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太陽光電模組光害評估驗證技術

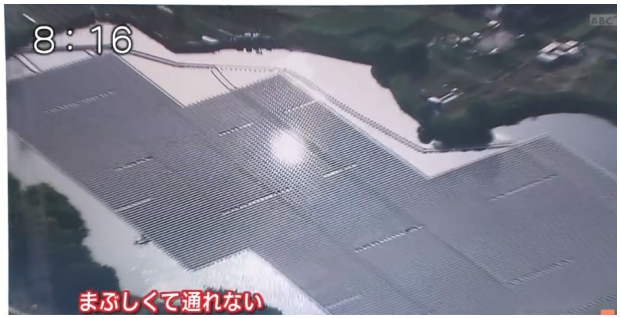
量測中心 能源與環境計量技術組
2019/09/27 梁瑋耘

什麼是眩光?

指視野中由於**不適宜亮度分布**，或在空間或時間上存在**極端的亮度對比**，以致**引起視覺不舒適**和**降低物體可見度**的視覺條件

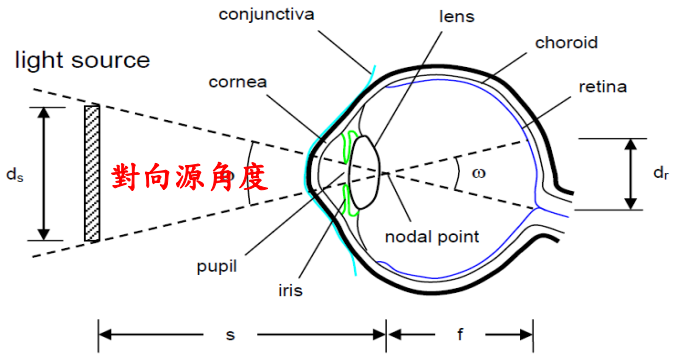
依眩光來源分為:

- **直接眩光:**由視野內的光源直接引起
- **反射眩光:**與目標物體的反射率直接相關



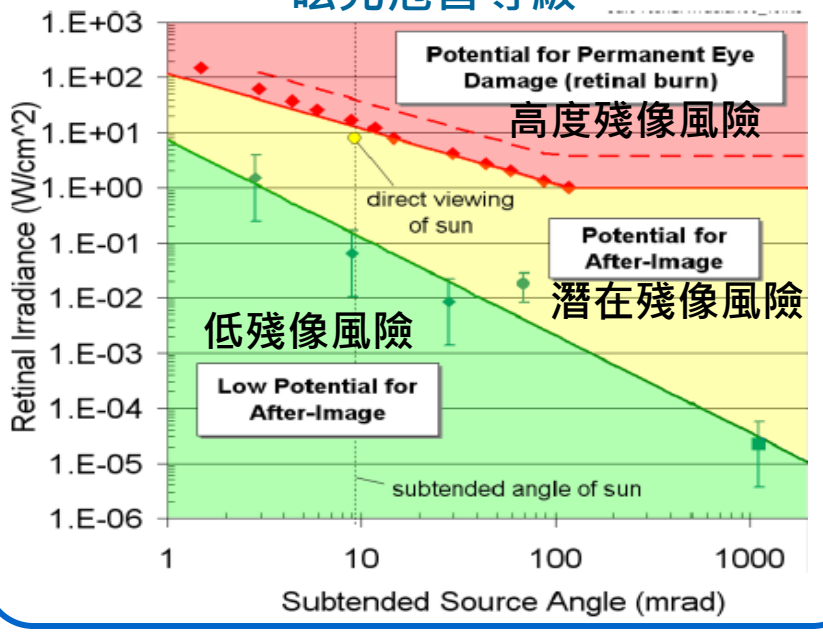
眩光相關因子

Impact of Light Entering the Eye



- Need to calculate
  - Power entering eye
    - Function of irradiance at the cornea (front of eye)
  - Subtended angle of glare source (size / distance)

眩光危害等級



眩光對視覺之影響因子:

- ✓ 直接法向輻照度
- ✓ PV模組反射率
- ✓ 陣列的尺寸和方向
- ✓ PV模組的光學性質和視覺參數。

對向源角度: 觀察者觀察到的眩光的大小，
視網膜輻照度: 影響觀察者視網膜接收能量大小

即使視網膜輻照度低，較大的源角也會導致高強度的眩光。

上述因子用於確定眩光危害等級圖中使用的視網膜輻照度和對向源角

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太陽光電模組眩光光害影響面面觀

眩光光害疑慮阻礙政策推動

- 2017/10/13 擔心光害輻射四湖鄉民反對太陽能板施工
- 2018/03/08 嘉義縣鹽業用地設置太陽光電專案開發計畫
- 2019/05/20 兆豐農場將設太陽能電廠-居民反彈
- 2019/04/02 台南鹽田太陽光電新建工程

眩光光害影響住宅品質

- (2013/08/17)香港將軍澳醫院天台光害擾民
- 2012 日本橫濱市屋頂型太陽能模組反射光訴訟案例
- 日本大阪狹山市安裝太陽能模組 反射光疑慮

眩光光害造成行車/航空安全

- 2012年，美國曼徹斯特/波士頓地區機場的空中交通管制塔眩光危害，嚴重干擾塔台交管員觀測影響飛安，最終以覆蓋黑色帆布解決。

太陽光電模組眩光光害 國內有法規要求?

目前僅內政部營建署 「建築技術規則」要求

建築物外牆、窗戶與屋頂所設之玻璃對戶外之可見光反射率不得大於0.25。(CNS 12381 入射角<15°)

有方法可解決眩光光害問題嗎?

太陽模組表面多角度反射率評估

場域模擬評估分析

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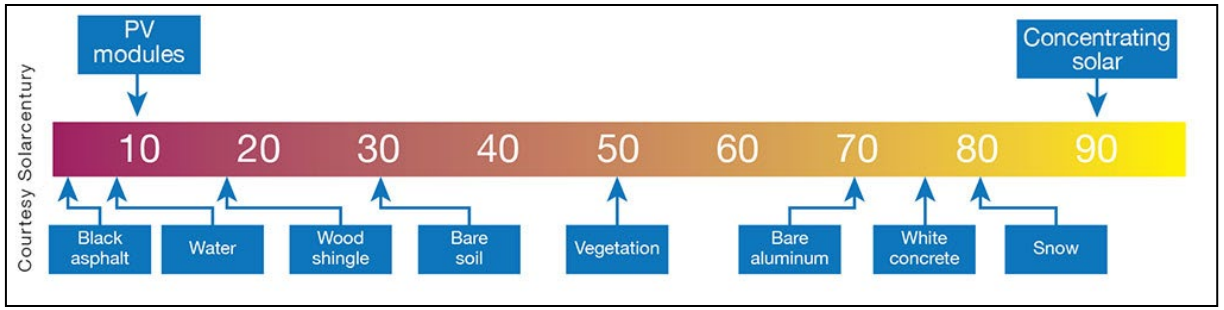
太陽模組表面反射率

各種材質反射程度比對值



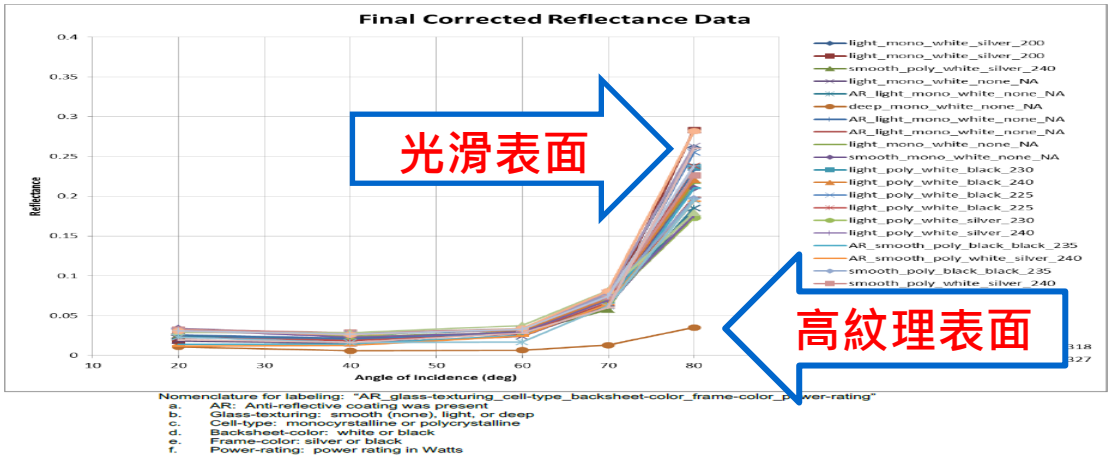
密集的太陽模組陣列
反射度比雪地反光嚴重

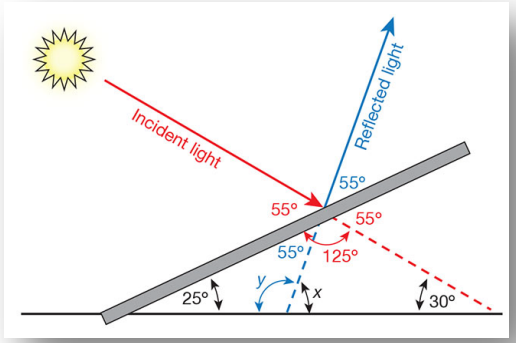
太陽模組表面反射率

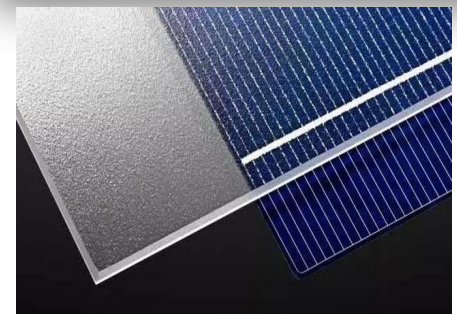
很大程度上取決於太陽光的入射角(相對於表面法線)大小

-小入射角玻璃的反射率相對較低（＜5%）

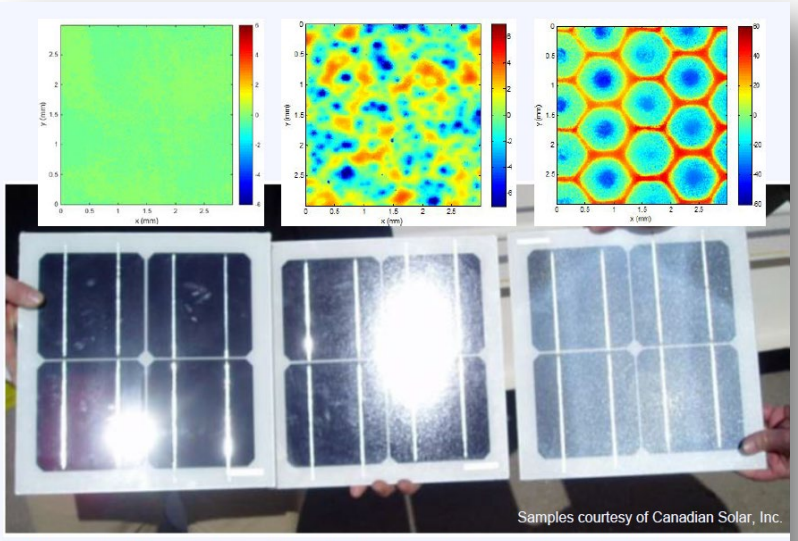
-60°以上迅速增加。較高的反射率會增加眩光強度







太陽光電模組表面特性對應眩光狀態



Smooth (float) glass, Lightly textured glass, Deeply textured glass

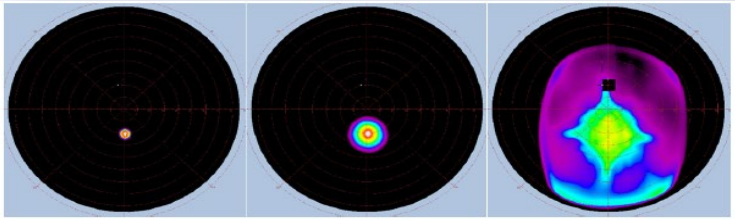
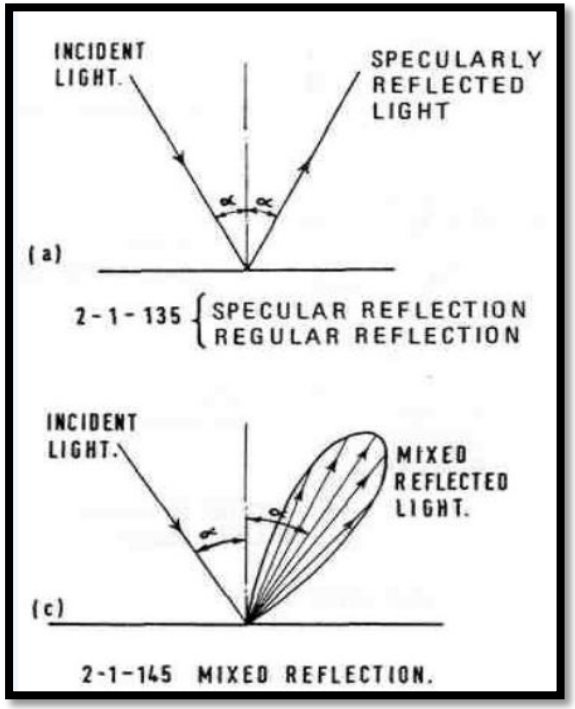


Fig. 2 Measured reflectance distribution function at an incident angle of 20° for three different glass types left: flat float glass, middle: rolled glass with a slightly structured surface, right: rolled glass with macroscopic pyramidal structure.

Fig. 3 photographic picture of the sun reflectedby three different glass types. left: flat float glass, middle: rolled glass with a slightly structured surface, right: rolled glass with macroscopic pyramidal structure.

表面粗化特性與眩光狀態示意圖



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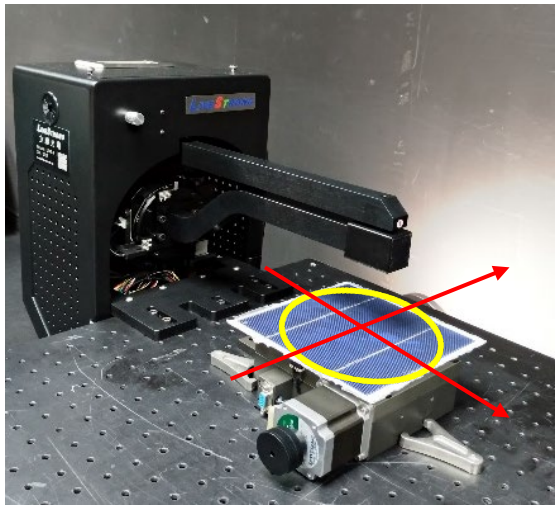
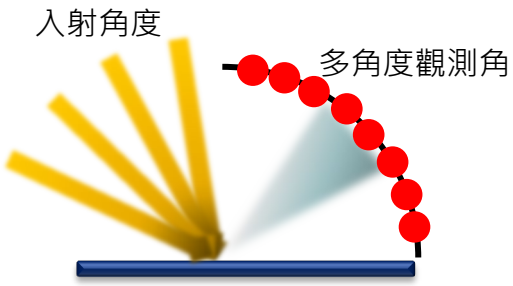
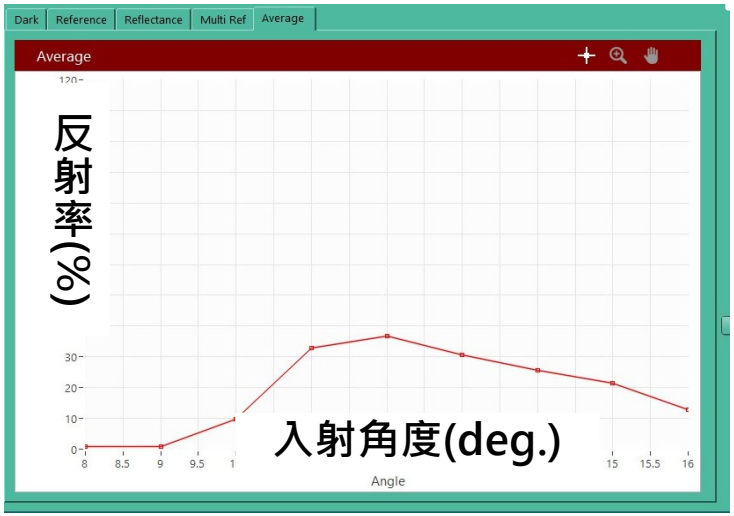
太陽光電模組表面眩光多角度反射率評估系統





不同入射角，固定反射角 反射率量測



模組反射率參數資訊　供後續模擬使用

Table 1 - Reflectance fit functions for PV cover types.

PV Glass Cover Type	Fit Function Defined over $0° \le \theta \le 60°$	Fit Function Defined over $60° < \theta < 90°$
Smooth Glass without Anti-Reflection Coating	$y = 1.1977E\text{-}5\ x^2 - 9.5728E\text{-}4\ x + 4.410E\text{-}2$	$y = 6.2952E\text{-}5\ e^{0.1019x}$
Smooth Glass with Anti-Reflection Coating	$y = 1.473E\text{-}5\ x^2 - 9.6416E\text{-}4\ x + 3.2395E\text{-}2$	$y = 4.7464E\text{-}5\ e^{0.1051x}$
Light Textured Glass without Anti-Reflection Coating	$y = 1.5272E\text{-}5\ x^2 - 1.1304E\text{-}3\ x + 4.305E\text{-}2$	$y = 7.3804E\text{-}5\ e^{0.0994x}$
Light Textured Glass with Anti-Reflection Coating	$y = 1.4188E\text{-}5\ x^2 - 1.0326E\text{-}3\ x + 3.9016E\text{-}2$	$y = 7.0179E\text{-}5\ e^{0.0994x}$
Deeply Textured Glass	$y = 6.8750E\text{-}6\ x^2 - 6.5250E\text{-}4\ x + 2.10E\text{-}2$	$y = 4.1793E\text{-}5\ e^{0.0834x}$

眩光分析

假設案例:水域型太陽光電模組

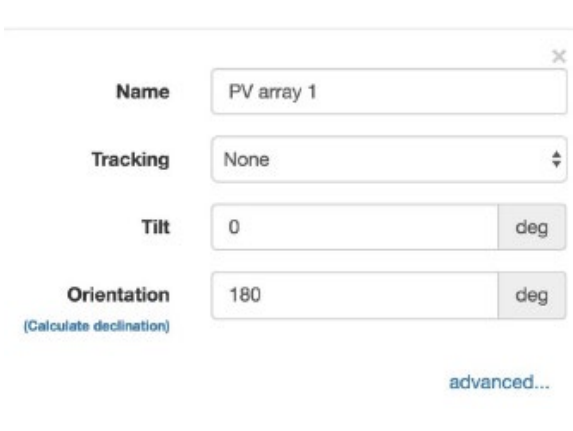
(1) 透過分析軟體，由Google Maps將方位標註建立，明確定義太陽能模組位置。進行模組參數設定

太陽模組參數設定

傾斜角 (安裝傾角大小)

方位角(朝南為180°)

表面反射率參數 (光滑, ARC, 紋理處理)



Name: PV array 1
Axis tracking: Fixed (no rotation)
Tilt: 10.0 deg
Orientation: 180.0 deg
Rated power: 1000.0 kW
Panel material: Deeply textured glass
Vary reflectivity with sun position? Yes
Correlate slope error with surface type? Yes
Slope error: 82.6 mrad

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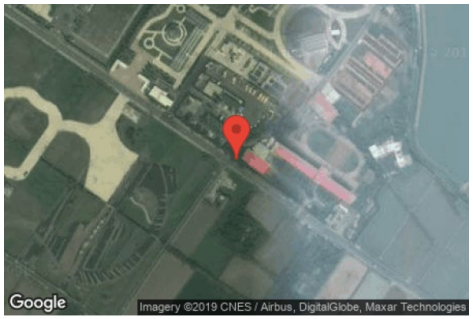
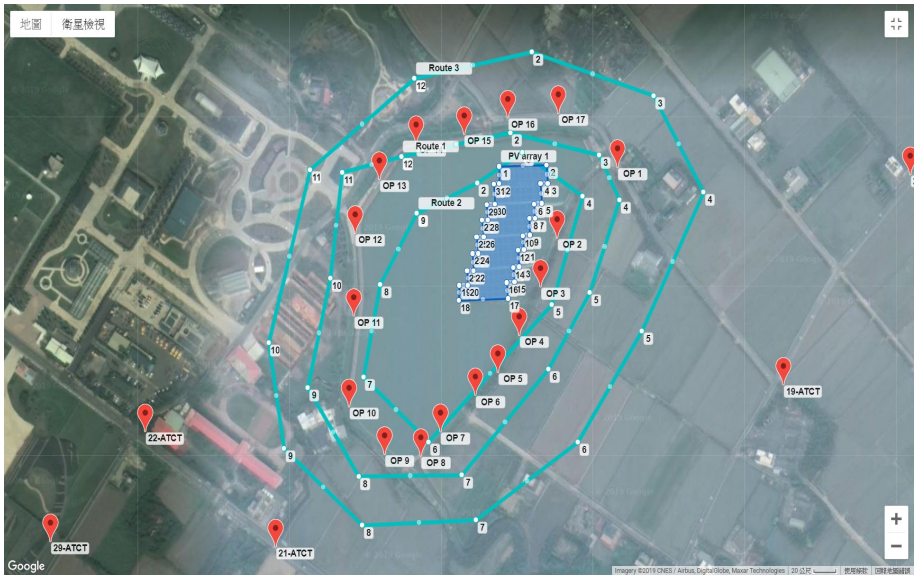
眩光分析

假設案例:水域型太陽光電模組

(2) 設定觀測點，點位置，路徑，塔台...等

Name: Route 1
Route type Two-way
View angle: 50.0 deg





觀測點參數設定

所在點高度

方位角(朝南為180°)

路徑(車道方向，單向/雙向)

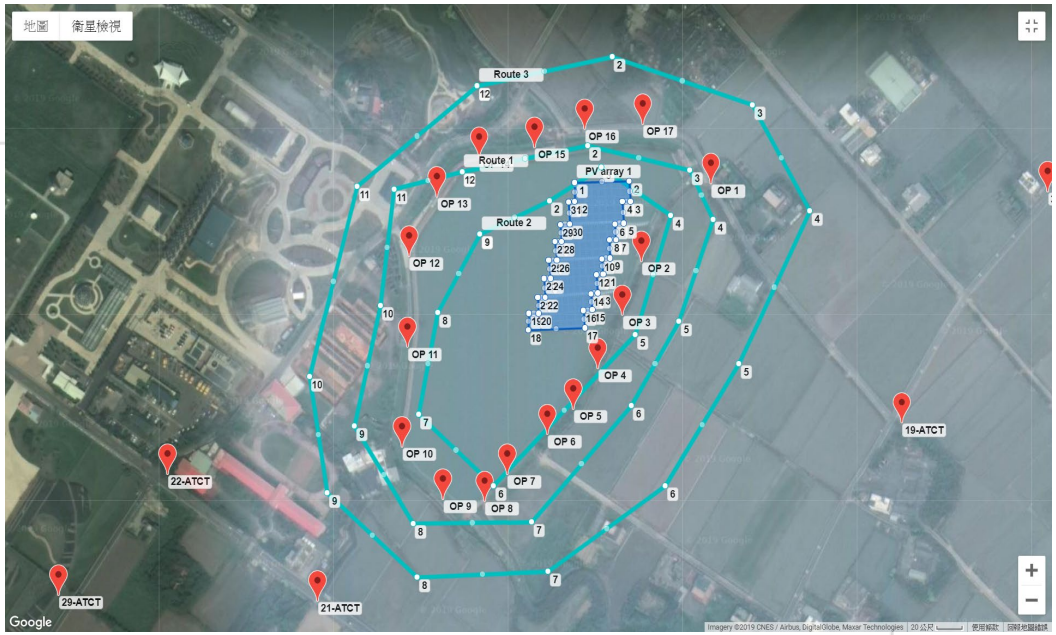
Discrete Observation Receptors

Number	Latitude	Longitude	Ground elevation	Height above ground	Total Elevation
	deg	deg	m	m	m
OP 1	25.006845	121.053080	23.80	1.50	25.30
OP 2	25.006324	121.052536	23.82	1.50	25.32
OP 3	25.005963	121.052382	24.43	1.50	25.93
OP 4	25.005608	121.052191	24.94	1.50	26.44
OP 5	25.005338	121.051999	25.00	1.50	26.50
OP 6	25.005164	121.051792	25.00	1.50	26.50
OP 7	25.004900	121.051478	25.01	1.50	26.51
OP 8	25.004719	121.051302	25.88	1.50	27.38
OP 9	25.004733	121.050973	26.61	1.50	28.11
OP 10	25.005081	121.050651	26.05	1.50	27.55
OP 11	25.005747	121.050697	24.10	1.50	25.60

眩光分析

Route Receptor(s)

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	25.006925	121.051123	23.09	30.00	53.09
2	25.007100	121.052110	20.84	30.00	50.84
3	25.006935	121.052915	23.17	30.00	53.17
4	25.006604	121.053097	24.21	30.00	54.21
5	25.005924	121.052829	24.49	30.00	54.49
6	25.005360	121.052454	25.12	30.00	55.12
7	25.004582	121.051670	25.76	30.00	55.76
8	25.004572	121.050737	26.88	30.00	56.88
9	25.005223	121.050276	25.51	30.00	55.51
10	25.006030	121.050479	24.15	30.00	54.15
11	25.006808	121.050587	23.76	30.00	53.76
12	25.006925	121.051123	23.09	30.00	53.09

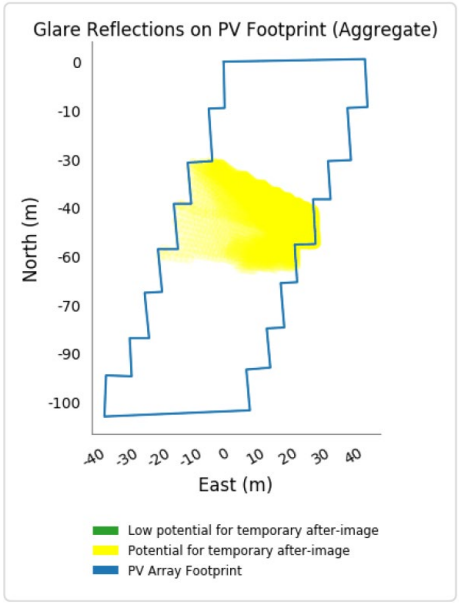
眩光分析

依據眩光光害模擬技術，可完成預建場域光害評估

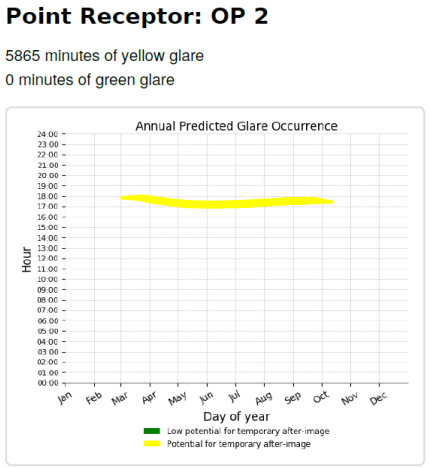
模擬結果

- 透過模擬得知眩光**產生足跡**，**年度眩光發生時刻及經歷時間**，並依據眩光危害分級表，列出**眩光光害等級**
- 透過模擬得知**最佳化安裝傾角**，兼顧眩光及發電能效，於安裝前預估模擬，避開眩光發生觀測點

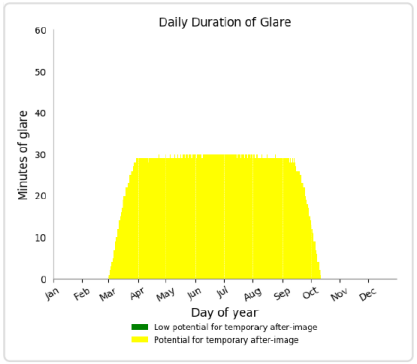
各觀測點眩光光害模擬



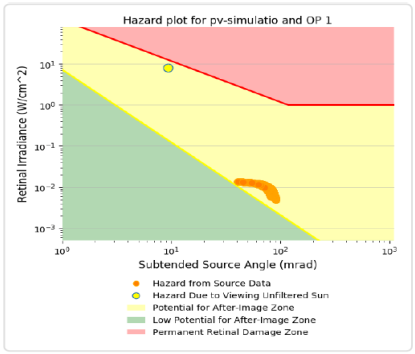
眩光產生足跡



年度眩光發生時刻



年度眩光經歷時間



眩光光害等級

眩光分析

模擬結果

安裝傾角最佳化評估

Results Per Component

Predicted minutes of worst glare per receptor. Hover over column headers for details.

PV Orientation	Tilt	% Max Energy	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7	OP 8	OP 9	OP 10	OP 11	OP 12	OP 13	OP 14	OP 15	OP 16	OP 17
180.0	25.0	100.0%	891 yellow	7,165 yellow	6,354 yellow	479 yellow	-	-	-	-	-	-	870 yellow	2,100 yellow	849 yellow	-	-	-	-
185.0	25.0	100.0%	271 yellow	6,482 yellow	5,737 yellow	440 yellow	-	-	-	-	-	-	954 yellow	2,315 yellow	1,450 yellow	45 yellow	-	-	-
175.0	25.0	100.0%	1,555 yellow	7,880 yellow	6,982 yellow	408 yellow	-	-	-	-	-	-	797 yellow	1,681 yellow	434 yellow	-	-	-	-
180.0	20.0	99.8%	1,025 yellow	6,768 yellow	5,979 yellow	51 yellow	-	-	-	-	-	-	750 yellow	2,286 yellow	985 yellow	-	-	-	-
185.0	20.0	99.8%	416 yellow	6,122 yellow	5,401 yellow	89 yellow	-	-	-	-	-	-	727 yellow	2,887 yellow	1,526 yellow	134 yellow	-	-	-
175.0	20.0	99.8%	1,662 yellow	7,427 yellow	6,569 yellow	26 yellow	-	-	-	-	-	-	735 yellow	2,107 yellow	510 yellow	-	-	-	-
180.0	15.0	99.0%	1,242 yellow	6,694 yellow	5,889 yellow	-	-	-	-	-	-	-	758 yellow	2,419 yellow	1,146 yellow	-	-	-	-
185.0	15.0	98.9%	625 yellow	6,061 yellow	5,323 yellow	-	-	-	-	-	-	-	814 yellow	2,974 yellow	1,466 yellow	261 yellow	-	-	-
175.0	15.0	98.9%	1,882 yellow	7,350 yellow	6,469 yellow	-	-	-	-	-	-	-	721 yellow	2,204 yellow	647 yellow	-	-	-	-
180.0	10.0	97.3%	1,597 yellow	7,039 yellow	6,067 yellow	-	-	-	-	-	-	-	791 yellow	2,576 yellow	1,279 yellow	132 yellow	-	-	-
185.0	10.0	97.3%	1,027 yellow	6,413 yellow	5,586 yellow	-	-	-	-	-	-	-	722 yellow	3,194 yellow	1,718 yellow	481 yellow	-	-	-
175.0	10.0	97.3%	2,253 yellow	7,638 yellow	6,700 yellow	-	-	-	-	-	-	-	811 yellow	2,290 yellow	954 yellow	-	-	-	-

眩光分析

模擬結果

安裝傾角最佳化評估

Tilt → / Orient ↓	5°	10°	15°	20°	25°	30°	35°	40°	45°
202°	94.8%	96.9%	98.4%	99.1%	99.2%	98.6%	97.2%	95.2%	92.5%
207°	94.7%	96.7%	98.1%	98.8%	98.8%	98.1%	96.7%	94.7%	92.1%
212°	94.5%	96.5%	97.7%	98.3%	98.3%	97.6%	96.2%	94.2%	91.5%
217°	94.4%	96.1%	97.3%	97.8%	97.7%	96.9%	95.5%	93.5%	90.9%
222°	94.2%	95.8%	96.9%	97.3%	97.1%	96.2%	94.8%	92.8%	90.2%
227°	94.0%	95.4%	96.3%	96.6%	96.3%	95.4%	94.0%	91.9%	89.4%
232°	93.8%	95.1%	95.8%	95.9%	95.5%	94.5%	93.0%	90.9%	88.4%
237°	93.6%	94.6%	95.2%	95.1%	94.6%	93.5%	91.9%	89.9%	87.3%
242°	93.3%	94.2%	94.5%	94.3%	93.6%	92.4%	90.8%	88.6%	86.1%
247°	93.1%	93.7%	93.7%	93.4%	92.5%	91.3%	89.5%	87.3%	84.7%
252°	92.8%	93.1%	93.0%	92.5%	91.4%	90.0%	88.1%	85.9%	83.2%

如何降低眩光光害 (模擬案例說明)

光滑無ARC表面處理

PV simulation potential temporary after-image

Component	Green glare (min)	Yellow glare (min)
OP: OP 1	0	3861
OP: OP 2	0	2653
OP: OP 3	0	2015
OP: OP 4	0	419
OP: OP 5	0	0
OP: OP 6	0	0

深度紋理表面處理

PV simulation low potential for temporary after-image

Predicted energy output: 2,389,000.0 kWh (assuming sunny, clear skies)

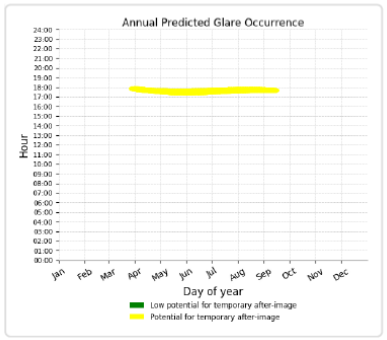
Component	Green glare (min)	Yellow glare (min)
OP: OP 1	25396	0
OP: OP 2	22908	0
OP: OP 3	14196	0
OP: OP 4	8157	0
OP: OP 5	6525	0
OP: OP 6	641	0

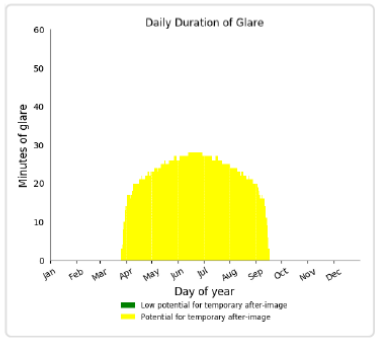
如何降低眩光光害 (模擬案例說明)

光滑無ARC表面處理

Point Receptor: OP 1

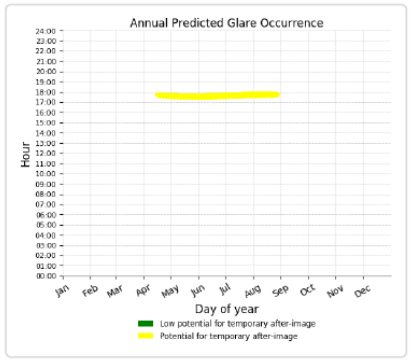
3987 minutes of yellow glare
0 minutes of green glare

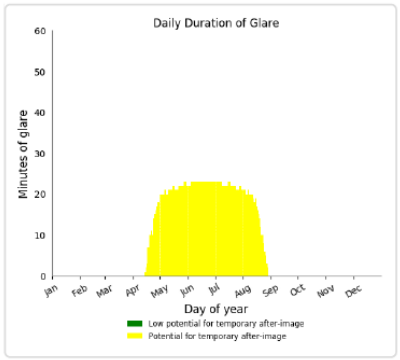




Point Receptor: OP 2

2652 minutes of yellow glare
0 minutes of green glare

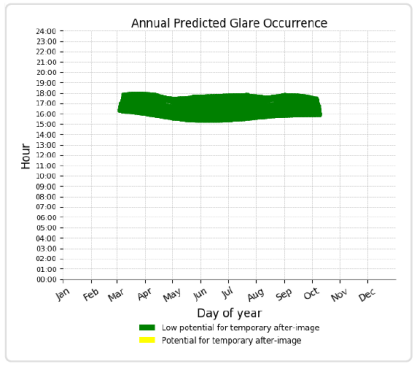


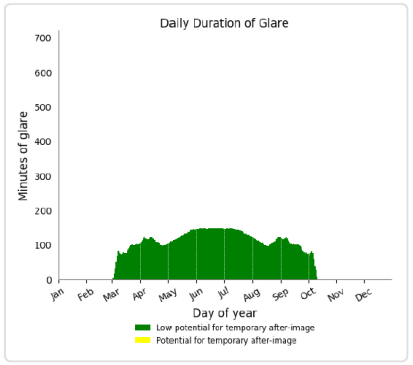


深度紋理表面處理

Point Receptor: OP 1

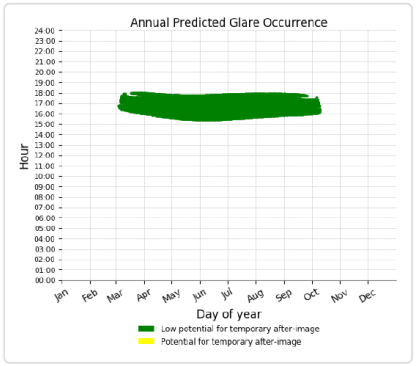
0 minutes of yellow glare
25396 minutes of green glare

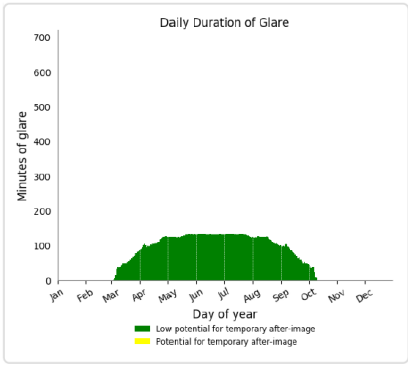




Point Receptor: OP 2

0 minutes of yellow glare
22908 minutes of green glare





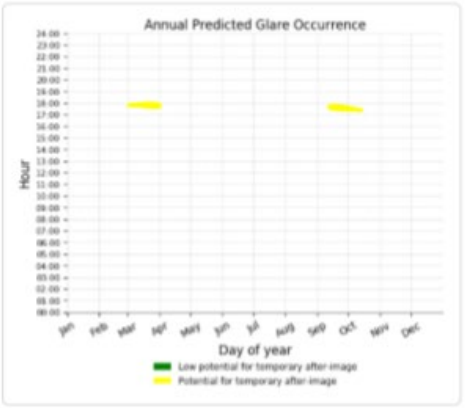
如何降低眩光光害 (模擬案例說明)

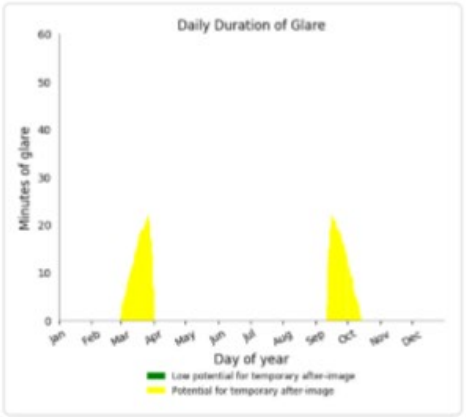
光滑無ARC表面處理

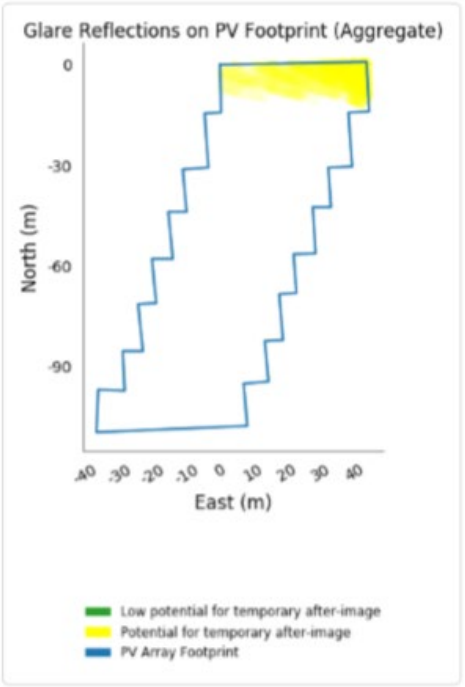
PV array 1 -tilt 15 deg - OP Receptor (OP 1)

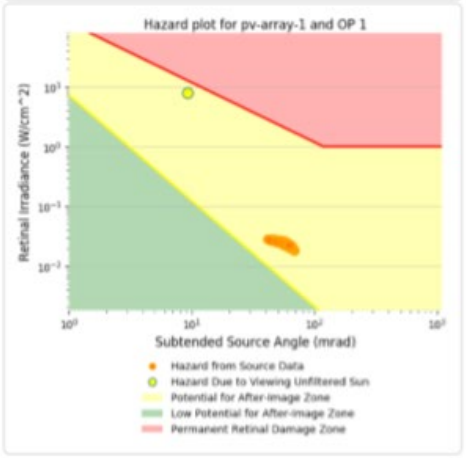
PV array is expected to produce the following glare for receptors at this location:

- 0 minutes of "green" glare with low potential to cause temporary after-image.
- 848 minutes of "yellow" glare with potential to cause temporary after-image.









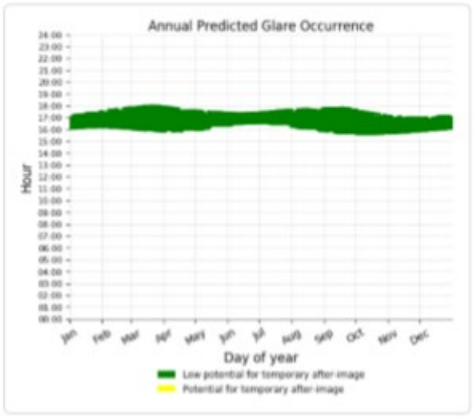
如何降低眩光光害 (模擬案例說明)

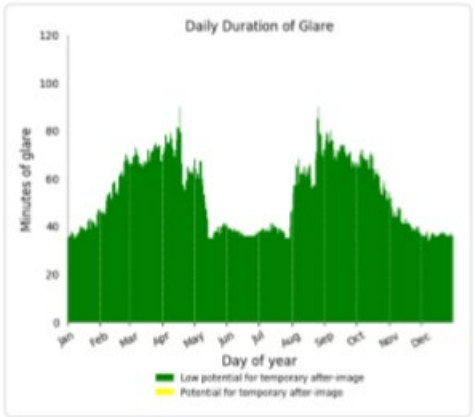
深度紋理表面處理模擬

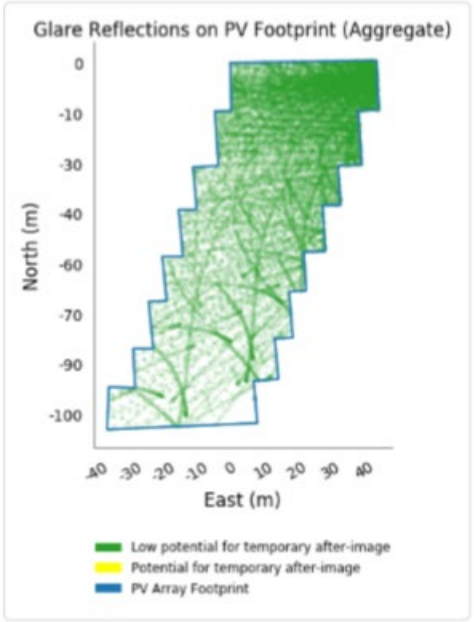
PV array 1 - OP Receptor (OP 1)

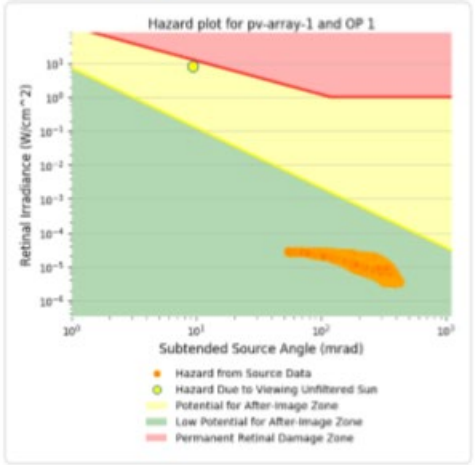
PV array is expected to produce the following glare for receptors at this location:

- 19,335 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.









眩光光害 (模擬案例說明)

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt (°)	Orient (°)	"Green" Glare min	"Yellow" Glare min	Energy kWh
PV array 1 -tilt 15 deg	15.0	180.0	193,031	81,579	-

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
OP 1	0	1185
OP 2	0	5782
OP 3	0	4634
OP 4	0	0
OP 5	0	0
OP 6	0	0

降低眩光光害之對策建議

模擬結論:

- 依模擬的地點進行設定，無法全方位都無眩光
- 深度紋理表面可大幅降低眩光狀況
- 安裝角度可影響眩光分佈及眩光等級，影響程度仍依表面處理狀況決定

建議:

- 使用高度紋理表面太陽光電模組=>模組表面反射率評估
- 建置前進行眩光模擬=>場域模擬
- 依模擬結果，改變安裝角度，或以遮蔽物阻隔眩光

模組表面反射率評估+場域模擬 ⟹

雙管齊下，最終降低眩光光害

謝謝聆聽 Q & A