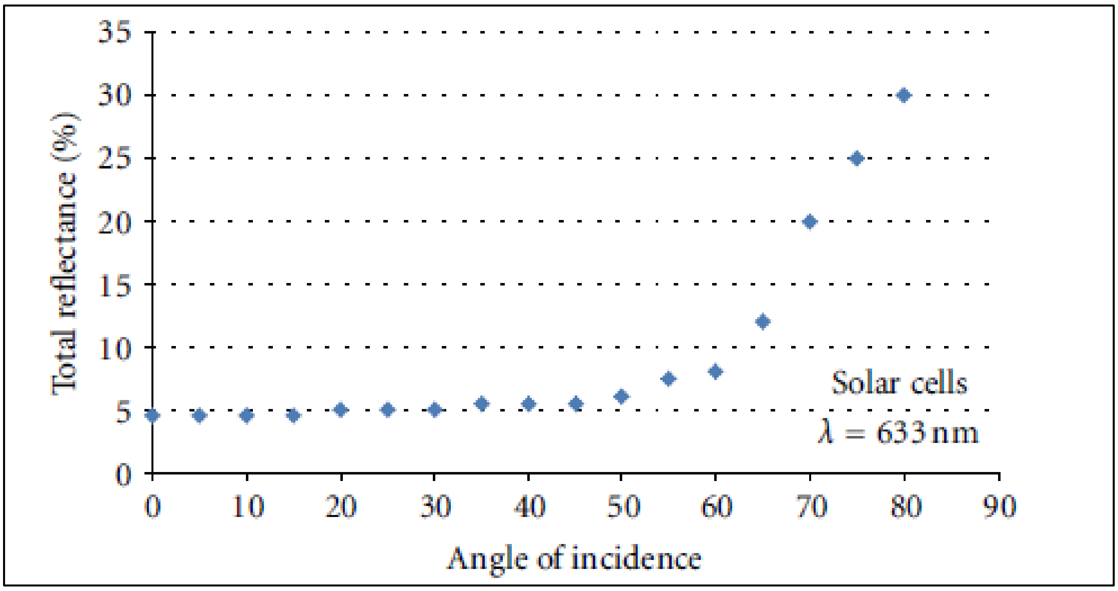
[30] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

Solar Reflection Studies

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

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

Evan Riley and Scott Olson published in 2011 their study titled: *A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems*[31]". 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.

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[31] 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"[32]

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

Surface	Approximate Percentage of Light Reflected[33]
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).

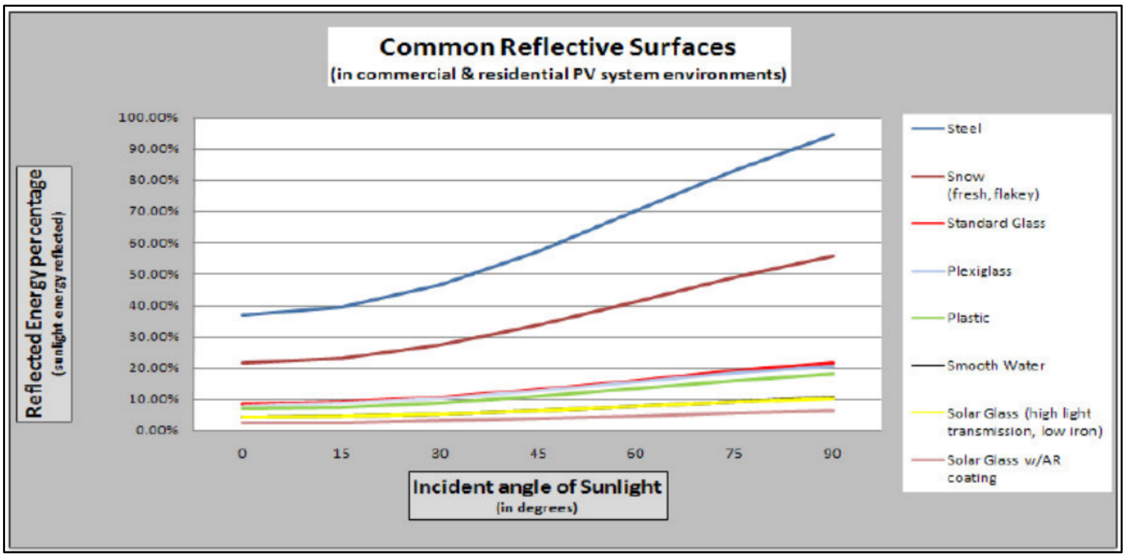
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

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

SunPower Technical Notification (2009)

SunPower published a technical notification[34] 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.

[34] 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:

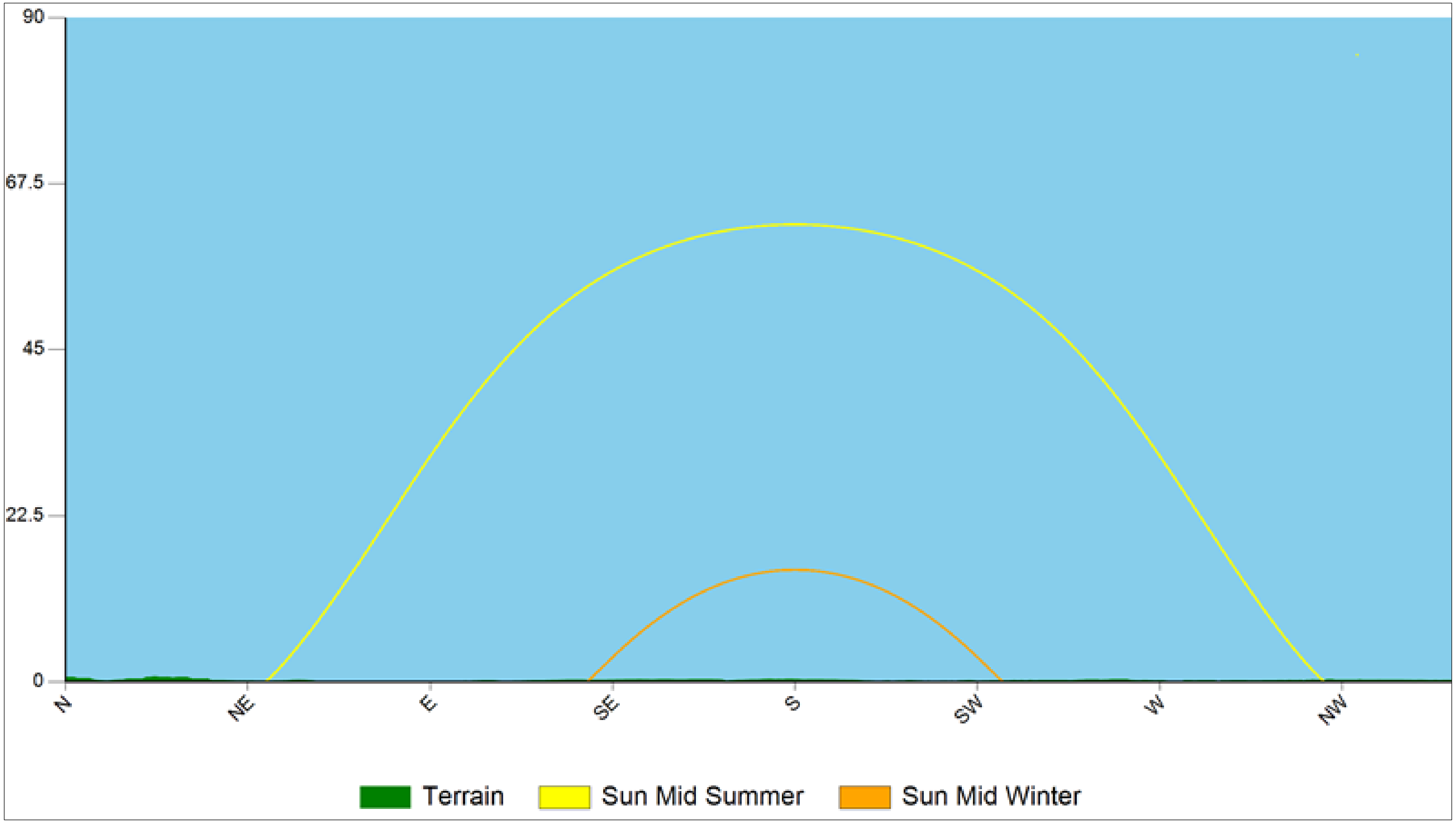
- Time;
- Date;
- Latitude;
- Longitude.

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 reaching a maximum elevation of approximately 60-65 degrees (longest day);
- On 21 December, the maximum elevation reached by the Sun is approximately 10-15 degrees (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.

Terrain Sun Curve - From lon:-0.423354 lat:51.466671



APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

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

Impact Significance Definition

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

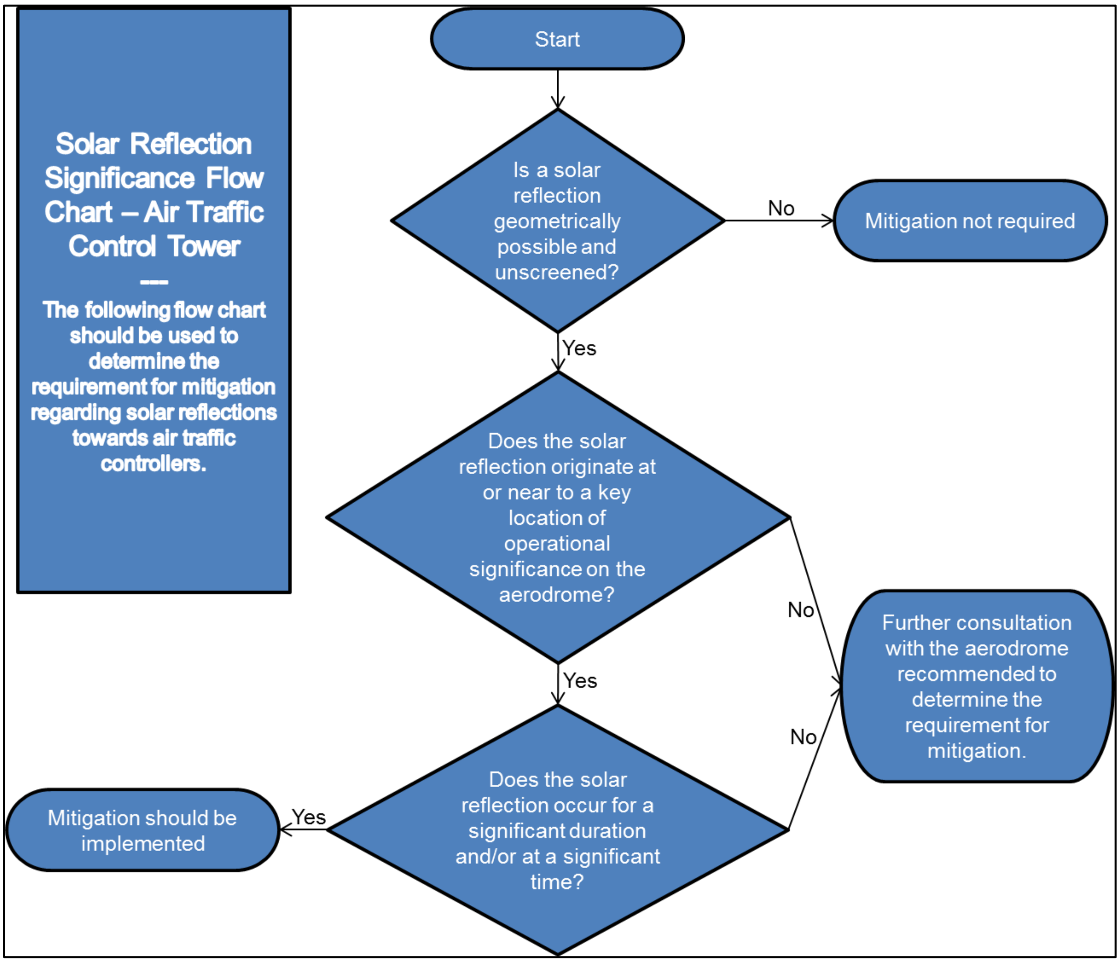
Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation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

Impact significance definition

The flow charts presented in the following sub-sections have been followed when determining the mitigation requirement for aviation receptors.

Assessment Process – ATC Tower

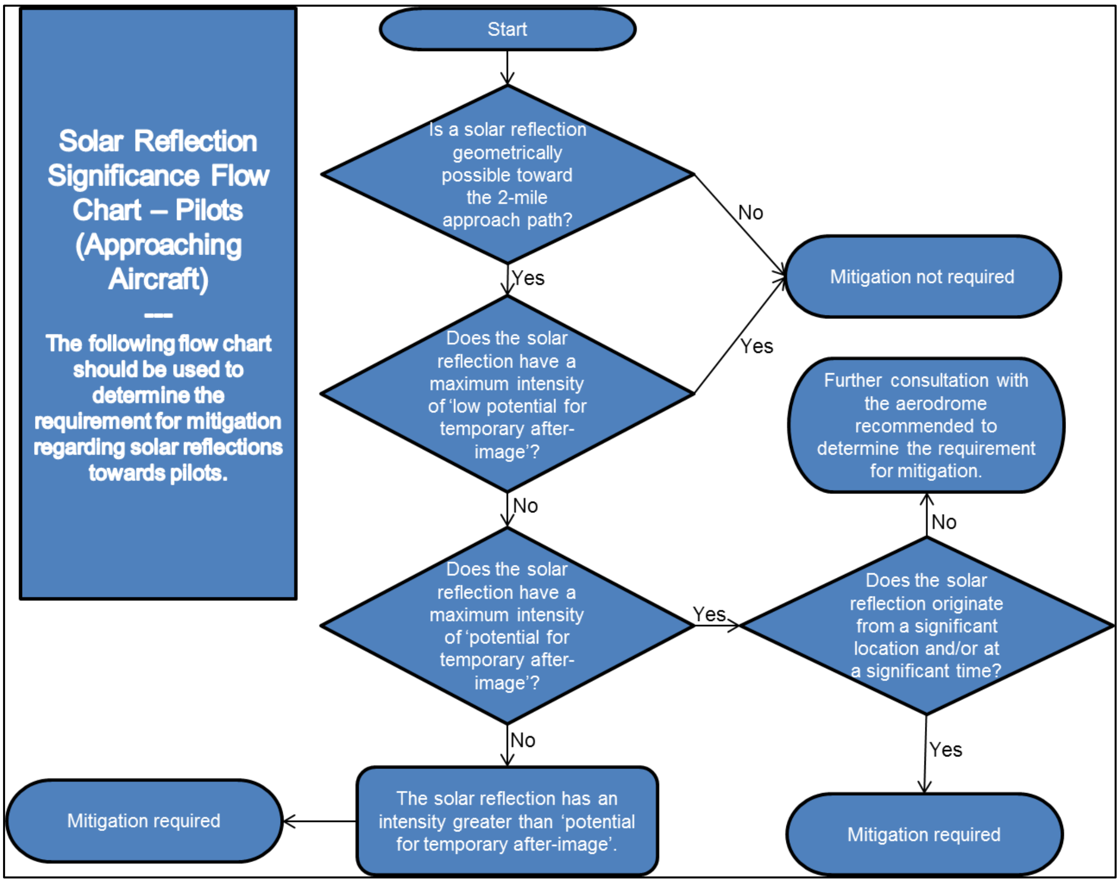
The charts relate to the determining the potential impact upon the ATC Tower.



ATC Tower mitigation requirement flow chart

Assessment Process – Approaching Aircraft

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



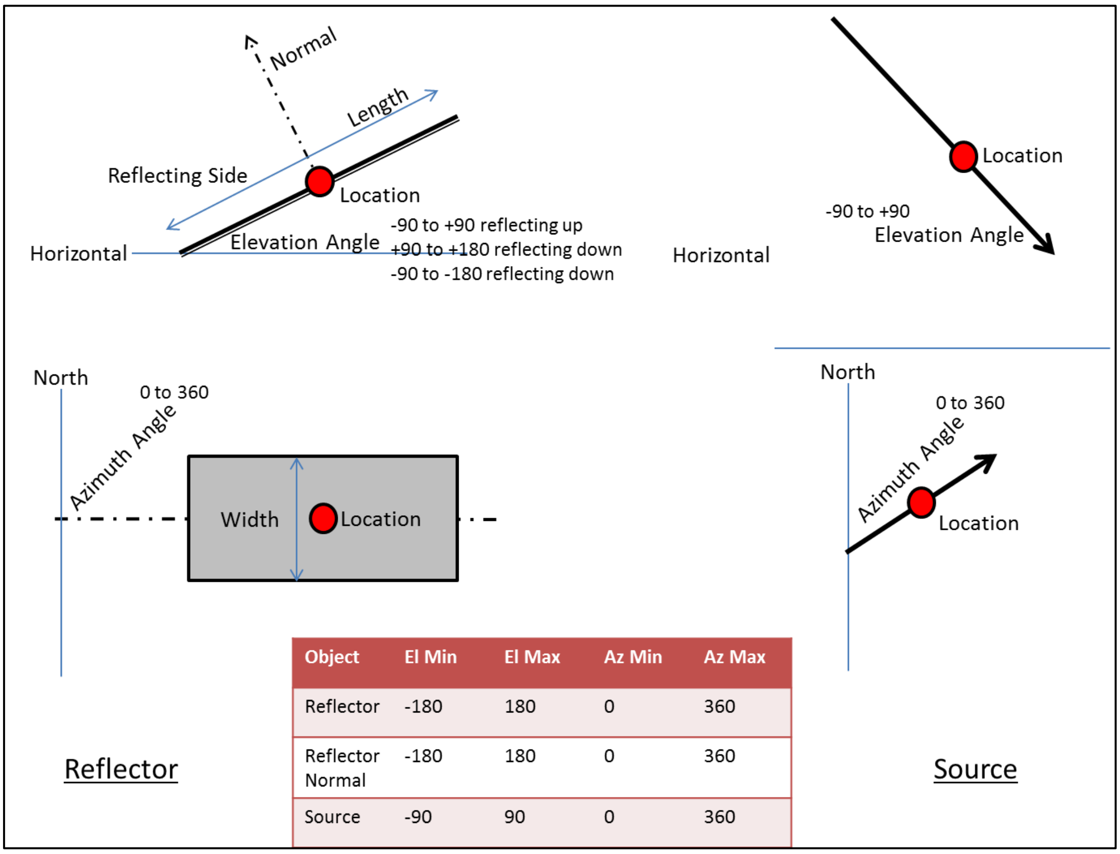
Approaching aircraft receptor mitigation requirement flow chart

APPENDIX E – PAGER POWER'S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

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

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



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

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

It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within the solar development.

It is assumed that the panel azimuth angle provided by the developer represents the azimuth angle for all of the panels within the solar development.

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

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

A finite number of points within the proposed development are chosen based on an assessment resolution so we can build a comprehensive understanding of the entire development. This will determine whether a reflection could ever occur at a chosen receptor. The calculations do not incorporate all of the possible panel locations within the development outline.

A single reflection point on the panel has been chosen for the geometric calculations. This will suitably determine whether a reflection can be experienced at a location and the general time of year and duration of this 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.

Whilst line of sight to the development from receptors has been considered, only available street view imagery and satellite mapping has been used. 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 considered unless stated.

Sandia National Laboratories' (SGHAT) Model

The following text is taken from the Solar Glare Hazard Analysis Tool (SGHAT) Technical Reference Manual[35] which was previously freely available. The following is presented for reference.

3. Assumptions and Limitations

Below is a list of assumptions and limitations of the models and methods used in SGHAT:

- The software currently only applies to flat reflective surfaces. For curved surfaces (e.g., focused mirrors such as parabolic troughs or dishes used in concentrating solar power systems), methods and models derived by Ho et al. (2011) [1] can be used and are currently being evaluated for implementation into future versions SGHAT.
- When enabled, PV array single- or dual-axis tracking does not account for backtracking or the effects of panel shading and blocking.
- SGHAT 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.
- SGHAT 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.
- SGHAT 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.
- 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 [2] 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.
- 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.

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[35] https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Technical_Reference-v5.pdf

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Receptor Details

The details are presented in the table below.

Longitude (°)	Latitude (°)	ATC Tower Altitude
-0.465531	51.47182	109.00m[36]

ATC tower receptor details

The Approach Path for Aircraft Landing on Runway 09L

The table below presents the data for the assessed locations for aircraft on approach to runway 09R. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
1	-0.48499	51.47750	Threshold	39.32
2	-0.48732	51.47749	Receptor 02	47.74
3	-0.48964	51.47748	Receptor 03	56.16
4	-0.49197	51.47747	Receptor 04	64.59
5	-0.49429	51.47747	Receptor 05	73.01
6	-0.49662	51.47746	Receptor 06	81.43
7	-0.49894	51.47745	Receptor 07	89.86
8	-0.50127	51.47744	Receptor 08	98.28
9	-0.50359	51.47743	Receptor 09	106.70
10	-0.50592	51.47742	Receptor 10	115.12
11	-0.50825	51.47742	Receptor 11 – 1 mile	123.55
12	-0.51057	51.47741	Receptor 12	131.97
13	-0.51290	51.47740	Receptor 13	140.39
14	-0.51522	51.47739	Receptor 14	148.81
15	-0.51755	51.47738	Receptor 15	157.24

[36] Heathrow Airport, NATS, date:2020.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
16	-0.51987	51.47737	Receptor 16	165.66
17	-0.52220	51.47737	Receptor 17	174.08
18	-0.52452	51.47736	Receptor 18	182.50
19	-0.52685	51.47735	Receptor 19	190.93
20	-0.52917	51.47734	Receptor 20	199.35
21	-0.53150	51.47733	Receptor 21 – 2 miles	207.77

Assessed receptor (aircraft) locations on the approach path for runway 09R

The Approach Path for Aircraft Landing on Runway 27R

The table below presents the data for the assessed locations for aircraft on approach to runway 27L. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
22	-0.43328	51.47768	Threshold	39.01
23	-0.43096	51.47768	Receptor 02	47.44
24	-0.42863	51.47769	Receptor 03	55.86
25	-0.42631	51.47770	Receptor 04	64.28
26	-0.42398	51.47770	Receptor 05	72.71
27	-0.42166	51.47771	Receptor 06	81.13
28	-0.41933	51.47772	Receptor 07	89.55
29	-0.41701	51.47773	Receptor 08	97.97
30	-0.41468	51.47773	Receptor 09	106.40
31	-0.41236	51.47774	Receptor 10	114.82
32	-0.41003	51.47775	Receptor 11 – 1 mile	123.24
33	-0.40770	51.47776	Receptor 12	131.66
34	-0.40538	51.47776	Receptor 13	140.09
35	-0.40305	51.47777	Receptor 14	148.51
36	-0.40073	51.47778	Receptor 15	156.93

37	-0.39840	51.47778	Receptor 16	165.35
38	-0.39608	51.47779	Receptor 17	173.78
39	-0.39375	51.47780	Receptor 18	182.20
40	-0.39143	51.47781	Receptor 19	190.62
41	-0.38910	51.47781	Receptor 20	199.04
42	-0.38678	51.47782	Receptor 21 – 2 miles	207.47

Assessed receptor (aircraft) locations on the approach path for runway 27R

The Approach Path for Aircraft Landing on Runway 09R

The table below presents the data for the assessed locations for aircraft on approach to runway 09L. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
43	-0.48231	51.46479	Threshold	38.10
44	-0.48464	51.46478	Receptor 02	46.52
45	-0.48696	51.46478	Receptor 03	54.95
46	-0.48929	51.46477	Receptor 04	63.37
47	-0.49161	51.46476	Receptor 05	71.79
48	-0.49394	51.46475	Receptor 06	80.21
49	-0.49626	51.46474	Receptor 07	88.64
50	-0.49859	51.46474	Receptor 08	97.06
51	-0.50091	51.46473	Receptor 09	105.48
52	-0.50324	51.46472	Receptor 10	113.90
53	-0.50556	51.46471	Receptor 11 – 1 mile	122.33
54	-0.50789	51.46470	Receptor 12	130.75
55	-0.51021	51.46469	Receptor 13	139.17
56	-0.51253	51.46469	Receptor 14	147.59
57	-0.51486	51.46468	Receptor 15	156.02
58	-0.51718	51.46467	Receptor 16	164.44
59	-0.51951	51.46466	Receptor 17	172.86

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
60	-0.52183	51.46465	Receptor 18	181.29
61	-0.52416	51.46465	Receptor 19	189.71
62	-0.52648	51.46464	Receptor 20	198.13
63	-0.52881	51.46463	Receptor 21 – 2 miles	206.55

Assessed receptor (aircraft) locations on the approach path for runway 09L

The Approach Path for Aircraft Landing on Runway 27L

The table below presents the data for the assessed locations for aircraft on approach to runway 27R. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
64	-0.43410	51.46495	Threshold	38.71
65	-0.43178	51.46496	Receptor 02	47.13
66	-0.42945	51.46496	Receptor 03	55.55
67	-0.42713	51.46497	Receptor 04	63.98
68	-0.42480	51.46498	Receptor 05	72.40
69	-0.42248	51.46499	Receptor 06	80.82
70	-0.42015	51.46499	Receptor 07	89.25
71	-0.41783	51.46500	Receptor 08	97.67
72	-0.41550	51.46501	Receptor 09	106.09
73	-0.41318	51.46501	Receptor 10	114.51
74	-0.41085	51.46502	Receptor 11 – 1 mile	122.94
75	-0.40853	51.46503	Receptor 12	131.36
76	-0.40620	51.46503	Receptor 13	139.78
77	-0.40388	51.46504	Receptor 14	148.20
78	-0.40155	51.46505	Receptor 15	156.63
79	-0.39923	51.46506	Receptor 16	165.05
80	-0.39690	51.46506	Receptor 17	173.47

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
81	-0.39458	51.46507	Receptor 18	181.89
82	-0.39226	51.46508	Receptor 19	190.32
83	-0.38993	51.46508	Receptor 20	198.74
84	-0.38761	51.46509	Receptor 21 – 2 miles	207.16

Assessed receptor (aircraft) locations on the approach path for runway 27R

The Approach Path for Aircraft Landing on Proposed Runway 09

The table below presents the data for the assessed locations for aircraft on approach to proposed runway 09. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
85	-0.46108	51.48699	Threshold	42.21
86	-0.45876	51.48698	Receptor 02	50.64
87	-0.45643	51.48696	Receptor 03	59.06
88	-0.45410	51.48694	Receptor 04	67.48
89	-0.45178	51.48692	Receptor 05	75.91
90	-0.44945	51.48691	Receptor 06	84.33
91	-0.44713	51.48689	Receptor 07	92.75
92	-0.44480	51.48687	Receptor 08	101.17
93	-0.44248	51.48685	Receptor 09	109.60
94	-0.44015	51.48683	Receptor 10	118.02
95	-0.43782	51.48682	Receptor 11 – 1 mile	126.44
96	-0.43550	51.48680	Receptor 12	134.86
97	-0.43317	51.48678	Receptor 13	143.29
98	-0.43085	51.48676	Receptor 14	151.71
99	-0.42852	51.48675	Receptor 15	160.13
100	-0.42620	51.48673	Receptor 16	168.55
101	-0.42387	51.48671	Receptor 17	176.98

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
102	-0.42154	51.48669	Receptor 18	185.40
103	-0.41922	51.48668	Receptor 19	193.82
104	-0.41689	51.48666	Receptor 20	202.25
105	-0.41457	51.48664	Receptor 21 – 2 miles	210.67

Assessed receptor (aircraft) locations on the approach path for proposed runway 09

The Approach Path for Aircraft Landing on Proposed Runway 27

The table below presents the data for the assessed locations for aircraft on approach to proposed runway 27. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
106	-0.51147	51.48682	Threshold	38.25
107	-0.51379	51.48684	Receptor 02	46.68
108	-0.51612	51.48685	Receptor 03	55.10
109	-0.51845	51.48687	Receptor 04	63.52
110	-0.52077	51.48689	Receptor 05	71.94
111	-0.52310	51.48691	Receptor 06	80.37
112	-0.52542	51.48693	Receptor 07	88.79
113	-0.52775	51.48694	Receptor 08	97.21
114	-0.53007	51.48696	Receptor 09	105.63
115	-0.53240	51.48698	Receptor 10	114.06
116	-0.53473	51.48700	Receptor 11 – 1 mile	122.48
117	-0.53705	51.48701	Receptor 12	130.90
118	-0.53938	51.48703	Receptor 13	139.32
119	-0.54170	51.48705	Receptor 14	147.75
120	-0.54403	51.48707	Receptor 15	156.17
121	-0.54635	51.48708	Receptor 16	164.59
122	-0.54868	51.48710	Receptor 17	173.01

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m) (amsl)
123	-0.55101	51.48712	Receptor 18	181.44
124	-0.55333	51.48714	Receptor 19	189.86
125	-0.55566	51.48716	Receptor 20	198.28
126	-0.55798	51.48717	Receptor 21 – 2 miles	206.71

Assessed receptor (aircraft) locations on the approach path for proposed runway 27

Modelled Reflector Site

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-0.423159	51.466911	3	-0.423546	51.466425
2	-0.422919	51.466697	4	-0.423792	51.466651

Modelled reflector Site 1

APPENDIX H – GEOMETRIC CALCULATION RESULTS- PAGER POWER RESULTS

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

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

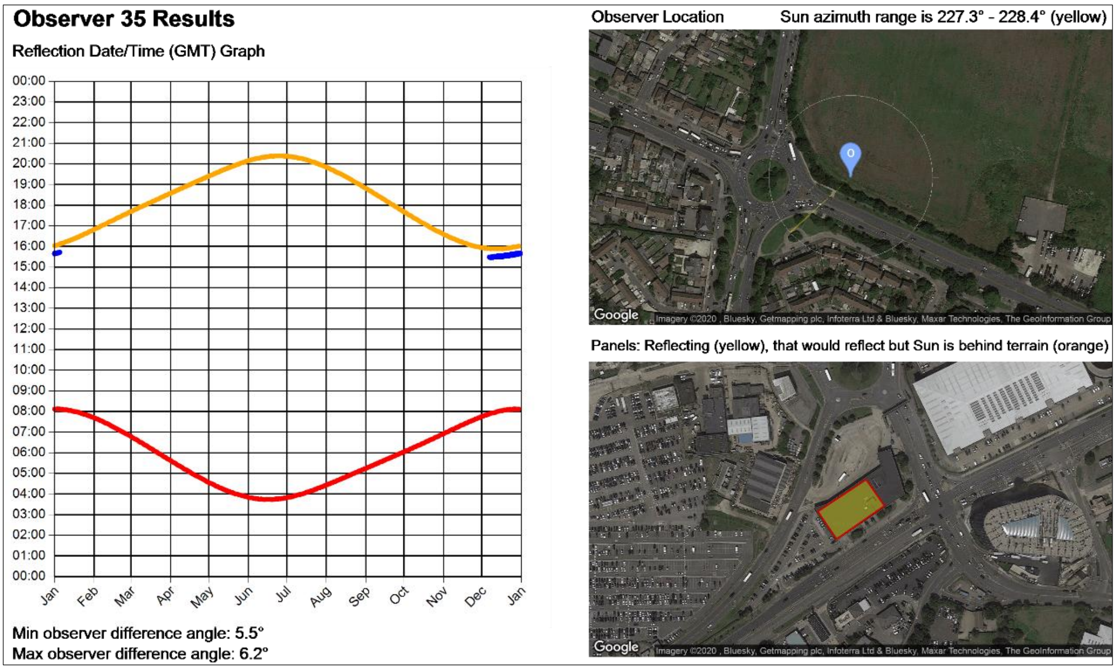
ATC Tower

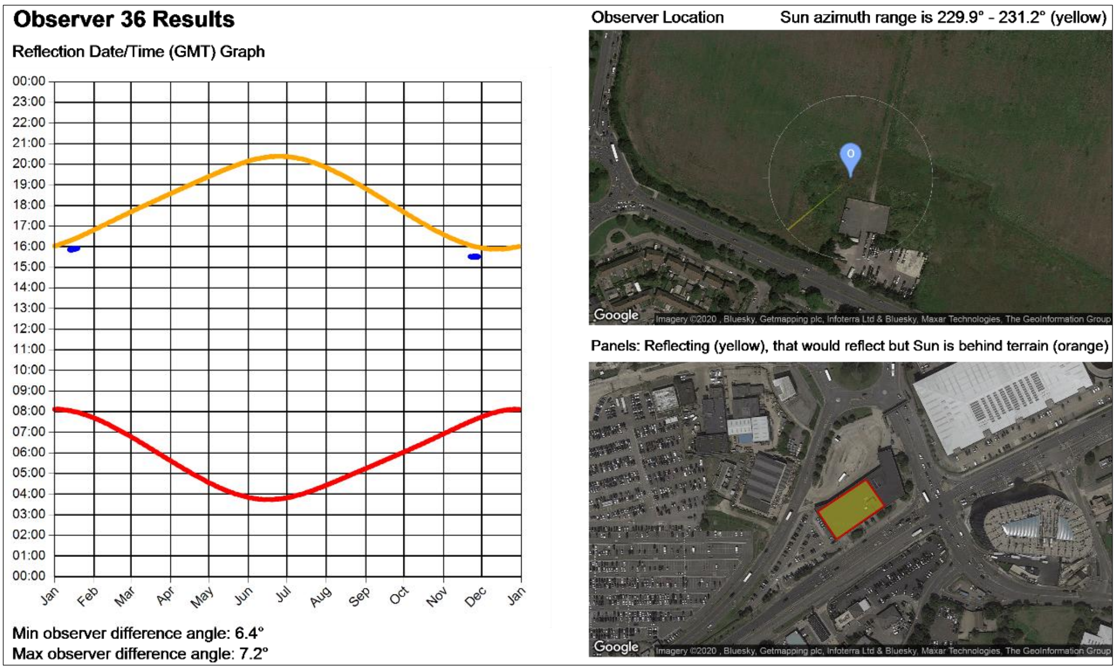
No reflection expected.

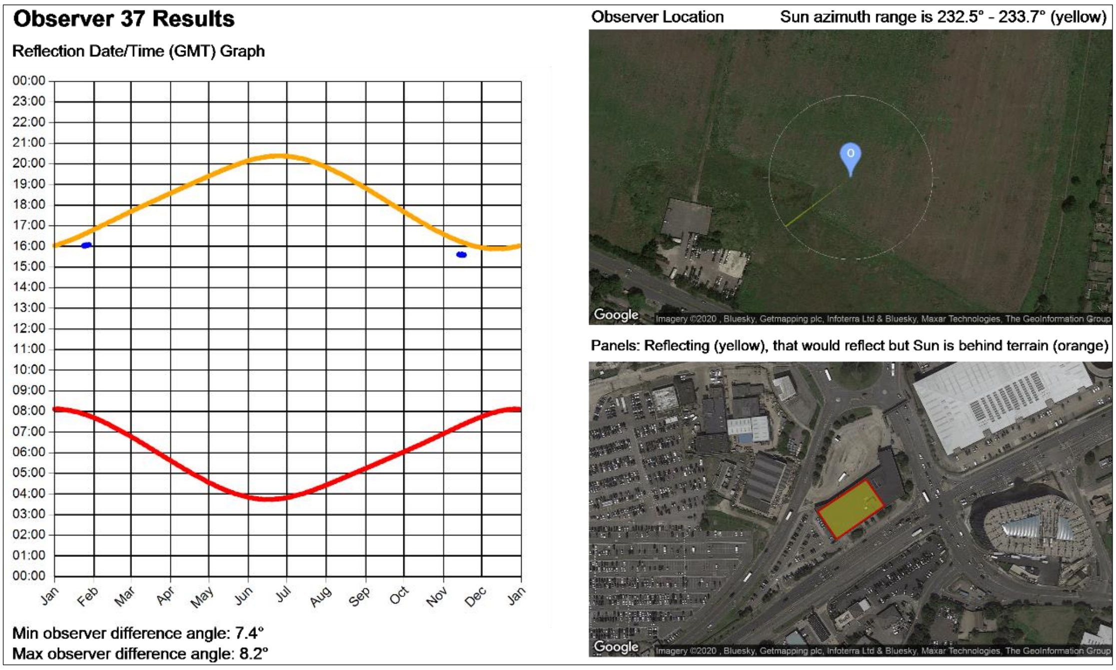
Approach 09L

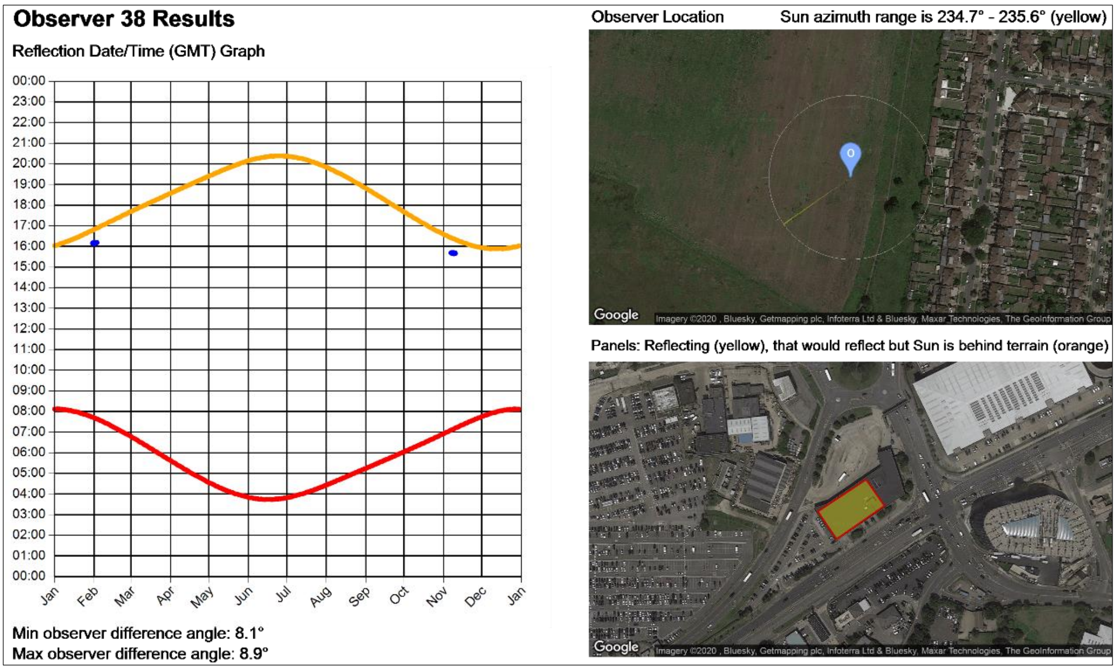
No reflection expected.

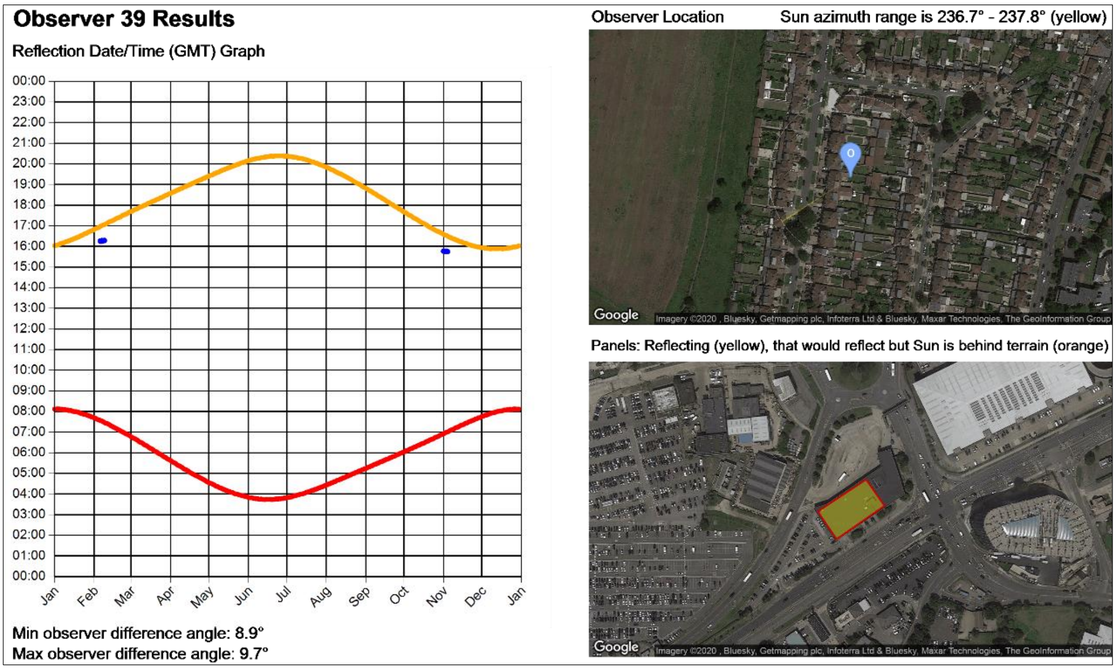
Approach 27R

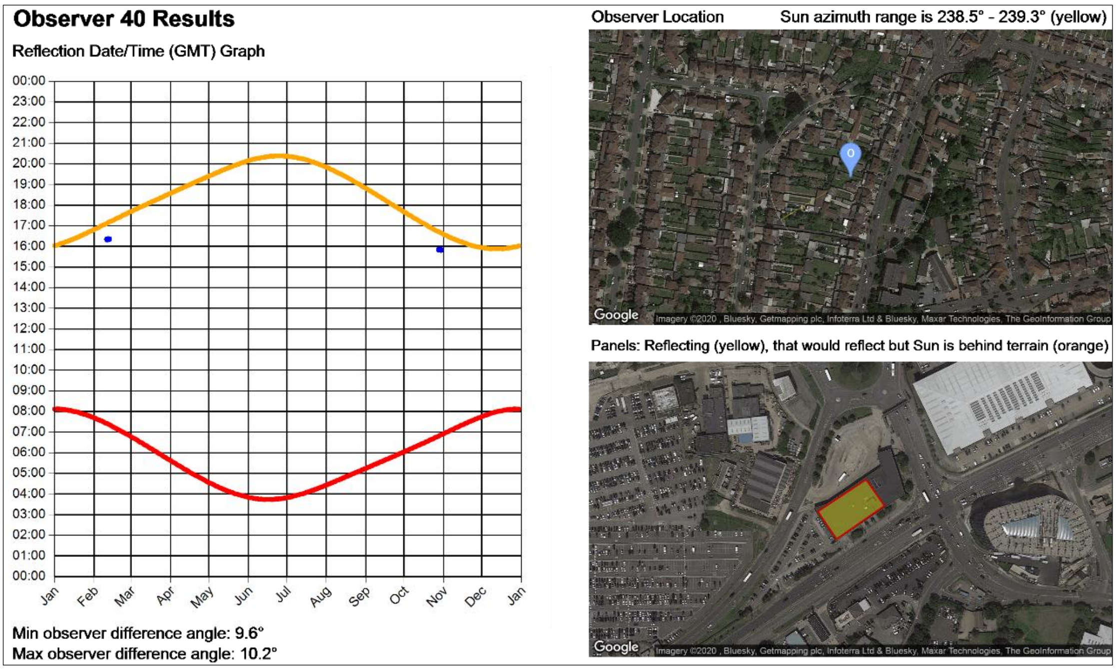


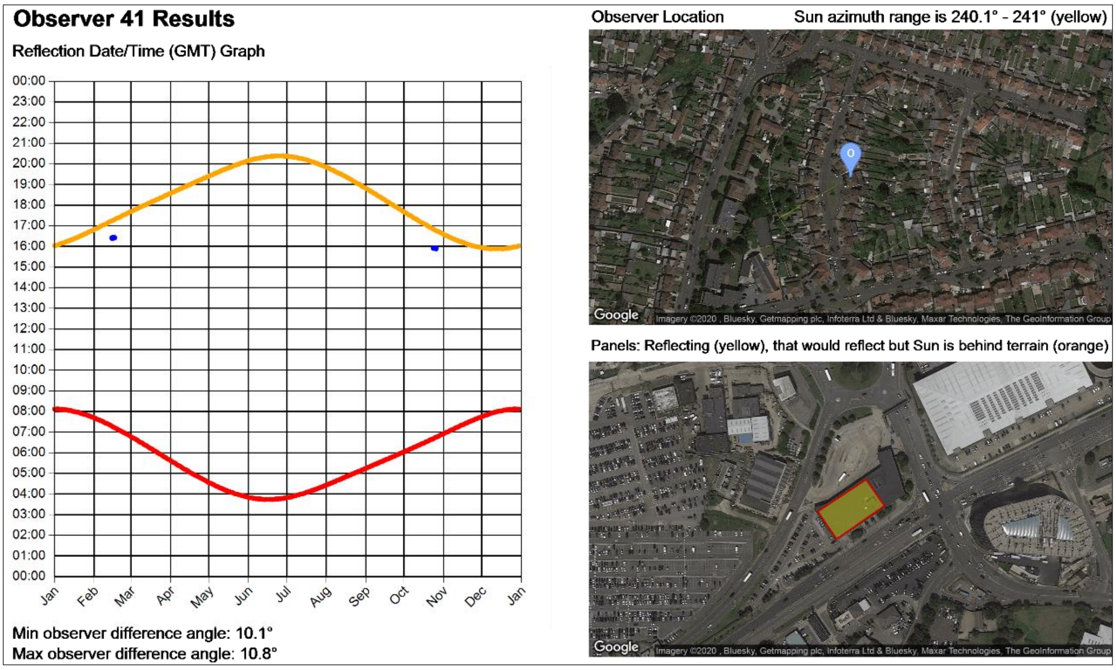


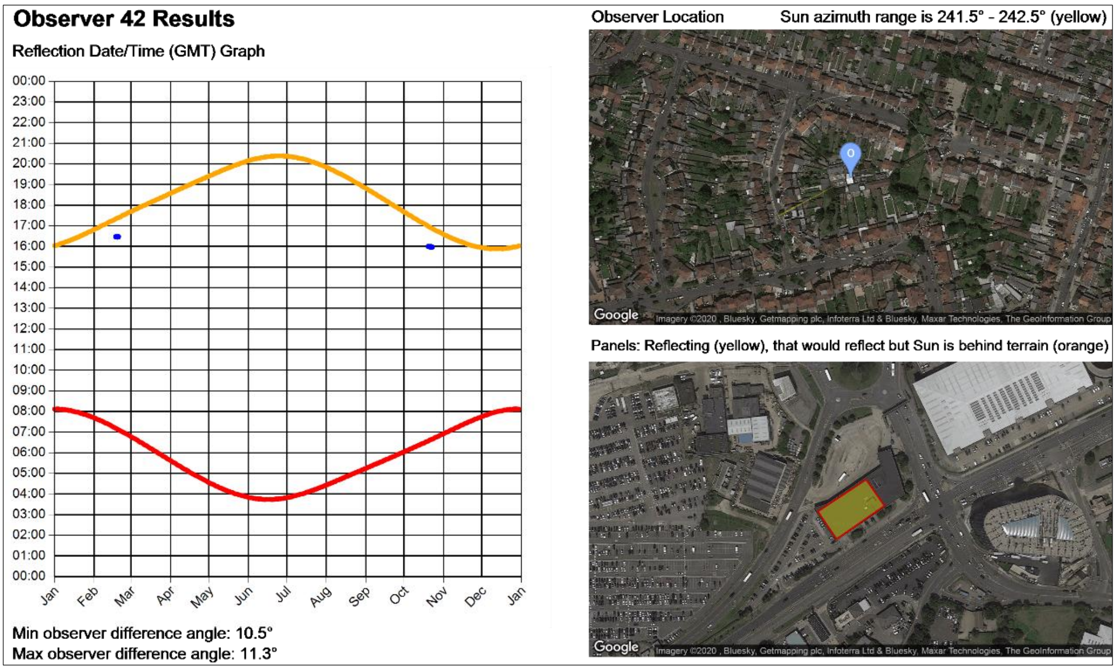

Observer 37 Results
Reflection Date/Time (GMT) Graph
00:00 23:00 22:00 21:00 20:00 19:00 18:00 17:00 16:00 15:00 14:00 13:00 12:00 11:00 10:00 09:00 08:00 07:00 06:00 05:00 04:00 03:00 02:00 01:00 00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 7.4°
Max observer difference angle: 8.2°
Observer Location
Sun azimuth range is 232.5° - 233.7° (yellow)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group


Observer 38 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: 8.1°
Max observer difference angle: 8.9°
Observer Location
Sun azimuth range is 234.7° - 235.6° (yellow)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group


Observer 39 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 236.7° - 237.8° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 8.9°
Max observer difference angle: 9.7°
Google


Observer 40 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 238.5° - 239.3° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 9.6°
Max observer difference angle: 10.2°
Google

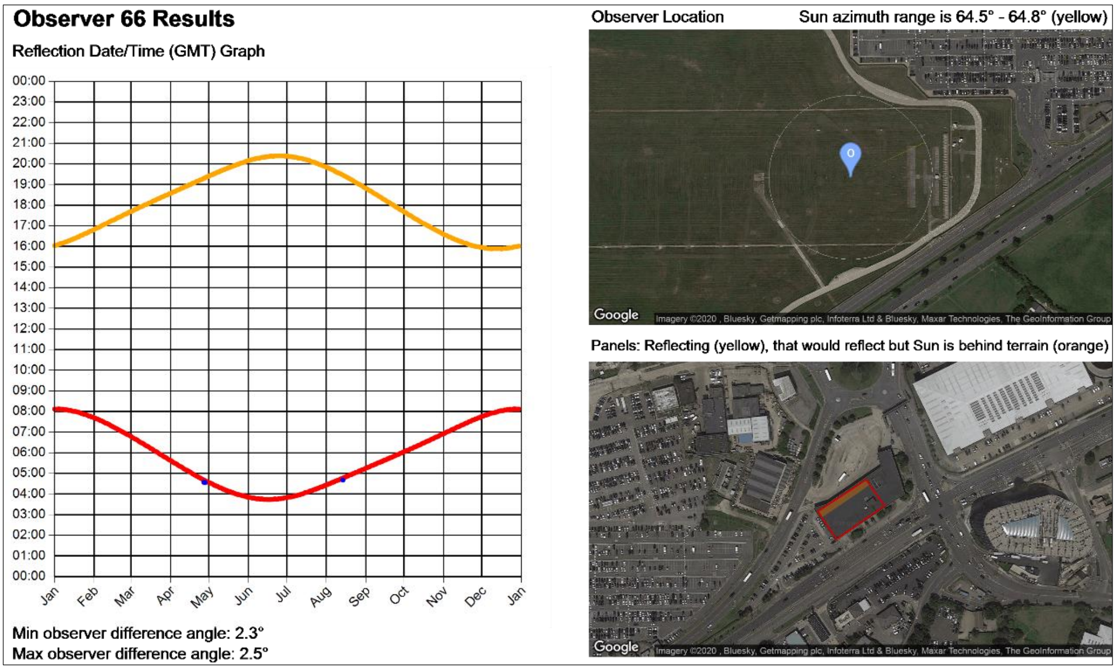

Observer 41 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 240.1° - 241° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 10.1°
Max observer difference angle: 10.8°

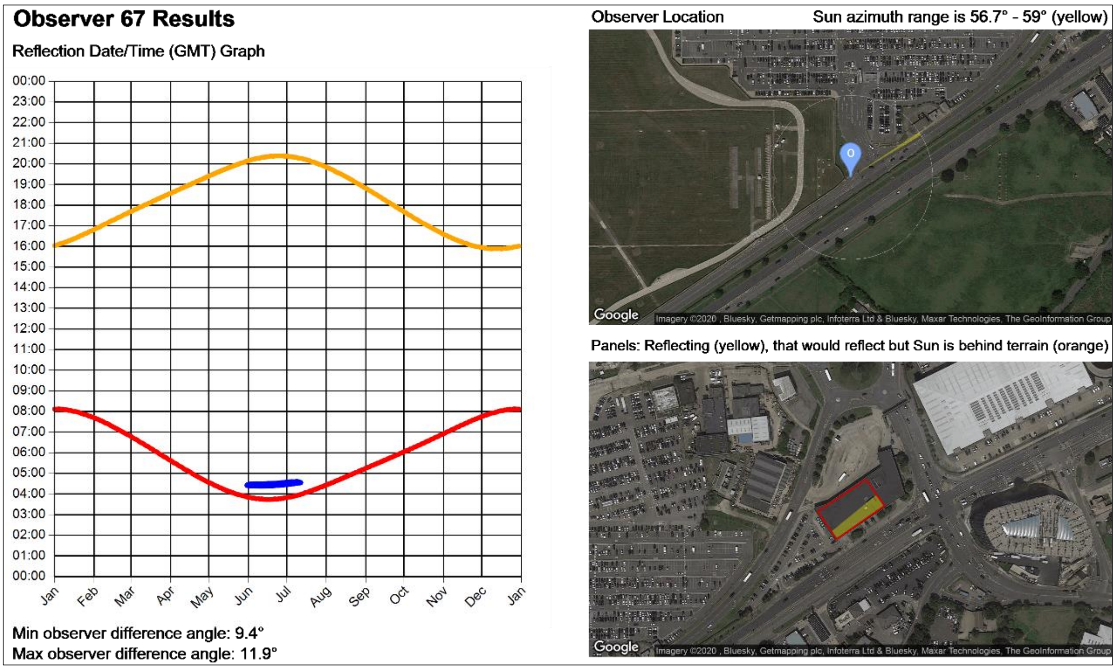

Observer 42 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 241.5° - 242.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 10.5°
Max observer difference angle: 11.3°

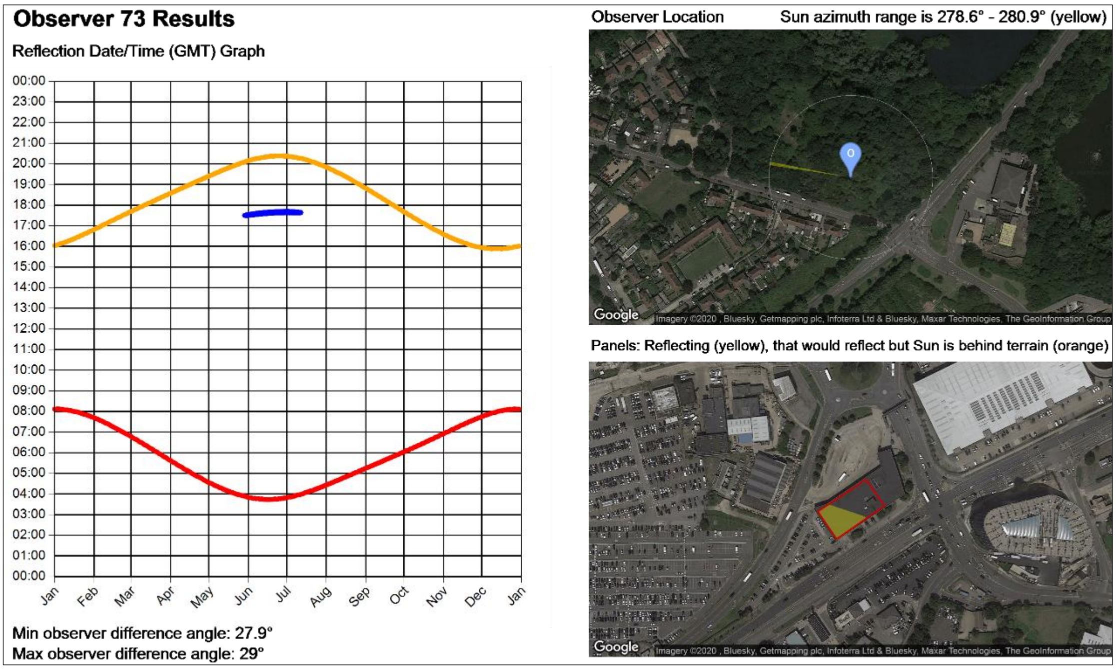
Approach 09R

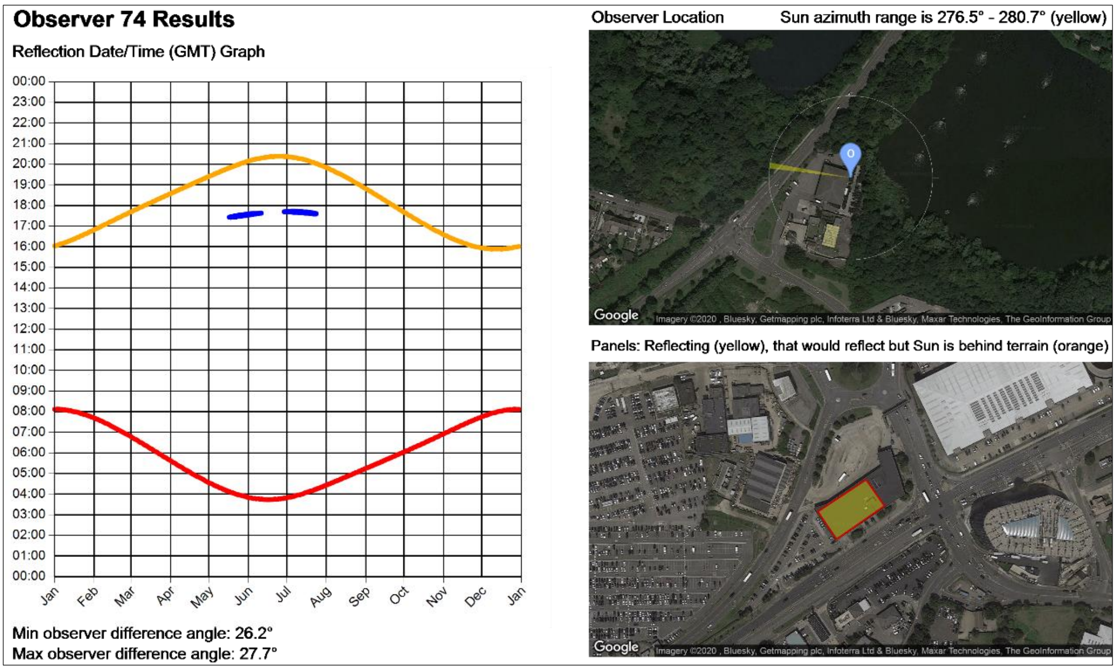
No reflection expected.

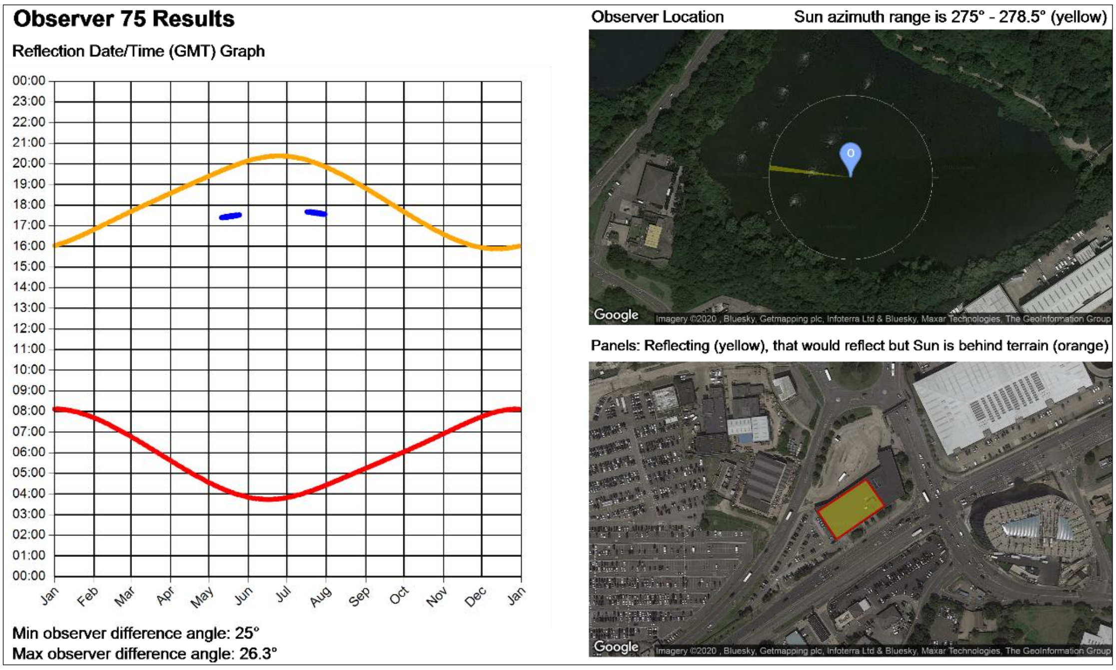
Approach 27L

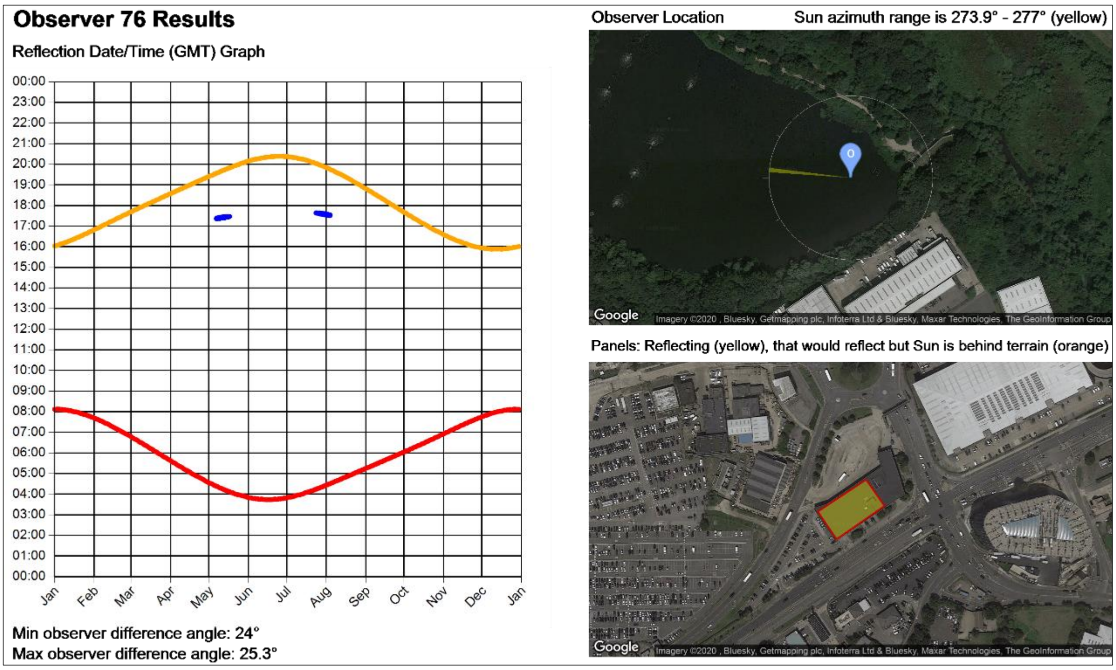


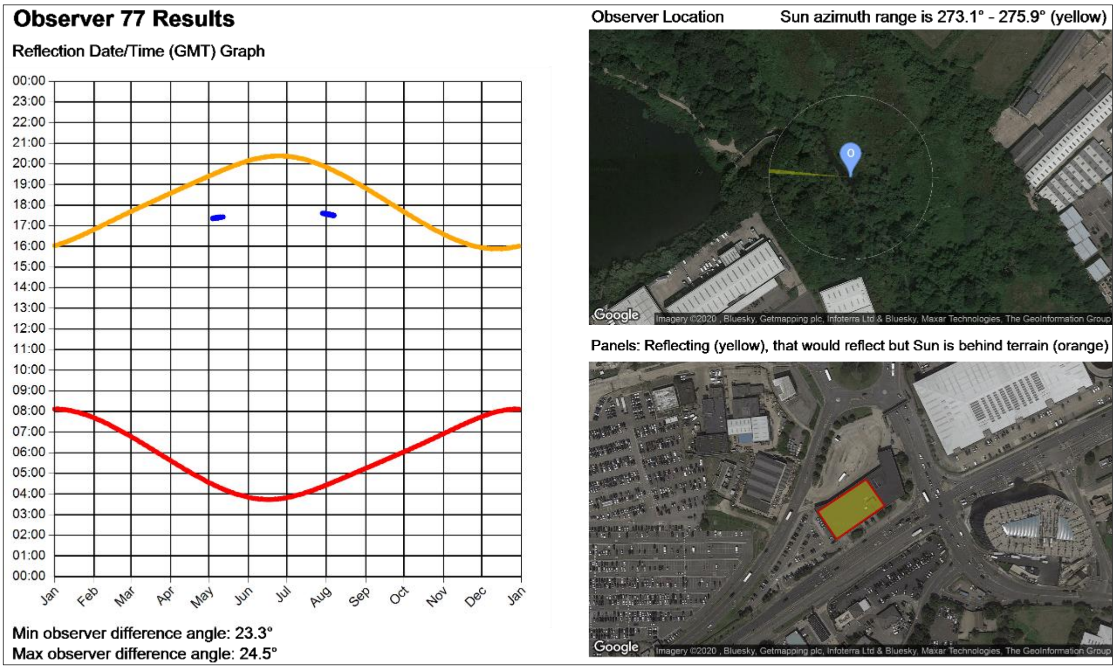


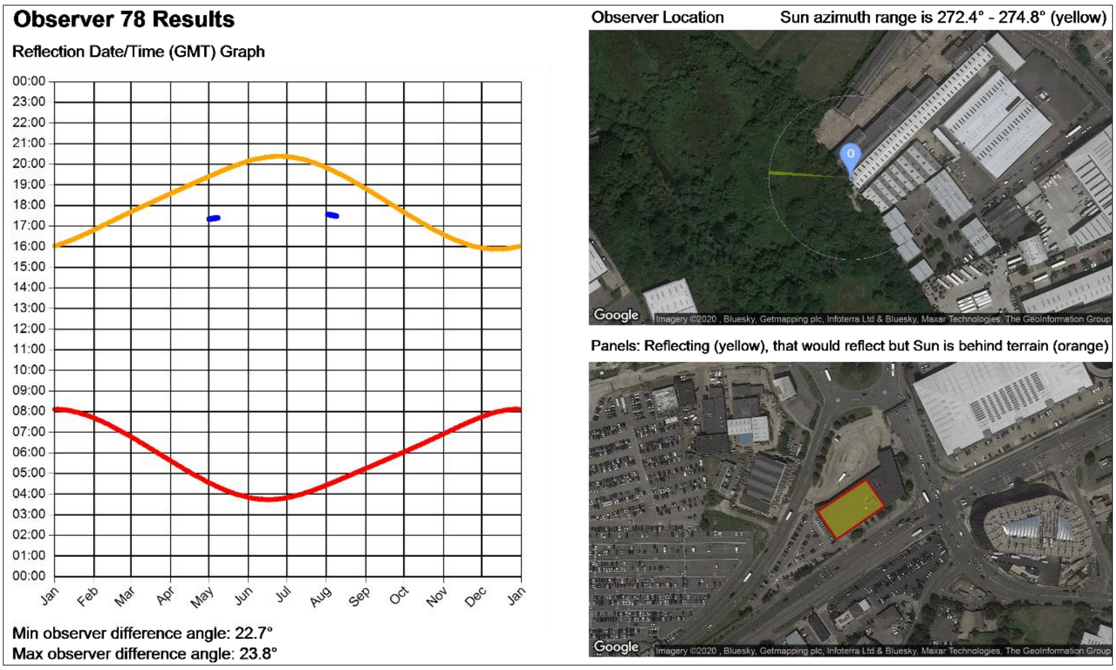

Observer 73 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 278.6° - 280.9° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 27.9°
Max observer difference angle: 29°
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group

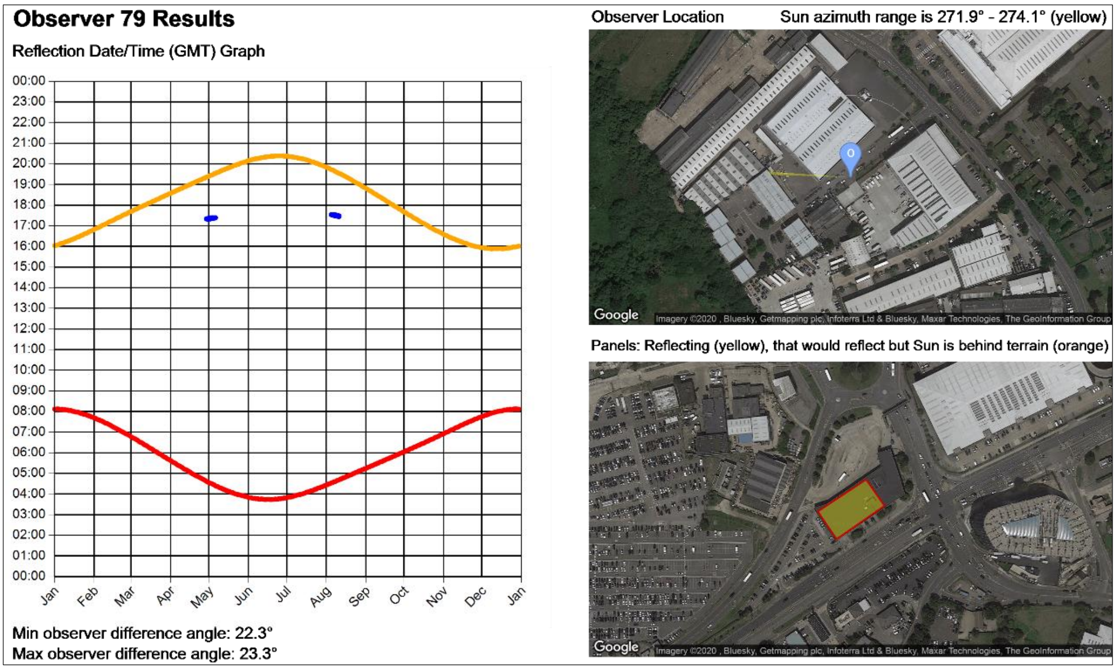

Observer 74 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 276.5° - 280.7° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Min observer difference angle: 26.2°
Max observer difference angle: 27.7°
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group

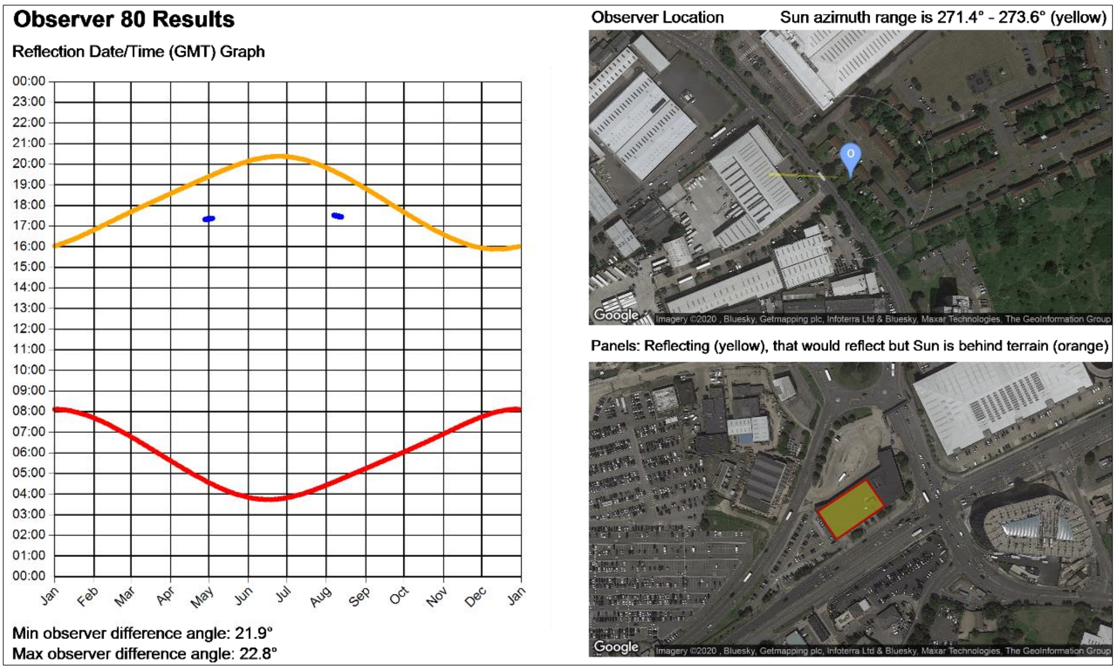

Observer 75 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 25°
Max observer difference angle: 26.3°
Observer Location
Sun azimuth range is 275° - 278.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

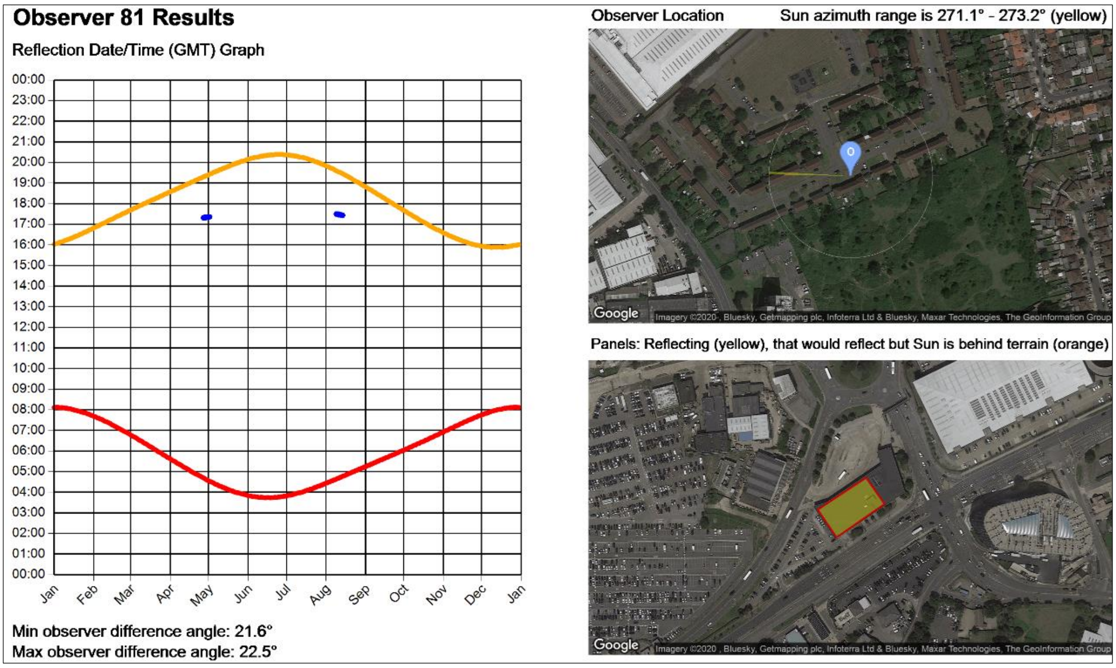

Observer 76 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 24°
Max observer difference angle: 25.3°
Observer Location
Sun azimuth range is 273.9° - 277° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

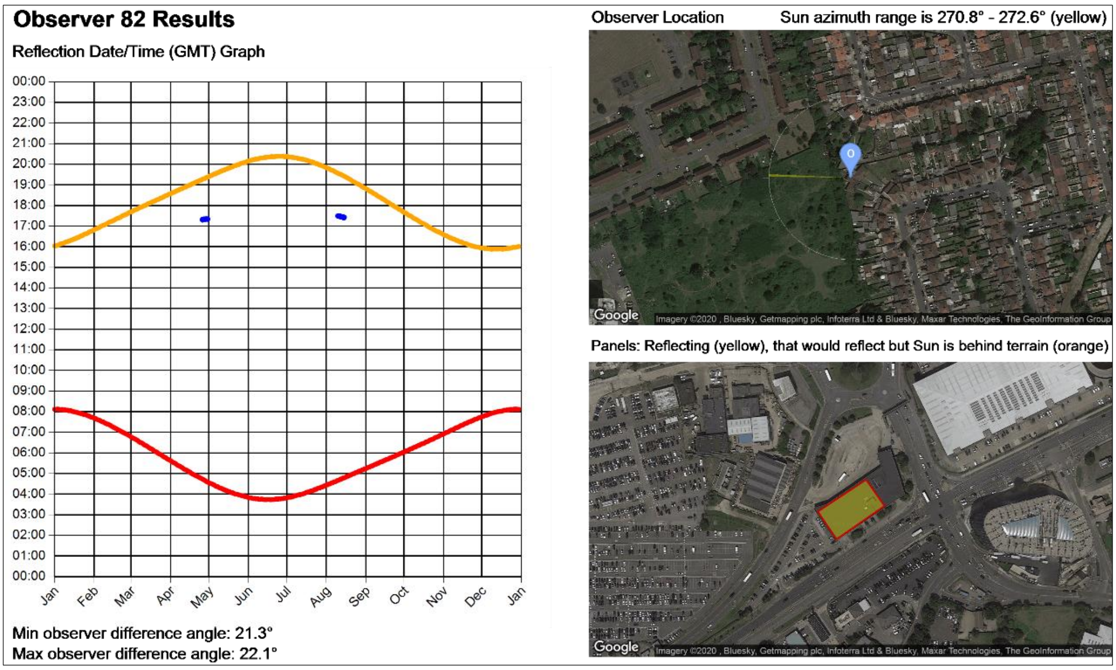

Observer 77 Results
Reflection Date/Time (GMT) Graph
00:00 23:00 22:00 21:00 20:00 19:00 18:00 17:00 16:00 15:00 14:00 13:00 12:00 11:00 10:00 09:00 08:00 07:00 06:00 05:00 04:00 03:00 02:00 01:00 00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 23.3°
Max observer difference angle: 24.5°
Observer Location
Sun azimuth range is 273.1° - 275.9° (yellow)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group

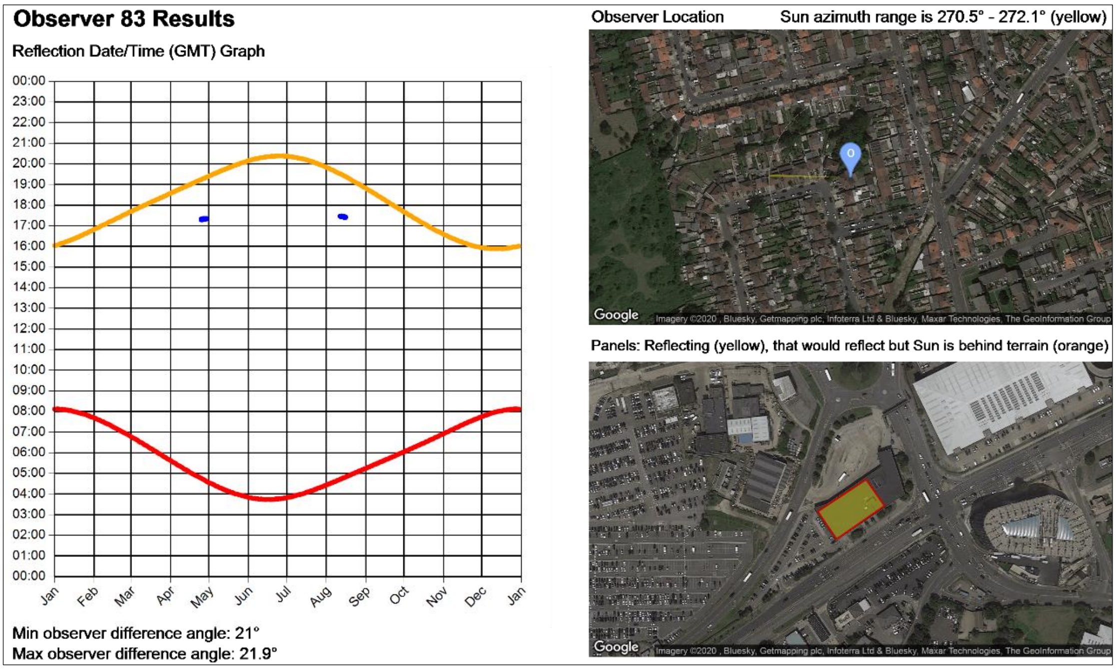

Observer 78 Results
Reflection Date/Time (GMT) Graph
00:00 23:00 22:00 21:00 20:00 19:00 18:00 17:00 16:00 15:00 14:00 13:00 12:00 11:00 10:00 09:00 08:00 07:00 06:00 05:00 04:00 03:00 02:00 01:00 00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 22.7°
Max observer difference angle: 23.8°
Observer Location
Sun azimuth range is 272.4° - 274.8° (yellow)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2020 , Bluesky, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, The GeoInformation Group


Observer 79 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 271.9° - 274.1° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 22.3°
Max observer difference angle: 23.3°
Google


Observer 80 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 271.4° - 273.6° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 21.9°
Max observer difference angle: 22.8°
Google


Observer 81 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 271.1° - 273.2° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 21.6°
Max observer difference angle: 22.5°
Google


Observer 82 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 270.8° - 272.6° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 21.3°
Max observer difference angle: 22.1°
Google


Observer 83 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 270.5° - 272.1° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 21°
Max observer difference angle: 21.9°
Google
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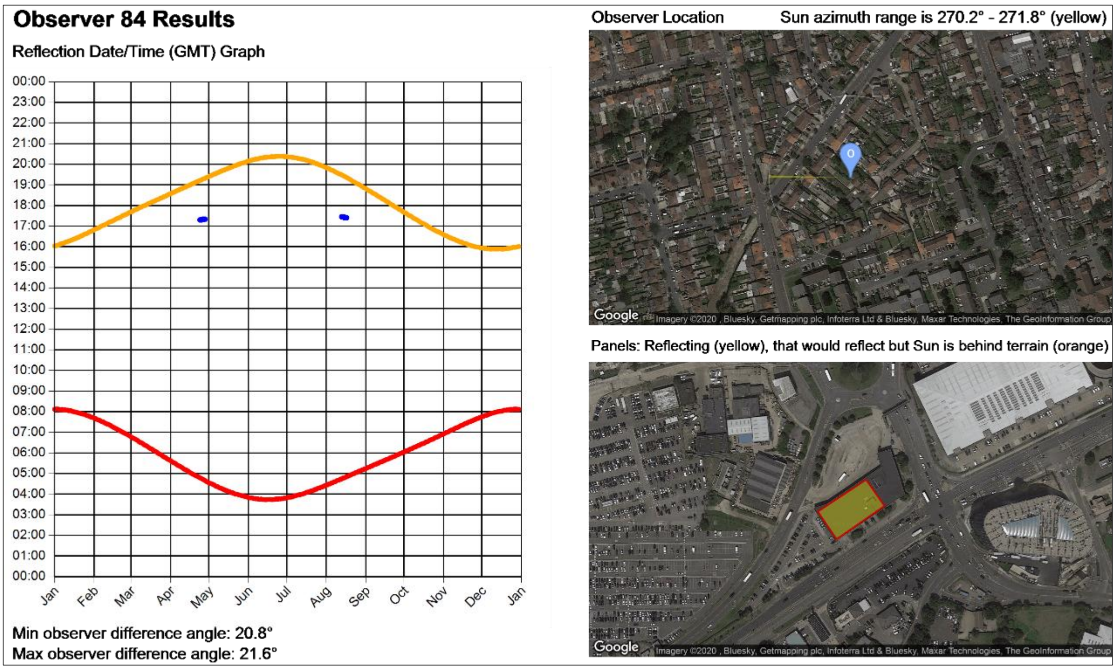
Observer 84 Results
Reflection Date/Time (GMT) Graph
Observer Location
Sun azimuth range is 270.2° - 271.8° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 20.8°
Max observer difference angle: 21.6°
Google
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Proposed Approach 09

No reflection expected.

Proposed Approach 27

No reflection expected.

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