



# 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

2019/09/25 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

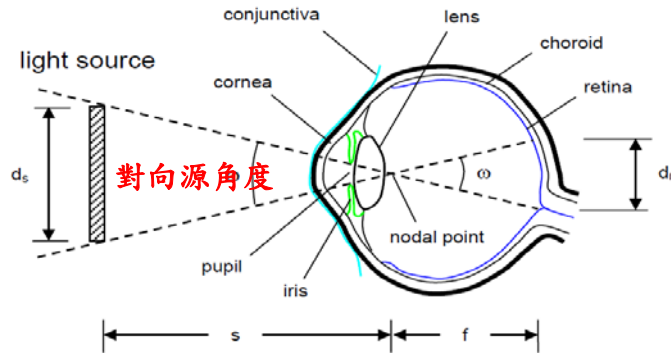
依眩光來源分為：

- ◆ **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



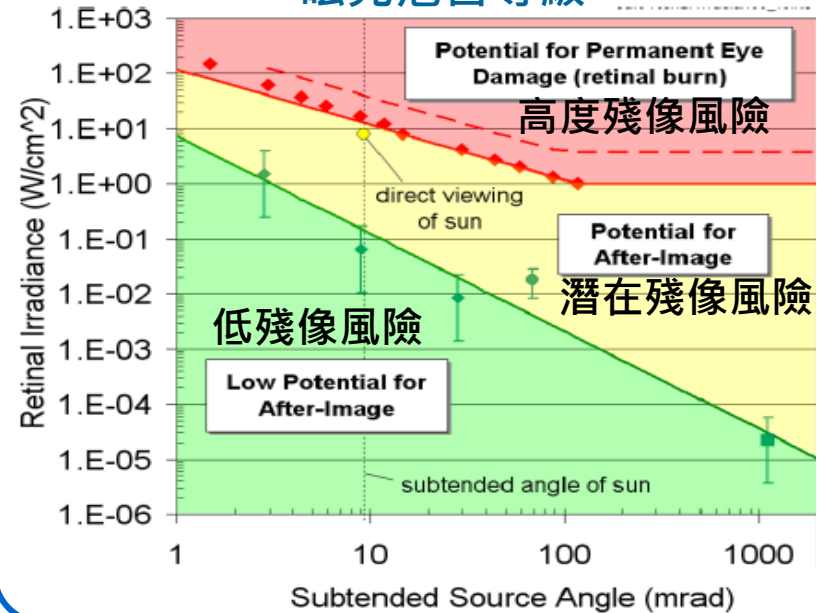
# 眩光相關因子

## 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**



## 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 $<15^\circ$ )

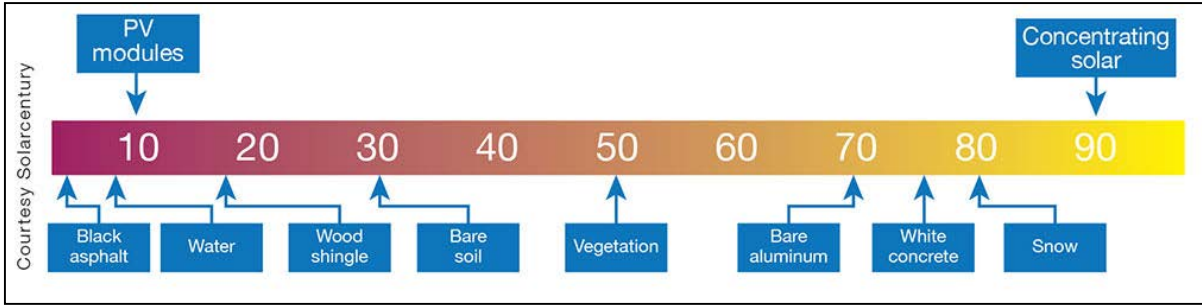


有方法可解決眩光光害問題嗎？

太陽模組表面多角度反射率評估  
場域模擬評估分析

# 太陽模組表面反射率

## 各種材質反射程度比對值



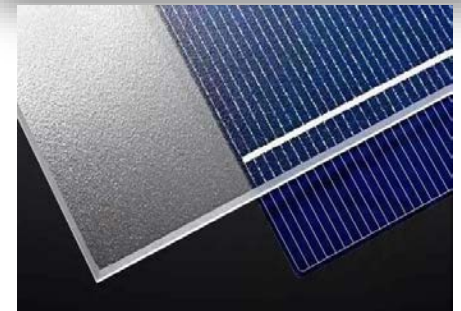
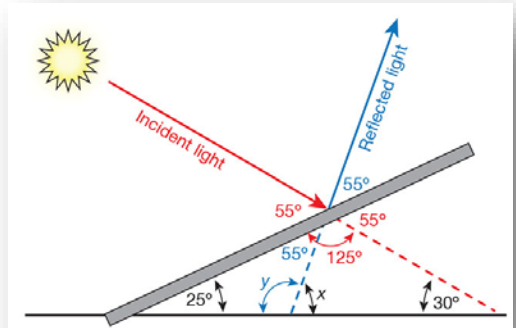
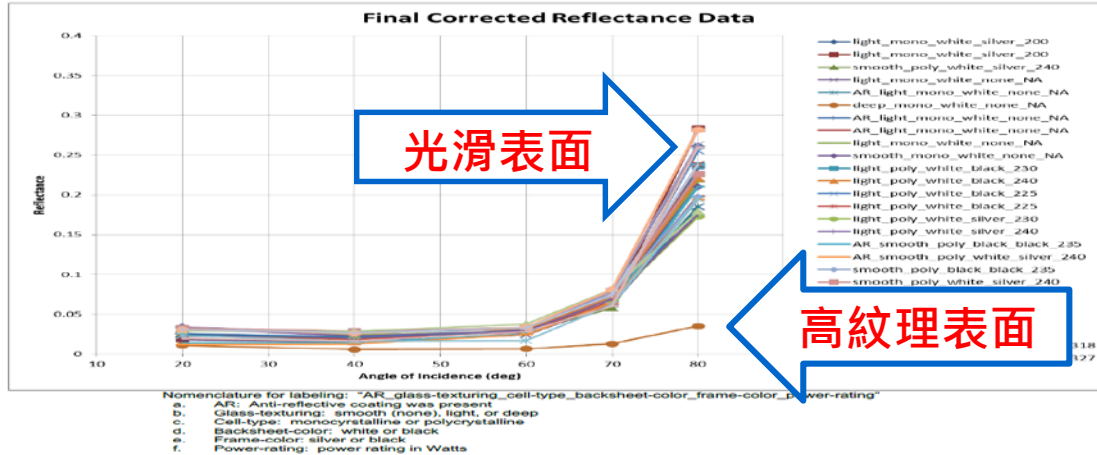
密集的太陽模組陣列  
反射度比雪地反光嚴重

## 太陽模組表面反射率

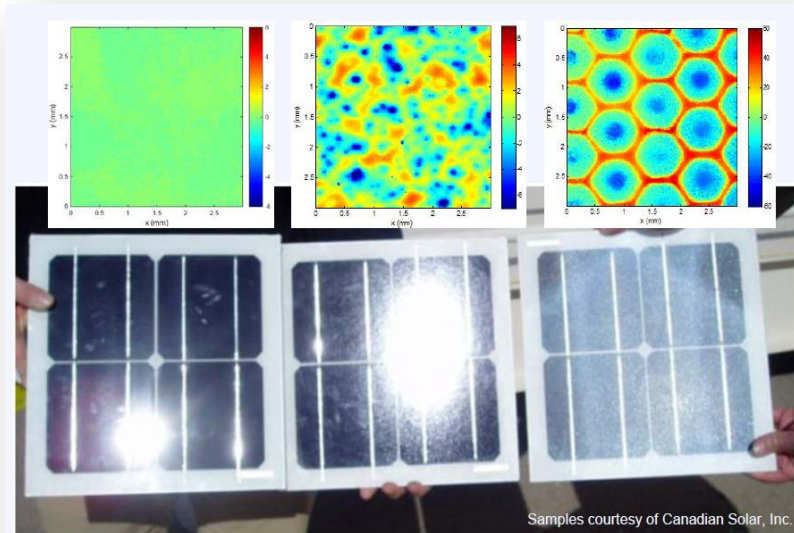
很大程度上取決於太陽光的入射角(相對於表面法線)大小

-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



## 表面粗化特性與眩光狀態 示意圖



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

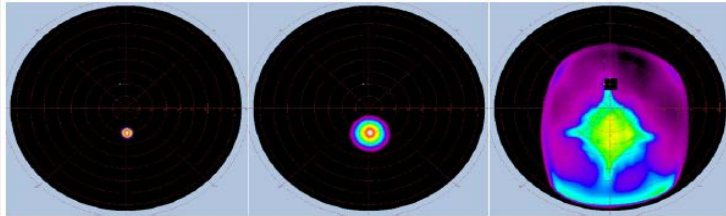
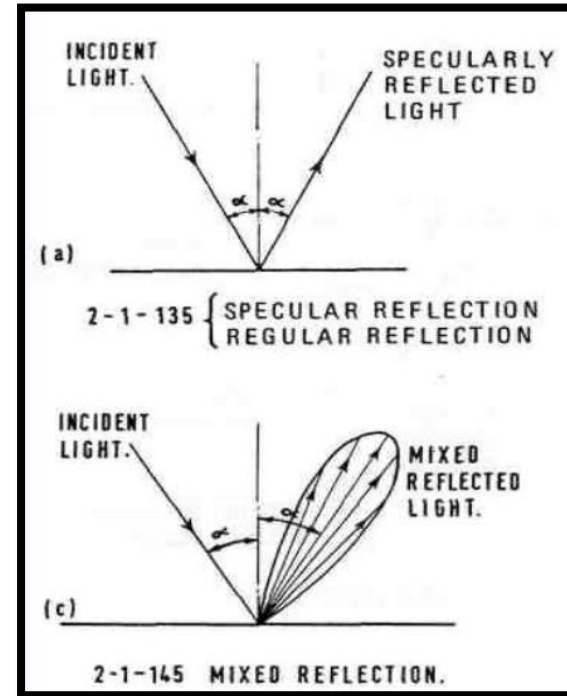


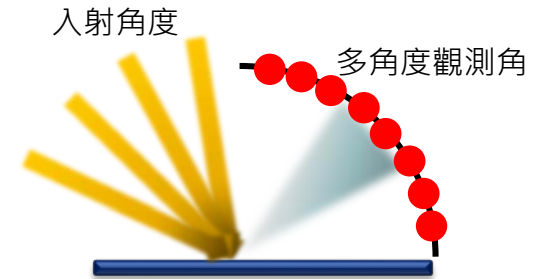
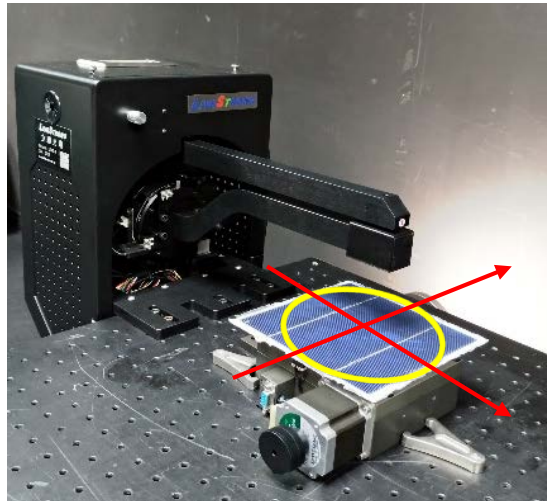
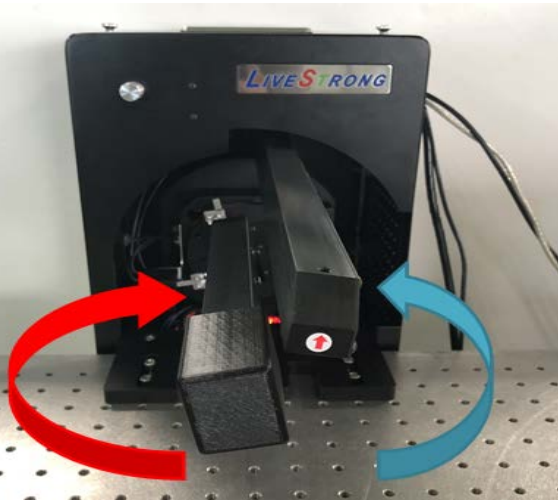
Fig. 2 Measured reflectance distribution function at an incident angle of 20° for three different glass types left: flat float glass, middle: rolled glass with a slightly structured surface, right: rolled glass with macroscopic pyramidal structure.



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







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

## 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 $180^\circ$ )

表面反射率參數 (光滑, ARC, 紋理處理)

Name	<input type="text" value="PV array 1"/>	<b>Name:</b> PV array 1
Tracking	<input type="text" value="None"/>	<b>Axis tracking:</b> Fixed (no rotation)
Tilt	<input type="text" value="0"/> deg	<b>Tilt:</b> 10.0 deg
Orientation	<input type="text" value="180"/> deg <small>(Calculate declination)</small>	<b>Orientation:</b> 180.0 deg
	<a href="#">advanced...</a>	<b>Rated power:</b> 1000.0 kW
		<b>Panel material:</b> Deeply textured glass
		<b>Vary reflectivity with sun position?</b> Yes
		<b>Correlate slope error with surface type?</b> Yes
		<b>Slope error:</b> 82.6 mrad

## 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



Discrete Observation Receptors

Number	Latitude deg	Longitude deg	Ground elevation m	Height above ground m	Total Elevation 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

## 觀測點參數設定

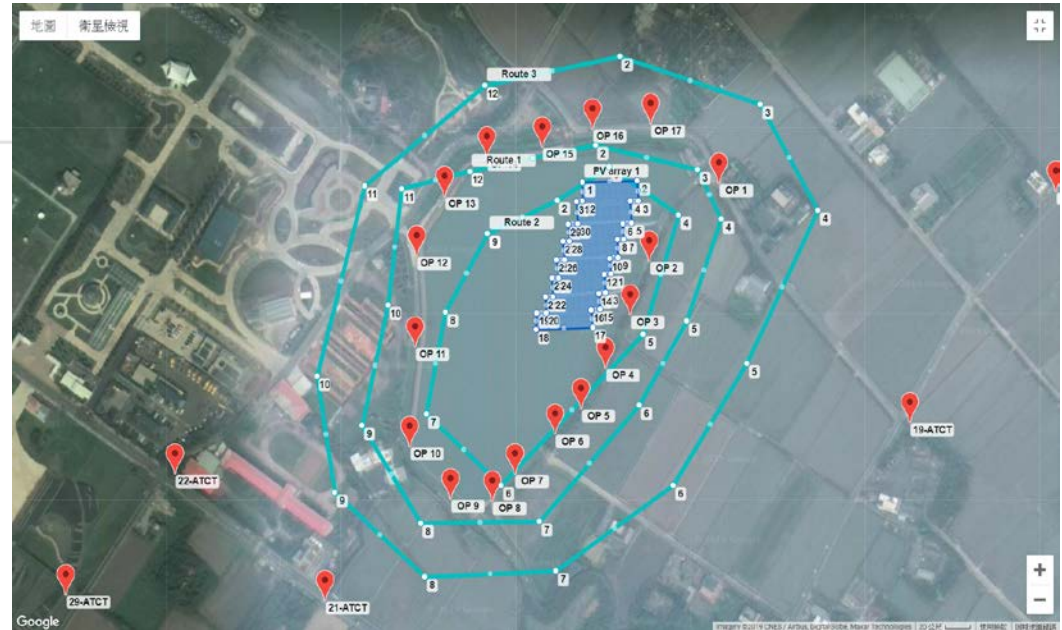
所在點高度

方位角(朝南為180°)

路徑(車道方向，單向/雙向)

## Route Receptor(s)

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



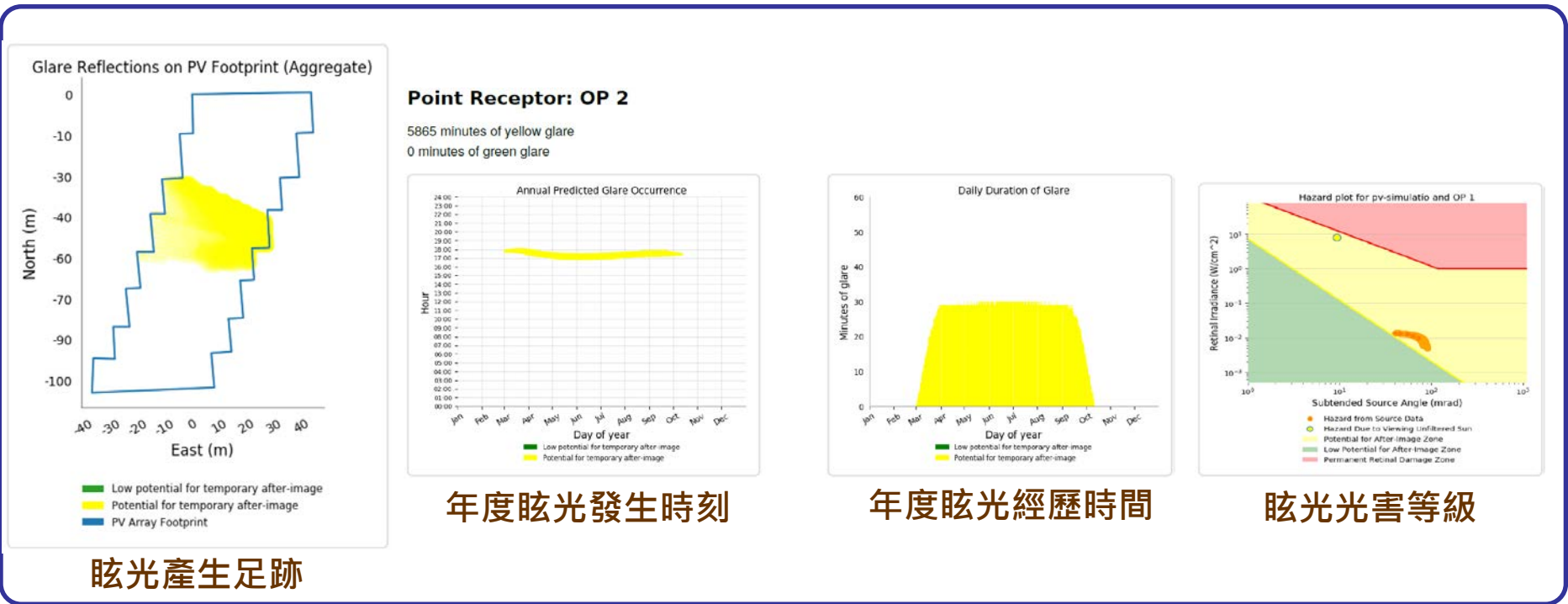
Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	25.006925	121.051123	23.09	30.00	53.09
2	25.007100	121.052110	20.84	30.00	50.84
3	25.006935	121.052915	23.17	30.00	53.17
4	25.006604	121.053097	24.21	30.00	54.21
5	25.005924	121.052829	24.49	30.00	54.49
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

## 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



## 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	-	-	-	-

## 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%

## 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)

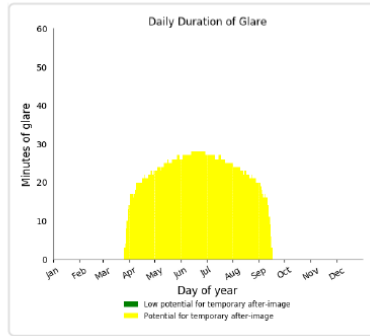
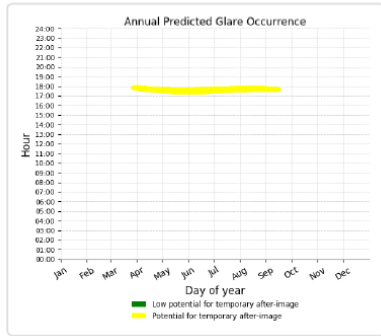
Component	Green glare (min)	Yellow glare (min)
OP: OP 1	25396	0
OP: OP 2	22908	0
OP: OP 3	14196	0
OP: OP 4	8157	0
OP: OP 5	6525	0
OP: OP 6	641	0



## 光滑無ARC表面處理

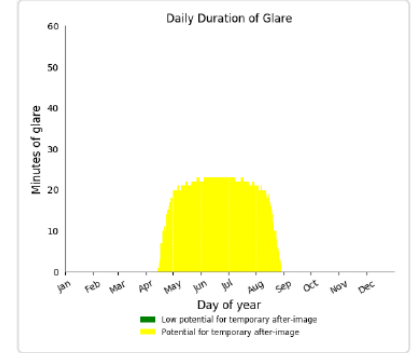
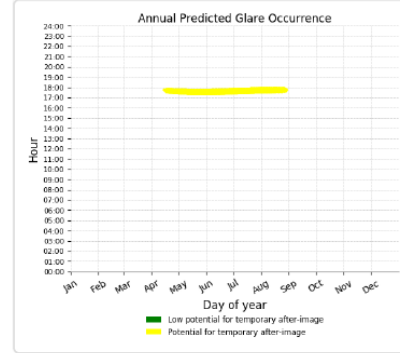
### Point Receptor: OP 1

3987 minutes of yellow glare  
0 minutes of green glare



### Point Receptor: OP 2

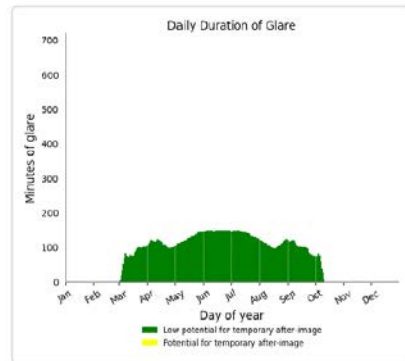
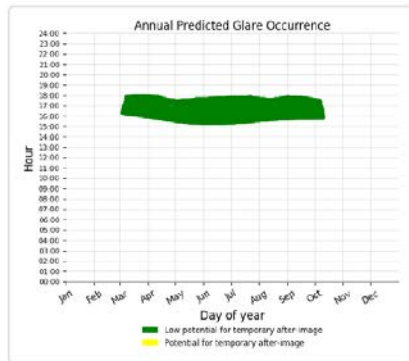
2652 minutes of yellow glare  
0 minutes of green glare



## 深度紋理表面處理

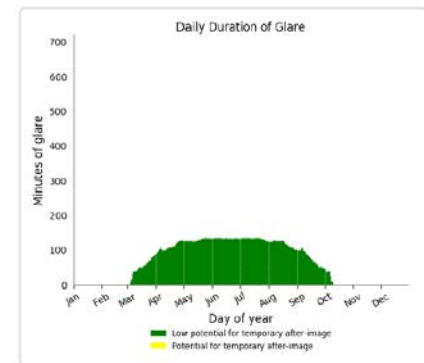
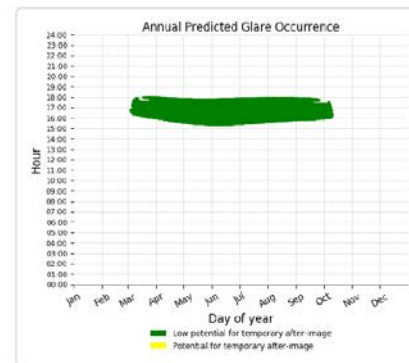
### Point Receptor: OP 1

0 minutes of yellow glare  
25396 minutes of green glare



### Point Receptor: OP 2

0 minutes of yellow glare  
22908 minutes of green glare



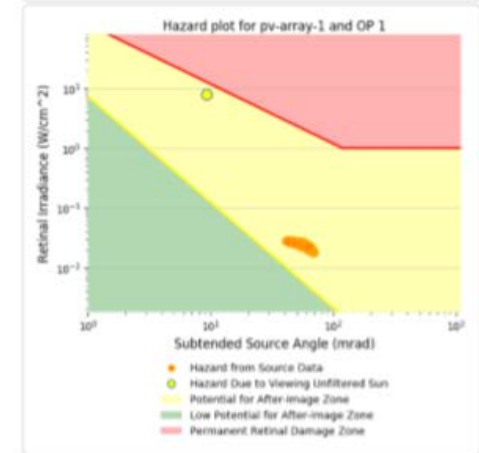
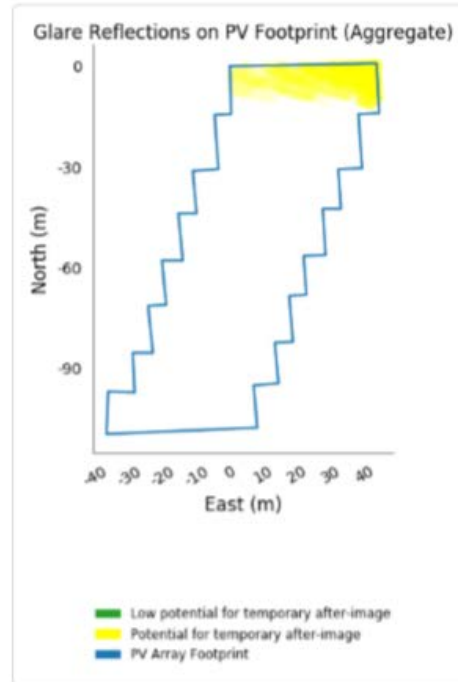
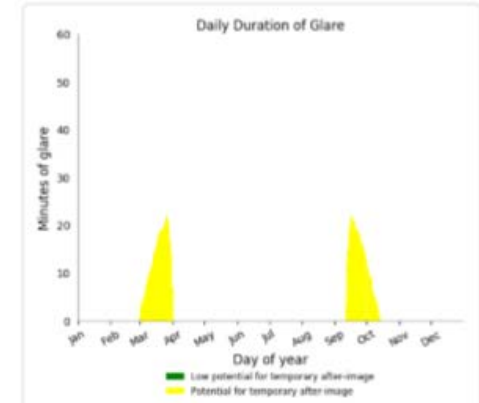
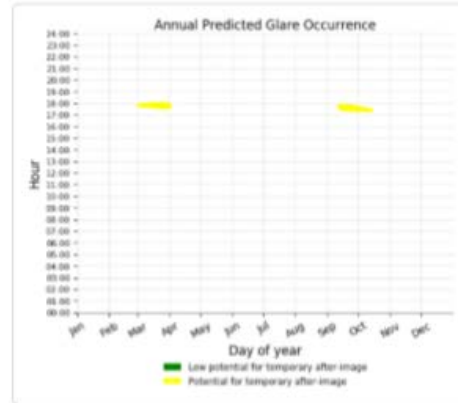
# 如何降低眩光光害 (模擬案例說明)

## 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)

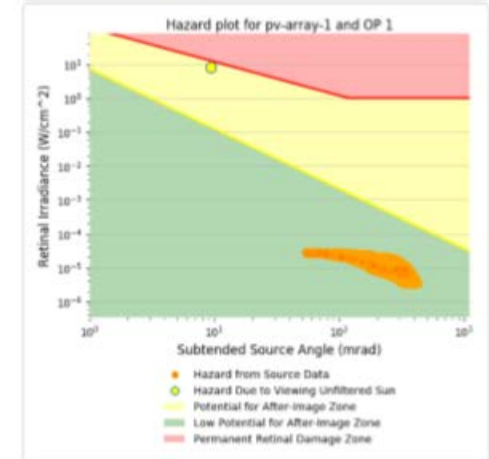
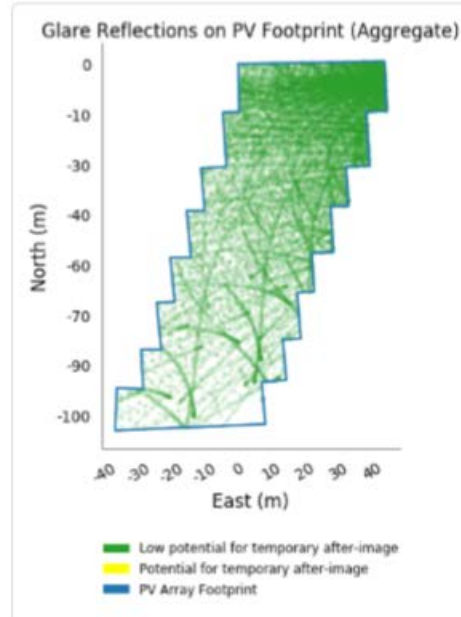
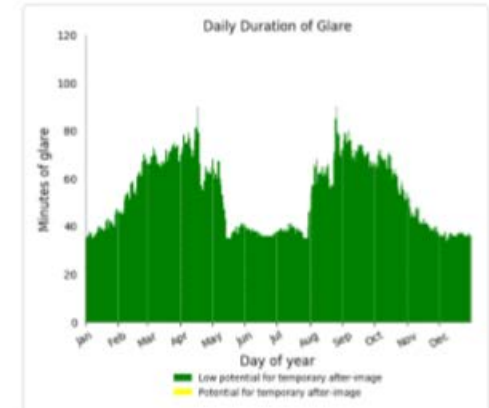
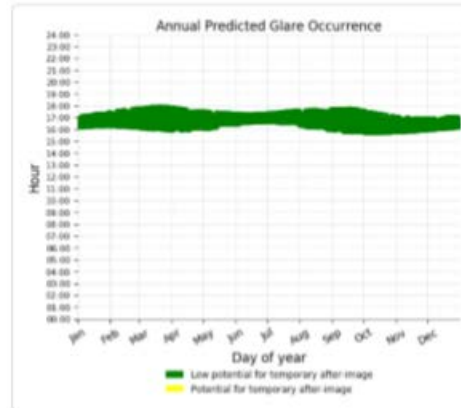
## 深度紋理表面處理模擬



### 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.



## 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

## 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

