PAGERPOWER

Urban & Renewables

Solar Photovoltaic Glint and Glare Study

RPS Group PLC

Thorpe Estate

October 2021

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 a proposed solar photovoltaic (PV) development located within the Thorpe Estate, Tamworth, B79 0LH, UK. This glint and glare assessment concerns the possible impact on surrounding road users and dwellings. A high-level overview of aviation concerns considering Catton Airfield, Grangewood Airfield, and Twycross Airfield has also been presented.

Pager Power

Pager Power has undertaken over 700 glint and glare assessments internationally. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders, including airports and aviation regulators.

Conclusions

No significant impacts are predicted on roads or dwellings in the surrounding area. Therefore, no mitigation requirement has been identified.

No significant impacts are predicted on aviation activity at Catton Airfield, Grangewood Airfield, and Twycross Airfield. No mitigation requirement has been identified.

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. However, a specific methodology for determining the impact on road safety, residential amenity, and aviation activity has yet to be established. 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 and methodology[1]. This methodology defines the process for determining the impact on road safety, residential amenity, and aviation activity.

Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, consider the screening (existing and/or proposed) between the receptor and the reflecting solar panels. The scenario in which a solar reflection can occur for all receptors is then identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

The available studies have measured the intensity of reflections from solar panels with respect to other naturally occurring and manmade surfaces. The results show that the reflections

[1] Source: Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021

produced are of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel[2].

Assessment Results

Roads

The modelling has shown that solar reflections are not geometrically possible towards the assessed section of road. No impacts are predicted, and no mitigation is required.

Dwellings

The modelling has shown that solar reflections are geometrically possible towards six of the seven assessed dwellings. Following a review of the available imagery and local topography, any solar reflections that are geometrically possible towards these dwellings are predicted to be significantly screened. No impacts are predicted, and no mitigation is required.

High-Level Aviation

Significant impacts are not predicted for aviation receptors at Catton Airfield, Grangewood Airfield, and Twycross Airfield because:

- Any reflections towards aircraft on approach to the runway at Catton Airfield would be outside a pilot's primary horizontal field of view for the final two miles, which is acceptable in accordance with the associated guidance and industry best practice.
- Any reflections towards aircraft on approach to the runway at Grangewood Airfield would be outside a pilot's primary horizontal field of view for the final two miles, which is acceptable in accordance with the associated guidance and industry best practice.
- Any reflections possible towards aircraft on approach to the runway at Twycross Airfield would likely at worst have a 'low potential for temporary after-image', based on Pager Power's extensive previous experience of assessing airfields at this distance and relative location. This is acceptable in accordance with the associated guidance and industry best practice.

Technical modelling is not recommended.

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

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 countries within 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 a proposed solar photovoltaic (PV) development located within the Thorpe Estate, Tamworth, B79 0LH, UK. This glint and glare assessment concerns the possible impact on surrounding road users and dwellings. A high-level overview of aviation concerns considering Catton Airfield, Grangewood Airfield, and Twycross Airfield has also been presented.

This report contains the following:

- Solar development details;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Overview of Sun movement;
- Assessment methodology;
- High-level aviation assessment;
- Identification of receptors;
- Glint and glare assessment for identified receptors;
- Results discussion;

Following this, a summary of findings and overall conclusions and recommendations from the desk-based analysis is presented. No site survey has taken place at this stage.

1.2 Pager Power's Experience

Pager Power has undertaken over 700 Glint and Glare assessments in the UK and internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Glint and Glare Definition

The definition of glint and glare 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.

2 PROPOSED SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Site Layout Plan

The site layout plan of the proposed solar development is shown in Figure 1[3] below.

Figure 1 *Site layout plan*

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[3] Source: Authored by and received from RPS.

2.2 Solar Panel Technical Information

The technical characteristics used for the modelling are presented in Table 1[4] below.

Solar Panel Technical Information	
Azimuth angle (°)	180 (south-facing)
Assessed centre height (m agl[5])	2
Elevation angle (°)	25

Table 1 *Solar panel technical information*

[4] Based on information received from RPS.

[5] above ground level

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 Guidance and Studies

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

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

3.2 Background

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

3.3 Methodology

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

- Identify receptors in the area surrounding the solar development.
- Consider direct solar reflections from the solar development towards the identified receptors by undertaking geometric calculations and intensity calculations where required.
- Consider the visibility of the panels from the receptor's location. If the panels are not visible from the receptor then no reflection can occur.
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur.
- Assess the glare intensity if applicable.
- Consider both the solar reflection from the solar development and the location of the direct sunlight with respect to the receptor's position.
- Consider the solar reflection with respect to the published studies and guidance.
- Determine whether a significant detrimental impact is expected in line with the process presented in Appendix D.

Within the Pager Power model, the solar development 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.

3.4 Assessment Limitations

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

4 HIGH-LEVEL AVIATION ASSESSMENT

4.1 Overview

Glint and glare analysis is often undertaken for solar developments that are adjacent to large aerodromes. The most common concerns are:

1. Potential reflections towards an Air Traffic Control (ATC) tower.
2. Potential reflections towards approaching pilots for the final two miles of the approach.

With regard to Point 2, these reflections are typically evaluated in the context of:

- Whether they are in a pilot's primary horizontal field of view (50° either side of the direction of travel).
- The intensity of the solar reflection.

There is no formal buffer distance within which aviation effects must be modelled. However, in practice, concerns are most often raised for developments within 10km of a licensed airport. Requests for modelling at ranges of 10-20km are far less common. Assessment of aviation effects for developments over 20km away is a very unusual requirement. A high-level aviation assessment has been undertaken considering the nearest aerodromes to the proposed development.

4.2 Catton Airfield

Catton Airfield is located approximately 5.16km west north-west of the proposed development. It appears to have one runway and no ATC Tower. An aerial image is shown in Figure 2[6] below.

Figure 2 *Catton Airfield – aerial image*

[6] Source: Copyright © 2021 Google.

4.3 Grangewood Airfield

Grangewood Airfield is located approximately 6.7km north-east of the proposed development. It appears to have one runway and no ATC Tower. An aerial image is shown in Figure 3[7] below.

Figure 3 *Grangewood Airfield – aerial image*

4.4 Twycross Airfield

Twycross Airfield is located approximately 11.5km east south-east of the proposed development. It appears to have one runway and no ATC Tower. An aerial image is shown in Figure 4[8] below.

Figure 4 *Twycross Airfield – aerial image*

[7] Source: Copyright © 2021 Google.
[8] Source: Copyright © 2021 Google.

The locations of these airfields relative to the proposed development are shown in Figure 5[6] below, with the last 2-miles of the runway approach paths represented by the red lines.

Figure 5 *Airfields relative to the proposed development*

4.5 High-Level Assessment Conclusions

Significant impacts are not predicted for aviation receptors at Catton Airfield, Grangewood Airfield, and Twycross Airfield because:

- Any reflections towards aircraft on approach to the runway at Catton Airfield would be outside a pilot's primary horizontal field of view for the final two miles, which is acceptable in accordance with the associated guidance and industry best practice.
- Any reflections towards aircraft on approach to the runway at Grangewood Airfield would be outside a pilot's primary horizontal field of view for the final two miles, which is acceptable in accordance with the associated guidance and industry best practice.
- Any reflections possible towards aircraft on approach to the runway at Twycross Airfield would likely at worst have a 'low potential for temporary after-image', based on Pager Power's extensive previous experience of assessing airfields at this distance and relative location. This is acceptable in accordance with the associated guidance and industry best practice.

Technical modelling is not recommended.

5 IDENTIFICATION OF GROUND-BASED RECEPTORS

5.1 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.

The above parameters and extensive experience over a significant number of glint and glare assessments undertaken show that consideration of receptors within 1km of panel areas is deemed appropriate for glint and glare effects on roads and dwellings. The panels are fixed south facing and solar reflections at ground level towards the north at this latitude are highly unlikely. Therefore, the assessment area has been designed accordingly as a 1km boundary from solar panels for roads and dwellings (yellow outlined areas on the proceeding figures). The area to the north of the north-most solar panels has been excluded.

Potential receptors are identified based on mapping and aerial photography of the region. The initial judgement is made based on a 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.

An overview of the one-kilometre assessment area is presented in Figure 6[9] on the following page.

[9] Source: Copyright © 2021 Google.

Figure 6 *One-kilometre assessment area overview – aerial image*

5.2 Road Receptors

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 of up to 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; and
- 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 considered any major national, national, and regional roads that:

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

A 0.48km section of B5493 was identified for assessment. This section is identified by the light blue line in Figure 7[9] below. In total, 13 associated receptors were identified, distanced circa 40m apart.

A height of 1.5 metres above ground level has been taken as a typical eye level for a road user[10]. This height has therefore been added to the ground height at each receptor location. Visibility and direction of travel is considered in the assessment of all receptors.

Figure 7 *Assessed road section and receptors – aerial image*

5.3 Dwelling Receptors

The analysis has considered dwellings that:

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

In total, seven dwellings were identified for assessment. A height of 1.8 metres above ground level has been taken as typical eye level for an observer on the ground floor of the dwelling since this is typically the most occupied floor of a dwelling throughout the day. Visibility from all storeys is considered for receptors where effects are possible based on the technical modelling.

An overview of all assessed dwelling receptors is shown in Figure 8[9] on the following page.

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[10] This height is chosen for modelling purposes, elevated drivers are considered in the results discussion where appropriate.

Figure 8 *Assessed dwelling receptors overview – aerial image*

6 ASSESSED REFLECTOR AREAS

6.1 Reflector Areas

A number of representative panel locations are selected within the proposed reflector areas with the number of modelled points being determined by the size of the reflector areas and the assessment resolution. The bounding coordinates for the proposed solar farm development have been extrapolated from the site plans. The data can be found in Appendix G.

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 areas. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output. If a reflection is experienced from an assessed panel location, then it is likely that a reflection will be viewable from similarly located panels within the proposed development.

Figure 9 below shows the assessed reflector areas that have been used for modelling purposes.

Figure 9 *Assessed reflector areas – aerial image*

7 GLINT AND GLARE ASSESSMENT – TECHNICAL RESULTS

7.1 Technical Results Overview

The tables in the following subsections present the results of the technical analysis for the ground-based receptors.

The predicted glare times are based solely on bare-earth terrain i.e. without consideration of screening from buildings and vegetation. The final column summarises the predicted impact considering the level of identified screening based on a desk-based review of the available imagery. The significance of any predicted effects has been evaluated in accordance with Pager Power's published guidance document[11].

The flowcharts setting out the impact characterisation and presented in Appendix D. The list of assumptions and limitations are presented in Appendix F. The modelling output for key receptors showing the precise predicted times and the reflecting panel area(s) can be found in Appendix H.

When evaluating visibility in the context of glint and glare, it is only the ***reflecting*** panel area that must be considered. For example, if the western half of the development is visible, but reflections would only be possible from the eastern half, it can be concluded that the reflecting area is not visible and no impacts are predicted. This is why there can be instances where visibility of the development is predicted, but glint and glare issues are screened.

Receptors are included within the assessment based on the potential visibility of the development as a whole, among other factors. Once the modelling output has been generated, the assessment can be refined to evaluate the visibility of the reflecting panel area specifically.

[11] Source: Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021

7.1 Geometric Calculation Results Overview – Road Receptors

The results of the geometric calculations towards the road receptors are presented in Table 2 below.

Receptors	Reflection possible towards the receptor(s)? (GMT)		Comments
	am	pm	
1 – 13.	No.	No.	Solar reflections are not geometrically possible. No impact is predicted.

Table 2 *Geometric analysis results – road receptors*

7.2 Geometric Calculation Results Overview – Dwelling Receptors

The results of the geometric calculations towards the dwelling receptors are presented in Table 3 below.

Receptors	Reflection possible towards the receptor(s)? (GMT)		Comments
	am	pm	
1.	Yes.	No.	Any solar reflections that are geometrically possible are predicted to be significantly screened by intervening terrain and vegetation. No impacts are predicted.
2.	Yes.	No.	Any solar reflections that are geometrically possible are predicted to be significantly screened by surrounding buildings. No impacts are predicted.
3.	No.	Yes.	Any solar reflections that are geometrically possible are predicted to be significantly screened by intervening terrain, existing vegetation, and proposed vegetation planting. No impacts are predicted.

Receptors	Reflection possible towards the receptor(s)? (GMT)		Comments
	am	pm	
4.	Yes.	No.	Any solar reflections that are geometrically possible are predicted to be significantly screened by intervening vegetation. No impacts are predicted.
5.	No.	No.	Solar reflections are not geometrically possible. No impact is predicted.
6.	No.	Yes.	Any solar reflections that are geometrically possible are predicted to be significantly screened by intervening terrain and vegetation. No impacts are predicted.
7.	No.	Yes.	Any solar reflections that are geometrically possible are predicted to be significantly screened by intervening terrain and vegetation. No impacts are predicted.

Table 3 *Geometric analysis results – dwelling receptors*

8 GEOMETRIC ASSESSMENT RESULTS DISCUSSION

8.1 Roads

The modelling has shown that solar reflections are not geometrically possible towards the assessed section of road. No impacts are predicted, and no mitigation is required.

8.2 Dwellings

The modelling has shown that solar reflections are geometrically possible towards six of the seven assessed dwelling receptors (1 – 4 and 6 – 7). The modelling output for these receptors showing the precise predicted times and the reflecting panel area(s) can be found in Appendix H.

The process for quantifying impact significance is defined in the report appendices. For dwelling receptors, the key considerations are:

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

Where reflections are geometrically possible but expected to be screened, no impact is predicted, and mitigation is not required.

Where effects occur for less than 3 months per year and less than 60 minutes per day[12], the impact significance is low, and mitigation is not required.

Where reflections are predicted to be experienced for more than 3 months per year or for more than 60 minutes per day[13], the impact significance is moderate and expert assessment of the following mitigating factors is required to determine the mitigation requirement:

- The separation distance to the panel area[14]. 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. The Sun is a far more significant source of light.
- Whether solar reflections will be experienced from all storeys. The ground floor is typically considered the main living space and therefore has a greater significance with respect to residential amenity.

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[12] Based on the modelling results or whereby (following a conservative assessment) screening is predicted to reduce the duration of effects within this threshold.

[13] Or if effects last for less than 3 months per year but more than 60 minutes per day, which is a scenario that is almost never seen in practice but could occur in theory.

[14] Which is often greater than the nearest panel boundary, because not all areas of the site cause specular reflections towards particular receptor locations.

- Whether the dwelling appears to have windows facing the reflecting areas. An observer may need to look at an acute angle to observe the reflecting areas.

Where effects last for more than 3 months per year and more than 60 minutes per day, the impact significance is high, and mitigation is required.

In the case of the proposed development, there are no instances of low, moderate or high impact, even under worst-case conditions.

Following a review of the available imagery and local topography, any solar reflections that are geometrically possible towards these receptors are predicted to be significantly screened. The screening is broken down in the list below:

- Dwelling Receptor 01 - screened by intervening terrain and vegetation.
- Dwelling Receptor 02 - screened by surrounding buildings.
- Dwelling Receptor 03 - screened by intervening terrain, existing vegetation, and proposed vegetation planting.
- Dwelling Receptor 04 - screened by intervening vegetation.
- Dwelling Receptor 06 - screened by intervening terrain and vegetation.
- Dwelling Receptor 07 - screened by intervening terrain and vegetation.

No impacts are predicted, and no mitigation is required.

8.3 Overall Conclusions

No significant impacts are predicted on roads or dwellings in the surrounding area. Therefore, no mitigation requirement has been identified.

No significant impacts are predicted on aviation activity at Catton Airfield, Grangewood Airfield, and Twycross Airfield. No mitigation requirement has been identified.

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

National Planning Policy within the planning practice guidance for Renewable and Low Carbon Energy[15] (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.'

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare are, however, provided for assessing the impact of solar reflections on surrounding roads and dwellings. Therefore, the Pager Power approach is to determine whether a reflection from the proposed 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

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

stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document[16] which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

[16] Source: Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

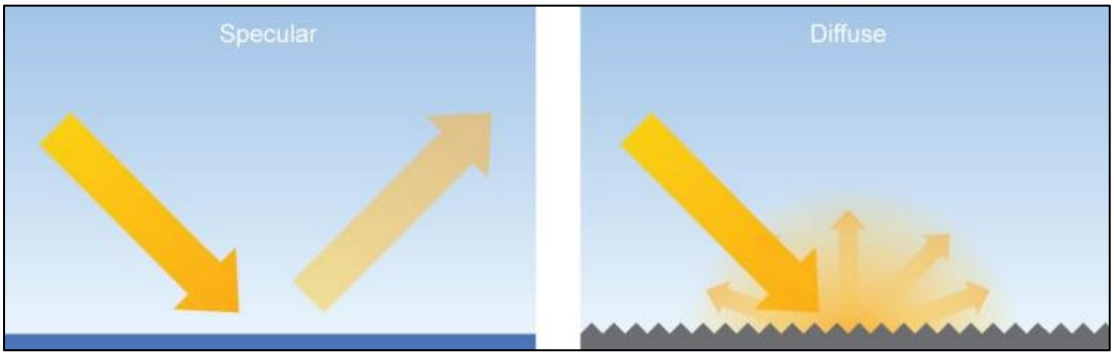
Overview

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

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

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance[17], 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

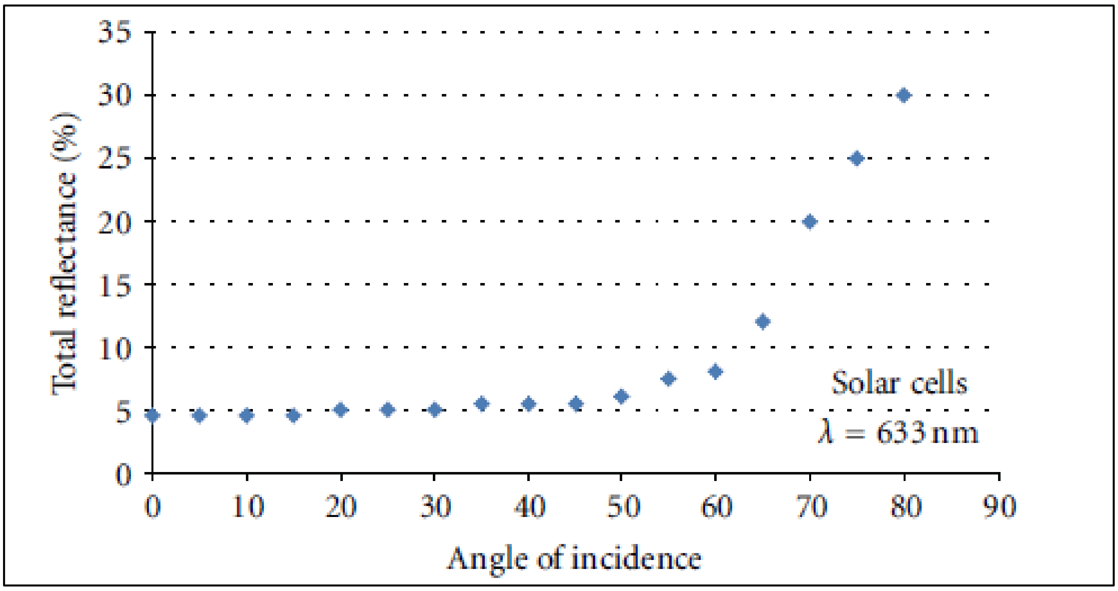
[17] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*[18]". 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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[18] 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"[19]

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[20]
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.

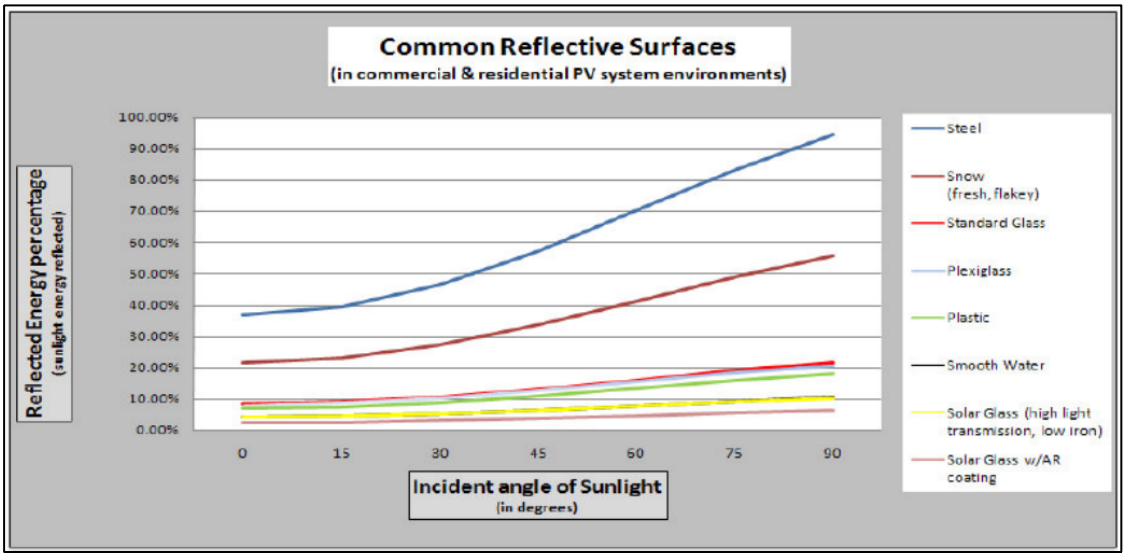
[19] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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

SunPower Technical Notification (2009)

SunPower published a technical notification[21] 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.

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

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

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

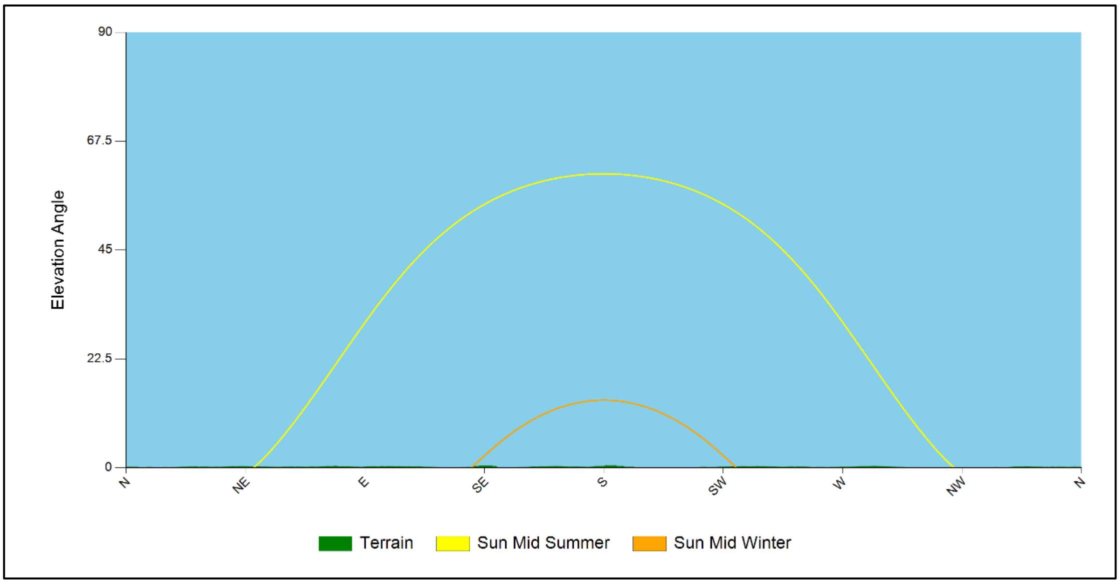
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

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

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

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

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector. The figure below shows terrain at the horizon as well as the sunrise and sunset curves throughout the year from lon: -1.642908 lat: 52.676747.



Terrain elevation at the horizon

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

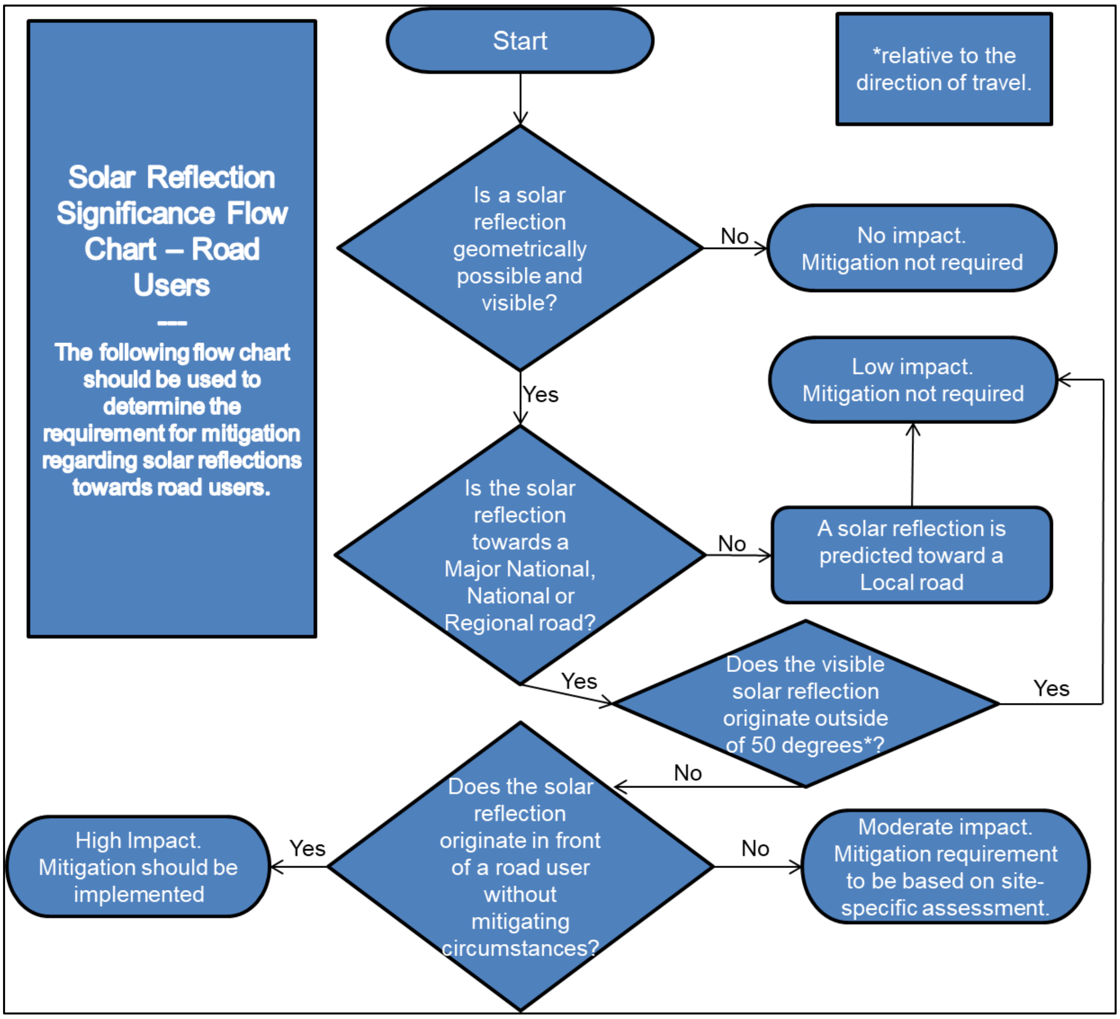
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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 solar development is to proceed.

Impact significance definition

Assessment Process for Road Receptors

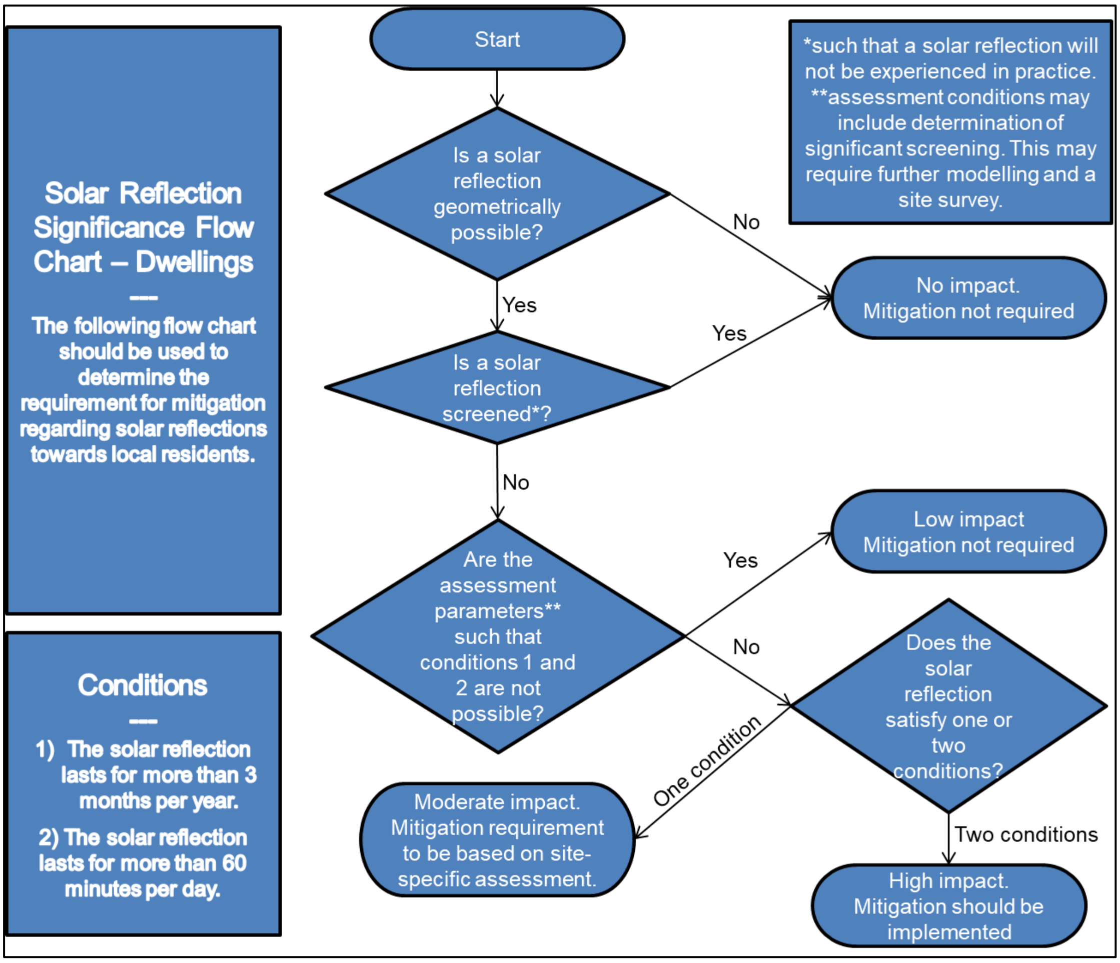
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Assessment Process 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

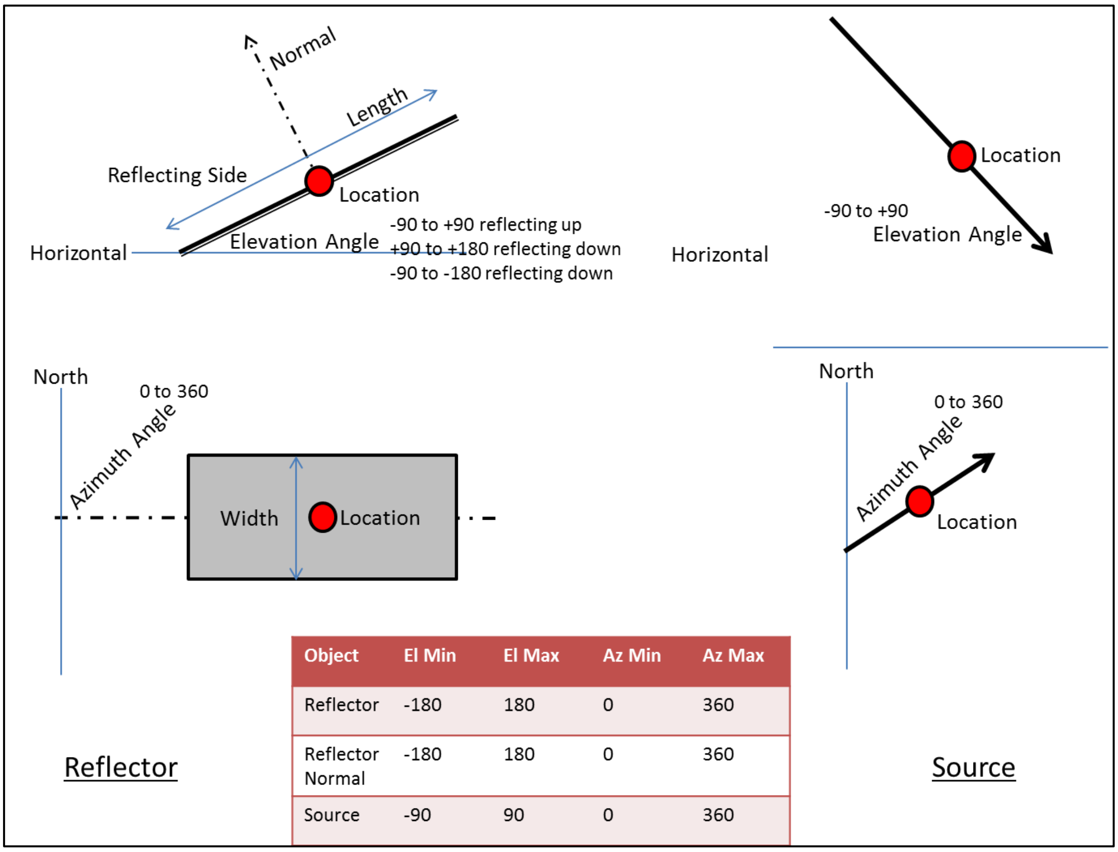
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

Pager Power'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

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)[22].

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

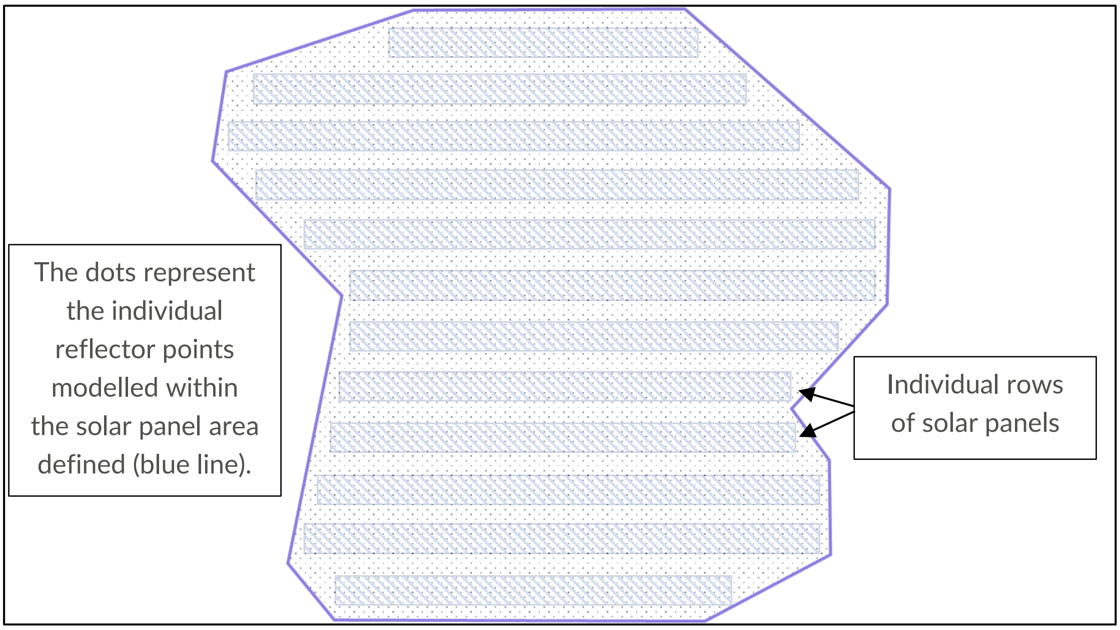
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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.

[22] 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.

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Terrain Height

Terrain Height was calculated from Pager Power's database (established on OS Panorama 50m DTM) based on the coordinates of the point of interest.

Road Receptor Data

The table below presents the coordinates for the assessed road receptors.

Location	Longitude (°)	Latitude (°)	Location	Longitude (°)	Latitude (°)
1	-1.634421	52.66196	8	-1.631094	52.6634
2	-1.633975	52.662214	9	-1.630514	52.663528
3	-1.633535	52.662459	10	-1.629945	52.663638
4	-1.633099	52.662681	11	-1.629385	52.663734
5	-1.632626	52.662894	12	-1.628825	52.663815
6	-1.632114	52.663097	13	-1.628146	52.663913
7	-1.631623	52.663251			

Road Receptor Data

Dwelling Receptor Data

The table below presents the coordinates for the assessed dwelling receptors.

Location	Longitude (°)	Latitude (°)	Location	Longitude (°)	Latitude (°)
1	-1.658231	52.676562	5	-1.651641	52.665283
2	-1.644936	52.675052	6	-1.628726	52.666083
3	-1.640728	52.673521	7	-1.621116	52.67929
4	-1.651815	52.670977			

Dwelling Receptor Data

Northern Panel Area Boundary Data

The table below presents the coordinates of the boundary points for the assessed northern panel area.

Location	Longitude (°)	Latitude (°)	Location	Longitude (°)	Latitude (°)
1	-1.644329	52.682281	19	-1.638671	52.676883
2	-1.645135	52.681975	20	-1.638857	52.676338
3	-1.645099	52.681804	21	-1.638837	52.675752
4	-1.646269	52.681412	22	-1.637394	52.675332
5	-1.647542	52.680765	23	-1.635888	52.676207
6	-1.648776	52.679904	24	-1.635718	52.677254
7	-1.649341	52.679330	25	-1.635560	52.678526
8	-1.649515	52.679022	26	-1.636407	52.679314
9	-1.650169	52.678751	27	-1.636588	52.680011
10	-1.650332	52.678467	28	-1.636495	52.680360
11	-1.650219	52.677851	29	-1.637555	52.680929
12	-1.650408	52.676836	30	-1.638248	52.681132
13	-1.649395	52.676751	31	-1.639057	52.681961
14	-1.647670	52.676391	32	-1.638826	52.682343
15	-1.645156	52.675662	33	-1.640432	52.682619
16	-1.643063	52.677623	34	-1.641763	52.682367
17	-1.641478	52.677438	35	-1.643068	52.683427
18	-1.640633	52.677280	36	-1.644581	52.682727

Northern Panel Area Boundary Data

Southern Panel Area Boundary Data

The table below presents the coordinates of the boundary points for the assessed southern panel area.

Location	Longitude (°)	Latitude (°)	Location	Longitude (°)	Latitude (°)
1	-1.644368	52.671807	10	-1.637822	52.670690
2	-1.646006	52.670862	11	-1.637679	52.671478
3	-1.645673	52.670674	12	-1.639183	52.671291
4	-1.645809	52.670568	13	-1.640828	52.672846
5	-1.644381	52.669848	14	-1.641764	52.672539
6	-1.642581	52.669849	15	-1.645309	52.673980
7	-1.640526	52.670175	16	-1.646538	52.674312
8	-1.640467	52.670374	17	-1.646810	52.673708
9	-1.639419	52.670656	18	-1.647318	52.673213

Southern Panel Area Boundary Data

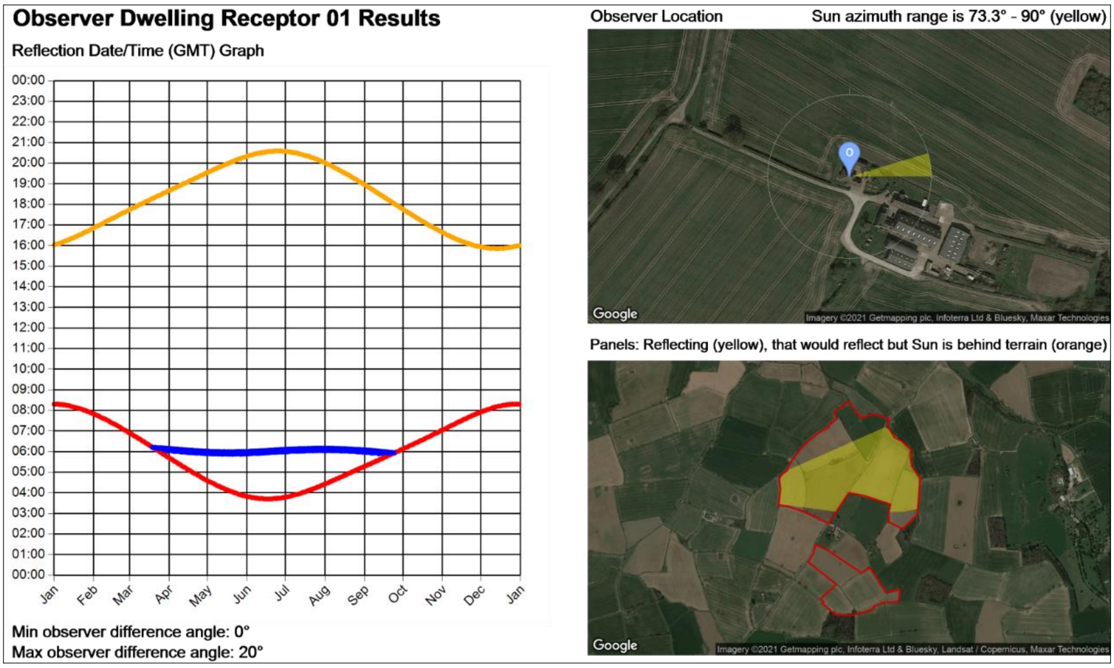
APPENDIX H – DETAILED MODELLING RESULTS

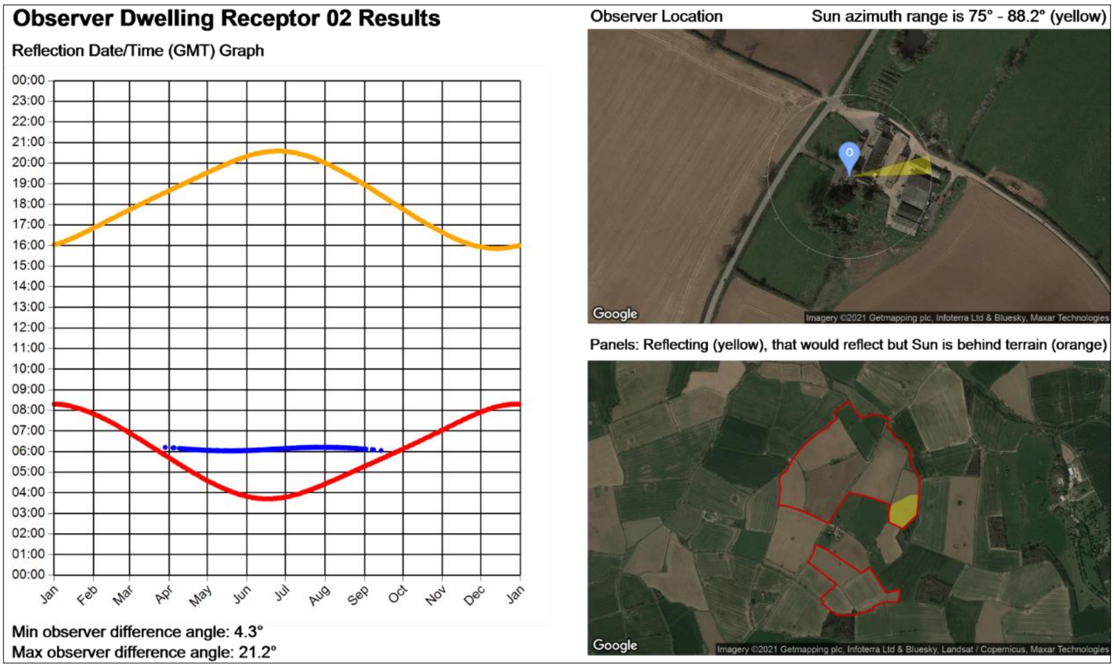
Overview

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

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

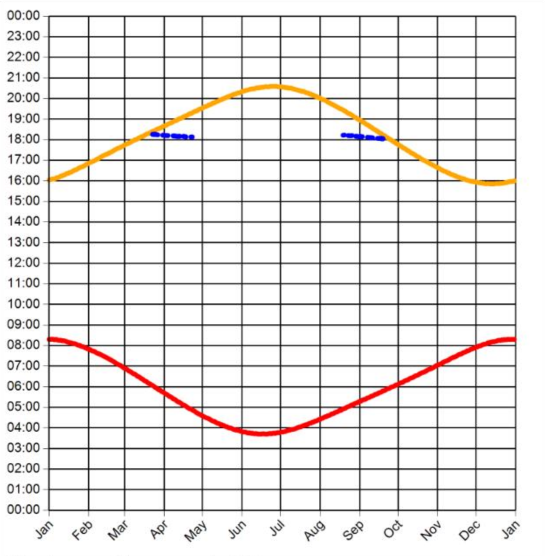
Dwelling Receptors





Observer Dwelling Receptor 03 Results

Reflection Date/Time (GMT) Graph



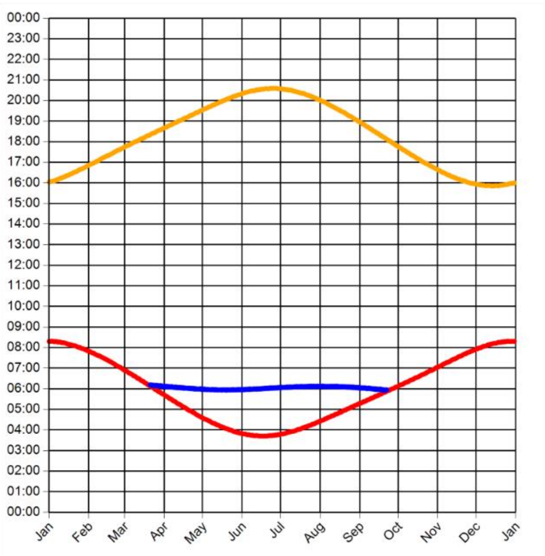
Min observer difference angle: 0.6°
Max observer difference angle: 10.2°

Observer Location Sun azimuth range is 271.2° - 278.4° (yellow)

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

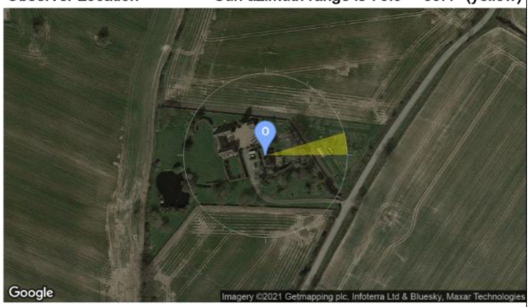
Observer Dwelling Receptor 04 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.2°
Max observer difference angle: 19°

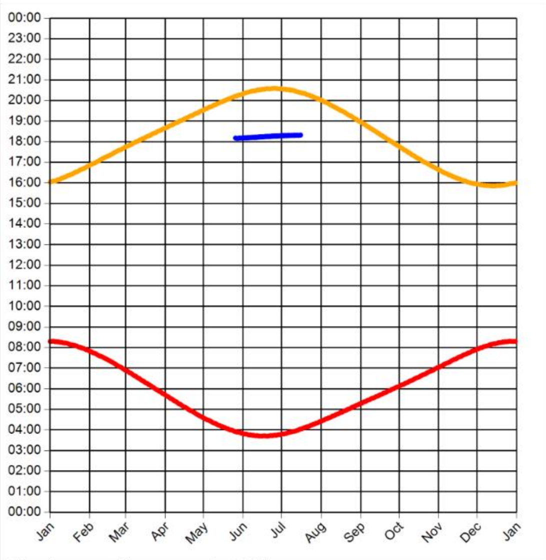
Observer Location Sun azimuth range is 73.9° - 89.4° (yellow)



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

Observer Dwelling Receptor 06 Results

Reflection Date/Time (GMT) Graph



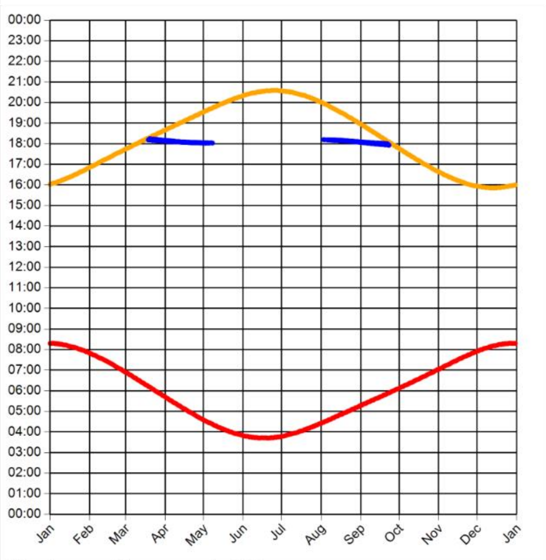
Min observer difference angle: 16.5°
Max observer difference angle: 18.5°

Observer Location — Sun azimuth range is 284.6° - 286.2° (yellow)

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

Observer Dwelling Receptor 07 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.6°
Max observer difference angle: 16.1°

Observer Location — Sun azimuth range is 269.2° - 280.6° (yellow)

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

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