

Solar Photovoltaic Glint and Glare Study

Savills UK Ltd.

Mynydd Fforch Dwm

May 2023

PLANNING SOLUTIONS FOR:

- Solar
- Defence
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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	October 2022	Initial issue
2	May 2023	New panel layout

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from a ground-mounted solar photovoltaic development located at Mynydd Fforch Dwn near Tonmawr, Wales. This assessment pertains to the potential impact upon road safety and residential amenity in the area surrounding the proposed development.

Overall Conclusions

No impact is predicted upon road safety and residential amenity, and no mitigation is required.

Guidance and Studies

There is no existing planning guidance for the assessment of solar reflections from solar panels towards roads and nearby dwellings. Pager Power has however produced guidance for glint and glare and solar photovoltaic developments, which was published in early 2017, with the fourth edition published in 2022¹. The guidance document sets out the methodology for assessing roads and dwellings, with respect to solar reflections from solar panels.

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

The available studies have measured the intensity of reflections from solar panels with respect to other naturally occurring and manmade surfaces. The results show that the reflections produced are of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel².

¹ Pager Power Glint and Glare Guidance, Fourth Edition, August 2022.

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

Assessment Conclusions - Roads

Solar reflections are not geometrically possible towards the assessed 0.7km section of Ton Mawr Road. No impacts are predicted, and no mitigation is required.

Assessment Conclusions – Dwellings

Solar reflections are geometrically possible towards 28 of the 118 assessed dwellings. Screening in the form of intervening terrain is predicted to significantly obstruct views of reflecting panels, therefore no impact is predicted and no mitigation is required.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 58 countries within Europe, Africa, America, Asia and Australasia.

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

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

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

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

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

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from a ground-mounted solar photovoltaic development located at Mynydd Fforch Dwn near Tonmawr, Wales. This assessment pertains to the potential impact upon road safety and residential amenity in the area surrounding the proposed development.

This report contains the following:

- Solar development details;
- Explanation of glint and glare;
- Overview of relevant guidance and relevant studies;
- Overview of Sun movement;
- Assessment methodology;
- Identification of receptors;
- Glint and glare assessment for identified receptors;
- 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 1,000 Glint and Glare assessments in the UK and internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Glint and Glare Definition

The definition of glint and glare is as follows³:

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

The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

³ These definitions are aligned with those presented within the Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) – published by the Department for Energy Security and Net Zero in March 2023 and the Federal Aviation Administration in the USA.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Overview

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

2.2 Proposed Development Red Line Boundary

Figure 1 below shows the redline boundary⁴ for the proposed development, with the solar panel area shown as the blue checked area.

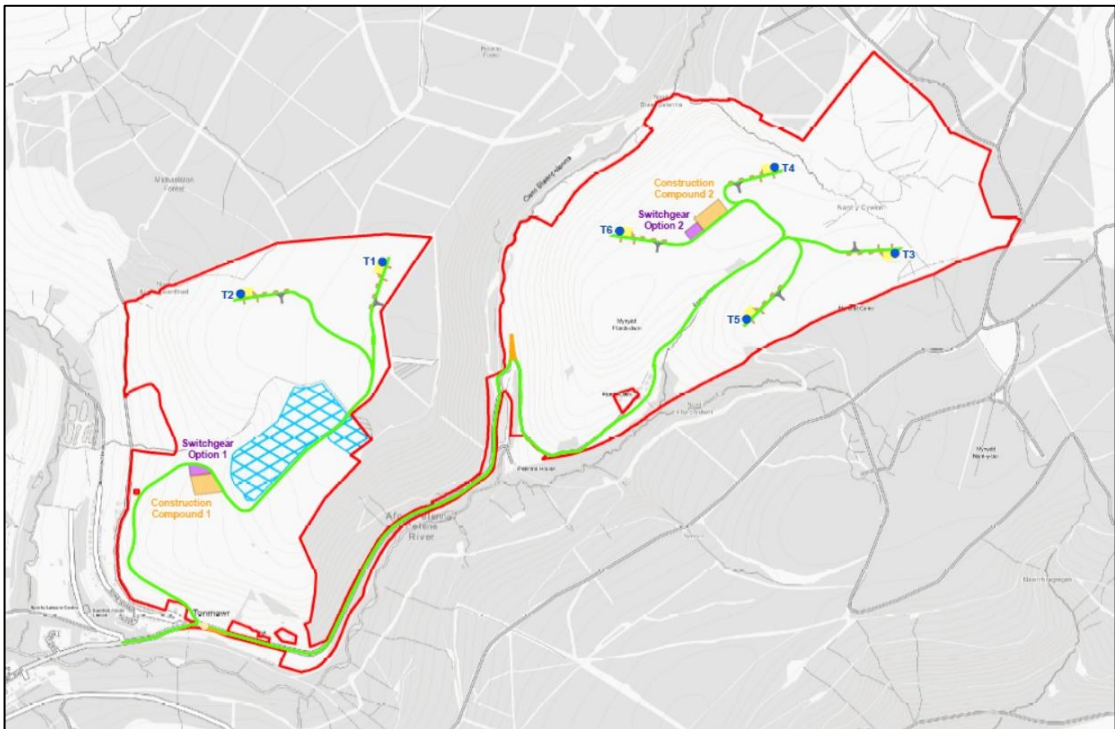


Figure 1 Proposed development red line boundary

⁴ Source: 10909.00002.0011.2 Design Freeze Layout - Aerial Overview PDF (cropped)

Figure 2 below shows the solar panel area overlaid onto aerial imagery.



Figure 2 Solar panel area for proposed development

2.3 Solar Panel Technical Information

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

Panel Details	
Azimuth Angle	180°
Elevation Angle	25°
Assessed Centre Height ⁵	1.75m agl ⁶

Table 1 Solar panel technical information

⁵ This is the midpoint between the highest and lowest points of the panels

⁶ 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 this glint and glare assessment 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;
- 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;
- 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 - including intensity calculations where appropriate;
- Determine whether a significant detrimental impact is expected in line with the process presented in Appendix D.

3.4 Assessment Methodology and Limitations

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

4 IDENTIFICATION OF RECEPTORS

4.1 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.

A 1km assessment area is considered appropriate for glint and glare effects on ground-based receptors. Receptors within this distance are identified based on mapping and aerial photography of the region. The assessment area is bounded by the orange outline in Figure 3 below. Receptors to the north of the development are not included because solar reflections would not be geometrically possible towards the north when the azimuth angle is considered⁷.

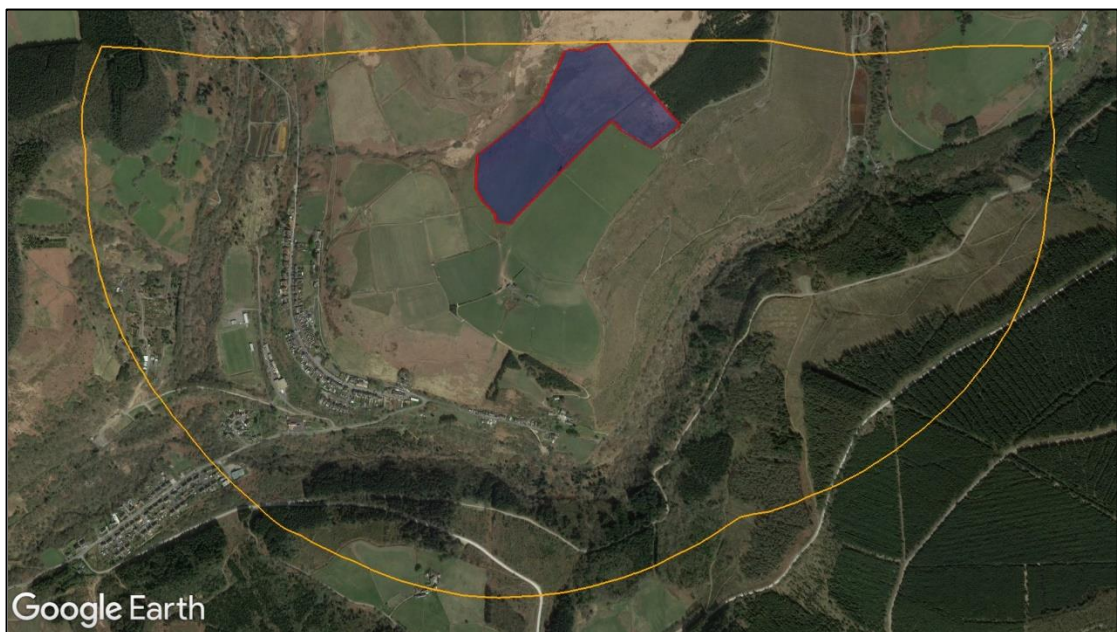


Figure 3 Assessment area

The details of the identified receptors are presented in Appendix G, and the terrain elevations have been interpolated based on OS Terrain 50 DTM⁸ data.

⁷ For fixed, south-facing panels at this latitude, reflections towards ground-based receptors located further north than any proposed panel are highly unlikely

⁸ Digital Terrain Model

4.2 Road Receptors

4.2.1 Overview

Road types can generally be categorised as:

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

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

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

4.2.2 Identified Road Receptors

A 0.7km section of Ton Mawr Road is within the assessment area. Receptors 1 to 8 are placed approximately 100m apart along this road. An additional height of 1.5 metres above ground level has been taken as the typical eye level of a road user. Figure 4 on the following page illustrates the receptors along Ton Mawr Road. Receptors have not been placed further west along this road, as beyond receptor 8, it is categorised as a local road.



Figure 4 Road receptors 1 to 8

4.3 Dwelling Receptors

4.3.1 Overview

The analysis has considered dwellings that:

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

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

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

4.3.2 Identified Dwelling Receptors

The assessed dwelling receptors are shown in Figures 5 to 15 on the following pages. In total, 118 dwellings have been assessed. An additional 1.8m height above ground is used in the modelling to simulate the typical viewing height of an observer on the ground floor⁹.

⁹Changes to this height are not significant, and views considered above the ground floor are considered where appropriate

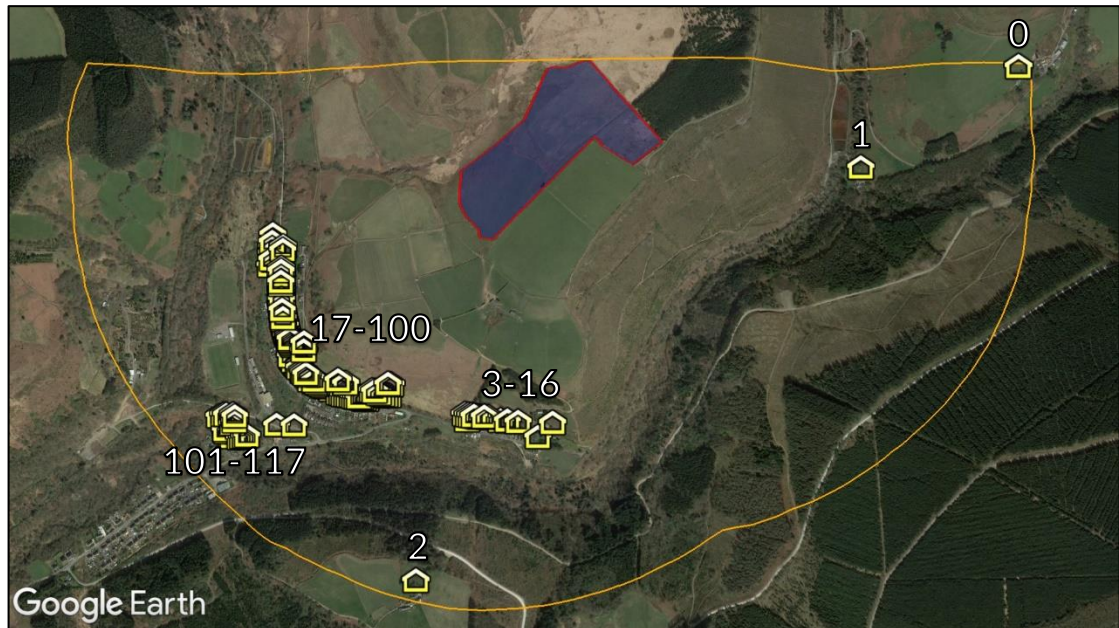


Figure 5 Overview of all assessed dwellings

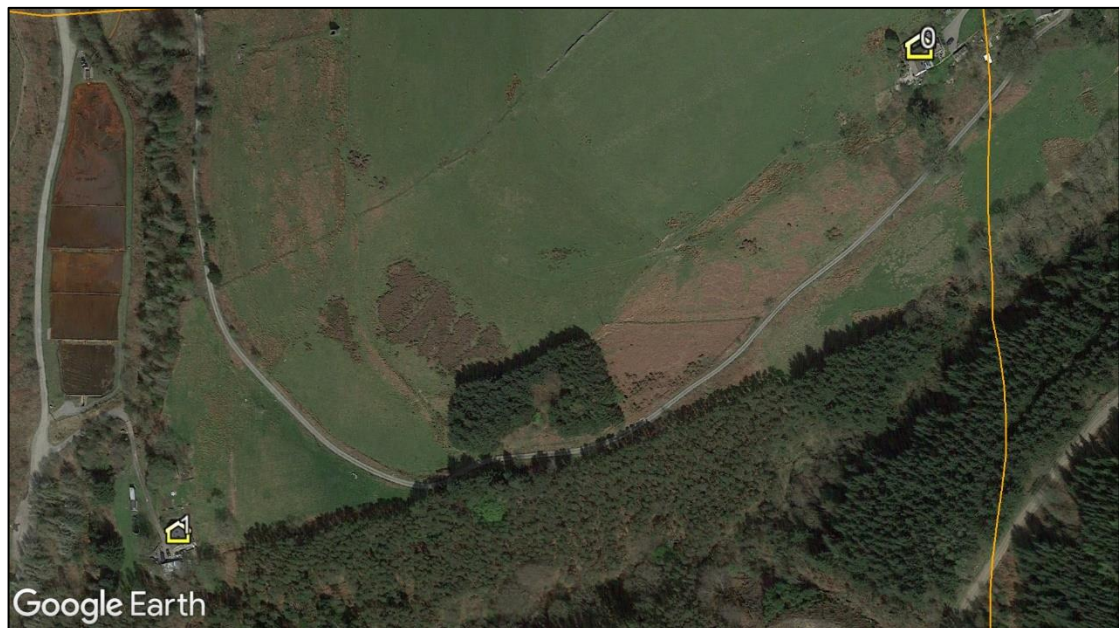


Figure 6 Dwellings 0 and 1



Figure 7 Dwelling 2

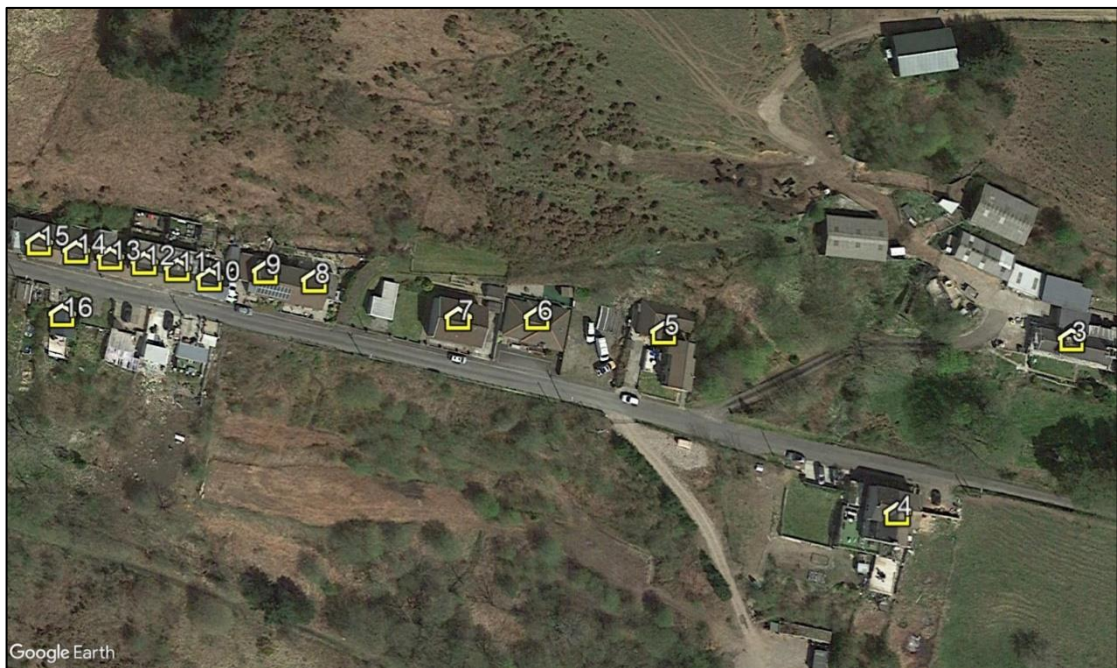


Figure 8 Dwellings 3 to 16



Figure 9 Dwellings 17 to 38



Figure 10 Dwellings 39 to 58



Figure 11 Dwellings 59 to 78

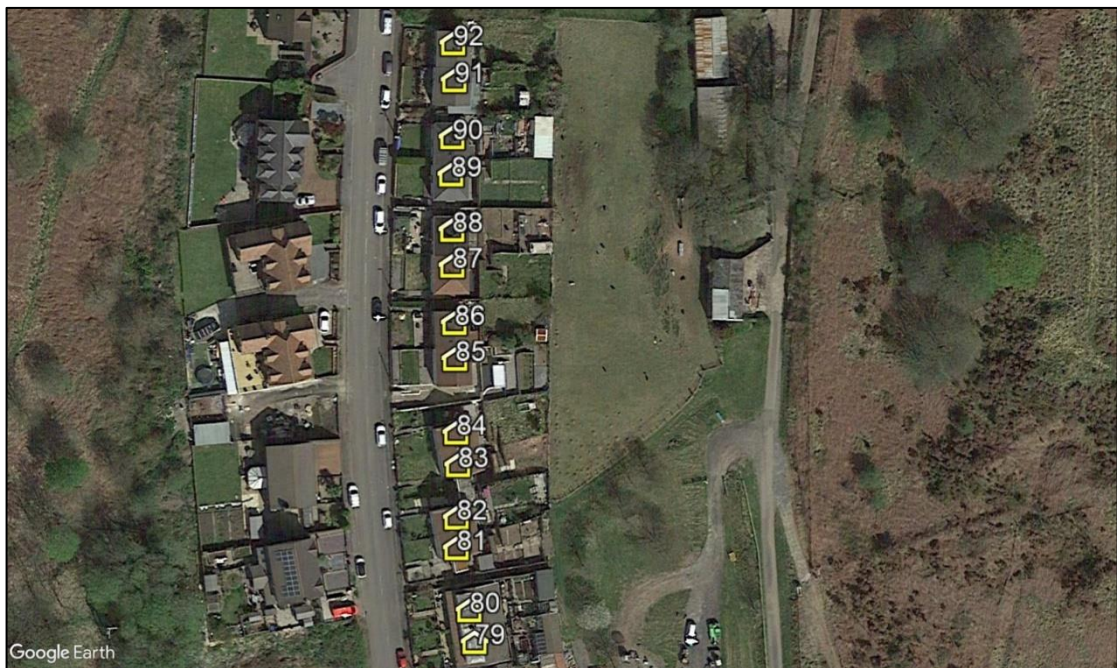


Figure 12 Dwellings 79 to 92



Figure 13 Dwellings 93 to 100



Figure 14 Dwellings 101 to 102



Figure 15 Dwellings 103 to 117

5 ASSESSED REFLECTOR AREA

5.1 Reflector Area

The bounding coordinates for the proposed development have been extrapolated from the site plans. The data can be found in Appendix G. Figure 16 below shows the assessed reflector areas that have been used for modelling purposes.

A resolution of 5m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 5m from within the defined area. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output. If a reflection is experienced from an assessed panel location, then it is likely that a reflection will be viewable from similarly located panels within the proposed solar development.

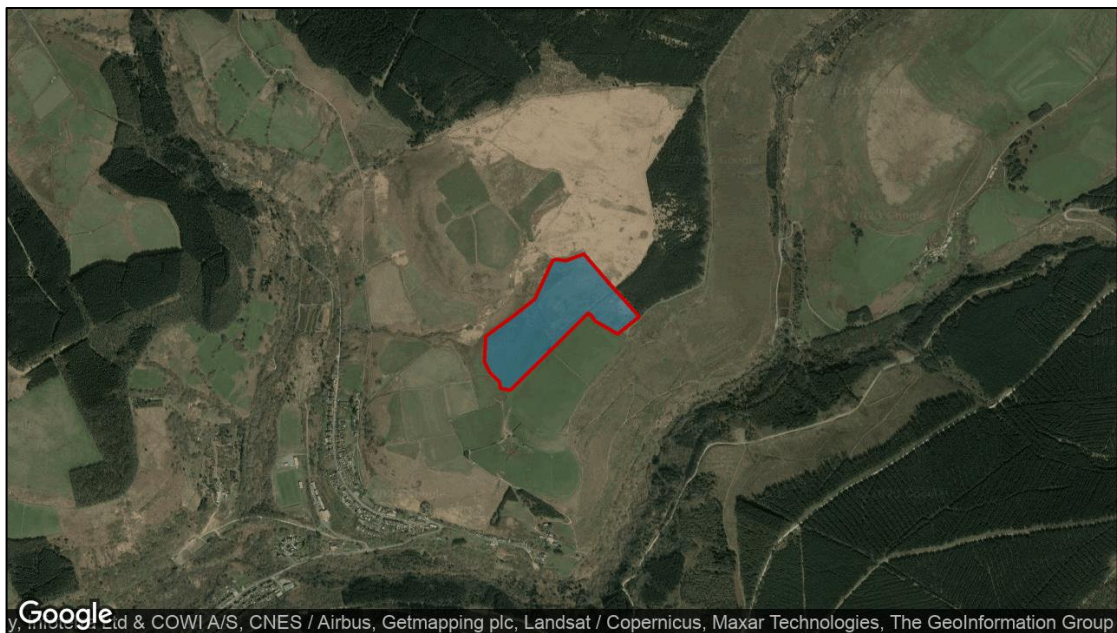


Figure 16 Assessed reflector area

6 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

6.1 Overview

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

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

6.2 Road Results

6.2.1 Impact Significance Determination

The process for quantifying the impact significance concerning road safety is outlined in Appendix D. The key considerations for road users along major national, national, and regional roads are:

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

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

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

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

- Whether visibility is likely for elevated drivers (relevant to dual carriageways and motorways¹⁰);
- Whether the solar reflection originates from directly in front of a road user. Solar reflections that are directly in front of a road user are more hazardous;
- The separation distance to the reflecting panel area. Larger separation distances reduce the proportion of an observer's field-of-view that is affected by glare;
- The position of the Sun. Effects that coincide with direct sunlight appear less prominent than those that do not. The Sun is a far more significant source of light.

Following consideration of these mitigating factors, where the solar reflection does not remain significant, a low impact is predicted, and mitigation is not recommended. Where the solar

¹⁰ There is typically a higher density of elevated drivers (such as HGVs) along dual carriageways and motorways compared to other types of roads.

reflection remains significant, the impact significance is moderate, and mitigation is recommended. Where reflections originate from directly in front of a road user and there are no further mitigating factors, the impact significance is high, and mitigation is required.

6.2.2 Results Discussion

The modelling has shown that solar reflections are geometrically possible towards none of the 8 assessed receptors. Table 2 below summarises the predicted impact at these receptors.

Road Receptor	Geometric Modelling Results (screening not considered)	Identified Screening (desk-based review)	Relevant Factors	Impact Classification	Mitigation Recommended?
1 – 8	No solar reflections geometrically possible	N/A	N/A	No impact	No

Table 2 *Impact classification – road receptors*

6.3 Dwelling Results

6.3.1 Impact Significance Determination

The process for quantifying the impact significance concerning residential amenity is outlined in Appendix D. The key considerations for residential dwellings are:

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

Where 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 on any given day, or the closest reflecting panel is over 1km from the road user, the impact significance is low, and mitigation is not recommended.

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

- The separation distance to the reflecting panel area¹¹. 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;
- 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.

Following consideration of these mitigating factors, where the solar reflection does not remain significant, a low impact is predicted, and mitigation is not recommended. Where the solar reflection remains significant, the impact significance is moderate, and mitigation is recommended. Where reflections originate from directly in front of a road user and there are no further mitigating factors, the impact significance is high, and mitigation is required.

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

¹¹ Which is often greater than the nearest panel boundary, because not all areas of the site cause specular reflections towards particular receptor locations.

6.3.2 Results Discussion

The modelling has shown that solar reflections are geometrically possible towards 28 of the 118 assessed dwellings. Table 3 below summarises the predicted impact at these receptors.

Dwelling Receptor	Geometric Modelling Results (screening not considered)	Identified Screening (desk-based review)	Relevant Factors	Impact Classification	Mitigation Recommended?
0	No solar reflections geometrically possible	N/A	N/A	No impact	No
1	Solar reflections geometrically possible for <u>less</u> than 3 months per year and <u>less</u> than 60 minutes on any given day	Intervening terrain is predicted to significantly obstruct views of reflecting panels	N/A	No impact	No
2 – 73	No solar reflections geometrically possible	N/A	N/A	No impact	No
74 – 91	Solar reflections geometrically possible for <u>less</u> than 3 months per year and <u>less</u> than 60 minutes on any given day	Intervening terrain is predicted to significantly obstruct views of reflecting panels	N/A	No impact	No
92 – 100	Solar reflections geometrically possible for <u>more</u> than 3 months per year but <u>less</u> than 60 minutes on any given day	Intervening terrain is predicted to significantly obstruct views of reflecting panels	N/A	No impact	No

Dwelling Receptor	Geometric Modelling Results (screening not considered)	Identified Screening (desk-based review)	Relevant Factors	Impact Classification	Mitigation Recommended?
101 – 117	No solar reflections geometrically possible	N/A	N/A	No impact	No

Table 3 *Impact classification – dwelling receptors*

6.3.3 Desk-Based Review of Imagery

The existing vegetation and terrain identified is shown in Figures 17 to 19 on the following pages. The cumulative reflective panel areas are shaded in yellow. High-level zones of theoretical visibility (ZTV) is generated by Google Earth Viewshed to indicate the visible terrain from a receptor¹².

¹² The green highlighted areas denote sections that are potentially visible to the observer at a height of 5m agl
Solar Photovoltaic Glint and Glare Study

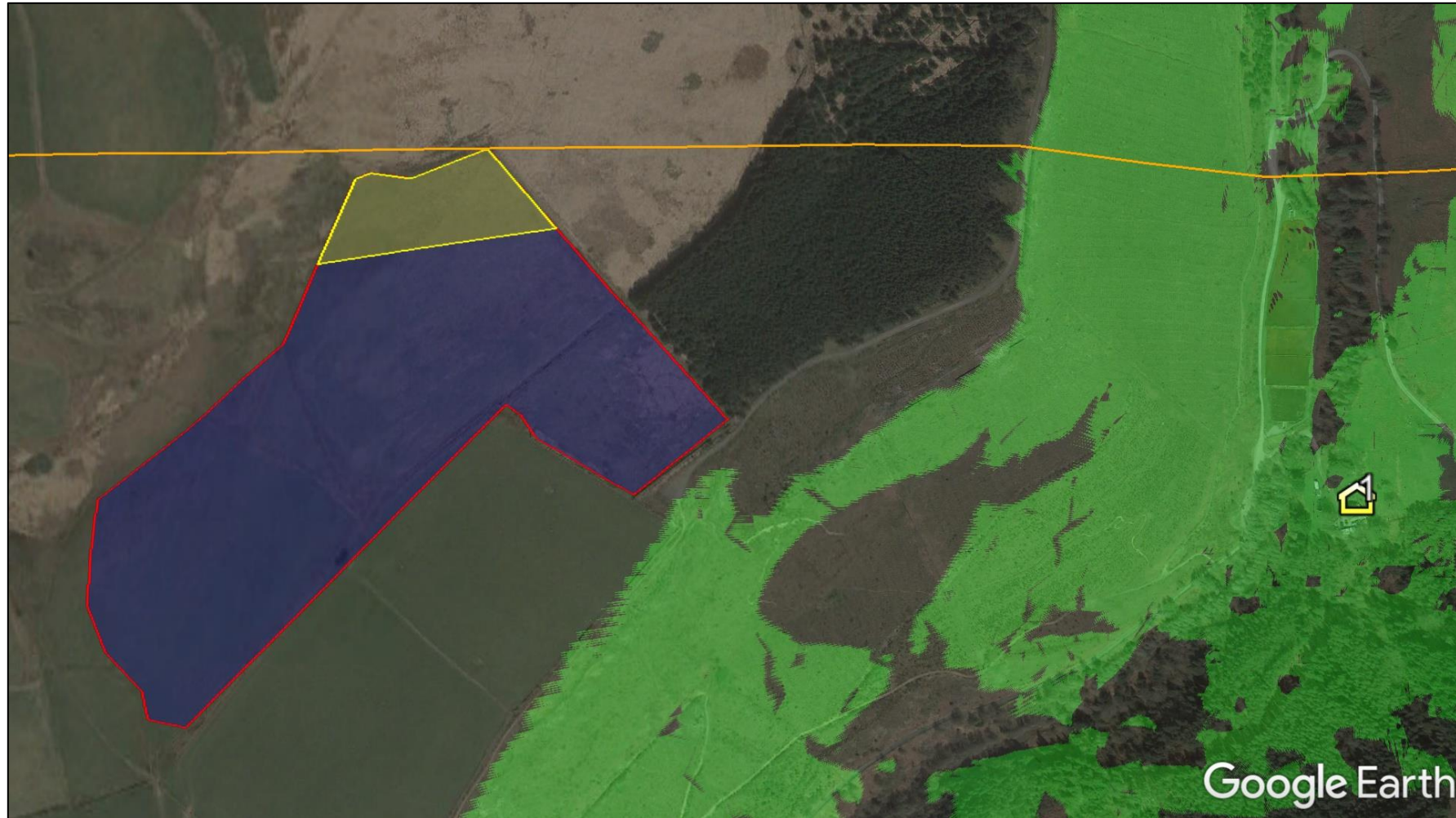


Figure 17 Reflective panel area and terrain mapping for dwelling 1

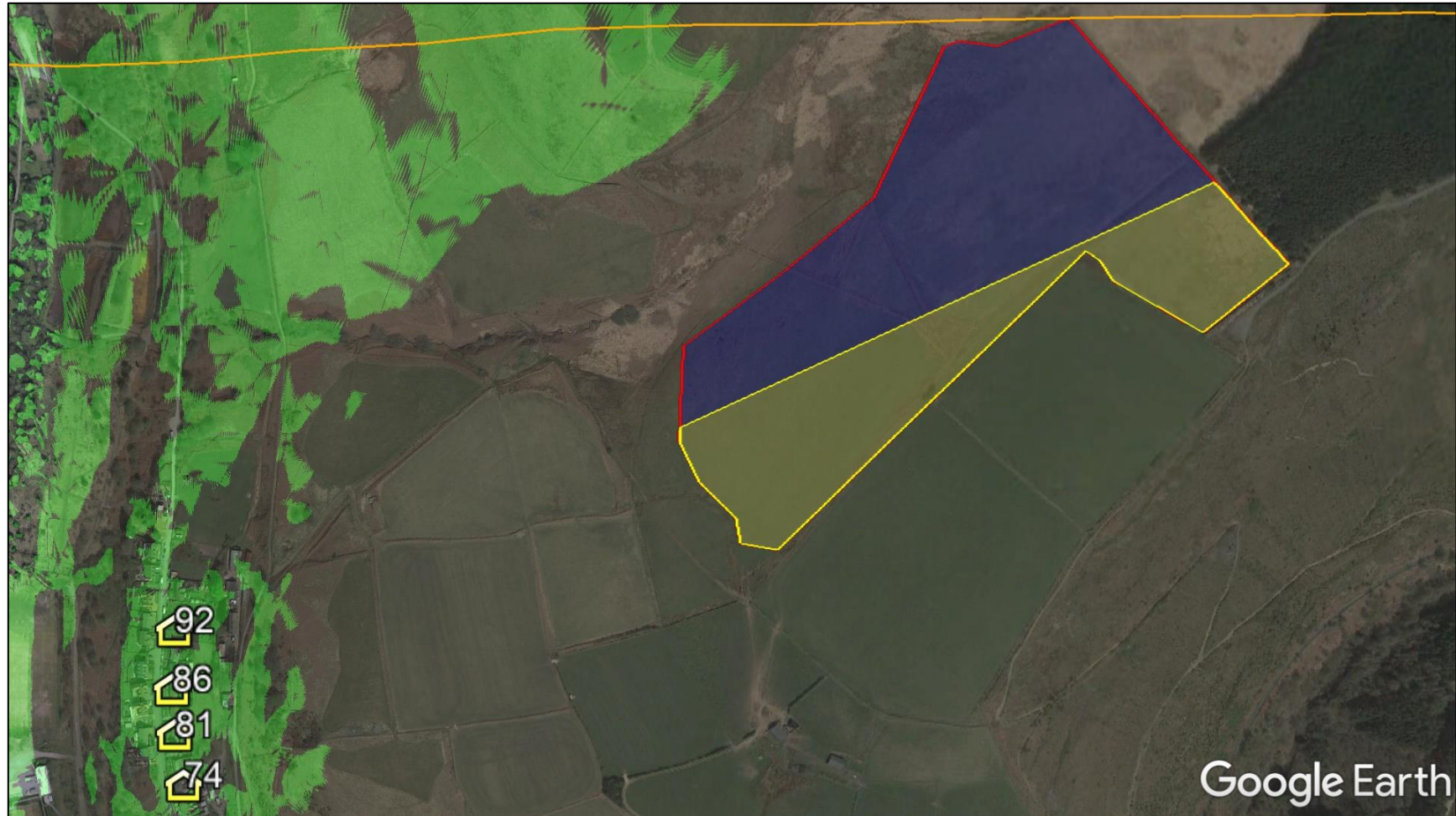


Figure 18 Reflective panel area for dwellings 74 to 92, including terrain mapping from dwelling 86

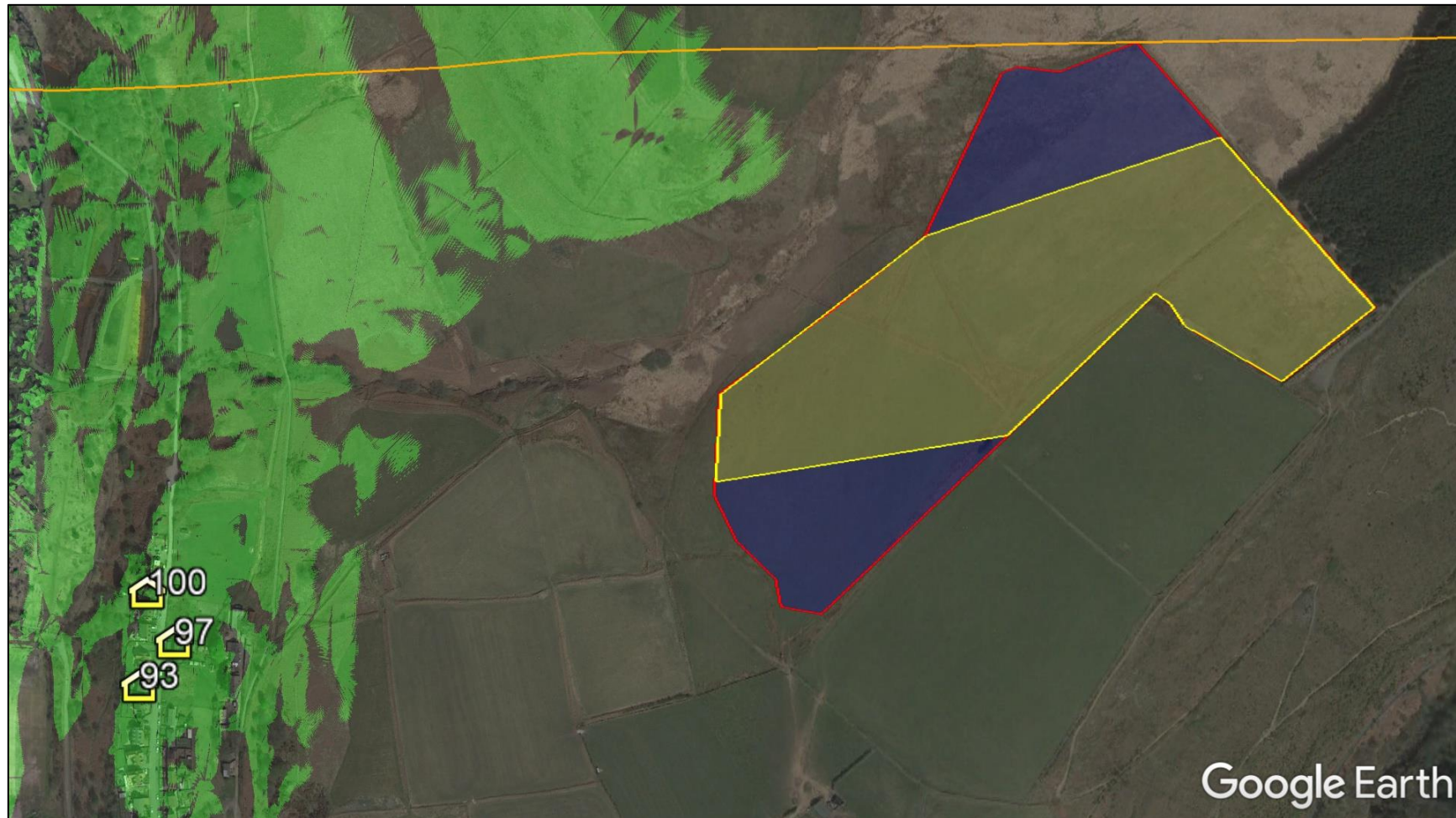


Figure 19 Reflective panel area for dwellings 93 to 100, including terrain mapping from dwelling 97

7 OVERALL CONCLUSIONS

7.1 Assessment Conclusions – Roads

Solar reflections are not geometrically possible towards the assessed 0.7km section of Ton Mawr Road. No impacts are predicted, and no mitigation is required.

7.2 Assessment Conclusions - Dwellings

Solar reflections are geometrically possible towards 28 of the 118 assessed dwellings. Screening in the form of intervening terrain is predicted to obstruct views of reflecting panels, therefore no impact is predicted and no mitigation is required.

7.3 Overall Conclusions

No impact is predicted upon road safety and residential amenity, and no mitigation is required.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

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

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

UK Planning Policy

Renewable and Low Carbon Energy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy¹³ (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.'

¹³ [Renewable and low carbon energy](#), Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 01/11/2021

Draft National Policy Statement for Renewable Energy Infrastructure

The Draft National Policy Statement for Renewable Energy Infrastructure (EN-3)¹⁴ sets out the primary policy for decisions by the Secretary of State for nationally significant renewable energy infrastructure. Sections 3.10.93-97 state:

- '3.10.93 Solar panels are specifically designed to absorb, not reflect, irradiation.¹⁵ However, solar panels may reflect the sun's rays at certain angles, causing glint and glare. Glint is defined as a momentary flash of light that may be produced as a direct reflection of the sun in the solar panel. Glare is a continuous source of excessive brightness experienced by a stationary observer located in the path of reflected sunlight from the face of the panel. The effect occurs when the solar panel is stationed between or at an angle of the sun and the receptor.*
- 3.10.94 Applicants should map receptors to qualitatively identify potential glint and glare issues and determine if a glint and glare assessment is necessary as part of the application.*
- 3.10.95 When a quantitative glint and glare assessment is necessary, applicants are expected to consider the geometric possibility of glint and glare affecting nearby receptors and provide an assessment of potential impact and impairment based on the angle and duration of incidence and the intensity of the reflection.*
- 3.10.96 The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and design. This may need to account for 'tracking' panels if they are proposed as these may cause differential diurnal and/or seasonal impacts.*
- 3.10.97 When a glint and glare assessment is undertaken, the potential for solar PV panels, frames and supports to have a combined reflective quality may need to be assessed, although the glint and glare of the frames and supports is likely to be significantly less than the panels.'*

The EN-3 does not state which receptors should be considered as part of a quantitative glint and glare assessment. Based on Pager Power's extensive project experience, typical receptors include residential dwellings, road users, aviation infrastructure, and railway infrastructure.

Sections 3.10.125-127 state:

- 3.10.125 Applicants should consider using, and in some cases the Secretary of State may require, solar panels to comprise of (or be covered with) anti-glare/anti-reflective coating with a specified angle of maximum reflection attenuation for the lifetime of the permission.*
- 3.10.126 Applicants may consider using screening between potentially affected receptors and the reflecting panels to mitigate the effects.*

¹⁴ Draft National Policy Statement for Renewable Energy Infrastructure (EN-3), Department for Energy Security & Net Zero, date: March 2023, accessed on: 05/04/2023.

¹⁵ Most commercially available solar panels are designed with anti-reflective glass or are produced with anti-reflective coating and have a reflective capacity that is generally equal to or less hazardous than other objects typically found in the outdoor environment, such as bodies of water or glass buildings.

3.10.127 Applicants may consider adjusting the azimuth alignment of or changing the elevation tilt angle of a solar panel, within the economically viable range, to alter the angle of incidence. In practice this is unlikely to remove the potential impact altogether but in marginal cases may contribute to a mitigation strategy.

The mitigation strategies listed within the EN-3 are relevant strategies that are frequently utilised to eliminate or reduce glint and glare effects towards surrounding observers. The most common form of mitigation is the implementation of screening along the site boundary.

Sections 3.10.149-150 state:

3.10.149 Solar PV panels are designed to absorb, not reflect, irradiation. However, the Secretary of State should assess the potential impact of glint and glare on nearby homes, motorists, public rights of way, and aviation infrastructure (including aircraft departure and arrival flight paths).

3.10.150 Whilst there is some evidence that glint and glare from solar farms can be experienced by pilots and air traffic controllers in certain conditions, there is no evidence that glint and glare from solar farms results in significant impairment on aircraft safety. Therefore, unless a significant impairment can be demonstrated, the Secretary of State is unlikely to give any more than limited weight to claims of aviation interference because of glint and glare from solar farms.

The latest version of the draft EN-3 goes some way in referencing that the issue is more complex than presented in the previous issue; though, this is still unlikely to be welcomed by aviation stakeholders, who will still request a glint and glare assessment on the basis that glare may lead to impact upon aviation safety. It is possible that the final issue of the policy will change in light of further consultation responses from aviation stakeholders.

Finally, the EN-3 relates solely to nationally significant renewable energy infrastructure and therefore does not apply to all planning applications for solar farms.

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare is provided for assessing the impact of solar reflections upon surrounding roads and dwellings. Therefore, the Pager Power approach is to determine whether a reflection from the proposed solar development is geometrically possible and then to compare the results against the relevant guidance/studies to determine whether the reflection is significant.

The Pager Power approach has been informed by the policy presented above, current studies (presented in Appendix B) and stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document¹⁶ which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

¹⁶ Pager Power Glint and Glare Guidance, Fourth Edition (4.0), September 2022.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

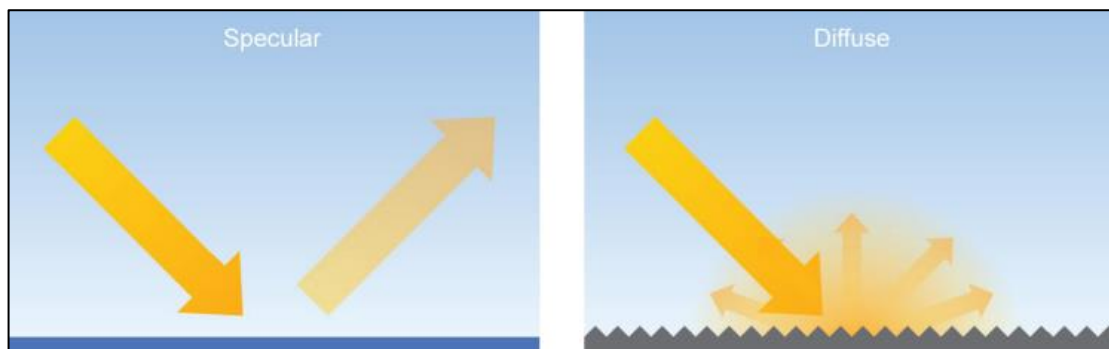
Overview

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 guidance¹⁷, 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

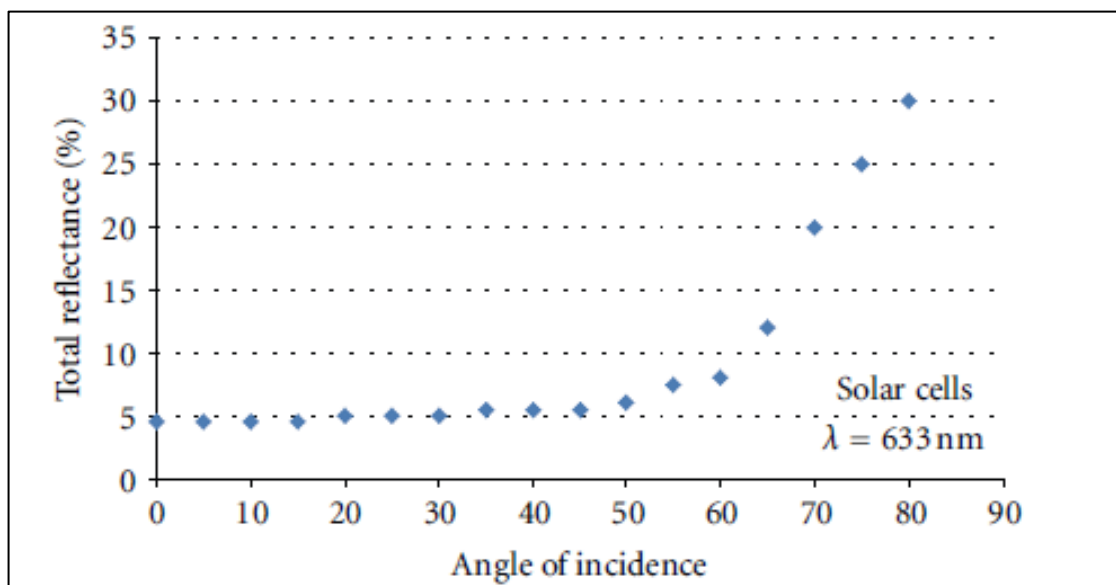
¹⁷Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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.

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.

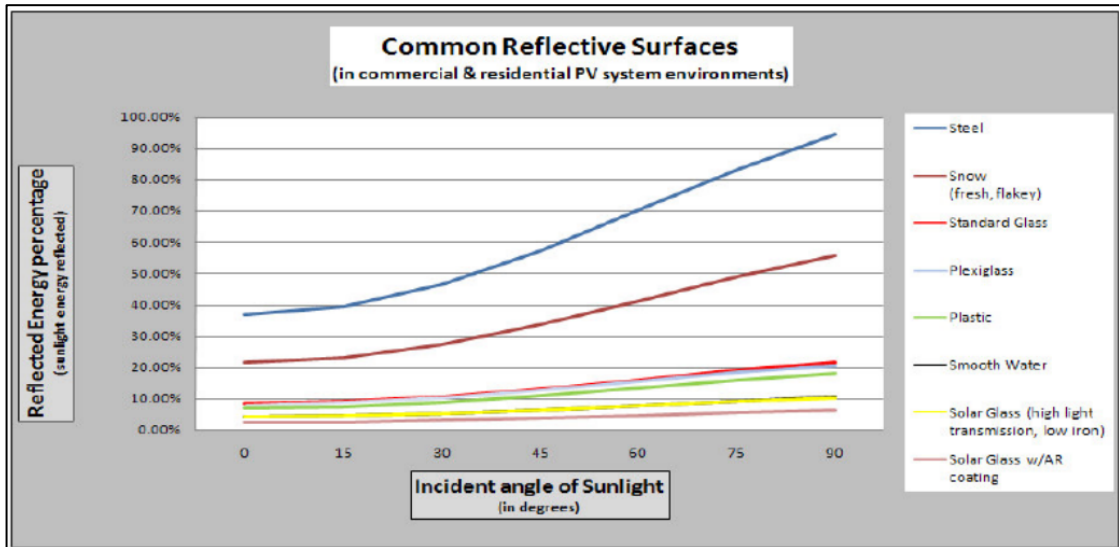
¹⁹ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

²⁰ Extrapolated data, baseline of 1,000 W/m² for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification²¹ 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).

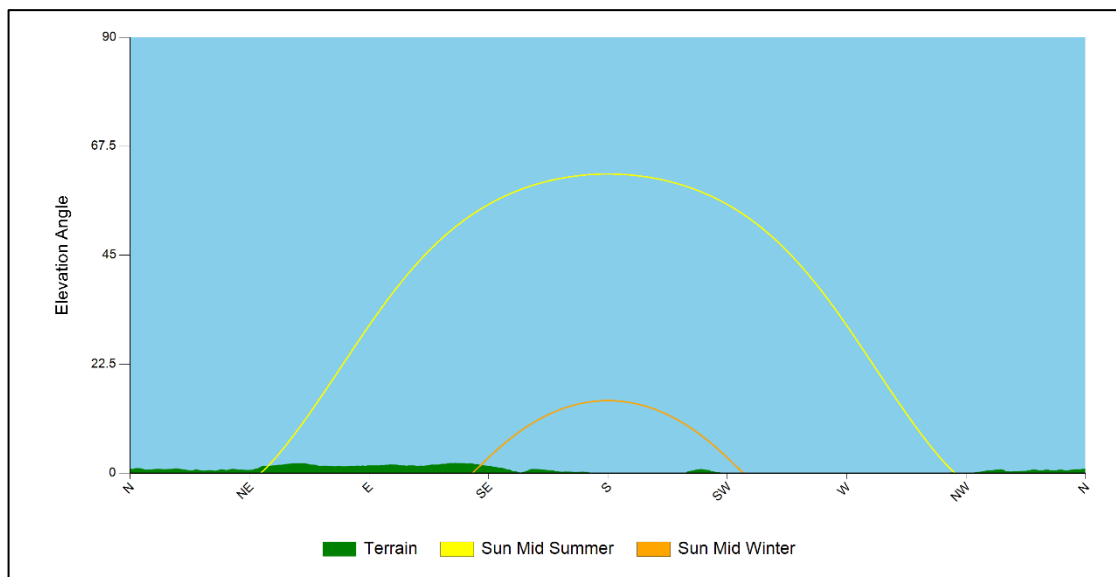
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

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



Terrain at the visible horizon and sun paths

APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

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

Impact Significance Definition

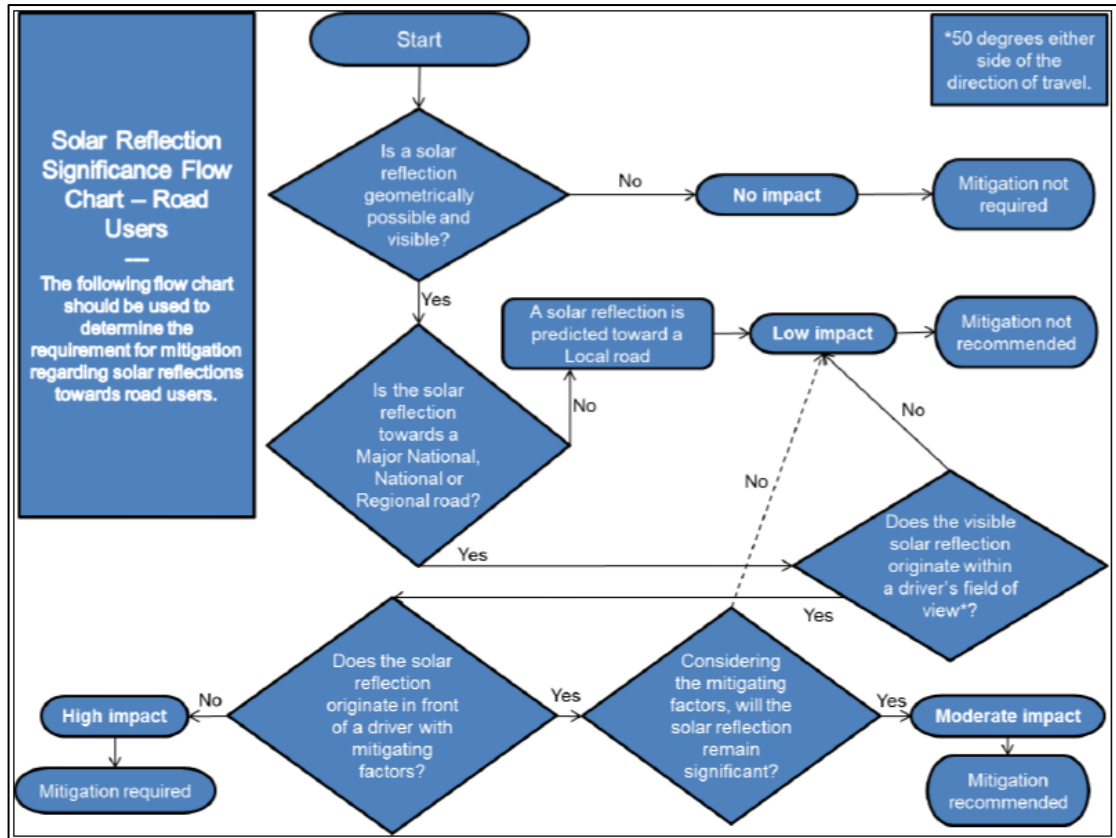
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels significantly.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case given individual receptor criteria.	Mitigation recommended.
Major	A solar reflection is geometrically possible and visible under worst-case conditions that will produce a significant impact given individual receptor criteria	Mitigation will be required if the proposed development is to proceed.

Impact significance definition

Impact Significance Determination for Road Receptors

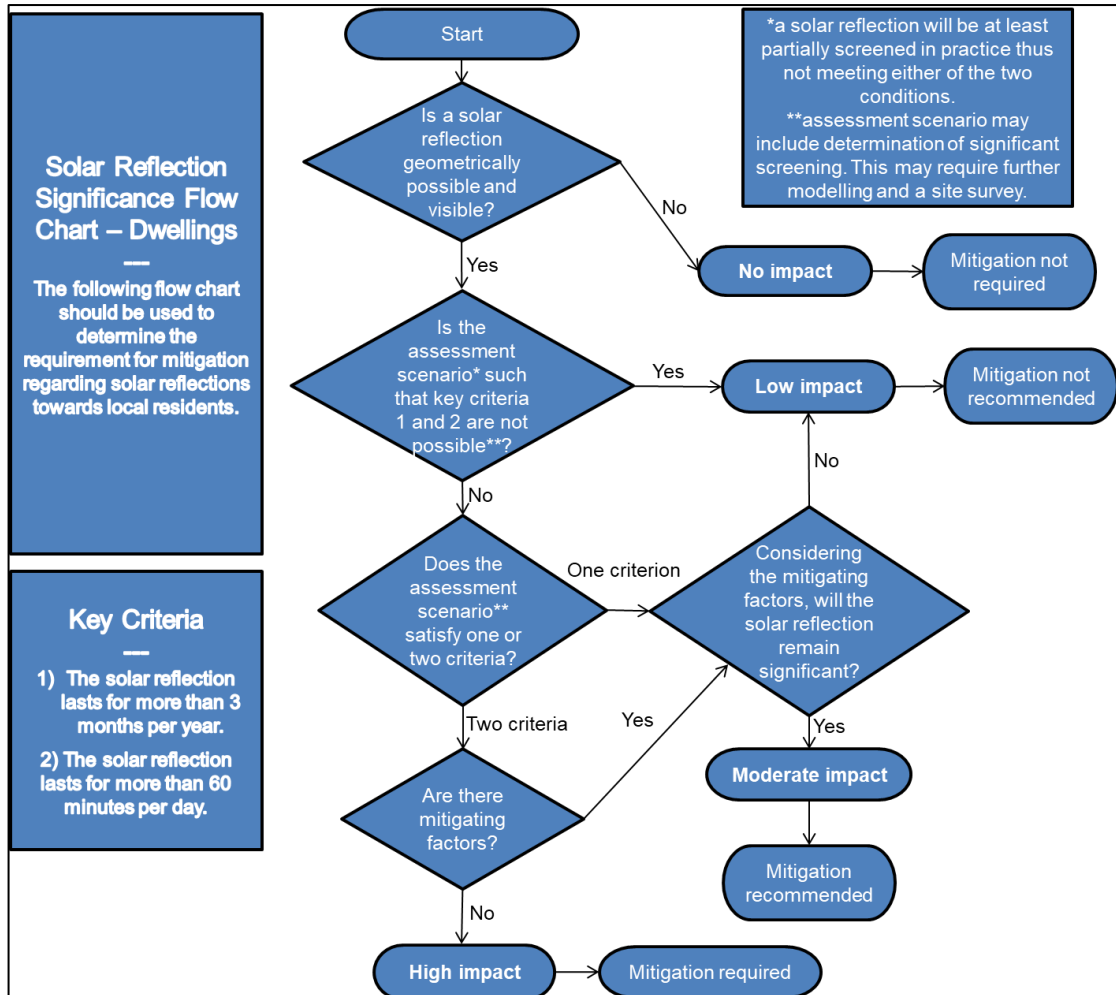
The flow chart presented below has been followed when determining the impact significance and mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Impact Significance Determination for Dwelling Receptors

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



Dwelling receptor mitigation requirement flow chart

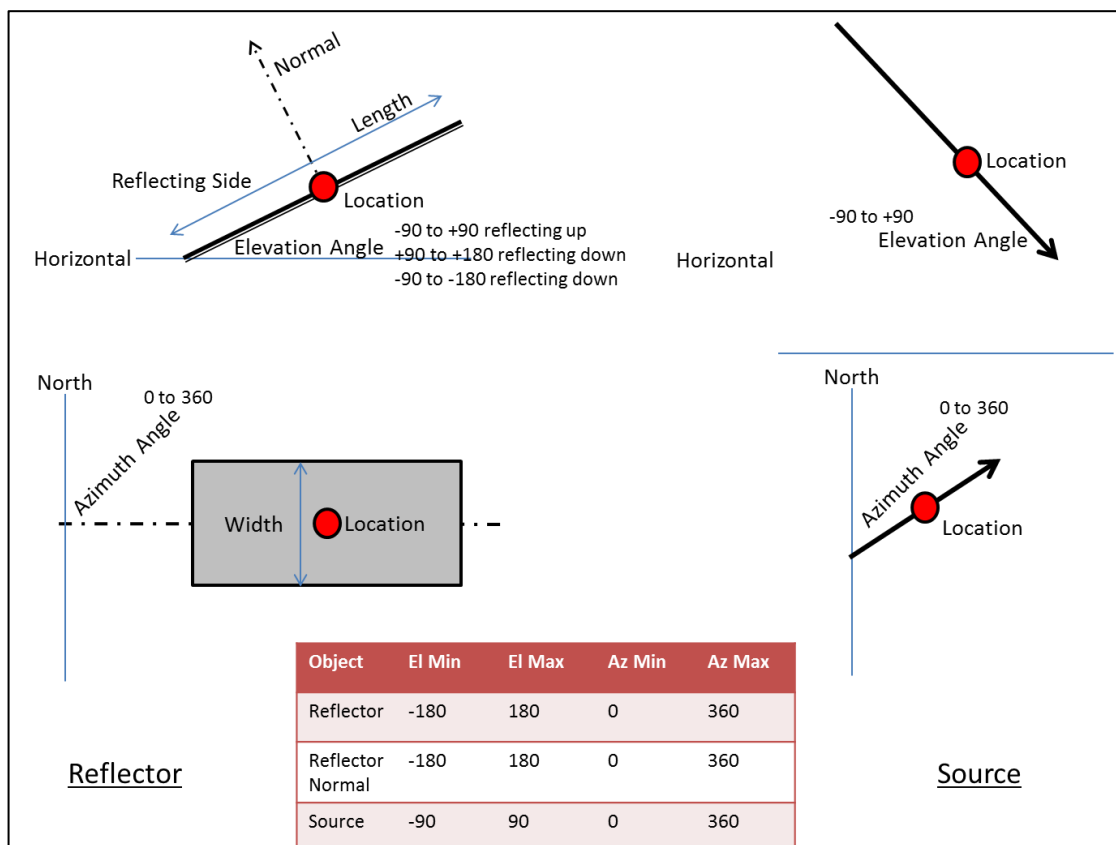
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

Pager Power Methodology

The calculations are three dimensional and complex, accounting for:

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

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



Reflection calculation process

The following process is used to determine the 3D Azimuth and Elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;
- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
 - The angle between source and normal is equal to angle between normal and reflection;
 - Source, Normal and Reflection are in the same plane.

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

The model considers 100% sunlight during daylight hours which is highly conservative.

The model does not account for terrain between the reflecting solar panels and the assessed receptor where a solar reflection is geometrically possible.

The model considers terrain between the reflecting solar panels and the visible horizon (where the sun may be obstructed from view of the panels)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.

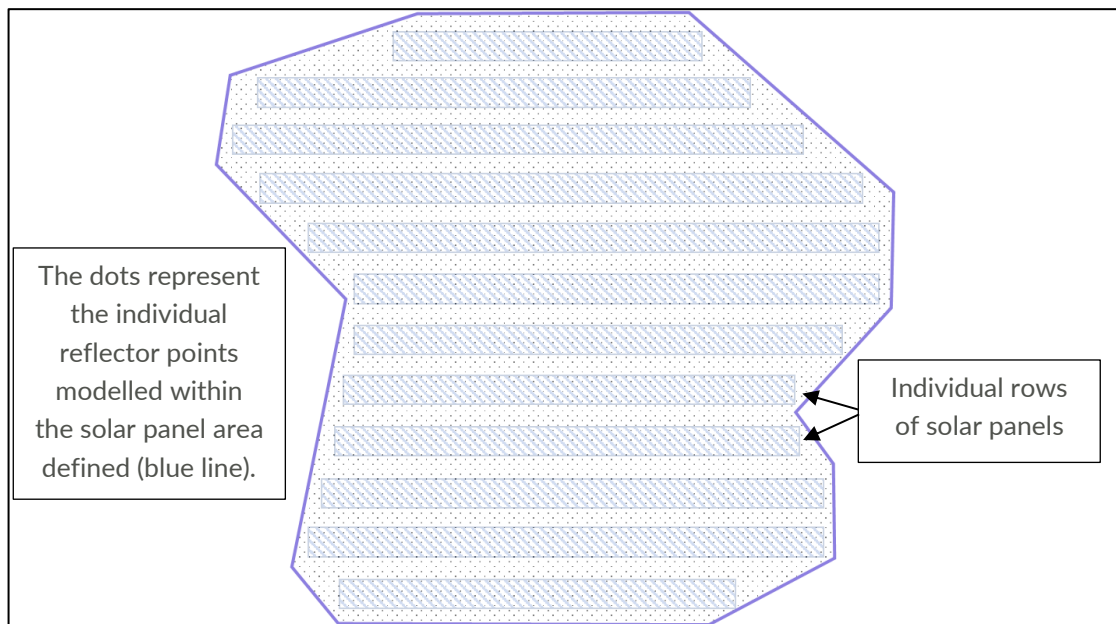
It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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 on the following page 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

Road Receptor Data

The road receptor data, extrapolated from OS Terrain 50 DTM data, is presented in the table below. An additional 1.5m height has been added to the elevation to account for the eye-level of a road user.

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
1	-3.73895	51.65145	119.37	5	-3.73349	51.65234	142.26
2	-3.73764	51.65182	120.97	6	-3.73212	51.65255	151.12
3	-3.73631	51.65212	128.99	7	-3.73079	51.65285	162.00
4	-3.73489	51.65220	137.21	8	-3.73109	51.65309	167.06

Road receptor data

Dwelling Receptor Data

The dwelling receptor data, extrapolated from OS Terrain 50 DTM data, is presented in the table on the following page. An additional 1.8m height has been added to the elevation to account for the eye-level of an observer at these dwellings.

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
0	-3.70688	51.66097	255.40	59	-3.73449	51.65424	170.23
1	-3.71257	51.65869	191.26	60	-3.73447	51.65443	171.74
2	-3.73000	51.64869	201.58	61	-3.73490	51.65437	171.06
3	-3.72467	51.65248	185.28	62	-3.73495	51.65442	168.12
4	-3.72526	51.65212	170.40	63	-3.73498	51.65446	168.48
5	-3.72604	51.65250	177.64	64	-3.73501	51.65450	169.34
6	-3.72646	51.65253	174.07	65	-3.73504	51.65453	169.21

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
7	-3.72673	51.65253	174.52	66	-3.73506	51.65458	169.26
8	-3.72721	51.65260	173.21	67	-3.73509	51.65461	169.28
9	-3.72737	51.65262	175.10	68	-3.73512	51.65466	169.29
10	-3.72756	51.65261	173.38	69	-3.73514	51.65469	169.26
11	-3.72767	51.65263	170.25	70	-3.73517	51.65474	166.16
12	-3.72778	51.65264	169.60	71	-3.73519	51.65478	166.32
13	-3.72789	51.65265	169.38	72	-3.73522	51.65482	166.48
14	-3.72801	51.65266	171.37	73	-3.73524	51.65486	166.71
15	-3.72813	51.65268	172.40	74	-3.73526	51.65490	166.90
16	-3.72805	51.65253	165.82	75	-3.73528	51.65494	166.91
17	-3.73105	51.65341	175.75	76	-3.73530	51.65499	166.97
18	-3.73116	51.65342	176.06	77	-3.73532	51.65503	167.08
19	-3.73116	51.65313	166.56	78	-3.73533	51.65508	167.22
20	-3.73128	51.65314	166.53	79	-3.73533	51.65517	167.53
21	-3.73141	51.65316	167.59	80	-3.73535	51.65523	167.68
22	-3.73154	51.65318	169.43	81	-3.73538	51.65536	167.80
23	-3.73170	51.65324	169.79	82	-3.73539	51.65540	167.92
24	-3.73181	51.65326	170.26	83	-3.73538	51.65551	168.17
25	-3.73204	51.65304	164.22	84	-3.73539	51.65555	168.30
26	-3.73215	51.65305	164.44	85	-3.73539	51.65568	168.64
27	-3.73224	51.65308	165.84	86	-3.73539	51.65575	168.75

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
28	-3.73233	51.65309	166.80	87	-3.73540	51.65585	168.80
29	-3.73242	51.65310	167.65	88	-3.73540	51.65592	168.80
30	-3.73251	51.65311	167.42	89	-3.73540	51.65602	168.80
31	-3.73261	51.65313	167.51	90	-3.73540	51.65608	168.80
32	-3.73273	51.65314	167.52	91	-3.73539	51.65619	168.80
33	-3.73283	51.65315	167.40	92	-3.73539	51.65625	168.70
34	-3.73294	51.65315	168.04	93	-3.73586	51.65632	160.34
35	-3.73303	51.65318	166.48	94	-3.73582	51.65648	160.59
36	-3.73313	51.65320	166.22	95	-3.73582	51.65659	160.80
37	-3.73285	51.65344	172.41	96	-3.73581	51.65667	161.06
38	-3.73315	51.65351	173.62	97	-3.73534	51.65670	166.71
39	-3.73342	51.65328	168.88	98	-3.73533	51.65678	166.62
40	-3.73364	51.65334	167.17	99	-3.73578	51.65690	161.26
41	-3.73376	51.65337	166.32	100	-3.73576	51.65709	162.54
42	-3.73386	51.65341	167.54	101	-3.73500	51.65238	139.09
43	-3.73393	51.65342	167.92	102	-3.73570	51.65239	137.38
44	-3.73399	51.65345	168.07	103	-3.73695	51.65211	130.06
45	-3.73409	51.65350	167.80	104	-3.73703	51.65208	126.51
46	-3.73426	51.65351	163.61	105	-3.73715	51.65207	124.82
47	-3.73438	51.65363	166.44	106	-3.73725	51.65205	122.38
48	-3.73443	51.65366	163.63	107	-3.73754	51.65207	122.71

No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)	No.	Longitude (°)	Latitude (°)	Assessed Height (m amsl)
49	-3.73450	51.65370	164.06	108	-3.73761	51.65210	122.64
50	-3.73456	51.65374	164.63	109	-3.73779	51.65219	123.49
51	-3.73469	51.65382	165.95	110	-3.73783	51.65224	123.66
52	-3.73474	51.65386	166.52	111	-3.73753	51.65240	126.70
53	-3.73480	51.65390	166.79	112	-3.73744	51.65246	127.64
54	-3.73485	51.65393	167.50	113	-3.73743	51.65259	128.80
55	-3.73491	51.65398	166.07	114	-3.73749	51.65264	128.80
56	-3.73496	51.65403	165.48	115	-3.73779	51.65263	127.11
57	-3.73500	51.65407	165.07	116	-3.73789	51.65263	126.28
58	-3.73504	51.65411	164.78	117	-3.73808	51.65259	123.98

Dwelling receptor data

Modelled Reflector Area

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-3.72163	51.66021	12	-3.72748	51.65748
2	-3.72188	51.66037	13	-3.72742	51.65727
3	-3.72330	51.66139	14	-3.72694	51.65723
4	-3.72419	51.66119	15	-3.72496	51.65843
5	-3.72467	51.66123	16	-3.72322	51.65950
6	-3.72485	51.66119	17	-3.72309	51.65958
7	-3.72573	51.66002	18	-3.72292	51.65950
8	-3.72679	51.65949	19	-3.72276	51.65935
9	-3.72817	51.65887	20	-3.72163	51.65894

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
10	-3.72822	51.65810	21	-3.72056	51.65947
11	-3.72795	51.65776	22	-3.72163	51.66021

Panel Area

APPENDIX H – DETAILED MODELLING RESULTS

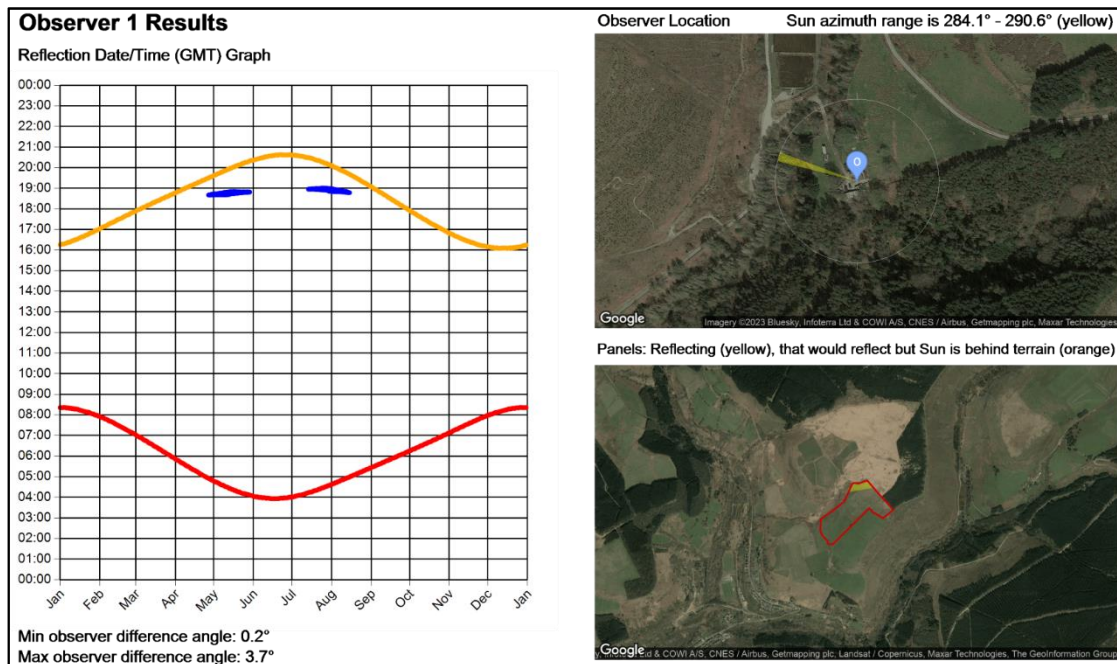
Overview

The Pager Power charts for receptors are shown on the following pages. Further modelling charts can be provided upon request. Each chart shows:

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

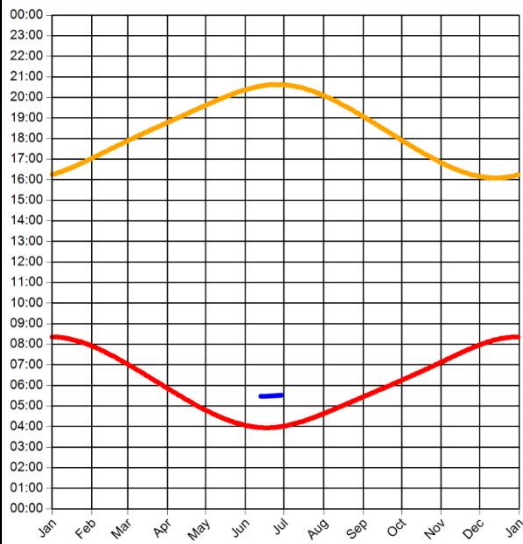
Dwelling Receptors

Selected results have been included for completeness, to show a range of representative results.



Observer 74 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 1.5°
Max observer difference angle: 1.6°

Observer Location

Sun azimuth range is 66.3° - 66.6° (yellow)

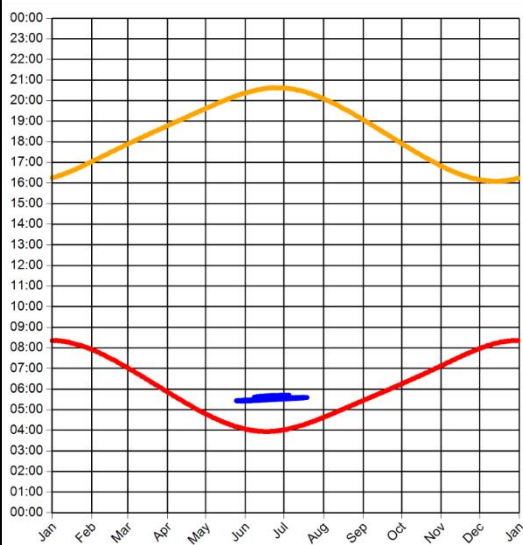


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 80 Results

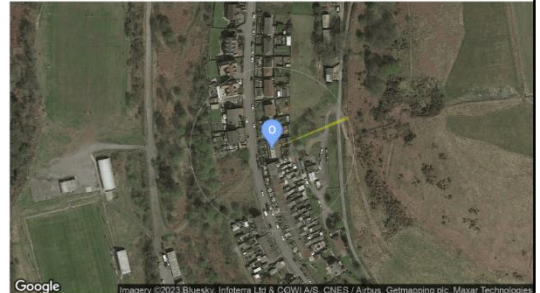
Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.1°
Max observer difference angle: 6.5°

Observer Location

Sun azimuth range is 66.3° - 68.7° (yellow)

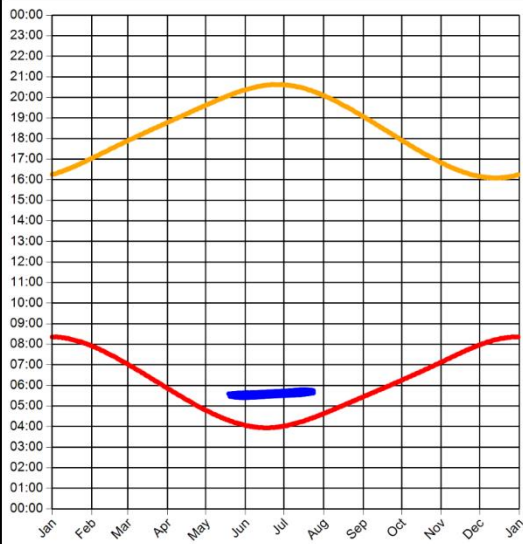


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 86 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 0°
Max observer difference angle: 6.4°

Observer Location

Sun azimuth range is 66.2° - 70.8° (yellow)

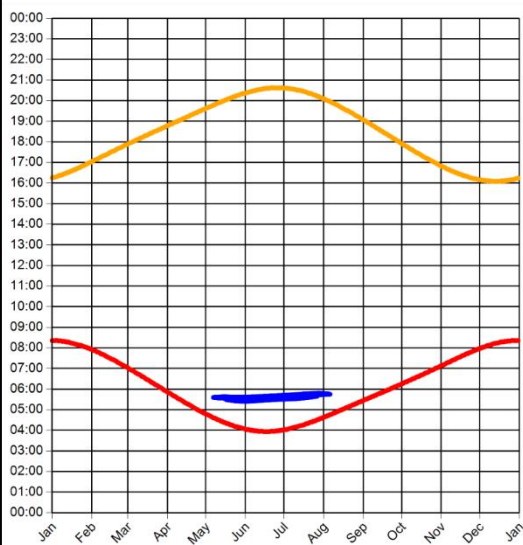


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



Observer 92 Results

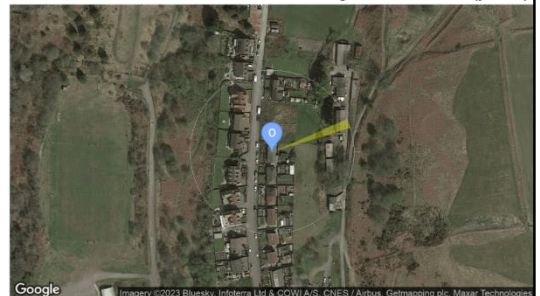
Reflection Date/Time (GMT) Graph



Min observer difference angle: 0°
Max observer difference angle: 5.8°

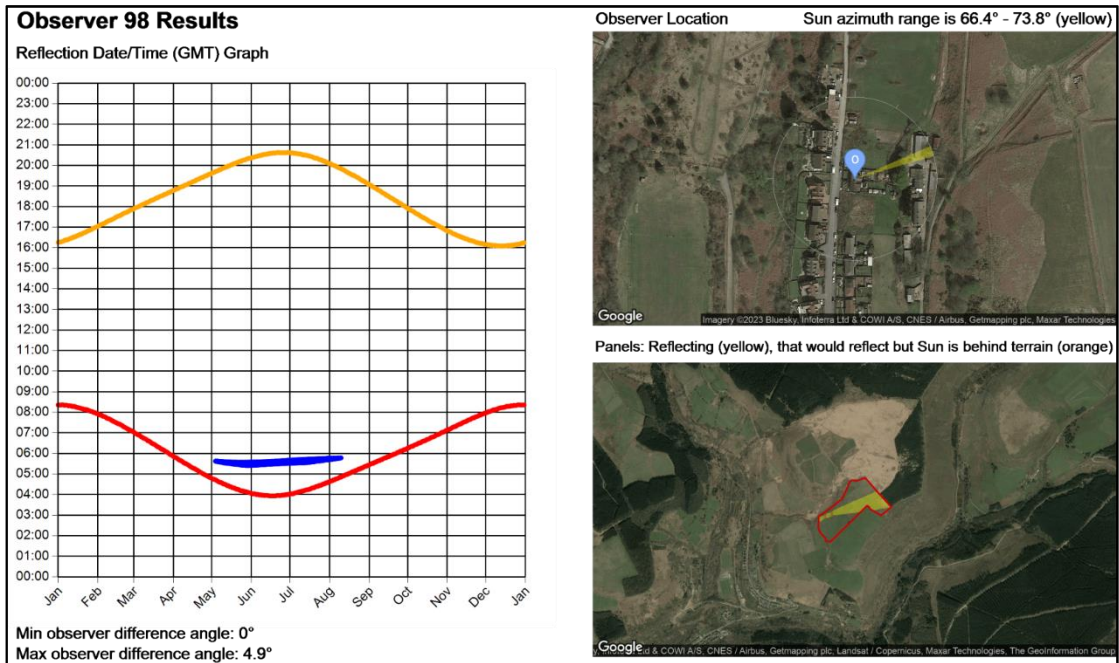
Observer Location

Sun azimuth range is 66.2° - 72.7° (yellow)



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







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