David Lloyd Clubs, Northwood

Solar Glare Assessment

Eden Sustainable Group

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Executive Summary

SLR Consulting Limited (SLR) has been engaged by Eden Sustainable Group to carry out an assessment of the reflected glare impacts for the proposed rooftop solar PV installation at David Lloyd Clubs, Northwood.

The project is located in outer northwest London near the corner of the A4180 and Rickmansworth Road. It comprises a 325 kW capacity solar system attached to Buildings 1-3 of the recreation club.

Using the Solar Glare Hazard Analysis Tool (SGHAT), SLR has run a baseline model and found there was the potential for glare leaving an after image for the circulation road and glare with a low potential for an after image at some surrounding observer locations. A supplementary model was run to include surrounding treelines, this model showed that the glare with the potential to leave an after image was eliminated along with most of the other glare conditions. Subsequent investigation of the remaining glare conditions showed that observer locations would be shielded either by Buildings 4 and 5 of the club or by additional existing vegetation.

Overall, it is expected that the proposed solar PV installation will have no glare impact at surrounding observer locations.

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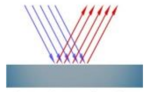
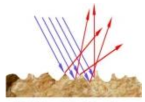
Acronyms and Abbreviations

PV Panel	Photovoltaic (PV) panels are designed to absorb solar energy and retain as much of the solar spectrum as possible in order to produce electricity.
Glare	Glare refers to the reflections of the sun off any reflective surface, experienced as a source of excessive brightness relative to the surrounding diffused lighting. Glare covers reflections: . Which can be experienced by both stationary and moving observers (the latter referred to as “glint”). Which are either specular or diffuse.
Specular	A reflection which is essentially mirror-like – there is virtually no loss of intensity or angle dispersion between the incoming solar ray and outgoing reflection.  Specular Reflection
Diffuse	A reflection in which the outgoing reflected rays are dispersed over a wide (“diffuse”) range of angle compared to the incoming (parallel) solar rays, typical of “rougher” surfaces.  Diffuse Reflection
KVP	Key View Points (KVPs) are offsite locations where receivers of interest have the potential to experience adverse reflective glare.
Glare	Condition of vision in which there is a discomfort or a reduction in the ability to see, or both, caused by an unsuitable distribution or range of luminance, or to extreme contrast in the field of vision. Glare can include: (a) Disability Glare – glare that impairs the visibility of objects without necessarily causing discomfort. Discomfort Glare – glare that causes discomfort without necessarily impairing the visibility of objects.
Threshold Increment (TI)	TI is the measure of disability glare expressed as the percentage increase in contrast required between an object and its background for it to be seen equally well with a source of glare present. Higher TI values correspond to greater disability glare.

1.0 Introduction

SLR Consulting Limited has been engaged by Eden sustainable Group to undertake a reflective glare assessment of the proposed rooftop solar installation at David Lloyd Clubs in Northwood

The project is located off the A4180 near the corner of Rickmansworth Road in the outer northwest of London. It consists of a 325 kW PV solar system attached to the large trapezoidal roofs of the club along with associated components such as inverters and support systems.

1.1 Structure of Report

The remainder of this report is structured as follows:

- Section 2 describes the Project and surrounding environment;
- Section 3 gives some background information regarding reflectivity and glare analysis;
- Section 4 outlines the requirements of the impact assessment; and
- Section 5 presents the analysis and results covering road and residential glare.

2.0 Proposed PV Solar Project

The project is seeking development approval for a 325-kW rooftop solar installation at the location shown in **Figure 1**.

Figure 1 Aerial View of Site

Image: Google Earth

The site is directly surrounded by greenspace to the north, south and west. Beyond this is Mount Vernon hospital to the north and residential dwellings to the east and south. Also worth noting is the Northwood Cricket Club oval to the northeast.

2.1 Site Description and Key Project Components

From a Reflective Glare point of view, the key components of the Project are the photovoltaic (PV) modules in relation to their daytime reflective glare potential.

The proposed roof mounted array (refer **Figure 2**) would consist of fixed tilt system attached to five of the six main roof sections, supporting 505 W monocrystalline solar panels (686 panels in total);

- Panel orientations vary with the directions of the buildings between 137^0 to 145^0 and 317^0 to 321^0 where north is 0^0. Panel tilts match the slope of the roof sections which is 12^0 up from horizontal.
- The maximum height to the top of the panels will be approximately 9.68 metres as shown in Error! Reference source not found..

Figure 2 Panel Layout

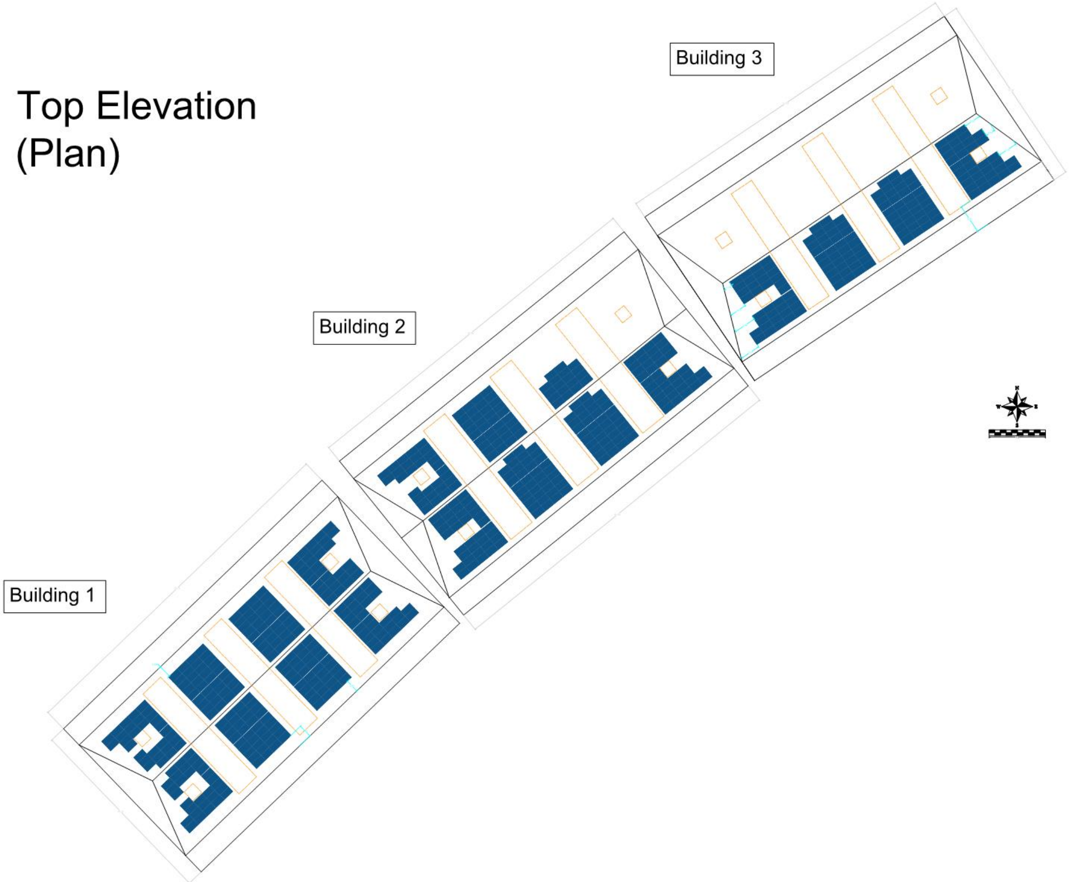
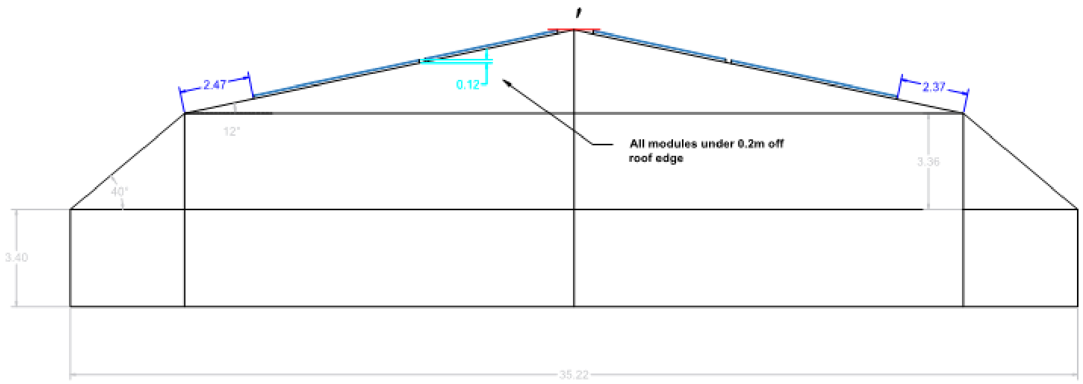


Figure 3 Elevation View



3.0 Background

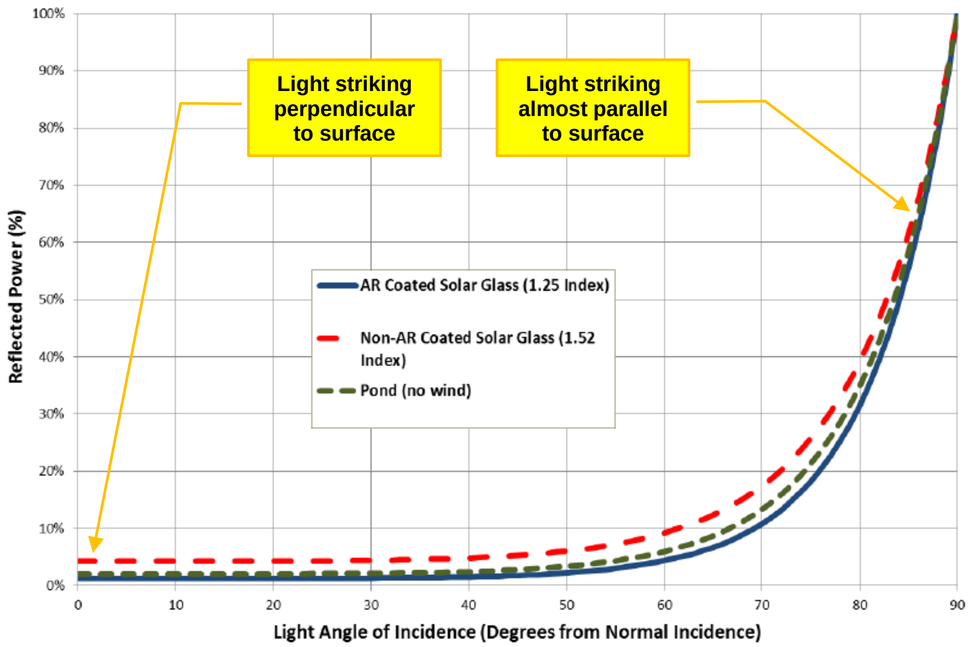
3.1 Solar Panel Reflectivity

Solar PV panels are designed to capture (absorb) the maximum possible amount of light within the layers below the front (external) surface. Consequently, solar PV panels are designed to minimise reflections off the surface of each panel. Reflections are a function of:

- the angle at which the light is incident onto the panel (which will vary depending on the specific location, time of day and day of the year), and
- the index of refraction of the front surface of the panel and associated degree of diffuse (non-directional) versus specular (directional or mirror-like) reflection which is a function of surface texture of the front module (reflecting) surface.

Representative reflectivity curves are shown in **Figure 4**.

Figure 4 Typical Reflectivity Curves as a Function of Incidence Angle



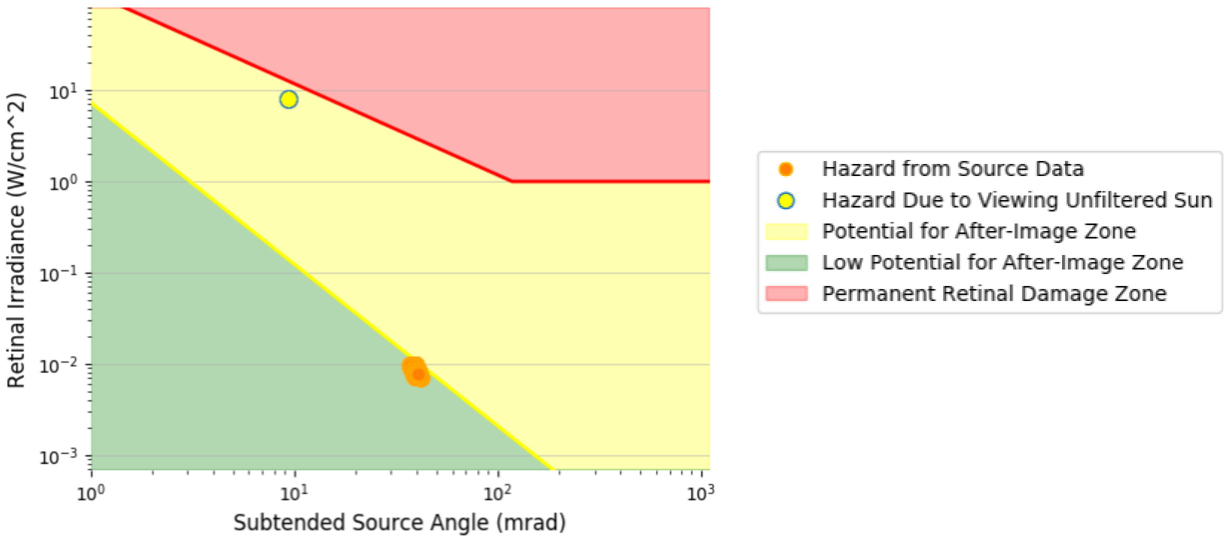
- When an oncoming solar ray strikes the surface of a solar PV panel close to perpendicular to the panel surface (ie low "incident" angle), reflectivity is minimal, less than 5% for all solar panel surface types.
- It is only when an incoming solar ray strikes the panel at large "incidence" angles, ie closer to parallel to the panel, that reflectivity values increase. When this happens, reflections become noticeable and potentially at "glare" level for all solar panel surface types.
- However, for very high incidence angles, it would almost always be the case that the observer (motorist, train driver, resident, etc) would perceive reflections coming from virtually the same direction as the incoming solar rays themselves. Such a condition would not constitute a glare situation as the intensity of the incoming solar ray itself would dominate the field of vision perceived by the observer.

3.2 Modelling Outputs

The SGHAT modelling provides output in the form of an ocular hazard analysis plot, a sample of this is shown in **Figure 5**.

The analysis contained in this plot is derived from solar simulations that extend over the entire calendar year in 1-minute intervals, sunrise to sunset.

Figure 5 Example Solar Glare Ocular Hazard Plot (SGHAT Software Output)



The following is noted regarding the figure above:

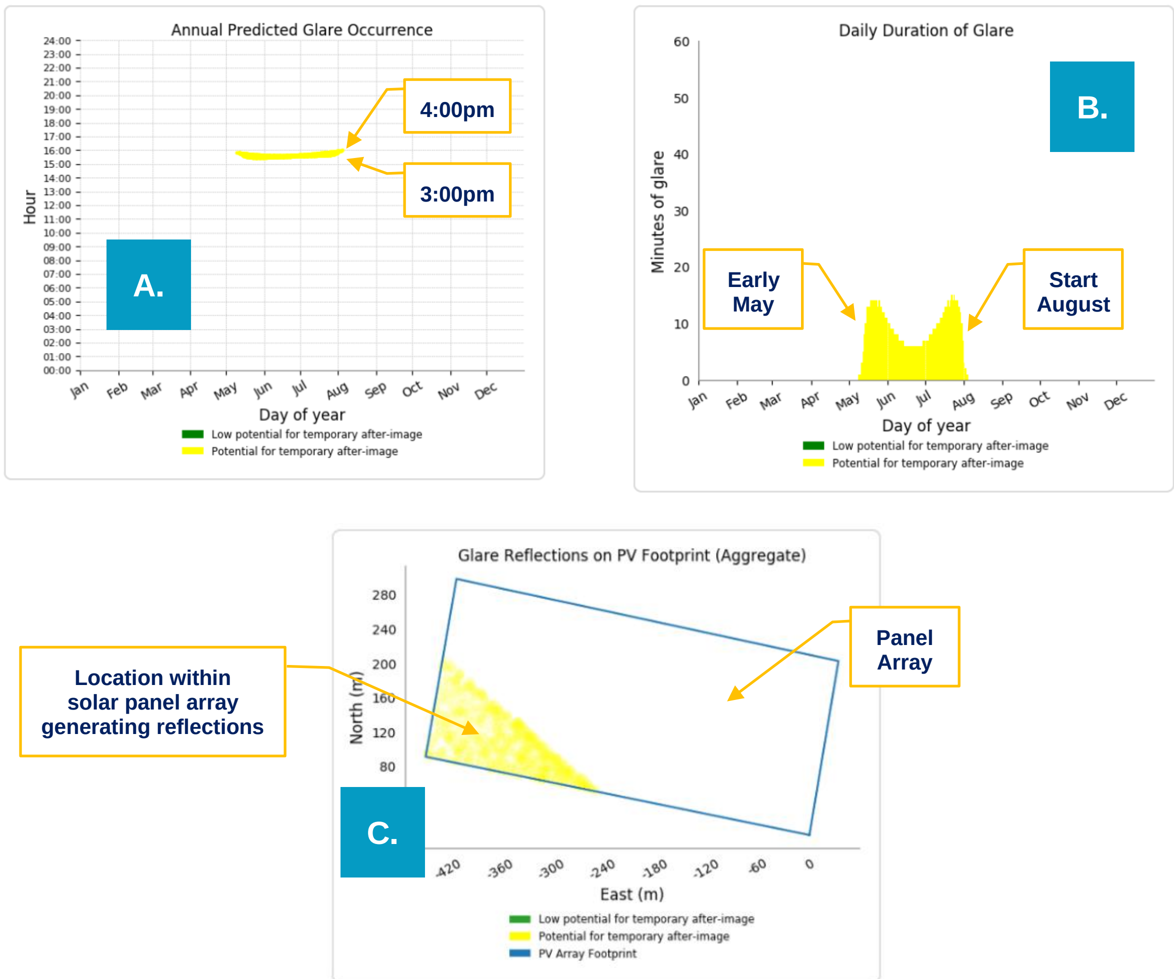
- SGHAT ocular impact is a function of both the "retinal irradiance" (ie the light seen by the eye) and "subtended source angle" (ie how wide an arc of view the light appears to be arriving from).
- SGHAT ocular impact falls into three categories:
  - . GREEN: low potential to cause "after-image"
  - . YELLOW: potential to cause temporary "after-image"
  - . RED: potential to cause retinal burn (permanent eye damage)
- "After Image" is the term applied to a common retinal phenomenon that most people have experienced at some point or other, such as the effect that occurs when a photo with flash is taken in front of a person who then sees spots in front of their eyes for a few seconds. A more extreme example of "after-image" occurs when staring at the sun. "After-image" (also known as "photo bleaching") occurs because of the de-activation of the cells at the back of the eye's retina when subjected to a very bright light.
- The SGHAT plot provides an indication of the relative intensity of both the incoming reflection and the sources of light itself (ie the sun).
  - . The occurrence of glare is shown in the plot as a series of **orange circles**, one circle for each minute that a reflection is visible.
  - . A reference point is also shown in each SGHAT plot, the **yellow circle** with the **green outline**, representing the hazard level of viewing the sun without filtering, ie staring at the sun.
- In **Figure 5**, it can be seen that the reflection visible by the receiver is roughly 1,000 times less intense than the light from the sun.

- Finally, in relation to PV Solar facilities, it is important to note that the third SGHAT Ocular Plot "RED" category is not possible, since standard PV modules do not focus reflected sunlight.

In addition to the above "assessment" output, the SGHAT software package also produces information which reveals the extent of visibility of reflections at any chosen receiver position, regardless of whether the reflections constitute a glare condition or not.

- **Figure 6-A**: shows the am/pm time periods when reflections occur at a specific position throughout the year, in this case typically between around 3:30 pm and 4:00 pm.
- **Figure 6-B**: shows the months during the year and the minutes per day when reflections occur at a specific position, in this case from early-May to the start of August, for periods ranging up to 13 minutes per day.
- As noted above, this information is made possible because the SGHAT analysis covers the entire solar annual cycle in 1-minute intervals to ascertain any potential impacts on surrounding receivers.
- Finally, **Figure 6-C** shows where within the solar panel array the reflection rays of interest are emanating from, in this case from panels near the southwest corner.

Figure 6 Example Solar Glare Output Plots (SGHAT Software Output)



3.3 Project Site Angles – Annual Variations

One of the challenging issues encountered with daytime solar panel glare is the varying nature of the reflections, whose duration will vary with time of day and day of the year as the sun's rays follow variable incoming angles between the two extremes of:

- summer solstice – sunrise incoming rays from just north of east, maximum angle altitude rays at midday, sunset incoming rays from just north of west.
- winter solstice – sunrise incoming rays from the southeast, minimum angle altitude rays at midday, sunset incoming rays from the southwest.

Any solar glare analysis must take into account the complete cycle of annual reflection variations noted above.

4.0 Requirements

The Department for Communities and Local Government states in the Planning Practice Guidance for Renewable and Low Carbon Energy that "the effect on landscape of glint and glare and on neighbouring uses and aircraft safety" should be considered. With this in mind the impact level of the modelling results needs to be determined. At SLR we typically use the New South Wales Large Scale Solar Energy Guideline which gives a minute value for each of its defined impact levels enabling interpretation of the SGHAT results. An extract from the NSW guideline is shown below and it should be noted that these requirements were created to apply to residential dwellings but will also be applied to vehicle users.

Figure 7 Extract form NSW Large-Scale Solar Energy Guideline

Table 2: Impact rating and performance objectives for glare impacts to residential dwellings

High glare impact	Moderate glare impact	Low glare impact
> 30 minutes per day > 30 hours per year	< 30 minutes & > 10 minutes per day < 30 hours & > 10 hours per year	< 10 minutes per day < 10 hours per year
Significant amount of glare that should be avoided.	Implement mitigation measures to reduce impacts as far as practicable.	No mitigation required.

5.0 Glare Impacts

5.1 Modelling Inputs

As shown in **Figure 8** the arrays were modelled on the roof sections. For simplicity the arrays were conservatively modelled as covering the whole of the roof sections rather than each individual section. Nearby roadways were included along with 15 surround viewer locations including the hospital, cricket ground, tennis courts and representative dwelling along the A4180. In the case of 2-storey dwellings the upper floor height of 4.5 metres above ground was used as this represents a worst case, for the ground level 1.5 metres was used. Two heights were used to model the arrays. A “low” version at 7.54 metres and a “high” version at 9.32 metres to capture the range of the array.

Figure 8 Modelled Arrays

Figure 9 Receiver Locations

5.2 Motorist Disability Glare

The roadways used for the analysis in the immediate vicinity of the Project are listed below:

- The club entry road
- Club car park circulation road

Other nearby roads were not included as they will either be shielded by vegetation or buildings.

The “low” model resulted in 403 minutes of glare with the potential for an after image (SGHAT yellow zone) along the circulation road and none for the entry road. The “high” model resulted in no glare with the potential for an after image for either roadway. Once treelines are other obstructions were included in the model all glare with the potential for an after image was eliminated for the roadways.

5.3 Residential Observer Glare

As stated, 15 representative receiver locations were included in the model. For both the “low” and “high” model there was no glare with the potential for an after image predicted at any of these locations.

With **no treelines** or obstacles included, potential SGHAT green zone glare was found for locations 1-3 and 5-10. Typically, this is excluded as green zone glare is deemed “allowable” for pilots during landing but due to the presence of areas such as the cricket pitch and tennis courts where this could be distracting it has been investigated further.

Firstly, the cricket pitch (Location 4) does not experience any glare from the proposed arrays.

Additional modelling was then undertaken to include the surround vegetation and other obstacles. This eliminated all glare conditions at locations 1-3, 5-7 and 10. This left observer location 8 at 20 Cygnet Close, Northwood and observer location 9 on the tennis court. Further investigation of the aerial views found additional vegetation which will prevent any views of the southeast facing roof sections from location 8. Similarly, a closer investigation of the tennis courts shows that the arrays will be shielded from view by Buildings 4 and 5 of the club along with the various treelines.

5.4 Mitigating Factors

The SGHAT model assumes sunny days all year round. Terrain and other natural obstacles are not considered by the software, this tends to lead to an overestimation of the actual total minutes of glare experienced at any particular site.

5.4.1 Weather

For London the sky is either overcast or mostly cloudy at least 42% of the time during summer months and up to 73% of the time during winter. this means that the total minutes of duration for any potential glare conditions can be reduced by this factor results in lower impacts.

5.4.2 High Incidence Reflections

Some of the reflection conditions occur at times when the incidence angle is very high. In these circumstances an observer would perceive the reflections coming from virtually the same direction as the direct incoming solar rays.

When the angle difference between incoming direct solar rays and their associated reflections are small (i.e. less than 10°), such reflections are not considered to be “glare”, as the brightness of the direct solar rays would be significantly higher than the reflection’s brightness and dominate an observer's field of view.

6.0 Conclusion

SLR has conducted a glare modelling exercise for the proposed rooftop solar arrays. Initial modelling showed the potential for glare at some surrounding locations. Further modelling and aerial inspection of the site showed that there would be no glare impact at the surrounding modelled locations due various treelines, buildings and other intervening obstacles.

7.0 References

For London's weather:

https://weatherspark.com/y/45061/Average-Weather-in-City-of-London-United-Kingdom-Year-Round

The weather stations contributing to this reconstruction are:

- London Weather Centre (EGRB, 89%, 2.3 km, southwest, 12 m elevation change)
- London City Airport (EGLC, 11%, 10 km, east, -22 m elevation change)

All other weather data, including cloud cover, precipitation, wind speed and direction, and solar flux, come from NASA's MERRA-2 Modern-Era Retrospective Analysis. This reanalysis combines a variety of wide-area measurements in a state-of-the-art global meteorological model to reconstruct the hourly history of weather throughout the world on a 50-kilometer grid.

Weather Spark gives the following caveats:

"We draw particular cautious attention to our reliance on the MERRA-2 model-based reconstructions for a number of important data series. While having the tremendous advantages of temporal and spatial completeness, these reconstructions: (1) are based on computer models that may have model-based errors, (2) are coarsely sampled on a 50 km grid and are therefore unable to reconstruct the local variations of many microclimates, and (3) have particular difficulty with the weather in some coastal areas, especially small islands."

Appendix A   Modelling Inputs

David Lloyd Clubs, Northwood

Solar Glare Assessment

Eden Sustainable Group

SLR Project No.: 403.065087.00001

15 September 2023

SLR SGHAT Input Data File

SLR Project No	**640.030886.00001**
Project Name	**Northwood Solar Glare**
SF Capacity	**325 kW**
Total No of Panels	**686**

Panel Manufacturer Model	**JAM66S30-505/MR**
Panel Type	**Monocrystalline**
Panel Coating	**Smooth Glass WITHOUT AR Coating**
Panel Power	**505 Wp**
Panel Dimensions	**2,093 mm x 1,134 mm**

Mounting Type	**Fixed Tilt**
Array Type	**Roof Mounted**
Panel Orientation	**Varies**
Panel Height	**N/A**
Tilt Angle	**12°**
Tracking Angle	**N/A**
Panel MAXIMUM Height	**9.68 m**
"LOW" Assessment Height	**7.54**
"HIGH" Assessment Height	**9.32**

Receiver Assessment Heights (AGL)

Aircraft - Height above Threshold	**N/A**
Roads - Cars	**1.5 m**
Roads - Medium	**N/A**
Roads - Trucks	**N/A**
Rail	**N/A**
Houses - Ground Floor	**1.5 m**
Houses - First Floor	**4.5 m**

Appendix B SGHAT Baseline Results

David Lloyd Clubs, Northwood

Solar Glare Assessment

Eden Sustainable Group

SLR Project No.: 403.065087.00001

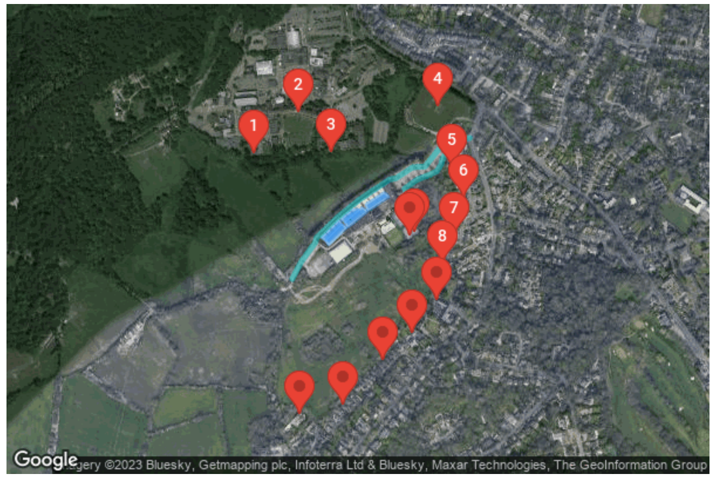
15 September 2023

FORGESOLAR GLARE ANALYSIS

Project: **David Lloyd Northwood**
Site configuration: **Base Low**

Created 31 Aug, 2023
Updated 31 Aug, 2023
Time-step 1 minute
Timezone offset UTC0
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 100 to 500 kW
(1,000 kW / 32,400 m^2 limit)
Site ID 99231.17294

Ocular transmission coefficient 0.5
Pupil diameter 0.002 m
Eye focal length 0.017 m
Sun subtended angle 9.3 mrad
PV analysis methodology V2



Summary of Results

Glare with potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
Building 1 North	12.0	317.0	6,650	110.8	403	6.7	-
Building 1 South	12.0	137.0	8,993	149.9	0	0.0	-
Building 2 North	12.0	321.0	5,616	93.6	0	0.0	-
Building 2 South	12.0	141.0	10,706	178.4	0	0.0	-
Building 3 South	12.0	147.0	2,598	43.3	0	0.0	-

Total glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Circulation Road	2,585	43.1	403	6.7
Entry Road	995	16.6	0	0.0
OP 1	2,437	40.6	0	0.0
OP 2	2,975	49.6	0	0.0
OP 3	4,857	81.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	855	14.2	0	0.0
OP 6	2,219	37.0	0	0.0
OP 7	4,999	83.3	0	0.0
OP 8	2,206	36.8	0	0.0
OP 9	5,301	88.3	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 10	5,134	85.6	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0
OP 15	0	0.0	0	0.0

Appendix C SGHAT Results Including Major Treelines

David Lloyd Clubs, Northwood

Solar Glare Assessment

Eden Sustainable Group

SLR Project No.: 403.065087.00001

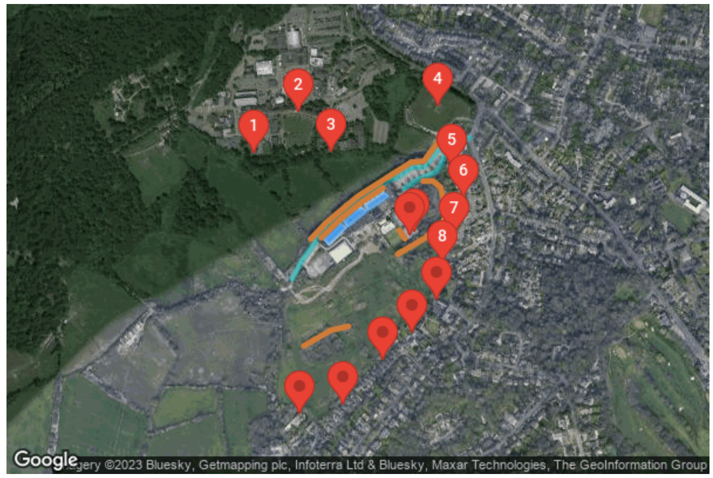
15 September 2023

FORGESOLAR GLARE ANALYSIS

Project: **David Lloyd Northwood**
Site configuration: **Low with obstacles**

Created 31 Aug, 2023
Updated 01 Sep, 2023
Time-step 1 minute
Timezone offset UTC0
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 100 to 500 kW
(1,000 kW / 32,400 m^2 limit)
Site ID 99235.17294

Ocular transmission coefficient 0.5
Pupil diameter 0.002 m
Eye focal length 0.017 m
Sun subtended angle 9.3 mrad
PV analysis methodology V2



Summary of Results

Glare with low potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
Building 1 North	12.0	317.0	54	0.9	0	0.0	-
Building 1 South	12.0	137.0	880	14.7	0	0.0	-
Building 2 North	12.0	321.0	0	0.0	0	0.0	-
Building 2 South	12.0	141.0	3,233	53.9	0	0.0	-
Building 3 South	12.0	147.0	319	5.3	0	0.0	-

Total glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Circulation Road	619	10.3	0	0.0
Entry Road	444	7.4	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	438	7.3	0	0.0
OP 9	2,985	49.8	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0
OP 15	0	0.0	0	0.0

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