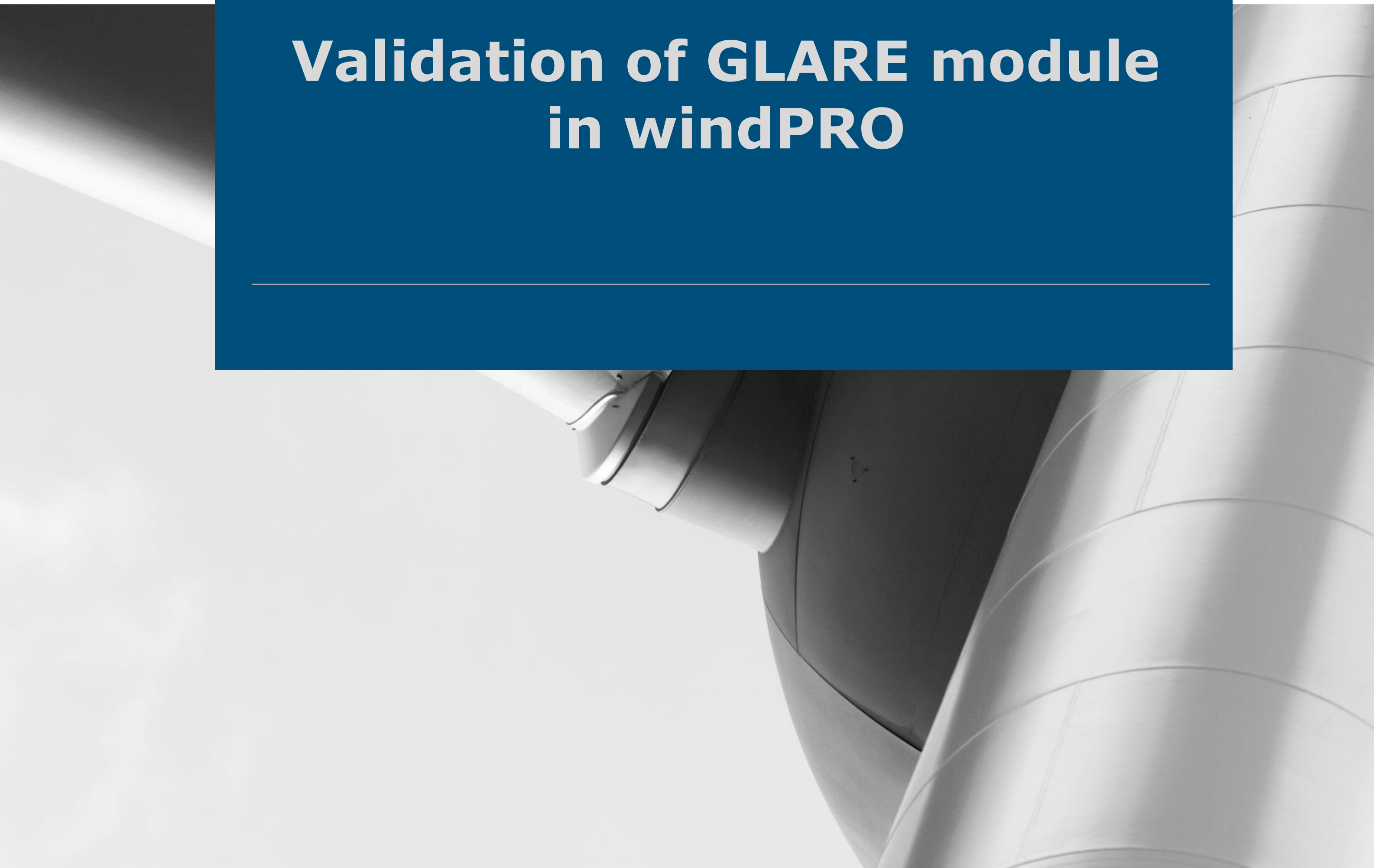
Technical Note:

Validation of GLARE module in windPRO



DATE

18 April 2023

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1.1

Contents

Executive Summary

This technical note presents the validation of the GLARE module in windPRO. It was performed with the use of results obtained using similar tools as well as real-world recorded glare observations. The validation was performed based on four different windPRO projects in multiple locations:

1. Manchester-Boston regional airport – report prepared with another tool.
2. PV installation in Wales – report prepared with another tool.
3. Building window in South Denmark – real observations.
4. Office window in North Denmark – real observations.

For all locations, the details of the projects and settings are described in this document in the corresponding chapters. The projects in windPRO are created to reflect in the best possible way the settings used in other tools or the conditions under which glare was observed. This applies to the location of both reflectors and receptors.

The comparison of the results obtained with the GLARE module in windPRO with real observations and results presented in other reports proves that the GLARE module calculates glare occurrence accurately from Solar PV panels or reflecting windows (3D objects).

As an example, for real observations recorded over one day the difference in the glare duration between the observation and the GLARE module calculation was only 4 min. Considering the total glare duration that day of 2h 12min, this discrepancy is well within the range of uncertainty.

Intended Use

This Technical Note is provided as a courtesy to existing and potential windPRO software users**.** Any reference to the information, results and conclusions contained in this Technical Note is only allowed provided that the name of the Technical Note and the author(s), EMD International A/S are referenced. Other use of the information requires the written permission of EMD International A/S.

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1 Manchester-Boston Regional Airport in USA

1.1 The Test Project

This test project analyzes glare from a PV installation on the roof of a parking garage near the air traffic control tower.

The aim of this project is to compare the calculations performed with the GLARE module in windPRO with the calculations performed using the Solar Glare Hazard Analysis Tool (SGHAT), which is the basis of commercial Forge Solar software [1]. The calculations using SGHAT are summarized in the user manual of the tool as a case study and example [2].

The locations of PV plant and the receptor in windPRO and SGHAT software used in this comparison are shown in Figure 1 and Figure 2 respectively.

Figure 1 Configuration of the PV plant and glare receptor in the windPRO project, the receptor is marked in yellow, left to the PV solar area (in green). Map Source: OpenStreetMap.

Figure 2 Configuration of the PV plant and glare receptor in SGHAT Tool, the receptor analysed in this comparison marked in red [2]. Map Source: Google Maps.

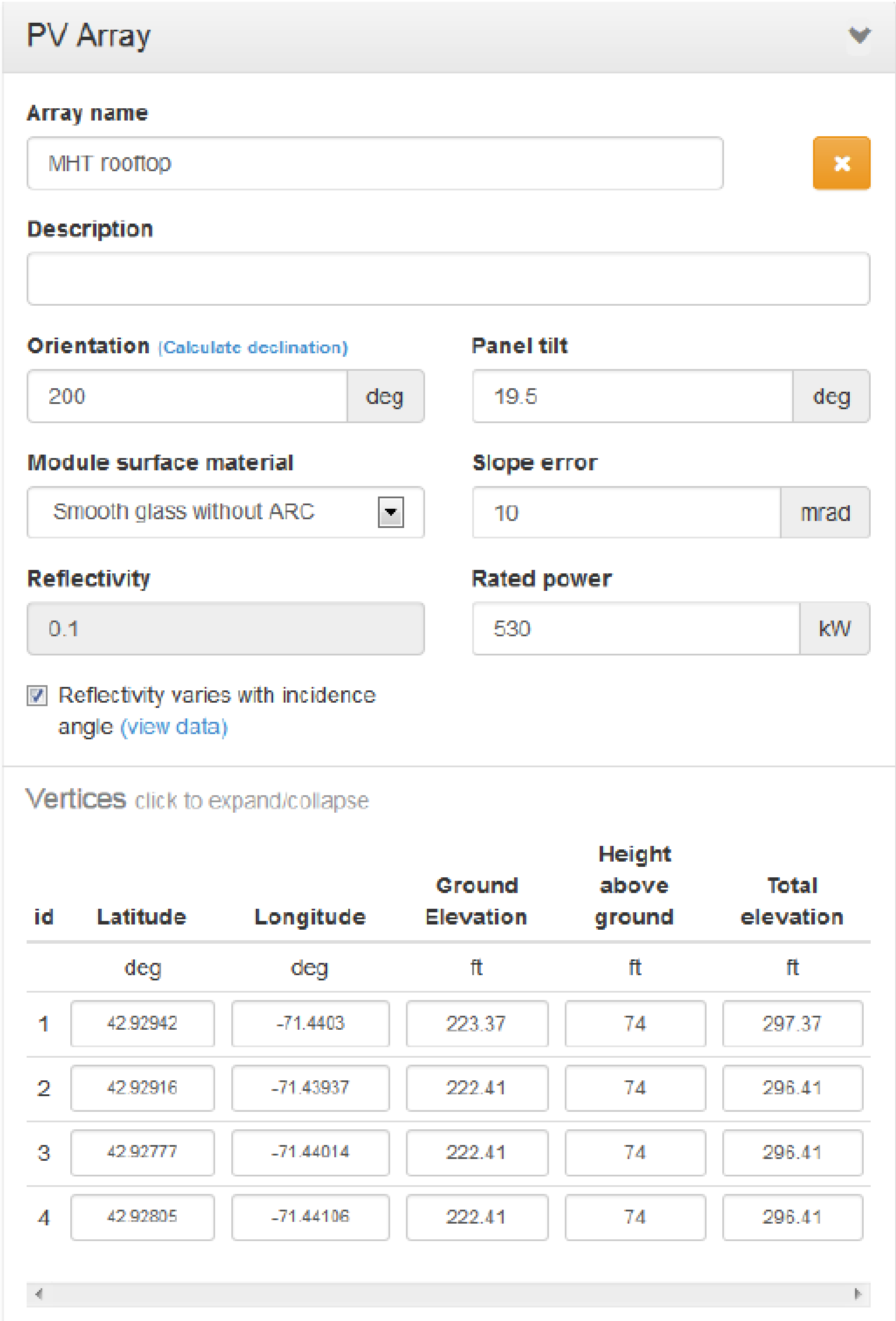

Figure 3 PV array input parameters used in SGHAT for glare analysis [2]

The settings of the PV plant in SGHAT are summarized in Figure 3. The same settings for PV orientation, tilt, module surface material and plant elevation were used in windPRO. Plant elevation in windPRO was considered by modifying the elevation data under the PV plant to have the elevation of 90.5 m (approx. 297 feet amsl). The total power varies slightly as no detail about the exact configuration of the panels was provided in [2] . The row spacing, table configuration, etc. are based on the plant photos provided. The settings of the PV plant and reflectivity in windPRO are shown in Figure 4 and Figure 5 respectively.

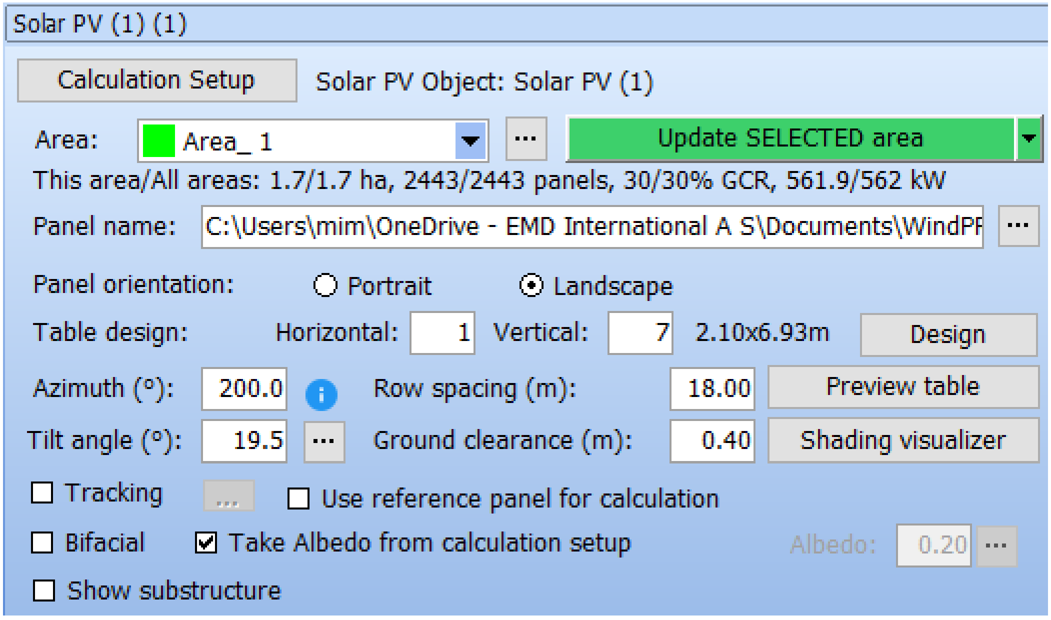

Figure 4 PV plant array parameters used in windPRO for glare analysis

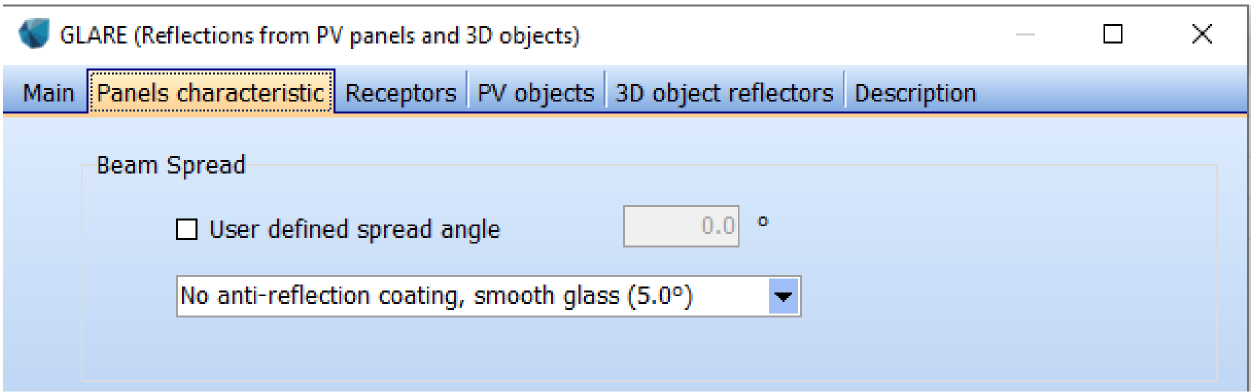

Figure 5 Panel beam spread setting in windPRO for glare analysis.

The exact receptor location (in the control tower position) used in SGHAT software is shown in Figure 6. The exact same position and height above ground was used in windPRO, as shown in Figure 7.

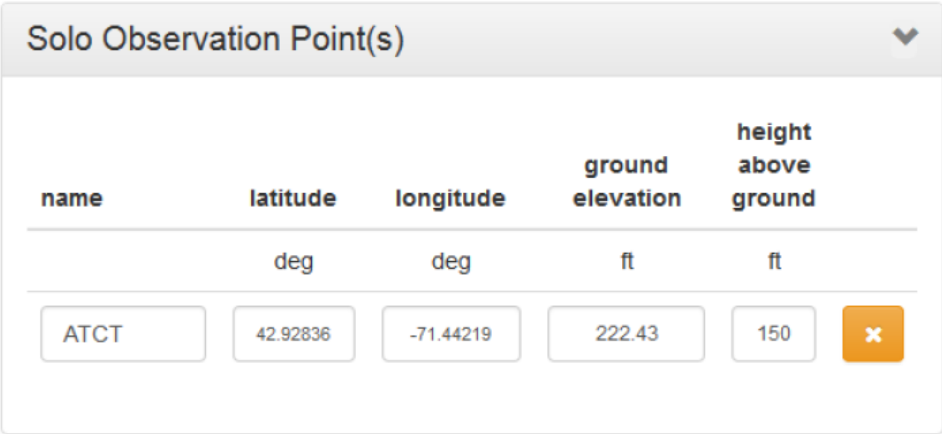

Figure 6 Control tower glare receptor position in SGHAT

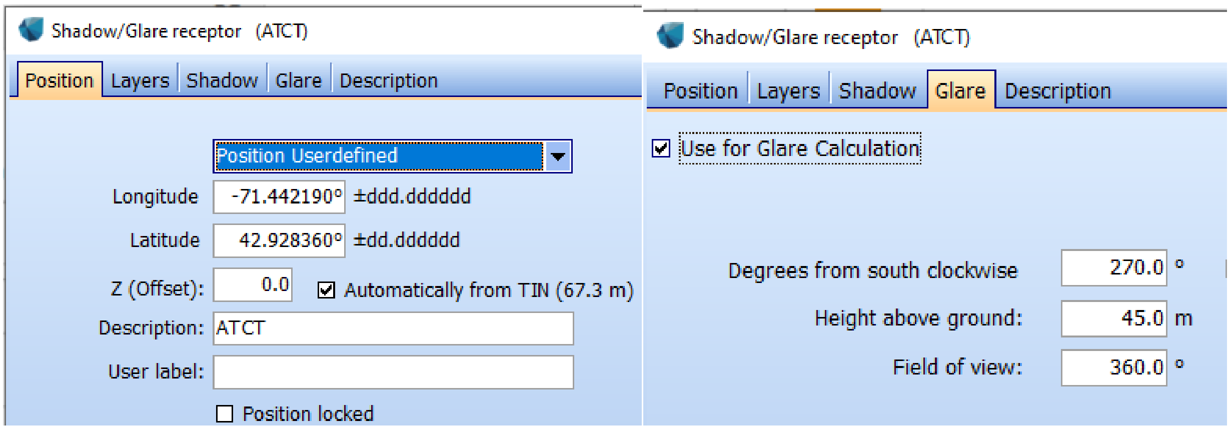

Figure 7 Receptor position and height above the ground of the glare receptor used in windPRO

1.2 Results

In this section, the comparison of results obtained using the two methods is shown. The evaluation is focused solely on glare occurrence calculation.

1.2.1 GLARE in windPRO results

For the setup described in the Section 1.1, the results of glare occurrence calculation using windPRO are summarized in Table 1 and a graph with glare time over the year is shown in Figure 8. Glare can be observed between 27th of January and 17th of November. The daily glare duration is around 40 min with maximum daily duration on 4th of November – 42 min. Glare will be visible approx. between 07:00 and 08:30 - daylight-saving time is considered.

Table 1 Glare occurrence calculation summary - windPRO

No.	Name	Total time with glare in a year [h/year]	Maximum daily glare duration [min/day]	Day with max glare duration [Date]
1	ATCT	173.3	42	4th November 07.41-08.23

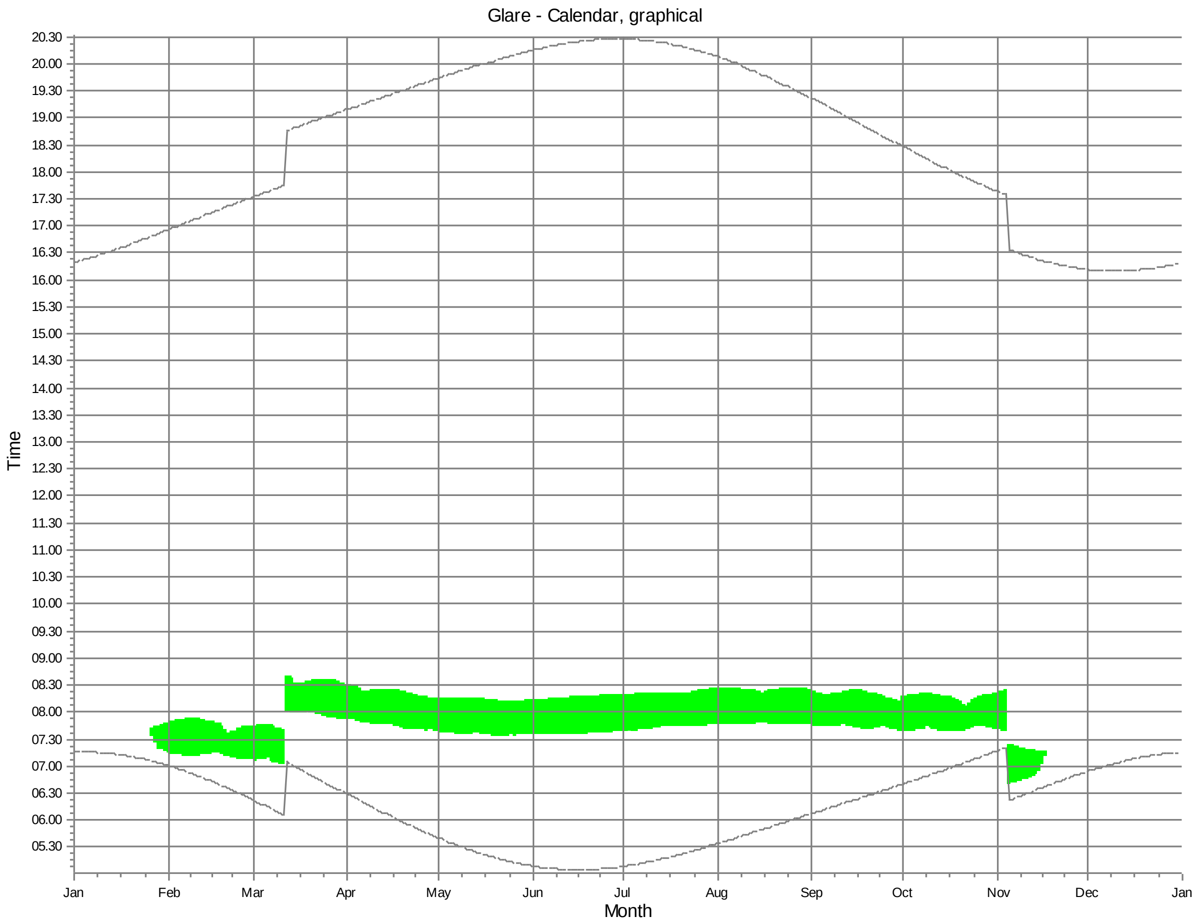

Figure 8 Glare occurrence times over the year calculated with GLARE module in windPRO

1.2.2 SGHAT software results

For the setup described in Section 1.1, the results of glare occurrence calculation using SGHAT are shown in Figure 9. Glare can be observed between the end of January and middle of November and the daily glare duration is below 1h. Glare will be visible between 7 and 8 am, however, the graph does not account for daylight-saving time in this location.

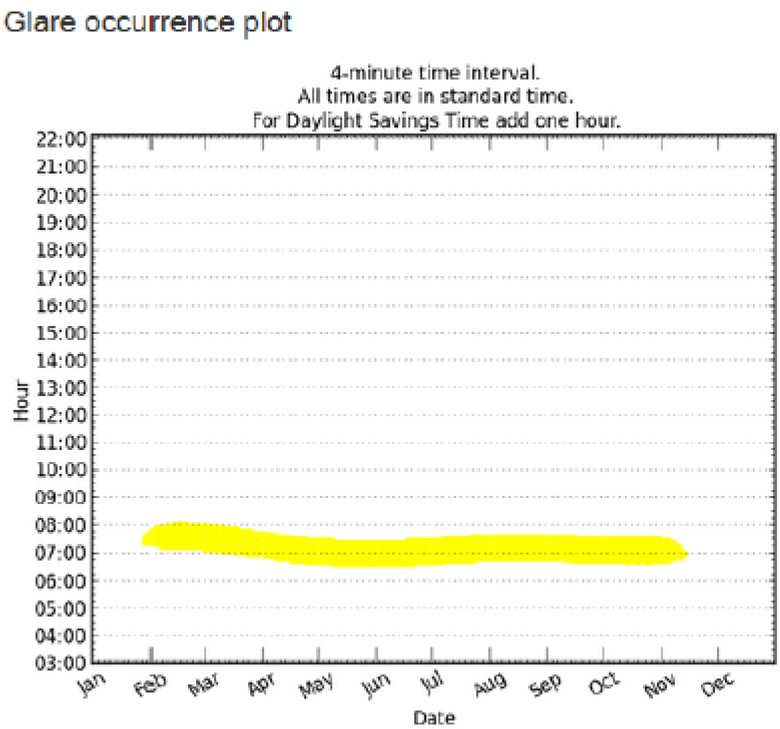

Figure 9 Glare occurrence plot for the control tower receptor calculated with SGHAT

No details about the exact start and stop time of glare are provided in the SGHAT case study.

1.3 Conclusions from comparison

The glare is predicted by the GLARE module and SGHAT tool to be present at similar times throughout the year. The start and stop times of glare throughout the year are consistent between the two calculation methods. From comparison of Figure 8 and Figure 9 the conclusion could be that the SGHAT tool estimates glare to last slightly longer throughout the day, however the exact time duration is not specified in the case study description.

Considering the accuracy of inputs to both calculations, one of the main reasons for discrepancies in the results could be the lack of exact panel location information. Another possibility is the difference in time interval for which the calculations are done – the SGHAT tool performs glare calculations with 4-minute resolution, whereas the GLARE module in windPRO by default performs the calculations with 1-minute resolution.

2 PV installation in Connah's Quay, Wales, UK

2.1 The Test Project

This test project analyzes glare from a PV installation in a residential area in north Wales, UK.

The aim of this project is to compare the calculations performed with the GLARE module in windPRO with the calculations performed by Pager Power as a glare assessment requested for this location – summarized in [3]. Pager Power use their own model which is based on the methodology of the SGHAT tool.

The configuration of the plant and location of the analyzed receptors in windPRO are shown in Figure 10. The plant area configuration together with the panel layout used in the Pager Power report are shown in Figure 11. The exact locations of the receptors from the Pager Power report are shown in Table 2. The positions used in windPRO for the three receptors are shown in Figure 12, Figure 13 and Figure 14. Different terrain height datasets are used in windPRO and Pager Power report. Since there was no detailed information about the terrain height in the PV plant location in the Pager Power report, it is assumed that the relative positions of the receptors and PV plant are the same using both terrain height data.

Figure 10 Configuration of the glare receptors and PV plant in the test project – windPRO. Map Source: OpenStreetMap.

Figure 11 PV plant configuration specified in Pager Power report [3]

Table 2 Exact analysed receptor locations

ID	Longitude (°)	Latitude (°)	Observer height (agl)	Overall height (amsl)
42	-3.049472	53.219831	1.5m	2.83
43	-3.049193	53.219413		3.28
44	-3.048915	53.218996		3.50

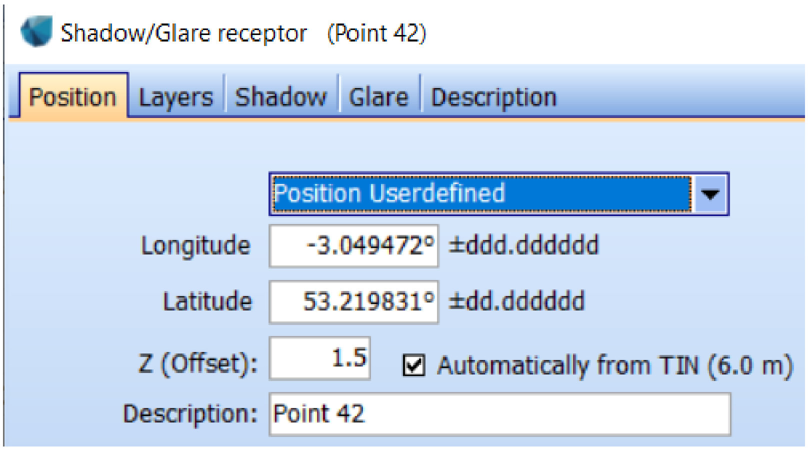

Figure 12 Exact position of receptor with ID 42 in windPRO

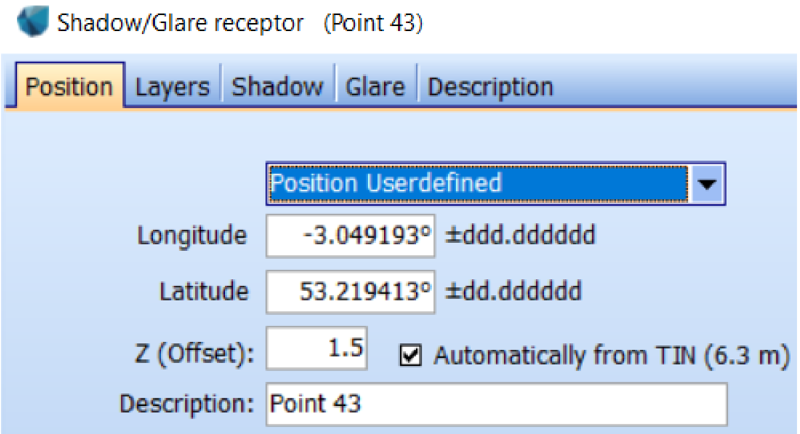

Figure 13 Exact position of receptor with ID 43 in windPRO

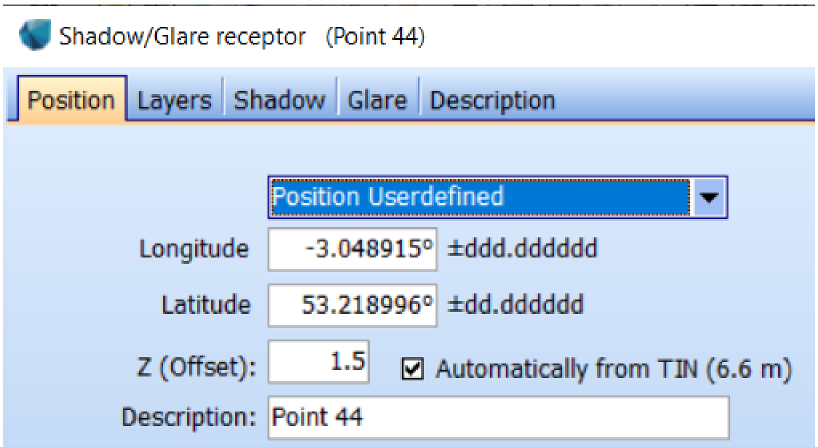

Figure 14 Exact position of receptor with ID 44 in windPRO

The receptors shown in Figure 12, Figure 13 and Figure 14 all have a field of view of 360°. Hence, glare coming from all directions is considered in the calculation.

The details about the PV plant configuration used in the Pager Power analysis are shown in Figure 15. The same parameters were used in the windPRO project – see Figure 16.

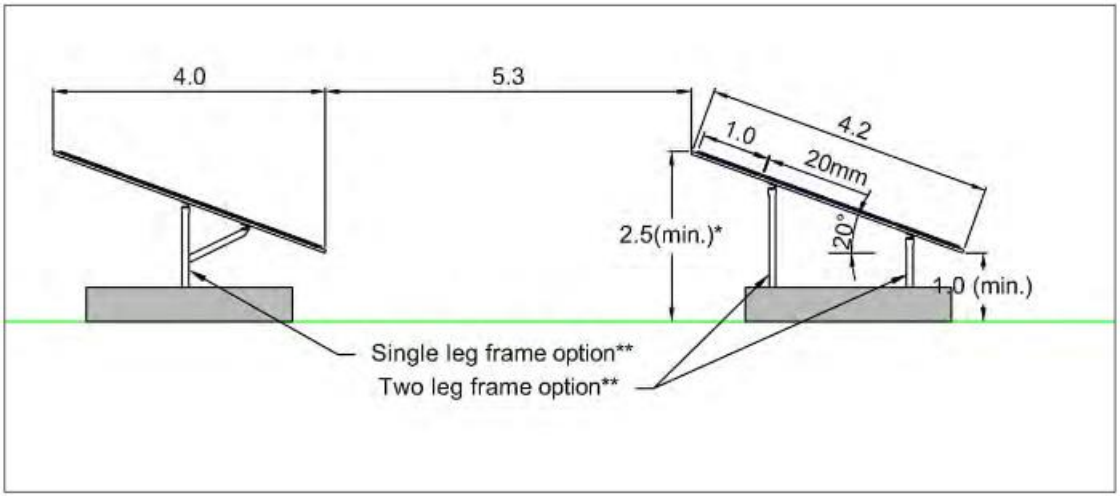

Figure 15 PV panels installation details specified in the Pager Power report [3]

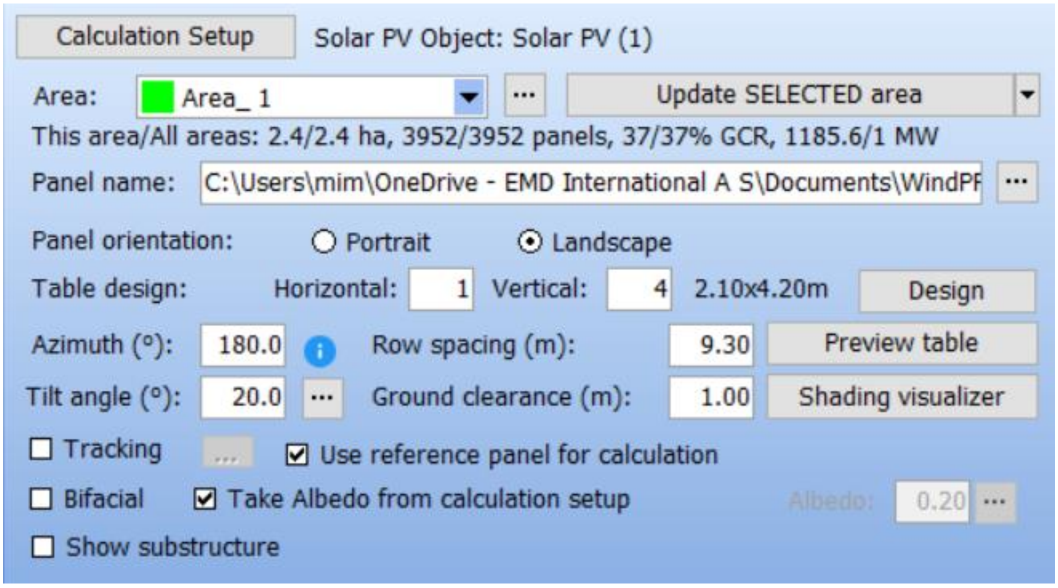

Figure 16 PV plant details specified in windPRO

The characteristics of the PV plant glass coating are not specified in the Pager Power report, hence the default windPRO setting was used: "No anti-reflection coating, smooth glass (5.0°)".

2.2 Results

In this section, comparison of the results obtained using the GLARE module in windPRO and those documented in the Pager Power report is made. The Pager Power report considers terrain obstruction between the PV plant and the receptors. This was not considered in the GLARE module and it can have influence on the results, where calculations from the GLARE module result in longer calculated time of glare occurrence.

Results from the GLARE module are corrected for daylight saving time, whereas the results in Pager Power report are not. Hence differences in the time occur.

2.2.1 GLARE in windPRO results

The results from the GLARE module in windPRO are summarized in Table 3. Detailed results per receptor are shown in Figure 17, Figure 18 and Figure 19: in green on the graph the time when glare can be observed at the location and in the lower right corner, a schematic of which panels are causing glare at the receptor.

Table 3 Summary of results from the GLARE module in windPRO for the receptor locations

No.	Name	Total time with glare in a year [h/year]	Maximum daily glare duration [min/day]	Day with max glare duration [Date]
1	Point 42	25.0	23	2nd April 19.11-19.34
2	Point 43	42.2	23	4th April 19.11-19.34
3	Point 44	64.9	24	3rd May 19.13-19.37

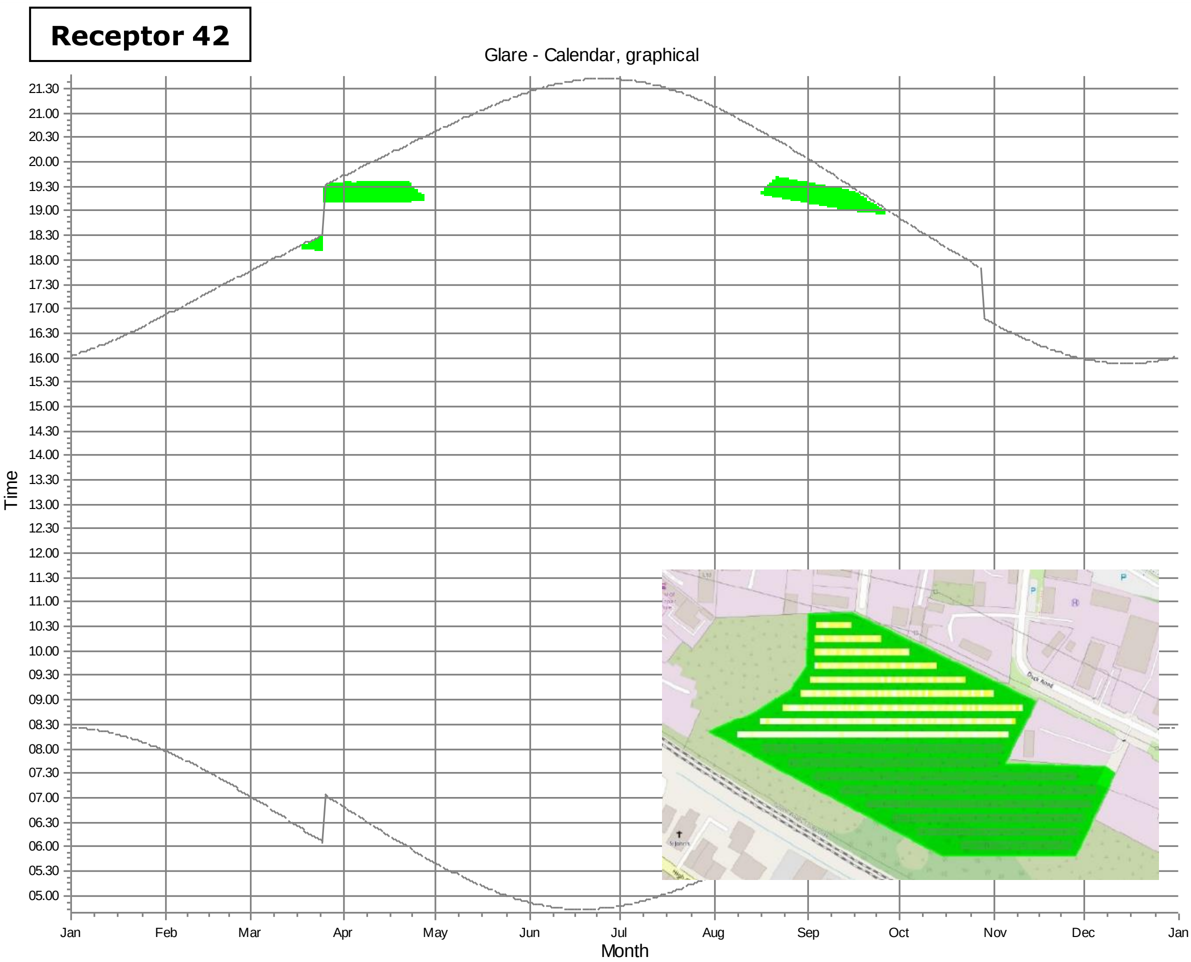

Figure 17 Detailed results for receptor 42 from the GLARE module in windPRO.

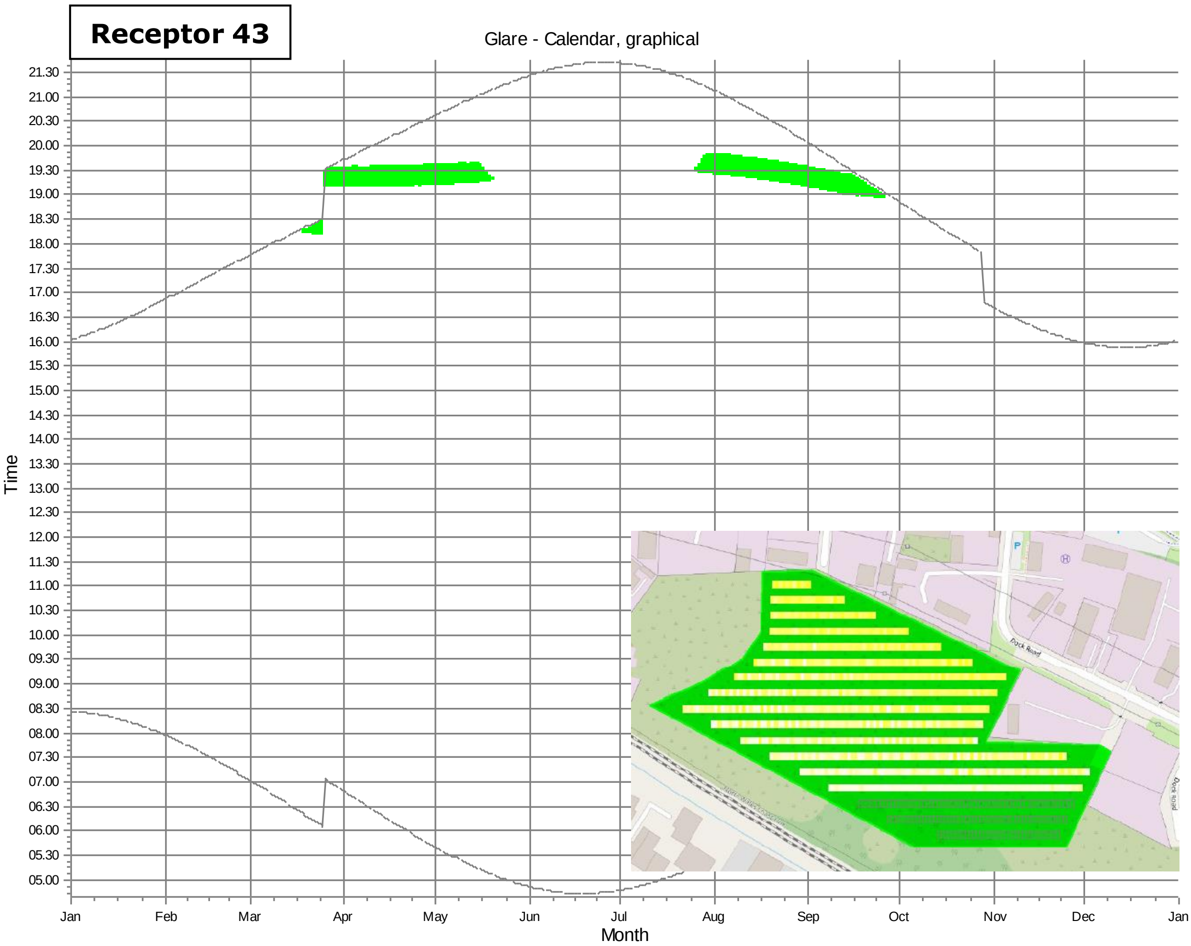

Figure 18 Detailed results for receptor 43 from the GLARE module in windPRO.

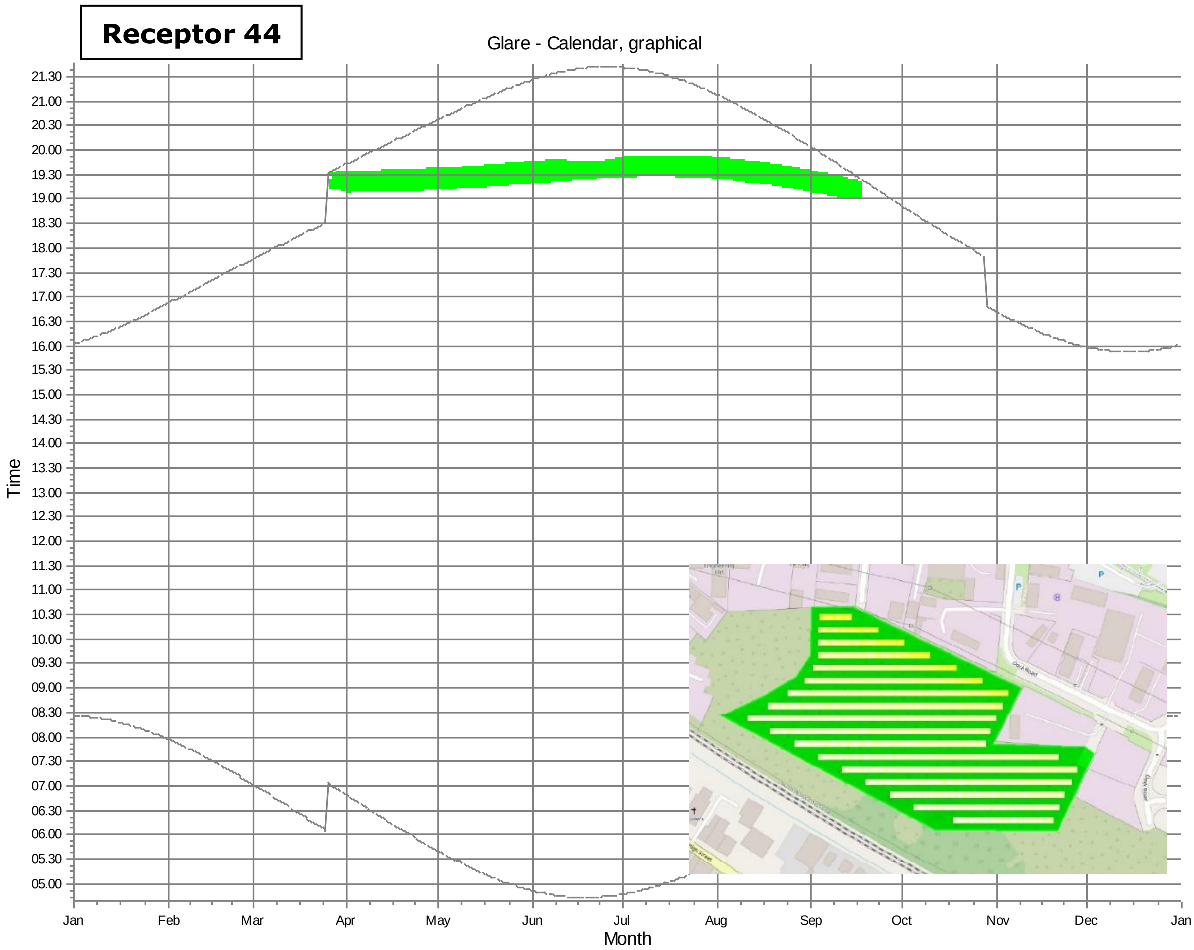

Figure 19 Detailed results for receptor 44 from the GLARE module in windPRO.

2.2.2 Pager Power report results

The approach used in the Pager Power calculation is based on calculation with 10 m resolution considering the PV plant. This approach differs from the calculation method used in the GLARE module where every PV panel table is considered separately.

The results from the Pager Power report are summarized in Table 4. Detailed results together with occurrence time graphs are presented for the individual receptors in Figure 20, Figure 21 and Figure 22.

Table 4 Result per receptor from the Pager Power report [3]

Dock Road Receptor	Pager Power Results		Comment
	Predicted reflection times towards Dock Road (GMT)		
	am	pm	
Observer 42	None.	Yes. Between 18:10 to 18:30 from April until late April, and again between 18:10 to 18:35 from mid-August until early September.	Solar reflection generating from the northern portion of the PV area. Sufficient screening in form of vegetation and buildings has been identified. No impact expected. No mitigation required.
Observer 43	None.	Yes. Between 18:10 to 18:30 from late March until mid-May, and again between 18:05 until 18:45 from late August until early September.	Solar reflection generating from the northern and central portion of the PV area. Sufficient screening in form of vegetation and buildings has been identified. No impact expected. No mitigation required.
Observer 44	None.	Yes. Between 18:00 to 18:50 from late March until mid-September.	Solar reflection generating from the complete surface of the PV area. Sufficient screening in form of vegetation has been identified. No impact expected. No mitigation required.

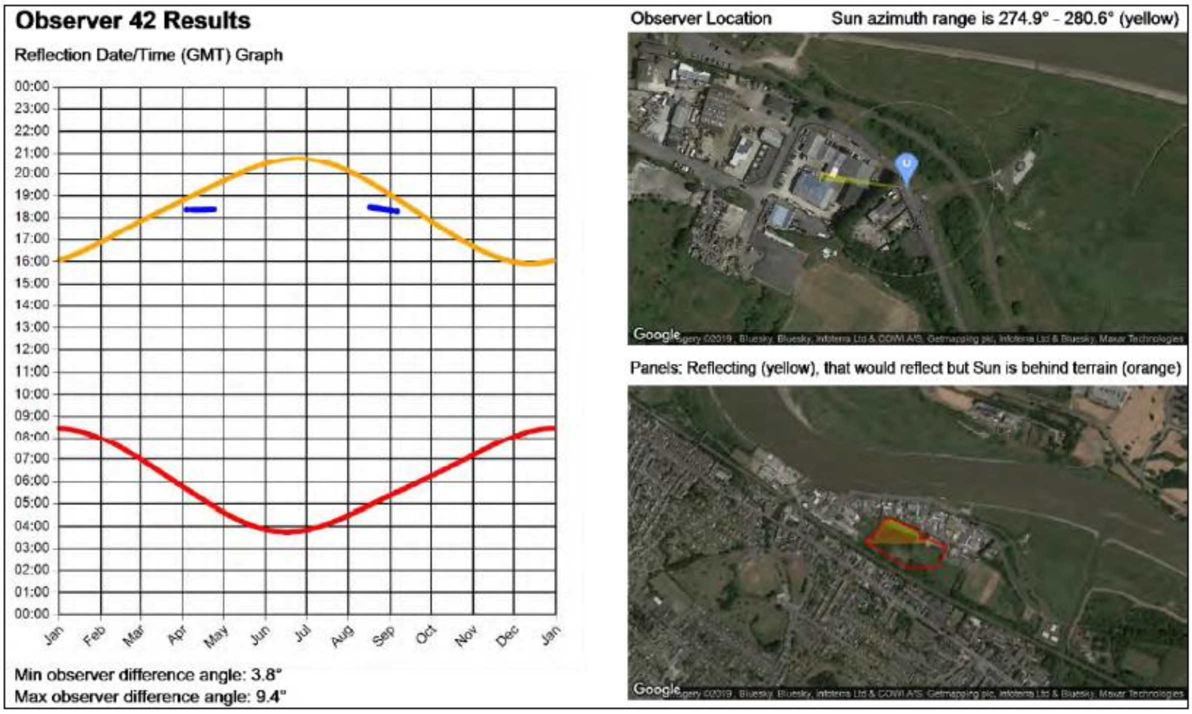

Figure 20 Detailed result for receptor 42 from the Pager Power report

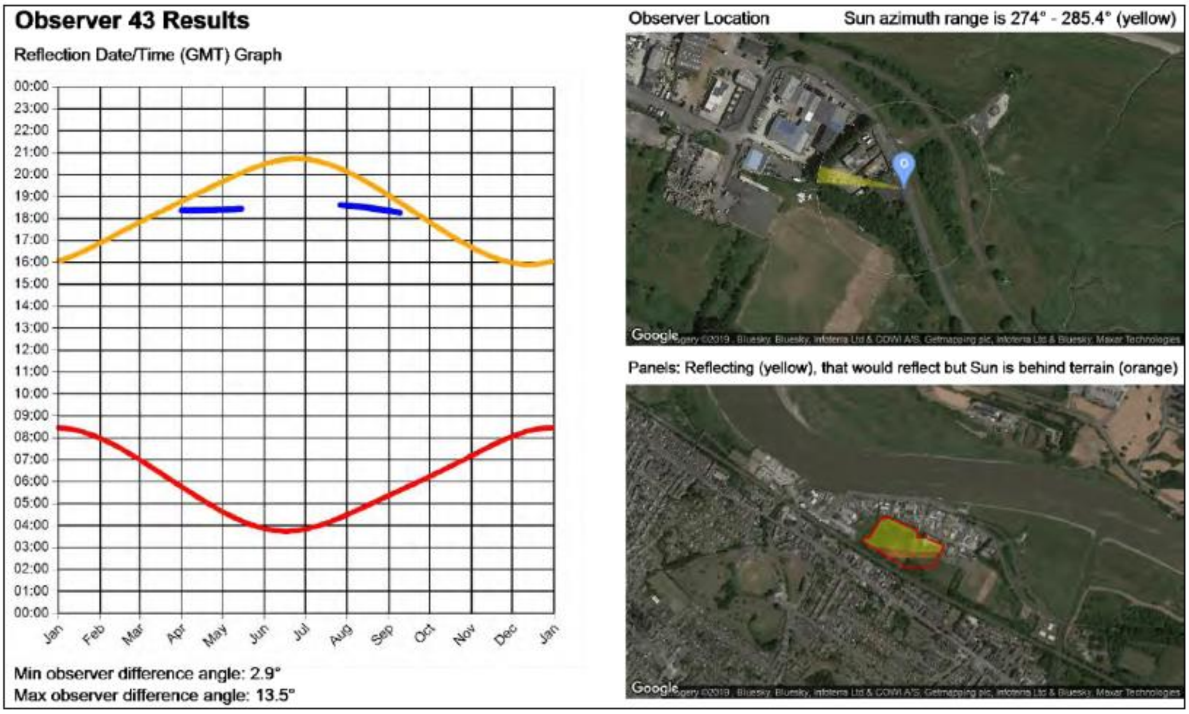

Figure 21 Detailed result for receptor 43 from the Pager Power report

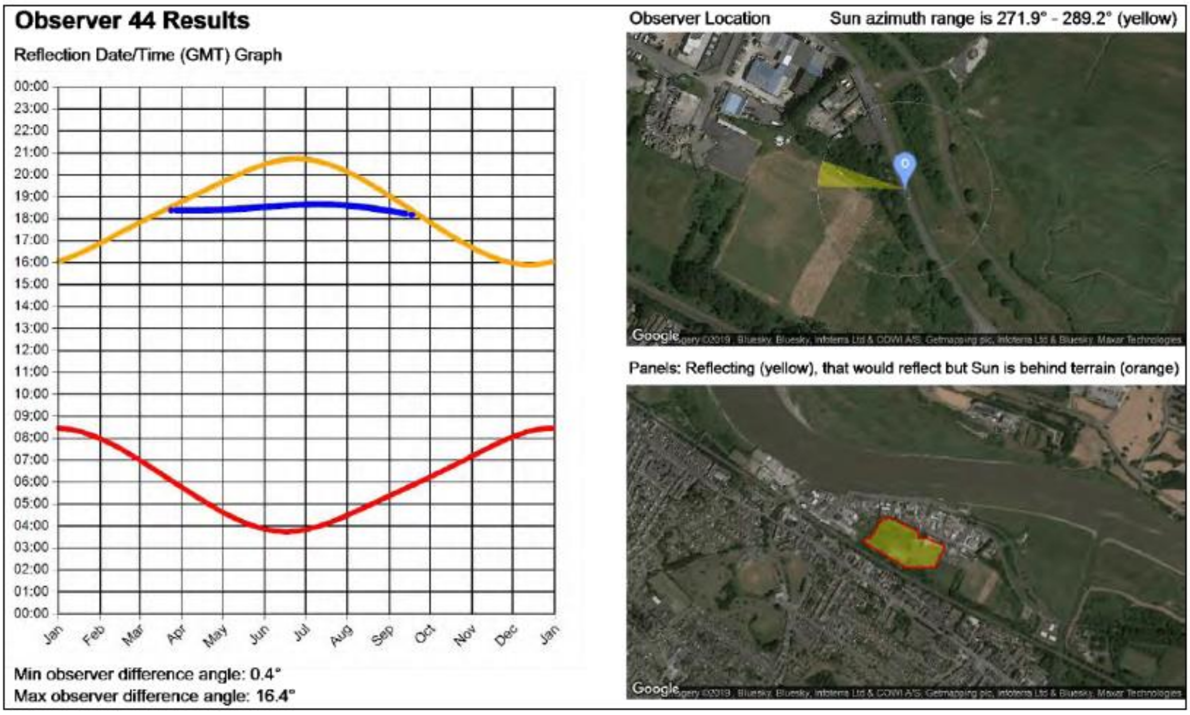

Figure 22 Detailed result for receptor 44 from the Pager Power report

2.3 Conclusions from comparison

The comparison of the results obtained in the Pager Power report with those obtained with the GLARE module is summarized in Table 5 – no daylight-saving time is considered here. Overall, calculations using the GLARE module estimate glare to occur sooner and last longer when looking at the glare periods. The time during the day aligns well between the calculations as well as the average daily duration. The differences may be caused by:

- Different approach to the calculation by Pager Power, where reflectors are defined as 10 m resolution grid in the solar PV area, whereas windPRO performs calculations for each of the corners of the tables.
- No consideration of topographic obstruction of the sun and of visibility of PV panels in the GLARE module will have an influence. PV panels, which are not reached by sun rays due to terrain topography should not be considered in the time of glare occurrence – see excluded PV panels marked in orange in Figure 20 and Figure 21.
- Elevation data – this will affect how the PV panels are placed and will have a lot of influence on the result – different elevation data could have been used in Pager Power analysis.
- What is the material of the PV panels coating considered in the Pager Power calculation. Difference in spread angle will have influence on the results.

Table 5 Comparison of results for glare occurrence calculation in Wales. Comparison done per receptor.

Receptor	Calculation source	Glare period	Hours with Glare (No DST)	Avg. daily duration
42	Pager Power report	Approx. dates 01.04 – 25.04 17.08 – 4.09	Between 18:10 and 18:35	20-25 min
	windPRO GLARE module	19.03- 27.04 17.08 – 26.09	Between 18:14 and 18:39	Around 23 min
43	Pager Power report	Approx. dates 29.03 – 15.05 27.07 – 06.09	Between 18:05 and 18:45	20-25min
	windPRO GLARE module	19.03 – 19.04 26.07 – 26.09	Between 17:56 and 18:48	Around 23 min
44	Pager Power report	Approx. dates 25.03 – 15.09	Between 18:00 and 18:50	20-25 min
	windPRO GLARE module	27.03 – 17.09	Between 18:02 and 18:51	Around 24 min

3 Building window Korshavn, Denmark

3.1 The Test Project

This test project analyzes real glare observation from a house with a large window in Korshavn, Denmark.

The observation was documented in a picture taken on 25th of December at 15:43 and can be seen in Figure 23.

Figure 23 Glare from a house with a large window. Observation at 25th of December at 15:43.

The calculation was performed by placing a PV plant at the location of the house and a glare receptor in place of the camera position from which the picture was taken. The map with a position of the PV plant and receptor can be seen in Figure 24 and the exact position of the PV plant simulating the large window in the front of the house in Figure 25. The PV plant specifications are shown in Figure 26, the window is assumed to be approx. 2 m high and 6 m wide.

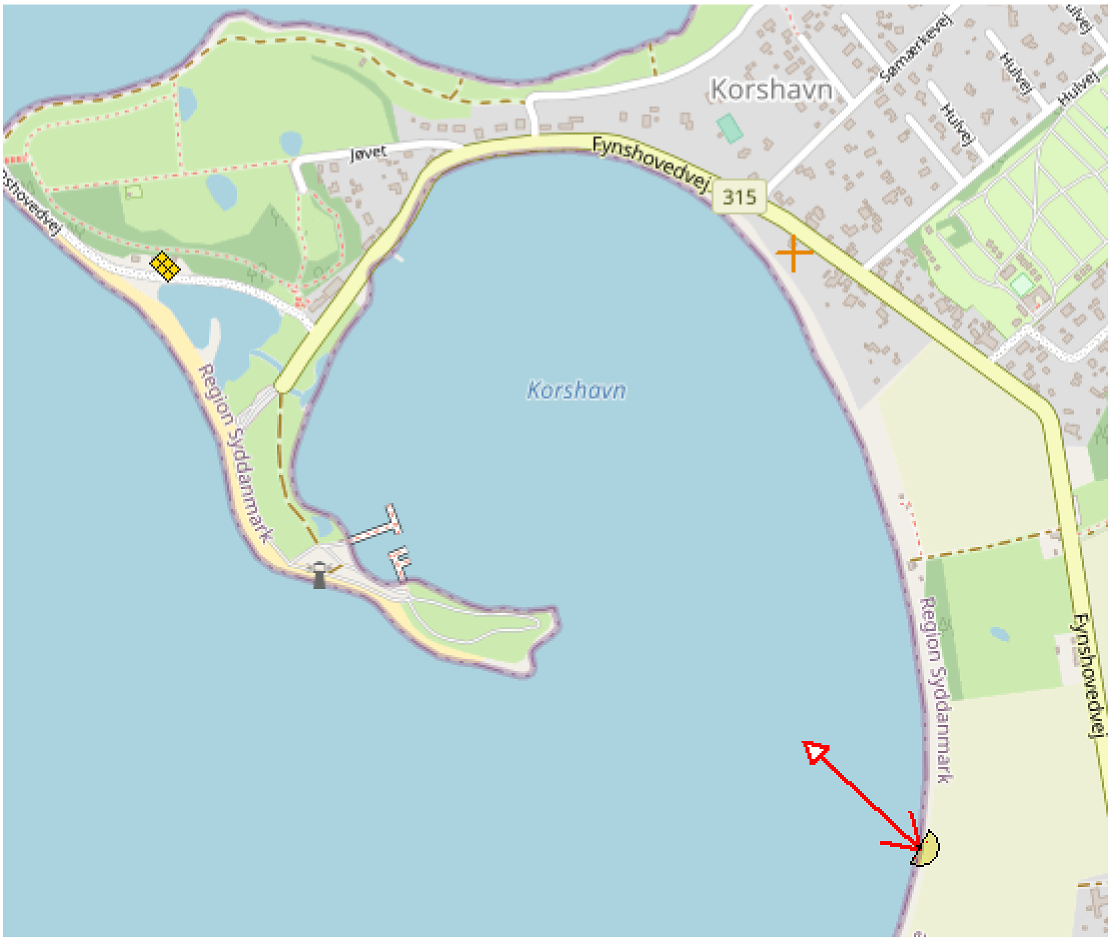

Figure 24 Map with position of the PV plant (upper left corner) and glare receptor/camera object. Map Source: OpenStreetMap

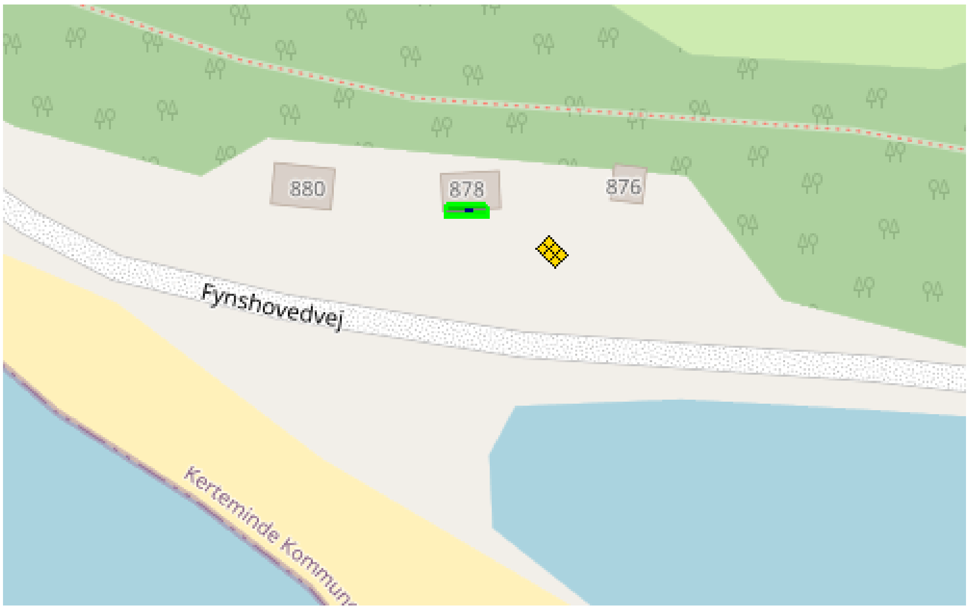

Figure 25 Closer view of the house where PV panels are used to simulate the large window in front of the house. Map Source: OpenStreetMap

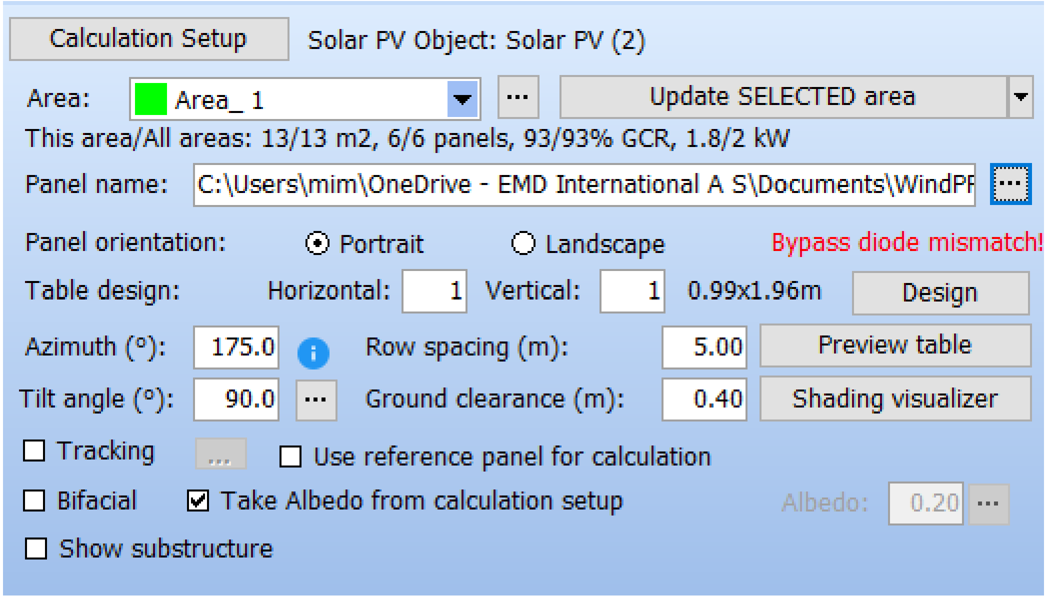

Figure 26 PV plant specification used in the simulation.

The setup of the glare receptor corresponded to the height of the camera above the ground when the photo was first taken. The exact configuration is shown in Figure 27.

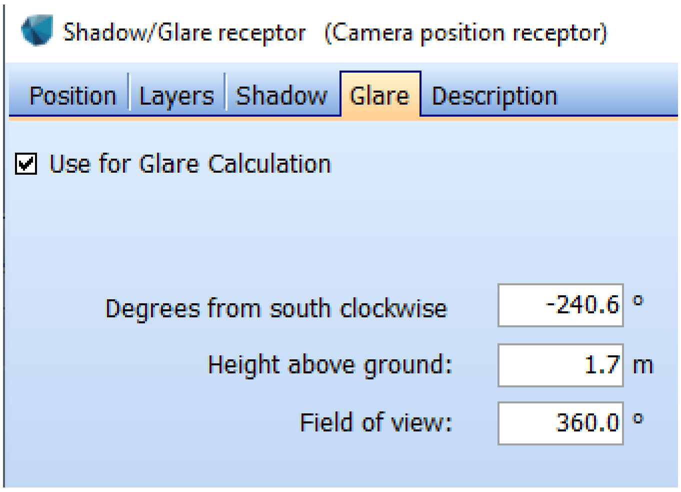

Figure 27 Glare receptor specification

3.2 Results and Conclusions

The glare occurrence time over the year is shown in Figure 28. On the date when the observation was made (25th of December) the calculation estimated glare to occur between 15:32 and 15:40, which is very close to the observation made at 15:43. The uncertainty of the exact placement of the camera and the exact placement of the window could explain the small discrepancy between the calculated and observed values.

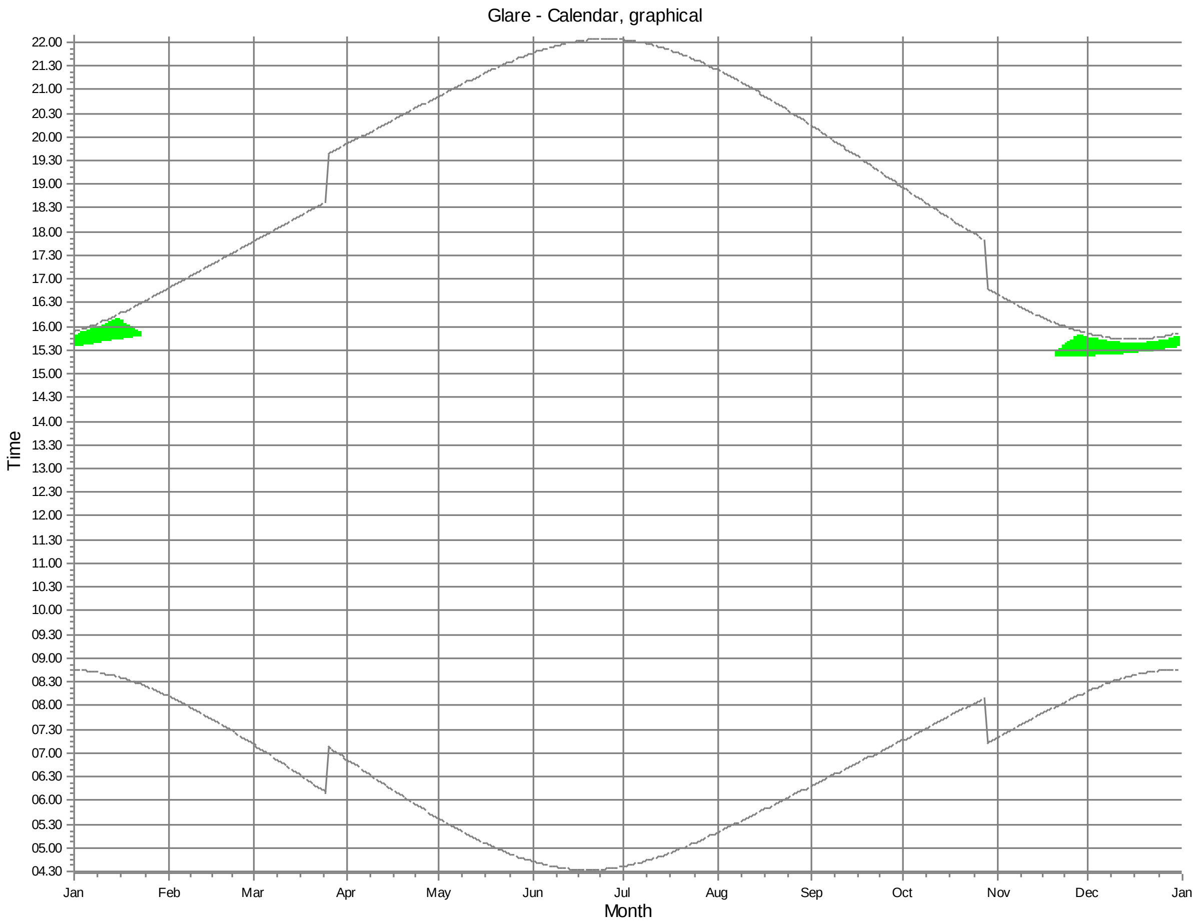

Figure 28 Glare occurrence time for the camera/receptor position

4 Office window in Aalborg, Denmark

4.1 The Test Project

This test project validates the GLARE module based on real observations from EMD's office in Aalborg, Denmark. Glare from a glass façade of a building was observed and recorded over a day. The project used in the validation is shown in Figure 29. The objects used in the calculation are a 3D object simulating the glass façade and glare receptor placed in the location of one of the offices.

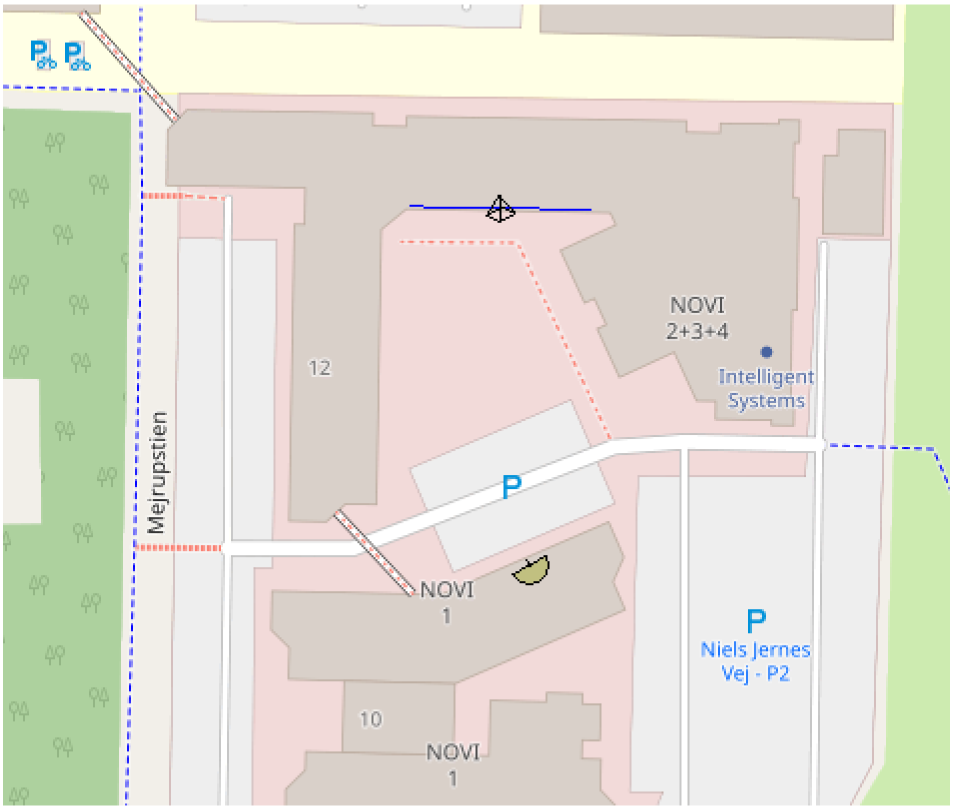

Figure 29 Map from windPRO with the positions of glare receptor and 3D object. Map Source: OpenStreetMap

The glare receptor was modelled with the settings shown in Figure 30. The glass characteristic chosen in the calculation was "No anti-reflection coating, smooth glass".

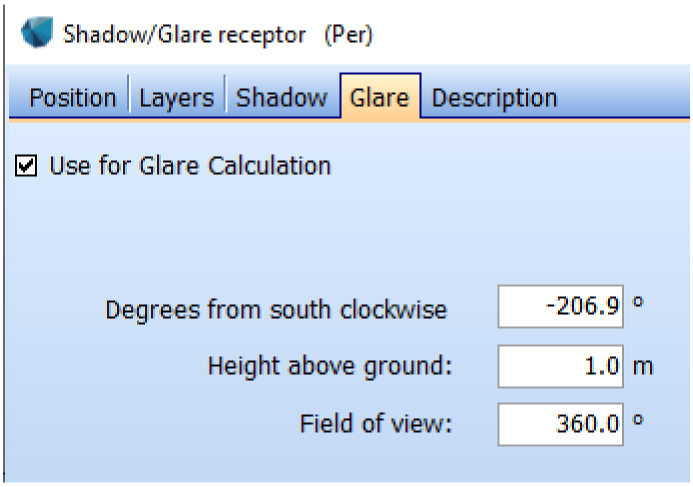

Figure 30 Settings of the glare receptor placed in the location of the office for which observations were made

The glass façade was included as a 3D object using the Sketchup integration tool in windPRO. First, the 3D model of the buildings was imported into Sketchup™ and then the windows in question were drawn and exported as a 3D object to the windPRO project. The exported windows from Sketchup™ are shown in Figure 31 - these correspond to the marked windows in Figure 32 from a photo taken from the office window. Only the top row of the windows was considered as the observed glare was caused only by the reflections from the top row.

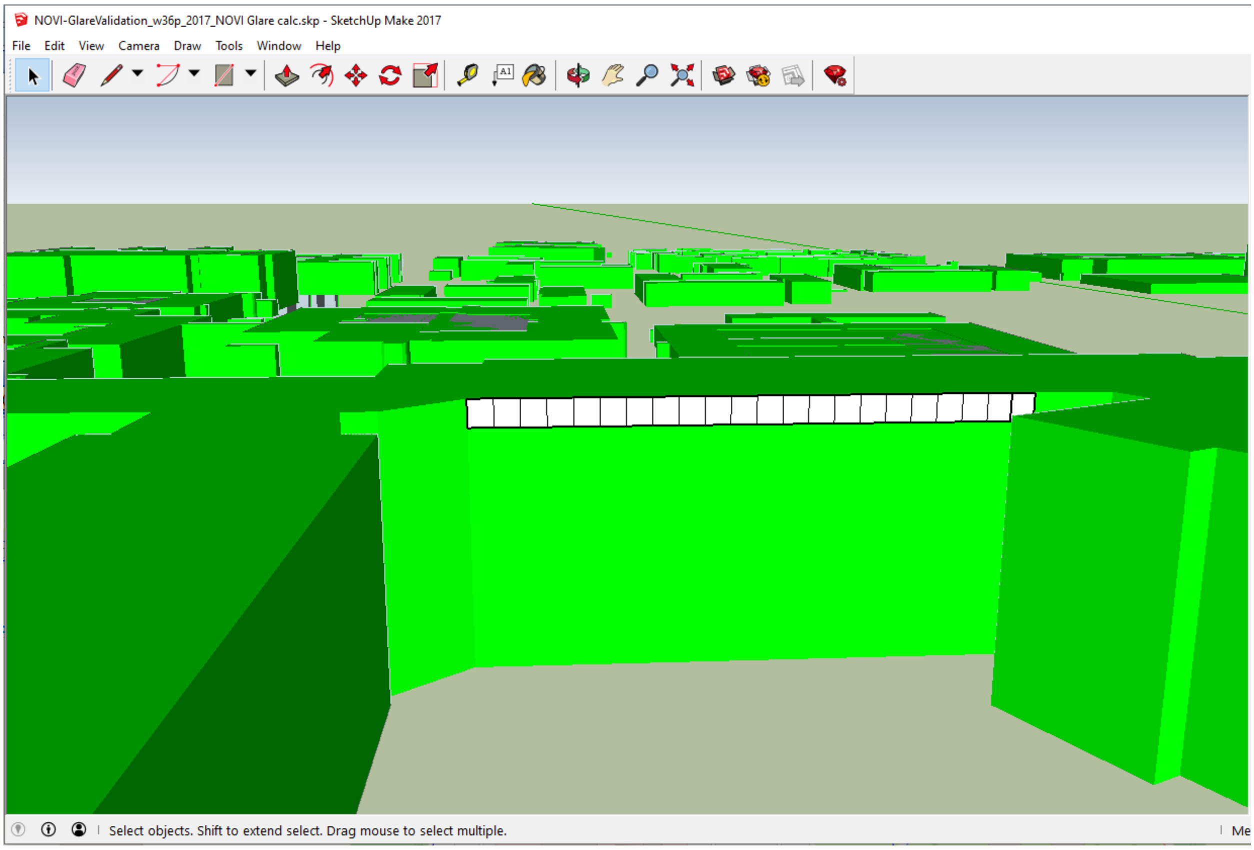

Figure 31 Sketchup model of the buildings together with the windows considered in the calculation

Figure 32 Windows considered in the calculation marked on a picture taken from the office

4.2 Results and Conclusions

The result overview of the GLARE calculation during a whole year and considering the top row of window is shown in Table 6. The glare occurrence time and glare occurrence sun angles are shown in Figure 33 and Figure 34 respectively.

Table 6 Result overview of the calculation in office in Aalborg

Receptor Name	Total time with glare in a year [h/year]	Maximum daily glare duration [min/day]	Day with max glare duration [Date]
Per (office)	107.8	131	1 January 11.52-14.03

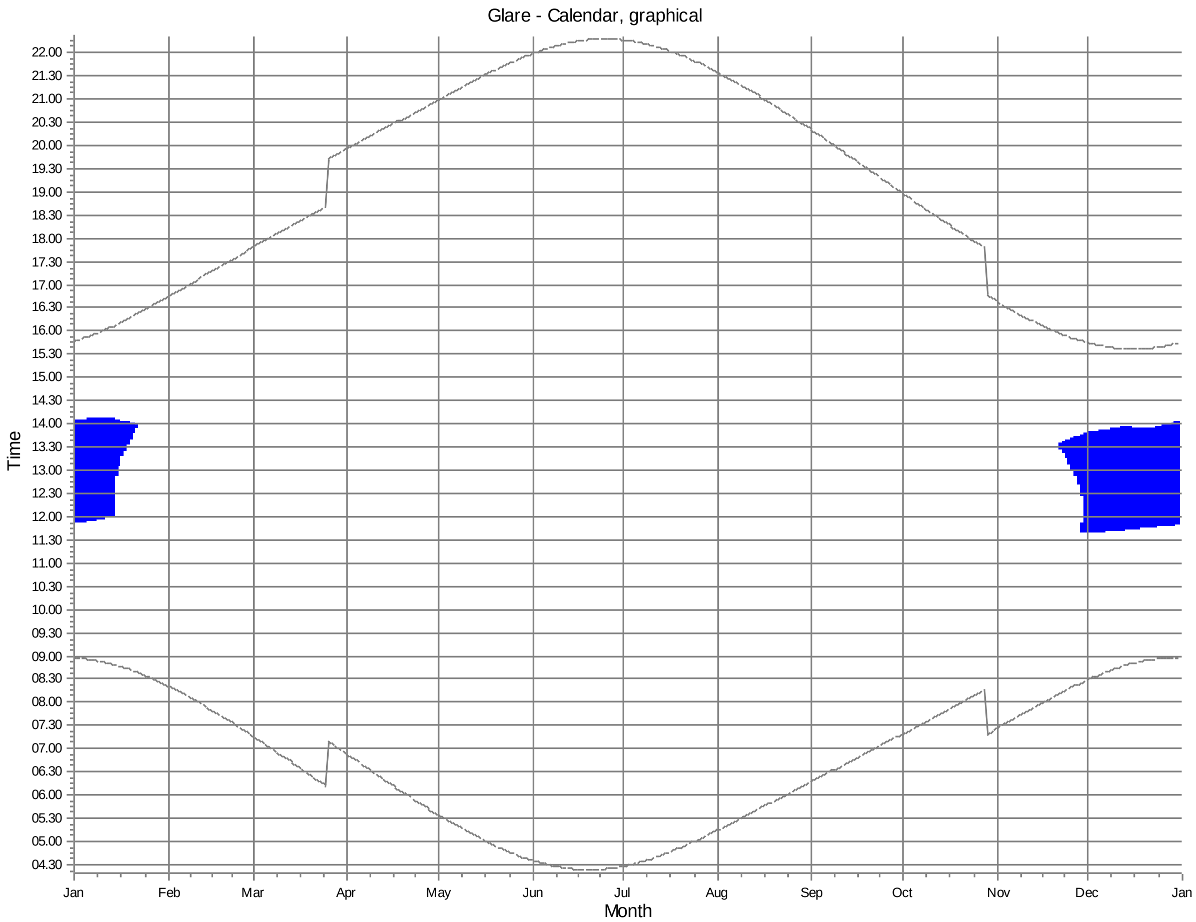

Figure 33 Occurrence time graph from the GLARE calculation in windPRO

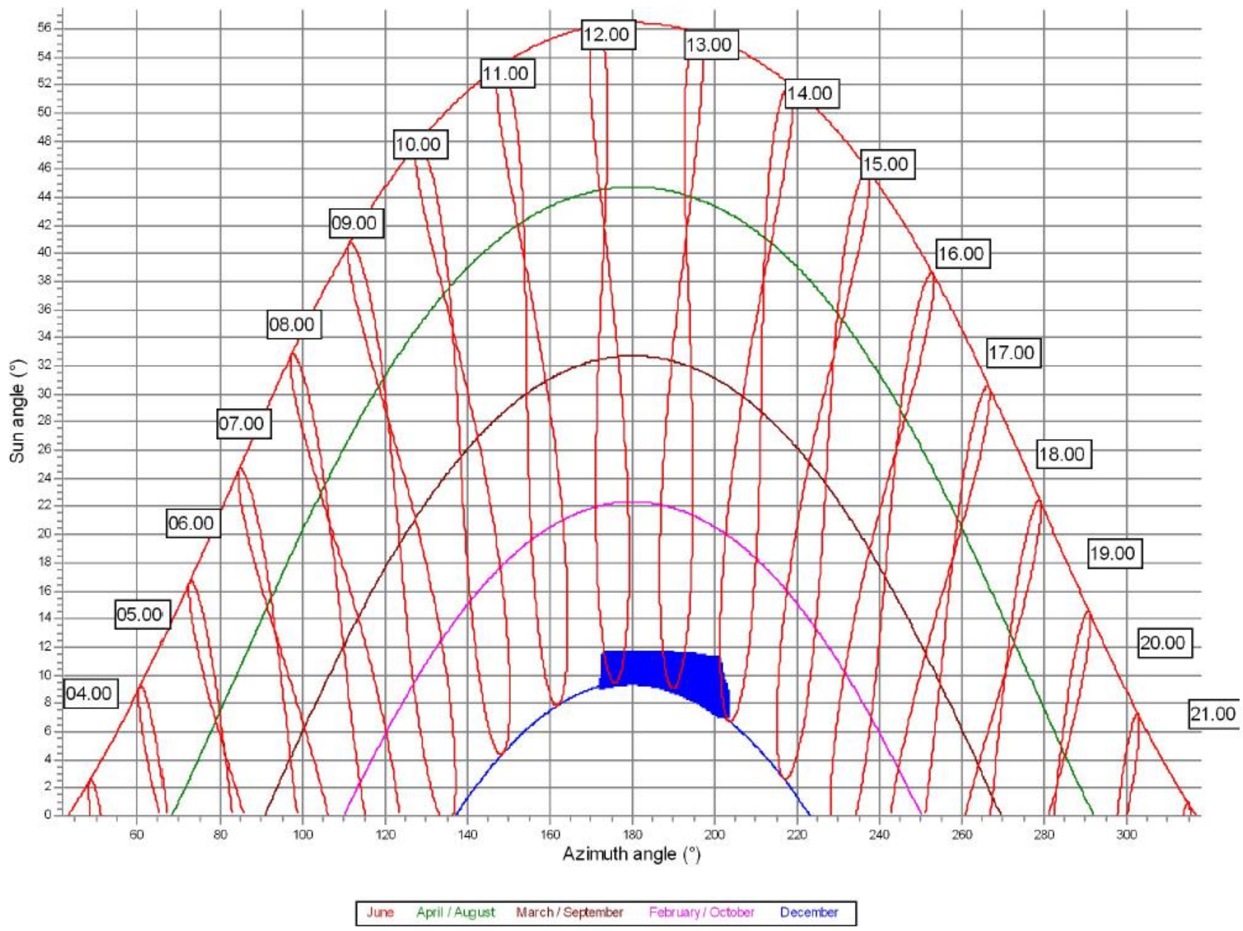

Figure 34 Occurrence sun angles graph from the GLARE calculation in windPRO

The glare observations were recorded on 10th of January. From the observations, the glare from the windows in question started around 11:55 and ended around 14:07. Hence, the total duration of glare was around 2h 12min. The glare observations extracted from a recorded time lapse are shown in Figure 35.

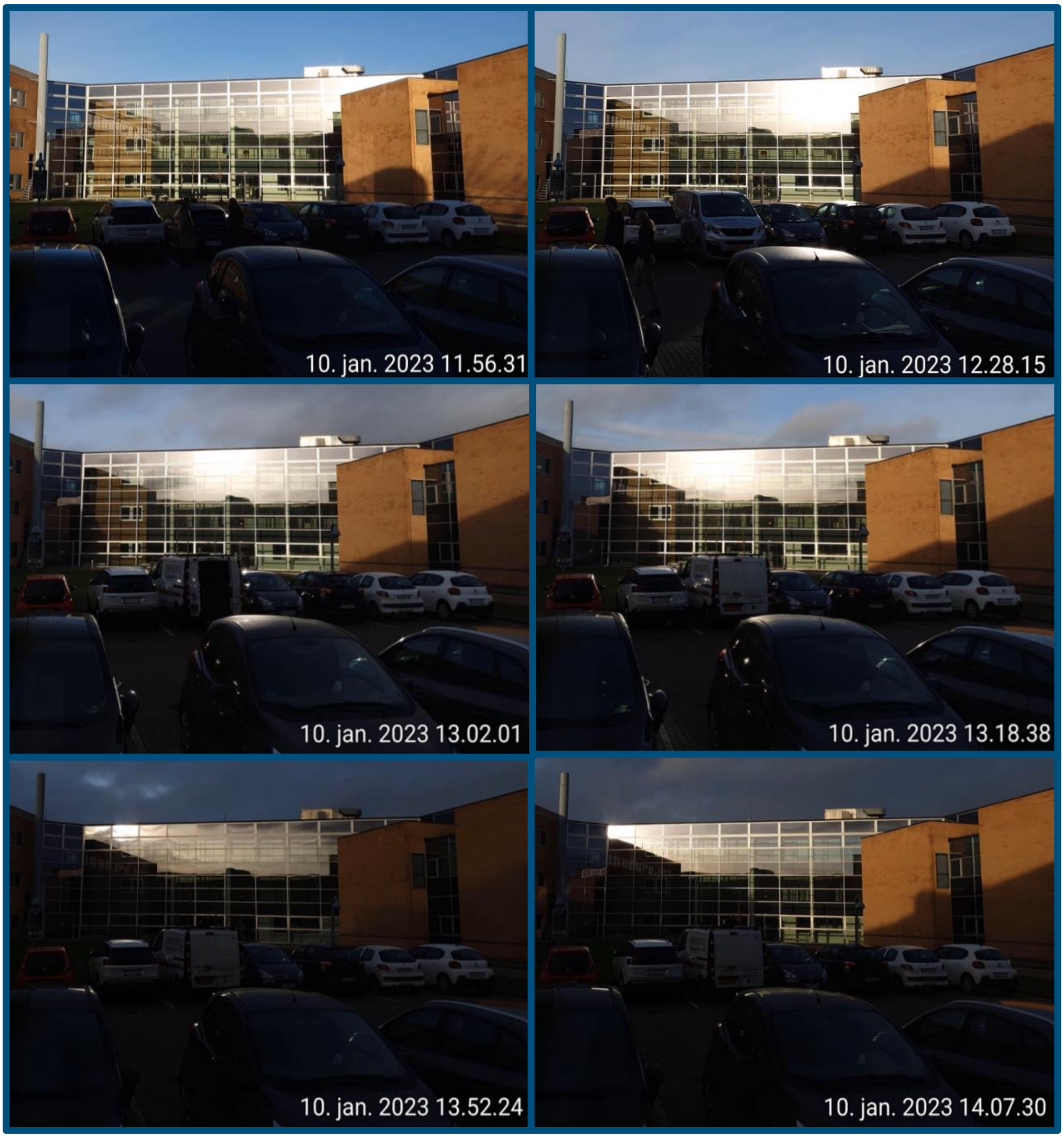

Figure 35 Glare observations from the receptor position in the office

The calculation made in the GLARE module in windPRO shows that glare will occur between 11:57 and 14:05. The specific sun angles for that day are shown in Figure 36.

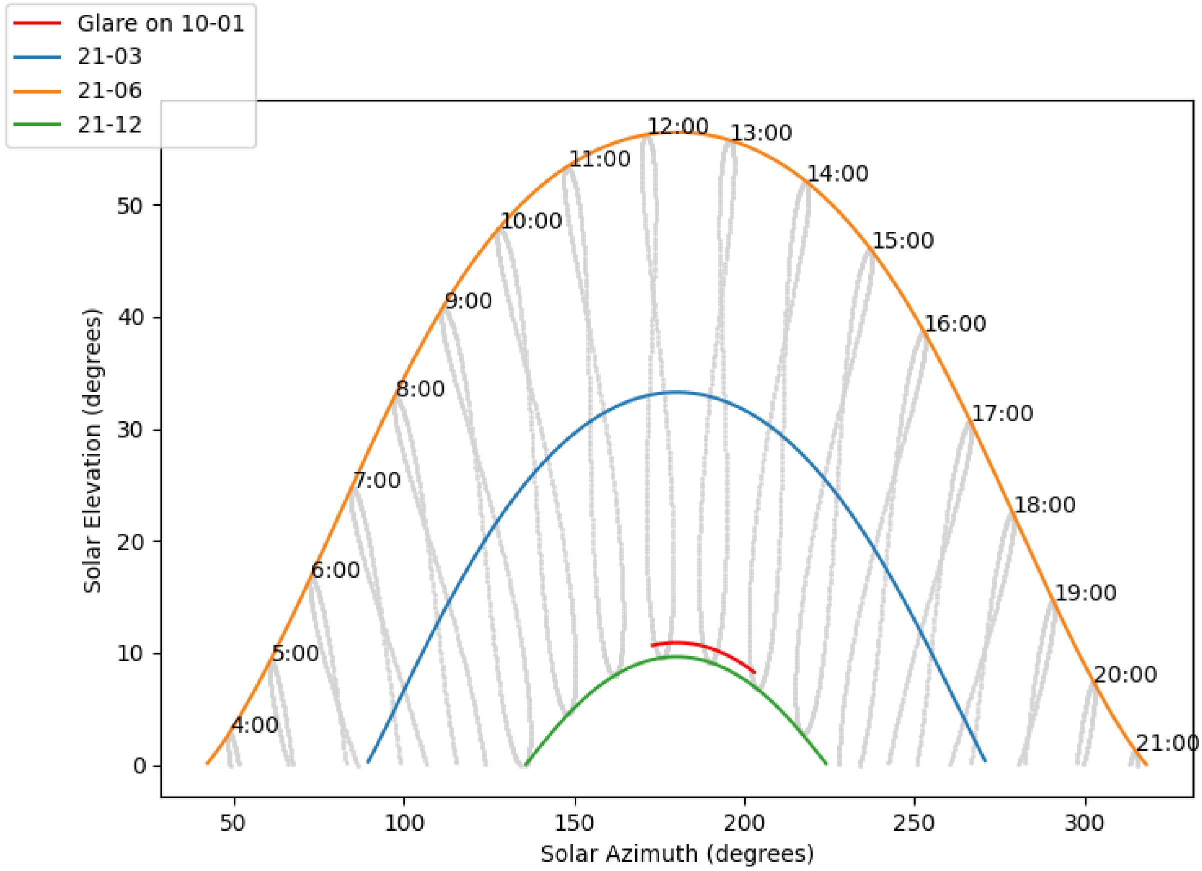

Figure 36 Sun angles for glare in the office receptor on 10th of January

The observed and calculated glare times and durations agree very well, with only 4 minutes difference. This could be caused by small differences in the exact placement of the receptor and/or due to different real properties of the glass.

5 Conclusions

The different test cases presented in this report for the illustrate that the GLARE module is reliable for the calculation of glare occurrence from either PV panels or other reflecting 3D windows or objects. It was tested against other software and consultancy reports as well against real glare observations.

The small discrepancies can be caused by unknown settings used in the other calculations or exact locations of the reflectors and receptors. Glare calculations are sensitive to such inputs and should be well specified before performing the calculation.

6 References

[1] “Home | ForgeSolar.” https://www.forgesolar.com/ (accessed Mar. 24, 2023).

[2] C. K. Ho, C. A. Sims, and J. E. Yellowhair, “Solar Glare Hazard Analysis Tool (SGHAT) User ’ s Manual v . 2G,” no. 505, pp. 1–36, 2015.

[3] A. Mariano, “Solar Photovoltaic Glint and Glare Study,” 2019. [Online]. Available: https://planning.agileapplications.co.uk/flintshire/application-details/50052