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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Experimental Performance of Solar Collector cum Regenerator for Coupling with a Liquid Desiccant Cooling System

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Outline

- Introduction to solar liquid desiccant cooling system
- Solar collector cum regenerator (C/R) assisted cooling systems
- Regeneration experimentation using two solar C/Rs
- Results and discussions
- Conclusions

Objectives

- To propose coupling method of solar C/R with liquid desiccant air cooling (LDAC) system
- Provides data on average evaporation rate of water for regeneration of weak, medium and high concentration liquid desiccant (a mixture of water and salt such as $CaCl_2$ and LiCl)
- Identifies effect of solar C/R size for regeneration of liquid desiccant
- Estimate absorber area of a solar C/R required for a unit cooling load

Solar liquid desiccant cooling system

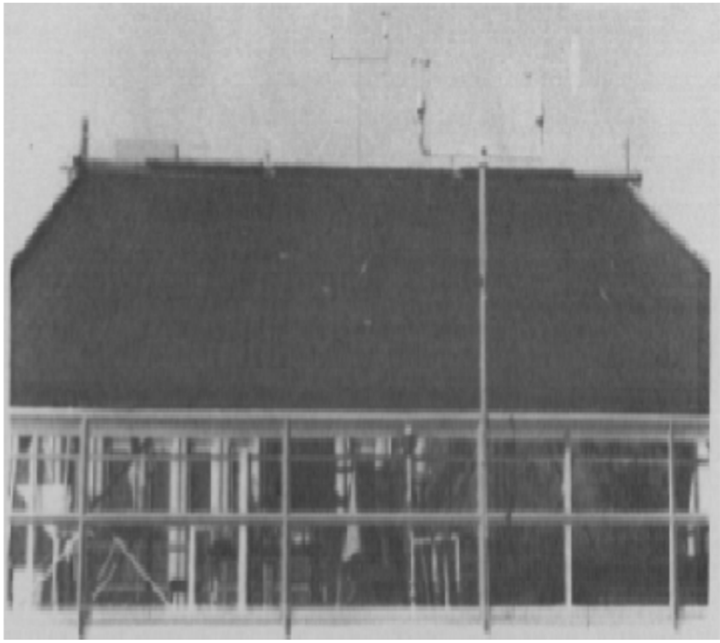
Cools air in two stage: Dehumidifcation of outdoor air using concentrated liquid desiccant and sensible cooling of the dehumidified air using direct/indirect evaporator

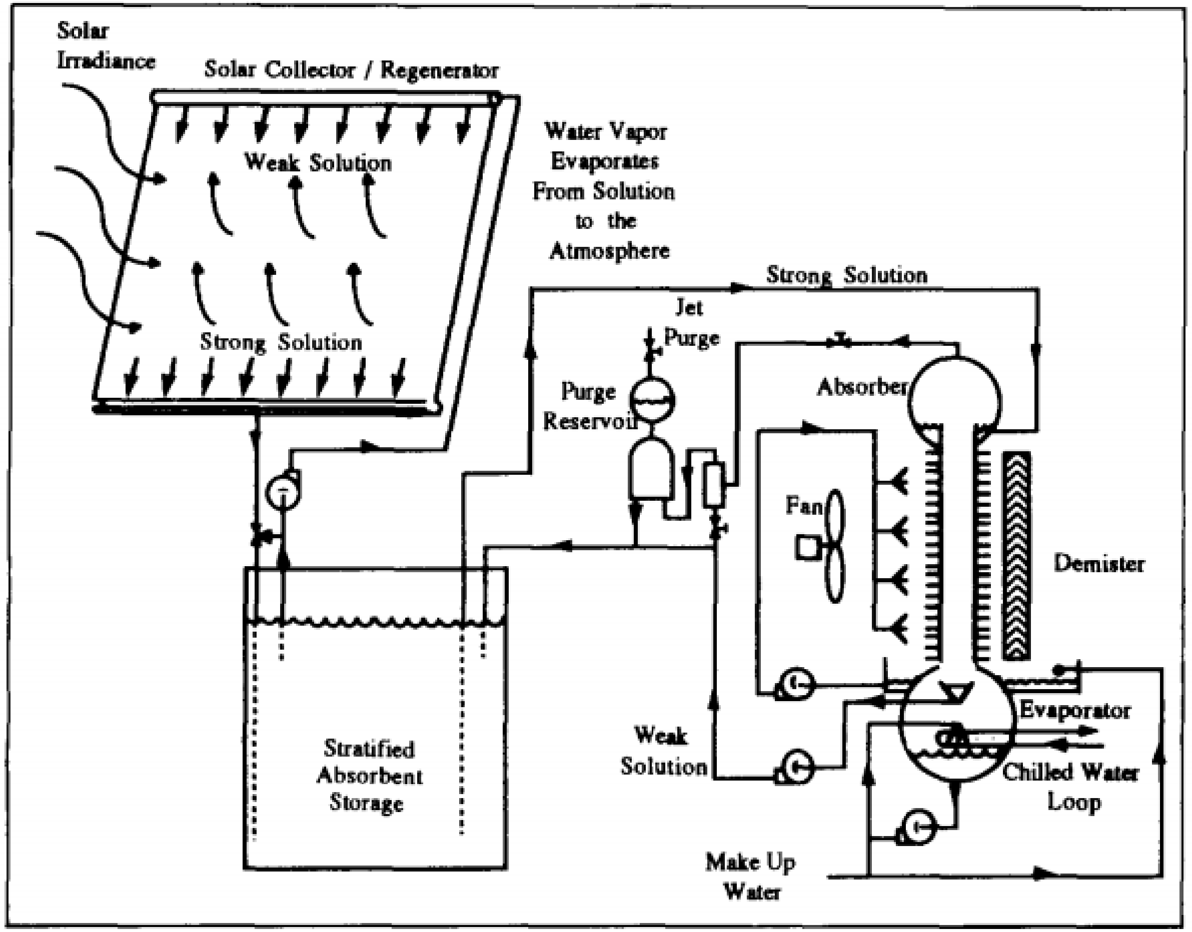
- Air dehumidifier and solar regenerator are critical components of the system.
- The performance of air dehumidifier depends on the desiccant concentration at inlet.
- The solar collector cum regenerator is used to produce the concentrated desiccant.

Solar C/R assisted LDAC systems

Hawlader et al. (1993) solar C/R assisted OCACs

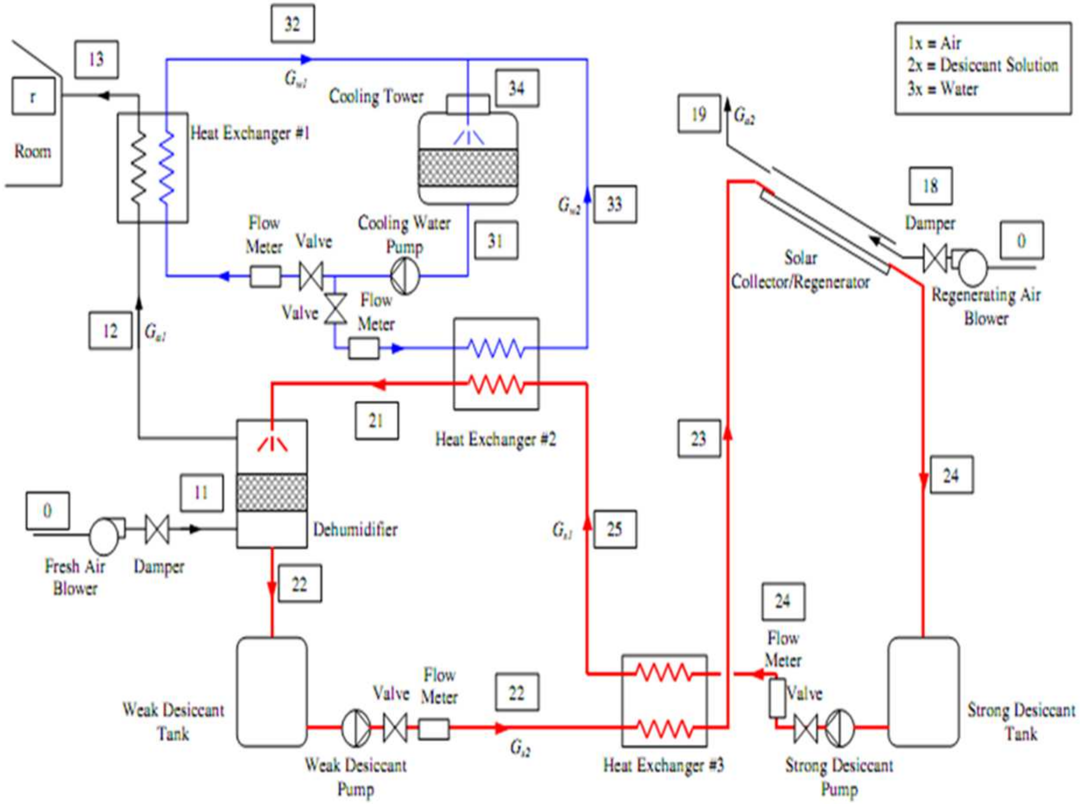
- Solar C/R (11 x 11m^2)



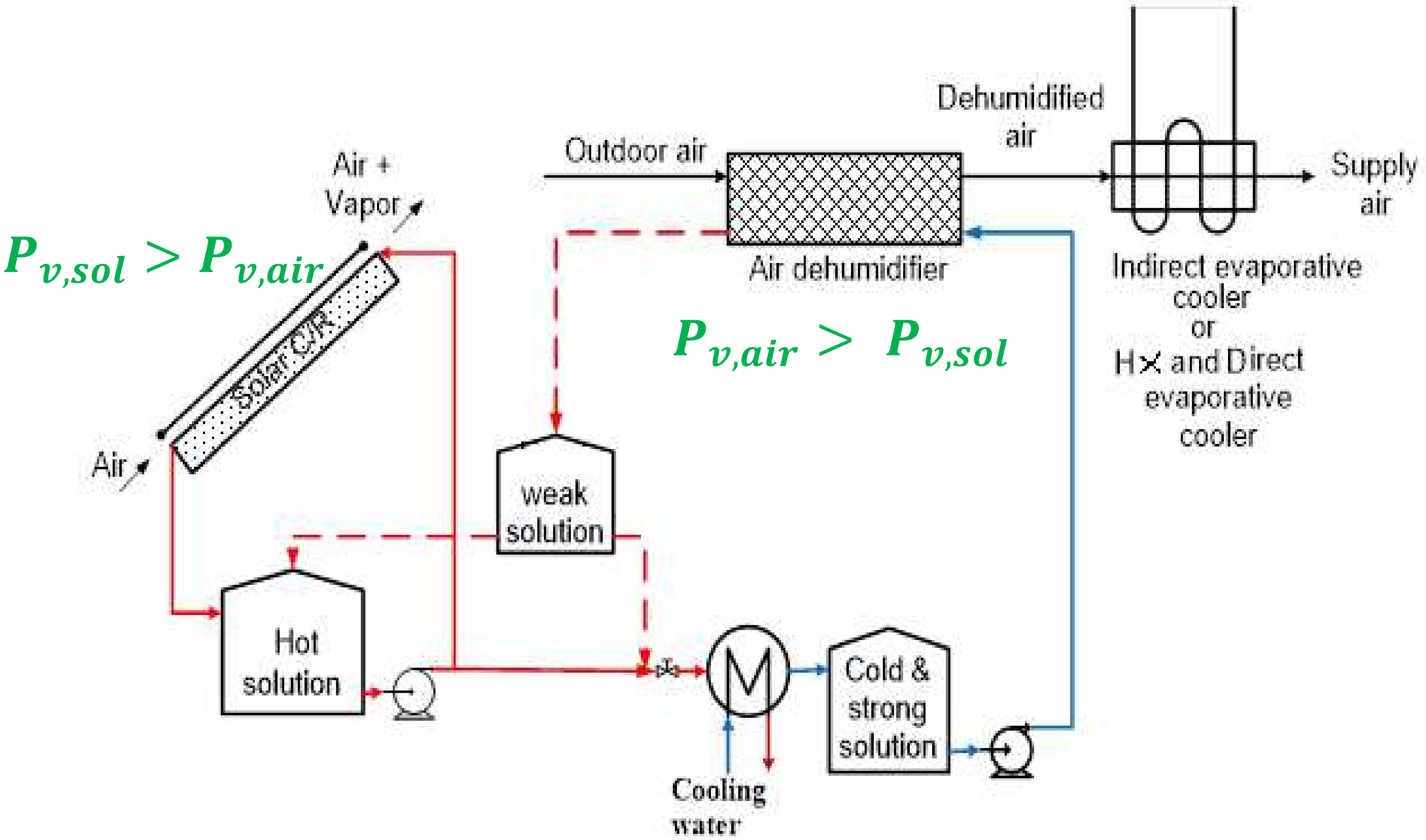


Kategenekarn et al. (2009)

4 solar C/Rs in series (each 1.72 m x 0.85 m) with once through coupling



Proposed coupling of solar C/R



Solar C/R used in the present work

Solar C/R-A

- Absorber area= 2.2 m x 1.84 m

Solar C/R-B

- Absorber area= 0.8 m x 1.84 m

Instruments

1) Thermocouple wires & RTDs
2) Digital densitometer

3. Measuring scale
4. Pyranometer

Calibration

RTDs, Thermocouple wires were calibrated at ice and boiling point of water

Densitometer was calibrated against density of water according to the manufacturer guideline

Uncertainty analysis

General uncertainty analysis method was used (Dunn, 2005):

$$U_R^2 = \sum_i^N \left(\frac{\partial R}{\partial x, i} U_{x,i} \right)^2$$

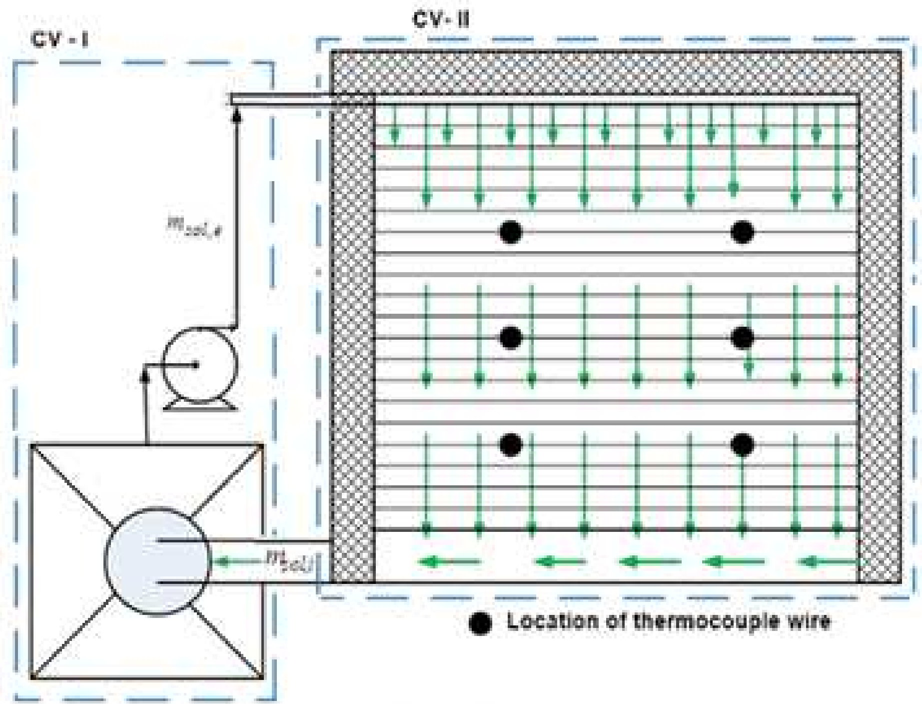
S. No.	Instrument	Uncertainty
1	Densitometer	$\pm 0.001\ g/cm^3$
2	Pyranometer	$\pm 3\ \%$ of pyranometer reading
3	Thermometer	$\pm 0.5^oC$
4	Thermocouple wire	$\pm 0.5^oC$
5	RTD	$\pm 0.5^oC$
6	Tape rule / Scale	$\pm 1\ mm$

❖ **Uncertainty in calculated parameters:**

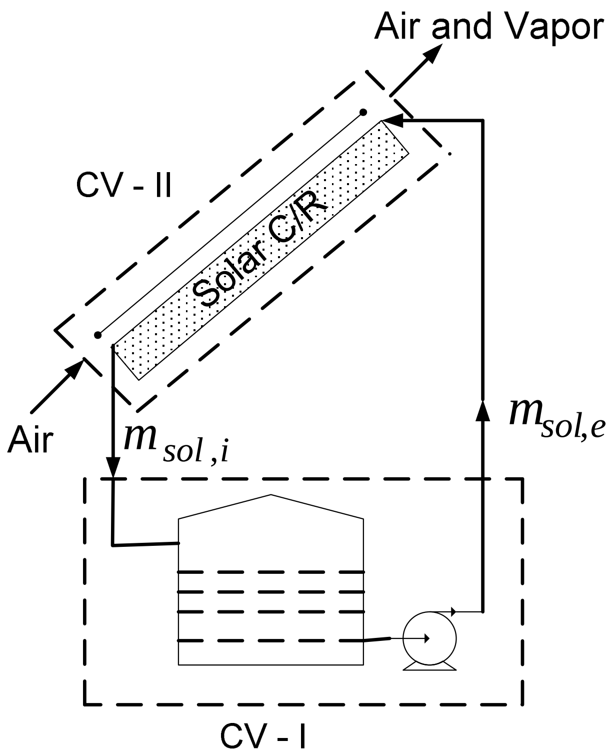
- **concentration of desiccant was 0.0014 kg/kg**
- **mass of water evaporated was in range of 0.02-0.04 kg (% error < 2%)**
- **solar C/R efficiency was in the range of 1.2-1.4% (% error <4%)**

Regeneration analysis

Top view



Side view



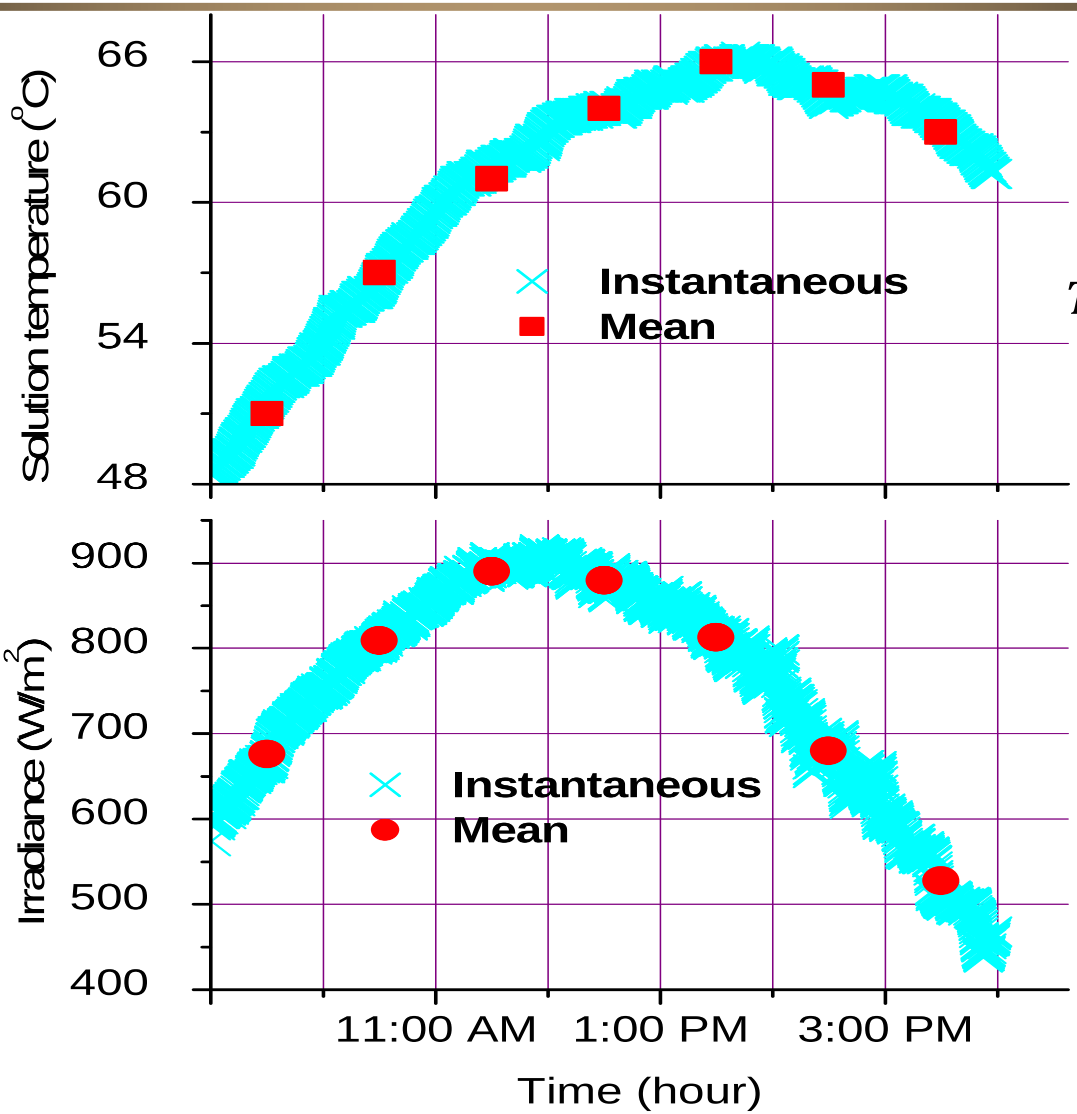
Data collection

Initial solution data in the tank at 9 am for solar C/R-A

	LiCl	$CaCl_2$
Measured		
Initial volume of solution	38.4 litre,	38.4 litre
Initial density of solution	1193 kg/m^3	1289 kg/m^3
Initial temperature of solution	49^{o}C	37^{o}C
Calculated		
Initial concentration	0.33	0.31
Initial mass of solution	45.8 kg	49.4 kg
Initial mass of desiccant in solution	15.2 kg	15.3 kg

Data collection (cont.)

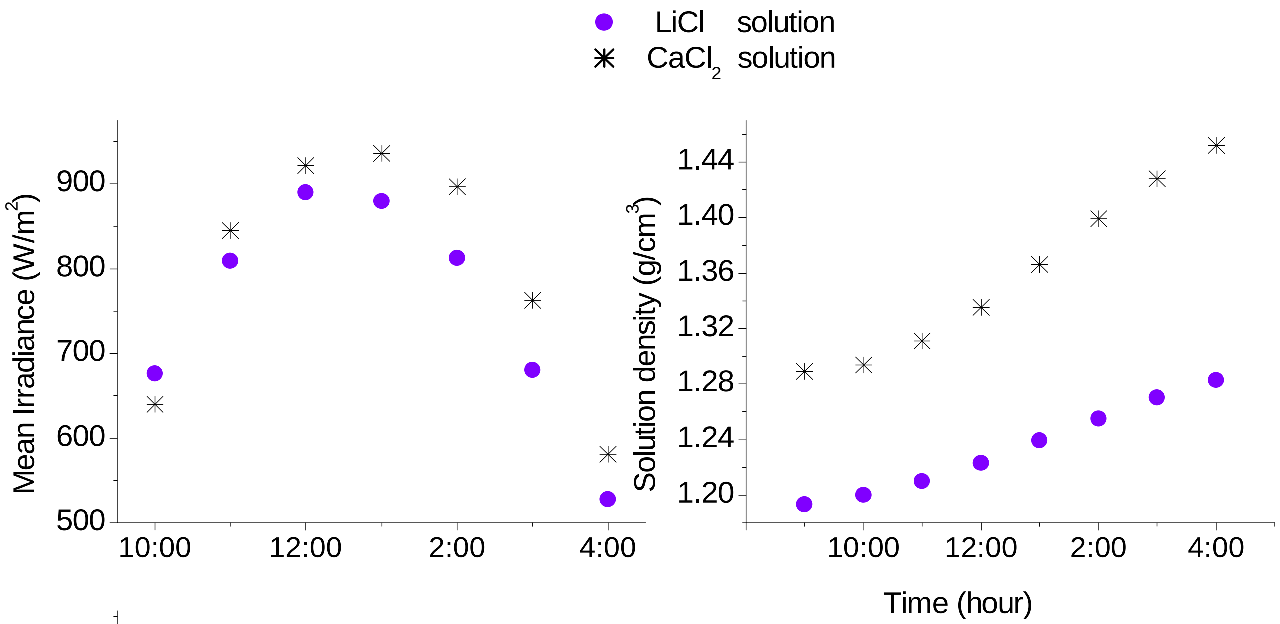
Irradiance & solution temperature were scanned every 10 seconds using DAQ system

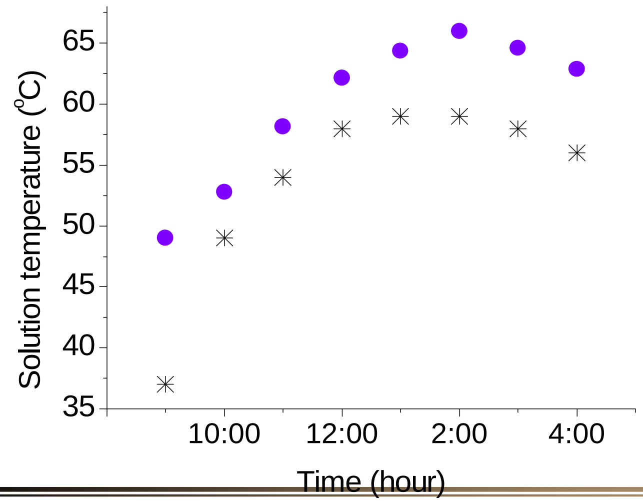


$$T_{mean} = \frac{\sum_{i=1}^{N} T_i}{N}$$

$$I_{mean} = \frac{\sum_{i=1}^{N} I_i}{N}$$

Data collection





Solution density was measured every 30 minute

Fig. Experimental Regeneration data for LiCl and $CaCl_2$ solutions

Performance analysis

Parameters

- Evaporation rate of water
- Increase in concentration of desiccant in the solution
- Energy of evaporation(cooling load)
- Solar C/R efficiency

Performance analysis

❖Concentration (Conde, 2004)

- **Calcium chloride**

$$0.105642\left(\frac{\xi}{1-\xi}\right)^3-0.4363\left(\frac{\xi}{1-\xi}\right)^2+0.836014\left(\frac{\xi}{1-\xi}\right)+1-\frac{\rho_{sol(\xi,T)}}{\rho_{H_2O(T)}}=0$$

- **Lithium chloride**

$$0.100791\left(\frac{\xi}{1-\xi}\right)^3-0.303792\left(\frac{\xi}{1-\xi}\right)^2+0.540966\left(\frac{\xi}{1-\xi}\right)+1-\frac{\rho_{sol}\left(\xi,T_{sol}\right)}{\rho_{H_2O}\left(T_{sol}\right)}=0$$

- **Density of water**

$$\rho_{H_2O}\left(T_{sol}\right)=0.322\begin{pmatrix}1+1.99377184\ 30\ \tau^{1/3}+1.09852116\ 04\ \tau^{2/3}\\ -0.50944929\ 96\ \tau^{5/3}-1.76191242\ 7\ \tau^{16/3}\\ -44.9005480\ 267\ \tau^{43/3}-723692.261\ 8632\ \tau^{110/3}\end{pmatrix}$$

Performance analysis (cont.)

❖ Energy of evaporation (Cooling load)

$$Q_{eva} = Q_o = m_{v,\Delta t} h_{fg,av} = m_{v,\Delta t} \left(2551 + \Delta h_d\right)$$

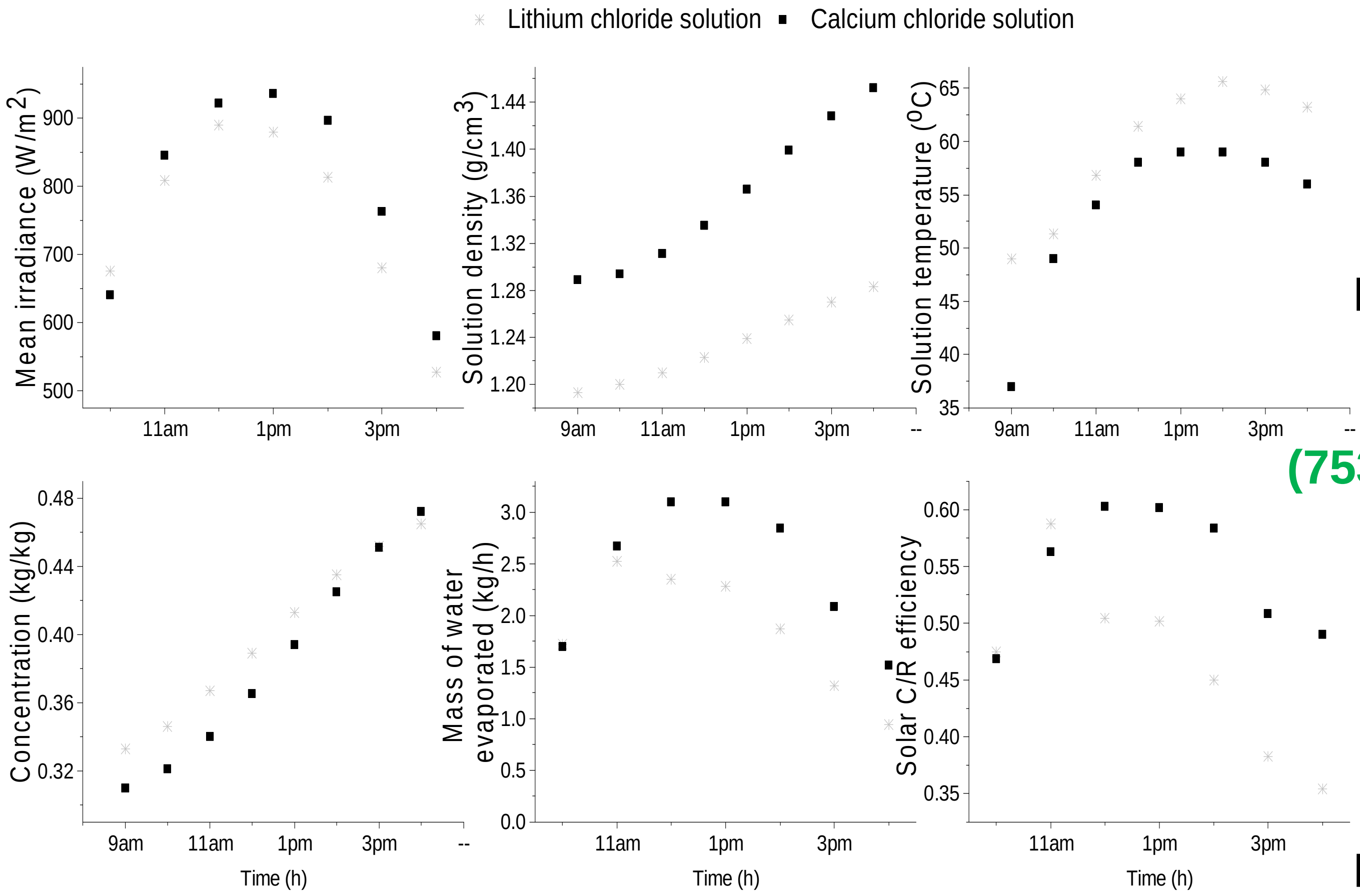
$$\Delta h_d = \left(169.105 + 457.85\theta\right)\left[1 + \left(\frac{\xi}{0.845\left(0.6 - \xi\right)}\right)^{-1.965}\right]^{-2.265}$$ (LiCl)

$$\Delta h_d = \left(-955.69 + 3011.974\theta\right)\left[1 + \left(\frac{\xi}{0.855\left(0.8 - \xi\right)}\right)^{-1.965}\right]^{-2.265}$$ ($CaCl_2$)

Solar collector cum regenerator efficiency

$$\eta_{CR} = \frac{Q_{eva}}{I . A_{ab} . \Delta t}$$

Diurnal performance of solar C/R-A



For LiCl

m_{total} evaporated
= 13.0 kg/day
(0.33 to 0.46 kg/kg)

Evaporation flux over the day
=0.45 kg/h.m^2
(753.7 W/m^2 & η_{CR}=0.46)

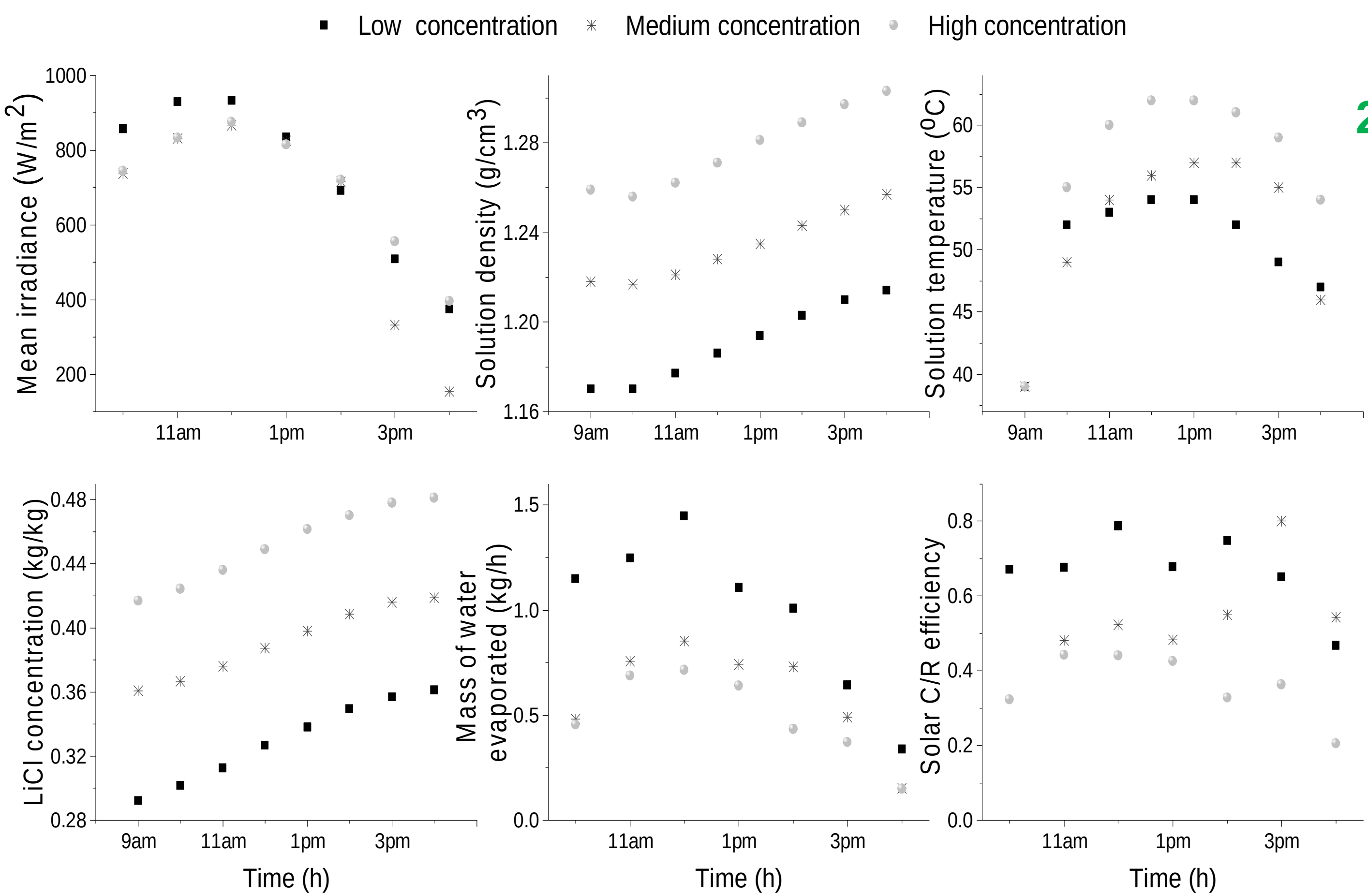
For $CaCl_2$

m_{total} evaporated
= 17.0 kg/day
(0.31 to 0.47 kg/kg)

Evaporation flux over the day
=0.6 kg/h.m^2
(797.6 W/m^2 & η_{CR}=0.54)

Diurnal performance of solar C/R-B

LiCl solution



Initial solution volume/ concentration:

31.2 L/ 0.29 (Low)
25.1 L/ 0.36 (Medium)
20.3 L/ 0.41 (Higher)

Total mass of water evaporated were

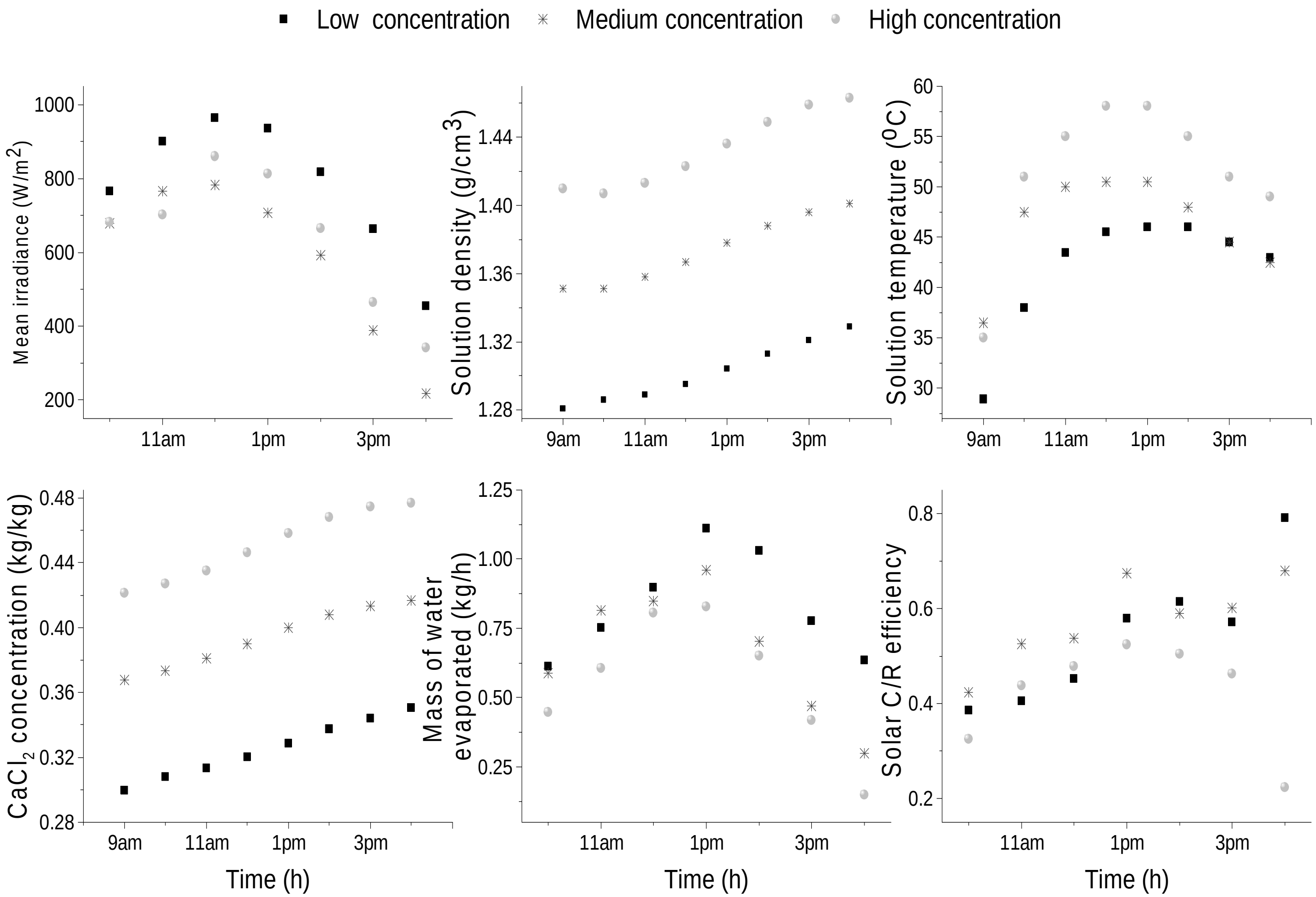
=6.9 kg/day (low)
=4.2 kg/day (Medium)
=3.4 kg/day (High)

Evaporation flux were

=0.67 kg/m^2.h (Low)
=0.41 kg (Medium)
=0.31 kg/m^2.h (High)

Effect of desiccant concentration

CaCl2 solution



Initial solution volume/ concentration:

35.8 L/ 0.30 (Low)
31.2 L/ 0.36 (Medium)
23.7 L/ 0.41 (Higher)

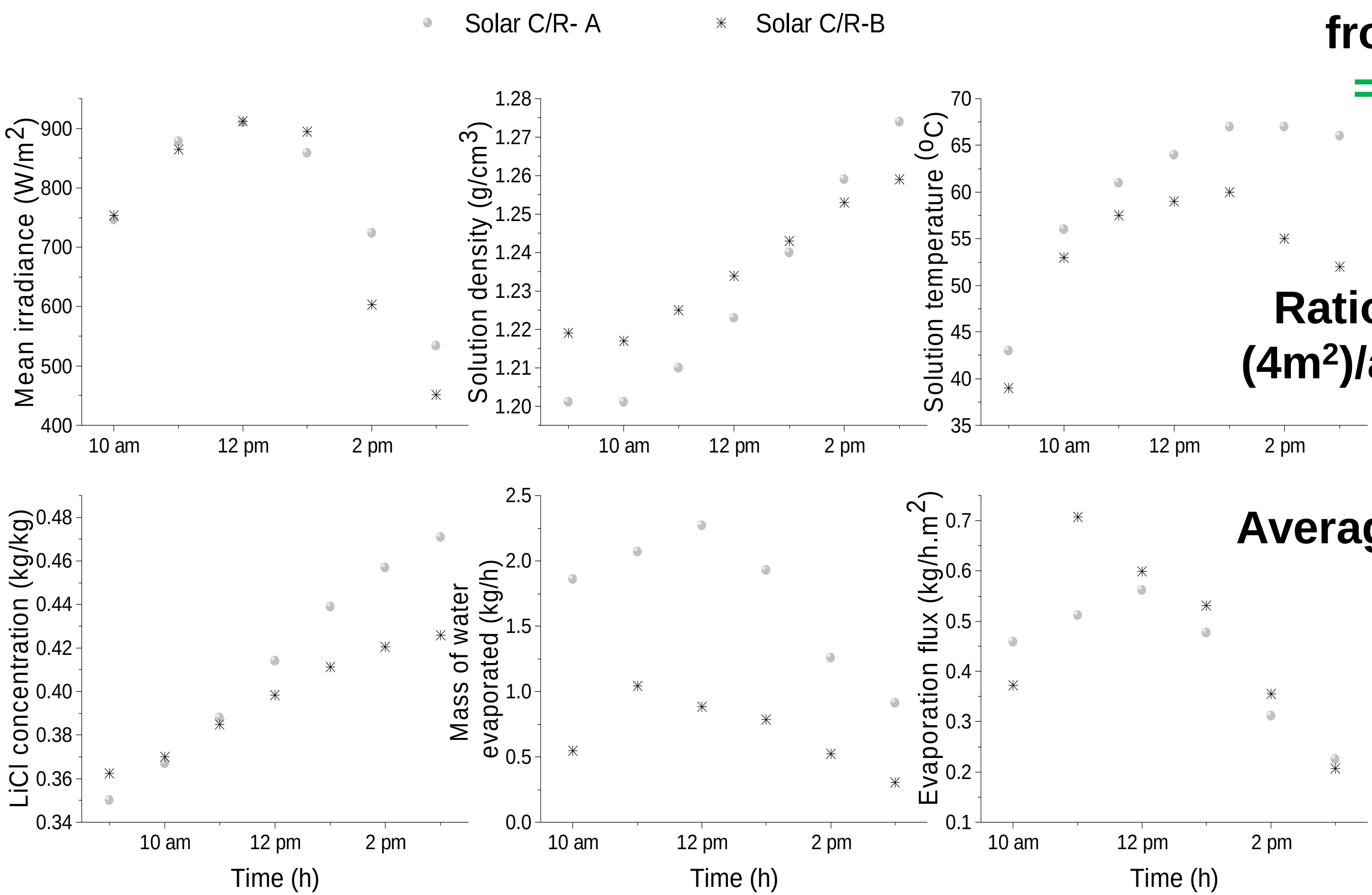
Total mass of water evaporated were

=6.5 kg/day (low)
=4.6 kg/day (Medium)
=3.9 kg/day (High)

Evaporation flux were

=0.63 $kg/m^2.h$ (Low)
=0.45 $kg/m^2.h$ (Medium)
=0.37 $kg/m^2.h$ (High)

Effect of solar C/R size (LiCl)

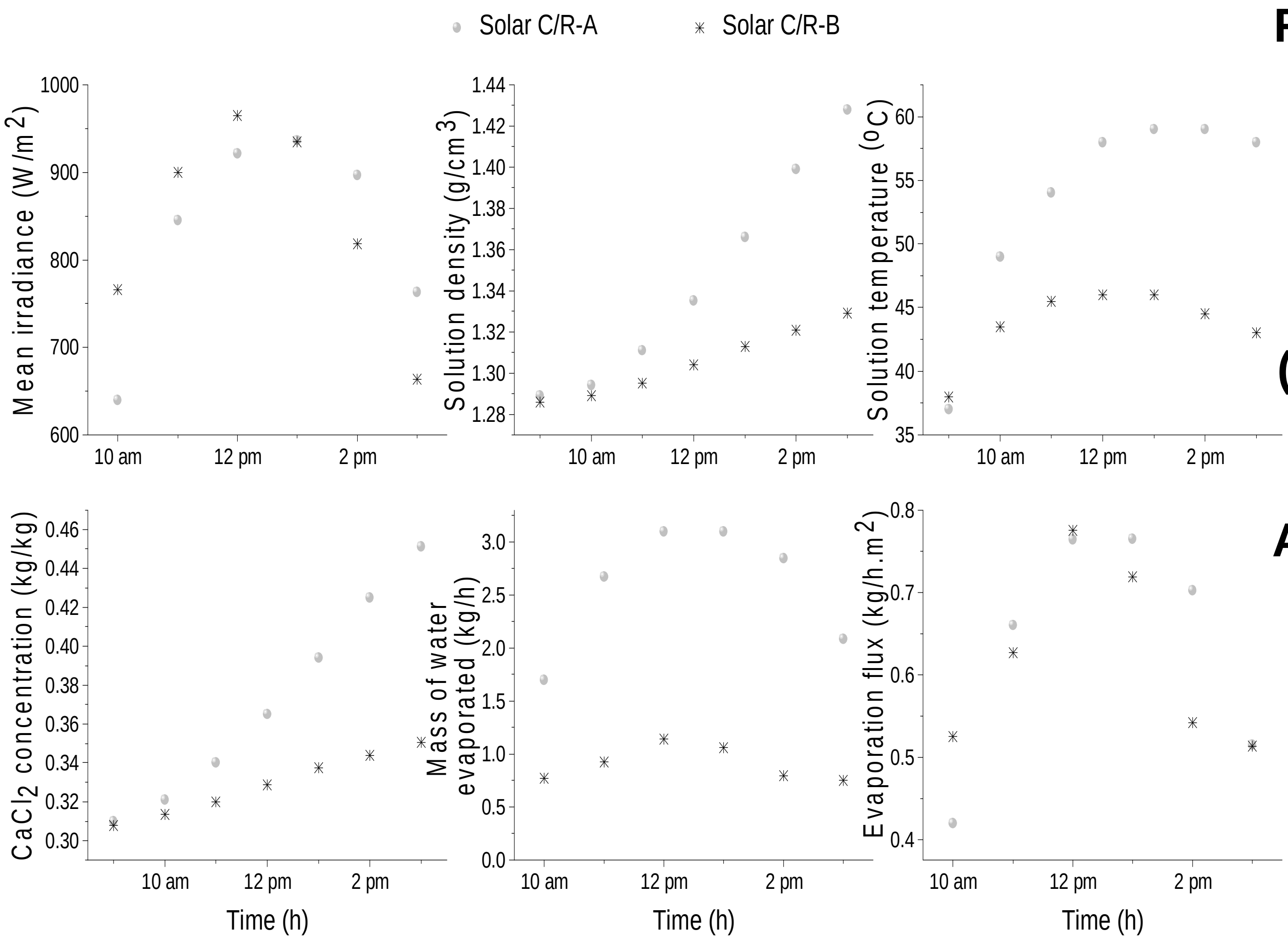


Ratio of m_{total} evaporated from CR-A/ CR-B
=10.3 kg/ 4 kg =2.57

Ratio of area of CR- A ($4m^2$)/area CR-B ($1.47m^2$)
=2.75

Average evaporation flux from:
I) solar CR-A
=0.42 kg/m^2.h
II) solar CR-B
=0.45 kg/m^2.h

Effect of solar C/R size ($CaCl_2$)



Ratio of m_{total} evaporated from CR-A/ CR-B =15.4 kg/ 5.4 kg =2.85

Ratio of area of CR-A ($4m^2$)/area CR-B ($1.47m^2$) =2.75

Average evaporation flux from:

I) solar CR-A =0.63 $kg/m^2.h$

II) solar CR-B =0.61 $kg/m^2.h$

Solar C/R area for unit cooling load

Cooling load

- Cooling load is same as energy of evaporation:

$$Q_o = \frac{Q_{eva}}{\Delta t} = \frac{m_{v,\Delta t}\left(2551 + \Delta h_d\right)}{\Delta t}$$

$$= A_{ab}\, m''\left(2551 + \Delta h_d\right)$$

Absorber area for cooling load

- The absorber area for any cooling load is given by

$$A_{ab} = \frac{Q_o}{m''\left(2551 + \Delta h_d\right)} = \frac{Q_o}{\eta_{CR} * I}$$

Absorber area for unit cooling load

Day average performance for regeneration of LiCl at concentration of 0.4 using solar C/R-A (4 m^2) in the month of May were

$I = 0.754$ kW/m^2

$\eta_{CR}=0.46$

m"=0.45 kg/h.m^2

hfg=(2551+Δh_d)=2808.5 kJ/kg

- Thus, the absorber area for unit cooling load is

$$A_{ab} = \frac{Q_o}{m''\left(2551+\Delta h_d\right)}$$

$$= \frac{3.52\,kW}{0.46 * 0.754\,kW / sq.m}$$

$$= 10.0\ sq.m$$

Conclusions

Solar C/R-B (1.47 m^2)

- For regenerating of lithium chloride solution, the day average vapor flux were found to be
  - 0.67 kg/h.m^2 low concentration (0.29-0.36),
  - 0.41 kg/h.m^2 medium concentration (0.36-0.41) and
  - 0.33 kg/h.m^2 high concentration (0.41 - 0.48) .
- For regeneration of calcium chloride solution, the day average evaporation flux of water was found to be
  - 0.63 kg/h.m^2 low concentration (0.30-0.35),
  - 0.45 kg/h.m^2 medium concentration (0.36 - 0.41) and
  - 0.37 kg/h.m^2 high concentration (0.41-0.48).

Conclusions (cont.)

Solar C/R- A (4.0 m^2)

- The day average evaporation flux of water for regeneration of
  - LiCl solution was 0.45 kg/h.m^2 (for concentration range 0.33-0.46)
  - CaCl2 solutions was 0.60 kg/h.m^2 (for concentration range 0.31-0.47)

Comparison of solar C/R-A with C/R-B

- The water evaporation per unit absorber area was found to be independent of C/R size for similar level of irradiance and initial desiccant concentration (for both LiCl and $CaCl_2$ solutions).

Conclusions (cont.)

Absorber area for a unit cooling load

- 10.2 m^2 solar C/R is needed for operating unit cooling load of a desiccant cooling system (at lithium chloride concentration of 0.4 in May).

Acknowledgement

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Thank for your attention.