PAGERPOWER
Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Energiekontor UK Ltd

New Rides Solar Farm

May 2021

PLANNING SOLUTIONS FOR:

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

www.pagerpower.com

ADMINISTRATION PAGE

Job Reference:	10169A
Date:	December 2020
Author:	Michael Sutton
Telephone:	01787 319001
Email:	michael@pagerpower.com

Reviewed By:	Waqar Qureshi; Andrea Mariano (Issue 3)
Second Reviewer:	Kai Frolic
Date:	December 2020
Telephone:	01787 319001
Email:	waqar@pagerpower.com; andrea@pagerpower.com; kai@pagerpower.com

Issue	Date	Detail of Changes
1	December 2020	Initial issue
2	January 2021	Discussion of updated layout
3	May 2021	Modelling of updated layout

Stour Valley Business Centre, Sudbury, Suffolk, CO10 7GB

T:*+44 (0)1787 319001* E:*info@pagerpower.com* W:*www.pagerpower.com*

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 to be located south of Eastchurch, on the Isle of Sheppey, Kent, UK.

This assessment pertains to the possible impact upon of glint and glare upon surrounding road users and dwellings.

Pager Power

Pager Power has undertaken over 600 glint and glare assessments in Europe, India and Australasia. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Overall Conclusions

Overall, no significant impacts upon surrounding road users and dwellings have been identified, and mitigation is therefore not required.

The assessment results are presented on the following page.

Guidance

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 upon road safety or residential amenity has not been produced to date. Therefore, Pager Power has reviewed existing guidelines and the available studies (discussed below) in the process of defining its own glint and glare assessment guidance document and methodology[1]. This methodology defines the process for determining the impact upon road safety and residential amenity.

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 steel[2].

---

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

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

Assessment Results – Roads

Most of the roads within 1km of the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

The B2231 is a regional road and located within 1km of the proposed development; however, it is located north of the panels and therefore solar reflections would not be geometrically possible.

No significant impacts upon road users along the surrounding roads are predicted.

Assessment Results – Dwellings

The results of the modelling indicate that solar reflections are geometrically possible towards 11 out of the 12 assessed dwelling receptors.

Mitigation is however not judged to be a requirement because complete screening of the reflecting panel areas has been identified for 10 of these receptors, and any remaining effects towards the final dwelling would occur for less than 3 months per year and less than 60 minutes per day.

No significant impacts upon surrounding dwellings are predicted.

LIST OF CONTENTS

Administration Page 2

Executive Summary 3

Report Purpose 3

Pager Power 3

Overall Conclusions 3

Guidance 3

Assessment Results – Roads 4

Assessment Results – Dwellings 4

List of Contents 5

List of Figures 7

List of Tables 7

About Pager Power 8

1 Introduction 9

1.1 Overview 9

1.2 Pager Power's Experience 9

1.3 Glint and Glare Definition 9

2 Solar Development Location and Details 10

2.1 Site Layout Plan 10

2.2 Solar Panel Details 11

3 Glint and Glare Assessment Methodology 12

3.1 Guidance and Studies 12

3.2 Background 12

3.3 Pager Power's Methodology 12

3.4 Assessment Methodology and Limitations 12

4 Identification of Receptors 13

4.1 Overview 13

4.2 Road Receptors 13

4.3 Dwelling Receptors 15

5 Assessed Reflector Areas 16
5.1 Reflector Areas 16
6 Glint and Glare Assessment Results 17
6.1 Summary of Results 17
6.2 Geometric Calculation Results Overview – Dwelling Receptors 17
7 Geometric Assessment Results and Discussion 19
7.1 Dwelling Results 19
8 Overall Conclusions 23
8.1 Assessment Results – Roads 23
8.2 Assessment Results – Dwellings 23
Appendix A – Overview of Glint and Glare Guidance 24
Overview 24
UK Planning Policy 24
Assessment Process – Ground-Based Receptors 24
Appendix B – Overview of Glint and Glare Studies 26
Overview 26
Reflection Type from Solar Panels 26
Solar Reflection Studies 27
Appendix C – Overview of Sun Movements and Relative Reflections 30
Appendix D – Impact Significance Definition 31
Assessment Process for Road Receptors 32
Assessment Process for Dwelling Receptors 33
Appendix E – Pager Power’s Reflection Calculations Methodology 34
Appendix F – Assessment Limitations and Assumptions 36
Pager Power’s Model 36
Appendix G – Receptor and Reflector Area Details 37
Receptor Data – Dwellings 37
Modelled Reflector Areas 37
Appendix H – Geometric Calculation Results 39
Overview 39

Dwelling Receptors 39

LIST OF FIGURES

Figure 1 Site layout plan 10
Figure 2 Solar panel cross section 11
Figure 3 Location of the B2231 relative to the proposed development 14
Figure 4 Assessed dwelling receptors 15
Figure 5 Assessed reflector areas 16
Figure 6 Identified screening overview 21
Figure 7 Screening adjacent to dwellings 7 to 10 21
Figure 8 Representative viewpoint for dwelling 7 22

LIST OF TABLES

Table 1 Solar panel characteristics 11
Table 2 Geometric analysis results – Dwelling receptors 18
Table 3 Assessment of mitigation requirement 20

ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 50 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 to be located south of Eastchurch, on the Isle of Sheppey, Kent, UK. This assessment pertains to the possible impact upon of glint and glare upon surrounding road users and dwellings.

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;
- 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.

This report is solely desk-based, and no site visit has taken place.

1.2 Pager Power's Experience

Pager Power has undertaken over 600 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 i.e. glint and glare.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Site Layout Plan

The proposed development site layout plan is shown in Figure 1[3] below. The solar panels areas are shown in pale pink.

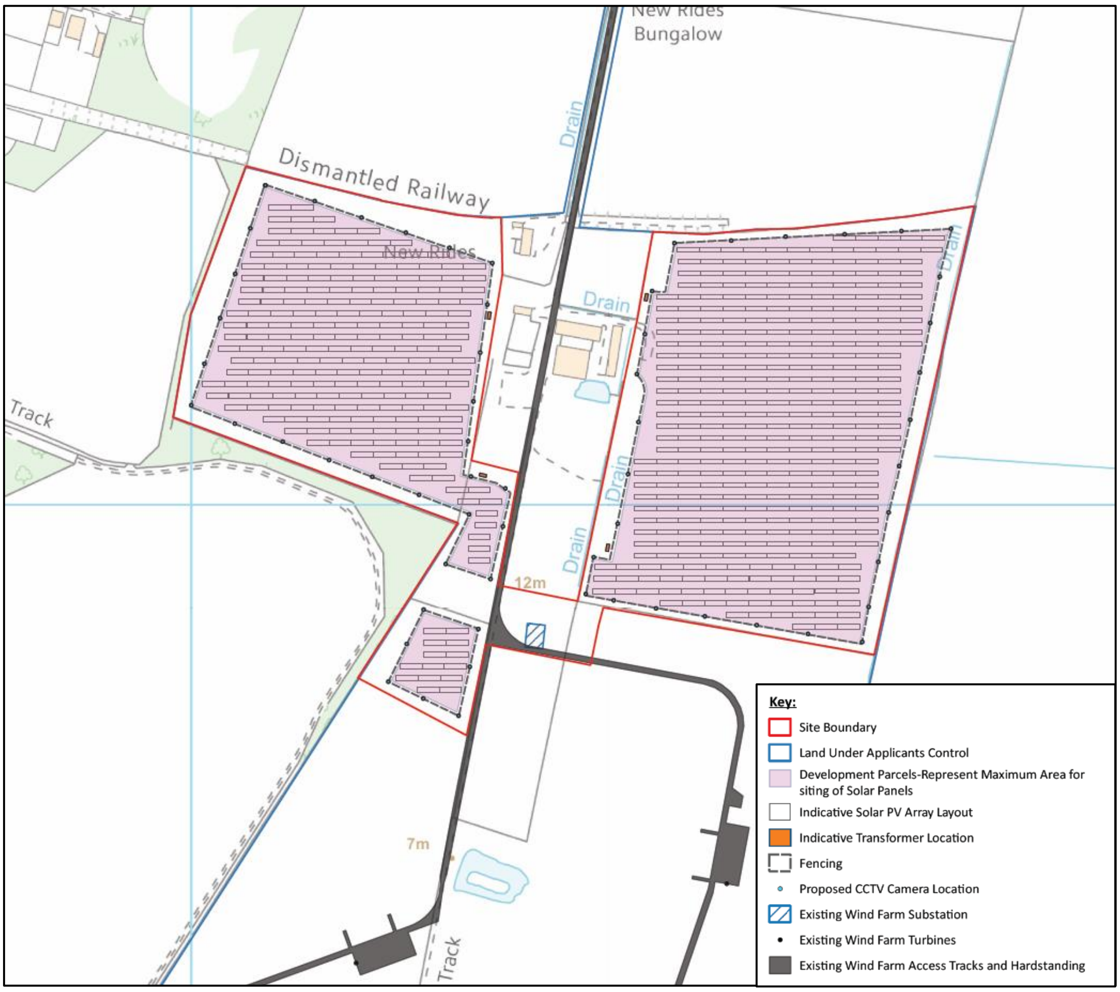


Figure 1 *Site layout plan*

[3] Source: NewRidesSolar_UpdatedDesign_20210510 (edited).

2.2 Solar Panel Details

The solar panel cross section is shown in Figure 2[4] below.

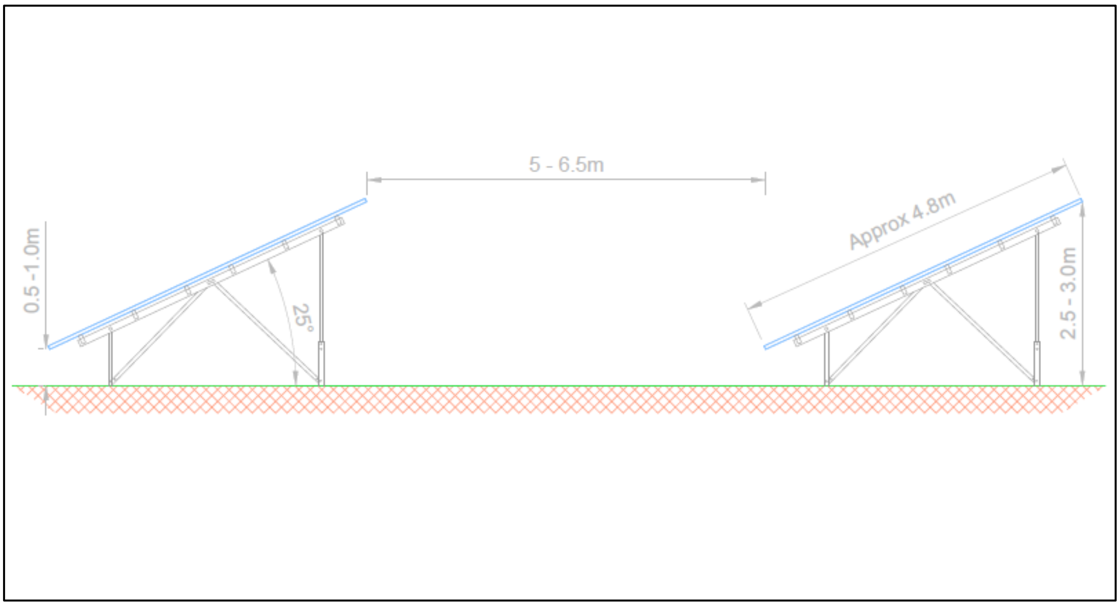


Figure 2 *Solar panel cross section*

The solar panel characteristics used in the assessment are presented in Table 1 below.

Panel Information	
Azimuth angle (°)	180 (south facing)
Elevation angle (°)	25
Panel centre height (m agl[5])	1.5 – 2[6]

Table 1 *Solar panel characteristics*

[4] Source: NewRidesSolar_SolarPanelCrossSection_20201217_A.
[5] Metres above ground level.
[6] A panel height of 2m agl has been used for this assessment. Based on previous project experience, it can be concluded that reducing this height within this range will not change the results and conclusions of the assessment.

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 Guidance and Studies

Appendix A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels. 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 Pager Power's Methodology

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

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

3.4 Assessment Methodology and Limitations

Further technical details regarding the methodology of the geometric calculations and limitations are presented in Appendix E and Appendix 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 buffer (orange outlined areas in the proceeding figures) 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.

Reflections towards ground-based receptors to the north of the panels are not deemed possible at this latitude for fixed panels facing south and are therefore not taken forward for geometric modelling. A more detailed assessment is made if the geometric modelling reveals a reflection would be geometrically possible.

The receptor details are presented in Appendix G and the terrain elevations have been interpolated based on OSGB36 data.

4.2 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.

Most of the roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

The B2231 is a regional road and located within the 1km of the proposed development; however, it is located north of the panels and therefore solar reflections would not be geometrically possible. The location of the B2231 relative to the proposed development is shown in Figure 3[7] below.

Considering all of the above, none of the surrounding roads have therefore been taken forward for detailed modelling, and no significant impacts upon road users are predicted.

Figure 3 *Location of the B2231 relative to the proposed development*

[7] Copyright © 2021 Google.

4.3 Dwelling Receptors

Dwellings have been identified within approximately 1km of the proposed solar development that are most likely to have visual line of sight to the solar panels (based on an initial high-level review of aerial photography[8] plus local topography). If visual line of sight exists between the solar development and the dwellings, then a solar reflection could be experienced. If there is no line of sight, then a reflection cannot be experienced.

For a dwelling receptor, a height of 1.8m has been added to the overall ground height to simulate the typical viewing height a ground floor window[9]. Where dwellings are adjacent to one another, one receptor point has been assessed with the results expected to be almost identical for adjacent dwellings.

The assessed dwelling receptor locations are shown in Figure 4[8] below.

Figure 4 *Assessed dwelling receptors*

[8] It is worth noting, however, that aerial and street view imagery may not provide the most up to date information of the surrounding area.

[9] Consideration of views from a first floor (if present) are discussed further in section 7.1.

5 ASSESSED REFLECTOR AREAS

5.1 Reflector Areas

A number of representative panel locations are selected within the proposed reflector areas. The number of modelled reflector points is determined by the size of the reflector area and the assessment resolution. The bounding co-ordinates for the proposed solar development have been extrapolated from the site plans and can be found in Appendix G. All ground heights have been based on OSGB36 terrain data.

A resolution of 10m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 10m 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 solar development.

The assessed reflector areas are shown in Figure 5 below.

Figure 5 *Assessed reflector areas*

6 GLINT AND GLARE ASSESSMENT RESULTS

6.1 Summary of Results

The tables in the following sub-sections summarise the results of the assessment. The predicted glare times are based solely on bare-earth terrain i.e. without consideration of screening from buildings and vegetation. The significance of any predicted impact is discussed in the subsequent report sections.

The modelling output showing the precise predicted times and the reflecting panel areas are shown in Appendix H.

6.2 Geometric Calculation Results Overview – Dwelling Receptors

The results of the geometric calculations for the dwelling receptors are presented in Table 2 below.

<table>
<tr><th rowspan="2">Receptor</th><th colspan="2">Solar Reflections Possible Towards the Dwelling Receptors? (GMT)</th><th rowspan="2">Comment</th></tr>
<tr><th>am</th><th>pm</th></tr>
<tr><td>1</td><td>05:45 – 06:10 from mid-March to late April and 05:40 – 06:05 from mid-August to late September.</td><td>None.</td><td rowspan="5">Solar reflections would originate from the northern sections of the two northern panel areas.

Discussed in Section 7.</td></tr>
<tr><td>2</td><td>05:45 – 06:10 from mid-March to late April and 05:40 – 06:05 from late August to late September.</td><td>None.</td></tr>
<tr><td>3 – 4</td><td>05:55 – 06:10 from mid-March to early April and 05:40 – 06:00 from early September to late September.</td><td>None.</td></tr>
<tr><td>5</td><td>05:50 – 06:10 from mid-March to mid-April and 05:40 – 06:00 from late August to late September.</td><td>None.</td></tr>
<tr><td>6</td><td>05:45 – 06:15 from mid-March to late April and 05:40 – 06:00 from mid-August to late September.</td><td>None.</td></tr>
</table>

Receptor	Solar Reflections Possible Towards the Dwelling Receptors? (GMT)		Comment
	am	pm	
7	05:40 – 06:10 from mid-March to late April and 05:40 – 06:00 from early August to late September.	None.	Solar reflections would originate from the northern sections of the two northern panel areas. Discussed in Section 7.
8	05:45 – 06:10 from mid-March to late April and 05:40 – 06:00 from mid-August to late September.	None.	
9	05:45 – 06:05 from mid-March to mid-April and 05:40 – 06:10 from late August to late September.	None.	
10	05:50 – 06:05 from late March to early April and 05:40 – 06:00 from early to mid-September.	None.	
11	None.	None.	No solar reflections geometrically possible. No impact predicted.
12	At sunrise in mid-March and late September.	17:55 – 18:10 from late March to late April and 17:50 – 18:10 from mid-May to mid-September.	Solar reflections would originate from the northern sections of the two northern panel areas. Discussed in Section 7.

Table 2 *Geometric analysis results – Dwelling receptors*

7 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

7.1 Dwelling Results

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 in practice.
- The duration of the predicted effects, relative to thresholds of:
    - 3 months per year.
    - 60 minutes per day.

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

Where effects last for more than 3 months per year and less than 60 minutes per day[10], the worst-case impact significance is moderate and expert assessment of any mitigating factors is required to determine the mitigation requirement (if any). Of particular relevance is the level of likely screening, the separation distance between the reflecting panels and the receptor location[11] and the extent to which effects coincide with direct sunlight.

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

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.

The dwellings for which reflections are predicted have been considered in the context of existing screening and the criteria set out above. Table 3 below summarises this step of the analysis.

Dwelling Receptor	Initial impact classification (modelling output)	Existing screening (desk-based review)	Predicted impact classification	Relevant factors	Mitigation recommended?
1 – 6	Low.	Substantial existing vegetation. Predicted to completely obstruct views.	No impact.	N/A	No.

[10] 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.

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

Dwelling Receptor	Initial impact classification (modelling output)	Existing screening (desk-based review)	Predicted impact classification	Relevant factors	Mitigation recommended?
7	Moderate.	Substantial existing vegetation. Predicted to completely obstruct views.	No impact.	N/A	No.
8	Low.	Inconclusive. Views of panels possible - particularly from first floor.	Low.	N/A	No.
9 – 10	Low.	Substantial existing vegetation. Predicted to completely obstruct views.	No impact.	N/A	No.
12	Low.	None identified.	Low.	N/A	No.

Table 3 *Assessment of mitigation requirement*

The screening identified through the desk-based review is shown in the figures[12] on the following pages. Specifically, each figure shows:

- Figure 6: An overview of the identified screening;
- Figure 7: A streetview image of the vegetation screening adjacent to dwellings 7-10 (the proposed development is to the right of the figure);
- Figure 8: A streetview image representing views at dwelling 7 and the significant vegetation screening that will obstruct views of the panels.

[12] Copyright © 2021 Google.

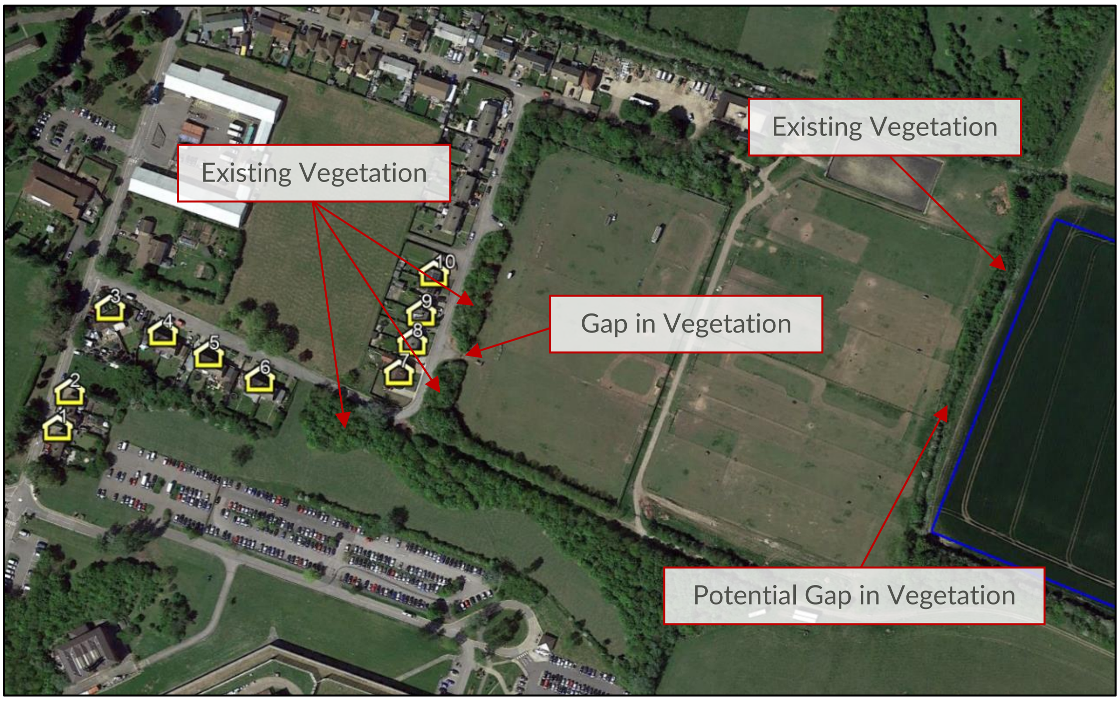


Figure 6 *Identified screening overview*


Figure 7 *Screening adjacent to dwellings 7 to 10*

Figure 8 *Representative viewpoint for dwelling 7*

8 OVERALL CONCLUSIONS

8.1 Assessment Results – Roads

Most of the roads within 1 kilometre of the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

The B2231 is a regional road and located within the 1km of the proposed development; however, it is located north of the panels and therefore solar reflections would not be geometrically possible.

No significant impacts upon road users along the surrounding roads are predicted.

8.2 Assessment Results – Dwellings

The results of the modelling indicate that solar reflections are geometrically possible towards 11 out of the 12 assessed dwelling receptors.

Mitigation is however not judged to be a requirement because complete screening of the reflecting panel areas has been identified for 10 of these receptors, and any remaining effects towards the final dwelling would occur for less than 3 months per year and less than 60 minutes per day.

No significant impacts upon surrounding dwellings are predicted.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

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

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

UK Planning Policy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[13] (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 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.

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

The Pager Power approach has been informed by the policy presented above, current studies (presented in Appendix B) and stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document[14] which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

[14] Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

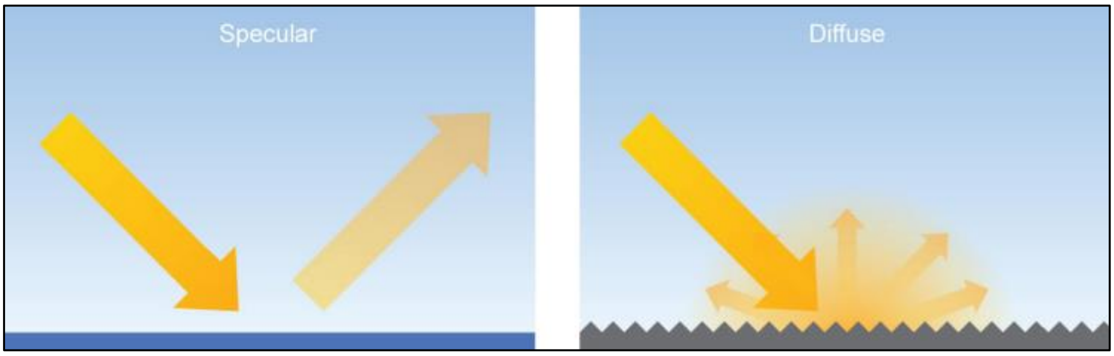
Overview

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[15], 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

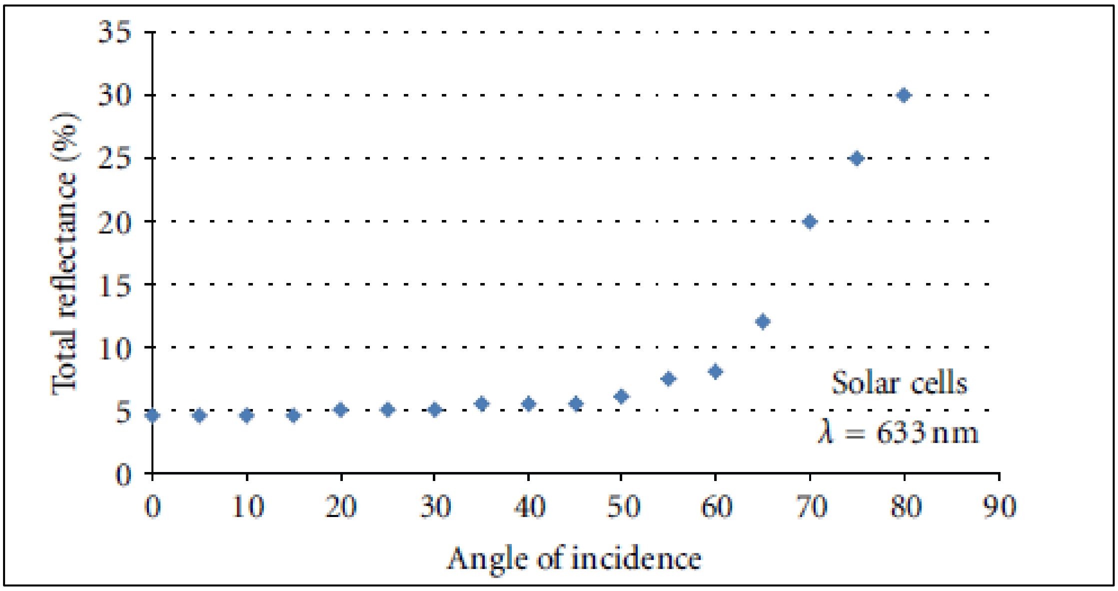
[15] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*[16]". 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.

[16] 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"[17]

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[18]
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).

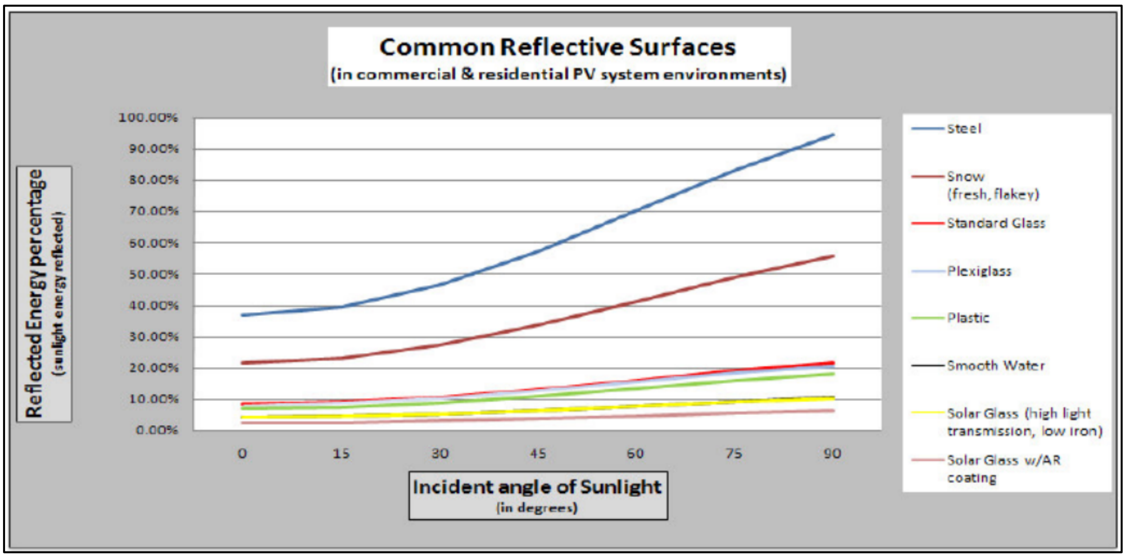
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

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

SunPower Technical Notification (2009)

SunPower published a technical notification[19] 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.

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

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

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

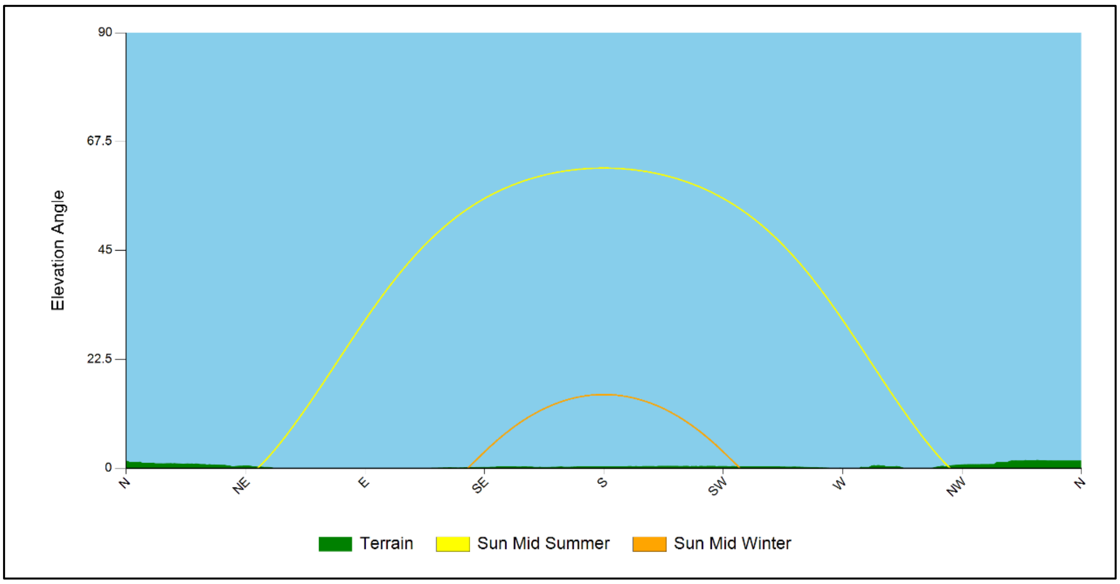
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

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

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

- The Sun is at its highest around midday and is to the south at this time;
- The Sun rises highest on 21 June reaching a maximum elevation of approximately 60-65 degrees (longest day);
- On 21 December, the maximum elevation reached by the Sun is approximately 10-15 degrees (shortest day).

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



APPENDIX D – 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.

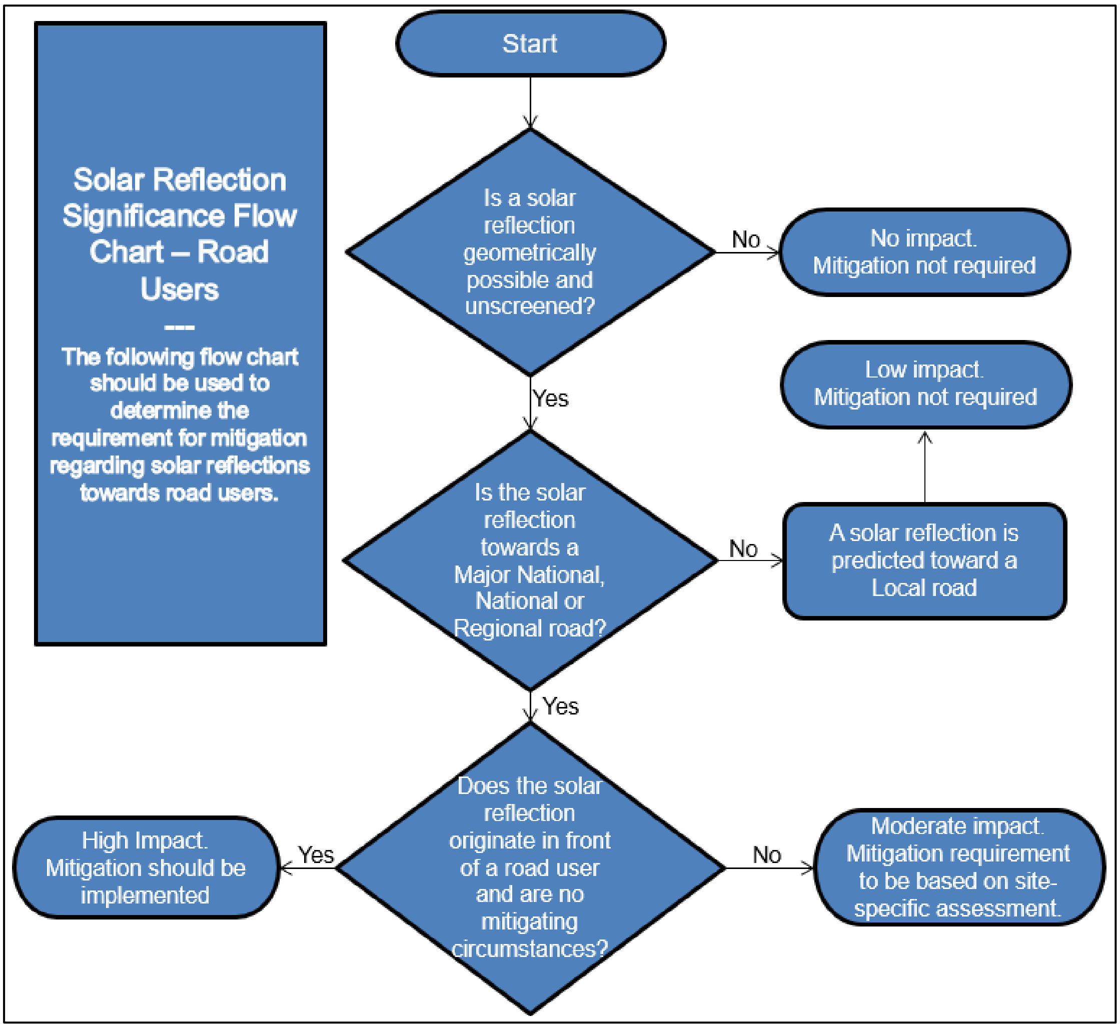
Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation 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

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

Assessment Process for Road Receptors

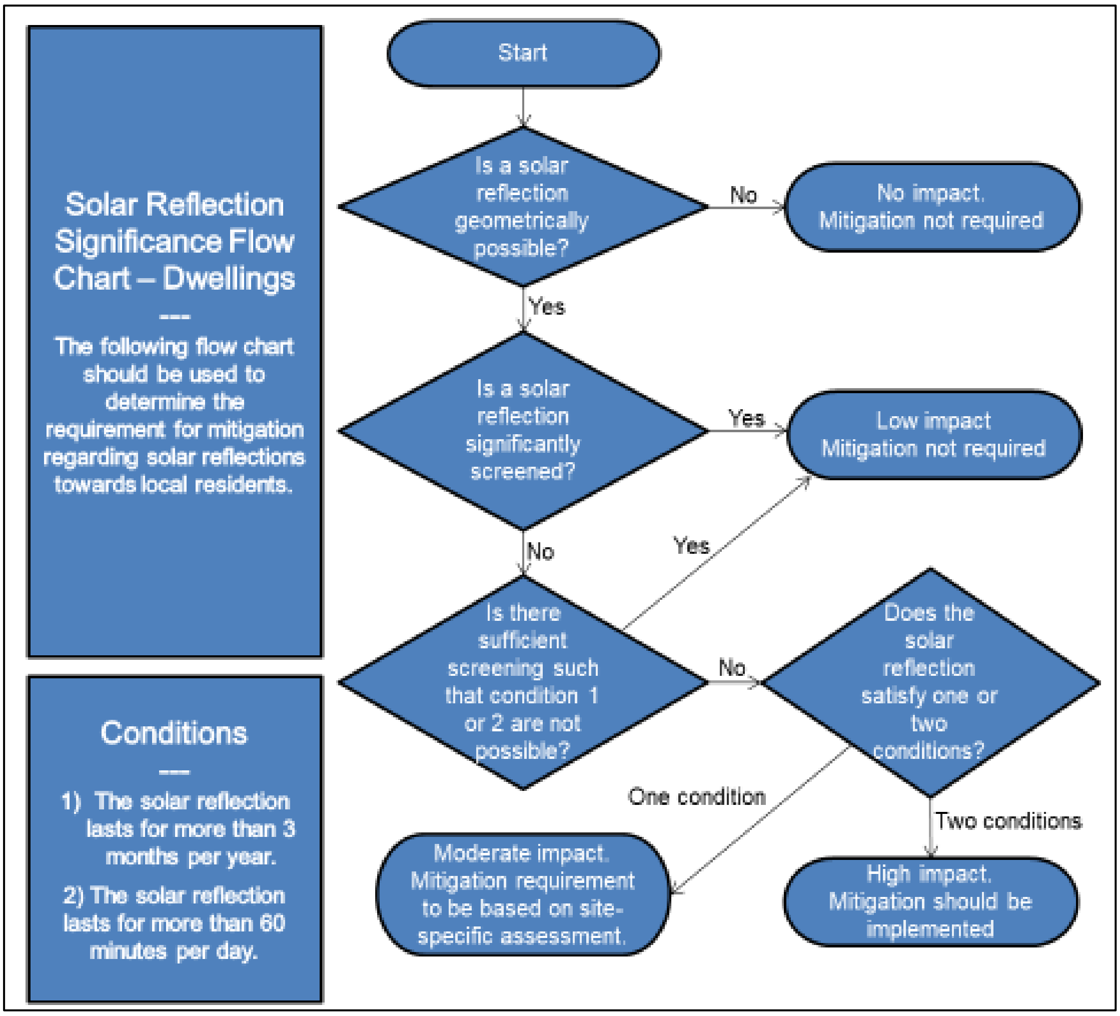
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



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.



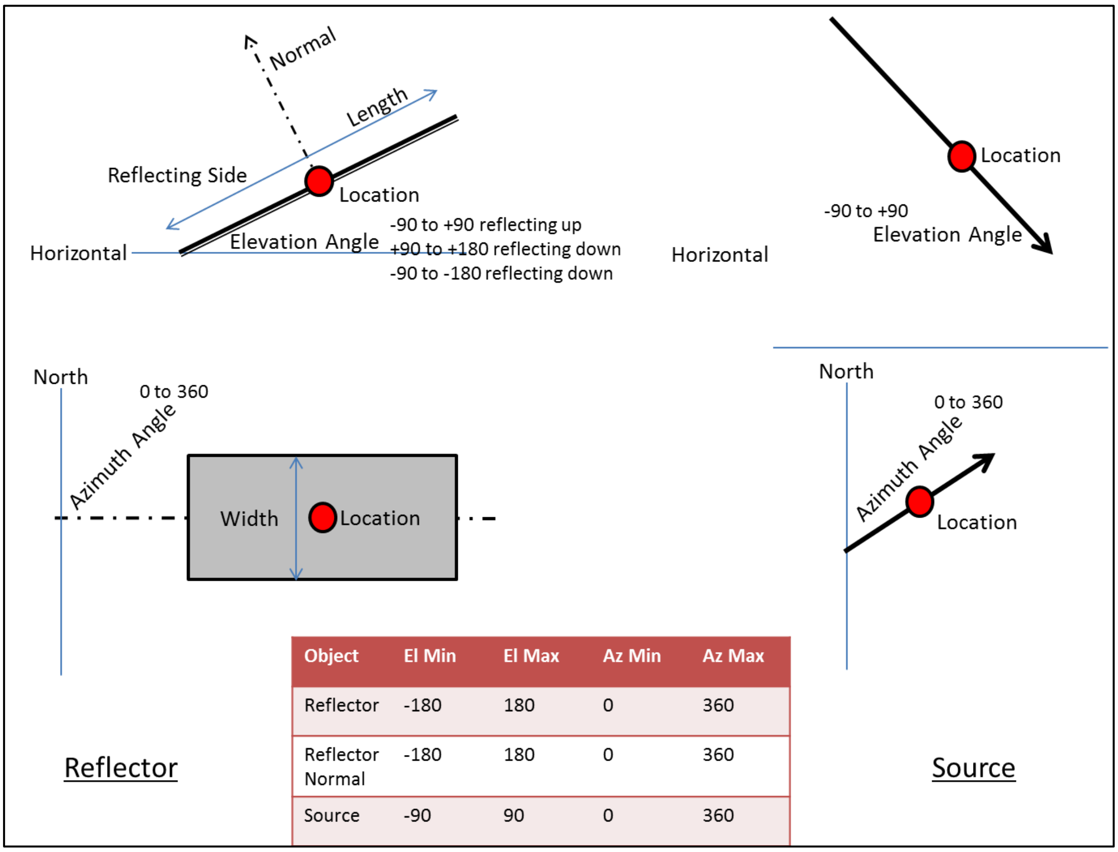
Dwelling receptor mitigation requirement flow chart

APPENDIX E – PAGER POWER'S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

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

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



Object	El Min	El Max	Az Min	Az Max
Reflector	-180	180	0	360
Reflector Normal	-180	180	0	360
Source	-90	90	0	360

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

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;

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

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

- It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within the solar development unless otherwise stated.
- It is assumed that the panel azimuth angle provided by the developer represents the azimuth angle for all of the panels within the solar development unless otherwise stated.
- Only a reflection from the face of the panel has been considered. The frame or the reverse of the solar panel has not been considered.
- The model assumes that a receptor can view the face of every panel within the proposed development area whilst in reality this, in the majority of cases, will not occur. Therefore, any predicted reflection from the face of a solar panel that is not visible to a receptor will not occur.
- A finite number of points within the proposed development are chosen based on an assessment resolution so we can build a comprehensive understanding of the entire development. This will determine whether a reflection could ever occur at a chosen receptor. The calculations do not incorporate all of the possible panel locations within the development outline.
- A single reflection point on the panel has been chosen for the geometric calculations. This will suitably determine whether a reflection can be experienced at a location and the general time of year and duration of this reflection. Increased accuracy could be achieved by increasing the number of heights assessed however this would only marginally change the results and is not considered significant.
- Whilst line of sight to the development from receptors has been considered, only available street view imagery and satellite mapping has been used. In some cases this imagery may not be up to date and may not give the full perspective of the installation from the location of the assessed receptor.
- Any screening in the form of trees, buildings etc. that may obstruct the Sun from view of the solar panels is not considered unless stated.

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Receptor Data – Dwellings

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

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	0.851737	51.395303	7	0.854585	51.395592
2	0.851842	51.395490	8	0.854699	51.395752
3	0.852183	51.395928	9	0.854776	51.395903
4	0.852624	51.395800	10	0.854883	51.396109
5	0.853004	51.395685	11	0.855041	51.396472
6	0.853426	51.395558	12	0.863253	51.396005

Dwelling receptor data

Modelled Reflector Areas

The tables below and on the following pages present the data for the modelled reflector areas.

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	0.860066	51.396476	6	0.862948	51.394129
2	0.859075	51.394841	7	0.862796	51.394196
3	0.862448	51.393973	8	0.862394	51.394268
4	0.861405	51.392751	9	0.862815	51.395840
5	0.862229	51.392487			

Modelled reflector area 1

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	0.865056	51.395955	6	0.864152	51.393599
2	0.864931	51.395592	7	0.863950	51.393627
3	0.864759	51.395600	8	0.863842	51.393356
4	0.864555	51.394981	9	0.867212	51.392931
5	0.864637	51.394872	10	0.868436	51.395997

Modelled reflector area 2

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	0.861848	51.393291	3	0.862242	51.392485
2	0.861393	51.392779	4	0.862479	51.393133

Modelled reflector area 3

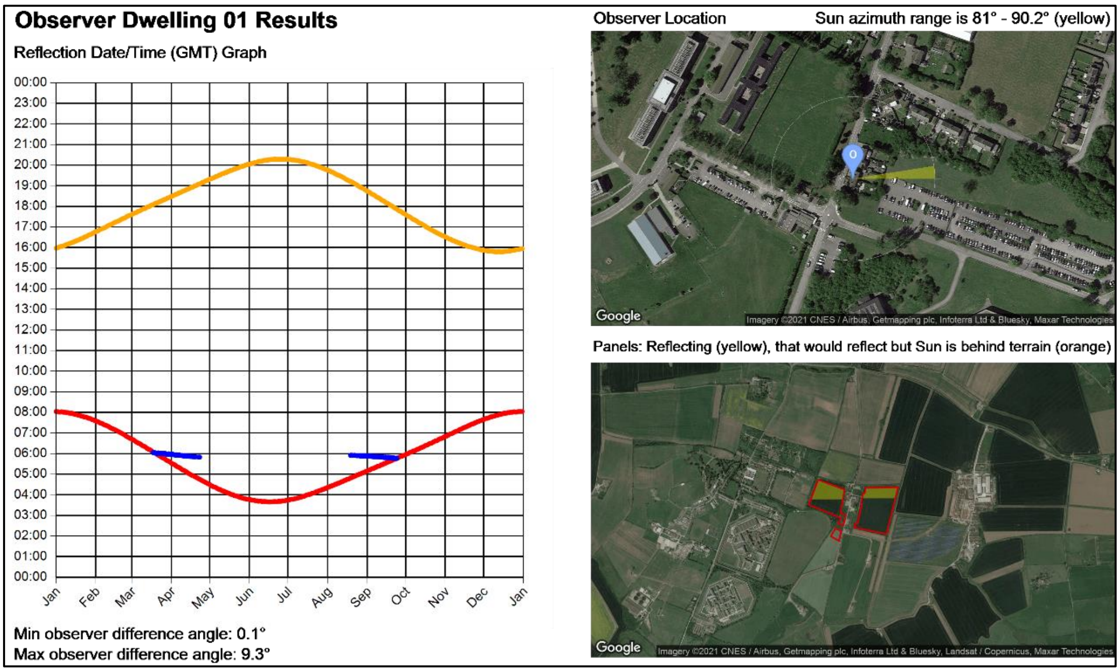
APPENDIX H – GEOMETRIC CALCULATION RESULTS

Overview

The charts for the receptors are shown below and on the following pages. In detail each chart shows:

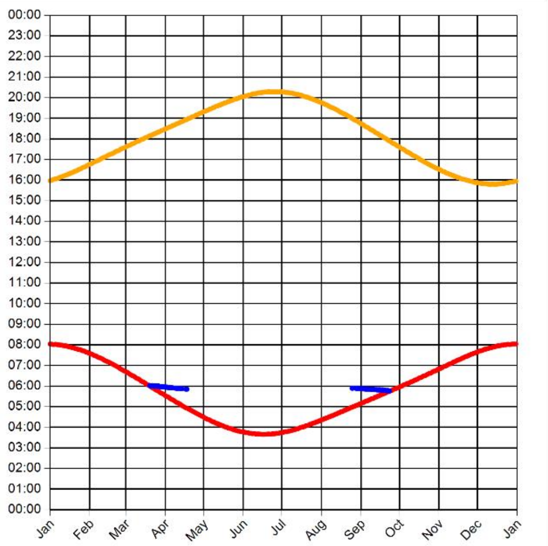
- The receptor (observer) location – top right image. This also shows the azimuth range of the Sun itself at times when reflections are possible. If sunlight is experienced from the same direction as the reflecting panels, the overall impact of the reflection is reduced as discussed within the body of the report;
- The modelled reflectors/ reflection areas – 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 reflector area 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.

Dwelling Receptors



Observer Dwelling 02 Results

Reflection Date/Time (GMT) Graph



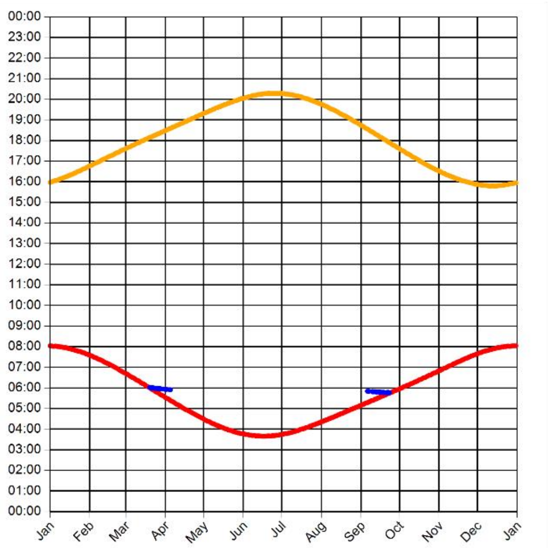
Min observer difference angle: 0.1°
Max observer difference angle: 7.9°

Observer Location — Sun azimuth range is 82.2° - 89.7° (yellow)

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

Observer Dwelling 03 Results

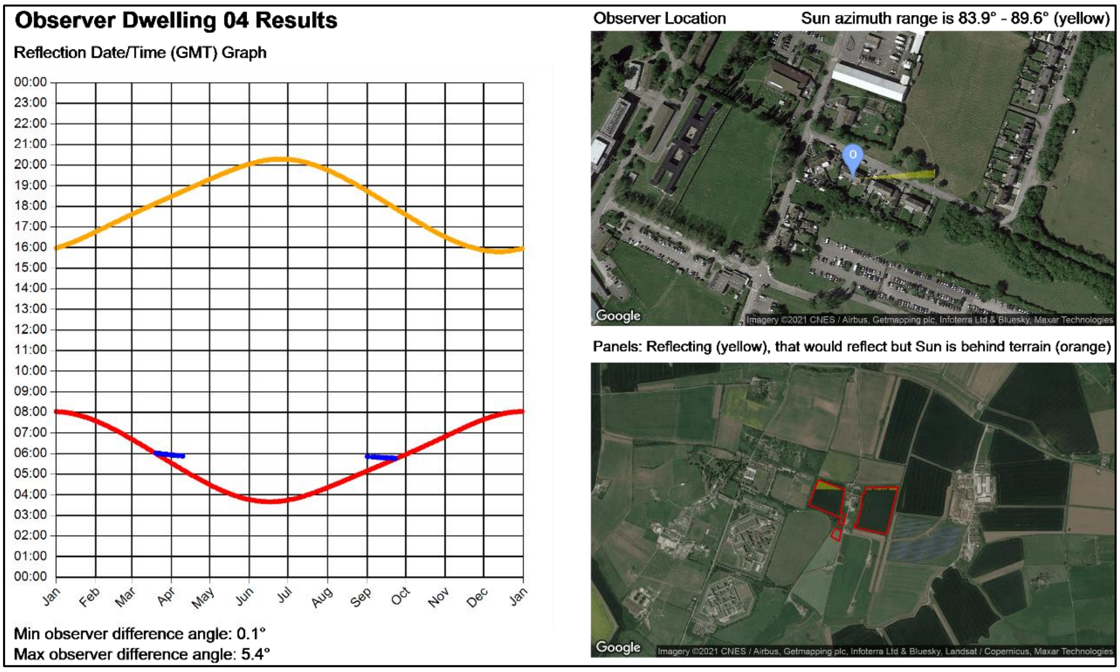
Reflection Date/Time (GMT) Graph

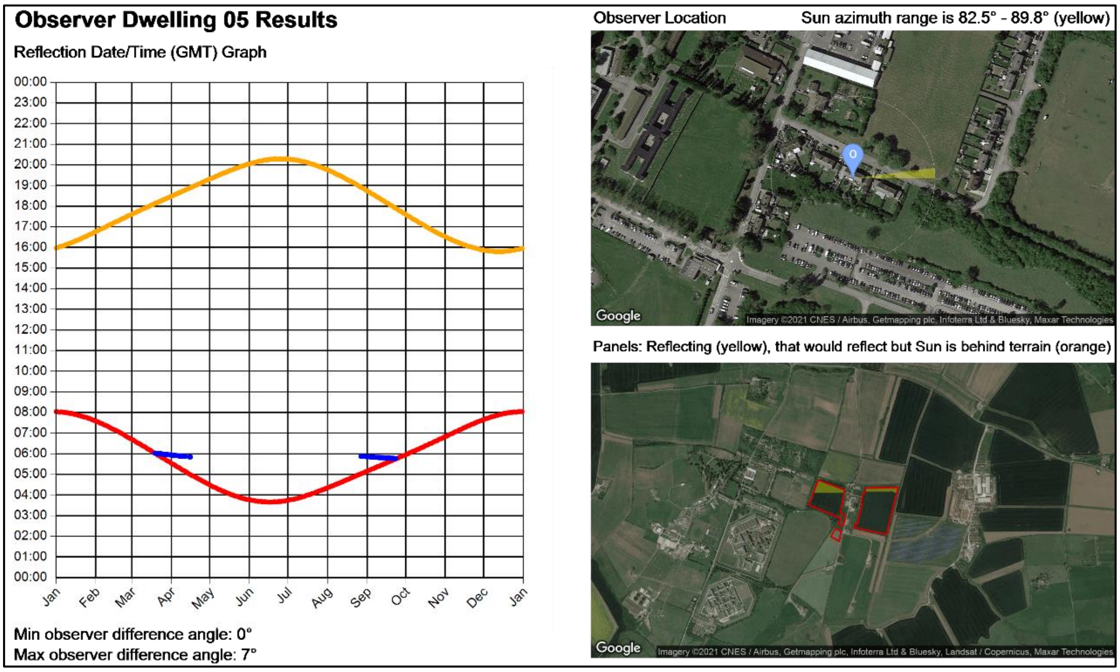


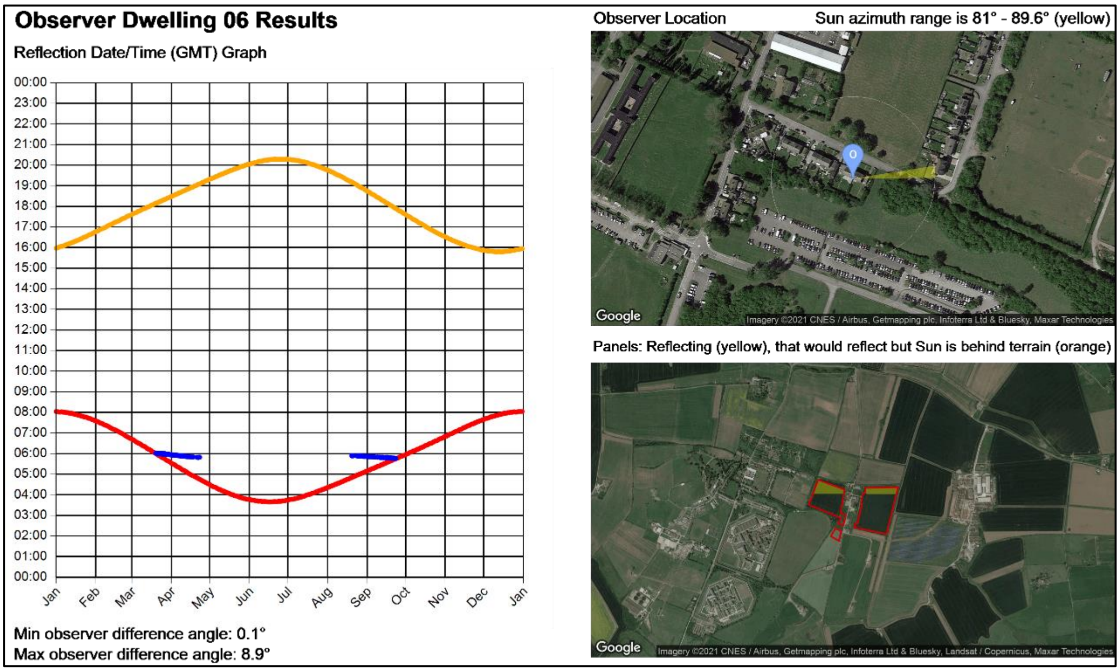
Min observer difference angle: 0°
Max observer difference angle: 4.1°

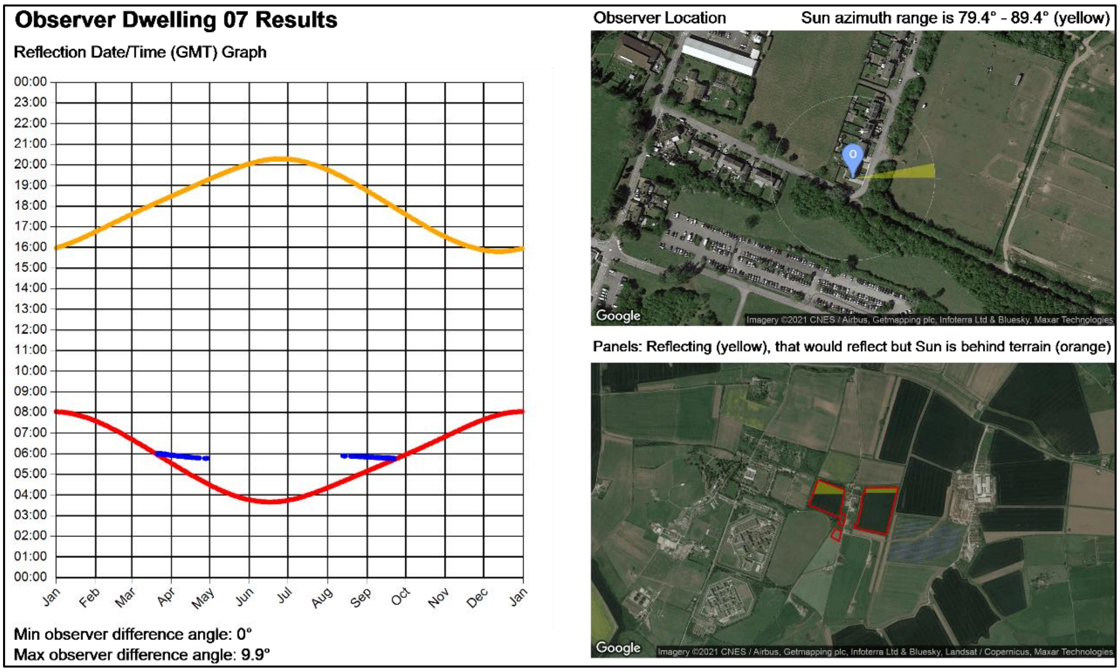
Observer Location — Sun azimuth range is 85.2° - 89.6° (yellow)

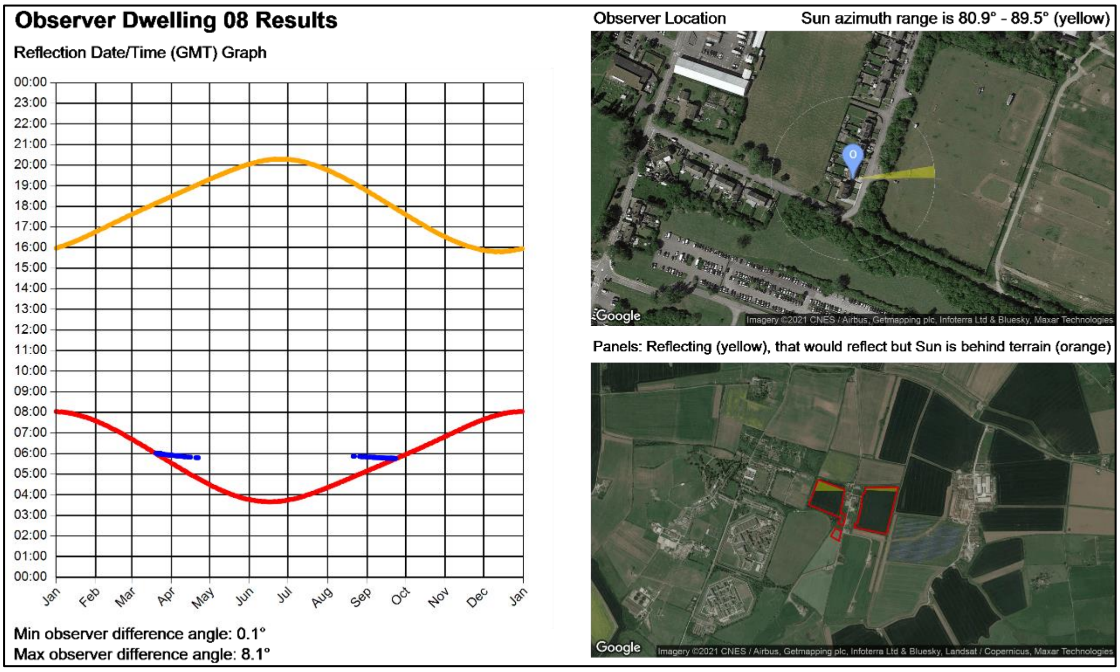
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

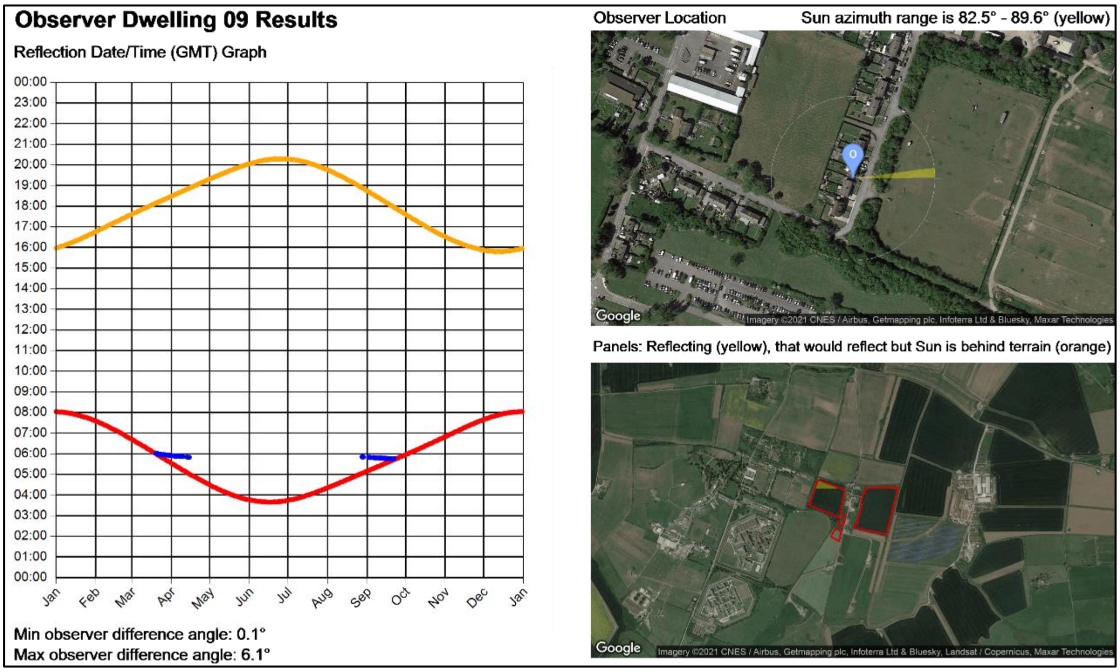

Observer Dwelling 04 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 0.1°
Max observer difference angle: 5.4°
Observer Location
Sun azimuth range is 83.9° - 89.6° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

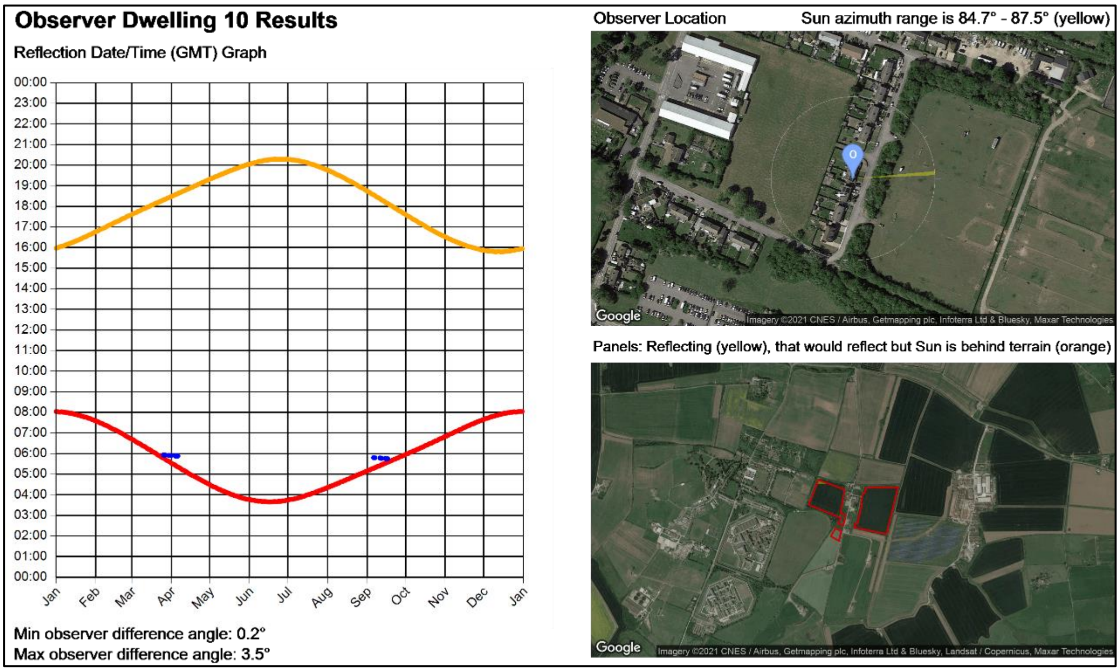

Observer Dwelling 05 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 0°
Max observer difference angle: 7°
Observer Location
Sun azimuth range is 82.5° - 89.8° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

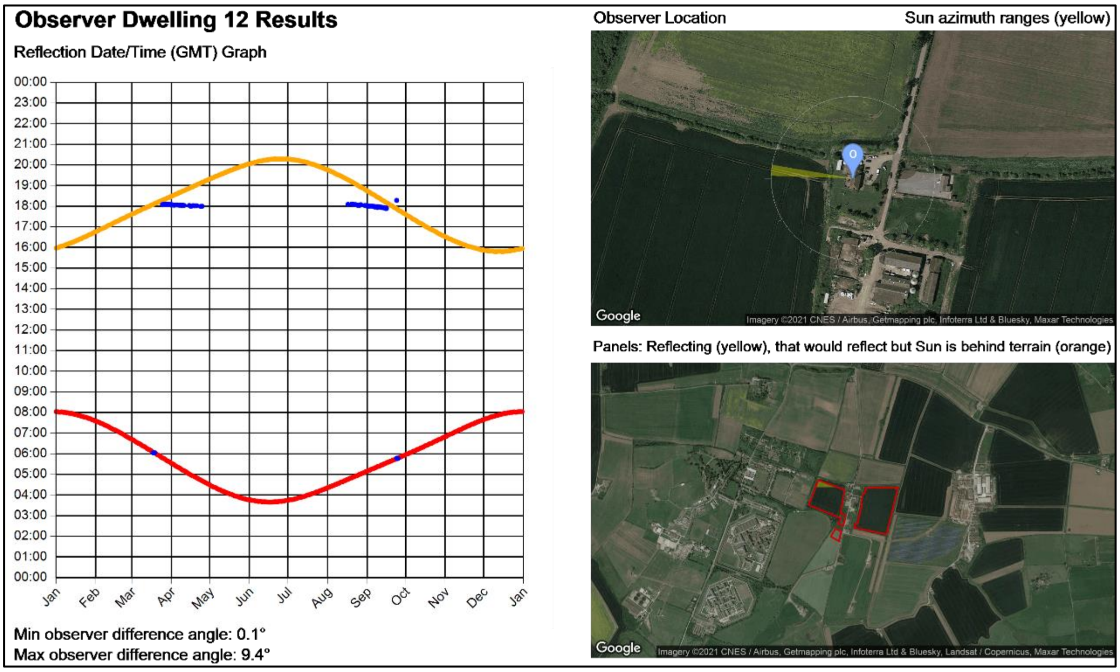

Observer Dwelling 06 Results
Reflection Date/Time (GMT) Graph
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.1°
Max observer difference angle: 8.9°
Observer Location
Sun azimuth range is 81° - 89.6° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer Dwelling 07 Results
Reflection Date/Time (GMT) Graph
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0°
Max observer difference angle: 9.9°
Observer Location
Sun azimuth range is 79.4° - 89.4° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer Dwelling 08 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 0.1°
Max observer difference angle: 8.1°
Observer Location
Sun azimuth range is 80.9° - 89.5° (yellow)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies


Observer Dwelling 09 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 0.1°
Max observer difference angle: 6.1°
Observer Location
Sun azimuth range is 82.5° - 89.6° (yellow)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies


Observer Dwelling 10 Results
Reflection Date/Time (GMT) Graph
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.2°
Max observer difference angle: 3.5°
Observer Location
Sun azimuth range is 84.7° - 87.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)


Observer Dwelling 12 Results
Reflection Date/Time (GMT) Graph
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.1°
Max observer difference angle: 9.4°
Observer Location
Sun azimuth ranges (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

PAGERPOWER

Urban & Renewables

Pager Power Limited
Stour Valley Business Centre
Sudbury
Suffolk
CO10 7GB

Tel: +44 1787 319001 **Email:** info@pagerpower.com **Web:** www.pagerpower.com