Solar Collector Integrated with a Pulsating Heat Pipe and a Compound Parabolic Concentrator

Rongji XU, Xiaohui Zhang, Ruixiang Wang, Shuhui Xu, Hua Sheng Wang

Beijing University of Civil Engineering and Architecture
Queen Mary University of London

Rongji Xu, Xiaohui Zhang, Ruixiang Wang, Shuhui Xu, Hua Sheng Wang, Experimental investigation of solar collector integrated with a pulsating heat pipe and a compound parabolic concentrator, ***Energy Conversion and Management***, 148 (2017), 68-77

Renewable Energy global innovations

BREAKING NEWS Solar collector integrated with a pulsating heat pipe and a compound parabolic concentrator

KEY SCIENTIFIC ARTICLES

Solar collector integrated with a pulsating heat pipe and a compound parabolic concentrator

February 24, 2018

Read More »

ENERGY AND SUSTAINABILITY 2018 SYMPOSIUM

About the author

Rongji Xu，PhD，Associate Professor

School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture

1 Zhanlanguan Road, Beijing 100044, China

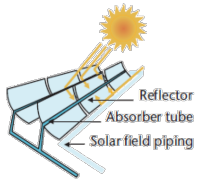
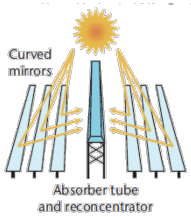
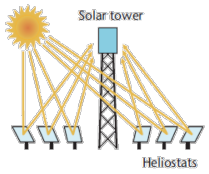
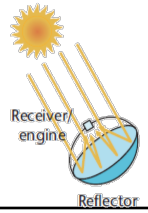
Email: xurongji@bucea.edu.cn

Background

Industry		Vapour Temp (℃)	Vapour Press (Pa)
Electric power generation	Ultra supercritical	610 ~ 630	> 335
	Supercritical	550	> 221
	Subcritical	540	167.7
	Ultra high pressure	540	138.3
	High pressure	540	99
	Middle and low pressure	400 ~ 450	35 ~ 39.2
Heating		127 ~ 188	2.5 ~ 12
Papermaking		265	7.9 ~ 12.8
Desalination		70 ~ 116	3.7 ~ 5.5
Tobacco manufacturing		195 ~ 400	10 ~ 13
Food processing		193	12.5
Printing and dyeing		170 ~ 180	6 ~ 8
Feed production		100 ~ 105	1.0 ~ 1.2

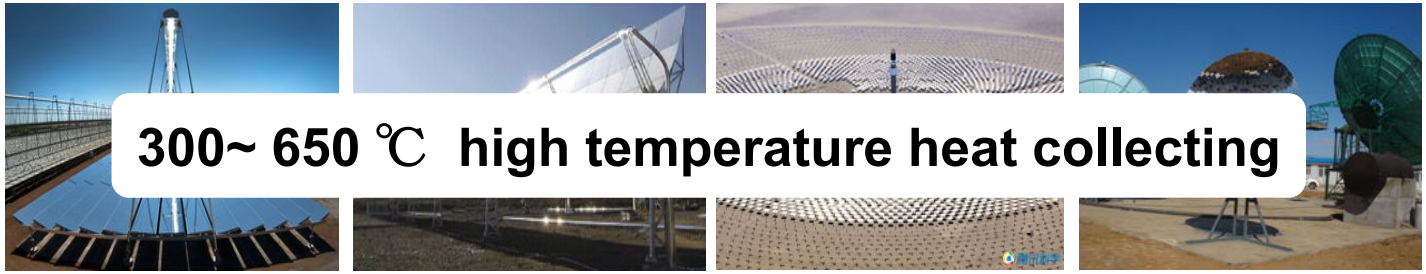
Demand：70-200℃ heat

Concentrating solar power (CSP) technology

Collector type		Thermodynamic efficiency	Operating temp. range ºC	Cost	Concentration ratio
Parabolic trough (PT)		Low	50-550	Low	15-45
Linear Fresnel (LF)		Low	50-550	Very low	10-40
Tower		High	300-2000	High	150-1500
Parabolic dish		High	150-1500	Very high	100-1000

Various temperature heat collecting

Fresnel lens | Solar parabolic through | Solar power tower | Dish solar



300~ 650 ℃ high temperature heat collecting

- km Scale
- High concentration
- Tracking device
- West China

< 100 ℃ low temperature heat collecting

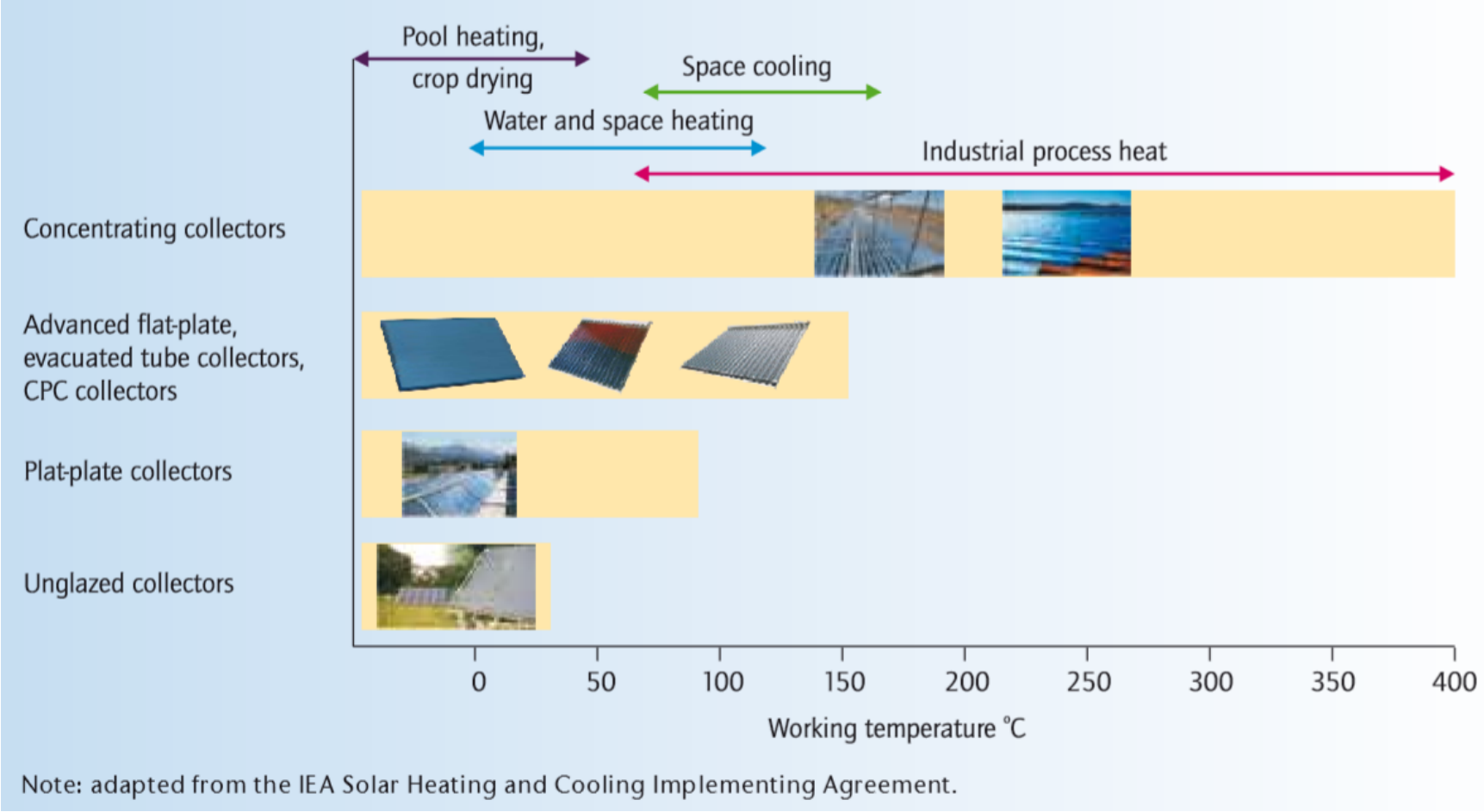
- m Scale
- No concentration
- No tracking
- Building integrated

Solar evaculated tube | Flat plate | Heat collector array

Demand : 70-200℃

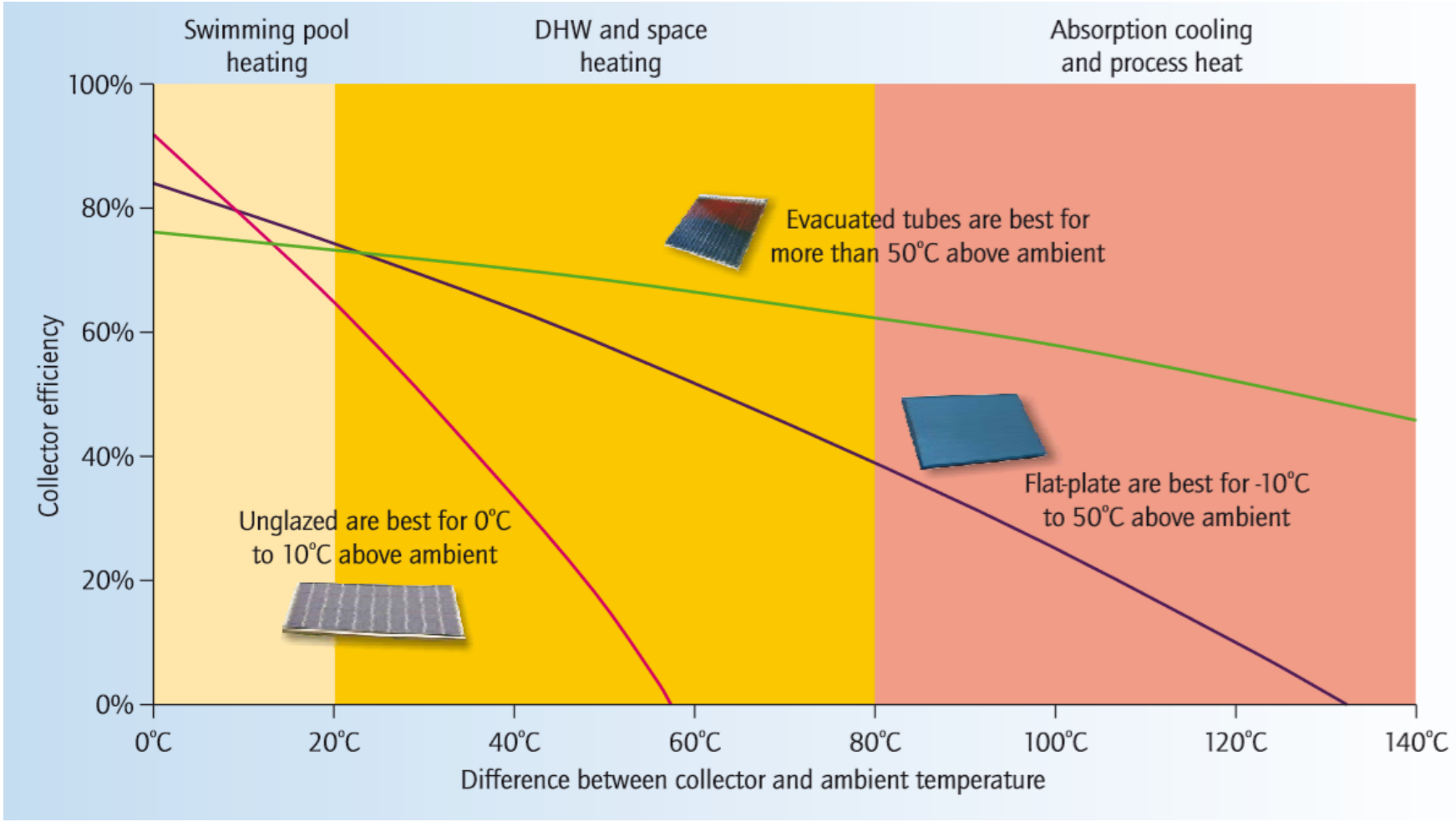
m scale + concentrating + no tracking + building intergrated

Working temperature for different solar collectors



https://webstore.iea.org/technology-roadmap-solar-heating-and-cooling

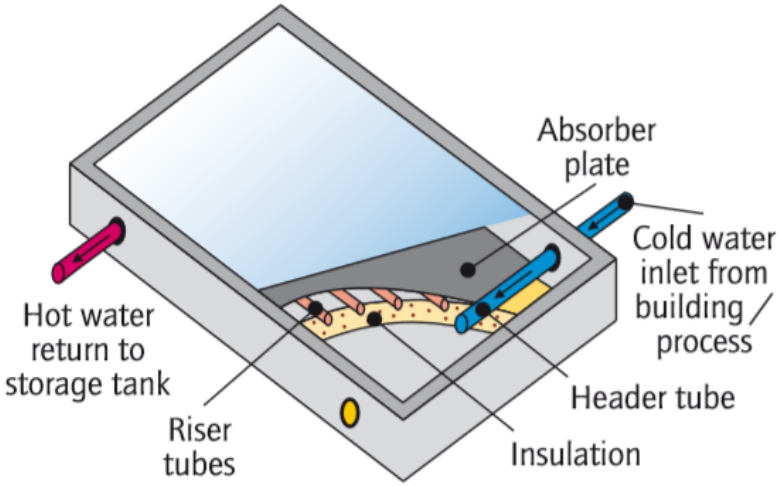
Comparison of collector efficiency



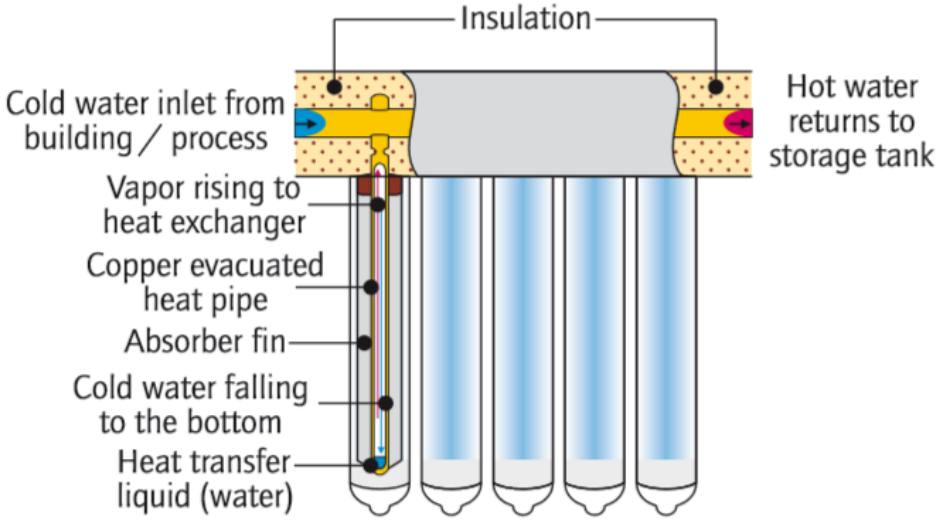
https://webstore.iea.org/technology-roadmap-solar-heating-and-cooling

Challengers of solar collectors

Flat Plate solar collector



Vacuum tube solar collector

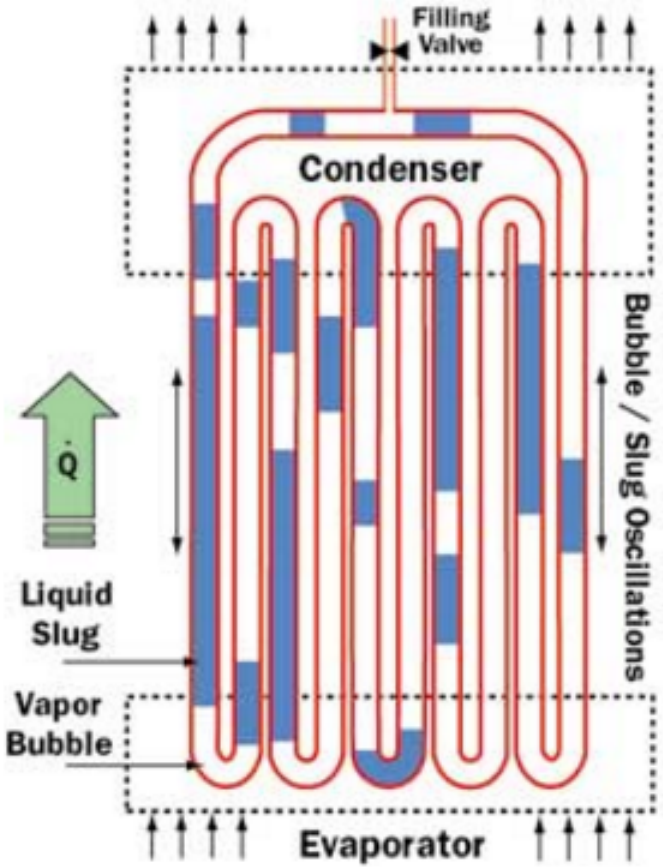


https://webstore.iea.org/technology-roadmap-solar-heating-and-cooling

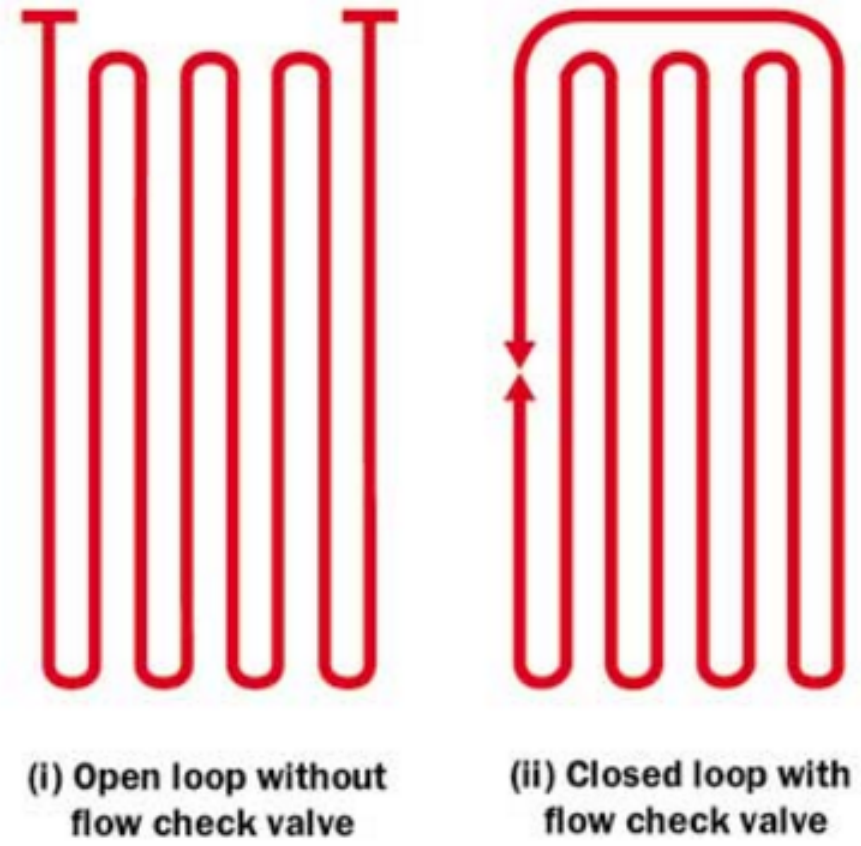
- **Low temperature（＜80℃）**
- **Low efficiency**
- **Building integrated**
- **Low cost**
- **High reliability**

- **Low temperature（＜150℃）**
- **High efficiency**

Pulsating heat pipe



Schematic of a closed loop PHP without check valve.



Two layouts (i) Open loop (ii) Closed loop.

Khandekar et al., 2003, An introduction to pulsating heat pipes, Electronics Cooling, Vol.9, No.2, pp.38-41.

Novel design of the solar collector

CPC+PHP

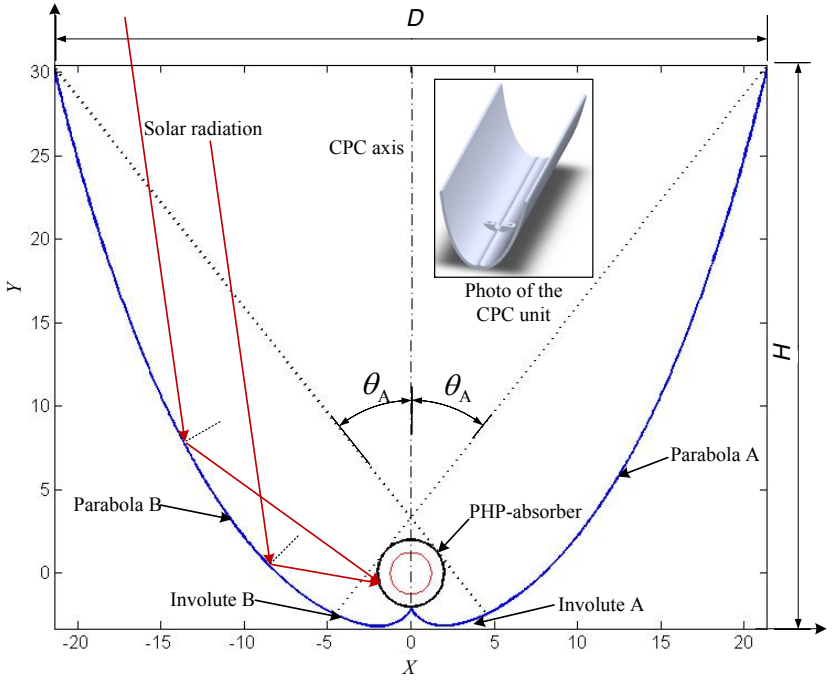
- Same scale to plate solar collector
- Collection temperature 70-200℃
- No tracking

PHP

- High heat transfer ability
- Simple structure
- Micochannel tube

CPC

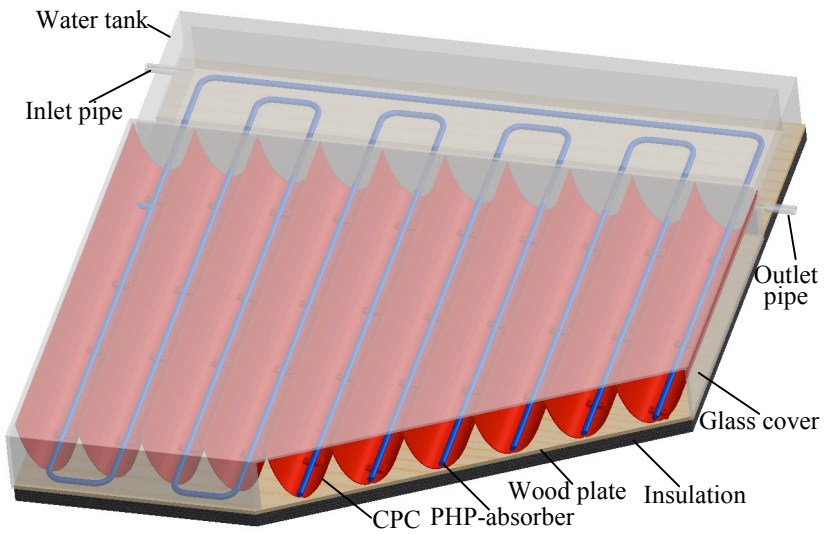
- Concentration ratio of 2~6
- No tracking
- High height to width ratio

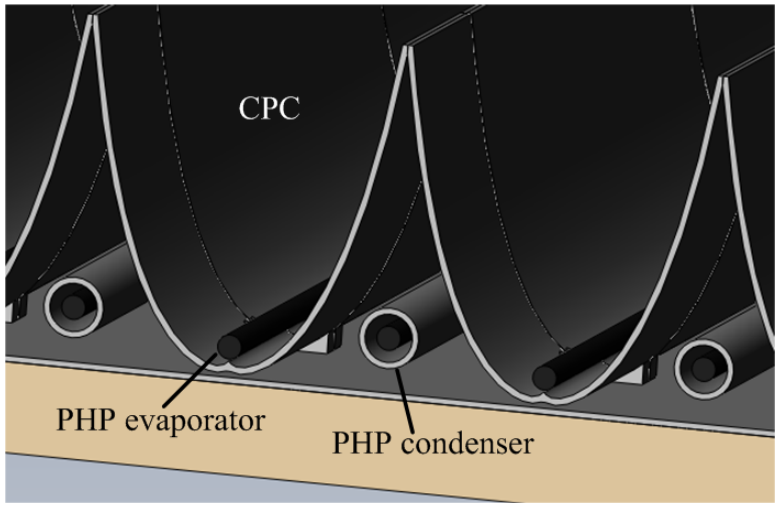


Design

Development of the CPC-PHP solar collector

- North-south orientation
- East-west orientation



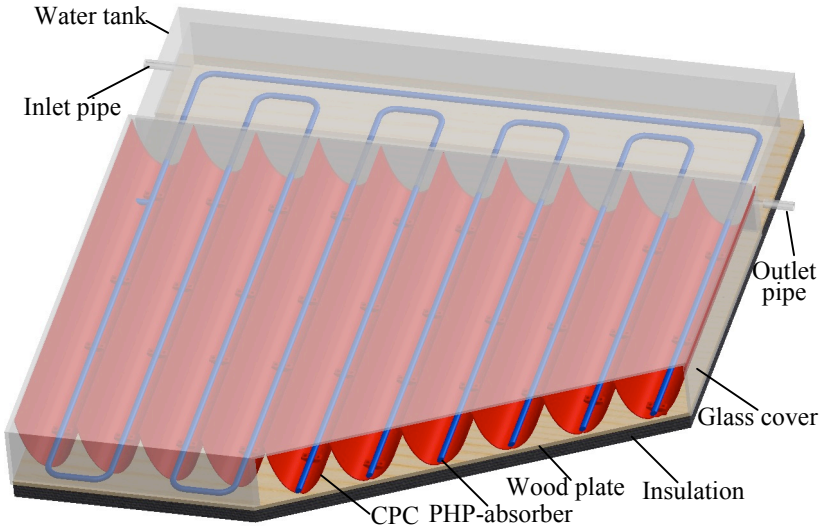


Numerical simulation of the solar collector

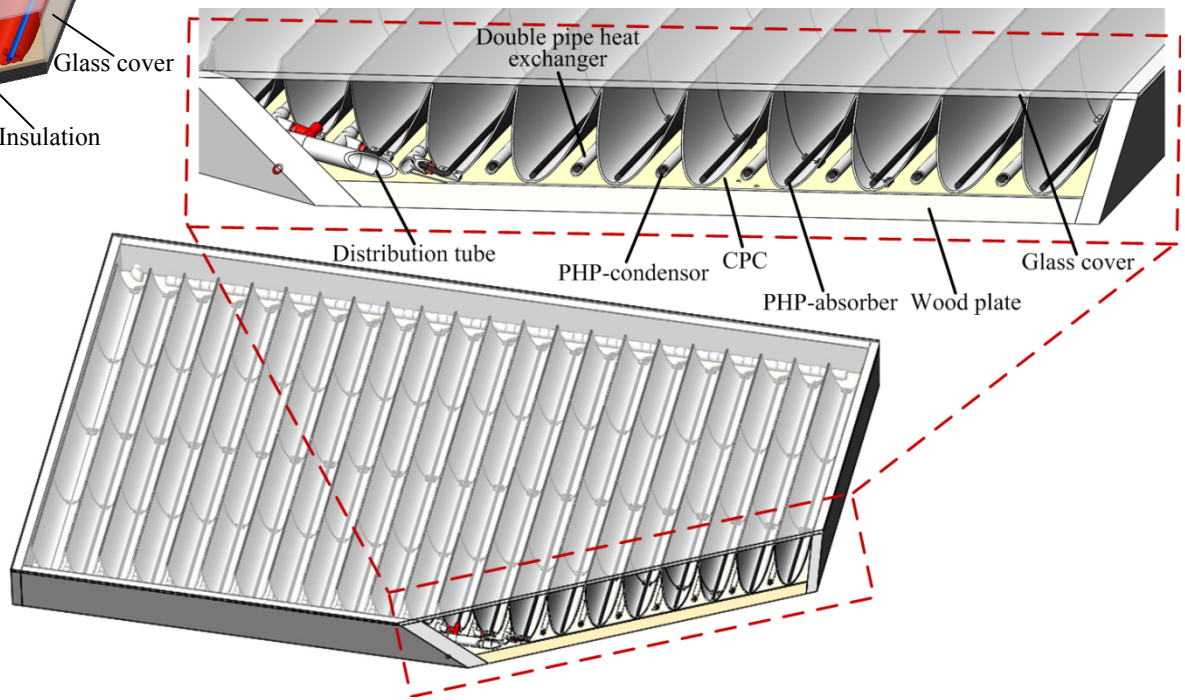
Experimental study of the solar collector

- Operating characteristics of the PHP absorber
- Heat collecting efficiency of the solar collector

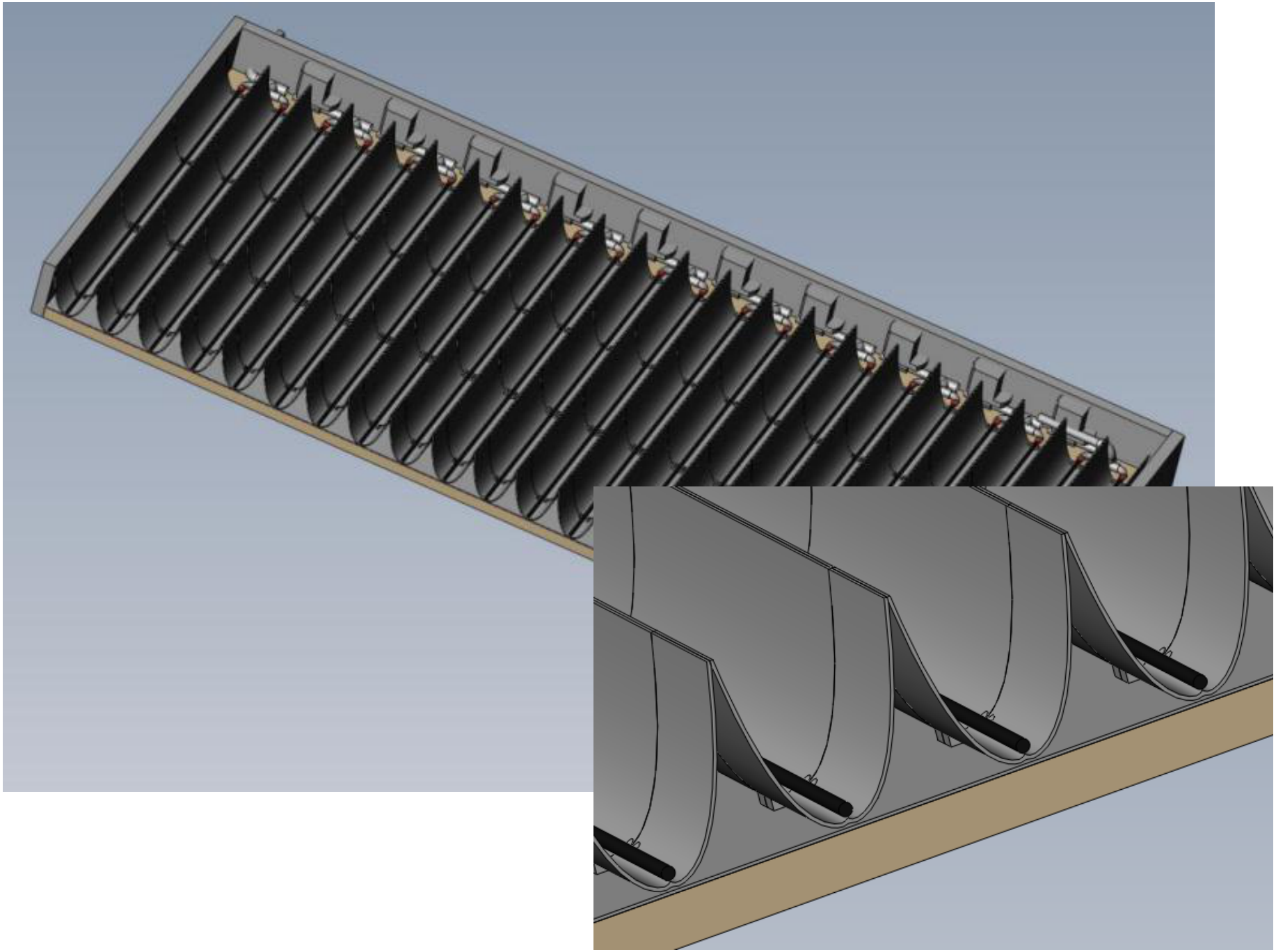
Design: Orientation

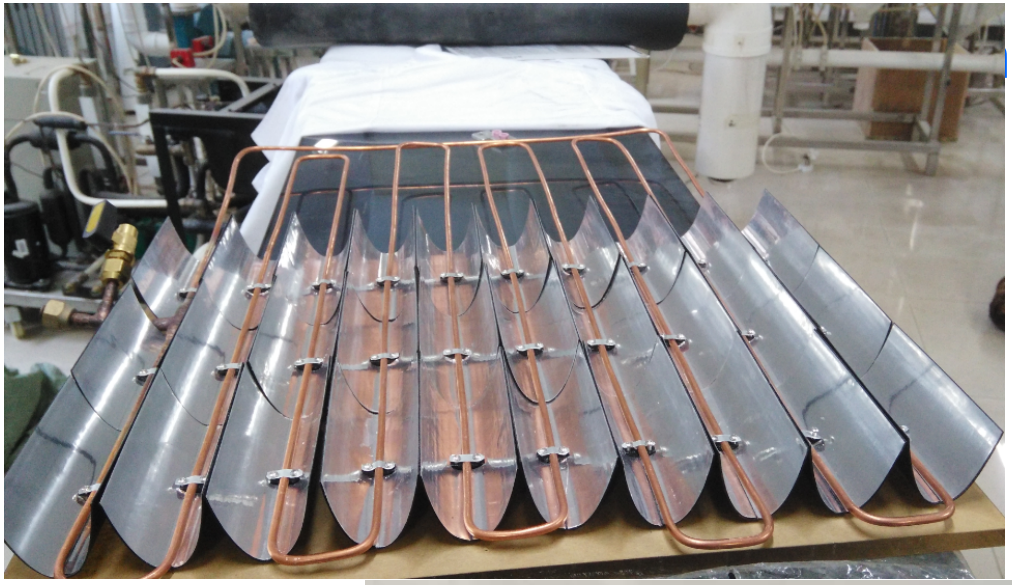


North-south orientation (with water tank)

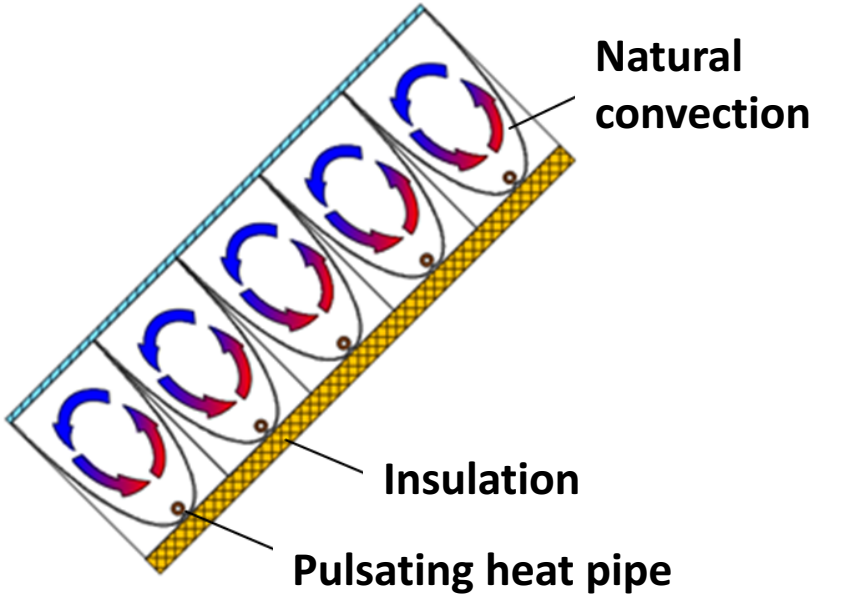


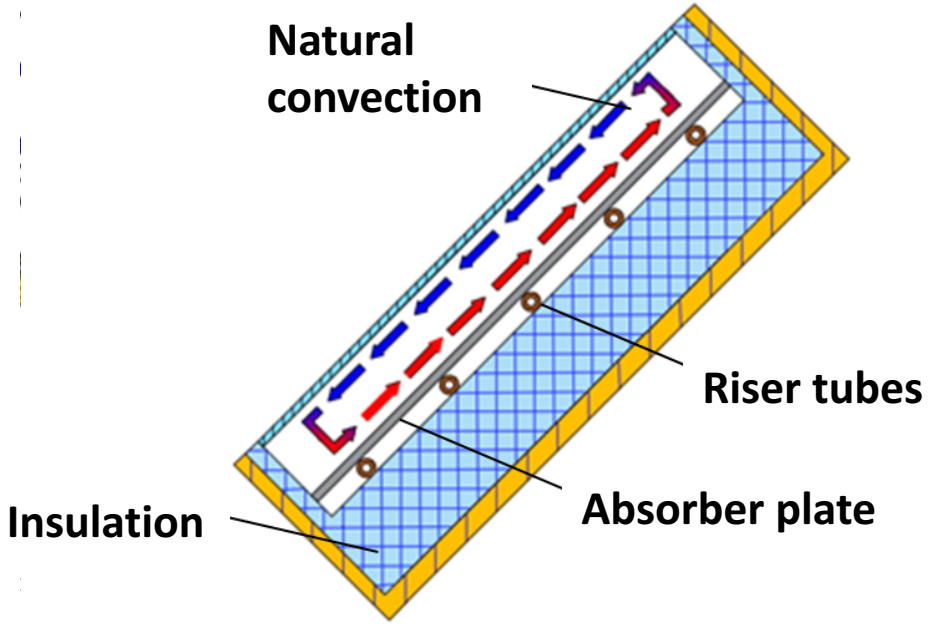
East-west orientation (without water tank)





Advantages of the novel solar collector

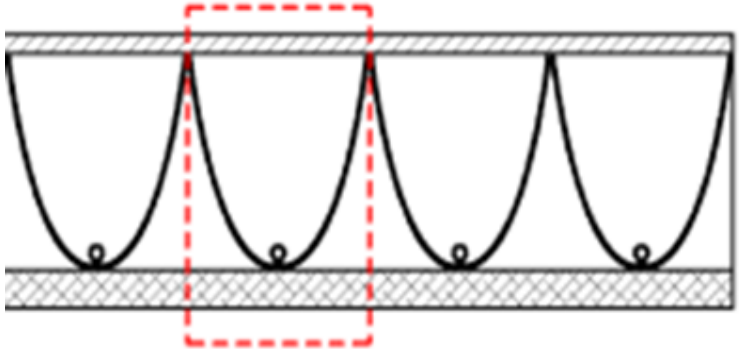


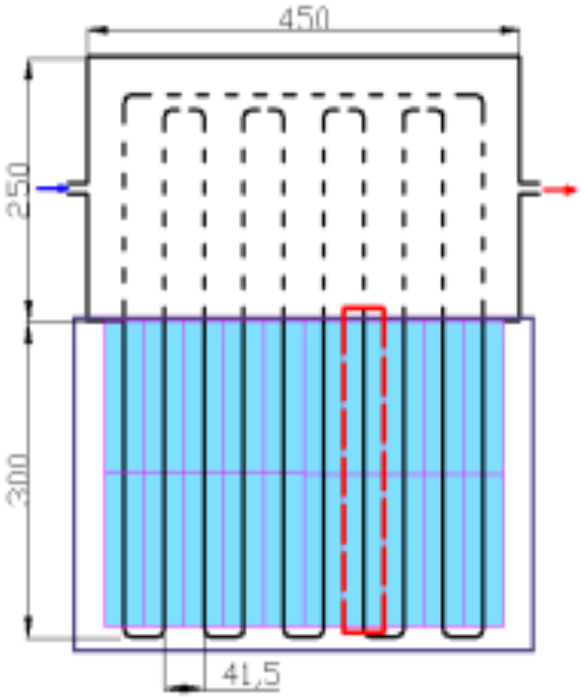


- CPC results in an increase in heat flux of PHP absorber so that the heat transfer capacity of PHP is fully utilized.
- The heat loss decreases due to the decrease in hot surface area.
- The diameter of PHP is usually less than 4 mm. When PHP is used as absorber, the size of CPC can be the same as plate solar collector.

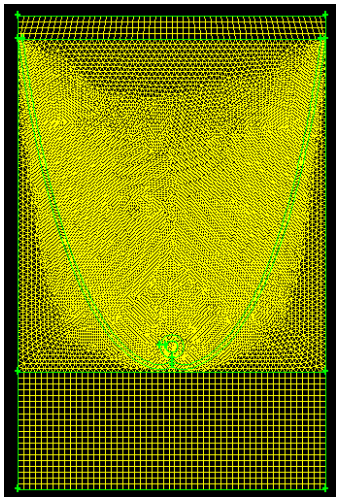
Numerical simulation of the solar collector

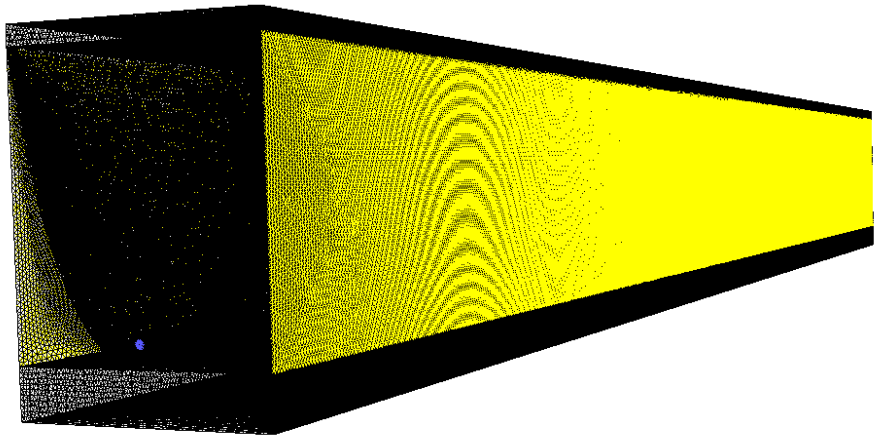
- **Model**



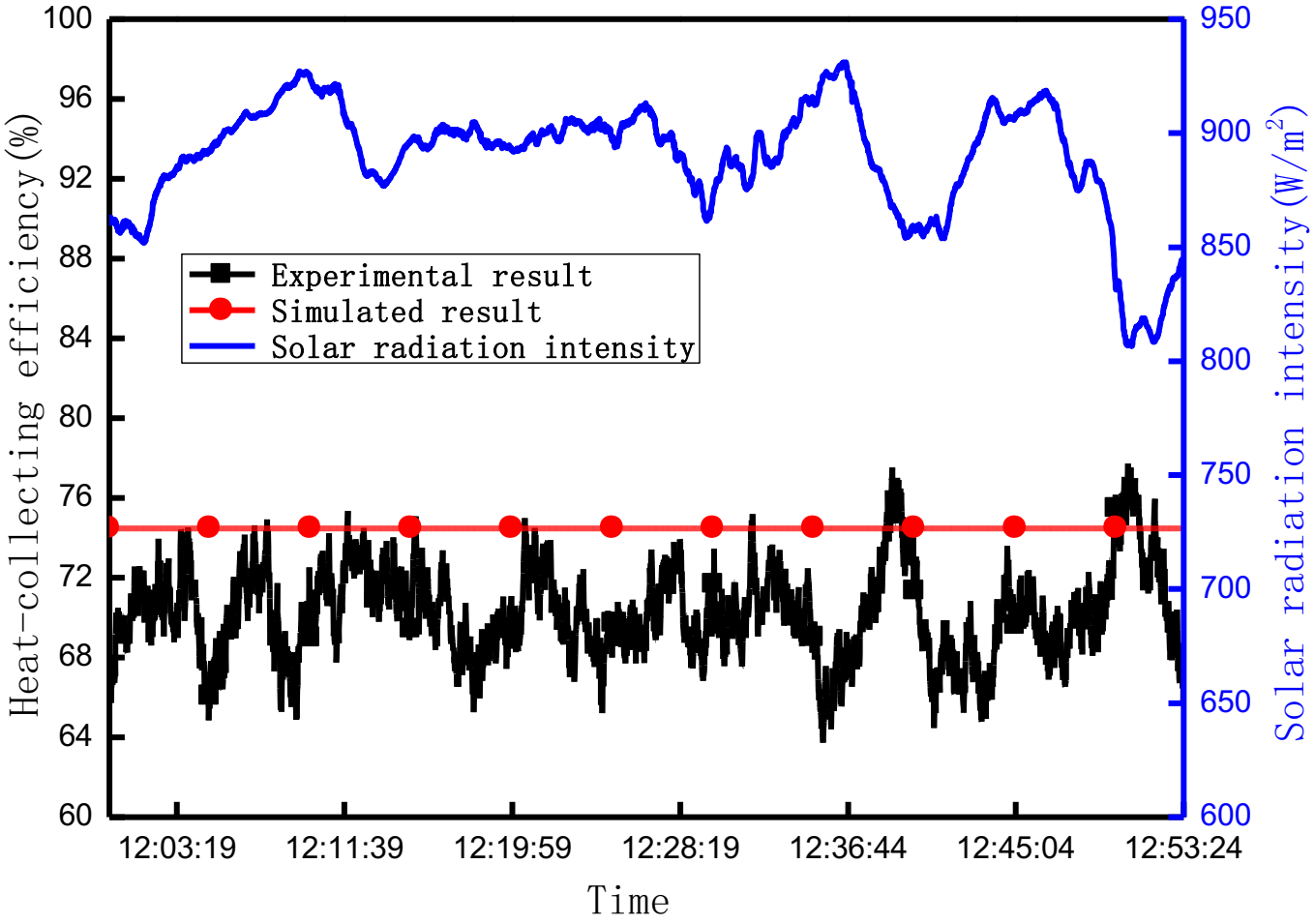


- **Mesh**





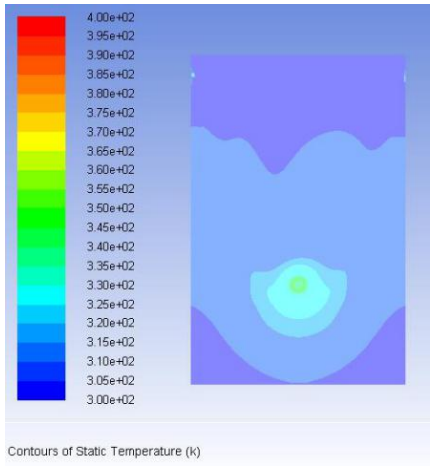
Model validation

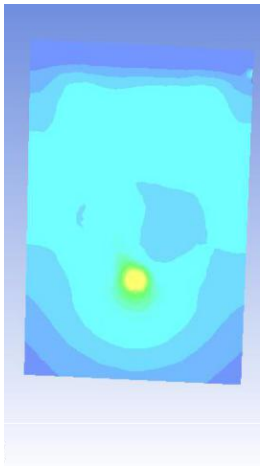


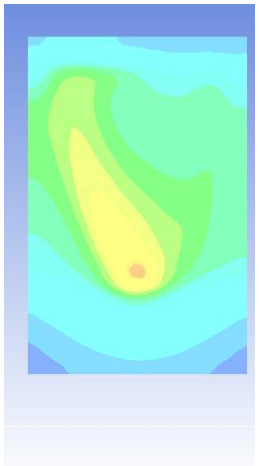
Comparison of validation results

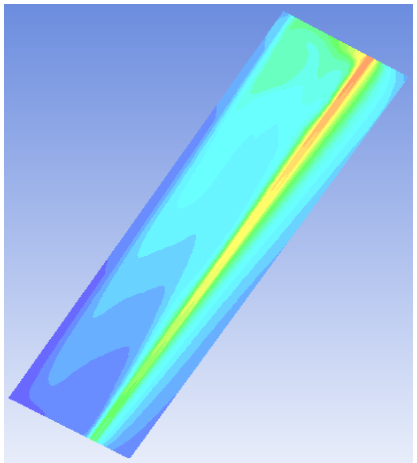
21/8/2015 12:00-13:00 , R134a , Filling Ratio 40%

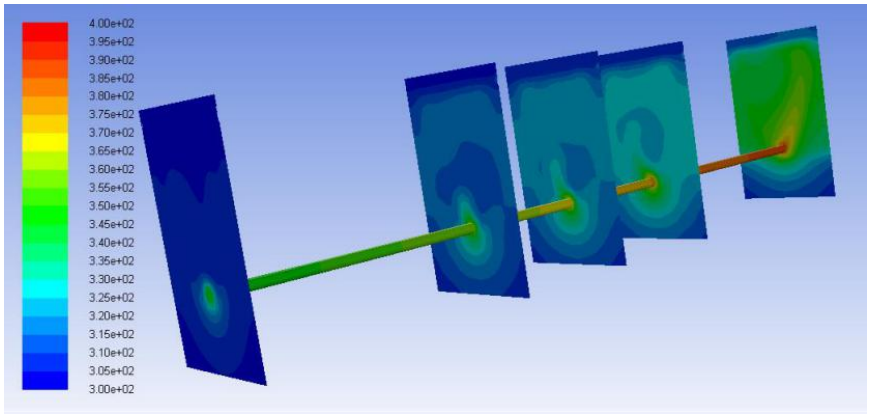
Temperature distribution

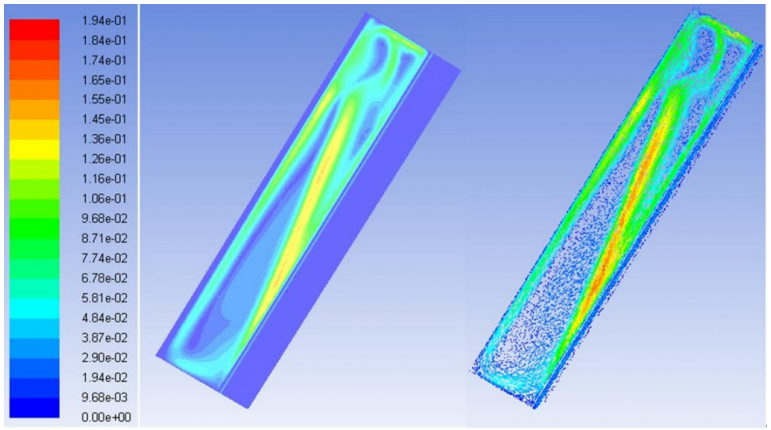




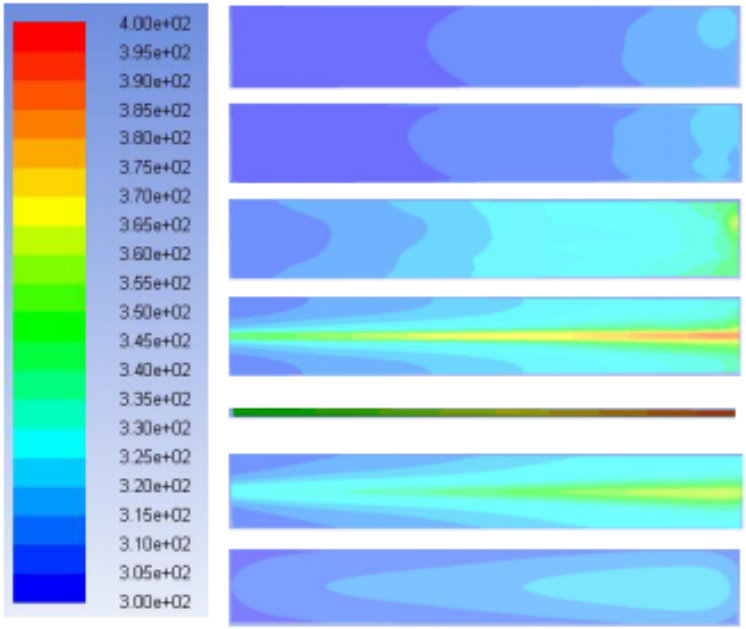








Temperature distribution



Outside surface of glass

Inside surface of glass

Air gap

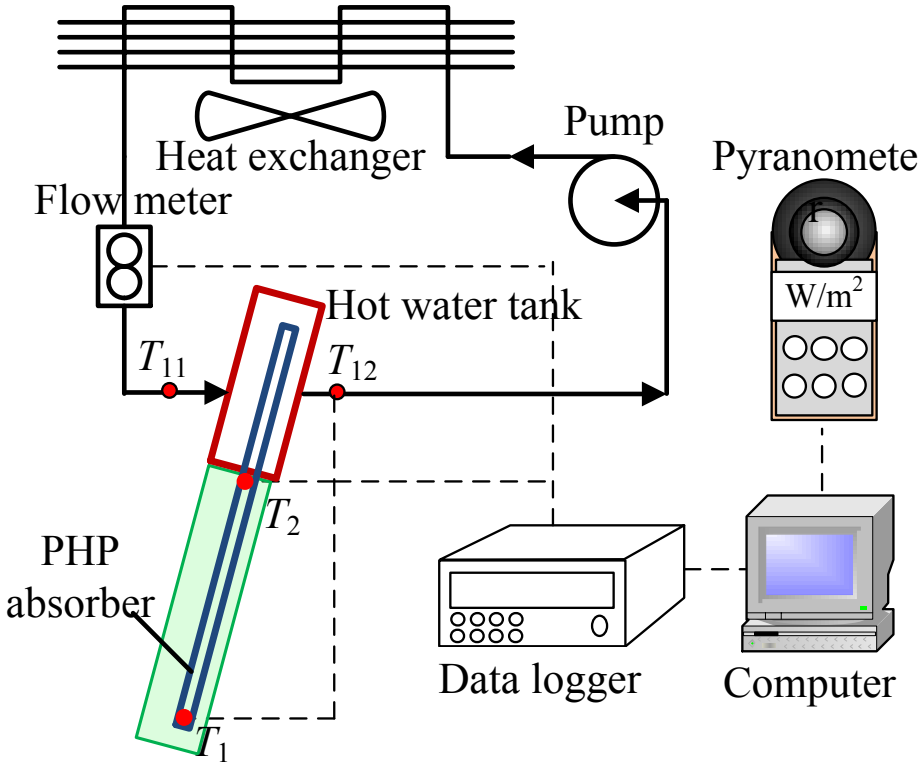
Cross section of heat collection tube

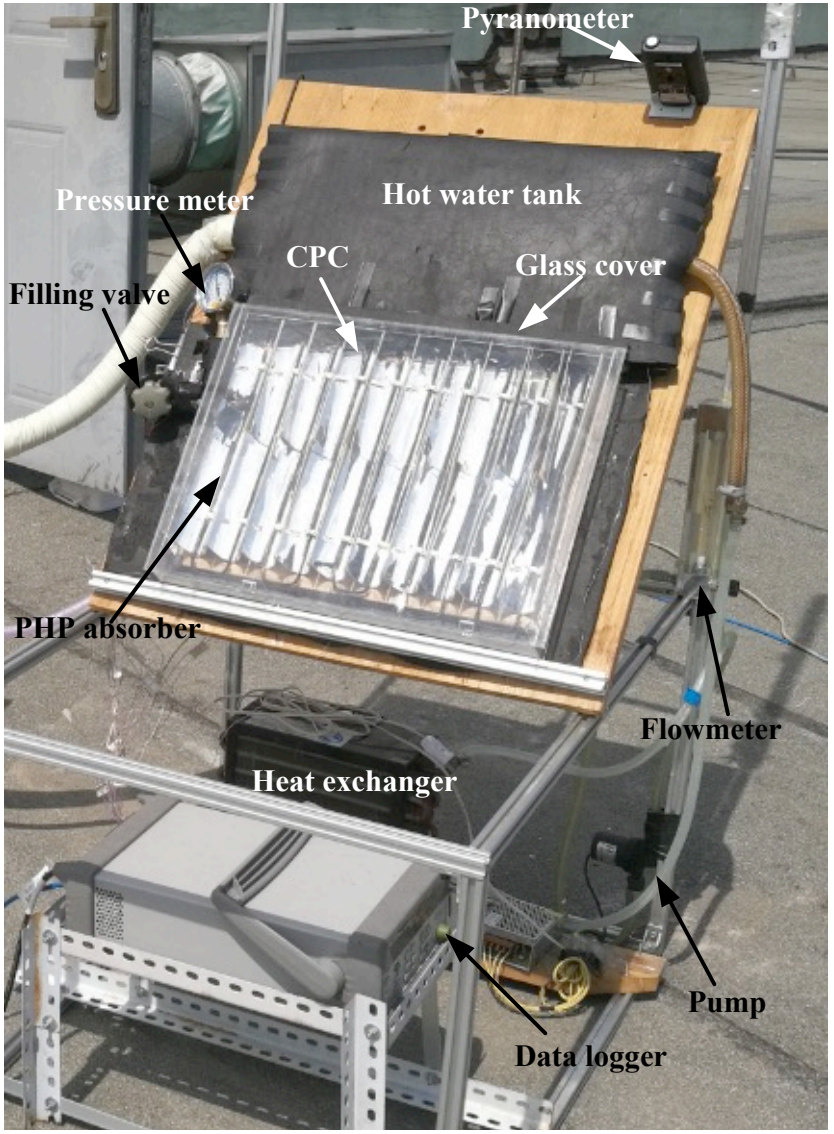
Surface of heat collection tube

Inside surface of bottom plate

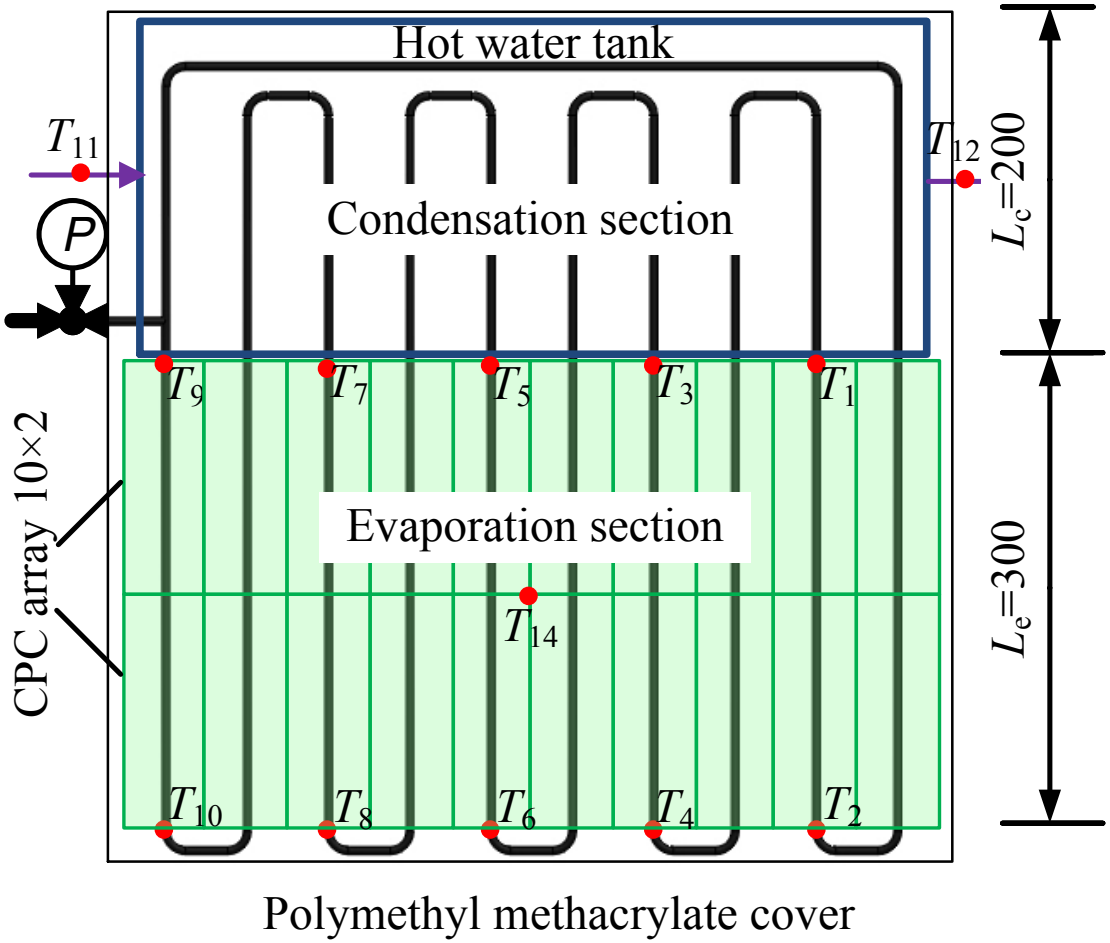
Outside surface of bottom plate

Test rig: the solar collector prototype





Dimensions and temperature measurement



$$R_{\mathrm{T}} = (T_{\mathrm{e}} - T_{\mathrm{c}}) / (IA)$$

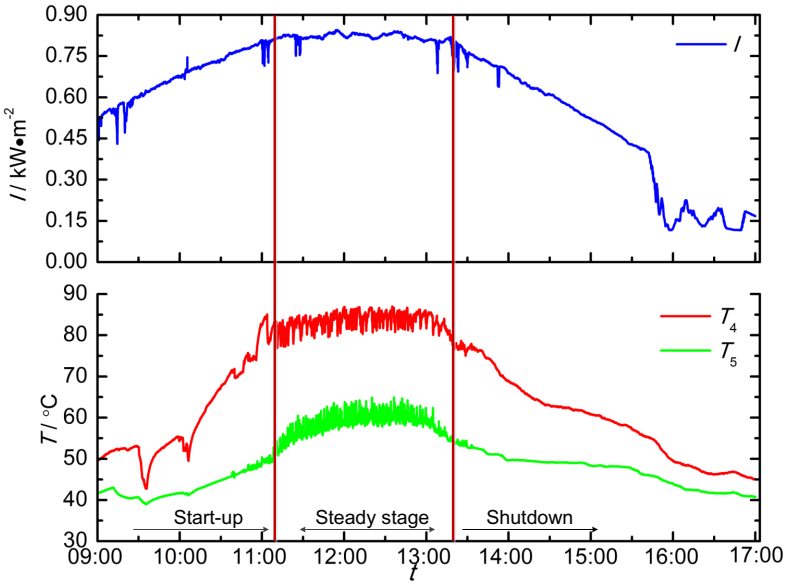
$$Q_{\mathrm{w}} = c_{\mathrm{w}} m_{\mathrm{w}} (T_{\mathrm{out}} - T_{\mathrm{in}})$$

$$\eta = \frac{c_{\mathrm{w}} m_{\mathrm{w}} (T_{\mathrm{out}} - T_{\mathrm{in}})}{IA}$$

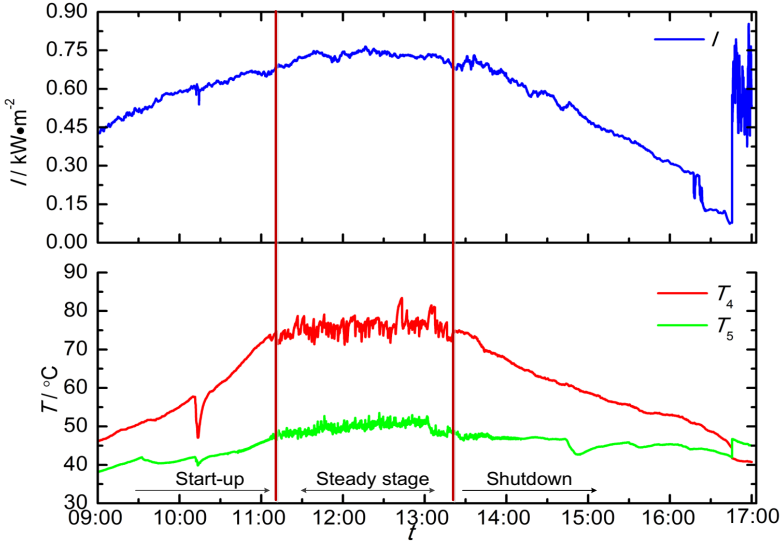
Characteristics of the PHP absorber

Measured solar irradiation intensity & temperatures vs local time

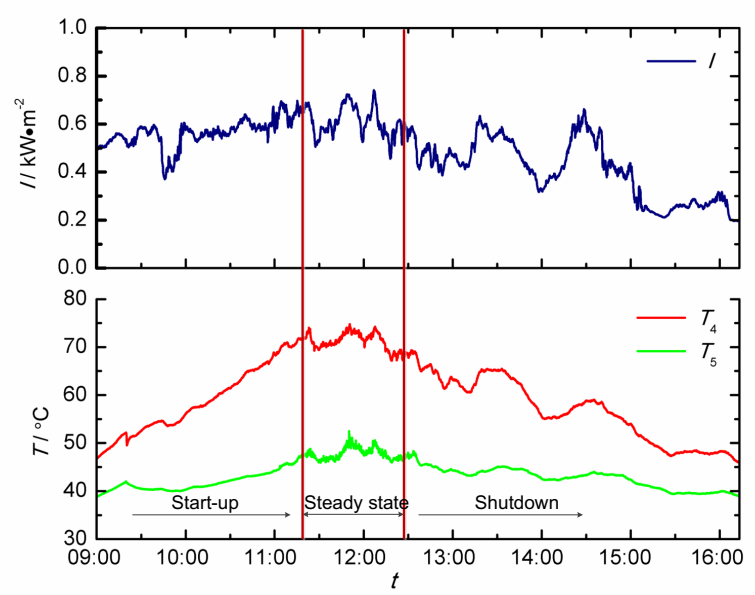
Case I
12/6/15



Case II
13/6/15

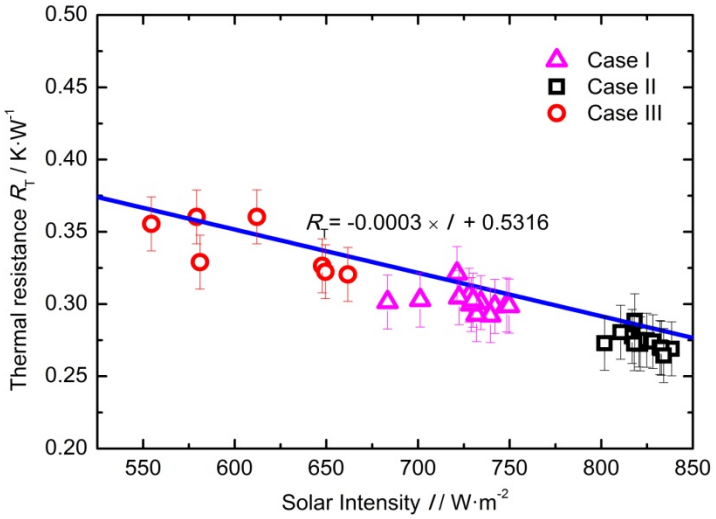


Case III
14/6/15

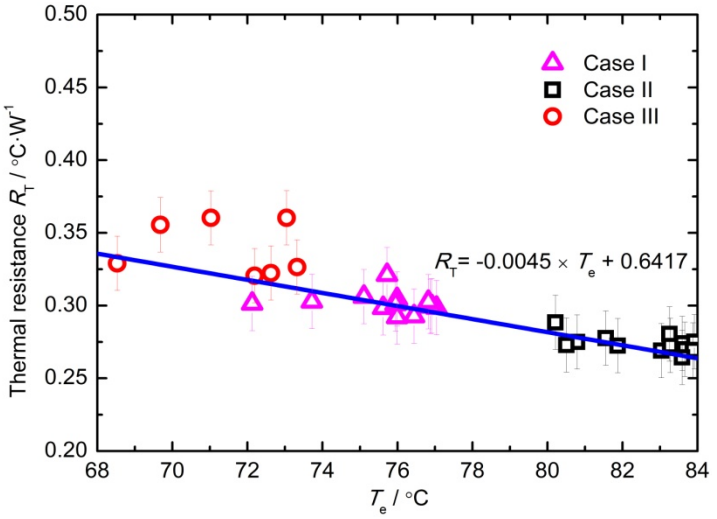


Characteristics of the PHP absorber

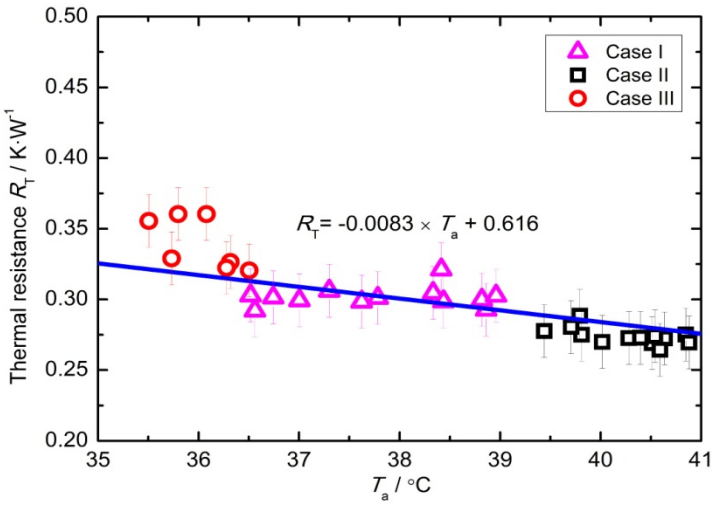
Thermal resistance of PHP absorber



Solar irradiation intensity

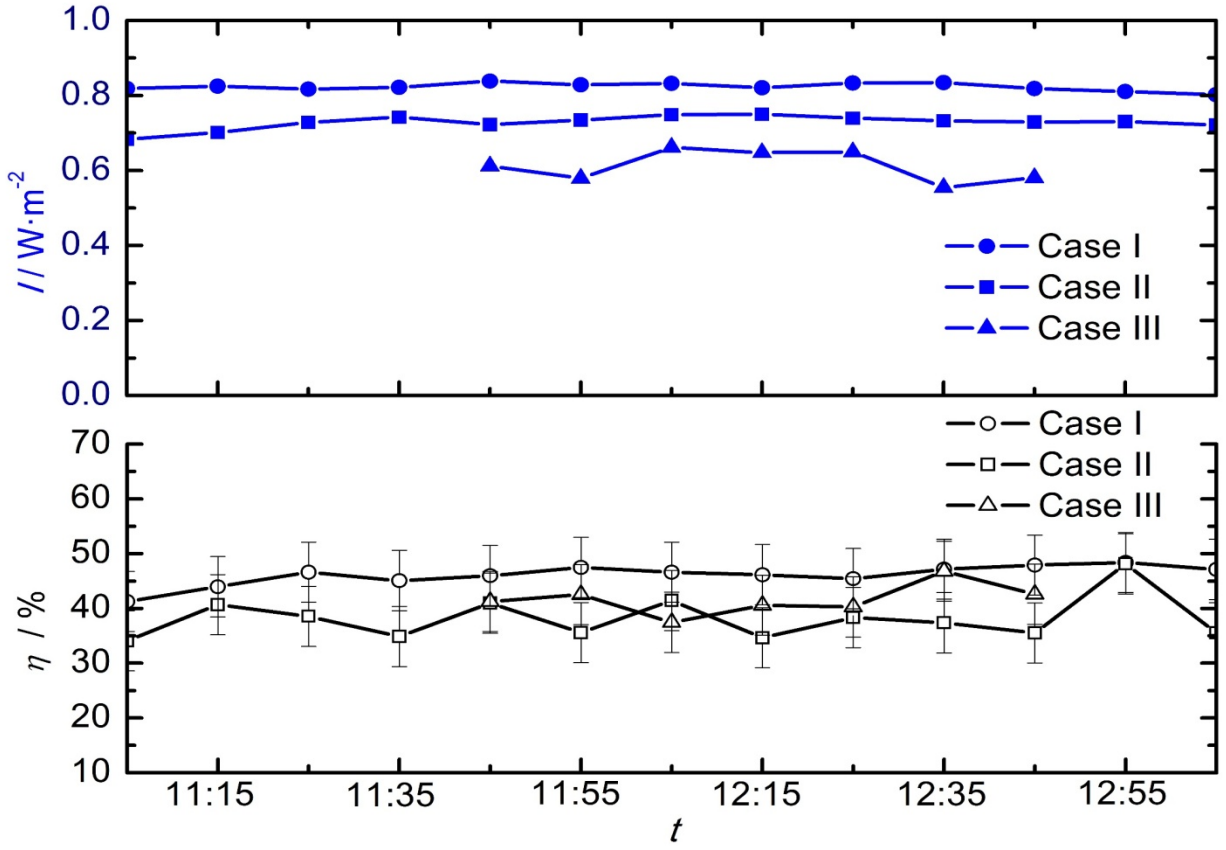


Evaporation temp.



Ambient temp.

Characteristics of the PHP absorber

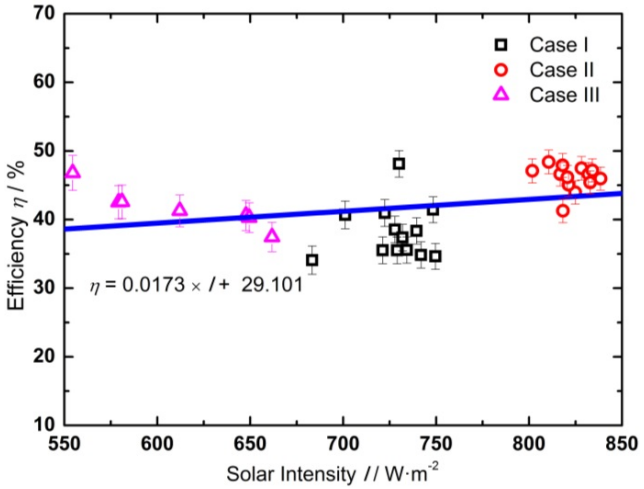


Variations of collector efficiency of solar collector with local time

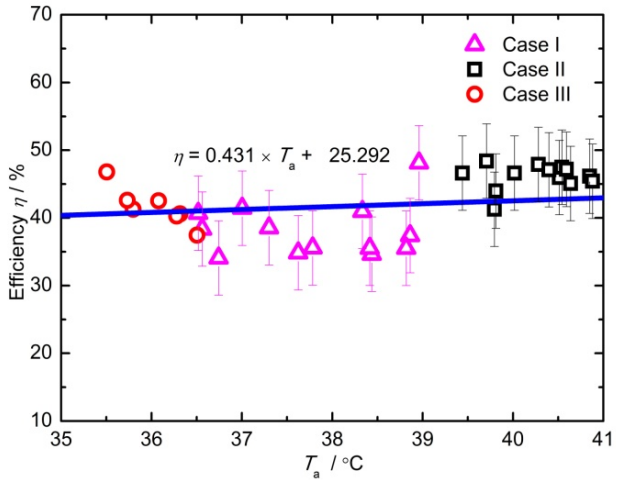
HFE7100, Filling Ratio 40%

Characteristics of the PHP absorber

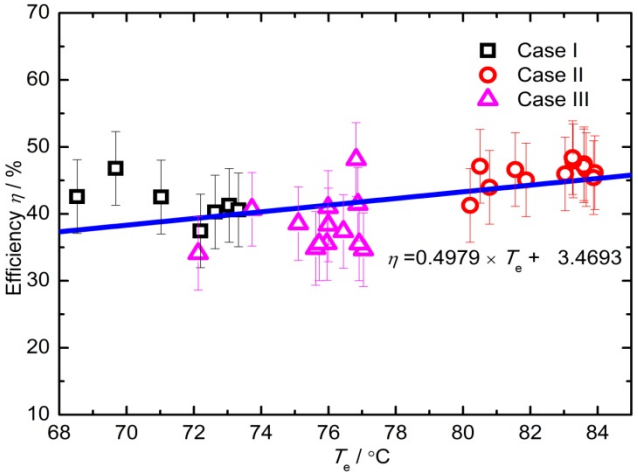
Heat-collecting efficiency of PHP absorber



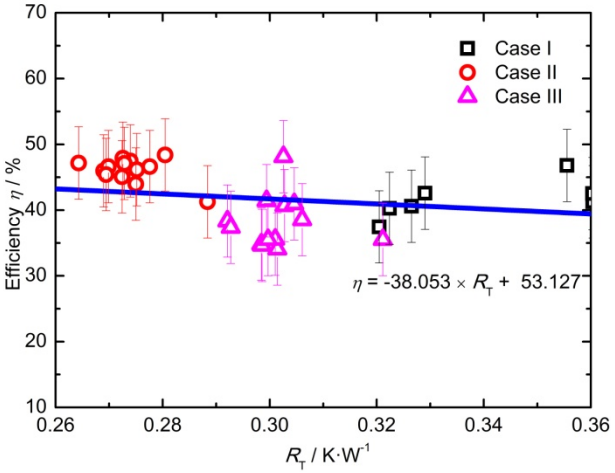
Solar irradiation intensity



Ambient temp.

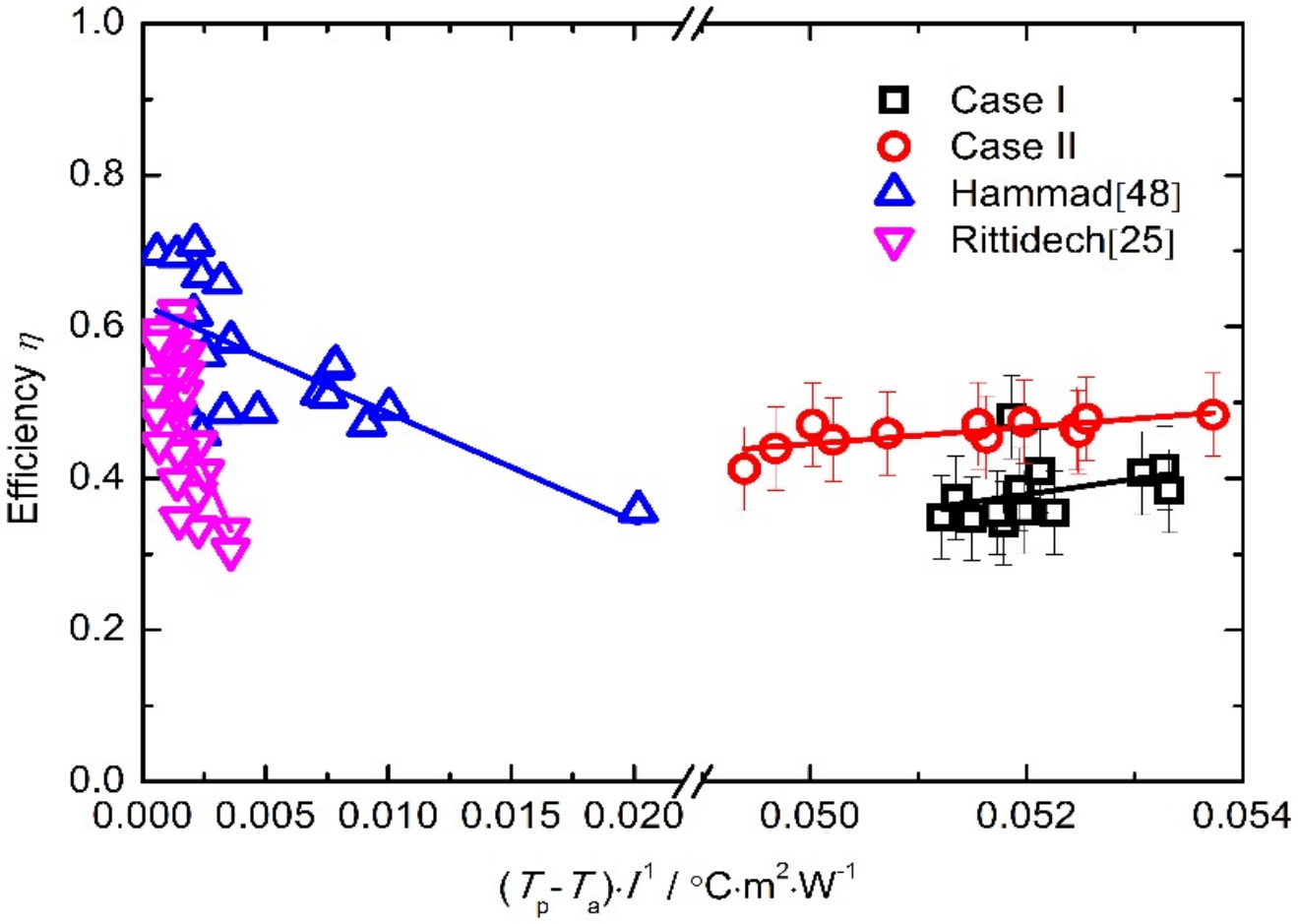


Evaporation temp.

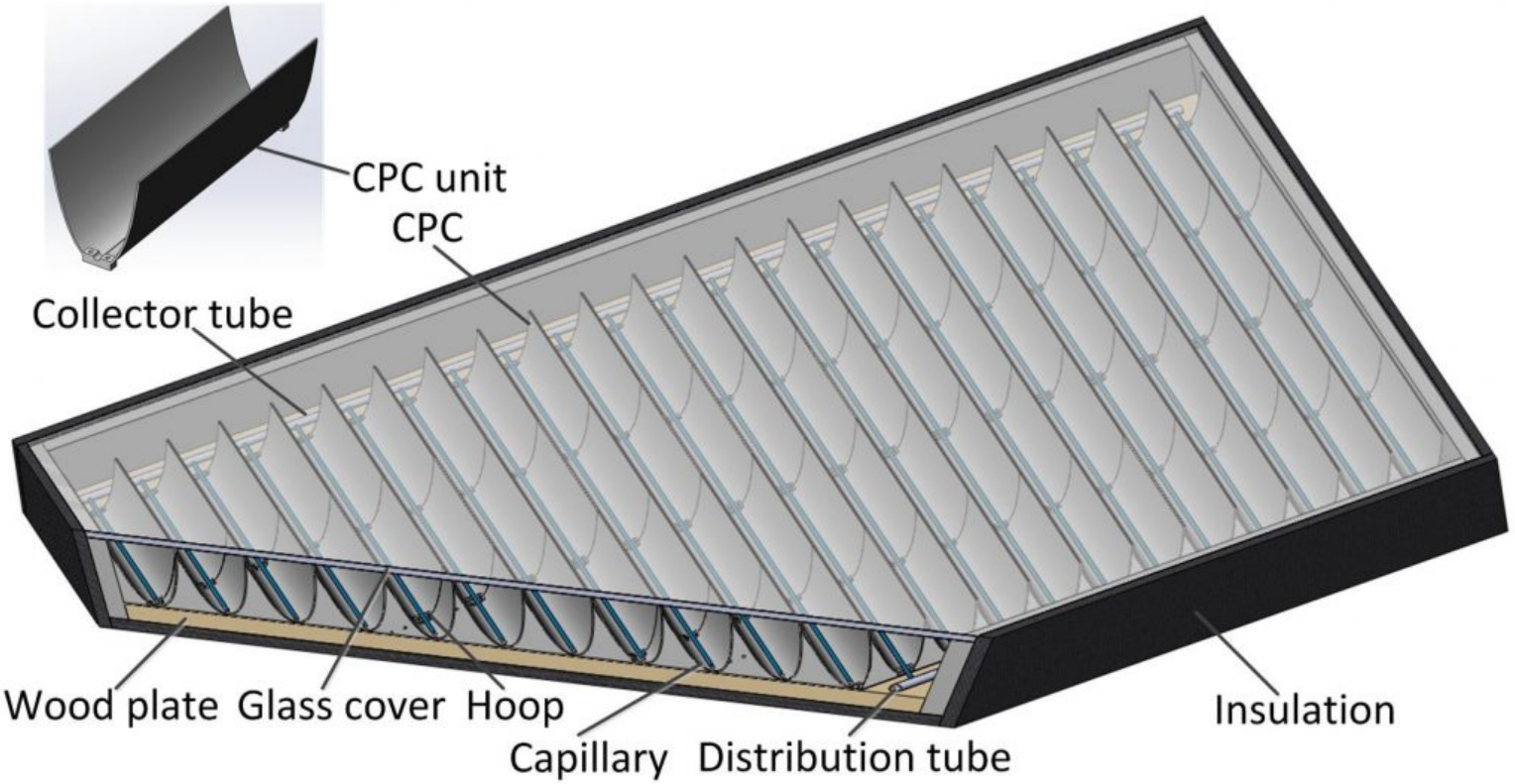


Thermal resistance

Collector efficiency vs (T_p-T_a) (T_p=(T_e+T_c)/2)

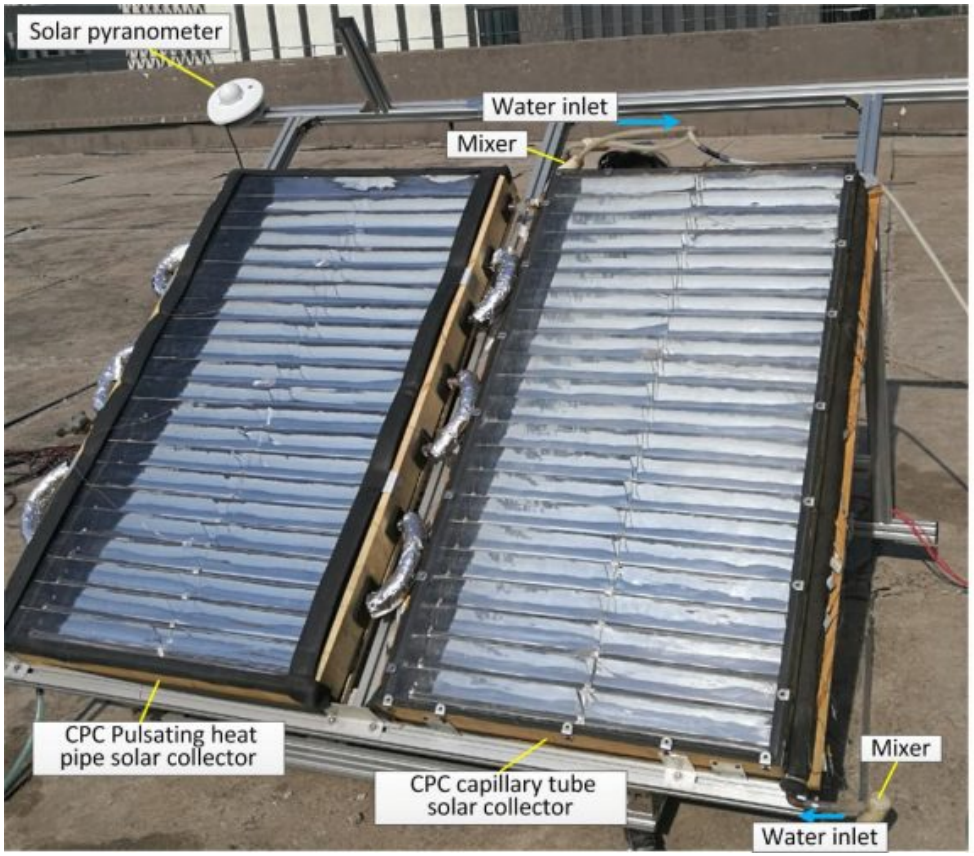


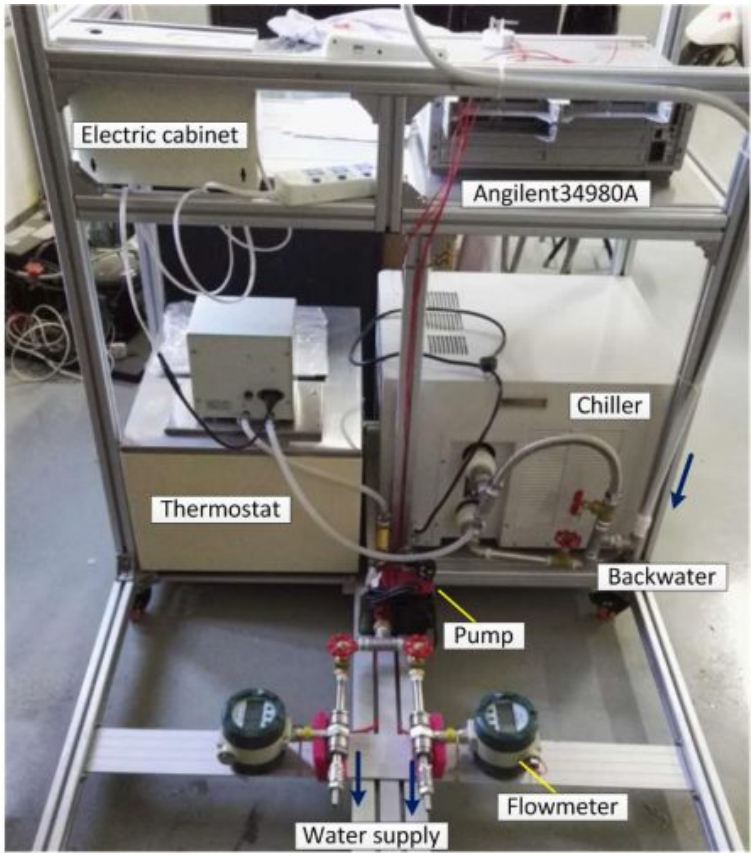
Another design



Materials: CPC - ABS; Frame - wood

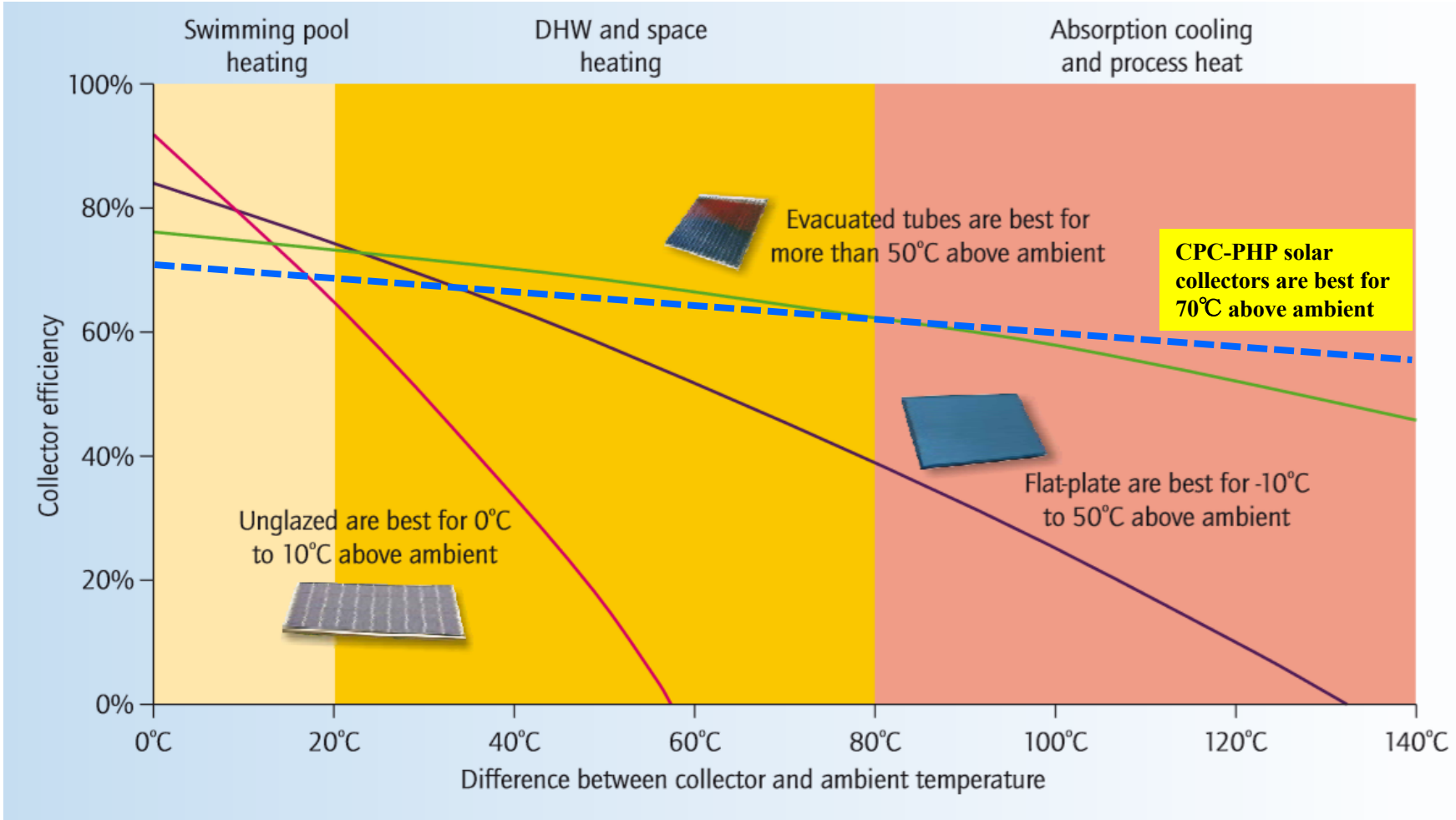
Solar collector – new design





Modification: (1) water tank is underneath the PHP; (2) capillary tube is used instead of PHP; (3) better insulation is installed; (4) working fluid is R134a; (5) collecting efficiency is higher than 70%.

Comparison of collector efficiency



https://webstore.iea.org/technology-roadmap-solar-heating-and-cooling

Conclusions

- The collector shows start-up, operational and shutdown stages with the starting and ending temperature at 75 ℃.
- The thermal resistance of the PHP absorber decreases with the increase in ambient temperature, solar irradiation intensity, and evaporation temperature. It can reach nearly 0.25 K/W.
- A concentration ratio of 3.4 is appropriate and the use of CPC is reasonable.
- The novel design offers a promising efficiency of 50% (HFE7100).
- The efficiency of the collector can reach up to 75% using R134a.

Acknowledgements

The National Natural Science Foundation of China (51506004), Beijing Natural Science Foundation (3162009), Scientific Research Project of Beijing Educational Committee (KM201410016001) and Research Fund of Beijing University of Civil Engineering and Architecture.

Thank you