THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

香港太陽能學會
Solar Energy Society of Hong Kong

Practical Utilizations of Solar Energy in Hong Kong

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Department of Building Services Engineering,

The Hong Kong Polytechnic University

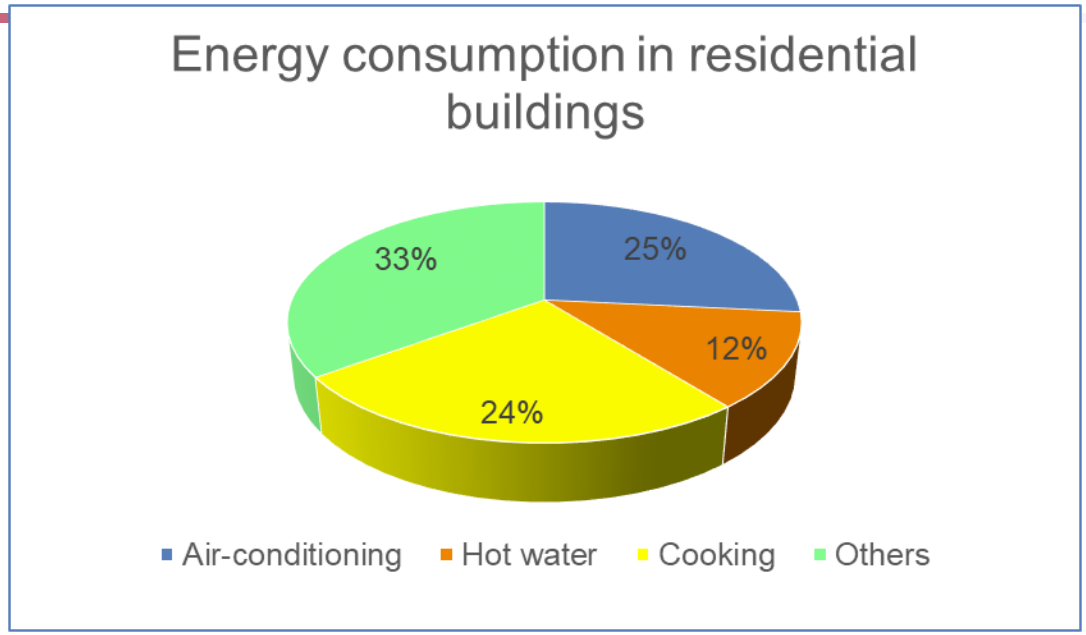
15-06-2019

Outlines

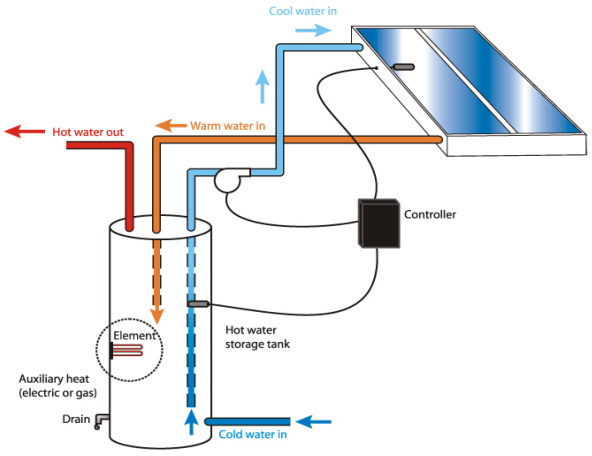
- ✓ Solar hot water utilization in Hong Kong
- ✓ Potential solar photovoltaic applications in the world and in Hong Kong
- ✓ Our research activities in BIPV applications
- ✓ Selection of solar PV panels
- ✓ Solar energy desiccant dehumidification for AC
- ✓ Conclusions

1. Solar hot water utilization in Hong Kong

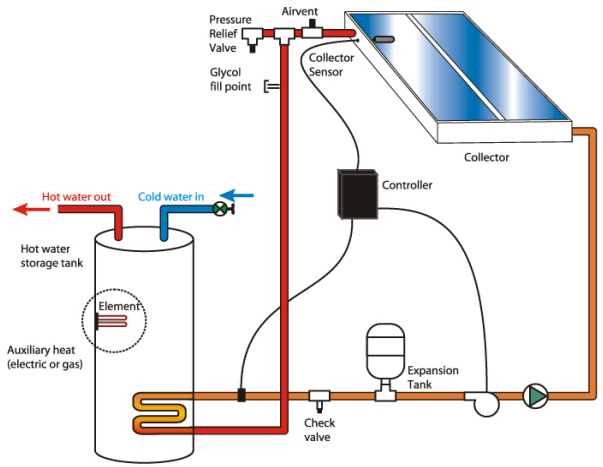
- Direct type (open-loop system)
- Indirect type (closed-loop system)



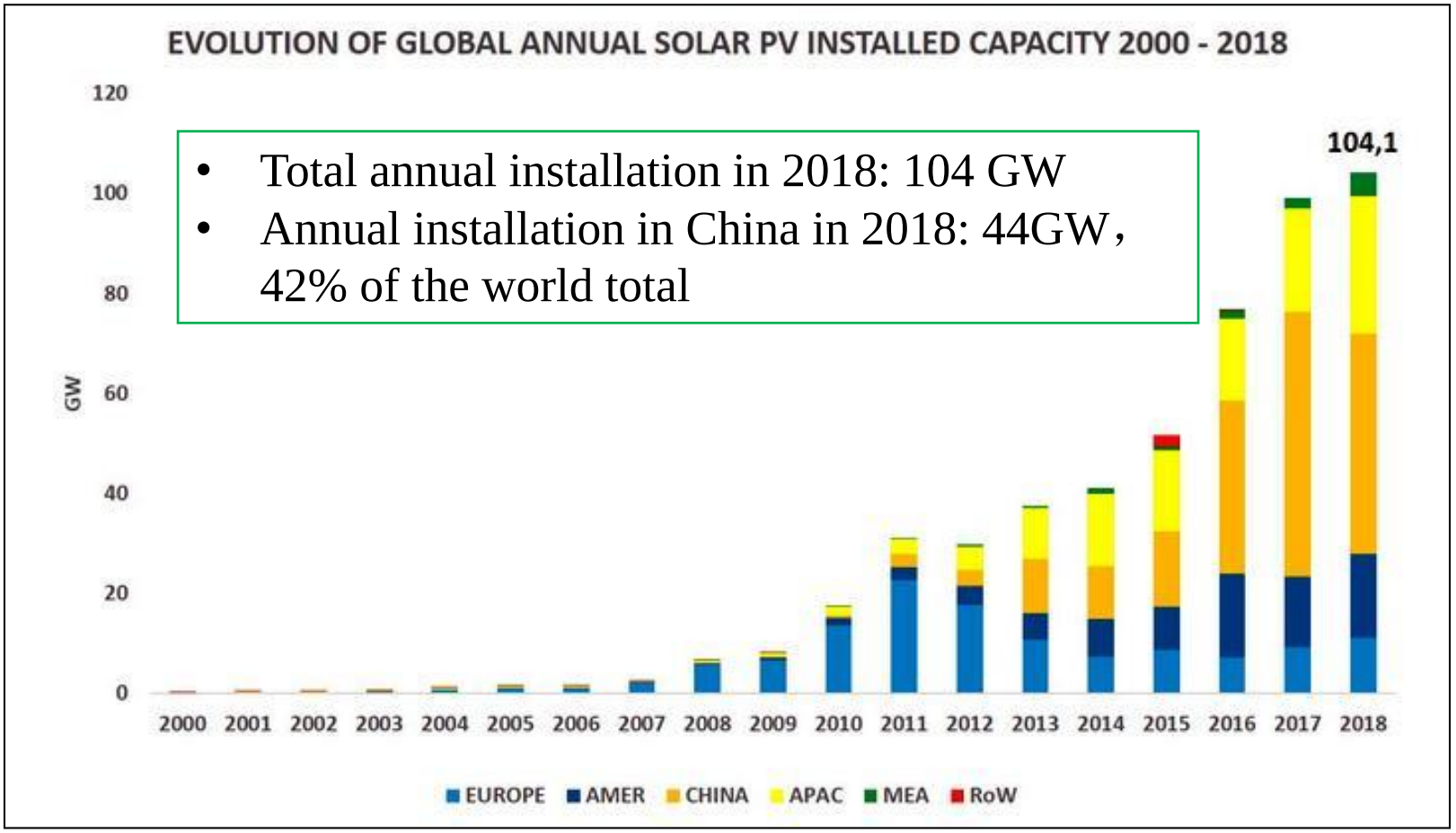
Active Open Loop System



Closed Loop, Freeze-Protection System

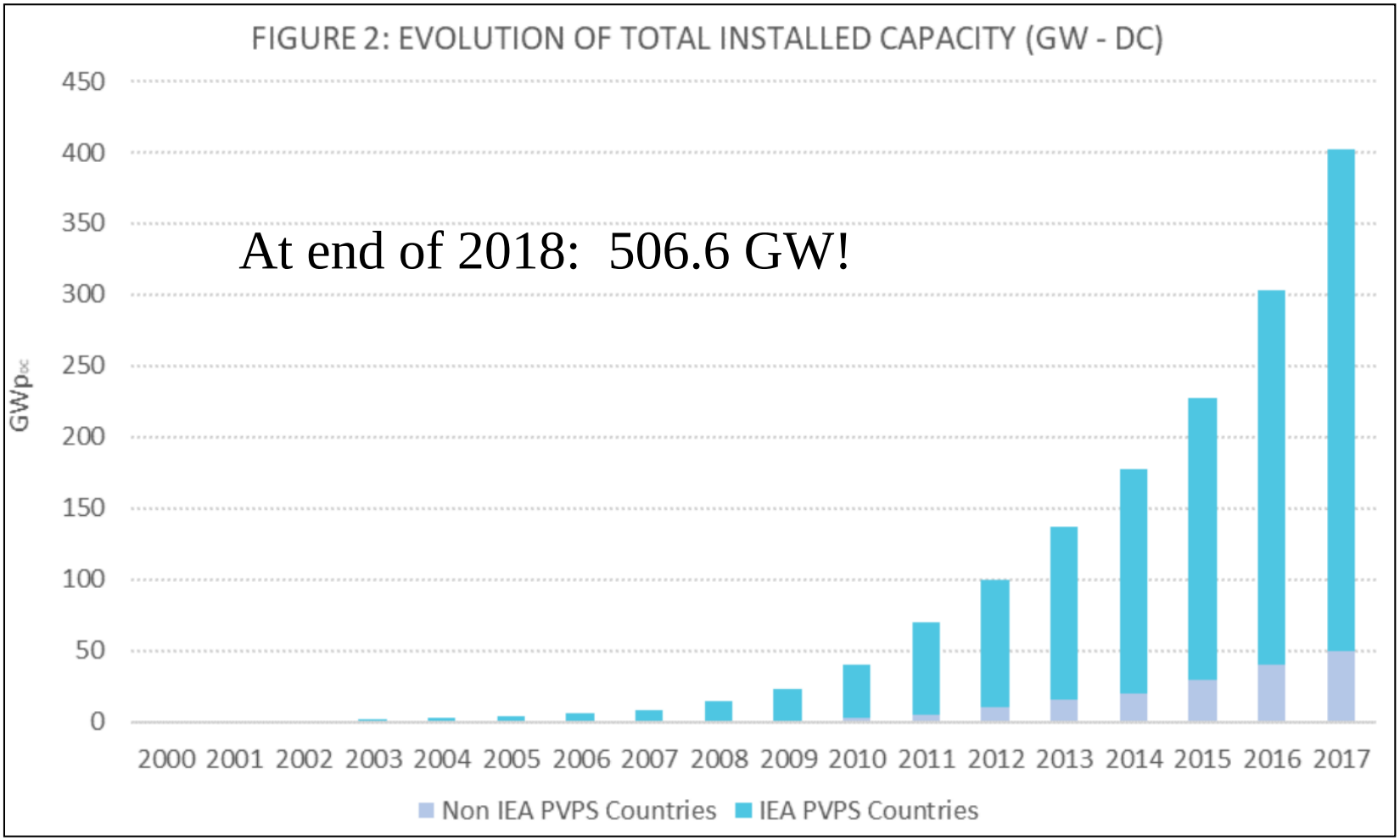


2. Potential solar photovoltaic applications in the world and in Hong Kong

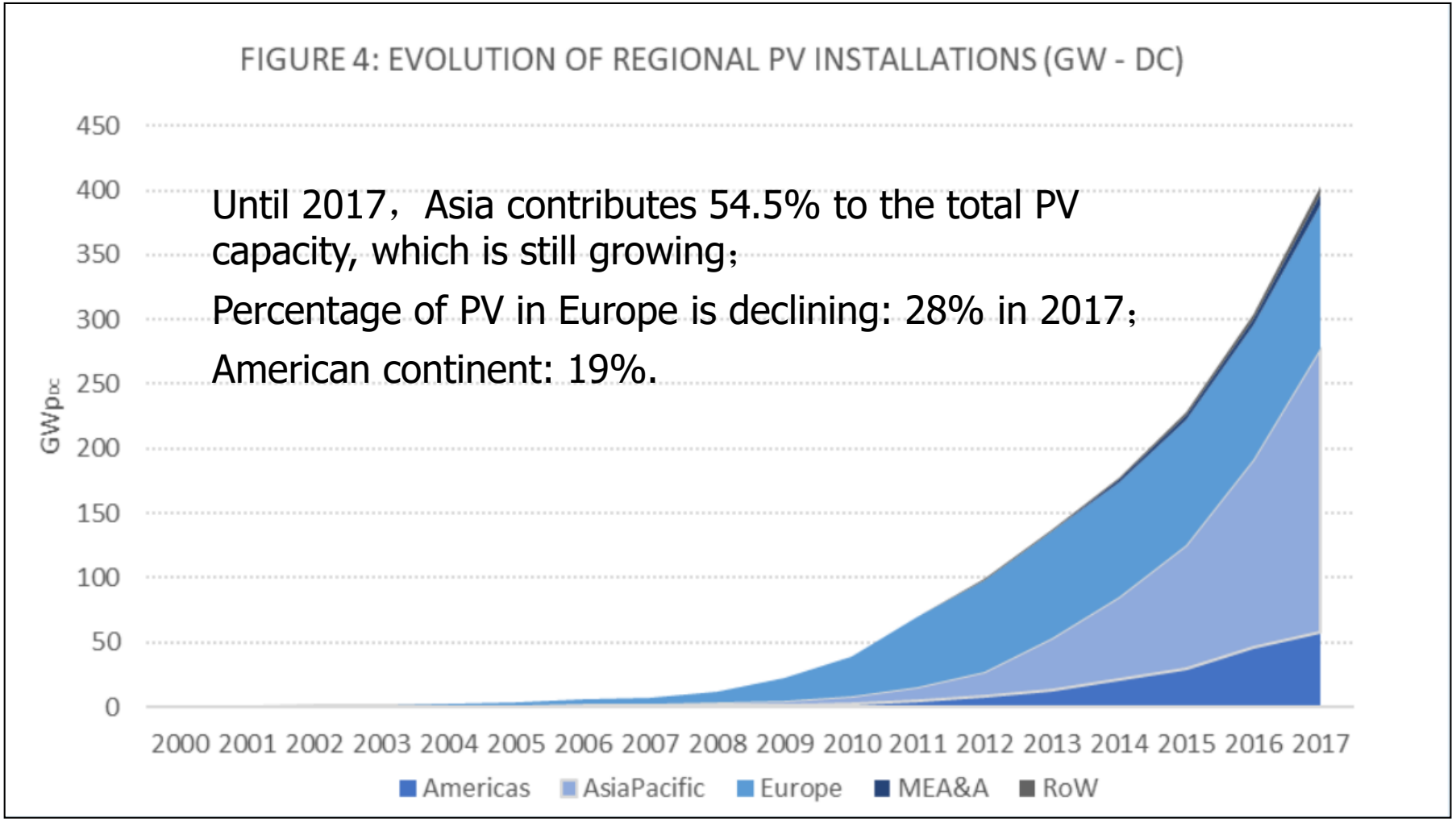


Source: grafic-solar-web: http://www.energynomics.ro/en/newly-installed-solar-capacity-increased-in-eu-by-36-in-2018-up-to-8-gw/

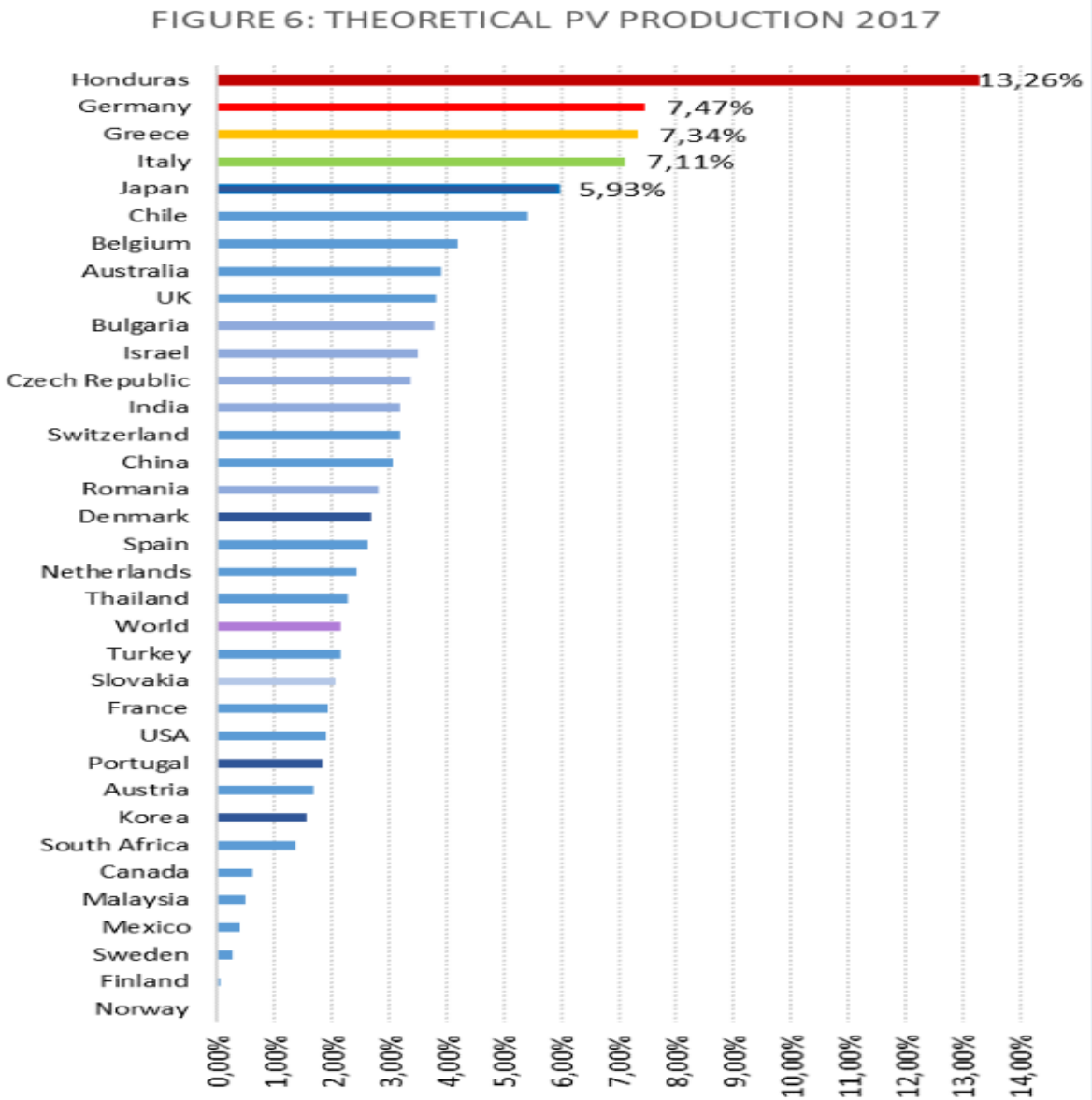
Accumulated PV capacity 2000-2018（GW, DC）



Total regional PV capacity 2000-2017（GW, DC）



Percentage of power generation in 2017（%）



>5%: 6 countries；

>3%: 15 countries；

>1%: 29 countries；

Honduras: 13.26%；

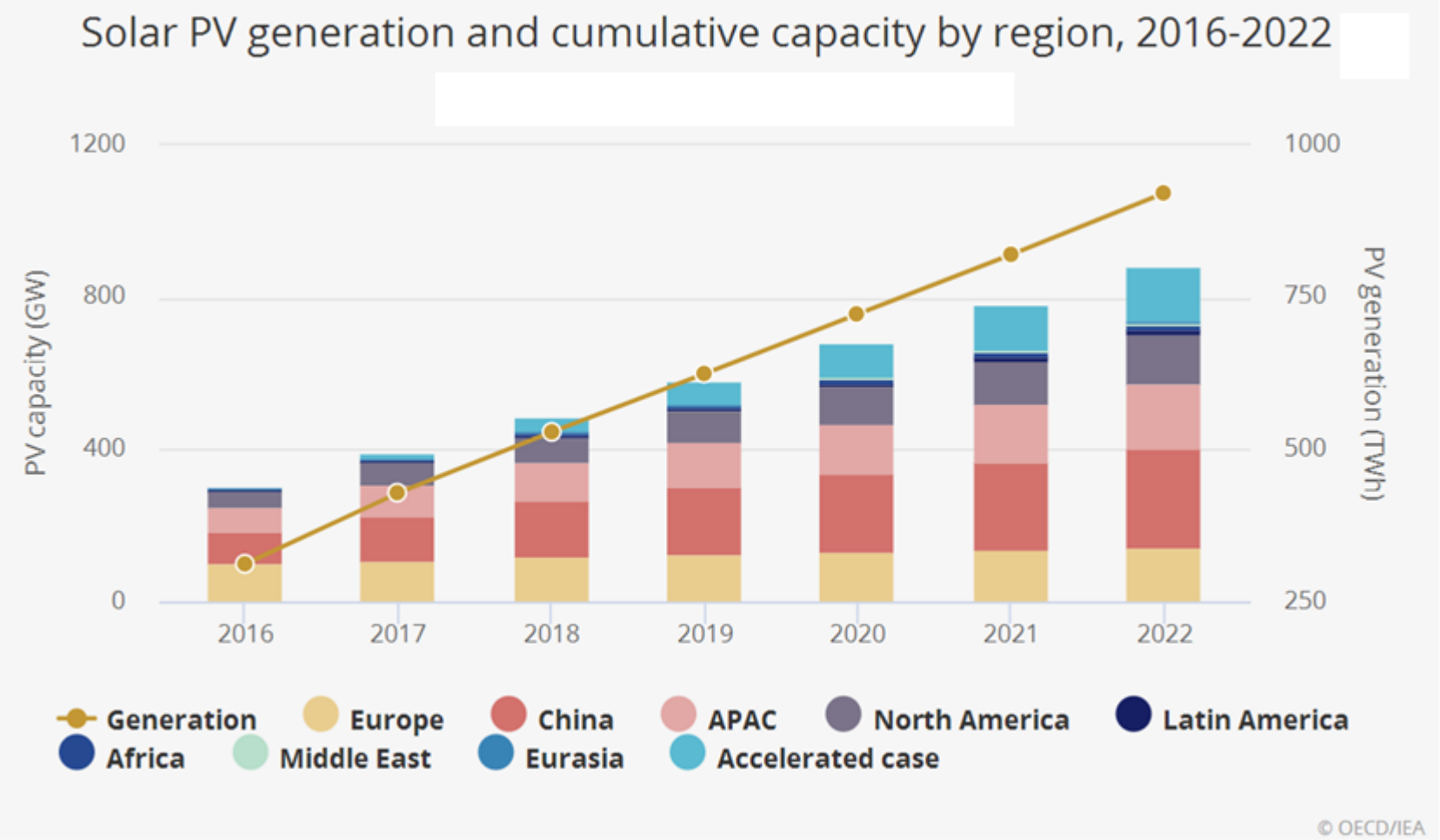
Germany: 7.47%；

Greece: 7.34%；

Europe: 4%；

China: 3%。

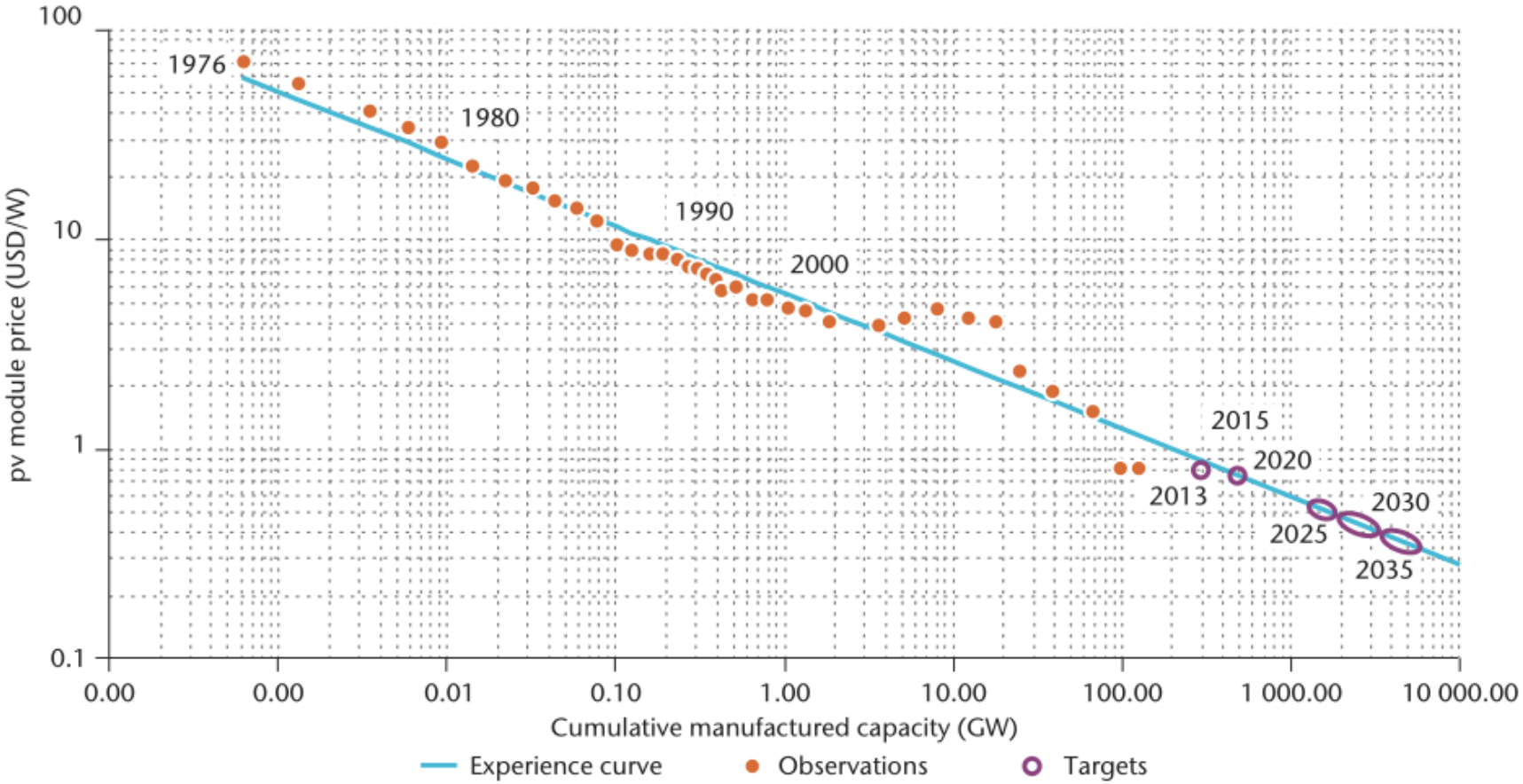
PV installation and power generation in 2022



In 2020，world PV installation capacity: 700GW, and power generation: 730TWh；
In 2022，wolrd PV installation capacity: 860GW，and power generation: 900TWh.

PV module cost in 2035

Figure 10: Past modules prices and projection to 2035 based on learning curve

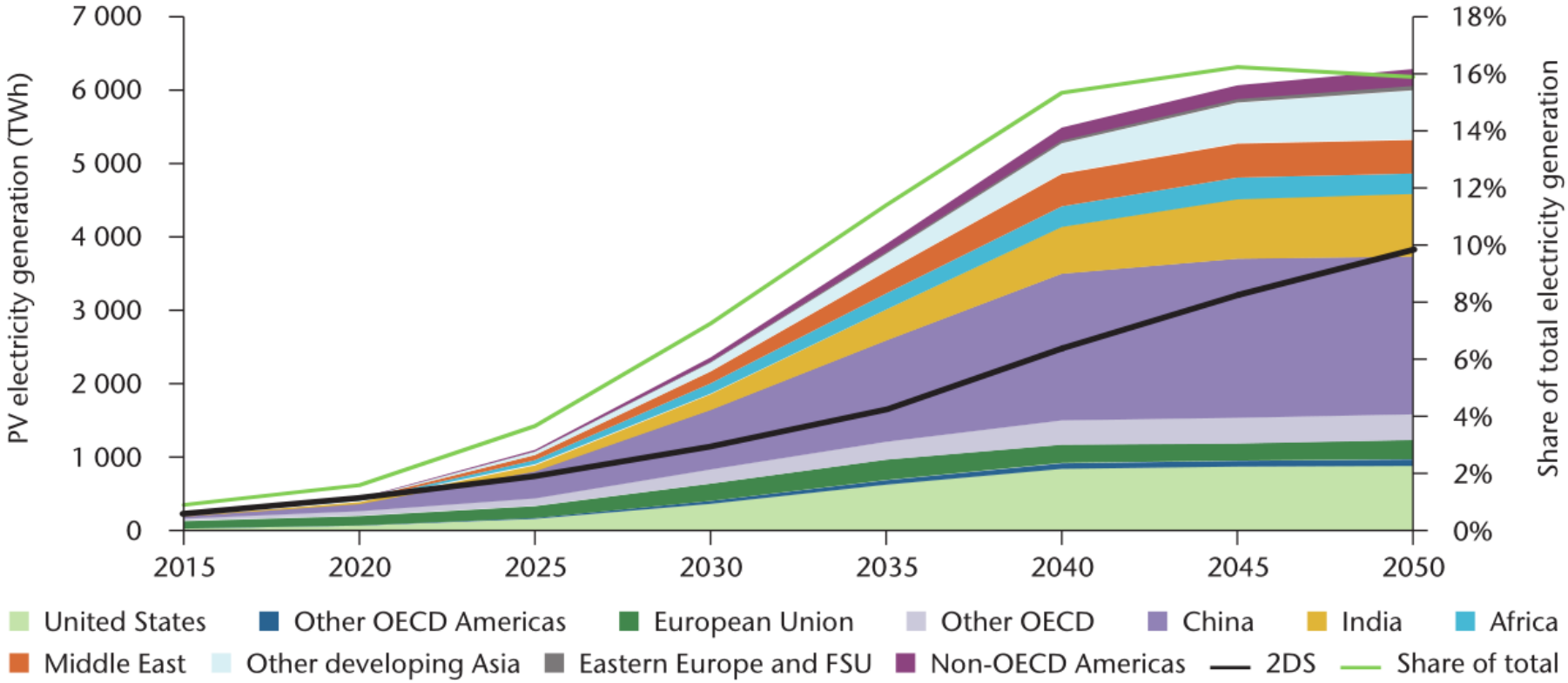


Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

In 2035，0.3USD/W --0.4USD/W.

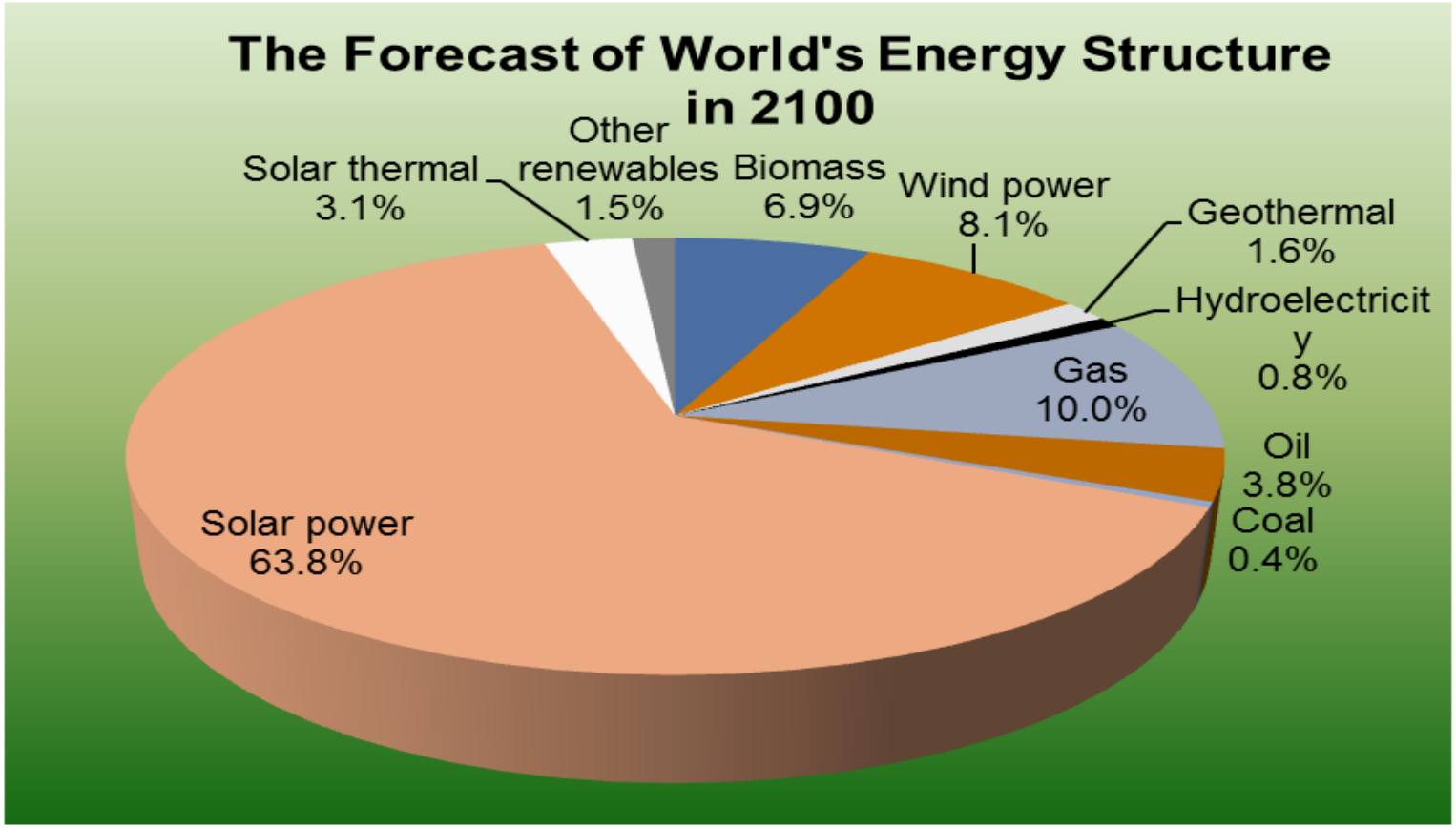
Prediction of PV power until 2050

Figure 8: Regional production of PV electricity envisioned in this roadmap



In 2050, total power will be 6300TWh, 16% of the total power consumption.

Prediction of energy resource structure



From German Advisory Council on Global Change（Title：World in Transition – Towards Sustainable Energy Systems, Flagship Report 2003）.

Rapid development of PV power in China



The world largest PV project:

1.547GW PV project at Zhongwei City, Ningxia, China



Kamuthi Solar Power Station, India

The project has a total generation capacity of 648 MW, covering 2,500 acres (10 sq km) and consisting of 2.5 million solar panels, enough power for 750,000 people, completed in September 2016 at a cost of approximately $679m.



Source: https://www.power-technology.com/wp-content/uploads/sites/7/2018/08/KamuthiSolarPark.jpg

3. BIPV applications

-Building integrated Photovoltaics (BIPV)

BIPV： refers to using photovoltaic materials, viz. solar cells and PV modules, to replace conventional building materials in parts of the building envelope such as the roof, skylights, windows or facades where the PV modules simultaneously serving as building envelope material and generating power.







Future trend of solar photovoltaic applications

——Building integrated Photovoltaics (BIPV)

Functions of BIPV

- Power generator
- Part of construction materials
- Water proof
- Shading
- Noise barrier
- Insulation
- Natural lighting

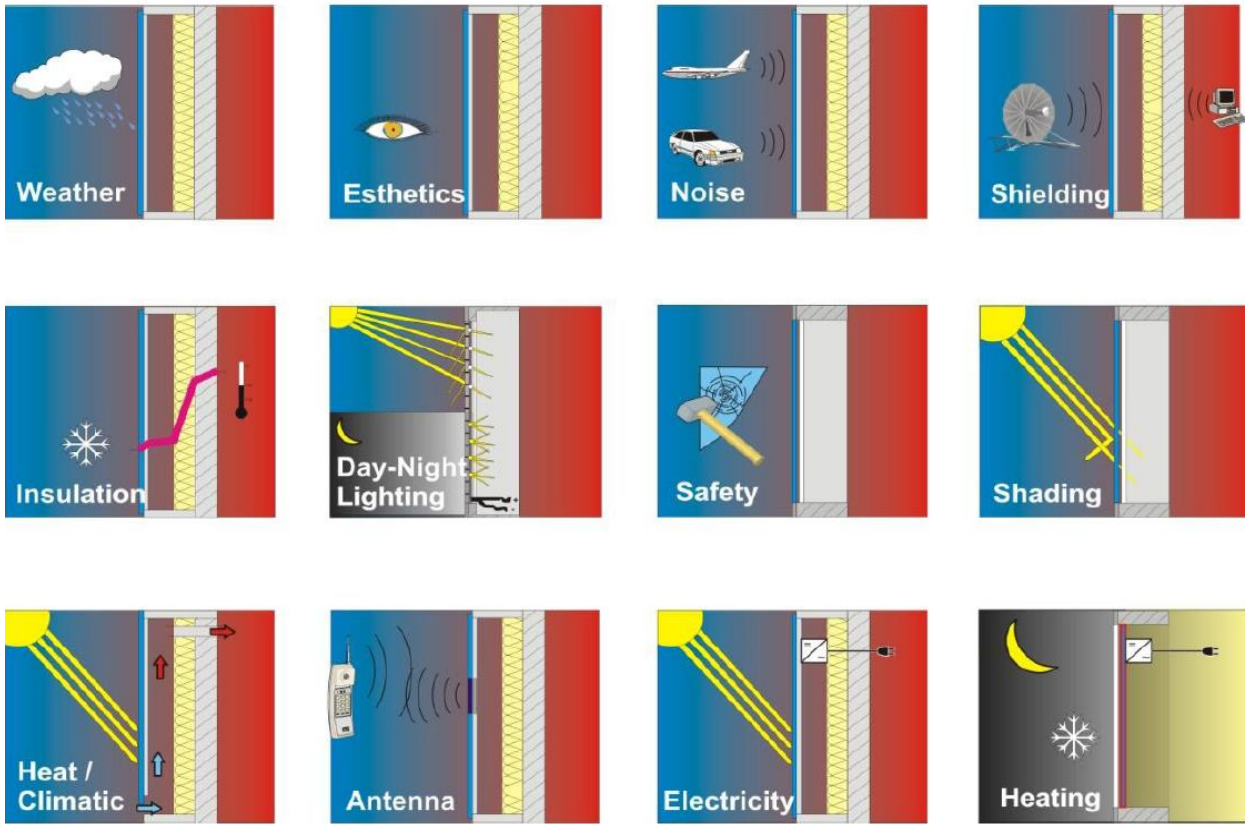
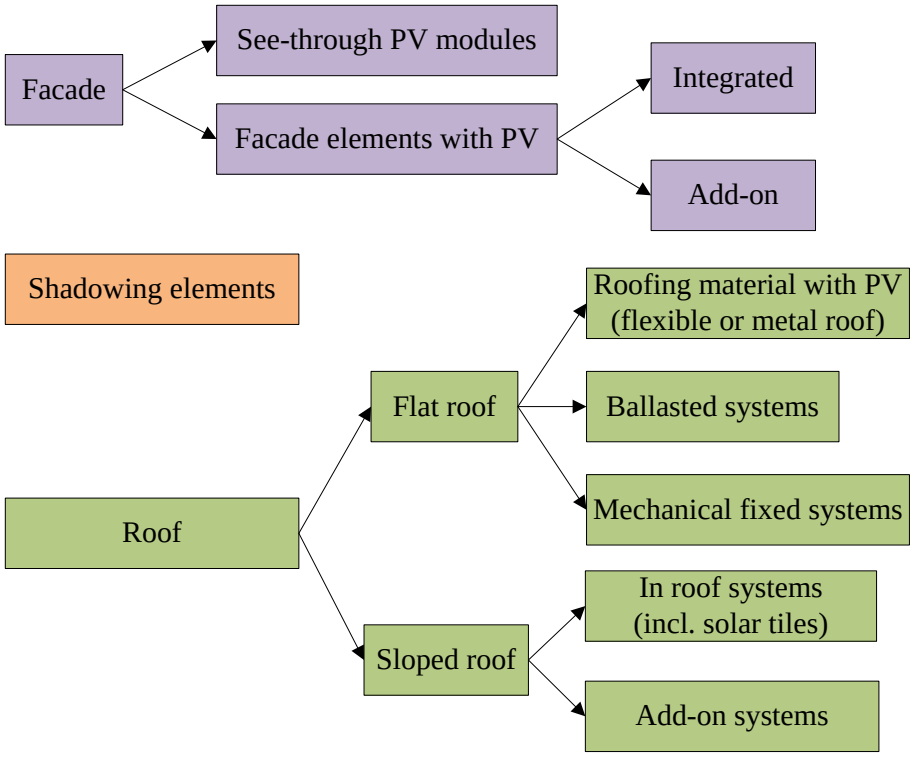
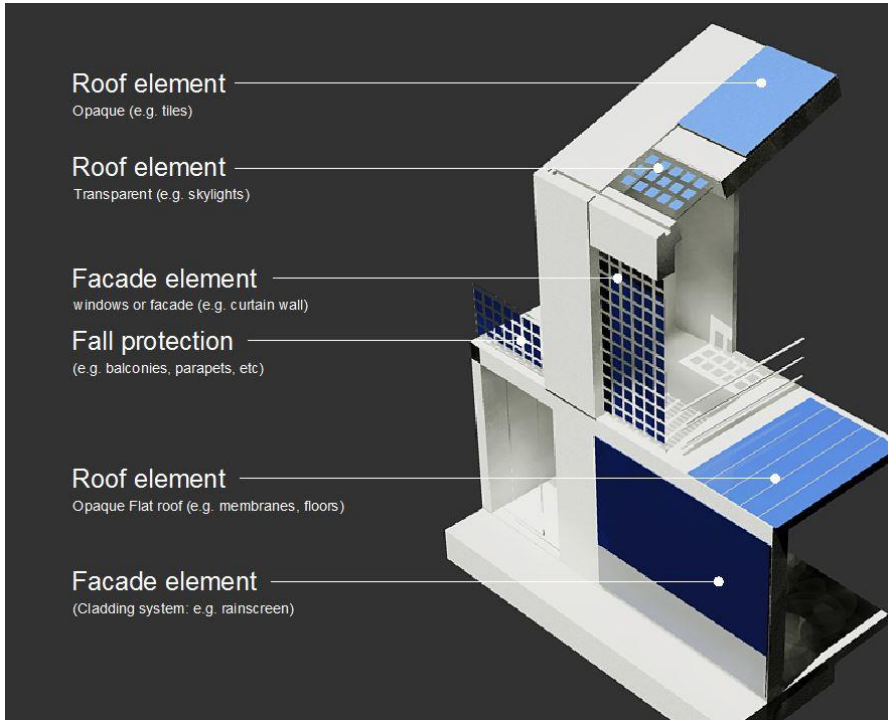


Figure 1. Multiple functions of PV modules. Source: Multielement project

BIPV applications





An overview of applications of PV modules in buildings.

BIPV projects-rooftop









BIPV facade







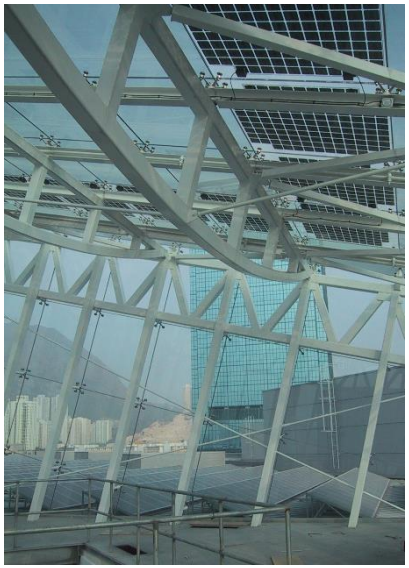


BIPV Projects

- **Skylight and atrium**





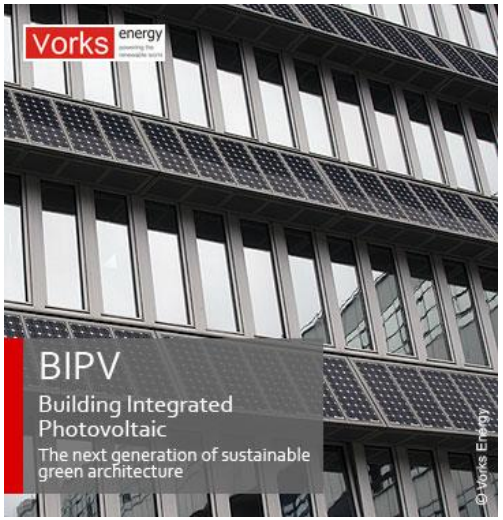


- **Shading type**









The 1MWp solar roof project in Shenzhen

- Shenzhen World Garden Flower Exhibition Park



BIPV of the South Railway Station in Nanjing



Installation capacity: 10.67 MW.
(The biggest single BIPV project in the world)
PV module type: Poly-Si



Annual energy output: 9.12 GWh
Annual CO_2 emission reduction: 9000 tons

BIPV of the Museum of Natural Science in Jiangxi



Installation capacity: 3.05 MW
PV module type: a-Si hollow PV module
Installation method: BIPV on facades and roof

BIPV of Zhujiang City in Guangzhou





Installation capacity: 185 kW
PV module type: a-Si PV module
Installation method: BIPV on the east and west facades

BIPV in Huangshi of Hubei



Installation capacity:
3 MW
PV module type:
Poly-Si PV module
Installation method:
BIPV on facades, roofs and shading panels

BIPV of Hanergy in Jiangsu



Installation capacity: 67 KW
PV module type: a-Si PV module
Installation method: BIPV on facades
Annual energy output: 33919 kWh
Annual CO_2 emission reduction: 10 tons

New BIPV claddings from Hanergy

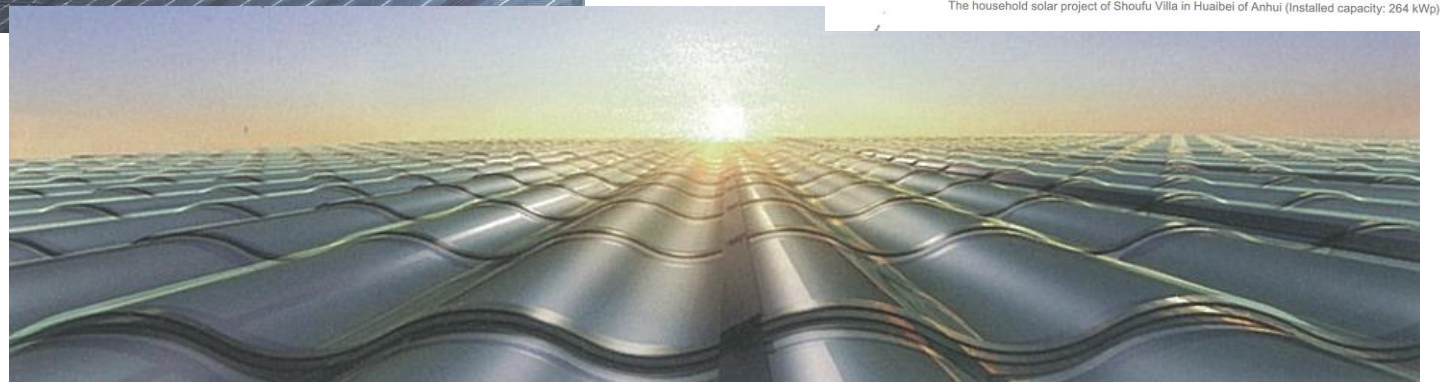



The household solar project in Guoyuan Community of Xucheng Town in Xuyi County of Jiangsu (Installed capacity: 4 kWp)


The household solar project on No. 2 Huaxia Road of Pudong New Area in Shanghai (Installed capacity: 1.5 kWp)


The household solar project in Huadu District of Guangzhou (Installed capacity: 33 kWp)


The household solar project of Shoufu Villa in Huaibei of Anhui (Installed capacity: 264 kWp)



BIPV applications in Taiwan



1MWp at Kaohsiung National Stadium (2009)

Table 1: Annual radiation comparison across different latitude [12, 13].

	Latitude	Annual solar radiation (Wh/m^2/year)
Taiwan-1 (Max)		1,560
Taiwan-2 (Average)	±23°N	1,059
Taiwan-3 (Min)		801
Sahara	25°00'N	2,500
Israel	33°00'N	2,000
Los Angles, USA	34°30'N	1,816
Athens, G	37°58'N	1,580
Trapani, I	38°00'N	1,800
New York, USA	40°47'N	1,424
Rome, I	41°48'N	1,529
Toronto, C	43°40'N	1,380
Freiburg, D	48°00'N	1,100
London, UK	51°29'N	898
Berlin, G	52°28'N	1,026
Helsinki, FIN	60°00'N	950
Lerwick, UK	60°00'N	775

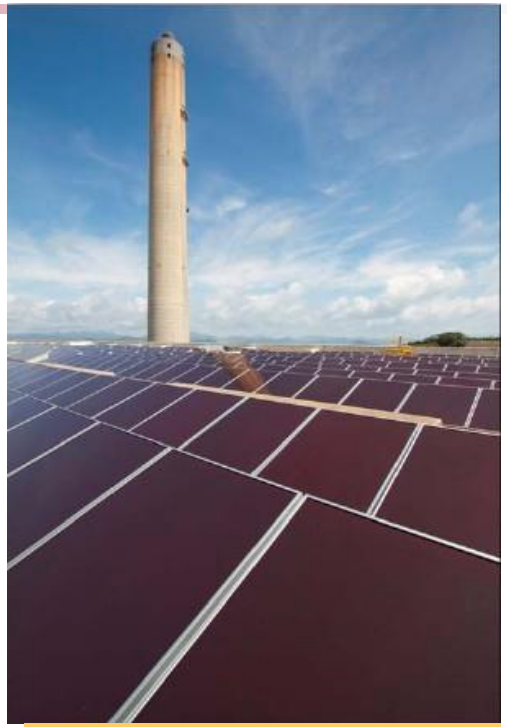
Solar PV utilizations in Hong Kong



PolyU in 1999

Wai Chai Tower





Lamma Power Plant



EMSD HQ in Hong Kong

Siu Ho Wan Sewage Treatment Plant

- Largest Solar Farm in Hong Kong
- Commissioned in 2016
- Located in North Lantau Island
- Polycrystalline PV panels



Solar Farm Area A & B



Solar Farm Area C

Floating PV in Hong Kong



Two Pilot Projects in Hong Kong

- Shek Pik Reservoir
- Plover Cove Reservoir

Location of FPV System	Annual Power generation (kWh)	Annual Carbon Doxide Reduction (kg)
Shek Pik Reservoir	94,109	66,606
Plover Cove Reservoir	72,227	50,558

Details of the FiT in Hong Kong

Three types of FiT rates will be offered according to the installation capacity of your RE system:

Capacity of the Renewable Energy System	FiT rate (per unit of electricity -kWh)
≤ 10 kW	HK$ 5
> 10 kW - ≤ 200 kW	HK$ 4
> 200 kW - ≤ 1MW	HK$ 3

The rates listed above are effective from 1 Oct 2018 onwards and will be reviewed regularly.

A sample local village house rooftop PV system



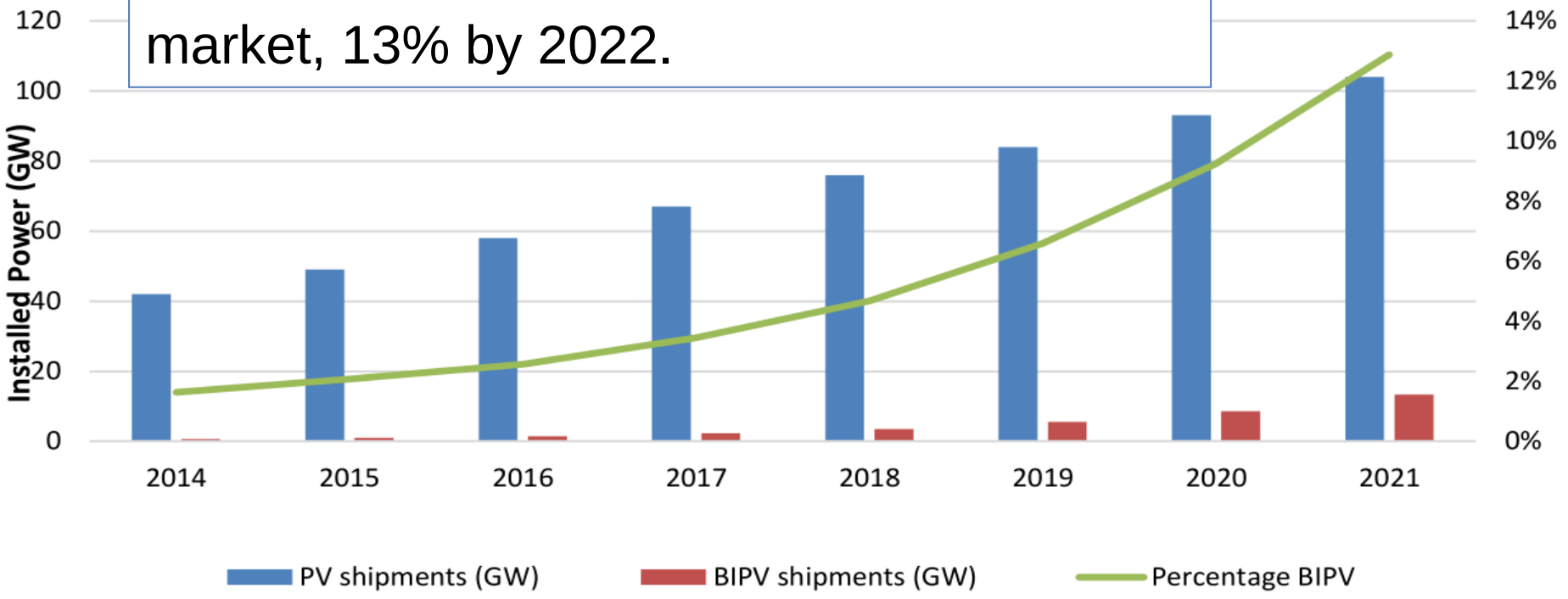
Comparisons of a solar PV on a residential house	
PV installation capacity: 3.0 kWp	
Average net tariff in 2018	HK$1.154 per kWh
Electricity generation by a small solar PV system without FiT	
Installation cost	HK$7900
Annual electricity generation	3,300 kWh
Annual earnings	HK$3808.2
Payback Period	21 years
Electricity generation by a small solar PV system with FiT	
Installation cost	HK$54000
Annual electricity generation	3,300 kWh
FiT tariff	HK$5.0
Annual earnings	HK$16,500
Payback Period	3.3 years

BIPV potential study in Europe

Available Roof Surface					
	Net Available Solar Surface (Km^2)	Installable PV "Potential" (GW)	Estimated Electricity production (Twh/year)	Residential Electricity consumption 2006 (TWh/year)	% of PV
Europe (75%: Germany, France, UK, Italy, Spain)	3.723	465,4 ($8m^2$/Kwp)	511,9	859	59%
		161,9 ($23m^2$/KWp)	178,1		20%
USA	4.563	570,4 ($8m^2$/Kwp)	570,4	1351	42%
		198,4($23m^2$/KWp)	198,4		14%
Japan	1.050	131,3 ($8m^2$/Kwp)	118,1	229	51%
		45,7 ($23m^2$/KWp)	41,1		18%

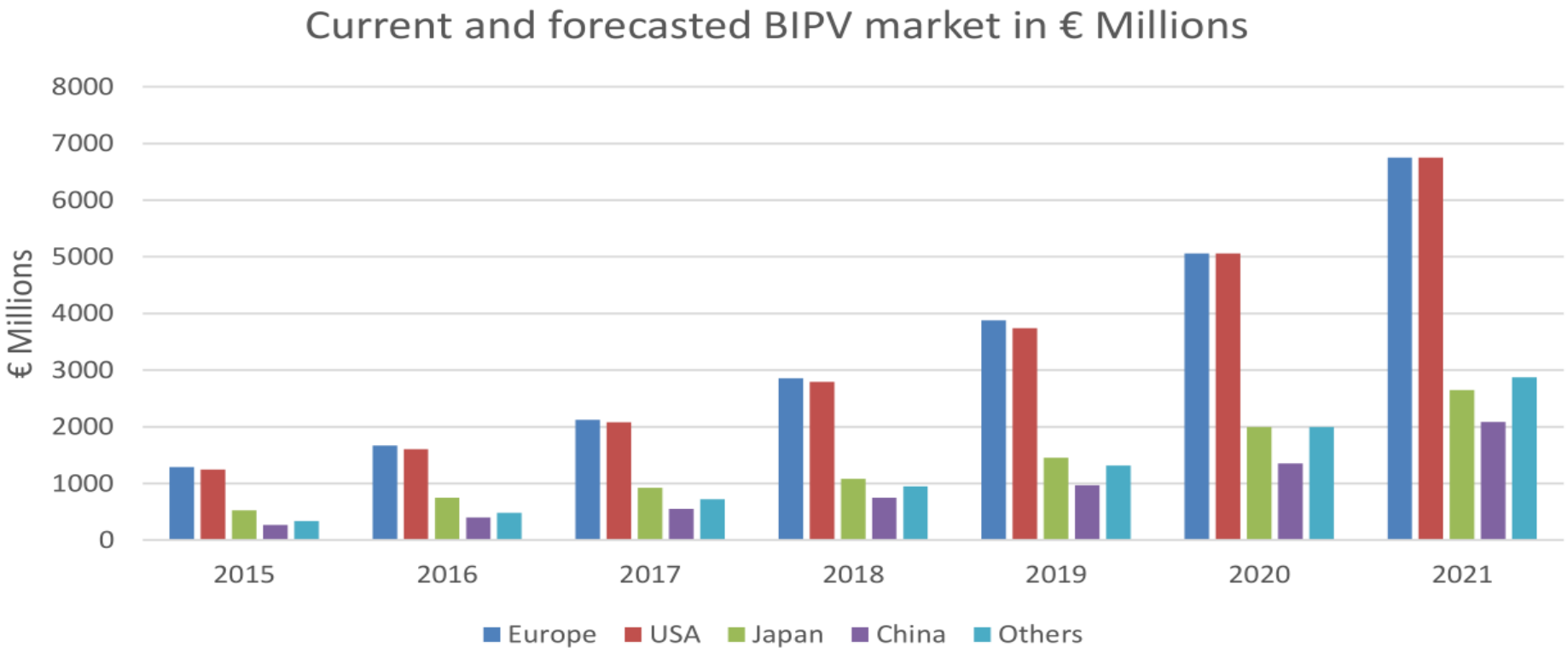
** Facades not included*

The global BIPV sales will triple by 2019, growth by 18.7%;
Currently the BIPV market holds a market share of around 2% of the overall PV market, 13% by 2022.



Source: Nanomarkets , “Nanomarkets report BIPV Market Analysis and Forecast 2014-2021,” 2015.

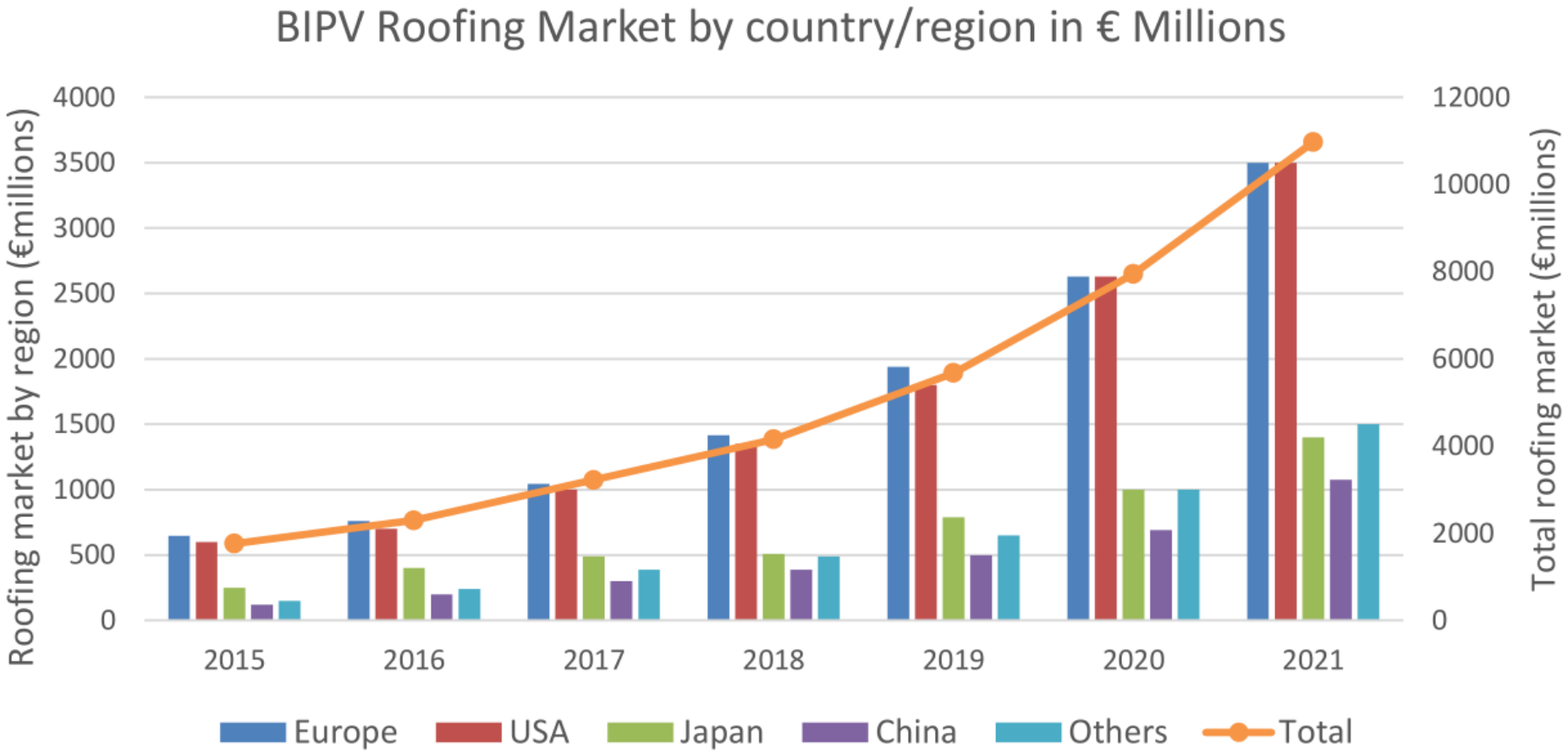
BIPV market



The most evolved BIPV market regions are Europe and the USA which combined currently account for around 70% of the worldwide market share.

Source: Nanomarkets , “Nanomarkets report BIPV Market Analysis and Forecast 2014-2021,” 2015.

Main applications for BIPV: roofing, walling and glass



For 2020, around 3.5B€ will be invested in BIPV roofing in each Europe and USA, with a total worldwide BIPV annual investment exceeding 10B€.

3. Our research activities in BIPV applications:

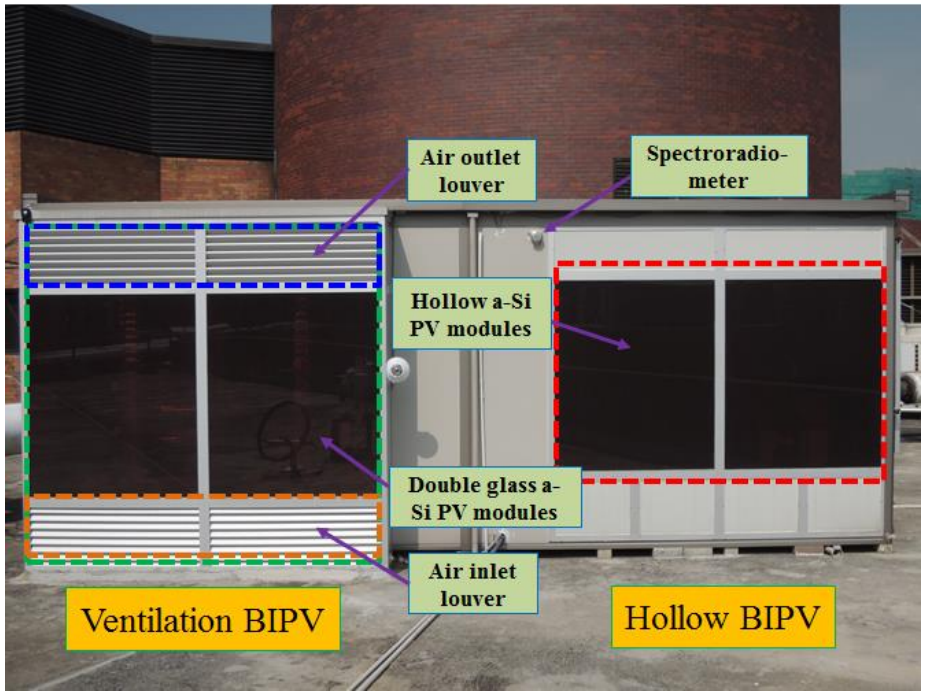
(1) Potential BIPN in Hong Kong

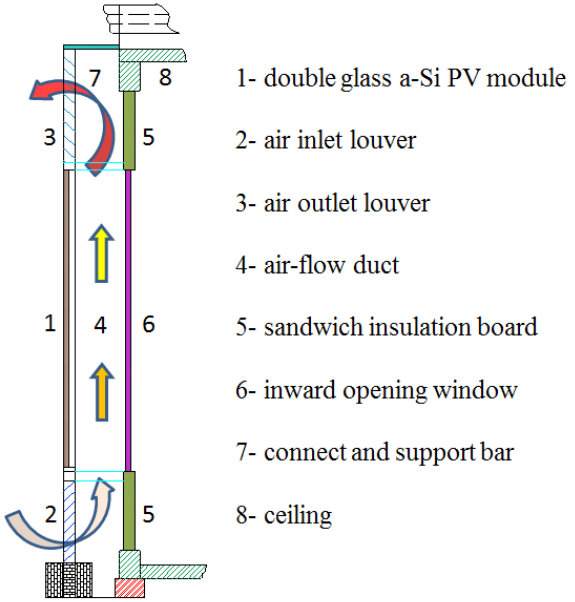
- The potential total active rooftop area of PV modules was calculated as 37.4km^2. The total potential installation capacity is estimated as 5.97 GWp. $A_{act.} = \frac{A_{pot.}}{A_{occu.}} \times A_{pv}$

$$E_{potential} = A_{act.} \times G_{optimal} \times \eta_{stc} \times \lambda$$

- The potential PV electricity output is about 5,981GWh, accounting for 14.2% of the total electricity use in 2011.
- Reduce the imports of coal and natural gas by 25% and 54% respectively and mitigate about 3 million tons of GHG emissions yearly.

(2) BIPV windows



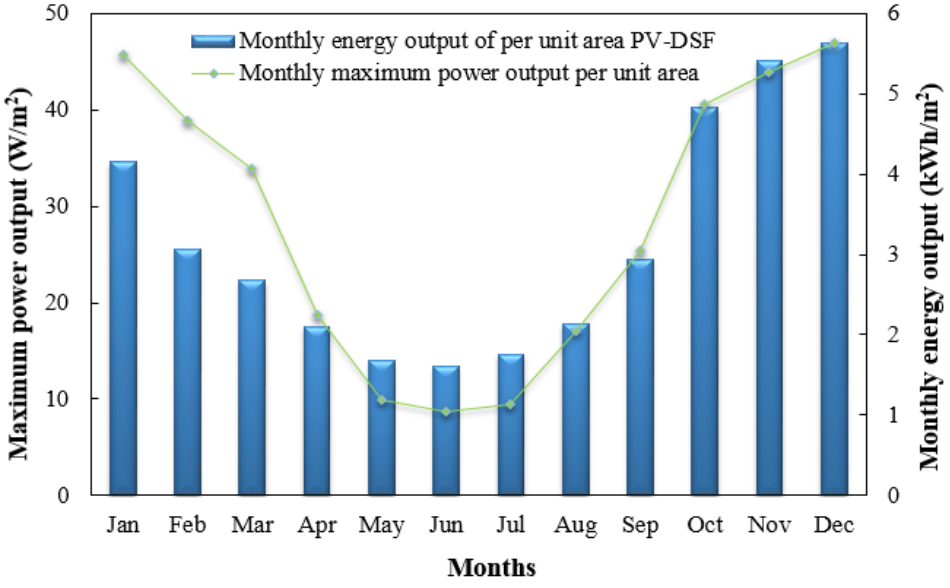


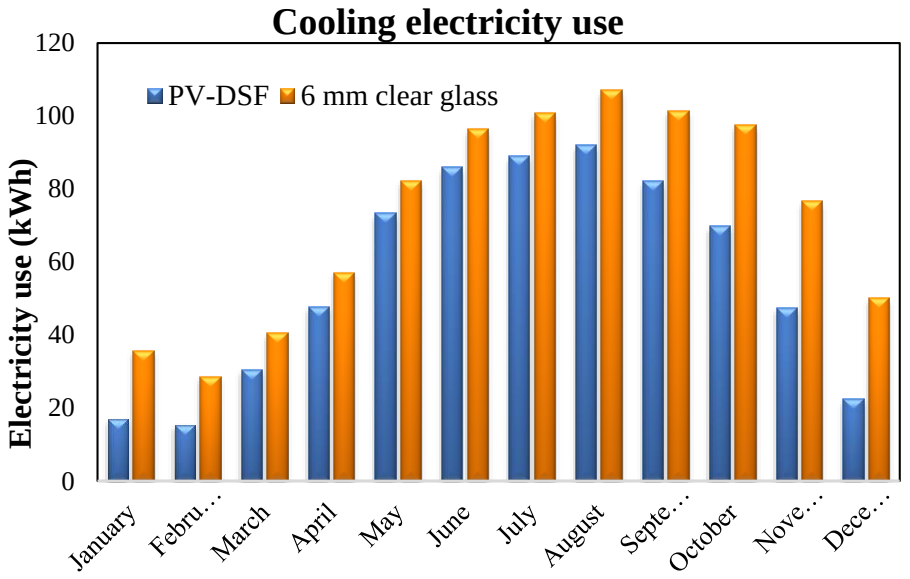
Study of the overall energy performance of BIPV facade:

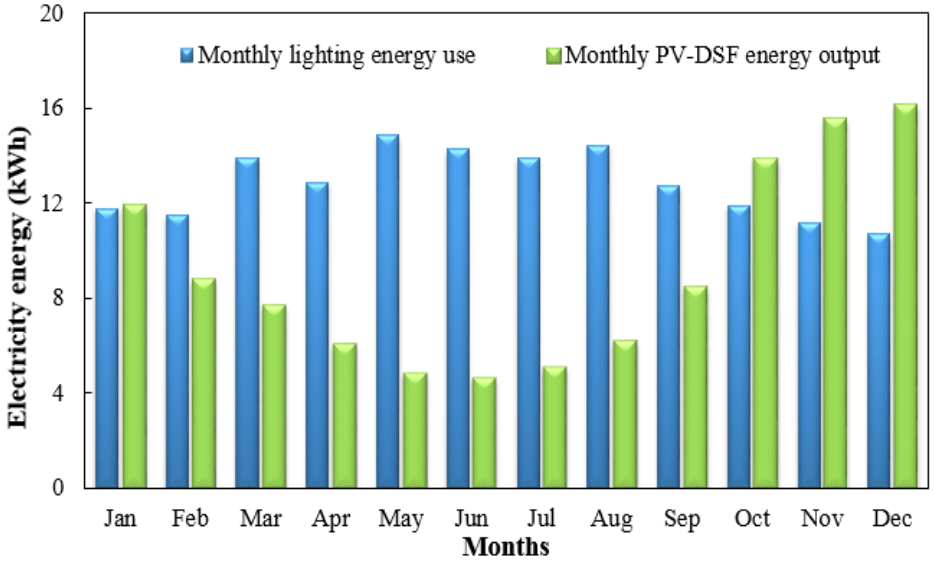
- real-time power generation performance
- thermal performance
- natural lighting performance



Annual overall performance in Hong Kong







- The maximum monthly energy output : 5.6 kWh/m^2
- Annual energy output: 38 kWh/m^2
- Saving cooling energy use: 70 kWh/m^2/yr.
- Lighting can be powered by the PV-DSF itself in winter.

Experimental studies



BIPV test bed at Tung Chung



PV-IGU



PV-DSF



PV shading

The Housing Authority BIPV project

- Roof integration
- PV walls
- PV windows







Study on semi-transparent solar PV windows

- Data acquisition system



Study on semi-transparent solar PV windows

- Inside views of PV windows



Ventilated PV window

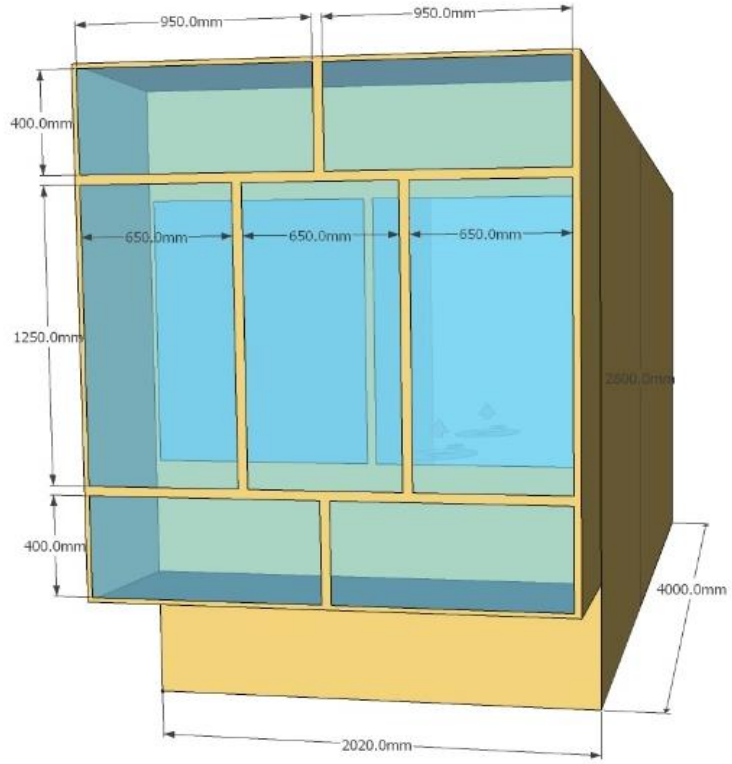
Efficiency: 6.8%
Transmittance: 20%
Rated power: 68W/m^2

Efficiency: 6.3%
Transmittance: 20%
Rated power: 63W/m^2

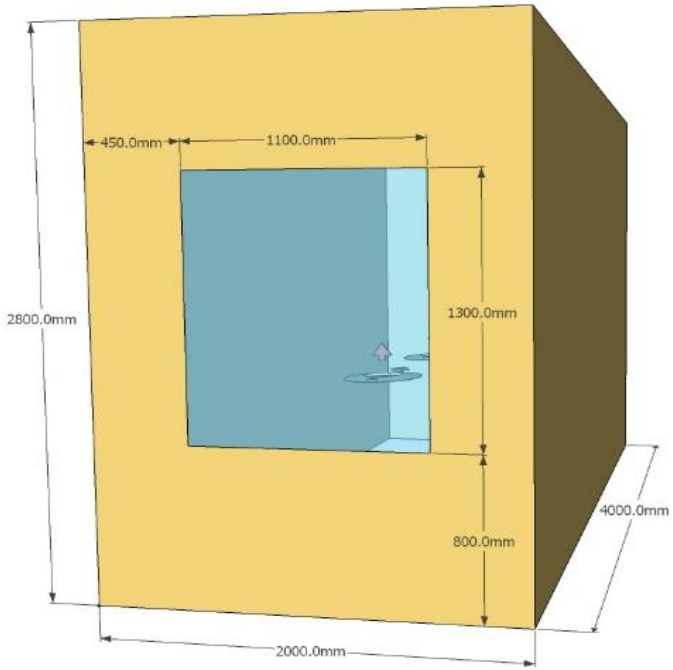


Hollow PV window

Energy performance of PV DSF and PV IGU



PV double skin façade

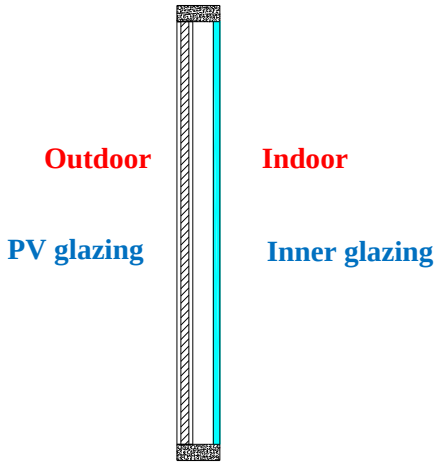


PV insulating glass unit

The heat transfer model, daylighting model and PV power generation model in EnergyPlus were adopted to investigate the corresponding performance simultaneously.

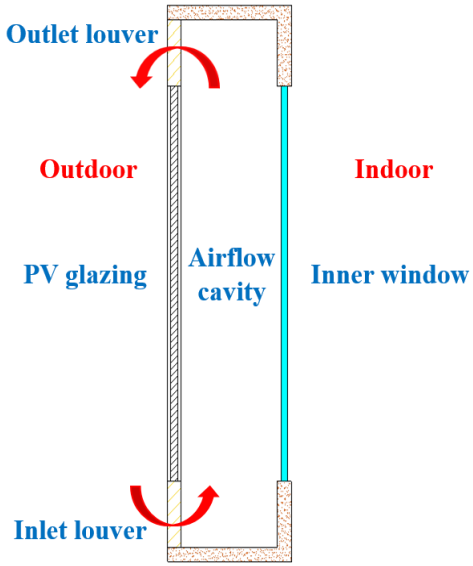
Structures of PV-IGU and PV-DSF

PV-IGU





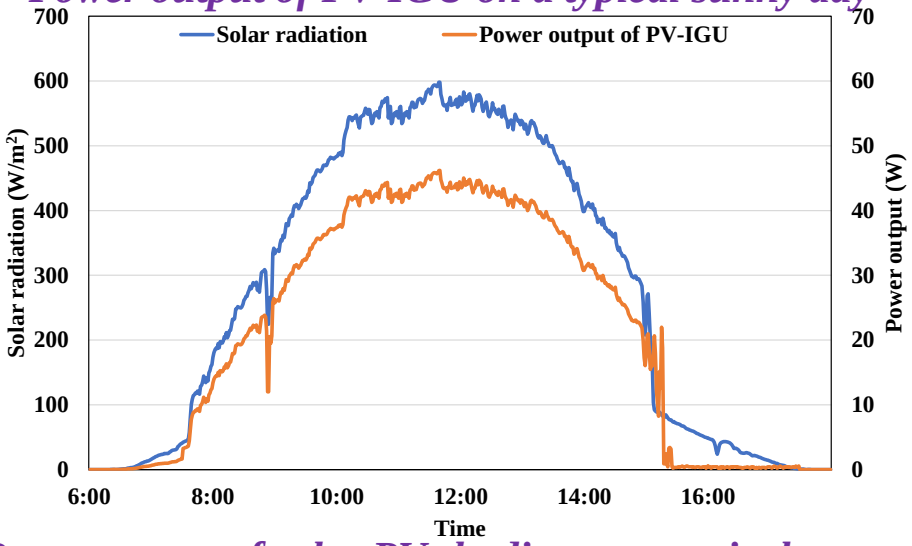
PV-DSF



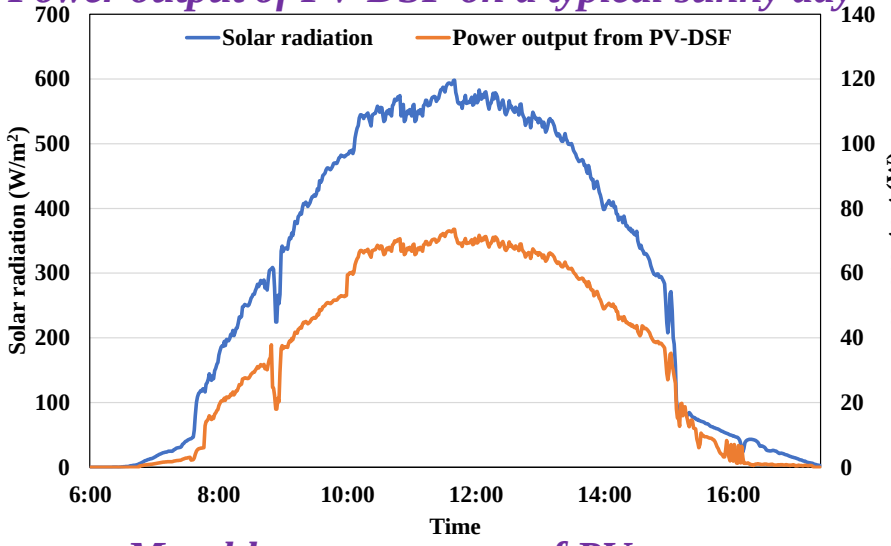


Experimental studies

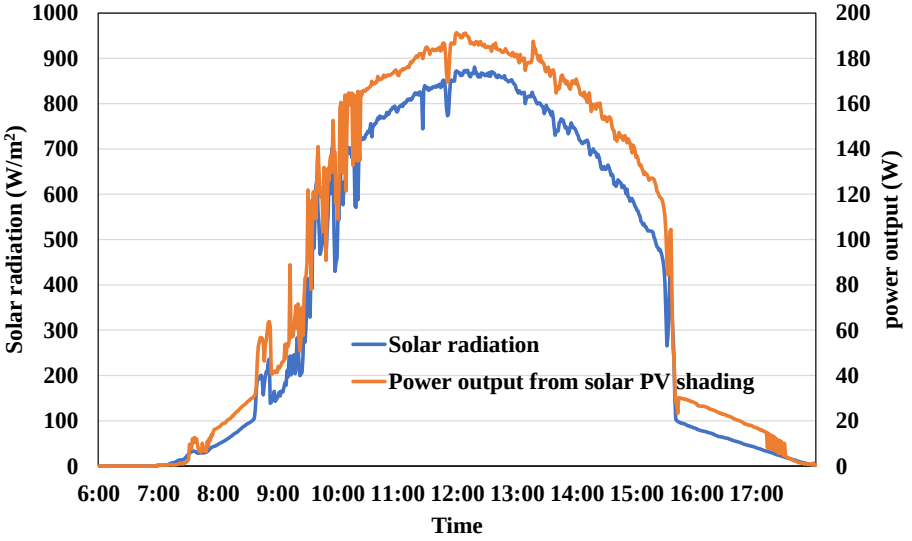
Power output of PV-IGU on a typical sunny day



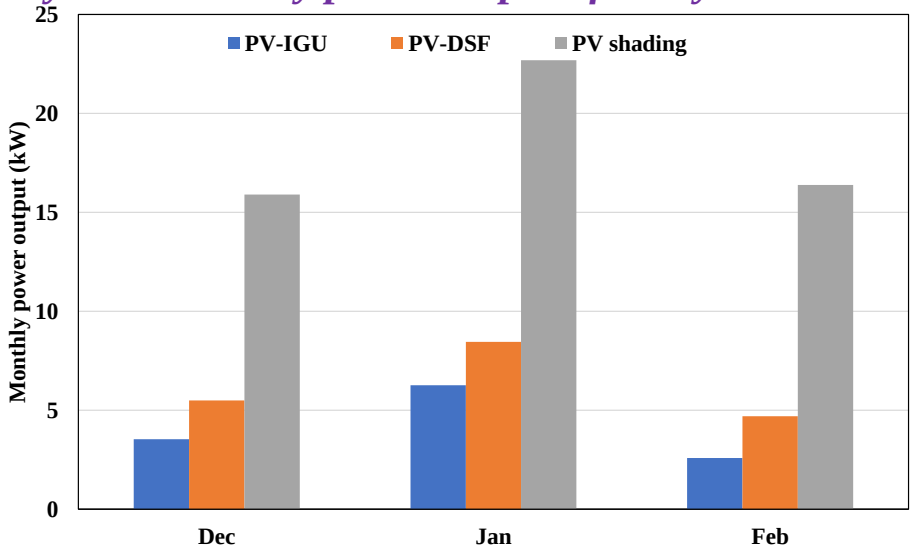
Power output of PV-DSF on a typical sunny day



Power output of solar PV shading on a typical sunny day

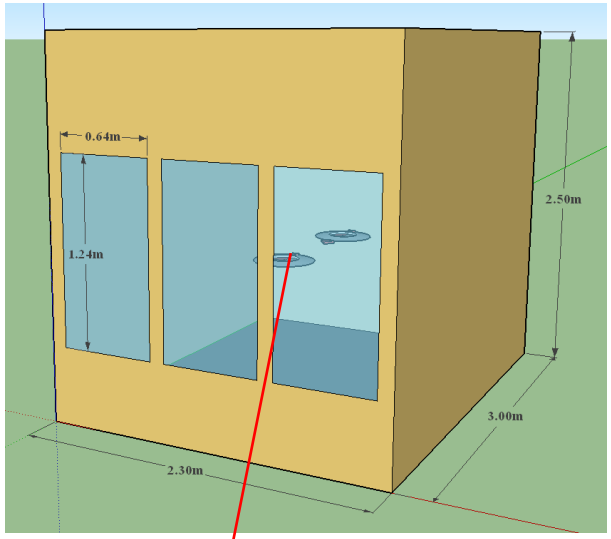


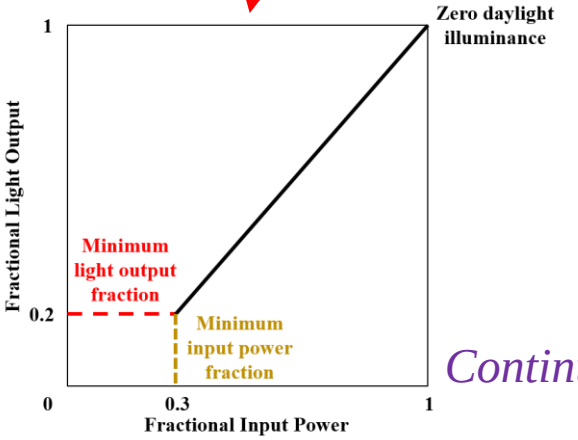
Monthly power output of PV systems



（3）Single-glazed PV glazing VS energy-efficient glazing

A generic representative model

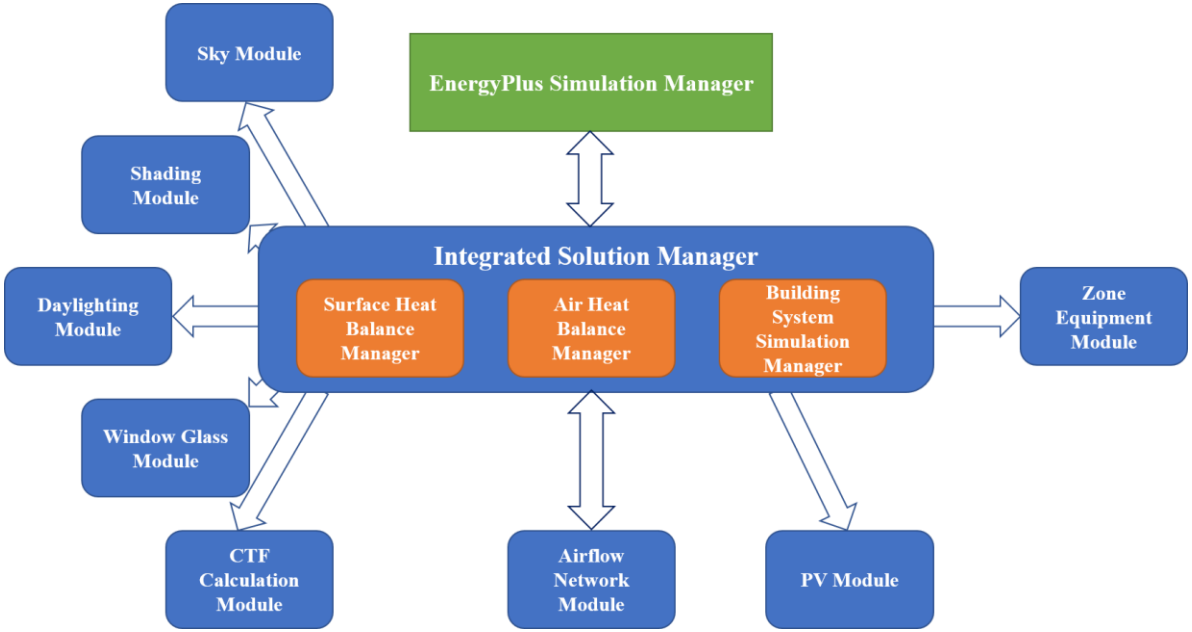




Continuous dimming control

Simulation tools:

Berkeley Lab WINDOW, EnergyPlus

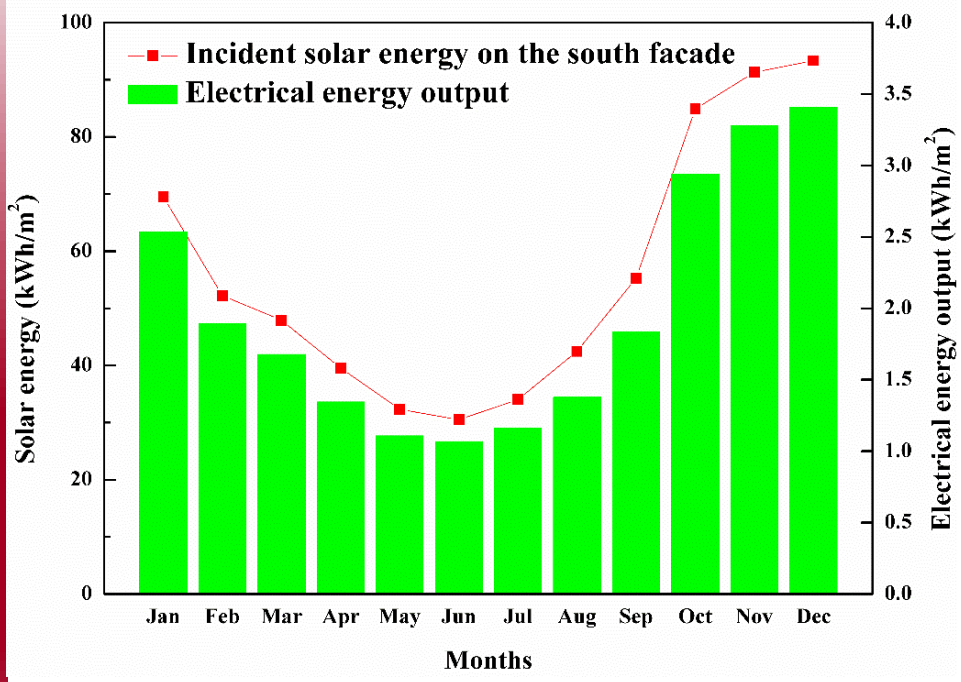


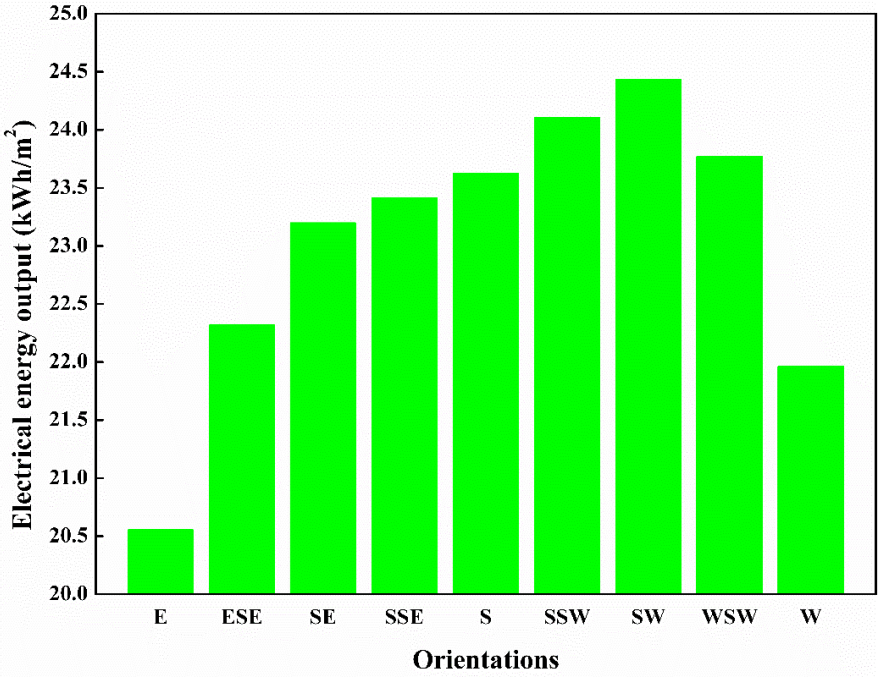
Sandia Array performance Model

- Empirical-based
- More accurate for thin-film solar cells

Single-glazed PV glazing

Power generation performance in Hong Kong





Monthly power output per unit area of south facing solar PV windows

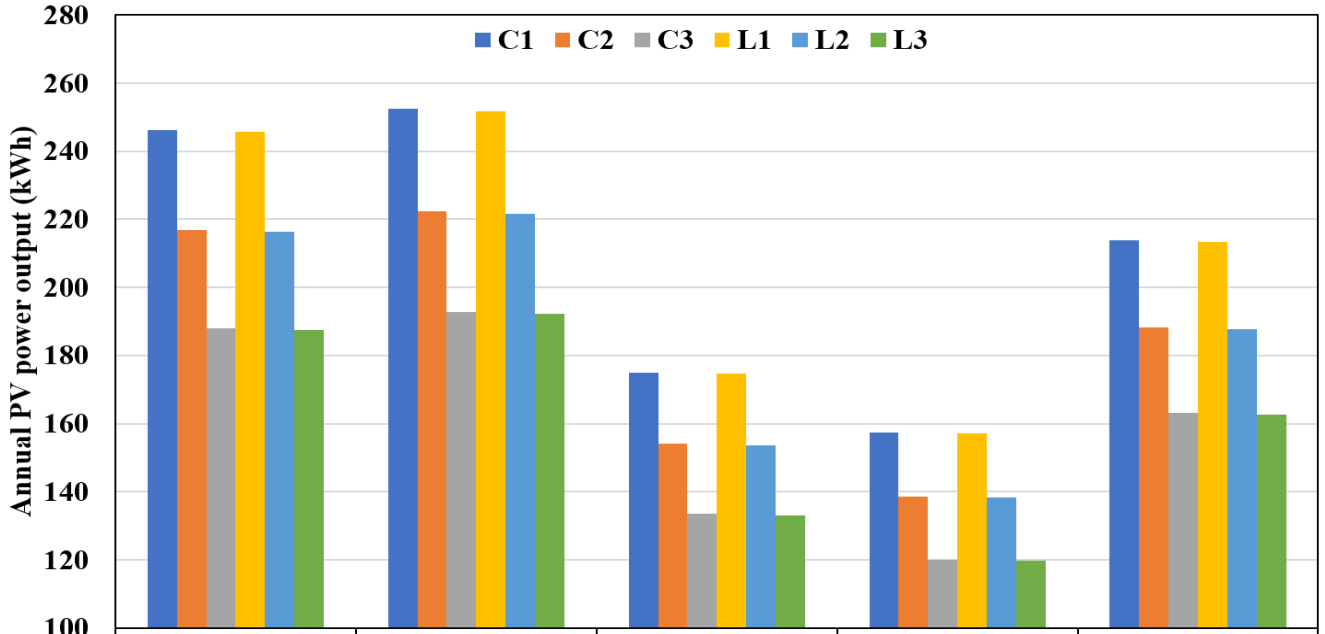
Annual power outputs per unit area of solar PV windows in different orientations

1) Significant difference among different months: more in winter and less in summer.

2) Annual electricity output varies with orientations: SW > SSW > WSW > S > … > E

Energy performance of PV-IGU

Annual PV power output



	Harbin	Beijing	Shanghai	Hong Kong	Kunming
C1	246.2	252.5	175.0	157.4	213.8
C2	216.8	222.4	154.1	138.6	188.3
C3	187.9	192.8	133.5	120.0	163.2
L1	245.8	251.8	174.6	157.0	213.3
L2	216.4	221.7	153.7	138.2	187.8
L3	187.5	192.2	133.1	119.7	162.7

Location: Beijing > Harbin > Kunming > Shanghai > Hong Kong

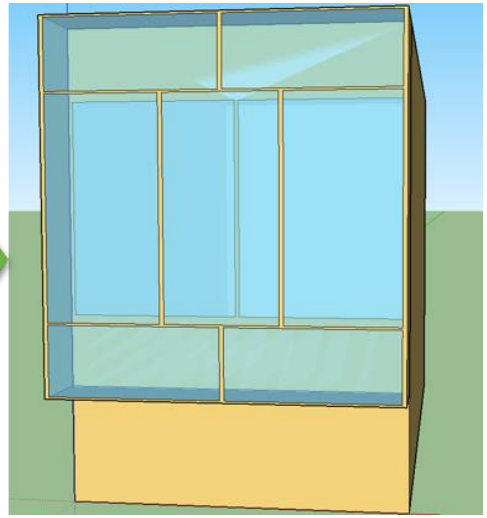
Higher transmittance → Lower power output

Energy performance of PV-DSF

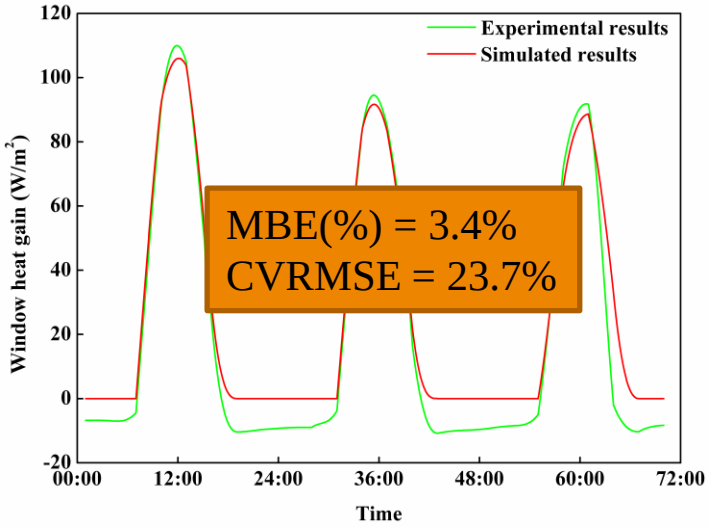
Model development and validation



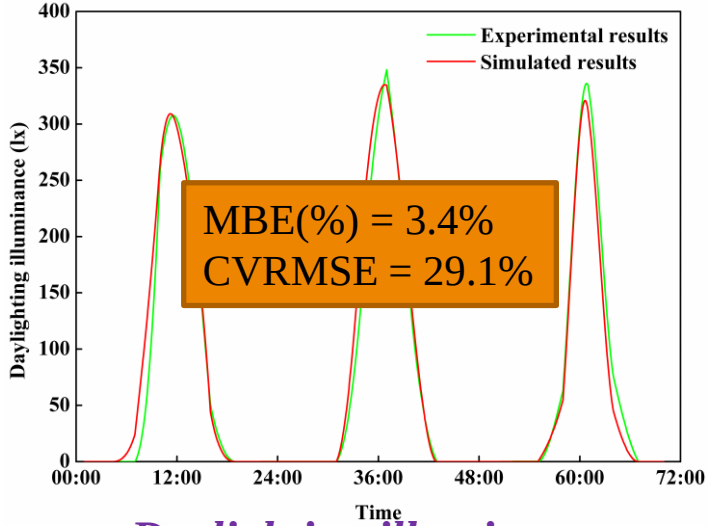
Test bed



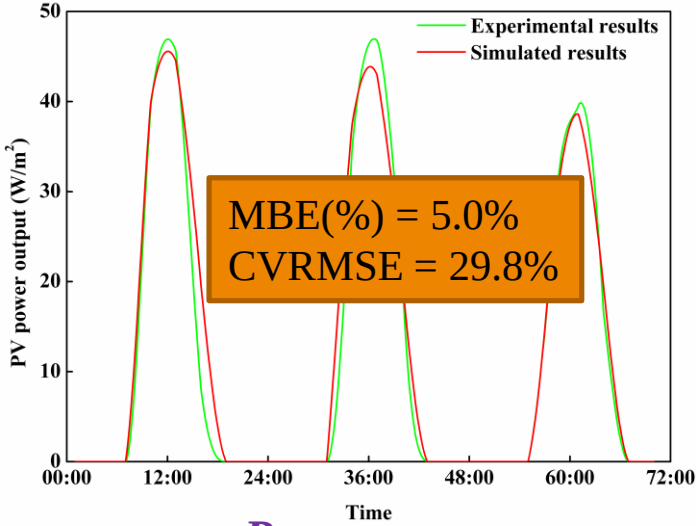
Simulation model



Window heat gain



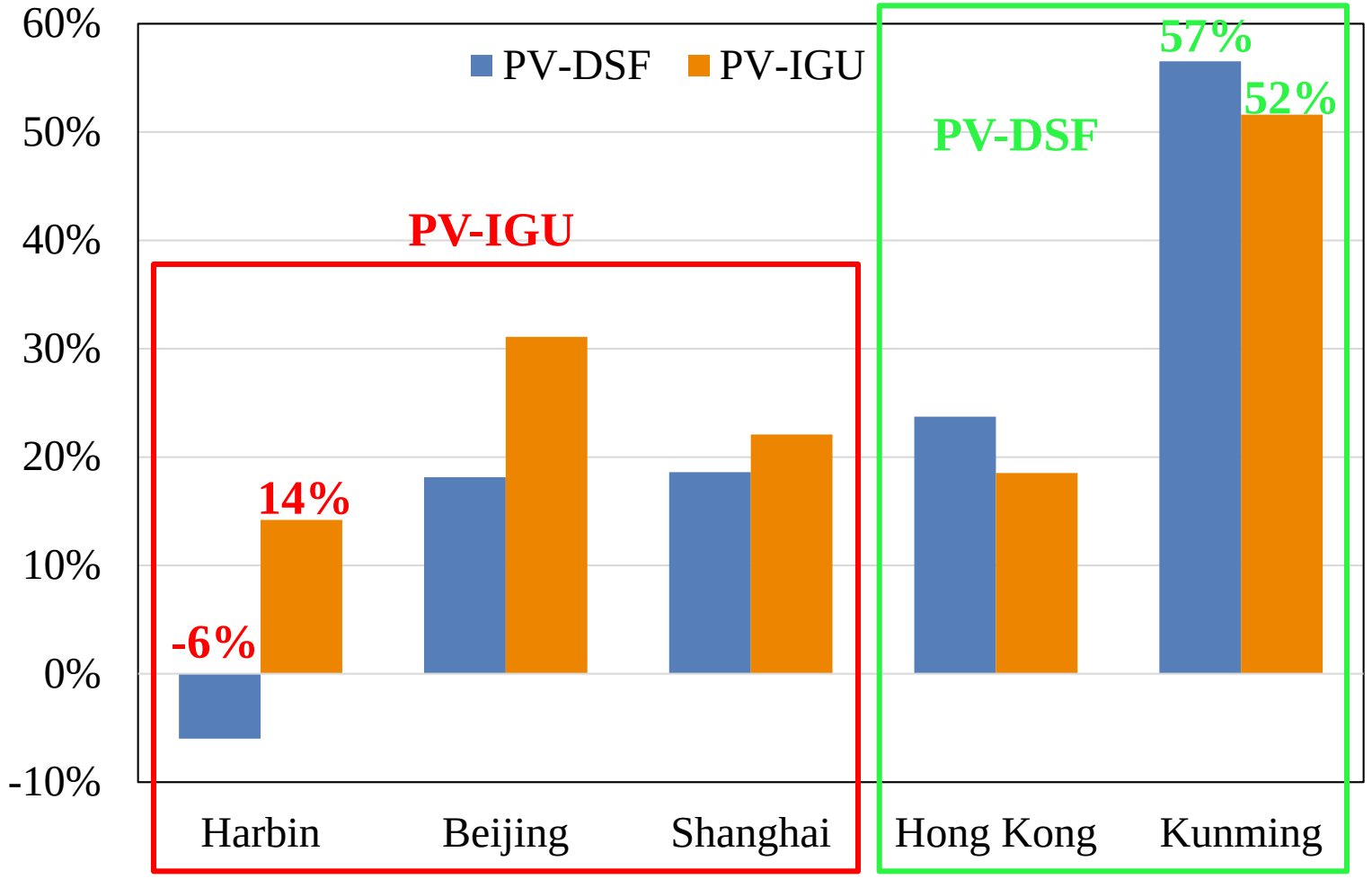
Daylighting illuminance



Power output

Energy performance of PV-DSF

Energy saving potential of PV-DSF and PV-IGU compared to reference window



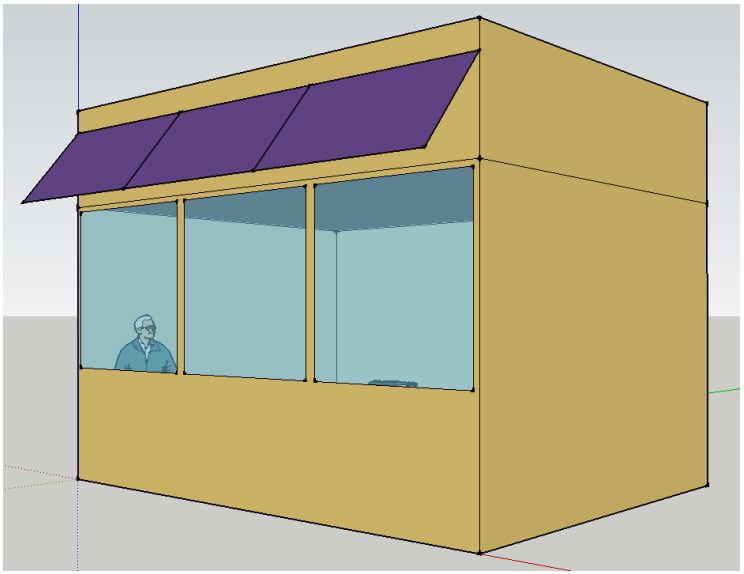
How to improve?

- Inner glazing
- Ventilation mode

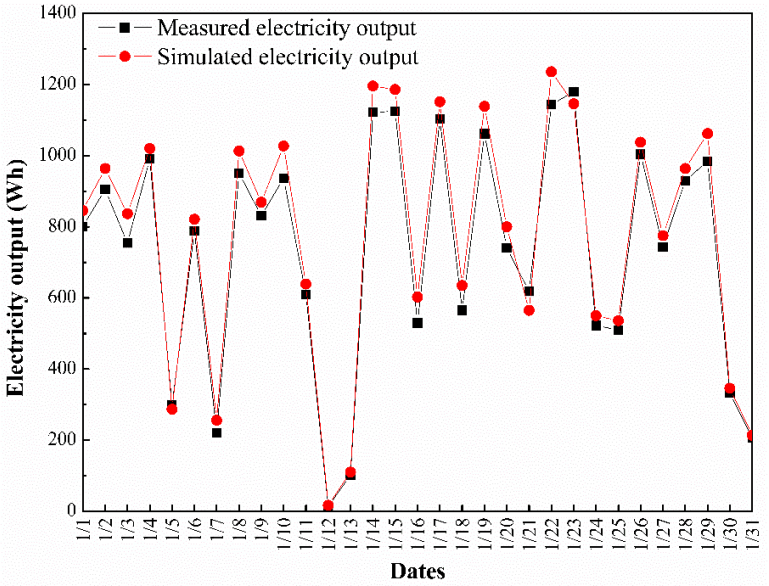
Energy saving potential of solar PV shadings

Research gap

- Daylighting performance is rarely considered in previous studies. However, both external and internal shadings affect the daylighting performance of the room.
- Comparison between external solar PV shadings and interior shading devices has not been reported yet.



Simulation model of solar PV shadings

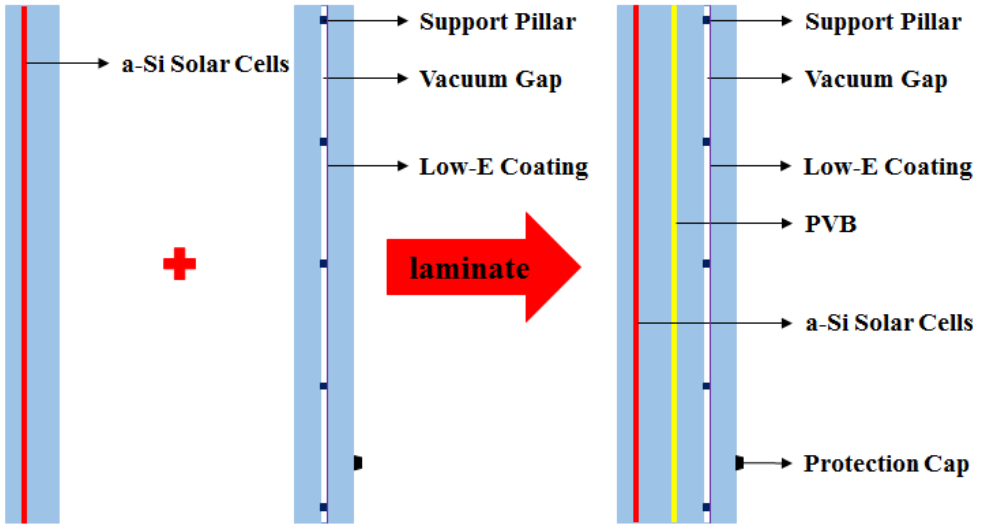


Validation of the electricity output

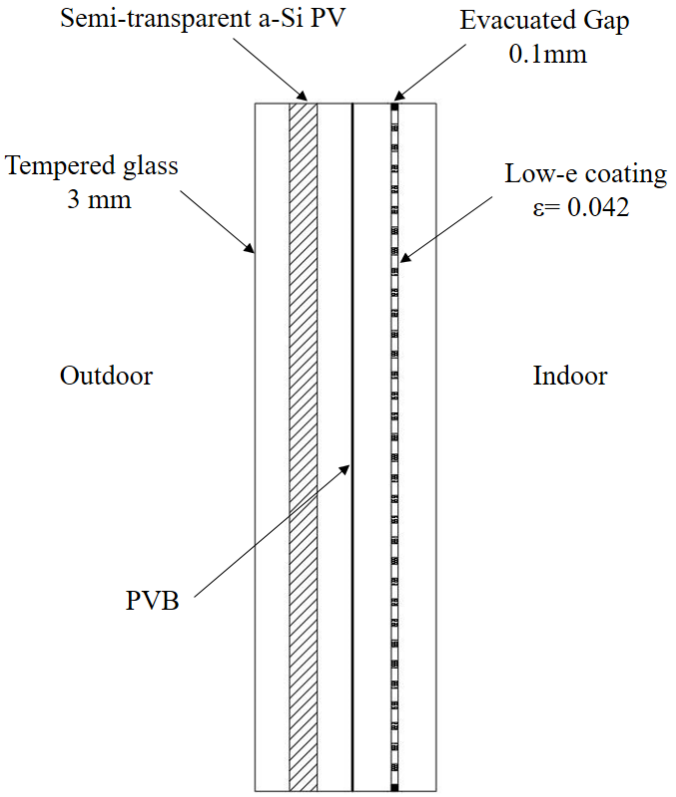
Due south, Tilt angle: 55˚, Error: 5%

(3) Advanced VPV IGU

- A novel vacuum PV insulated glass unit (VPV IGU) is proposed to combine the advantage of the high thermal insulation performance of vacuum glazing and the power generation capability of STPV windows.



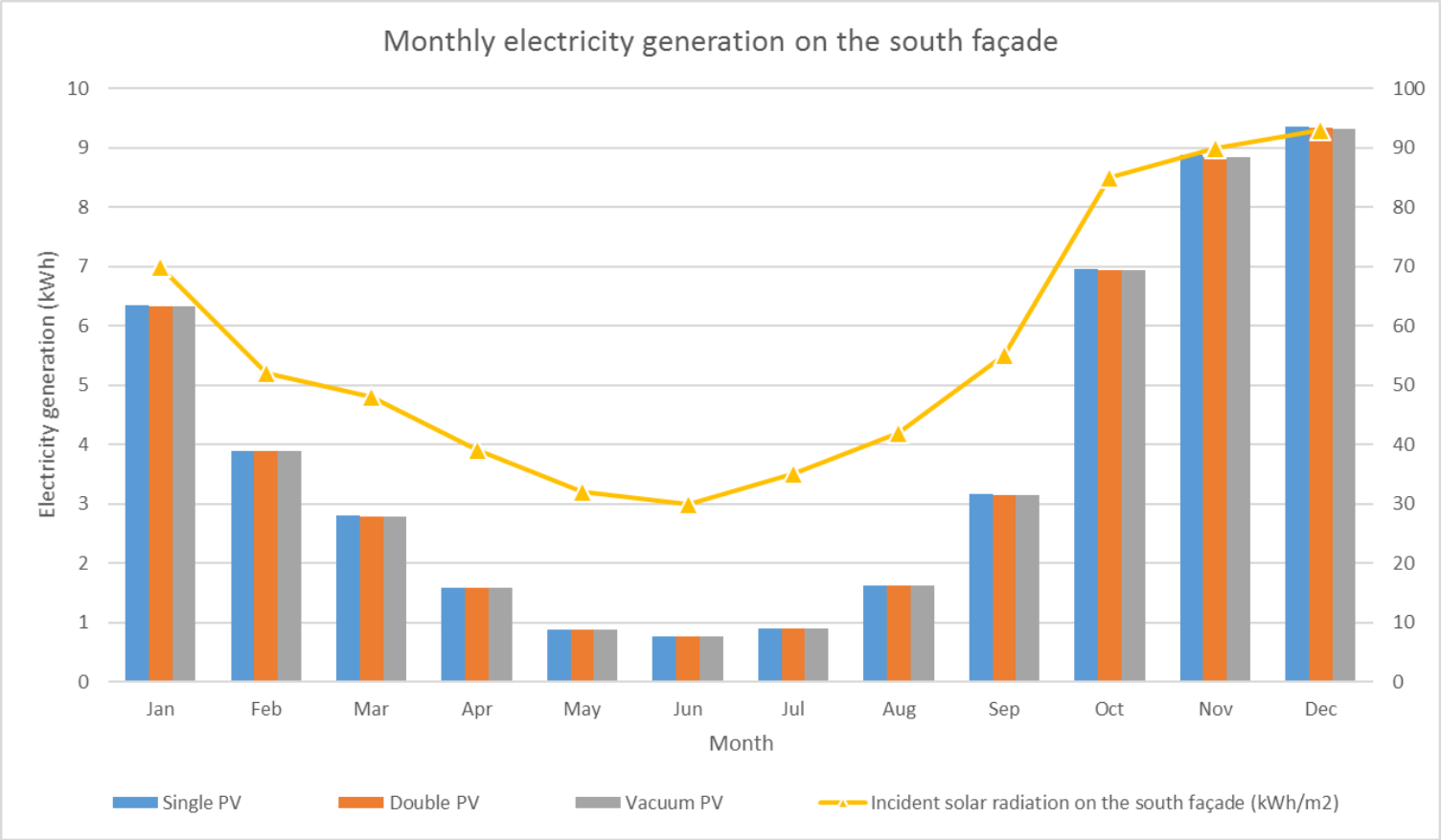
The structural details of VPV IGU



The cross-section of VPV IGU

Power generation Performance

- The difference of the power generation among different BIPV systems is less than 1%, and the single-pane PV glazing produced the most electricity output.



(4) Development of self-cleaning nano-coating for PV



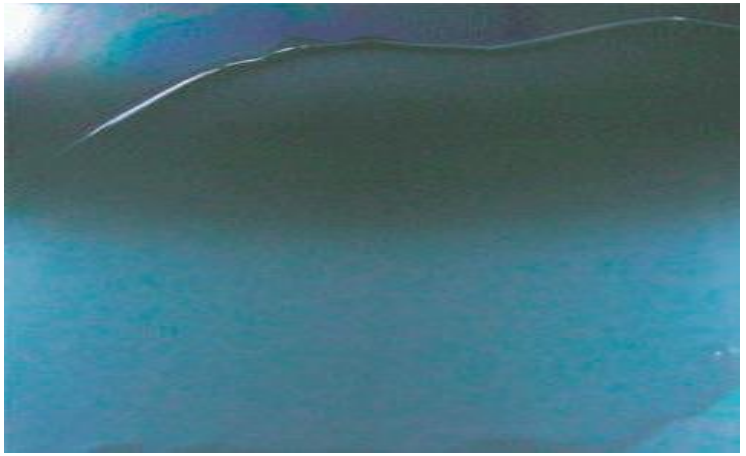
Super-hydrophobic , θ(Lotus leaf):>150°



Super-hydrophobic self-cleaning glass



Super-hydrophilic, θ(clean glass surface):<10°



Super-hydrophilic self-cleaning glass

Advantages of our product: Superior self-cleaning property and cheaper cost



The comparison between two PV modules after two months in Shenzhen.

The self-cleaning coating has superior super-hydrophilicity.

Advantages of our product: Superior self-cleaning property and cheaper cost

With self-cleaning coating

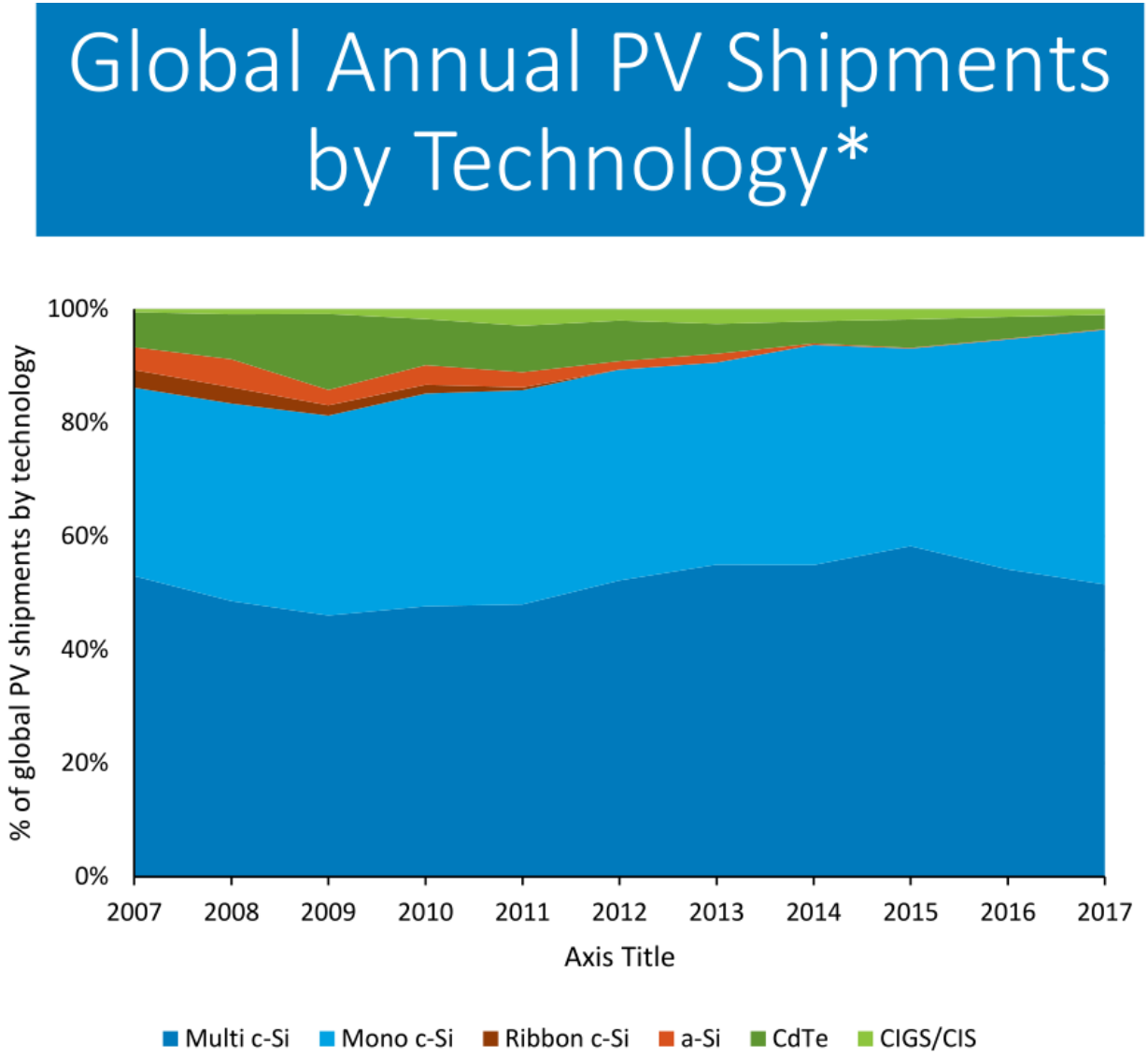


Without self-cleaning coating



Comparisons between two PV modules after about one year in Hong Kong.
The self-cleaning coating has superior super-hydrophilicity.

(4) Selection of PV modules



In 2017:

- Monocrystalline: 45%;
- Poly-crystalline: 51%;
- Thin film: 4%。

Experimental study



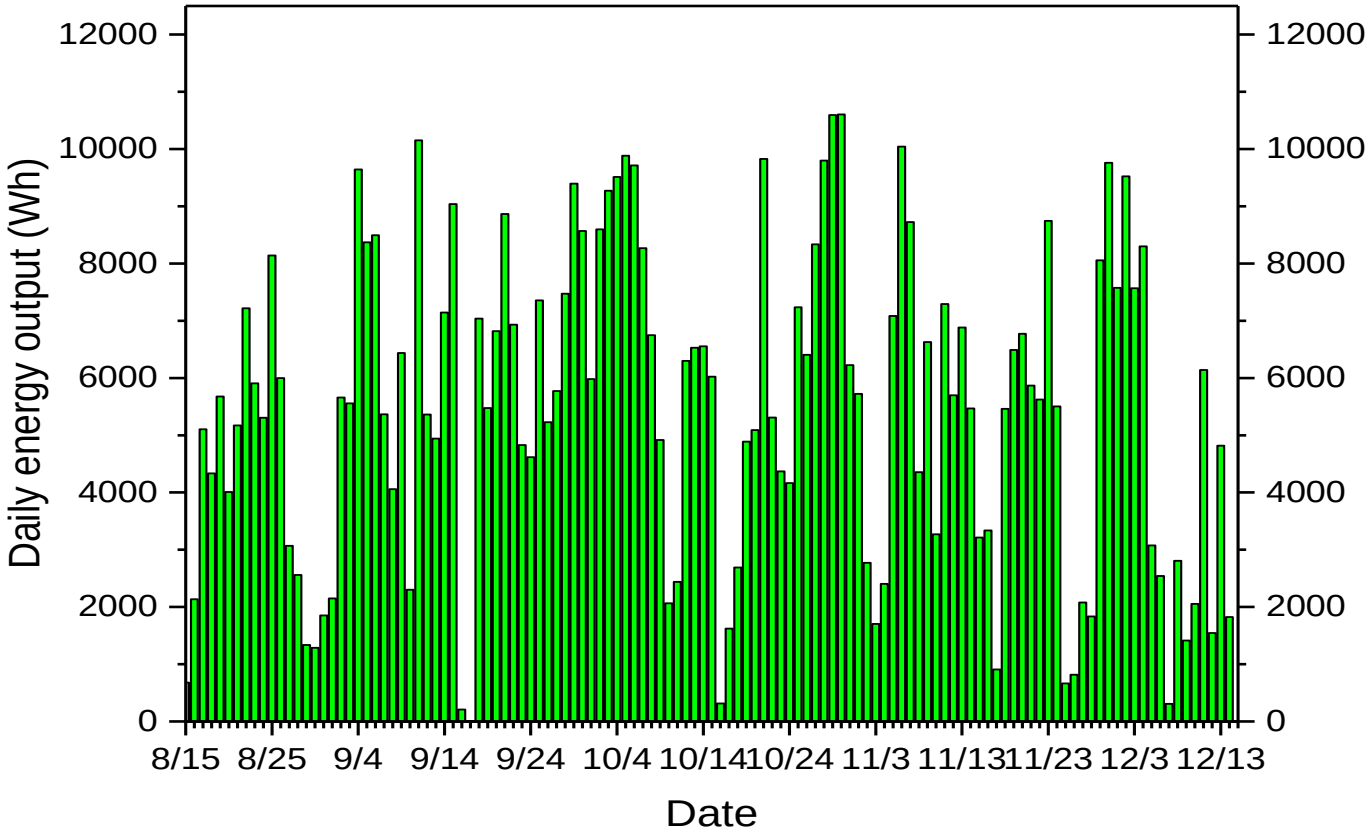
The PV system testing rig in the New Territories

In order to obtain the actual energy performance of PV modules, an on-site test system was developed in Hong Kong. All the ten solar PV panels are installed facing south with a tilt angle of 22^{o}.

Selection of solar PV panels for detailed study -- 5 different types

Solar Cell-technologies	Mono-Si 1	Mono-Si 2	Poly-Si 1	Poly-Si 2	A-Si 1	A-Si 2	CIGS 1	CIGS 2	CdTe 1	CdTe 2
Model										
Nominal Power (W)	305	300	280	275	140	130	140	115	107.5	80
Short circuit current (A)	9.94	9.77	9.37	9.35	5.28	2.65	1.79	4.52	1.75	0.95
Open circuit voltage (V)	40.2	39.76	38.65	38.72	42.3	71	106.7	37.6	86.6	118.9
Current at maximum power (A)	9.24	9.26	8.86	8.77	4.34	2.22	1.62	3.87	1.57	0.85
Voltage at maximum power (V)	33.0	32.41	31.61	31.36	32.2	54	86.5	29.7	68.6	94.1
Maximum system voltage (V)	1000 (IEC)	1000 (IEC) 1000 (UL)	1000/ 1500 DC(IEC)	1000 (IEC) 1000 (UL)	N/A	1000	1000 (IEC) 600 CSA/UL	1000 (IEC) 600 (UL)	1000V (class II) 1500V class 0	N/A
Module Efficiency (%)	18.7	18.0	17.1	16.5	9.6	9.1	14.9	12.0	14.9	11.1
Weight (kg)	18.2	18.8	18.2	18.8	18.3	25	16.5	2.7	12	11.8
Dimension (mm × mm × mm)	1650*991*40	1670*1000*32	1650*991*35	1670*1000*32	1310*1110*40	1300*1100*6.8	1190*790*7.3	2598*370*17	1200*600*6.8	1200*600*6.8

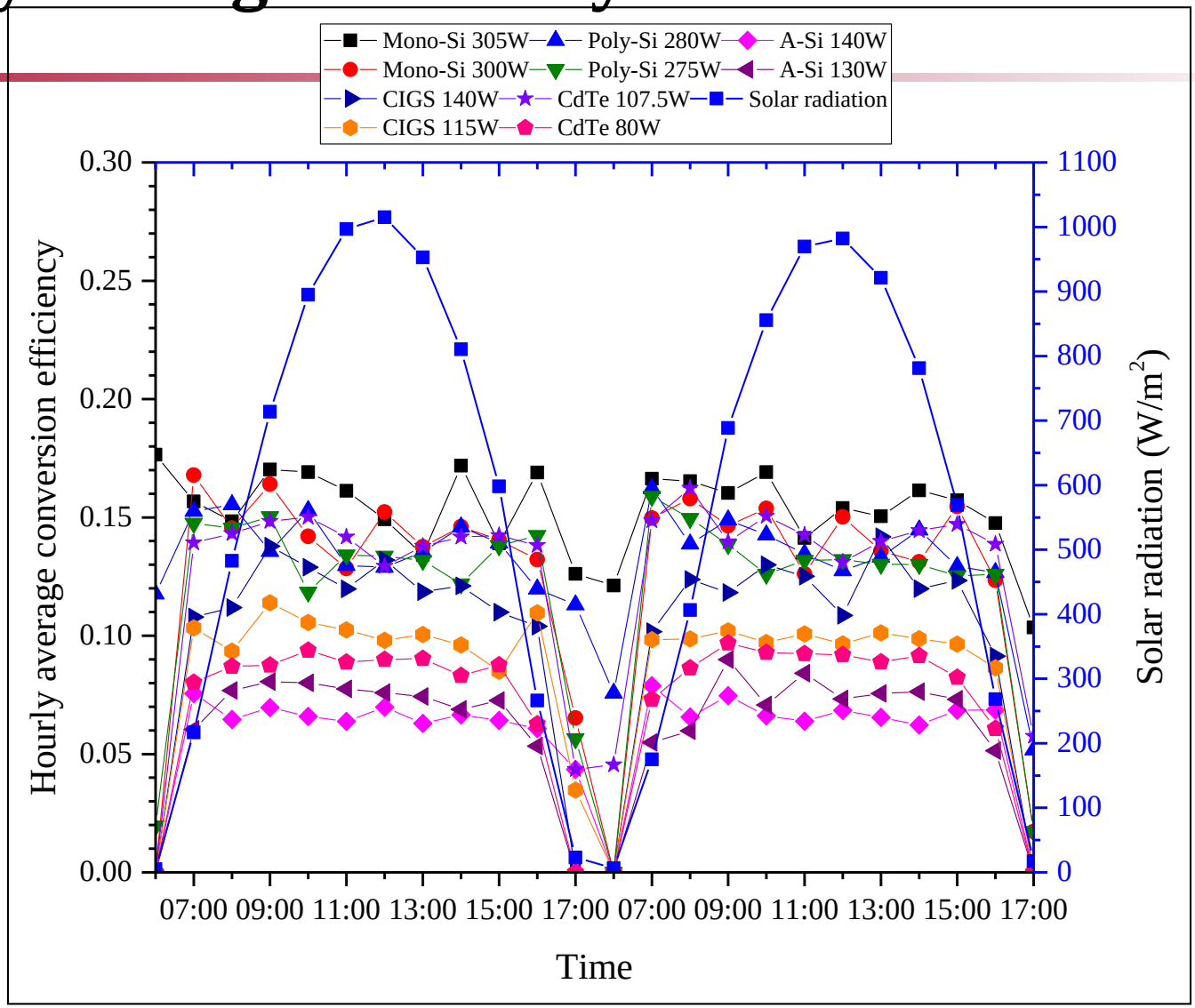
Daily power generation from the whole system



The PV system has been working very well for 10 months. The highest daily energy output is 10.6 kWh on 30th November 2018.

Hourly average efficiency of PV modules

In typical sunny days (30th Oct and 6th Nov 2018):

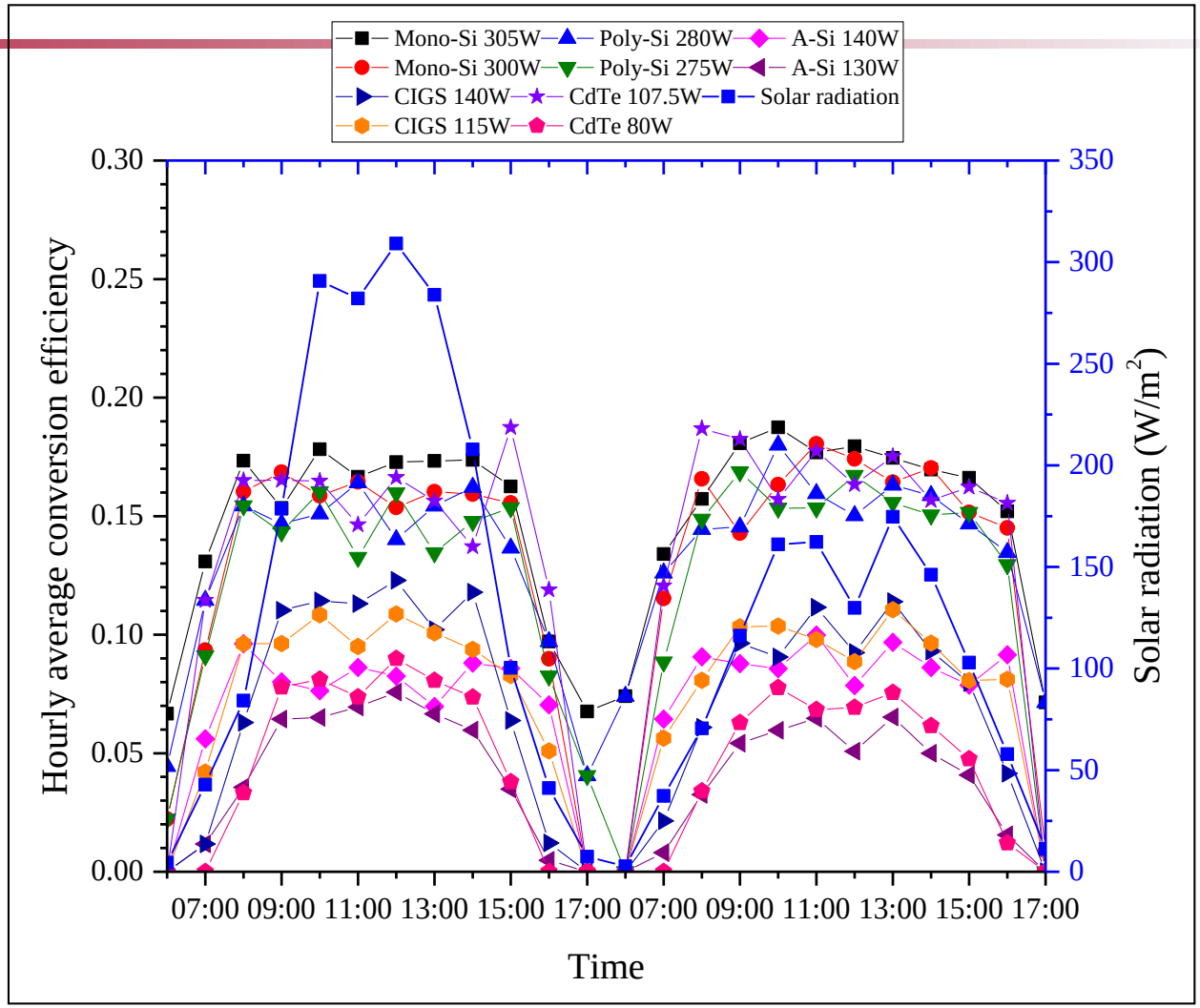


Energy conversion efficiencies:

Mono-Si > CdTe (107.5Wp) >Poly-Si > CIGS >A-Si

Hourly average efficiency of PV modules

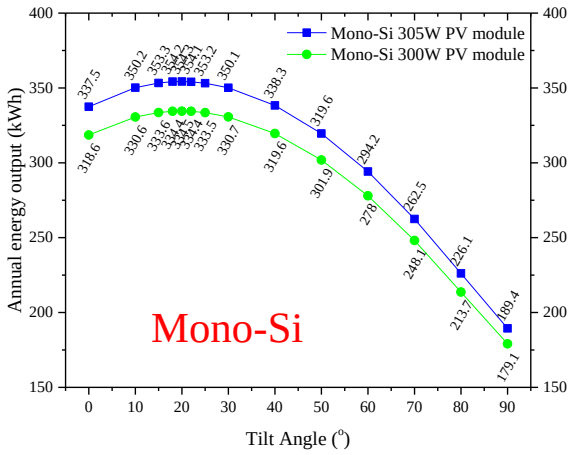
In typical cloudy days (2nd Nov and 3rd Nov 2018):

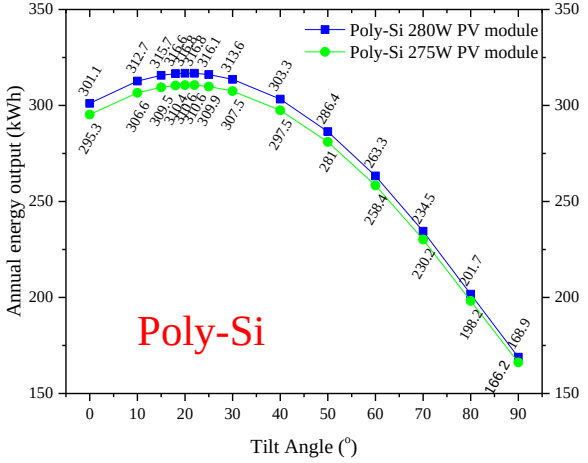


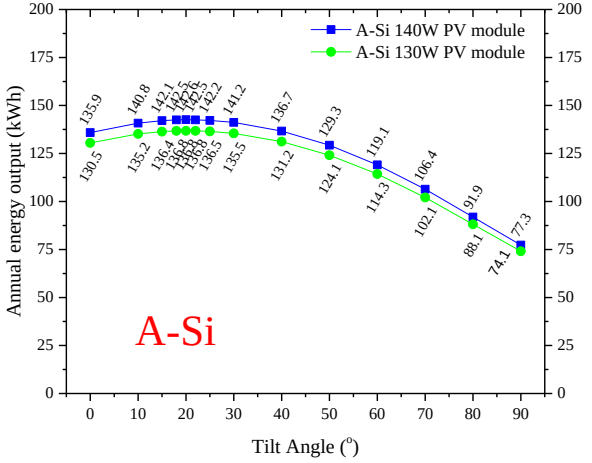
Energy conversion efficiencies:

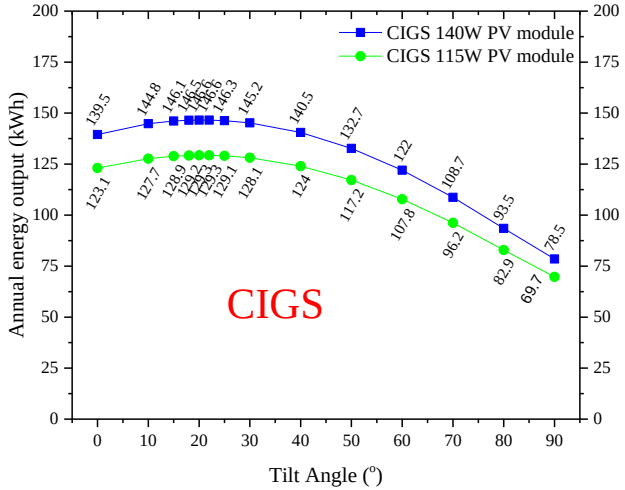
Mono-Si > CdTe (107.5Wp) > Poly-Si > > CIGS >A-Si

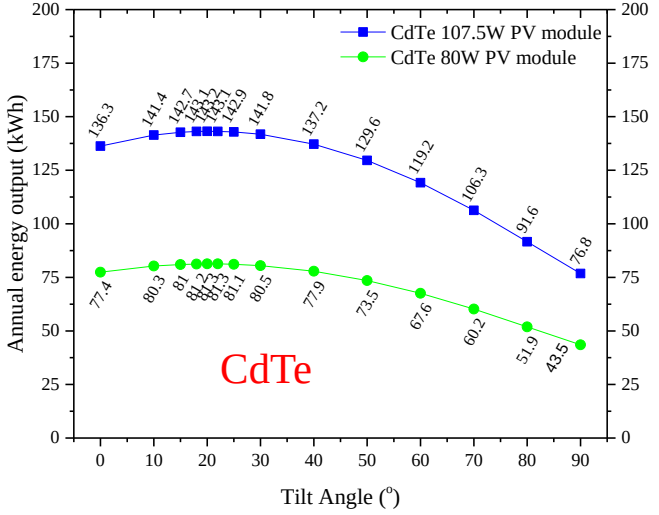
Simulation of annual power generation for different tilt angles (south)











The optimal tilt angles of PV modules are found to be 18-22° depending on local latitude and weather.

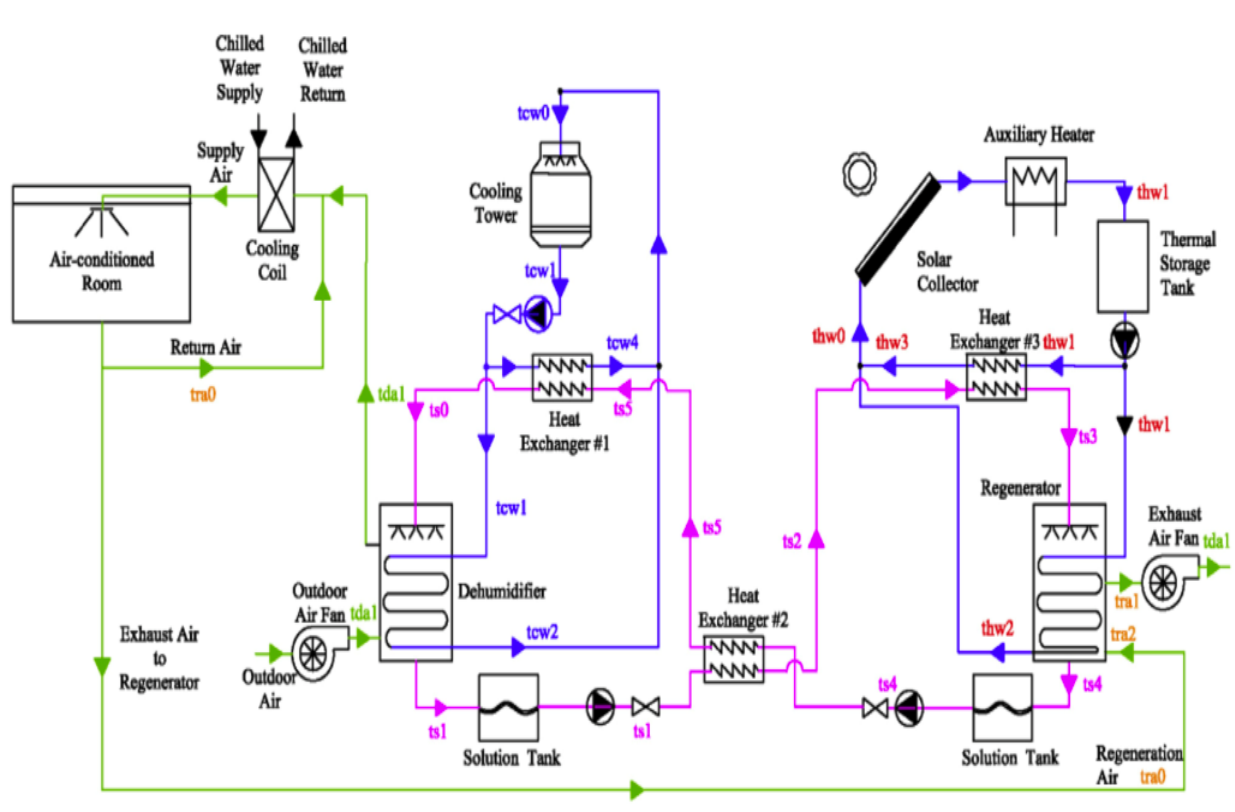
Simulation results: Annual power generation at best position (azimuth=180°, and tilt angle=22°)

Solar PV panel	Mono-Si 305W	Mono-Si 300W	Poly-Si 280W	Poly-Si 275W	A-Si 140W	A-Si 130W	CIGS 140W	Flexible CIGS 115W	CdTe 80W	CdTe 107.5 W
Annual total (kWh)	354.1	334.4	316.7	310.6	142.6	136.8	146.6	129.4	81.3	143.2
Annual output (kWh/m^2)	215.9	200.2	193.1	186.0	98.3	95.7	156.0	134.8	112.9	198.9
Annual output (kWh/Wp)	1.16	1.11	1.13	1.13	1.02	1.05	1.05	1.12	1.02	1.33

Per m^2 (kWh/m^2): Mono-Si > CdTe > Poly-Si > CIGS > a-Si

Energy yield (kWh/Wp): CdTe (107.5Wp) > Mono-Si > Poly-Si > CIGS > A-Si

(5) Solar liquid desiccant air-conditioning (SLDAC)

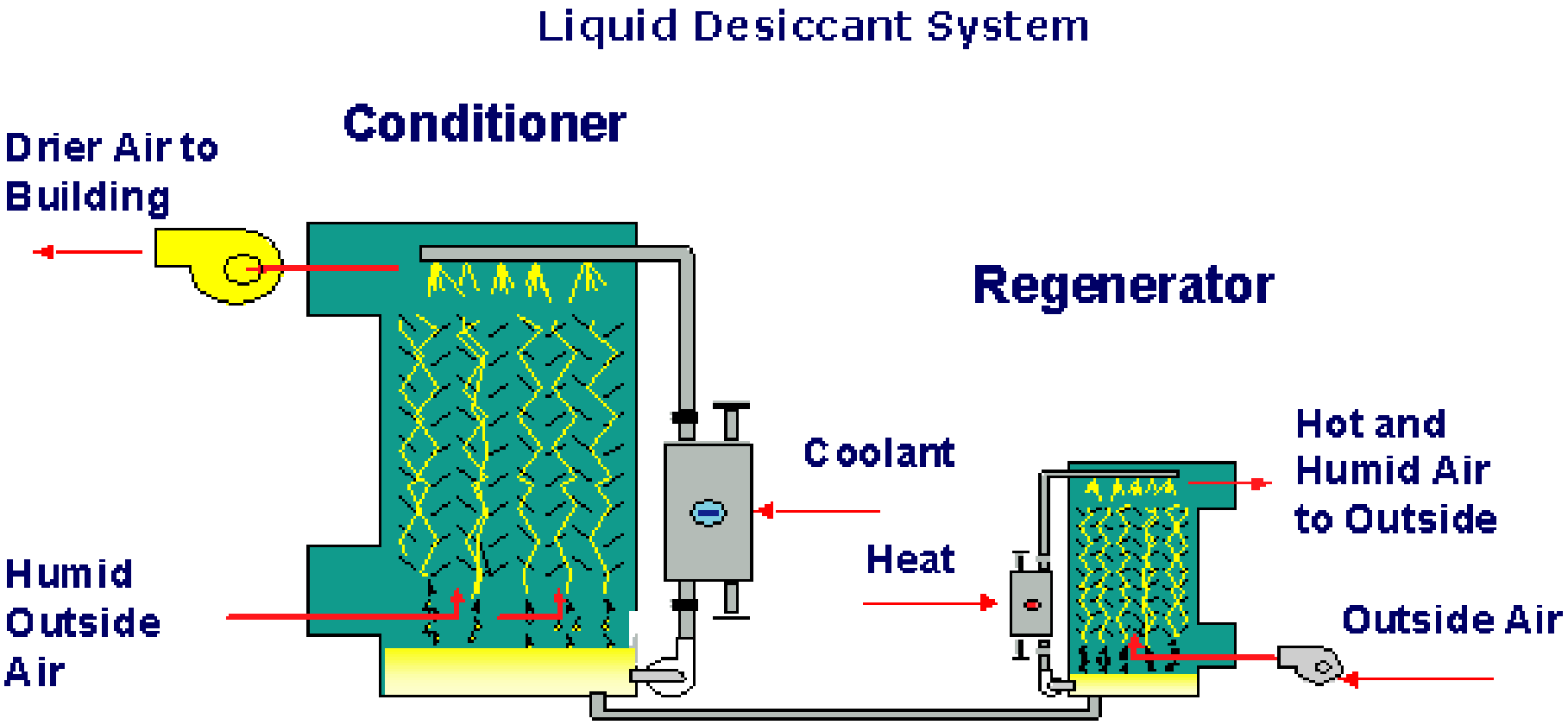


Equipment

- Dehumidifier
- Solar Collector/ Regenerator
- Solution storage tank
- Heat exchanger

- Green line: Air flow path
  - Supplied by outdoor air fan
  - Moisture is removed in dehumidifier
  - Further cooled by AHU

Possible Configurations of the System

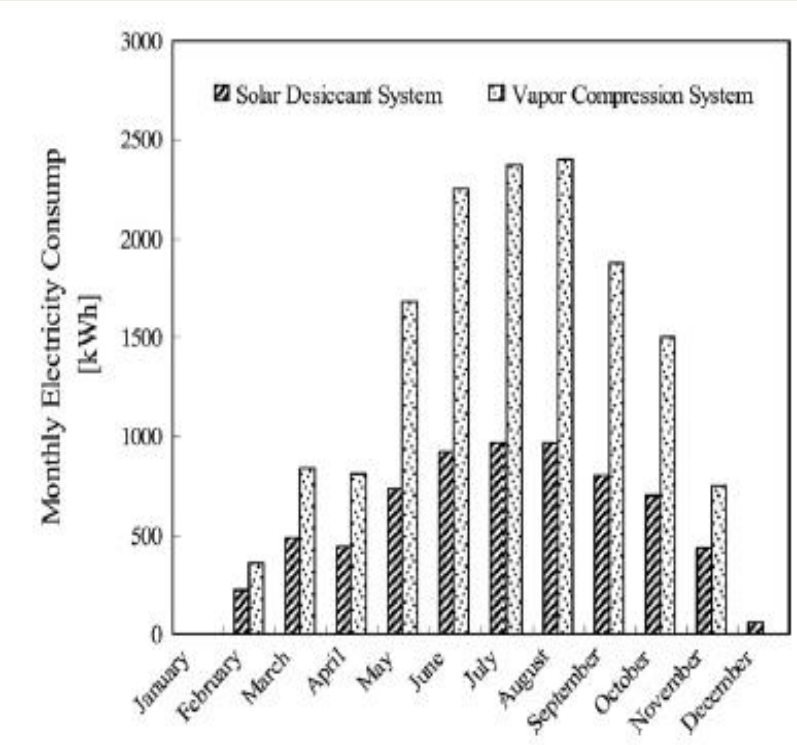


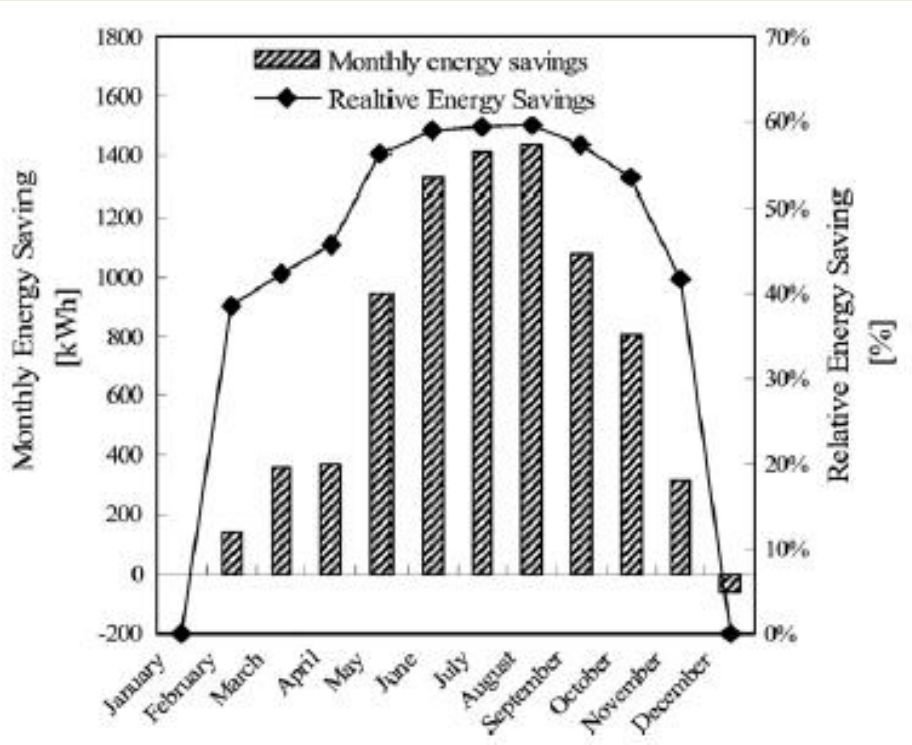
Annual energy performance – bigger share in latent load

114-
>52kWh/m2

annual air-conditioning energy index :

$$\frac{\textit{Annual energy consumption of AC system}}{\textit{Total floor area}}$$





Solar Desiccant Air Conditioning

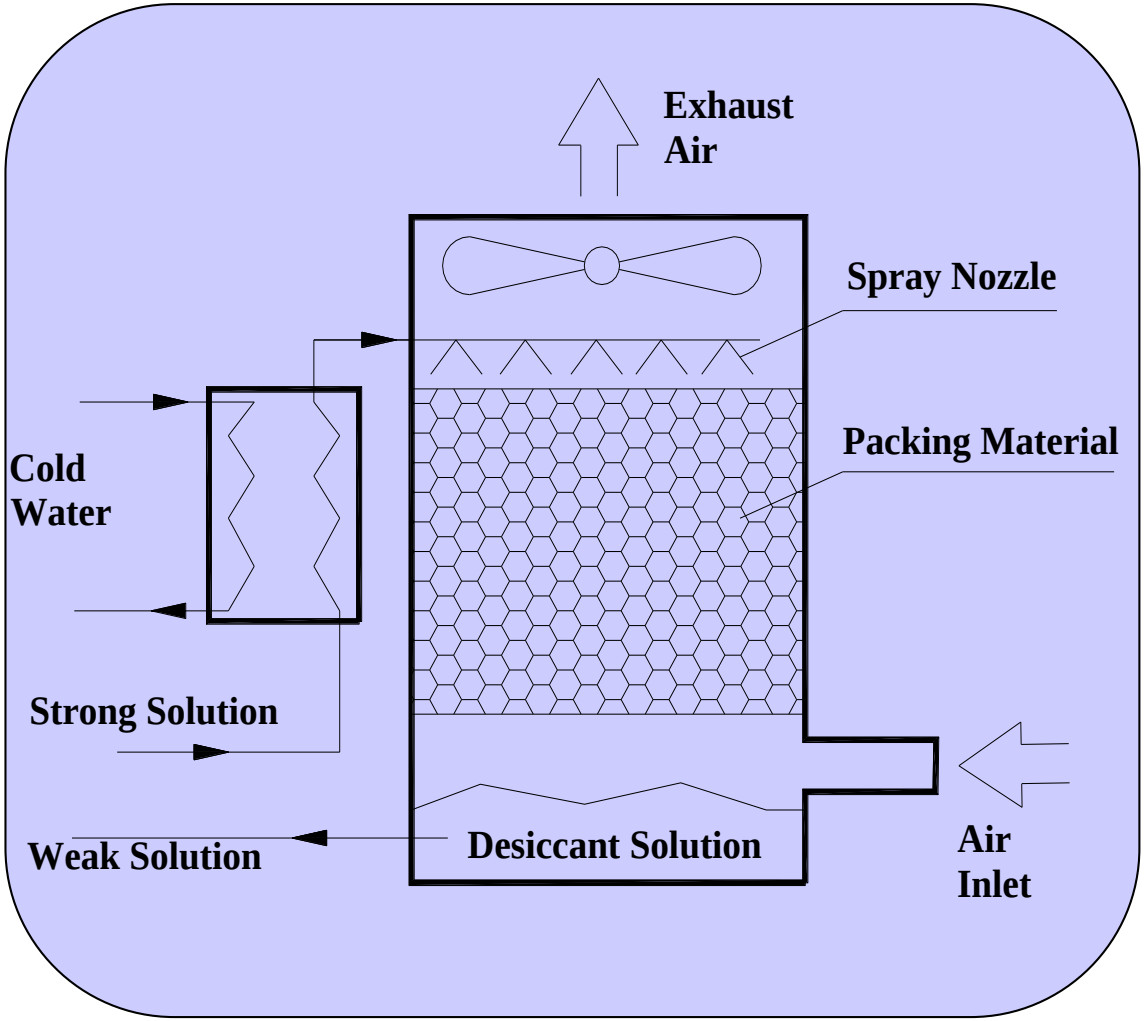
----solar assisted air conditioning

Moisture Control → Desiccant Dehumidification → Latent Load

Temperature Control → Air cooling → Sensible Load

Separate handling of latent and sensible loads.

The Desiccant Dehumidifier





Raschig Ring

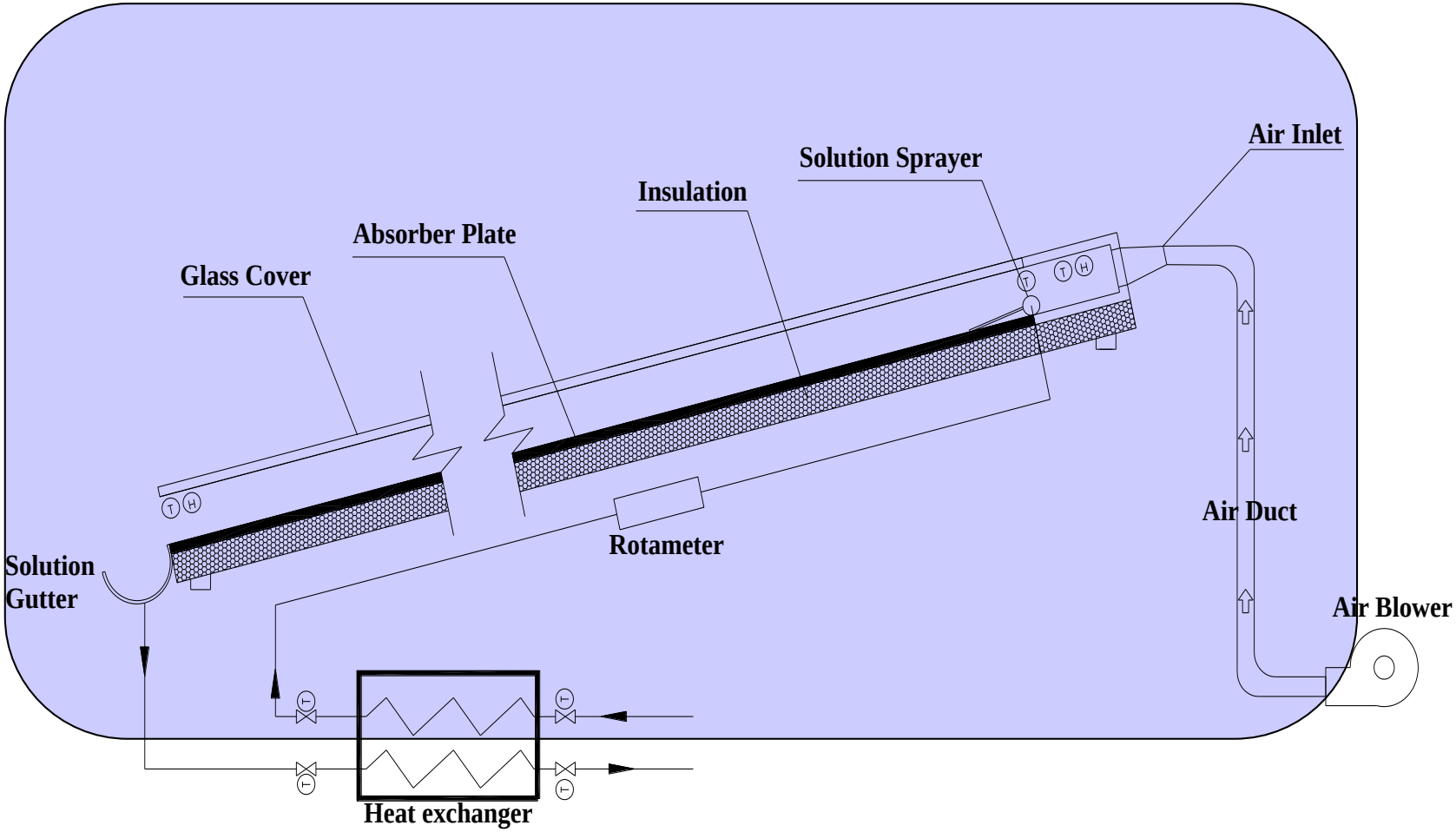


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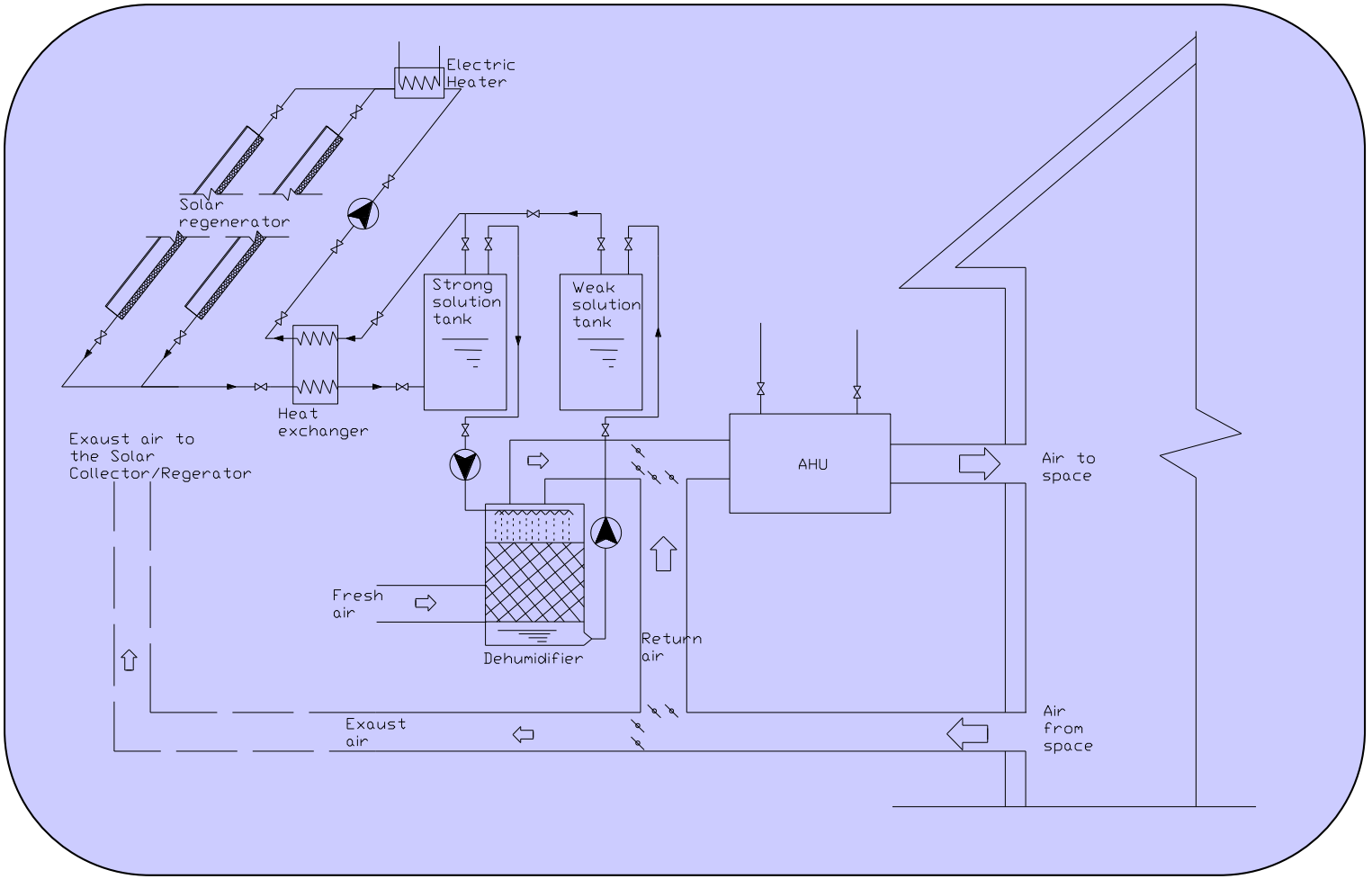


Pall Ring

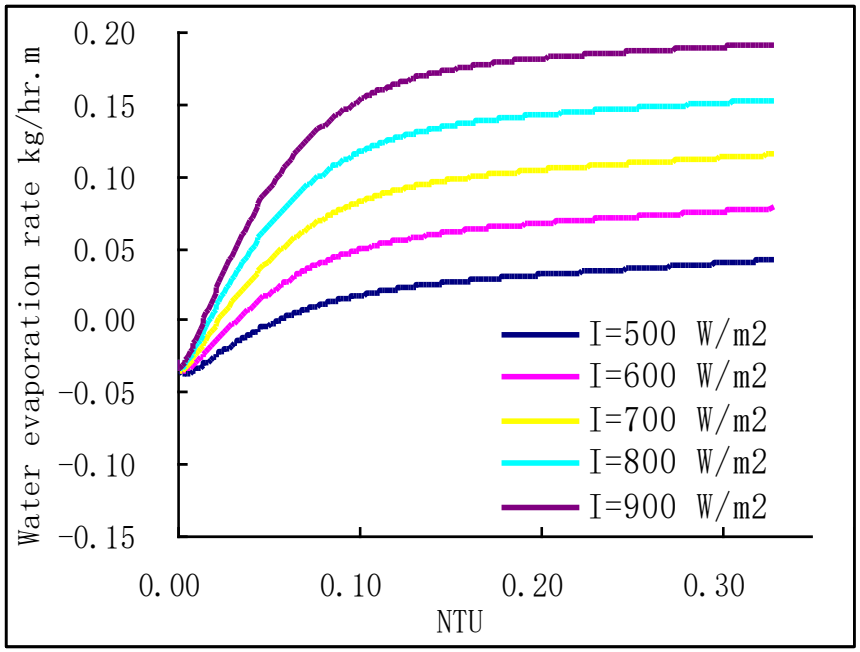
The Open Cycle Solar Collector/Regenerator



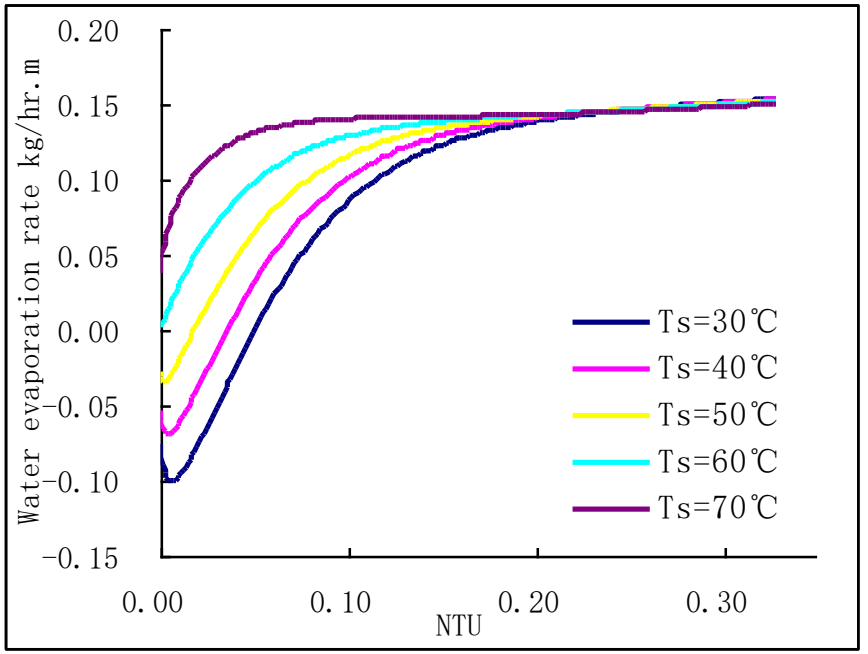
Possible Configurations of the System



Parametric analysis



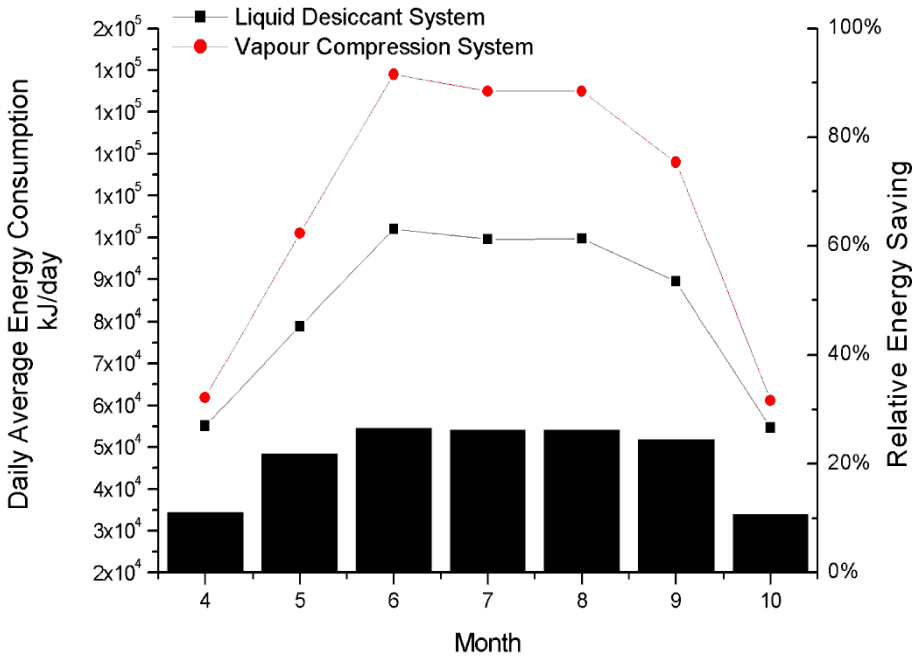
(a) Solar radiation



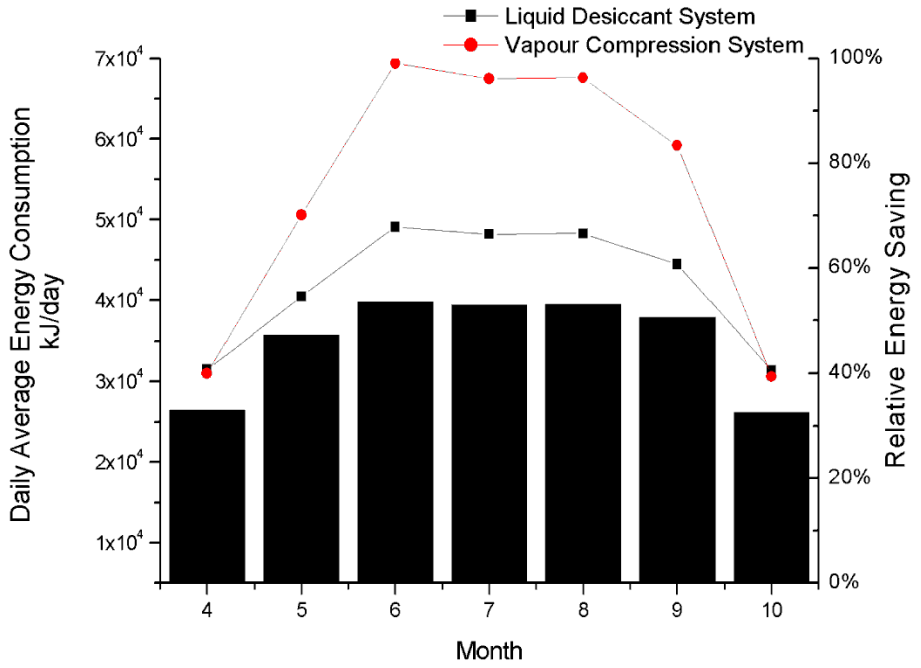
(b) Solution temperature

Effects of the main parameters on a solar C/R

System Performance on Design Day



Energy savings for low latent load condition (SHF=0.8)



Energy savings for high latent load condition (SHF=0.6)

Conclusions

- Policy is needed to support solar hot water production.
- Solar photovoltaic develops very fast. The cost is nearly close to traditional energy resources for power generation.
- BIPV represents the future of renewable power generation in urban areas.
- Introduction of the FiT leads to bright future for BIPV in Hong Kong, but long-time policy is needed.
- Vacuum PV glazing façade has the lowest U-value as well as SHGC compared with double-pane glass, double PV glazing and pure vacuum glazing.
- Solar desiccant dehumidification is an effective way to produce cooling for air-conditioning.

Thank you for your attention !

Q & A