DAY Zero;
Water
Has
Value…

SPREE SEMINAR

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School of Photovoltaic and Renewable Energy Engineering (SPREE), UNSW

THE UNIVERSITY OF MELBOURNE

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SPREE SEMINAR

Solar Desalination System

for

low-cost water generation

at remote areas

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The University of Melbourne

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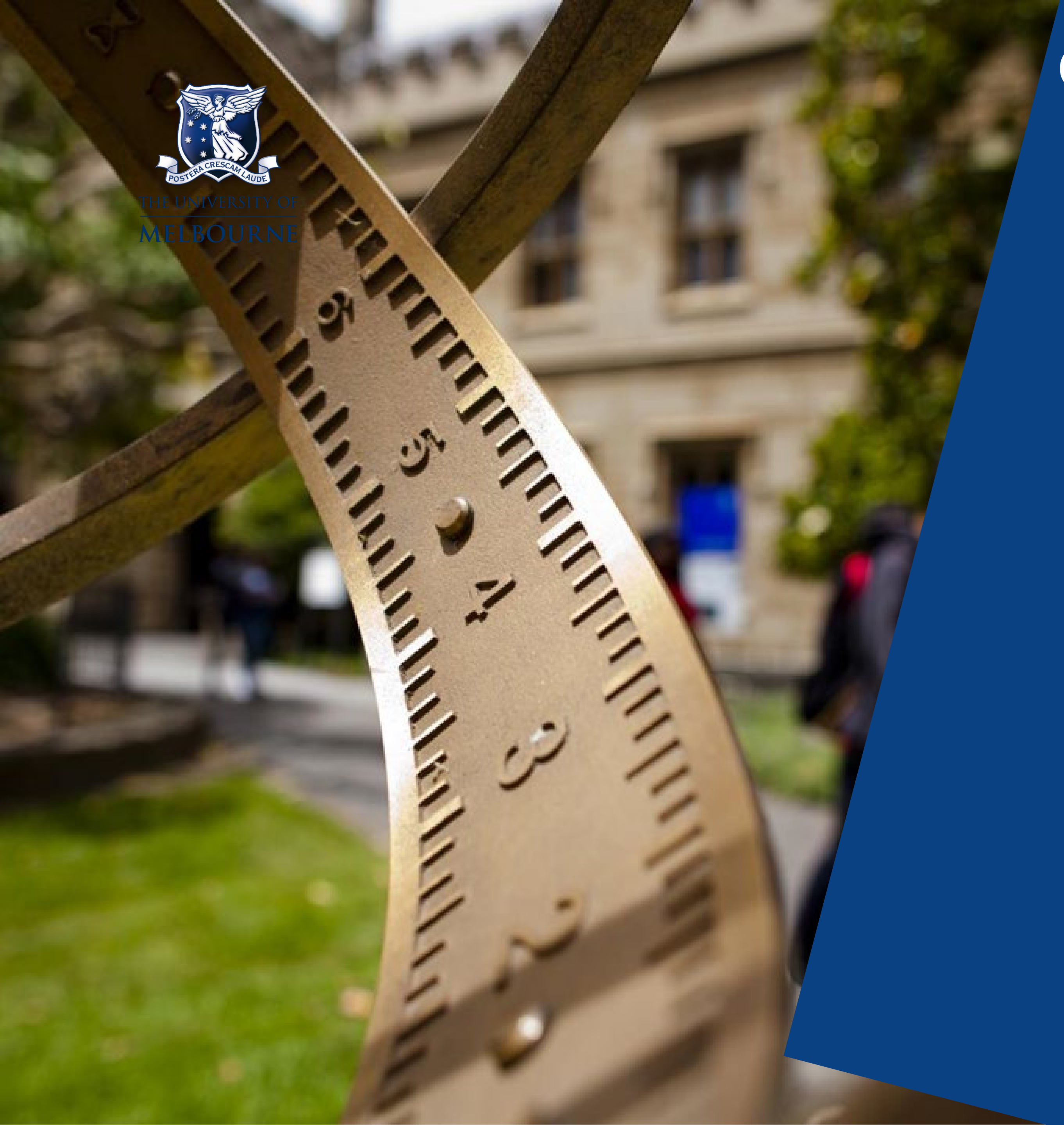

OUTLINE

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Introduction: The Problem

The global potable water scarcity

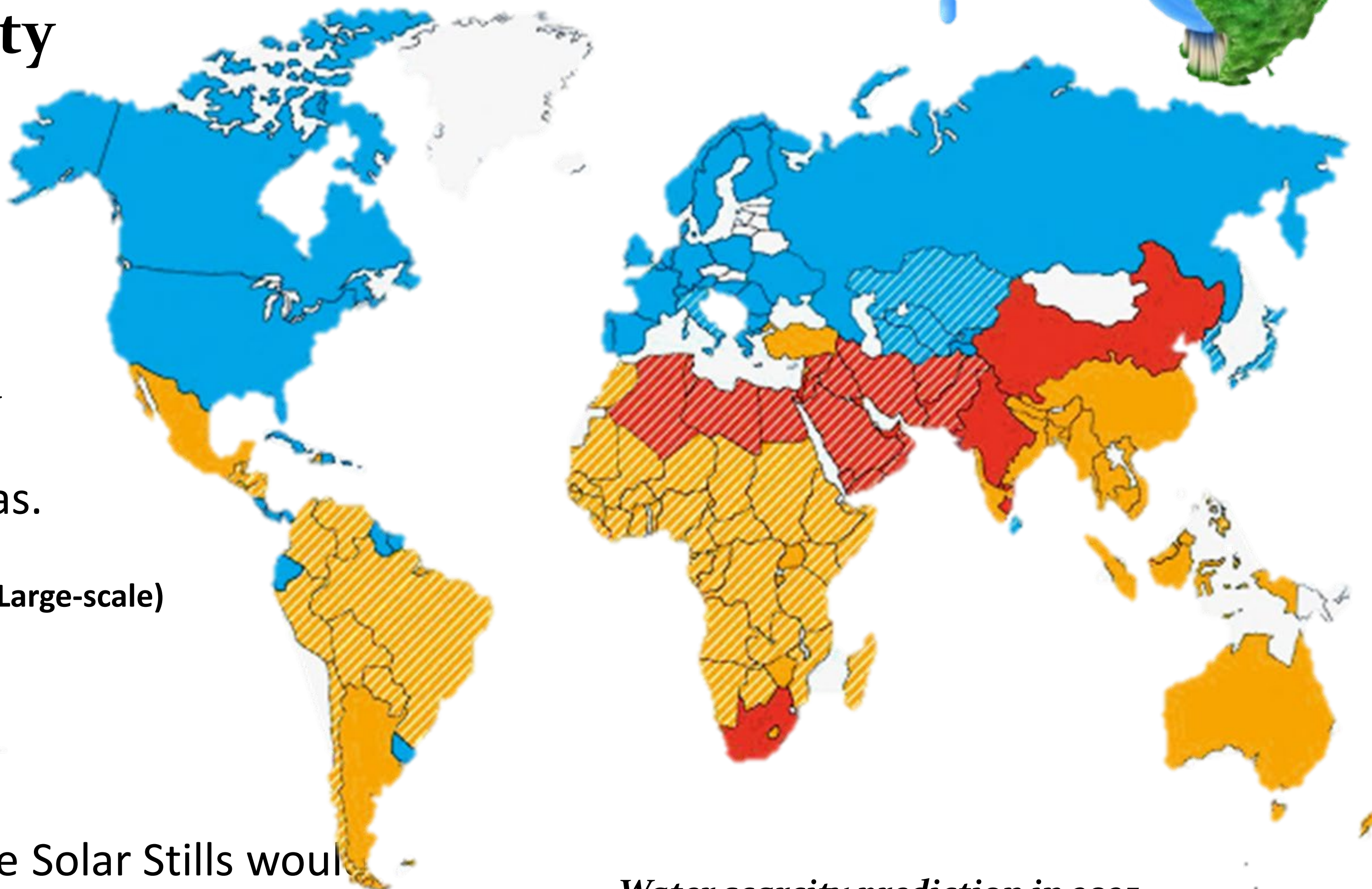
- **2.5%** is the share of freshwater.
- Over **1.8 billion** people will be affected in remote areas.

The challenges of water scarcity

- **Poor and small communities in** remote areas.
- Conventional water treatments **expensive** **(Large-scale)** **& requires elec. power**.

What is the solution

- **Solar Energy** is a widely available & Passive Solar Stills woul be the best option (Small-scale solar assisted desalination)

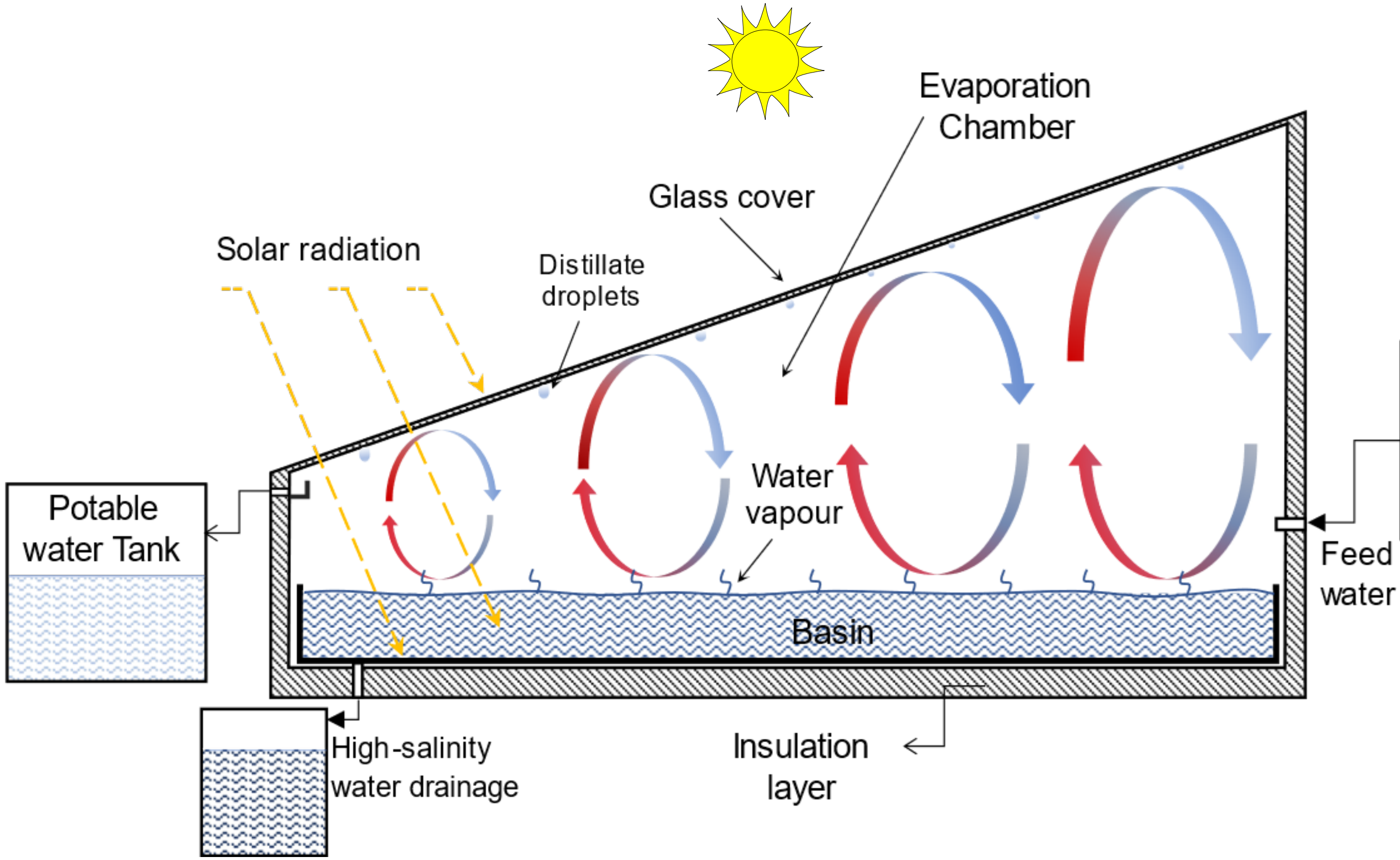


Water scarcity prediction in 2025

Passive Solar Still (PSS), Solar Thermal Distillation

How it works & what's Advantages

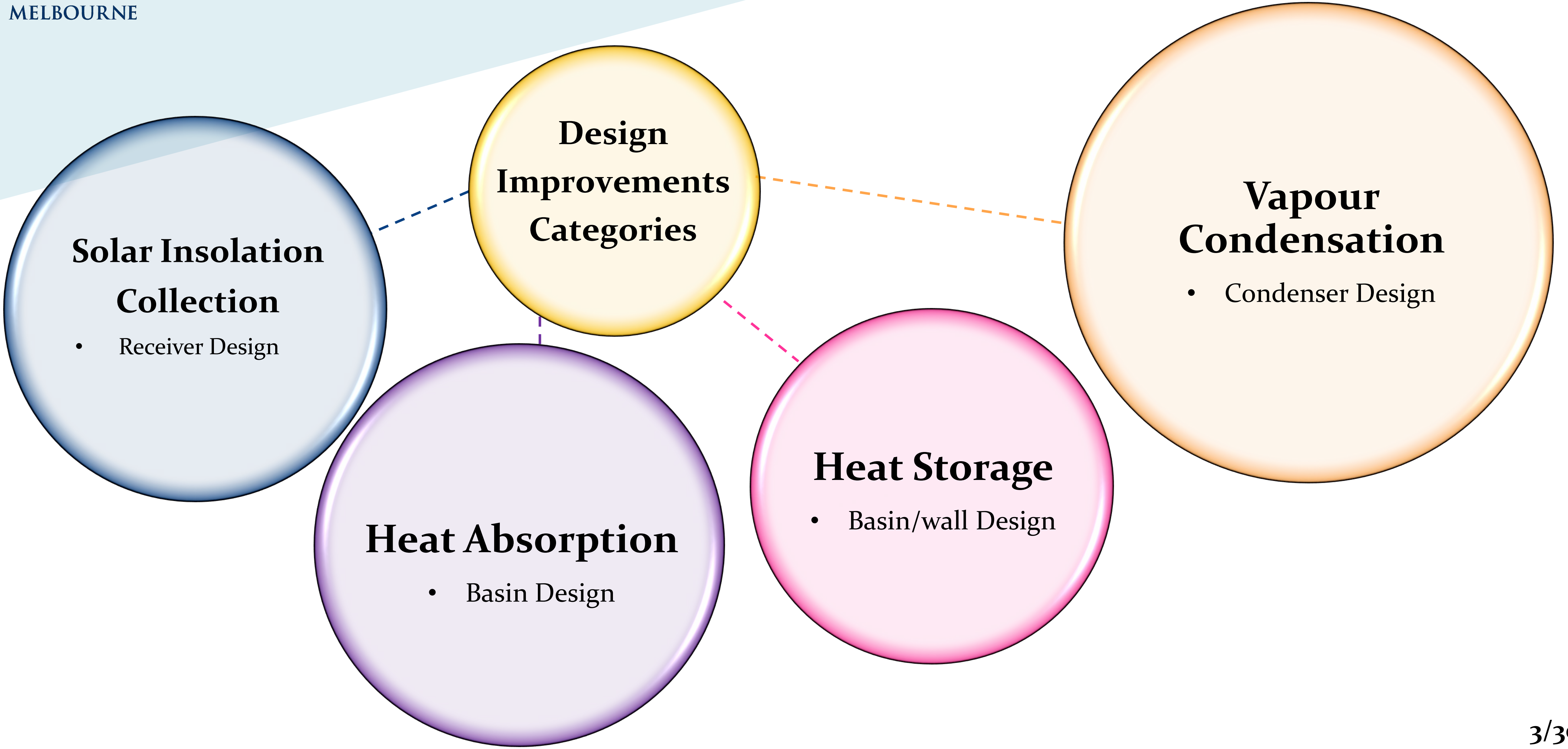
- ***Simple*** distillation ***technique,***
- ***Directly*** supplied by the **Sun,**
- Works with **evaporation & condensation.**



What's the issue with the process

- ***Low*** Evap-Cond rate due to large bulk water.
- ***Sun obstruction*** caused by distillate droplets.
- ***Periodic cleaning and refill*** required.

Lit. review: Design Improvements of PSS



Lit. review: Design Improvements of PSS

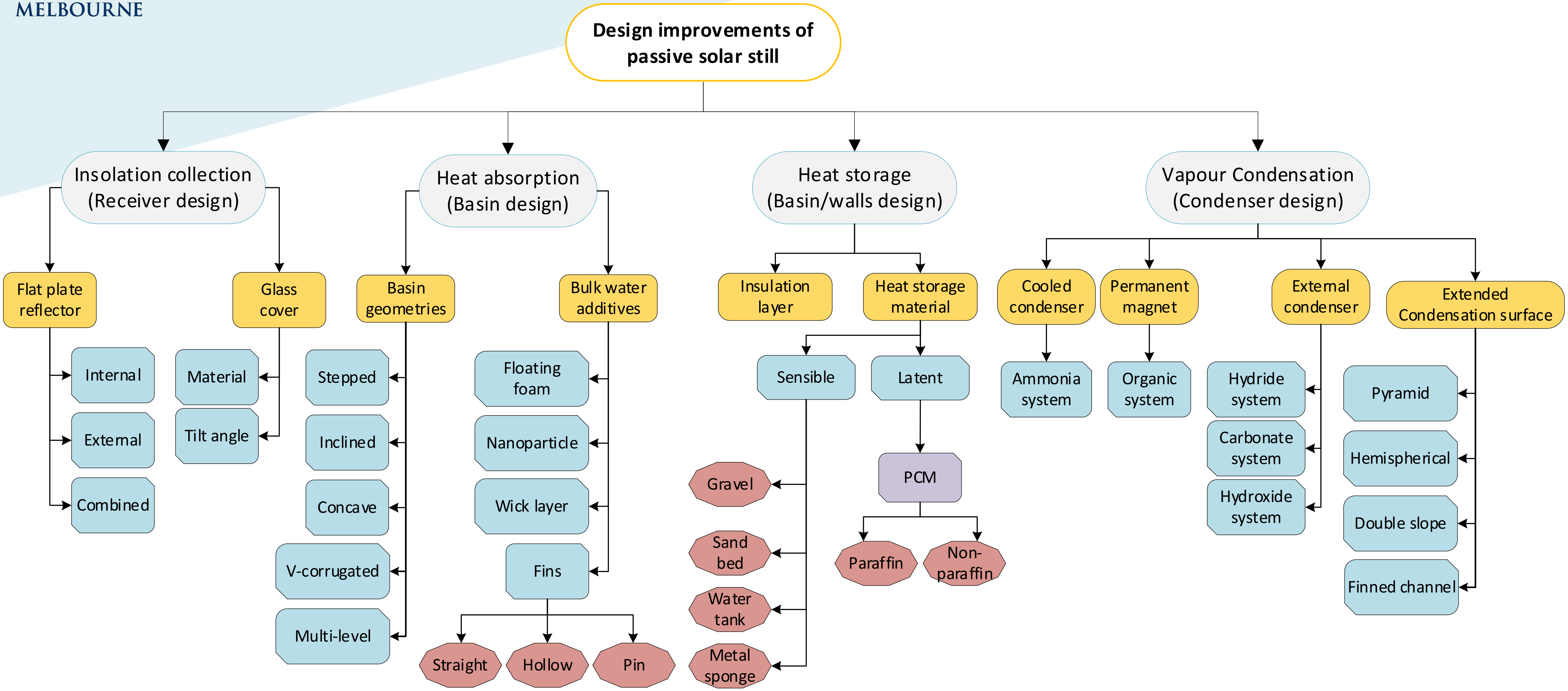
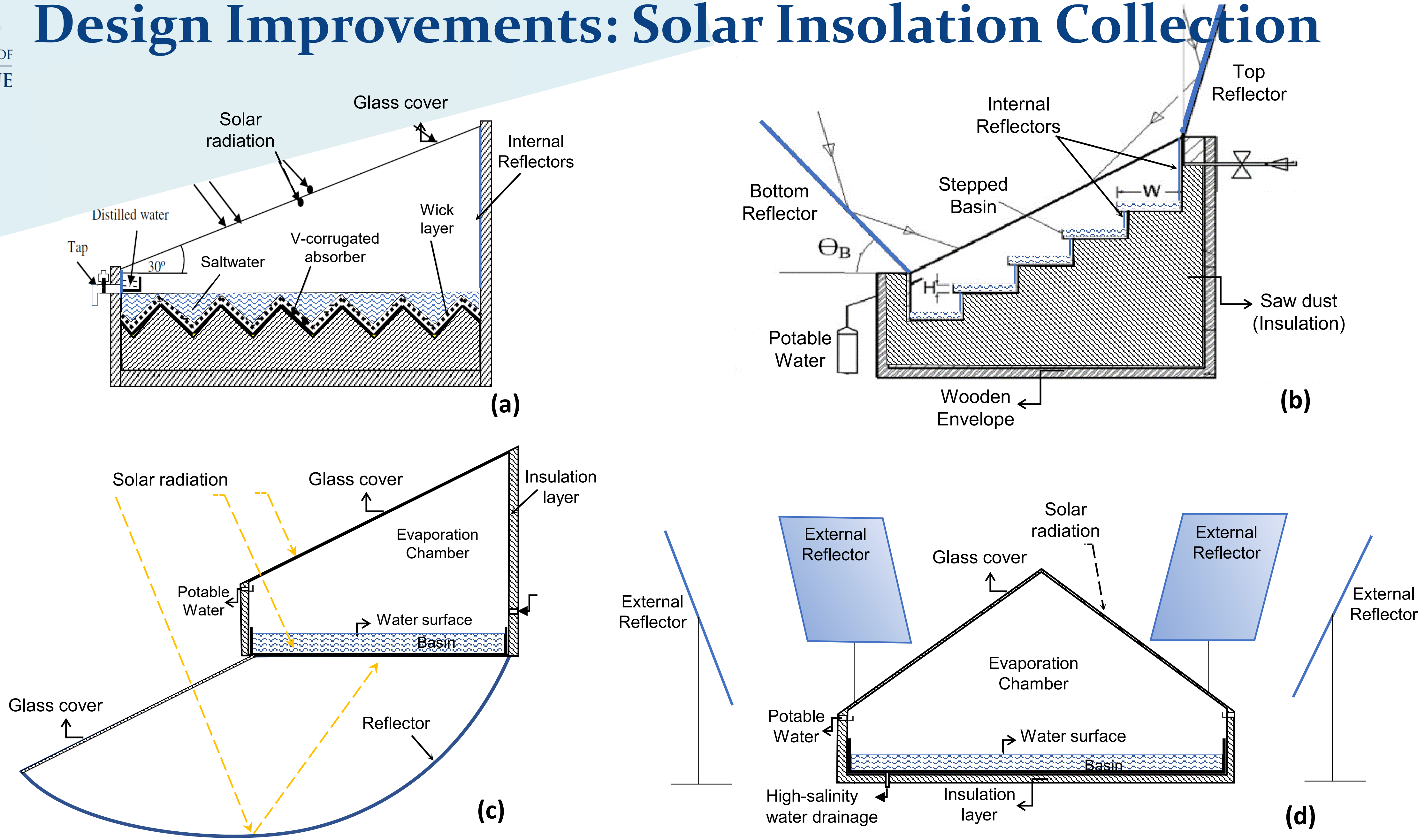
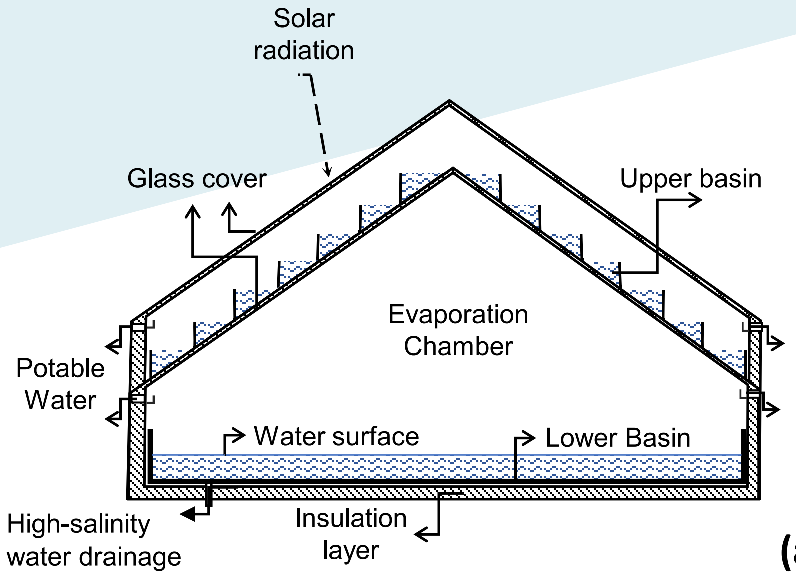


Fig. Various design improvements and modifications on PSS discussed in the review article (Mohsenzadeh et al., 2021)

Design Improvements: Solar Insolation Collection



Design Improvements: Basin Design and Geometry



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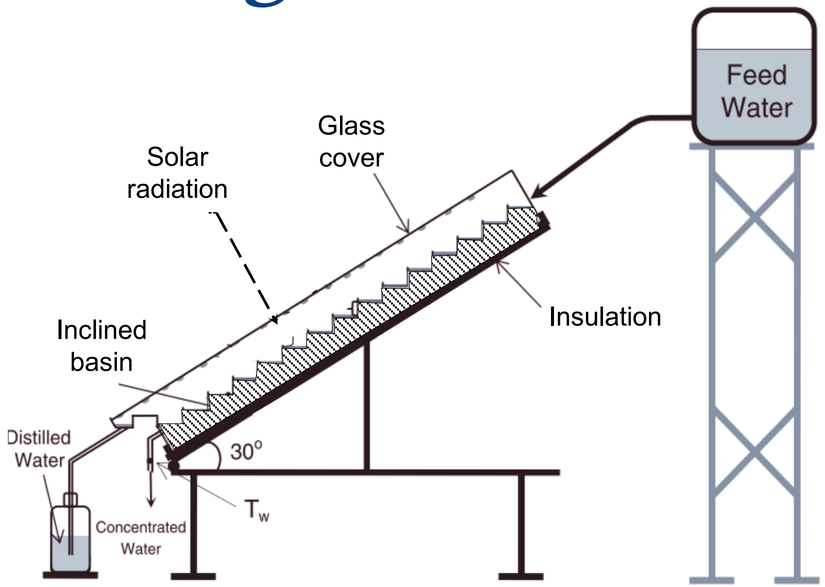

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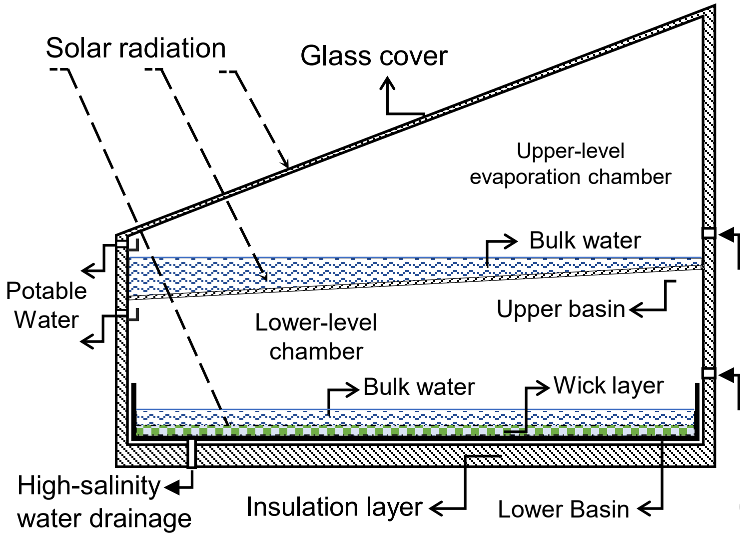

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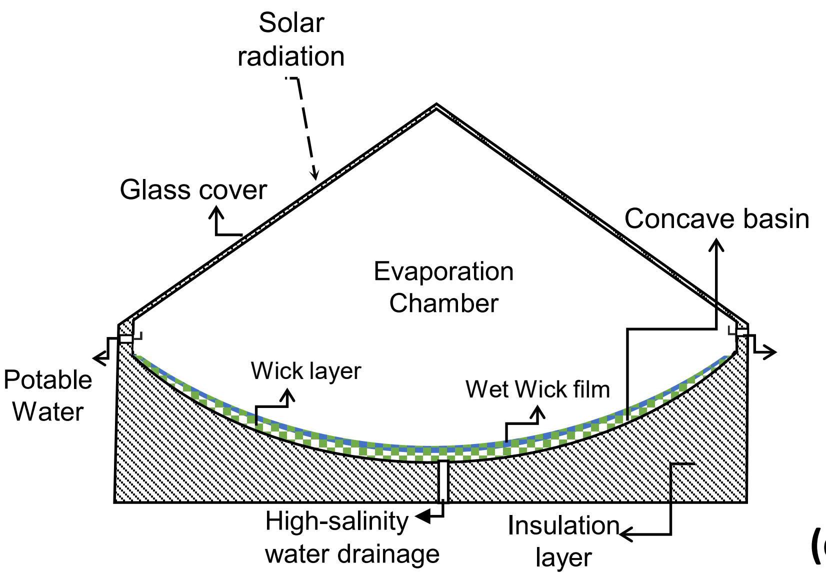
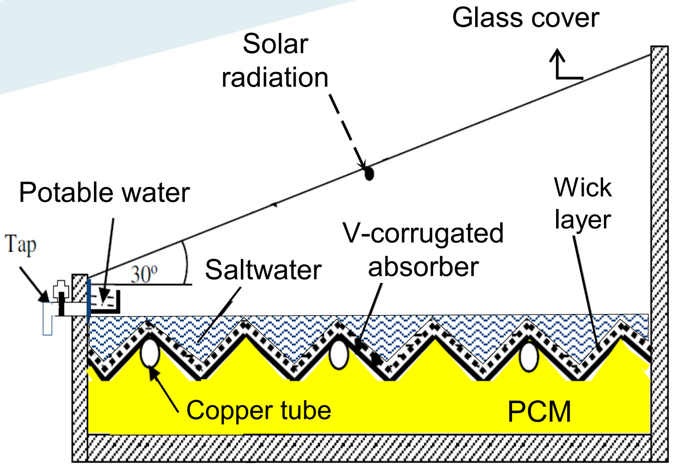


(d)

Design Improvements: Basin incorporated with PCM, etc.



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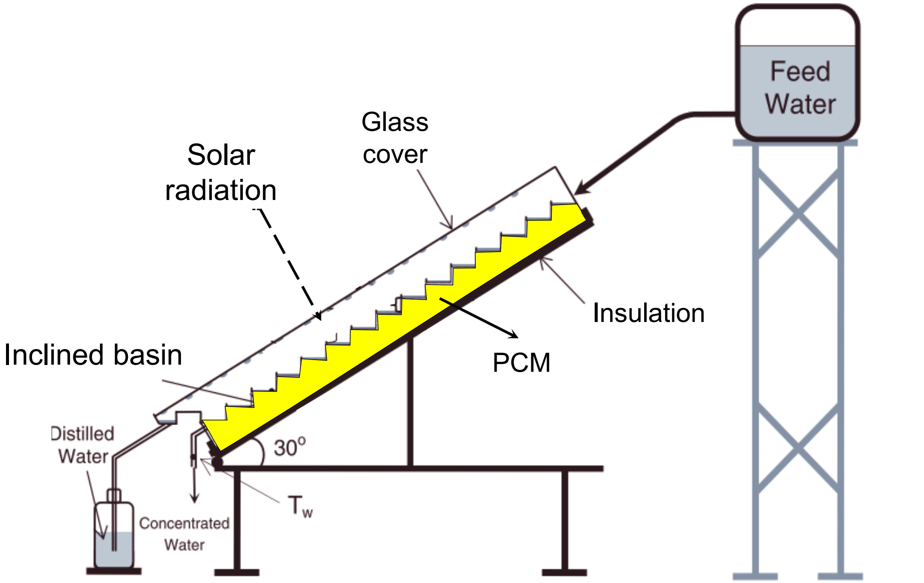

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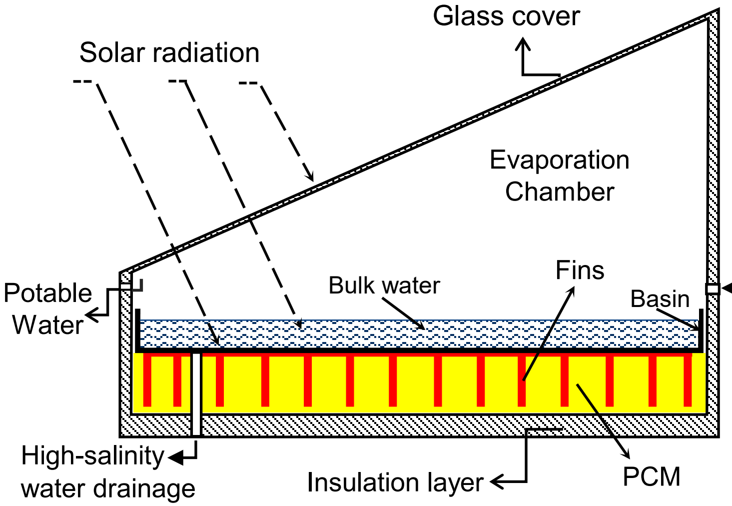

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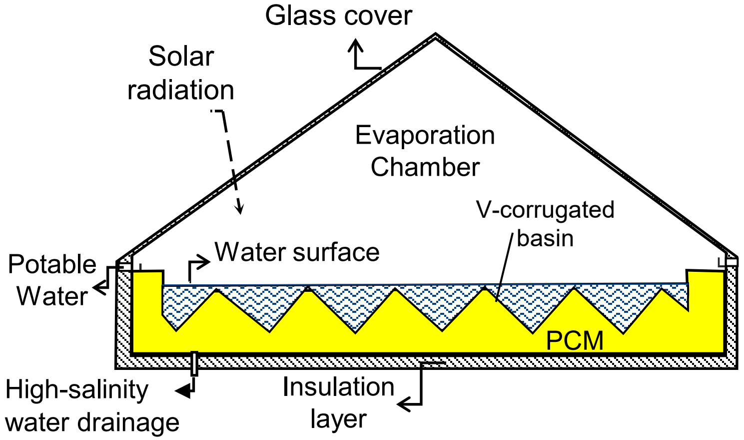

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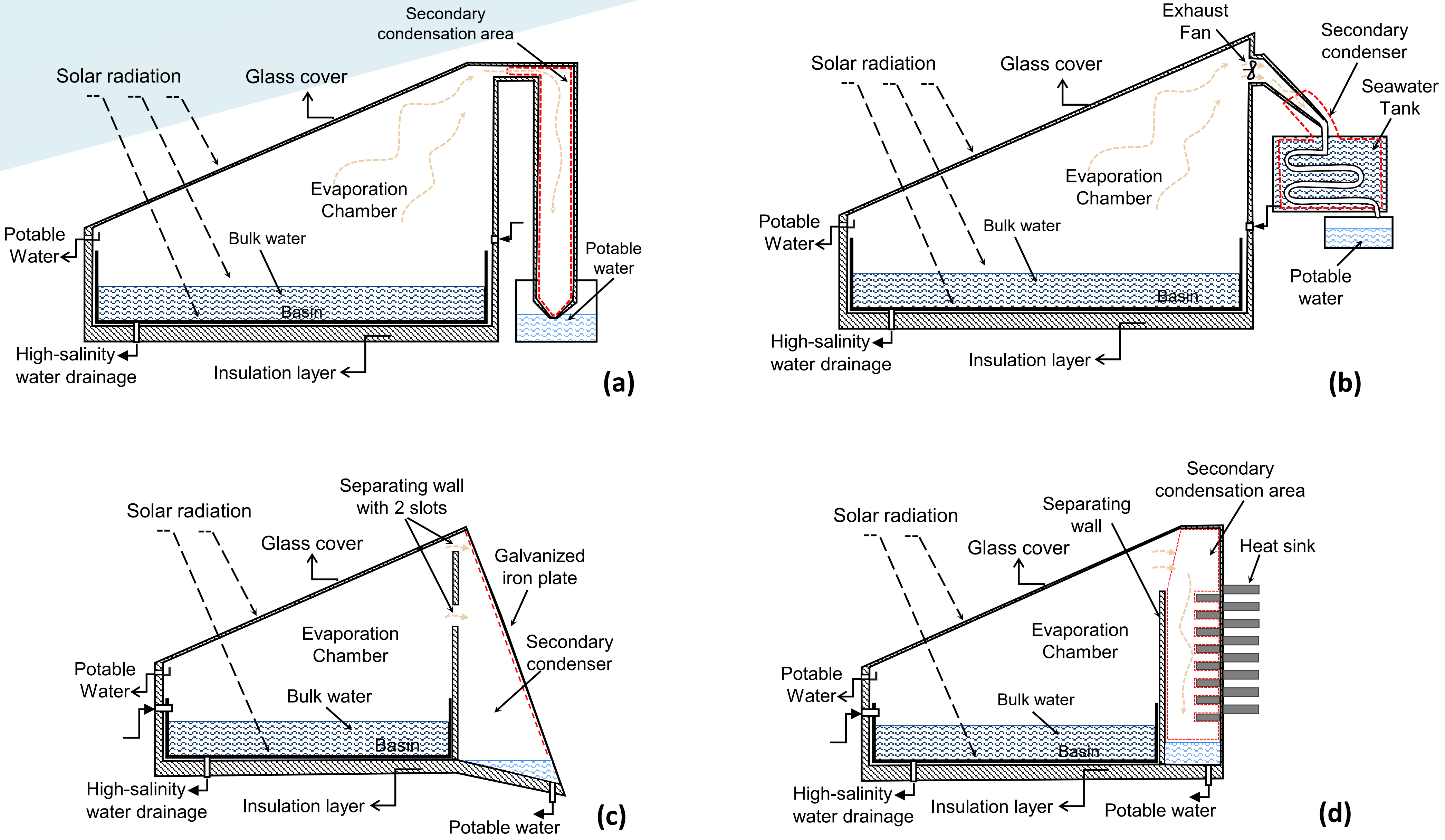
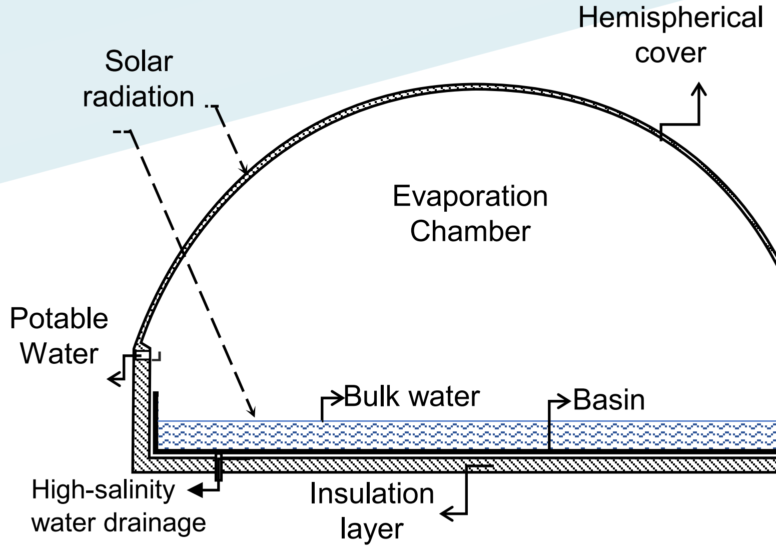
Design Improvements: Ext. Condenser Design



Design Improvements: Condensing Cover Geometry



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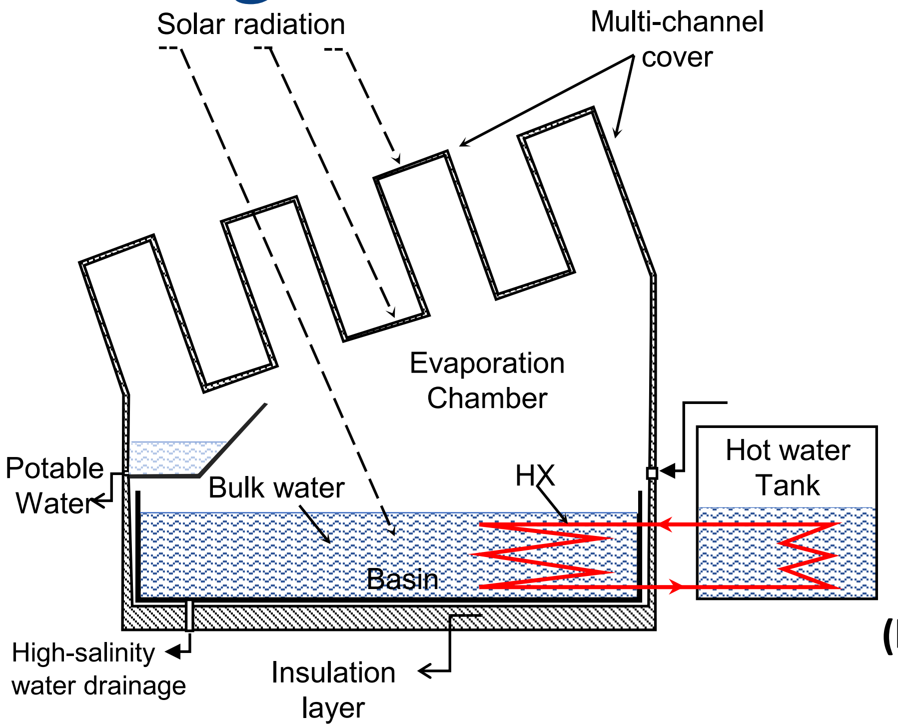

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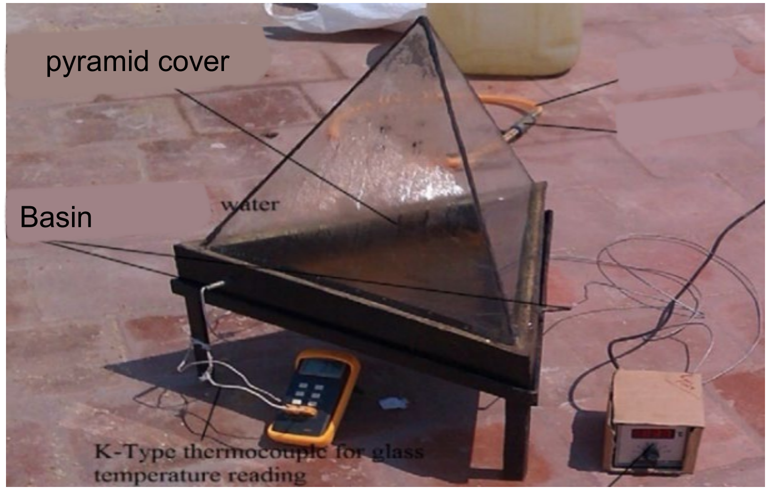

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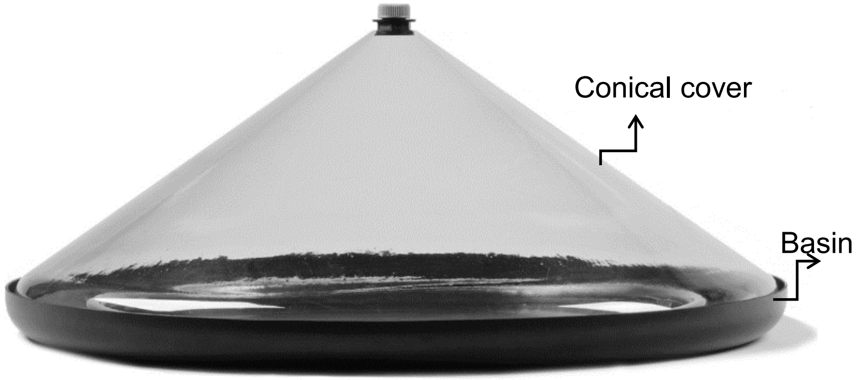

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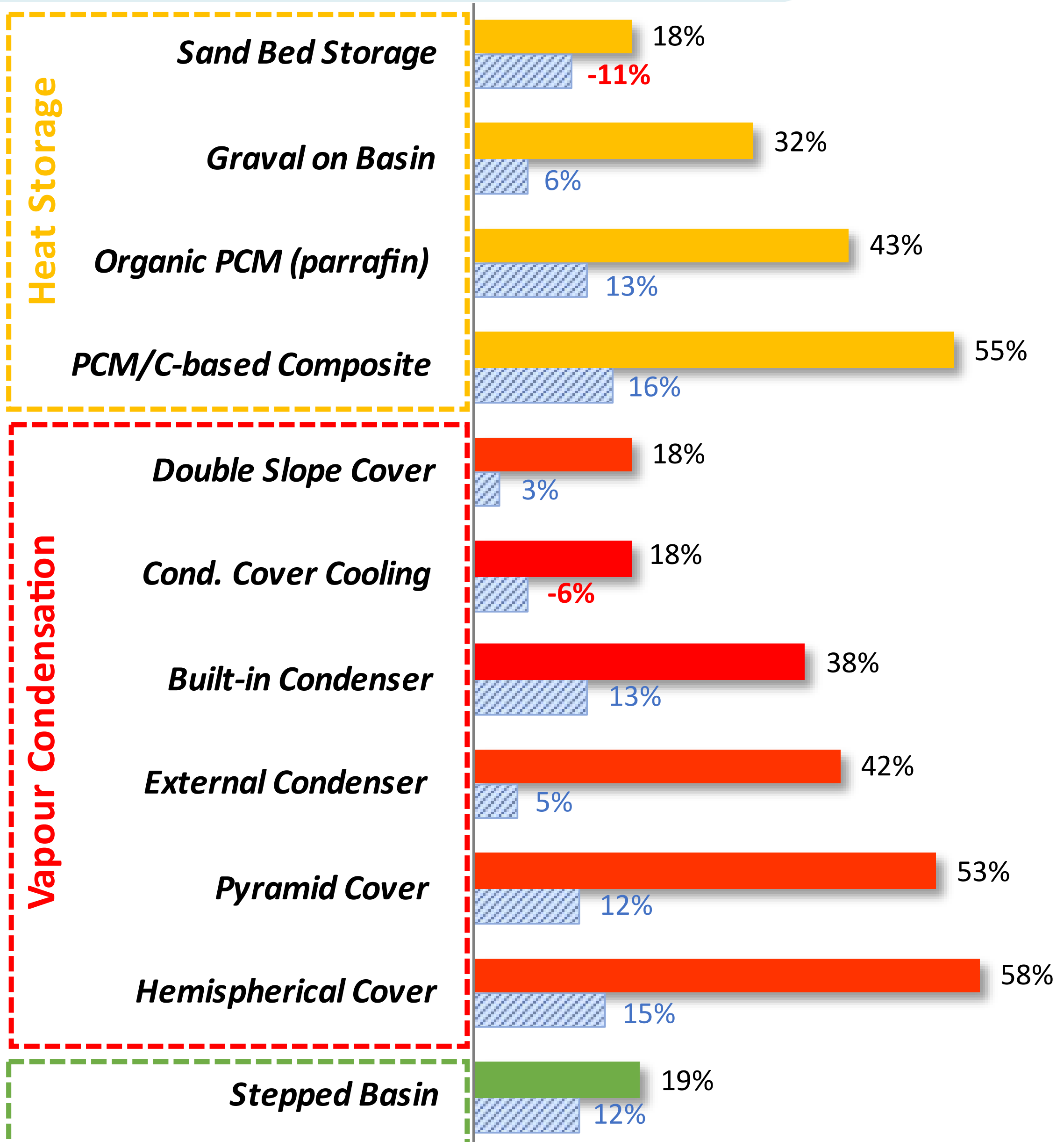
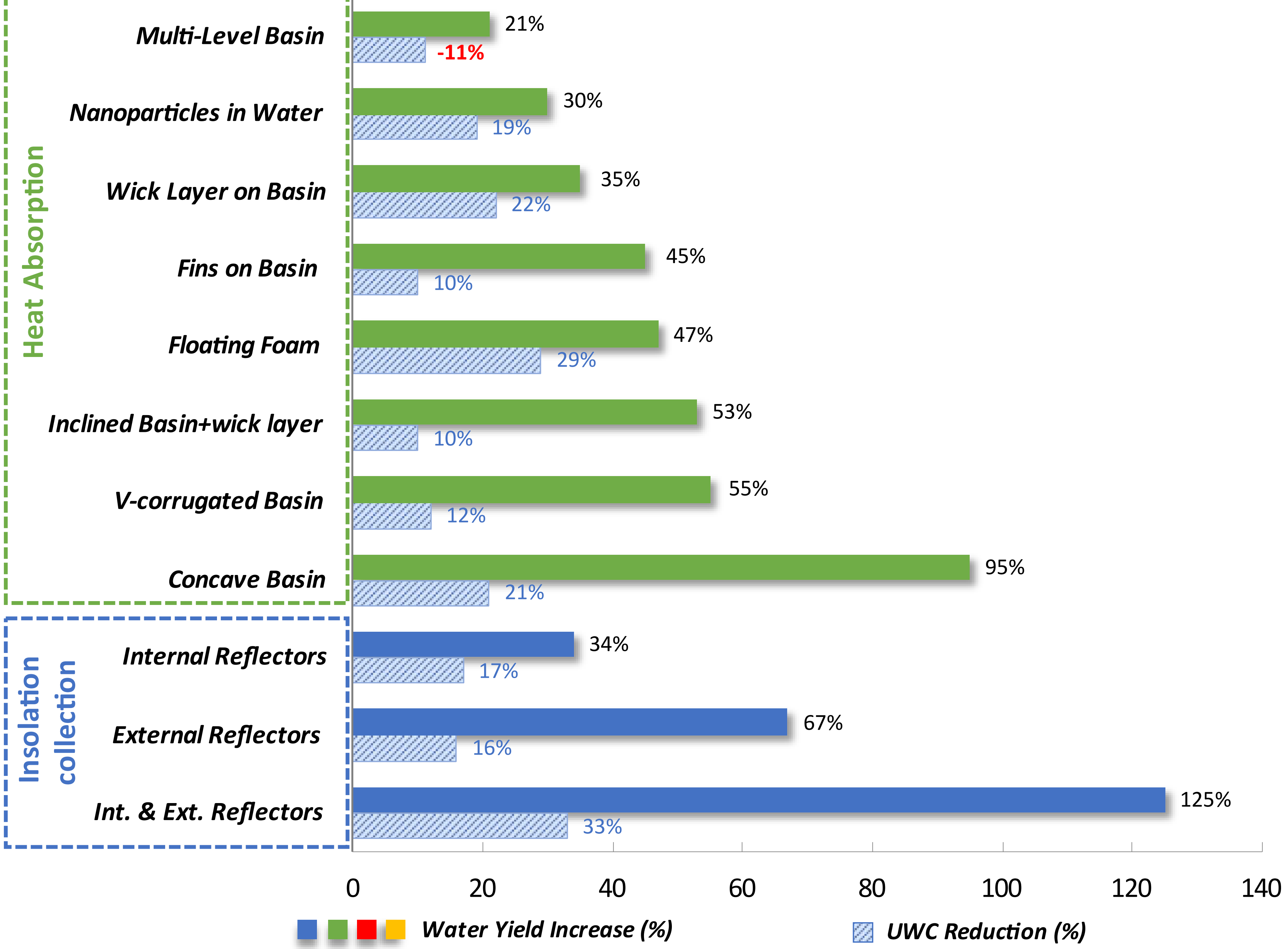
Design Improvements of PSS: Suitable design of comp.





Heat Absorption
Multi-Level Basin
21%
-11%
Nanoparticles in Water
30%
19%
Wick Layer on Basin
35%
22%
Fins on Basin
45%
10%
Floating Foam
47%
29%
Inclined Basin+wick layer
53%
10%
V-corrugated Basin
55%
12%
Concave Basin
95%
21%
Insolation collection
Internal Reflectors
34%
17%
External Reflectors
67%
16%
Int. & Ext. Reflectors
125%
33%
0
20
40
60
80
100
120
140
Water Yield Increase (%)
UWC Reduction (%)

Research Method: Steps taken

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Step 1

Literature review

- Initial design
- Performance Est.

Step 2

Computer modelling

- Developing Theoretical model
- Sizing the components

Development

- Conceptual design
- Try-and-error

Step 3

Experimental setup

- Validation of Simulation

Step 4

EES, TRNSYS Simulation

- Performance results
- Modifying design

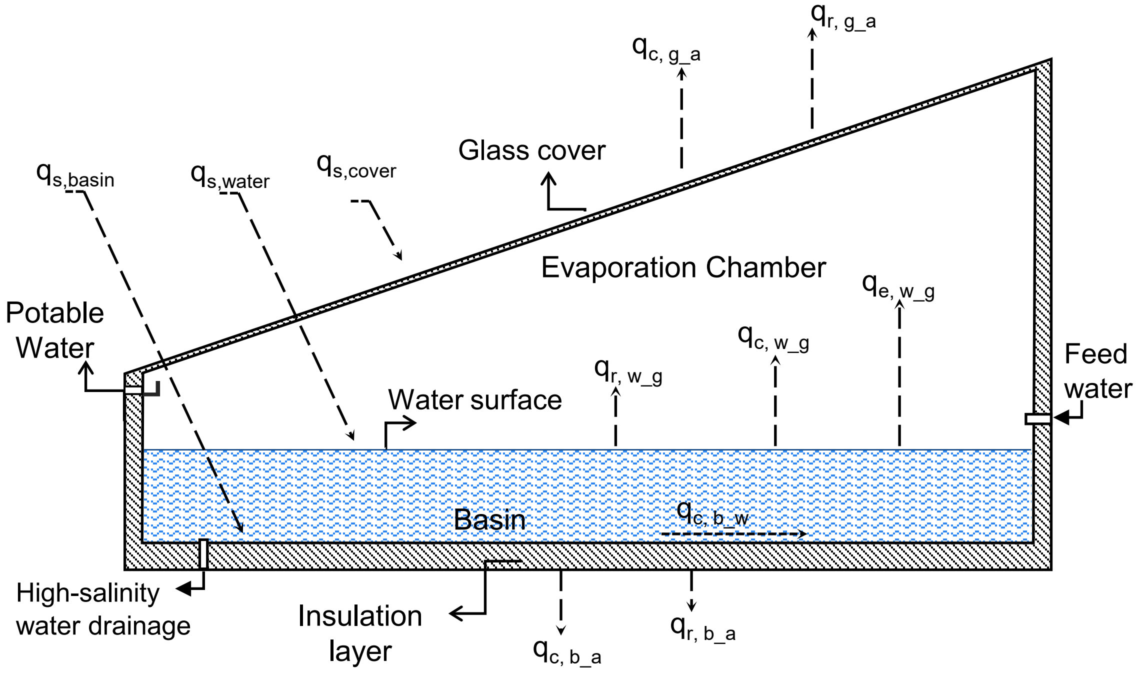
Step 5

Performance analysis

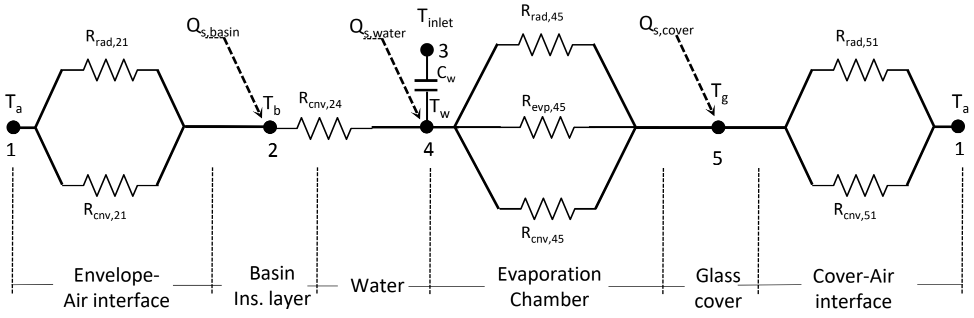
- Variables behaviour
- Climate change

Computer Modelling: PSS Transient Thermal Model

Developing trans. model of sys. considering the aspect ratio of evap. chamber



(a)



(b)

Fig. Schematics of (a) passive solar still with heat fluxes, (b) the equivalent thermal circuit of the system

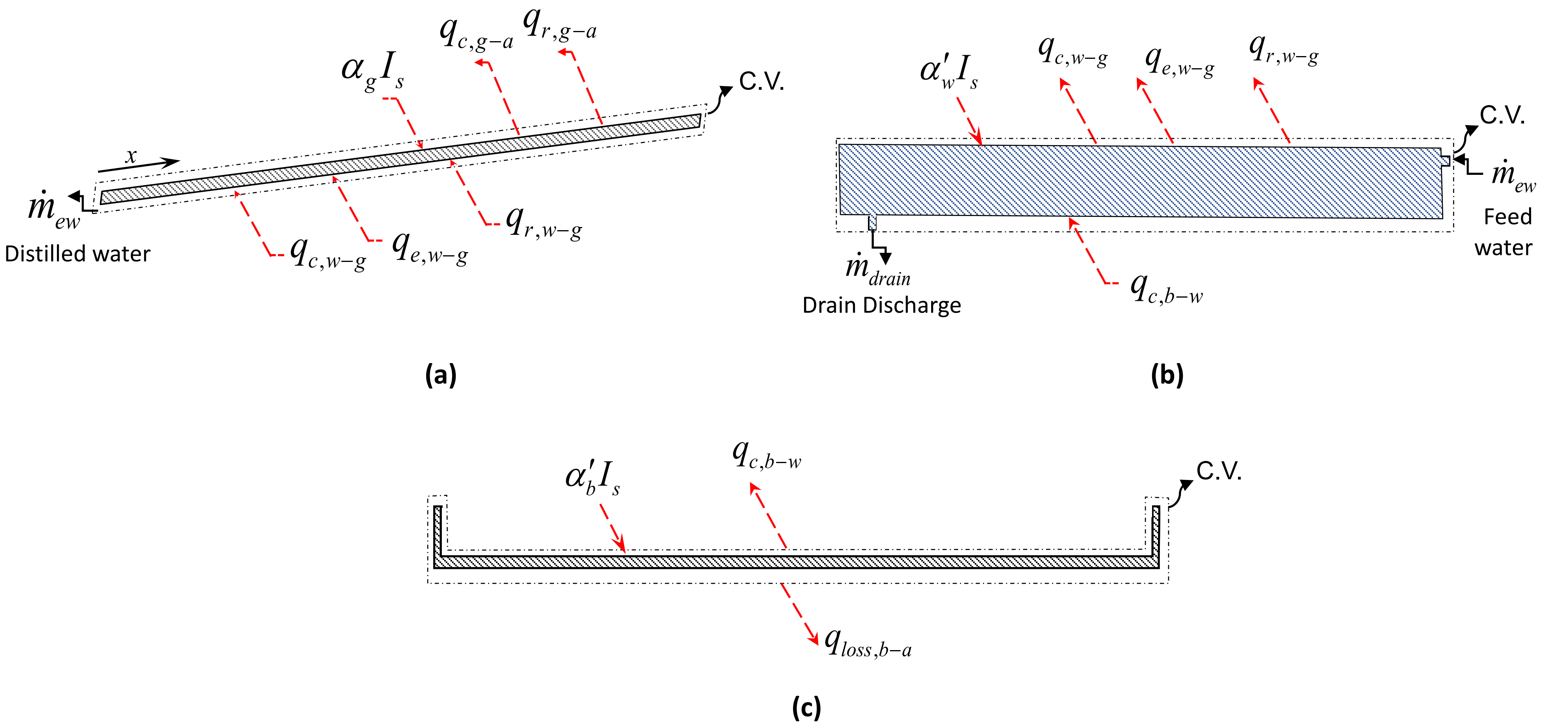
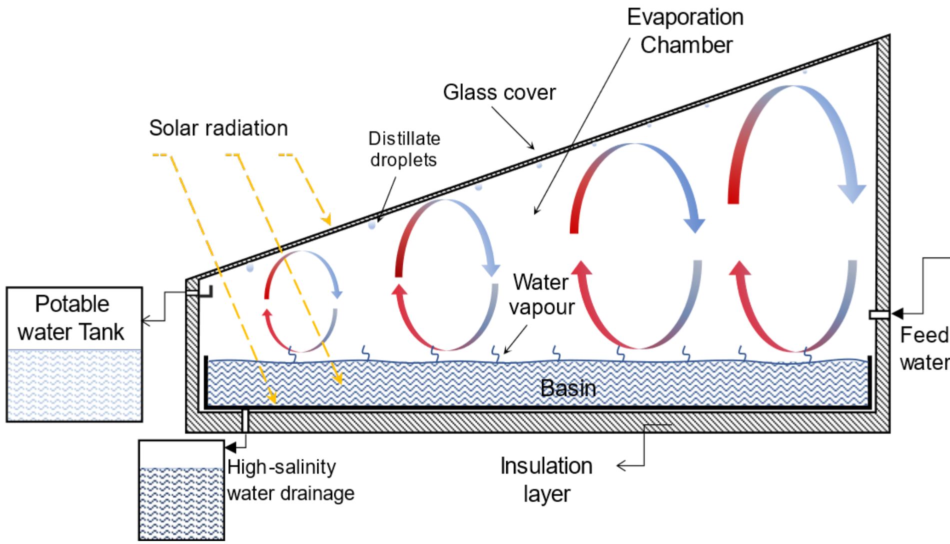


Fig. Schematics of the control volume around (a) the glass cover, (b) bulk water, and (c) basin indicating the thermal heat fluxes.

Computer Modelling: PSS Transient Thermal Model

The features of the developed model: (Mohsenzadeh et al., 2021)

- **transient model** instead of S.S or quasi S.S.
- chamber **aspect ratio** and **thermal inertias** considered.
- **Significance of thermal** inertias in performance explored.
- The **profile of Transmissivity** applied instead of **constant** value.
- The effect of **distillate on the transmissivity** of the cover was examined.
- The **larger the aspect ratio** of the chamber, the **higher the daily** water yield.



Experiments: RPSS experiment series (1)

Focuses

- Validation of HT model
- Droplets Obstruction effect
- Reference PSS.

(a) (b) (c) (d)

Computer Modelling: New HT Correlation Develop.

The necessity of developing new model

- Relative humidity not considered in avail. models
- The dimensions of the Evap. Camber is not considered

The process taken to develop correlation

- Using **theoretical** approach to develop the general form
- Setting up **experiments** to produce data
- Applying a **Regression** analysis to calculate constants

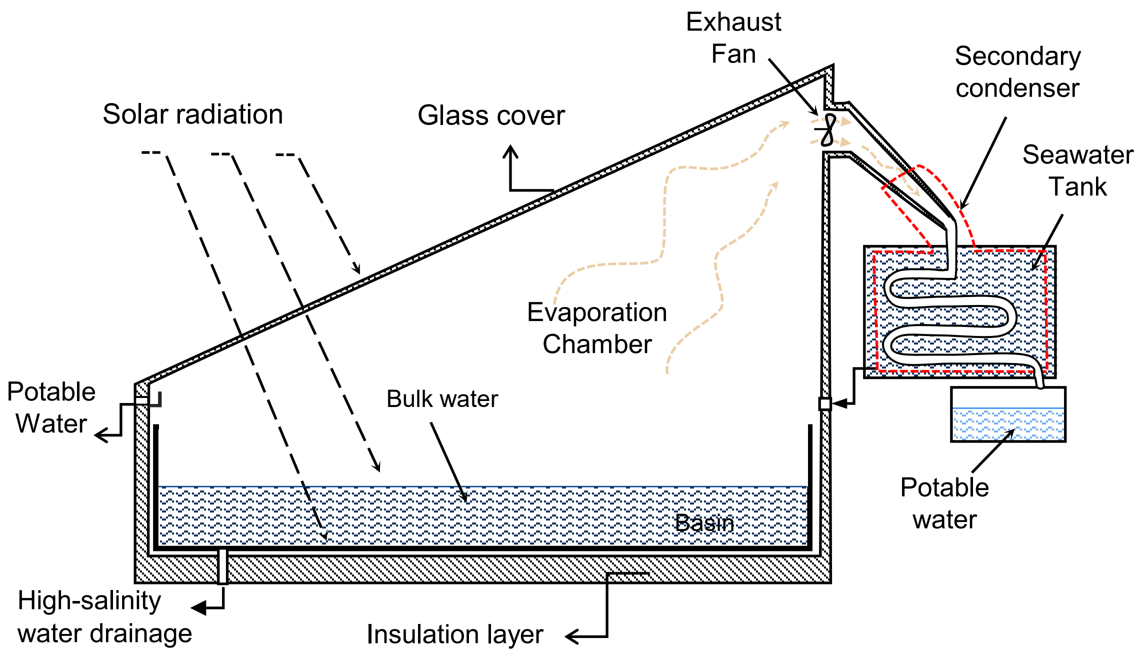
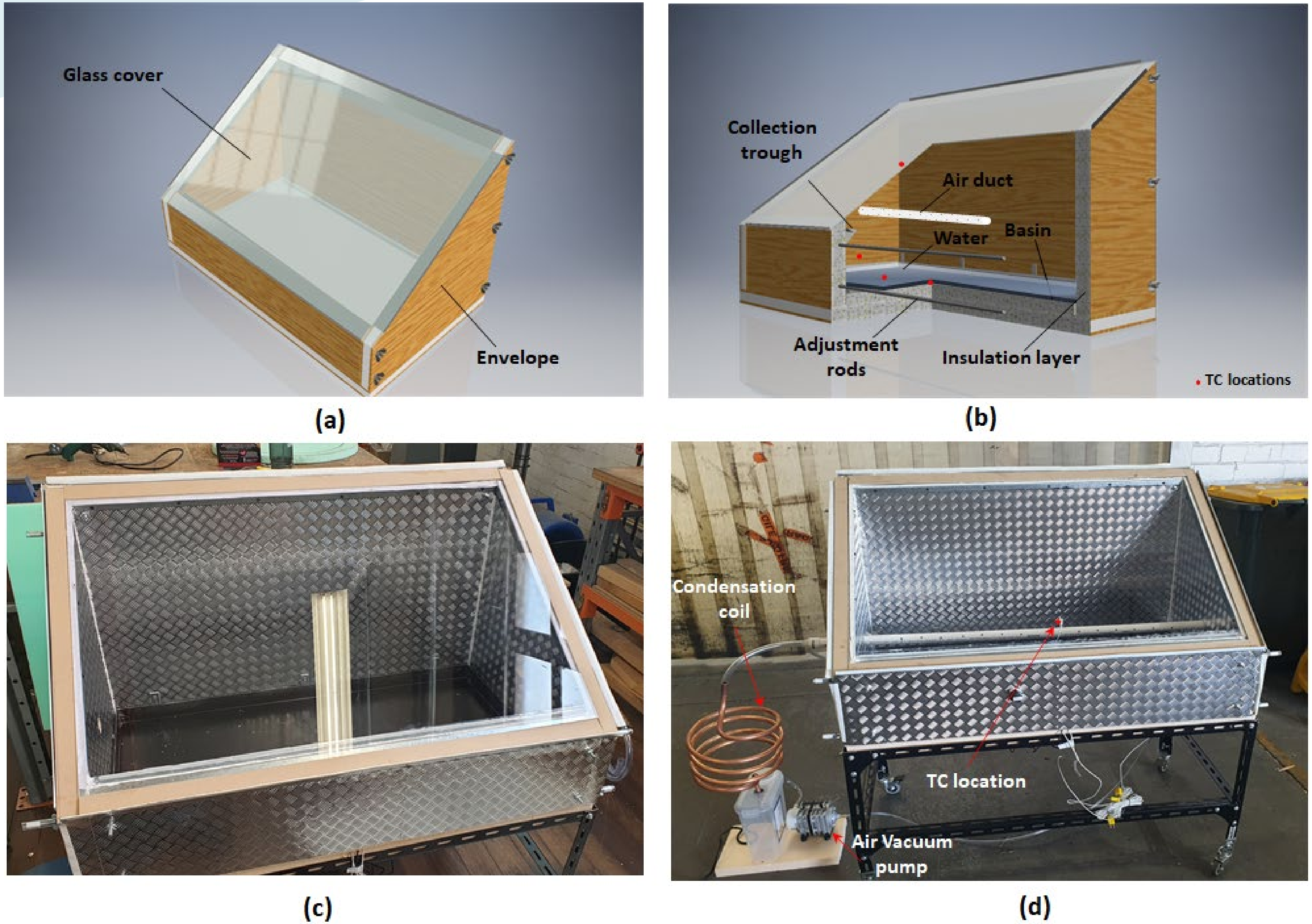


Fig. Schematic of experiment designed for low humidity single-slope single-basin solar still.

Experiments: LHPSS experiment series (2)

Focuses

- Aspect Ratio of chamber
- Low vacuum in chamber



Computer Modelling: New HT Correlation Develop.

Semi-empirical correlation estimating convection & evaporation inside solar still using:

- Rayleigh number,
- relative humidity,
- and the aspect ratio of the evaporation chamber (Mohsenzadeh et al., 2022)

Mohsenzadeh et. al Eq:

$$Nu = 0.0732\,(A_R)^{0.15}\,(Ra')^{0.33}\,(\phi)^{0.08} \quad , \quad Ra' = Gr'\,.\mathrm{Pr}$$

Results: The obstruction effect of droplets

- 21% reduction in transmissivity
- Initial Transmissivity at 0.87.
- Down to 0.69 on average.

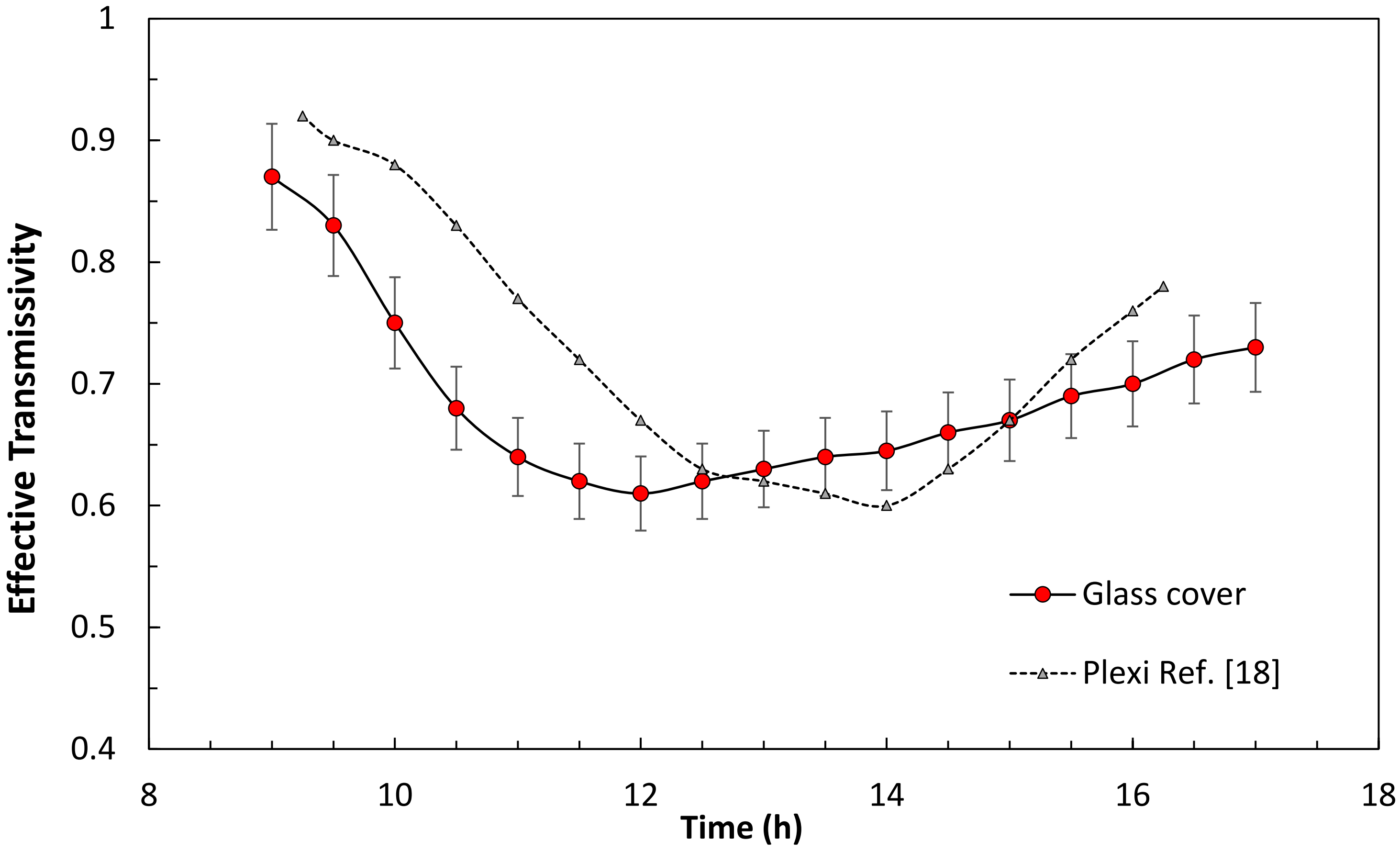


Fig. The variation of the effective transmissivity of the glass cover during the day and compares it with plexiglass at ref.
(Mohsenzadeh et al., 2021)

Results: Performance analysis: Depth of water

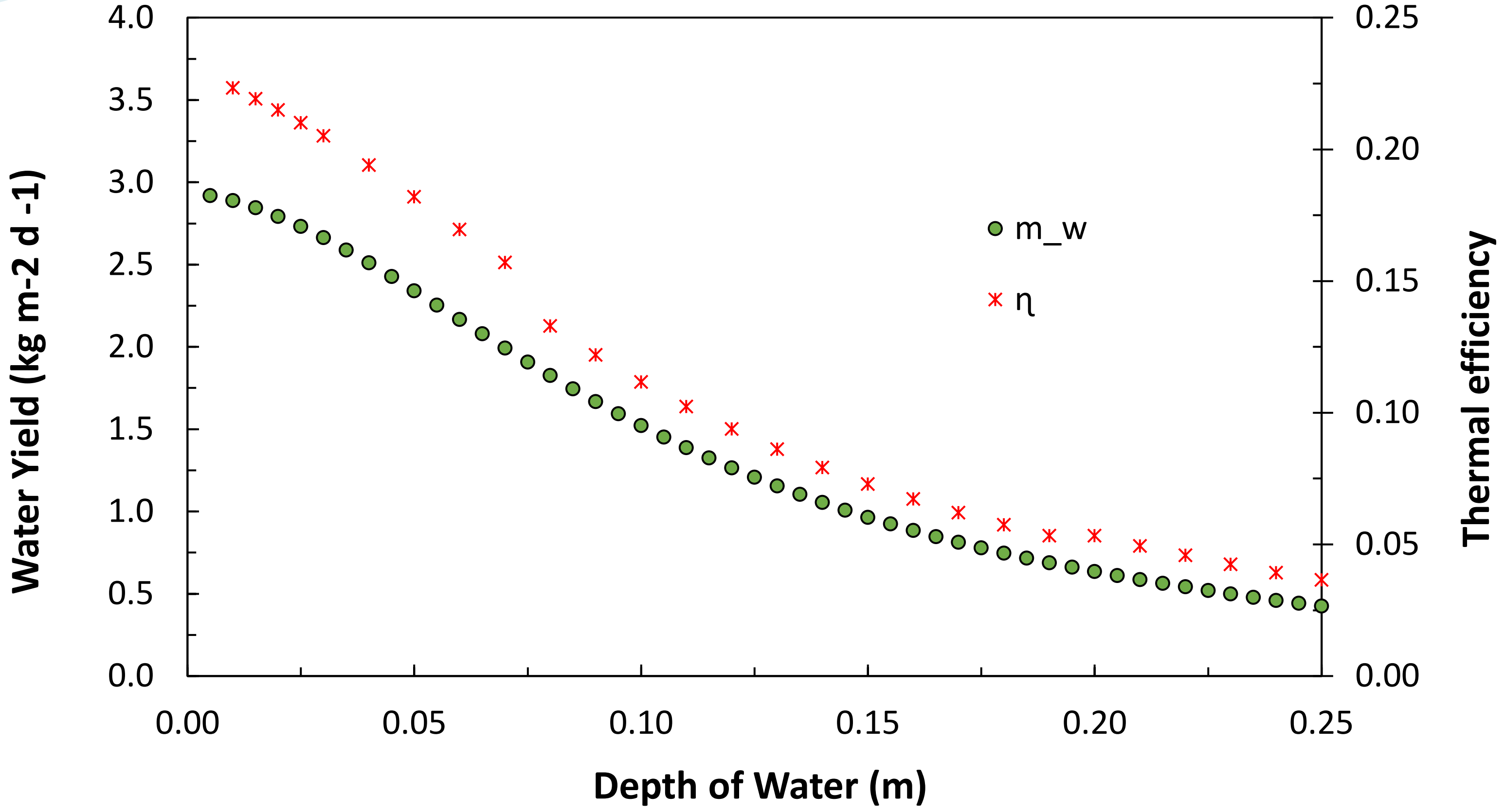


Fig. The variation of the daily water yield and the thermal efficiency under different depths of bulk water in **PSS.**
(Mohsenzadeh et al., 2021)

Results: Performance analysis: Aspect Ratio

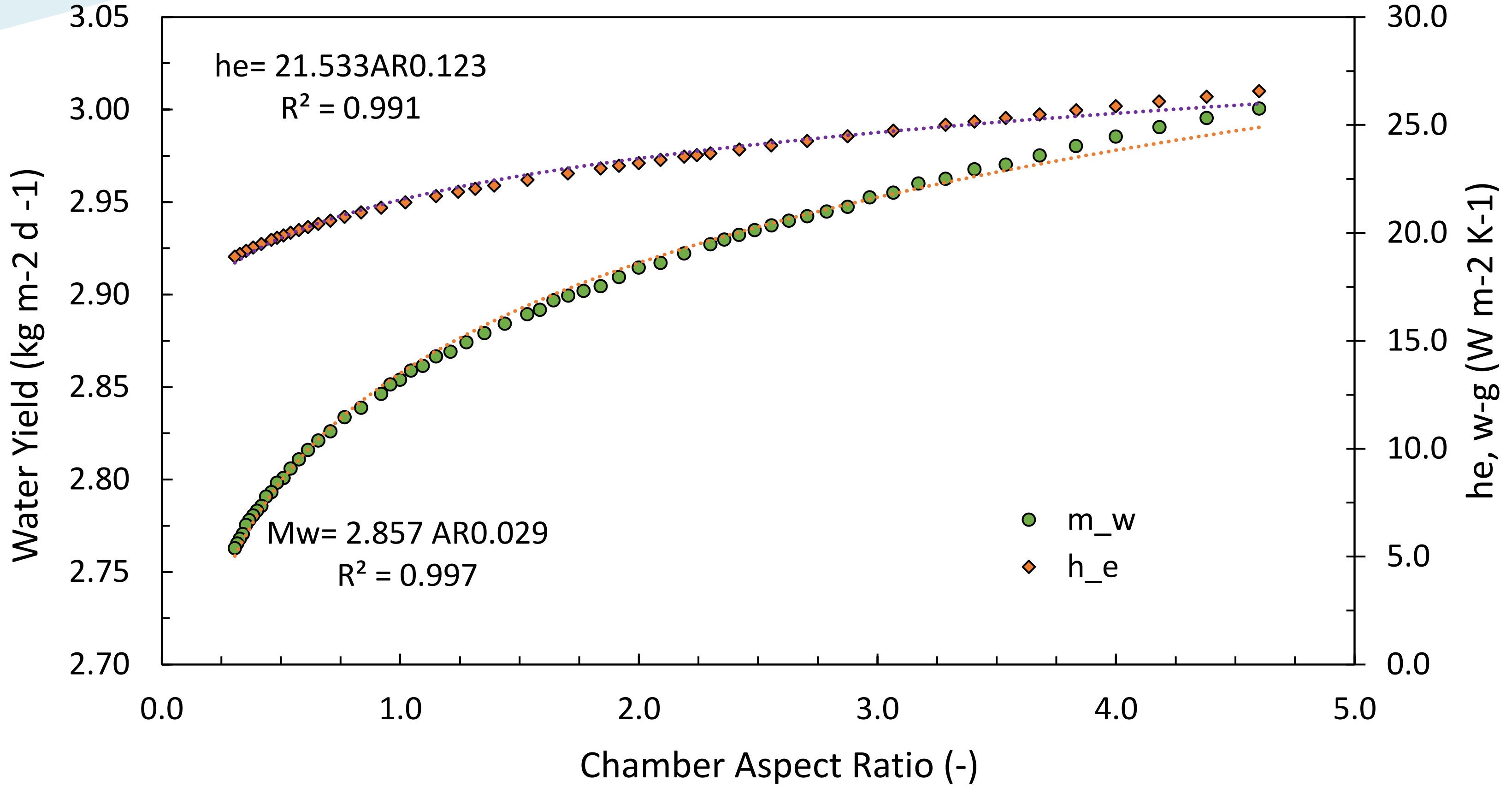
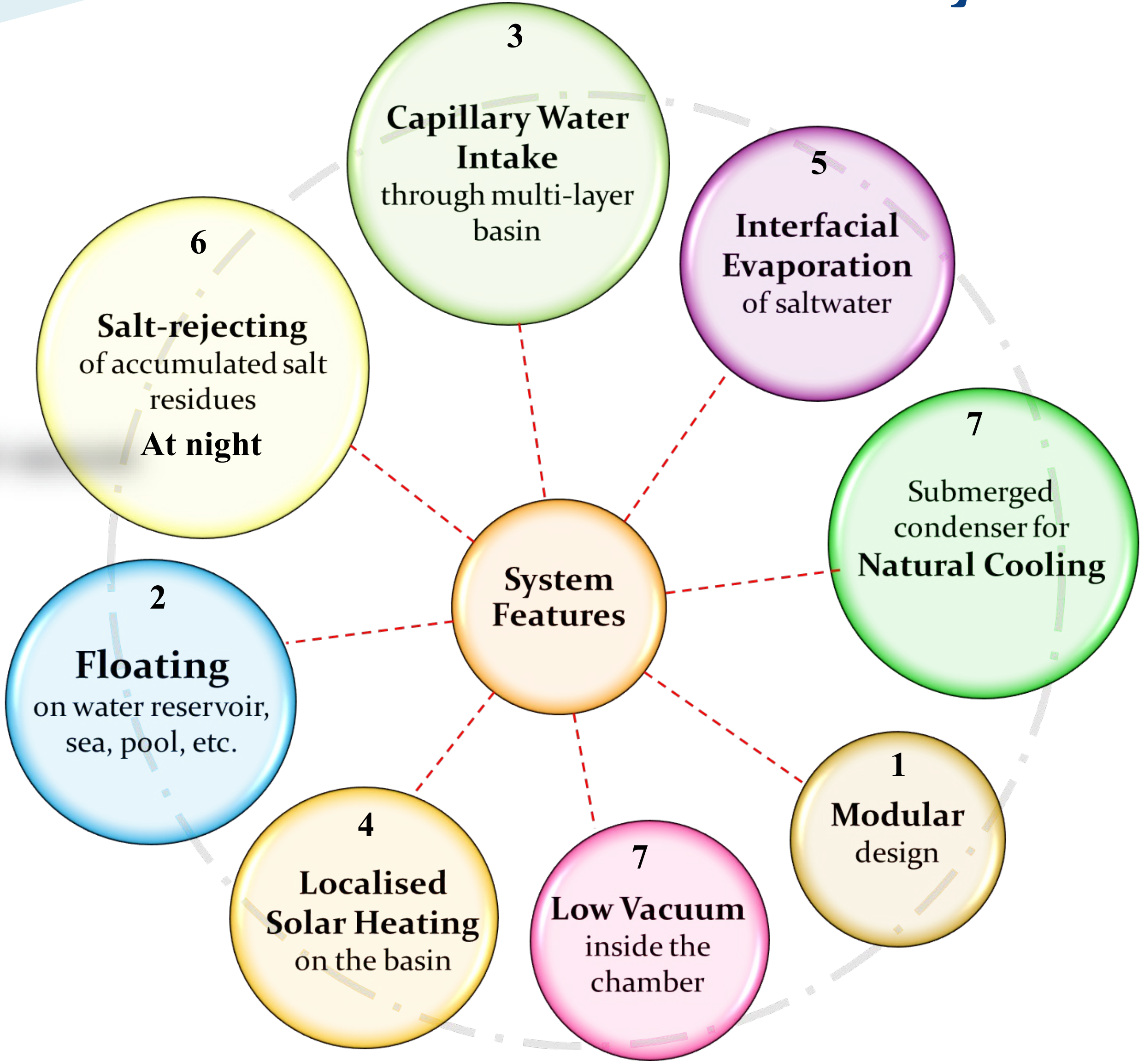


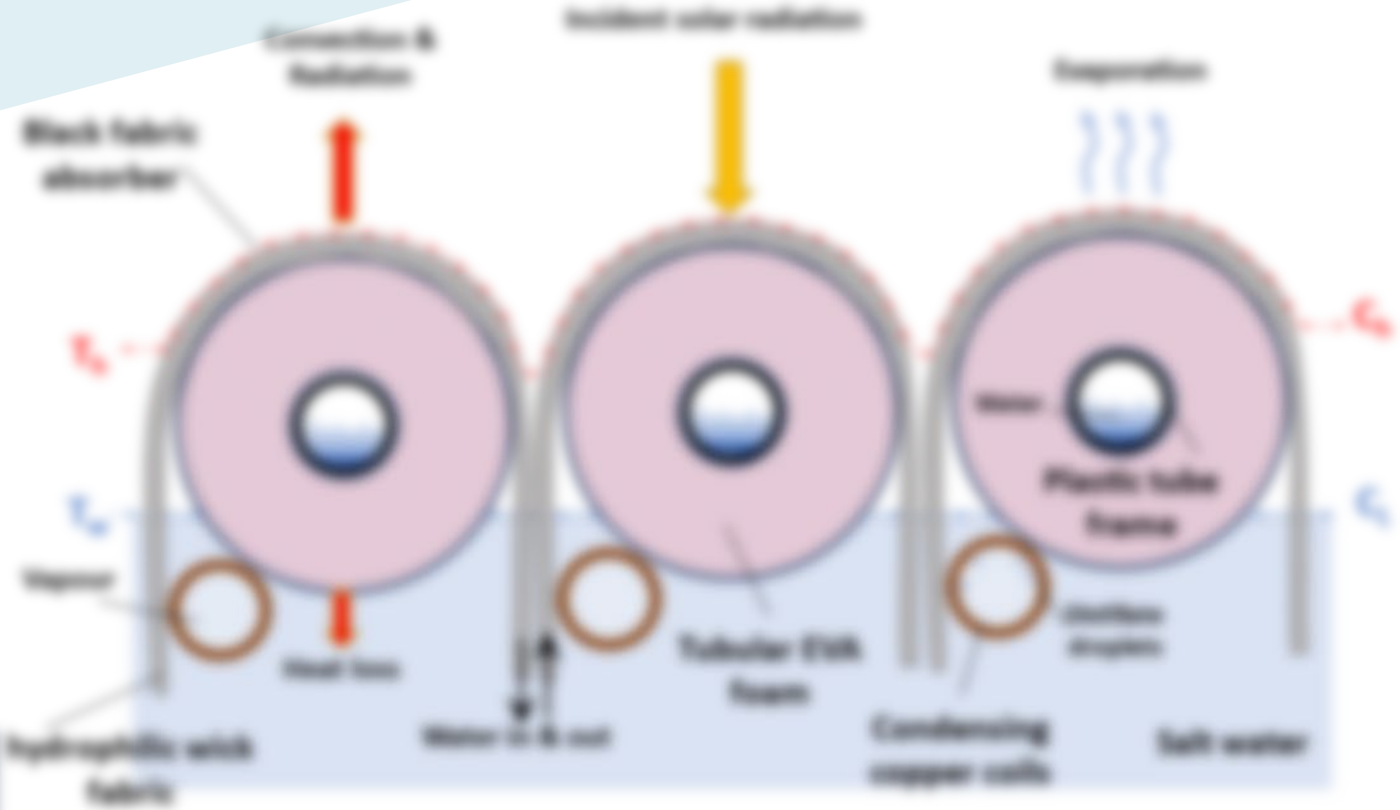
Fig. The variation of the daily water yield and the thermal efficiency under different Aspect ratios of the chamber. (Mohsenzadeh et al., 2021)

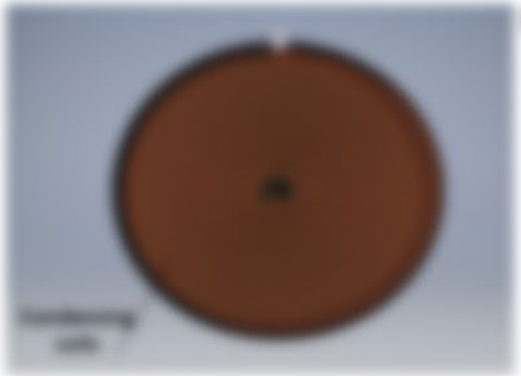
System Development : Novel Solar Desalination Sys.



Hemispherical Floating Self-Cleaning Solar Still

Multi layer tubular basin for experimental trial





Temperature outputs of multi layer basin

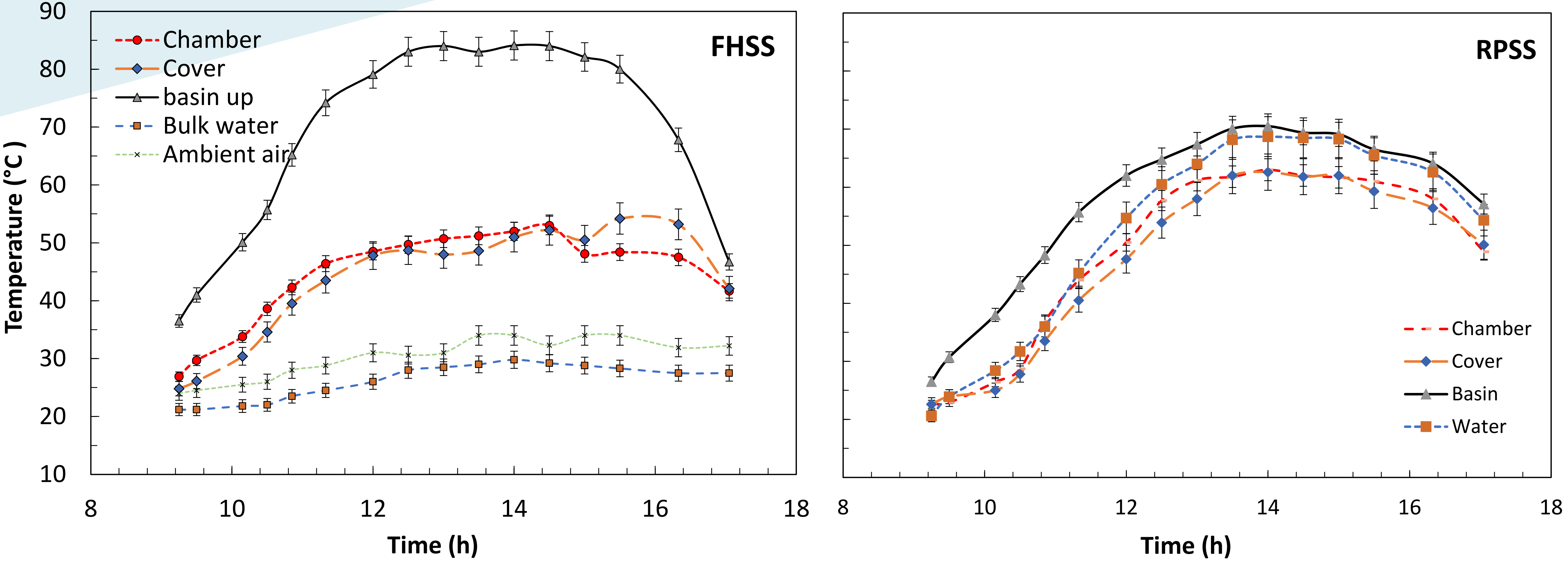
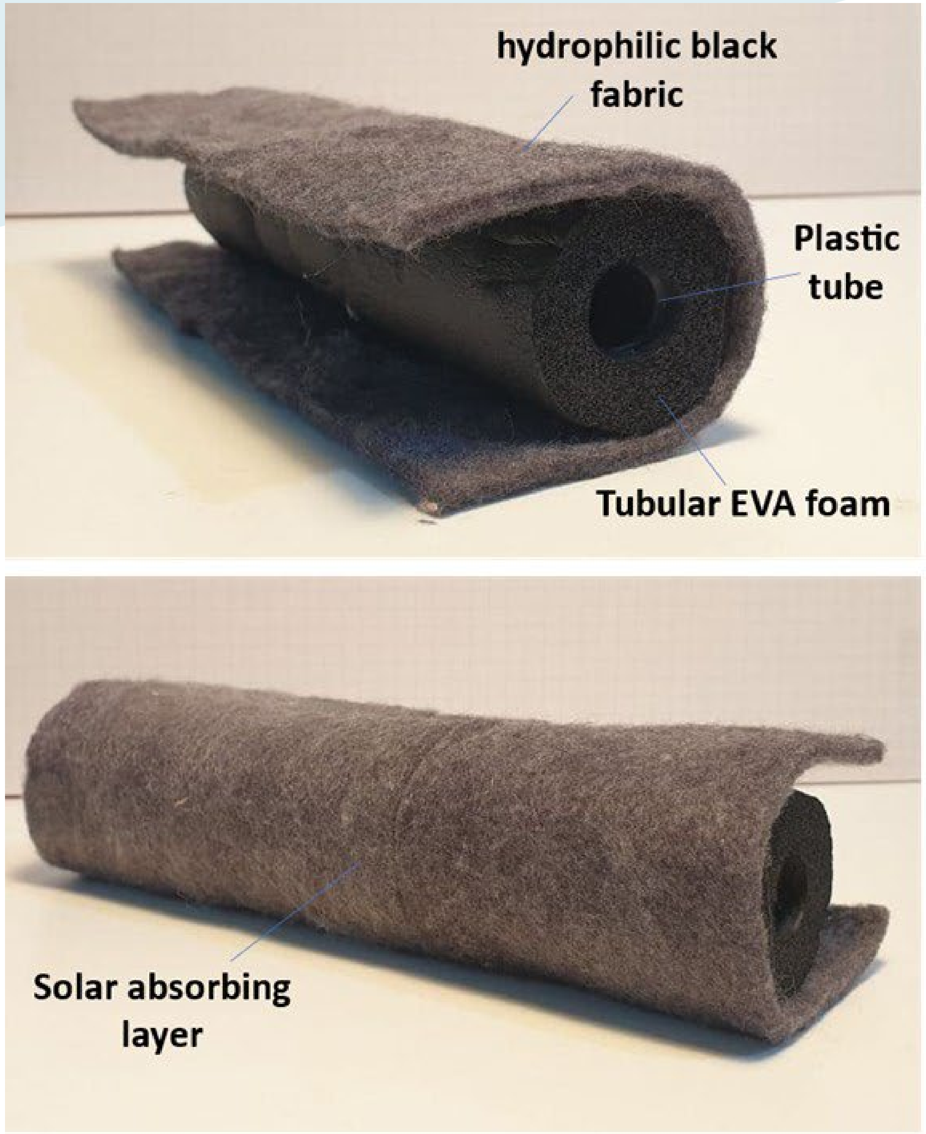
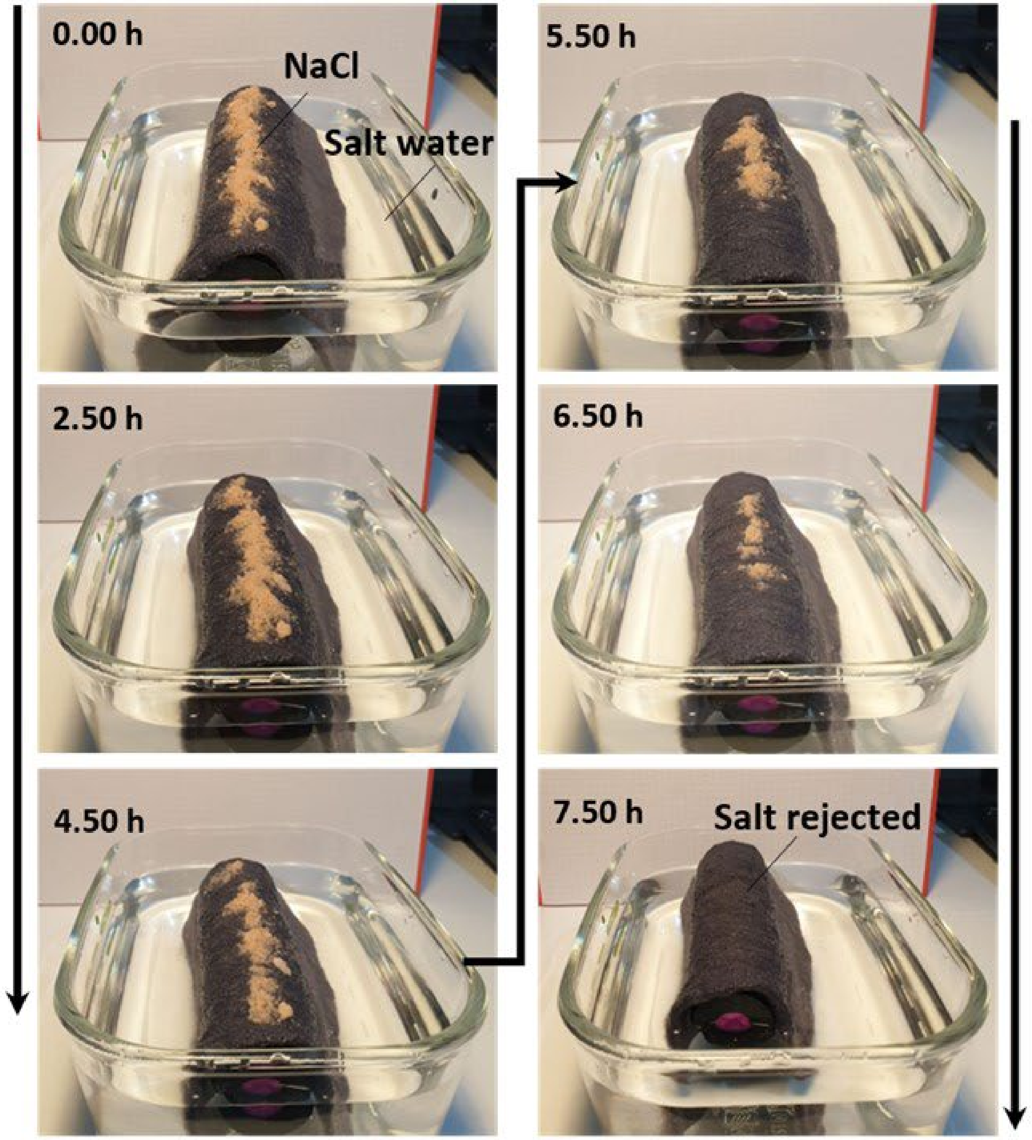


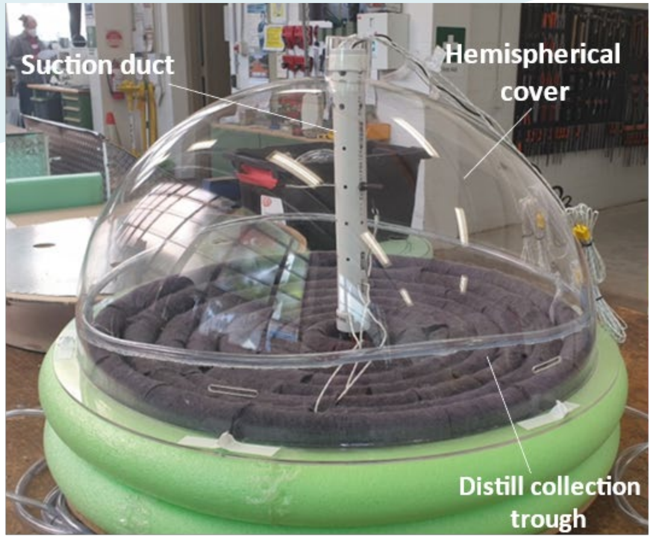
Fig: Temperature on different comp. of FHSS and RPSS setups.

Experiments: Indoor Salt-rejecting experiment (3)



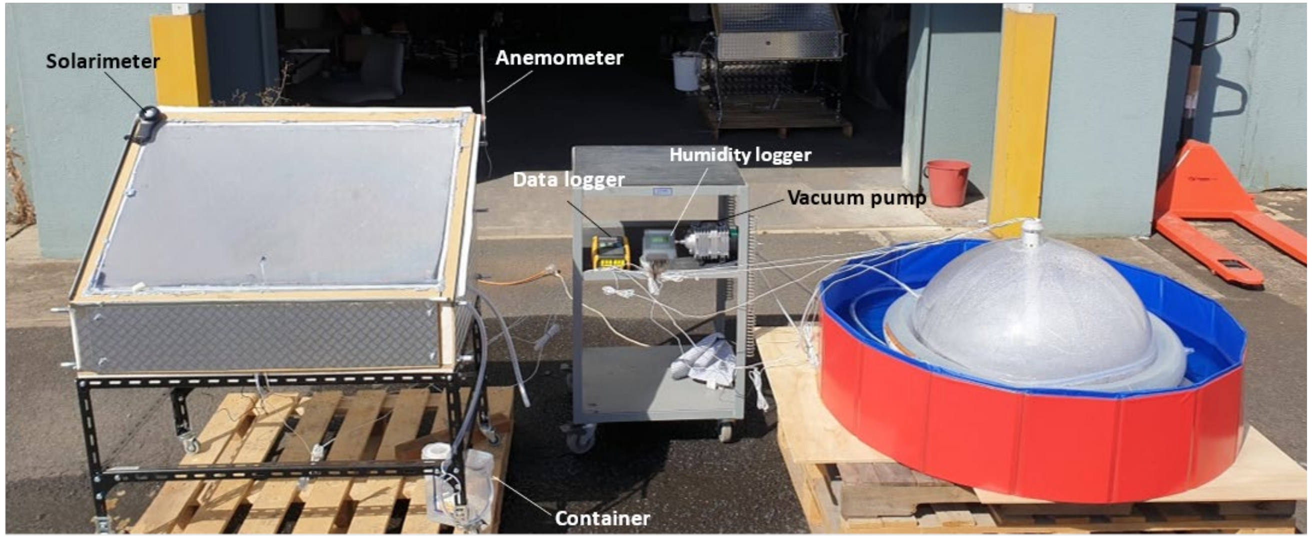


Experiments: FHSS experiment series (4)



(a)

(b)



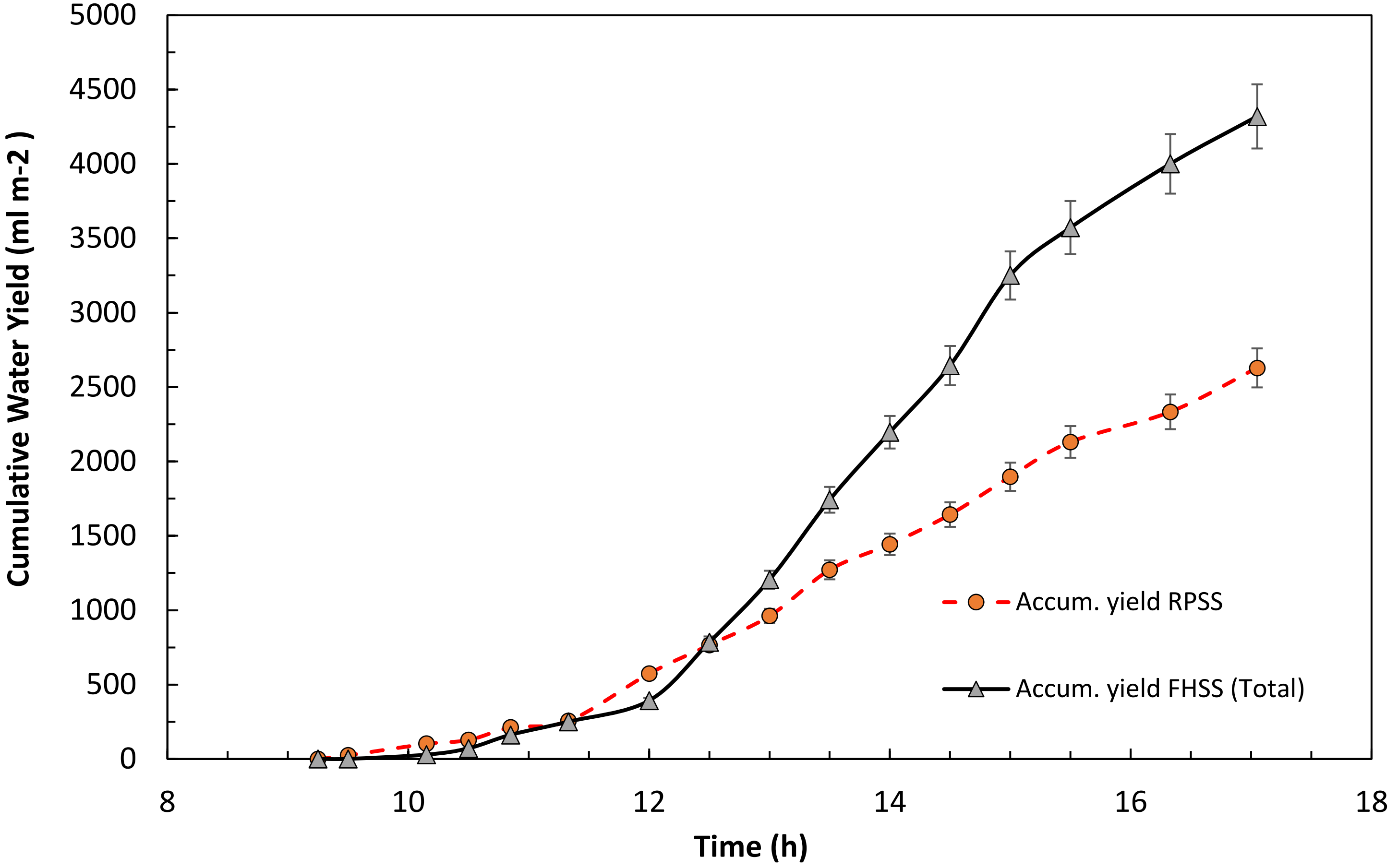
(c)

- **<u>Tests conducted on:</u>**
  - Summer, December 2020 - March21 (COVID 3rd stage)
  - at Heidelberg Campus Unimelb.
  - Running tests between 9:00 am - 5:00 pm.
  - with 2 hrs preparation, 1 hr wrapping up.

Results: Daily Water Yield of FHSS v.s RPSS (Exp.)

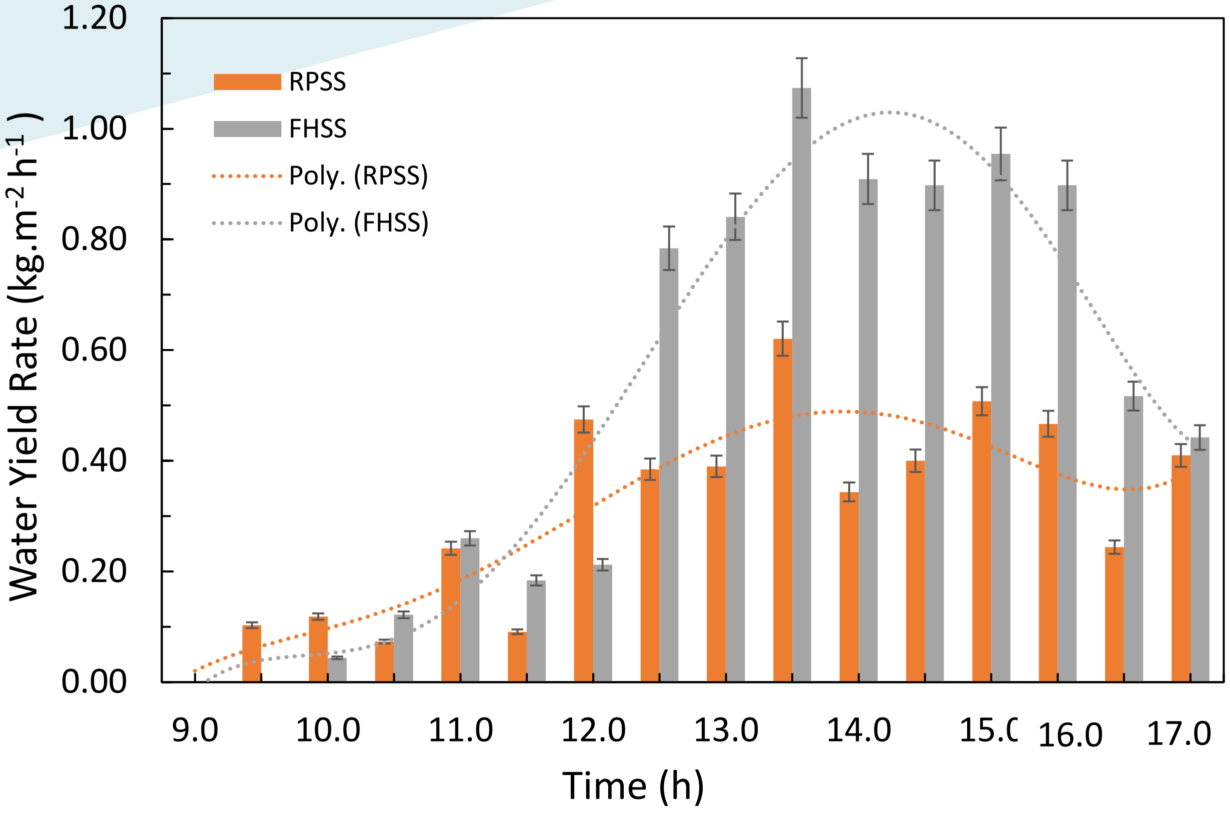
- 64% increase in water yield
- 4.3 L m^{-2} d^{-1} v.s RPSS with 2.3 L m^{-2} d^{-1}
- 36% Distil. Eff. v.s 18 % for RPSS

  (Mohsenzadeh et al., 2021)



Test condition: Melbourne, summer, Clear sky with the peak insulation rate of 990 W m^{-1} , ambient temperature 30 °C, wind velocity of 4 km h^{-1}, and Humidity level at 34%, salt concentration 3% wt.

Results: Yield & Distillation Eff. of FHSS v.s RPSS (Exp.)



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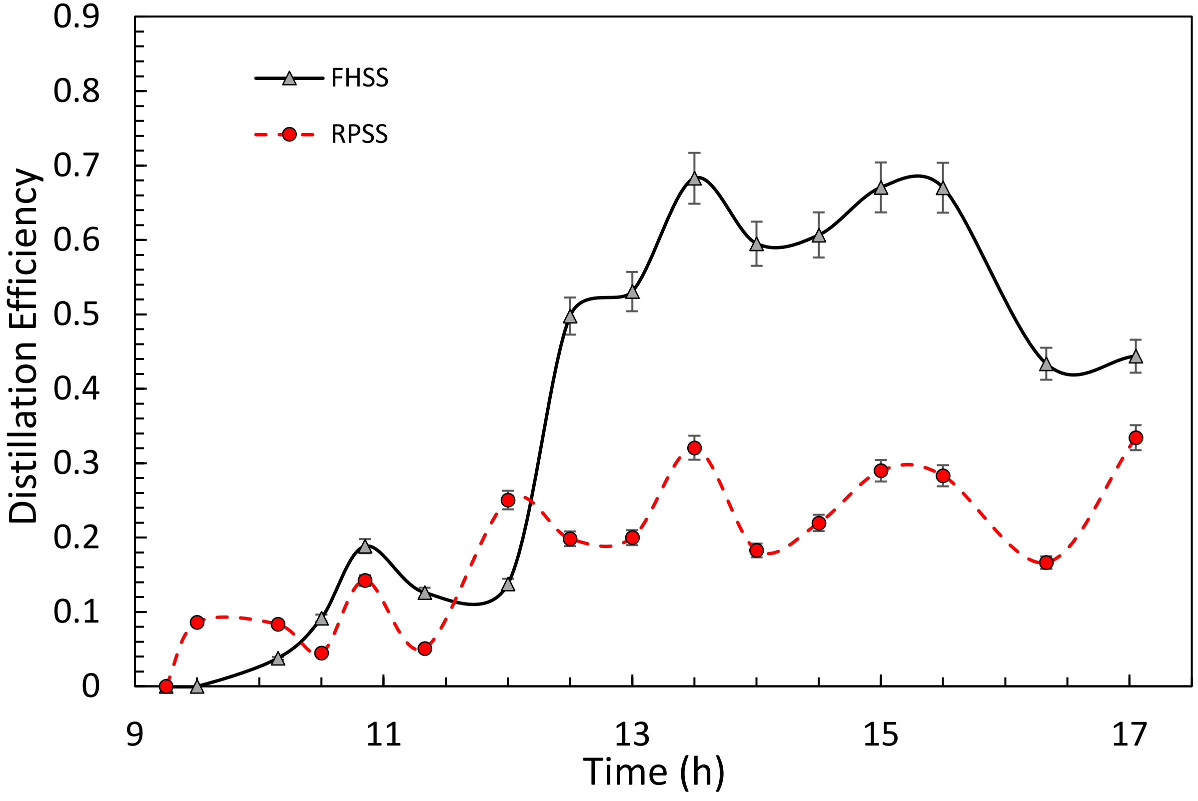

(b)

Test condition: Melbourne, summer, Clear sky with the peak insulation rate of 990 W m^{-1} , ambient temperature 30 °C, wind velocity of 4 km h^{-1}, and Humidity level at 34%, salt concentration 3% wt.

Results: Life Cycle Cost Analysis of FHSS v.s RPSS

Table 1. List of the raw materials cost and labour cost (in USD) for the FHSS system.

Components	Specifications	Cost (USD)
Hemispherical Cover	Clear Acrylic (700 mm Dia.)	68.00
Hydrophilic fabric wick	Cellulose, Zorb	11.00
Expanded porous foam	Tubular EVA (28 mm Dia.)	6.00
Condensing coils	Annealed Copper (3/8" Dia.)	32.00
Air pump	15 W, 20 L min^{-1}	15.00
Connector and clamps	Stainless Steel	3.50
Pipeline	Polyvinyl	5.00
Framework	Polyethylene tubes	12.00
Labour	15 hrs (rate of $4 per hour)	60.00
Total costs		212.50

Table 2. The unit water cost analysis breakdowns (in USD) for FHSS and RPSS .

Parameter	RPSS	FHSS
Operation life, a	10	8
Interest rate, %	4.0	4.0
Capital cost, $	249	213
Net Aperture area for solar, m^2	0.48	0.35
Salvage value, $	27	64
Capital recovery factor	0.12	0.15
Sinking-fund factor	0.08	0.11
Annual Salvage Value, $	2.25	6.95
First annual cost, $	30.70	31.64
Annual maintenance cost, $	4.60	1.58
Annual cost, $	33.06	26.27
Average daily water yield, L	1.03	1.52
Annual yield (Ave. daily yield × 365), L	375.95	554.80
Unit water cost, ¢ L^{-1}	8.8	4.7

- Unit Water Cost of FHSS: **4.7 US ¢ L^{-1}**
- Total cost of the FHSS module: **~ 210 USD**
- **46% reduction** in Life-Cycle Unit Water

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Conclusion

Key Outcomes:

- A daily rate of 4.3 L m^{-2} day^{-1} with the distillation efficiency of 35.6 % during summer in Melbourne, Australia.
- 64% increase, in daily water yield compared to RPSS.
- Life cycle cost of water (LCCW) is estimated at 4.7 US ¢ L^{-1} , 46% reduction compared to RPSS.
- Efficient Multi-layer basin with adequate rate of salt-rejecting and capillary water intake
- This system is expected to have a lower maintenance cost as no need to a water pump and no warrant as much periodic cleaning.

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Conclusion

Future considerations :

- **The creation of water droplets on the cover** still need to be addressed(by redirecting into condensation coils 77%).
- **Applying a long-term lasting Anti-Fog** / Water Repellent coating on the surface.
- Furthermore, **The heat loss via the wick fabric into the bulk water** needs further study to avoid heat loss to the bulk water instead of pre-heating wick fabric.

List of Publications, Presentations

Journal Papers:

- Development and exp. analysis of an innovative self-cleaning low vacuum floating solar still for low-cost desal. ***Energy Conversion and Management.*** (2021)
- A review on various designs for performance improvement of passive solar stills for remote areas. ***Solar Energy***. (2021)
- Development and validation of a transient model for a passive solar still considering the aspect ratio of the evaporation chamber. ***Solar Energy***. (2022)
- A semi-empirical correlation estimating convection and evaporation inside a single-slope passive solar still... ***Applied Thermal Engineering***. (2022)

Conference Presentations and Peer reviewed extended abstract:

- An innovative Cost-effective floating solar still with integrated condensation coils. ***Asia-Pacific Solar Research Conference (APSRC)*** (16-17 Dec. 2021)

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

A review on various designs for performance improvement of passive solar stills for remote areas

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A R T I C L E I N F O

Keywords:
Solar still
Desalination
Design enhancement
Water cost
Remote area
Review

A B S T R A C T

Potable water scarcity is one of the major issues that has been affecting millions of lives. It became serious in underprivileged remote communities that are unable to afford conventional water supply and treatment systems. Passive solar desalination systems as a cost-effective option for water supply are becoming more feasible in remote areas. However, low water yield and poor reliability are the main deficiencies that need improvement. This article reviews recent studies conducted on performance improvement and water cost reduction of passive solar stills associated with new designs and modifications appropriate for remote areas to identify the most effective designs. The individual effect of each component's design on performance parameters (water yield, thermal efficiency, and unit water cost) has been reported and discussed. The design specifications and outcomes of studies were reviewed and presented in tables to give a broad view of activities in the area, and to provide future studies with data for validation purposes. This article shows knowledge gaps and opportunities for future research through a distinct classification of studies to shape a clear roadmap on the development of passive solar stills. The most effective designs of components with respect to their application in remote or disaster-stricken areas with no access to power infrastructure were determined. In addition, issues around the structural design complexity and operational reliability associated with new designs were presented.

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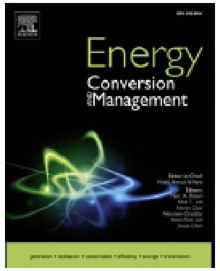
Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman



Development and experimental analysis of an innovative self-cleaning low vacuum hemispherical floating solar still for low-cost desalination

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ARTICLE INFO

Keywords:
Floating solar still
Interfacial evaporation
Capillary water supply
Self-cleaning
Remote areas
Life cycle cost

ABSTRACT

In this article, a novel floating salt rejecting solar still with a low vacuum condition on the evaporation chamber is developed and the performance is experimentally investigated. The new design adopts solar heat localization for interfacial evaporation and capillary water circulation to improve the evaporation rate and prevent the basin surface from residual salt accumulation. The basin is made in tubular structure composed of multi layers of porous foam and hydrophilic cellulose fabric for improved capillary water supply. The solar still consists of an external condensing coils coupled with the basin structure. It completely submerges into the water while the solar still is floating in the saline water reservoir (e.g. oceans). This enables the natural cooling of the condensing coils which increases the condensation rate. A low-cost hemispherical clear acrylic cover is used to capture the solar radiation from all directions on the basin. The system performance was examined under different scenarios. The system was found to generate distilled water at a daily rate of 4.3 L m^{-2} d^{-1} with the distillation efficiency of 35.6% during summer in Melbourne, Australia. The life cycle cost per litre of drinking water generated by the solar still is calculated at 4.7US ¢ L^{-1} which is substantially lower than conventional solar stills. This system is expected to have a lower maintenance cost as it does not require as much periodic cleaning. The new system developed is a feasible alternative to address the water security challenge for water-stressed communities at remote areas or disaster-stricken areas with no access to an energy infrastructure.

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Award for Best Buildings Related Paper by a Student
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for

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Thank You!

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