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SOLAR THERMAL ENERGY RESEARCH GROUP

Design and performance evaluation of a HYDROSOL space heating and cooling system

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Overview

1. Background and motivation
2. Project objectives
3. System design and modelling
4. System operation
5. Preliminary results
6. Conclusion

Background & Motivation

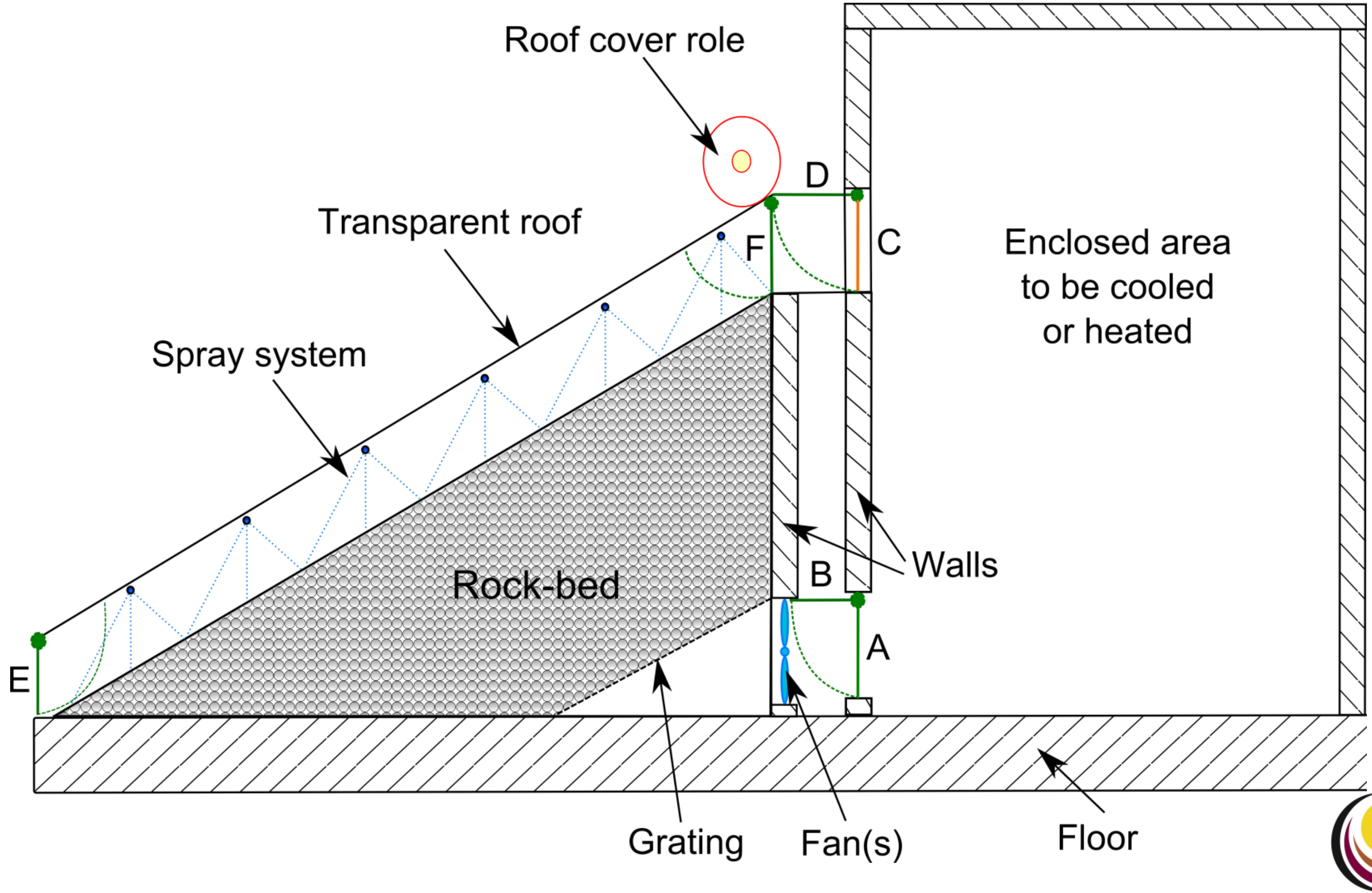
- HYDro, ROck & SOLar (HYDROSOL)
- Conventional space heating and cooling systems are expensive to operate
- HYDROSOL is a combined solar air heater and evaporative cooler
- Rock, solar heat and to a lesser degree water are available in most places in South-Africa
- Wide expected range of applications (poultry farms, offices, shopping centres, warehouses etc.)

Project objectives

- Main objective is to design and build a cost effective, sustainable system used for space heating (solar) and/or cooling (evaporative and/or convective cooling)
- Verify numerical results with experimental data
- Identify suitable applications for use
- Control and operate the HYDROSOL system to meet the demand for specific applications

System design

- Practical concept



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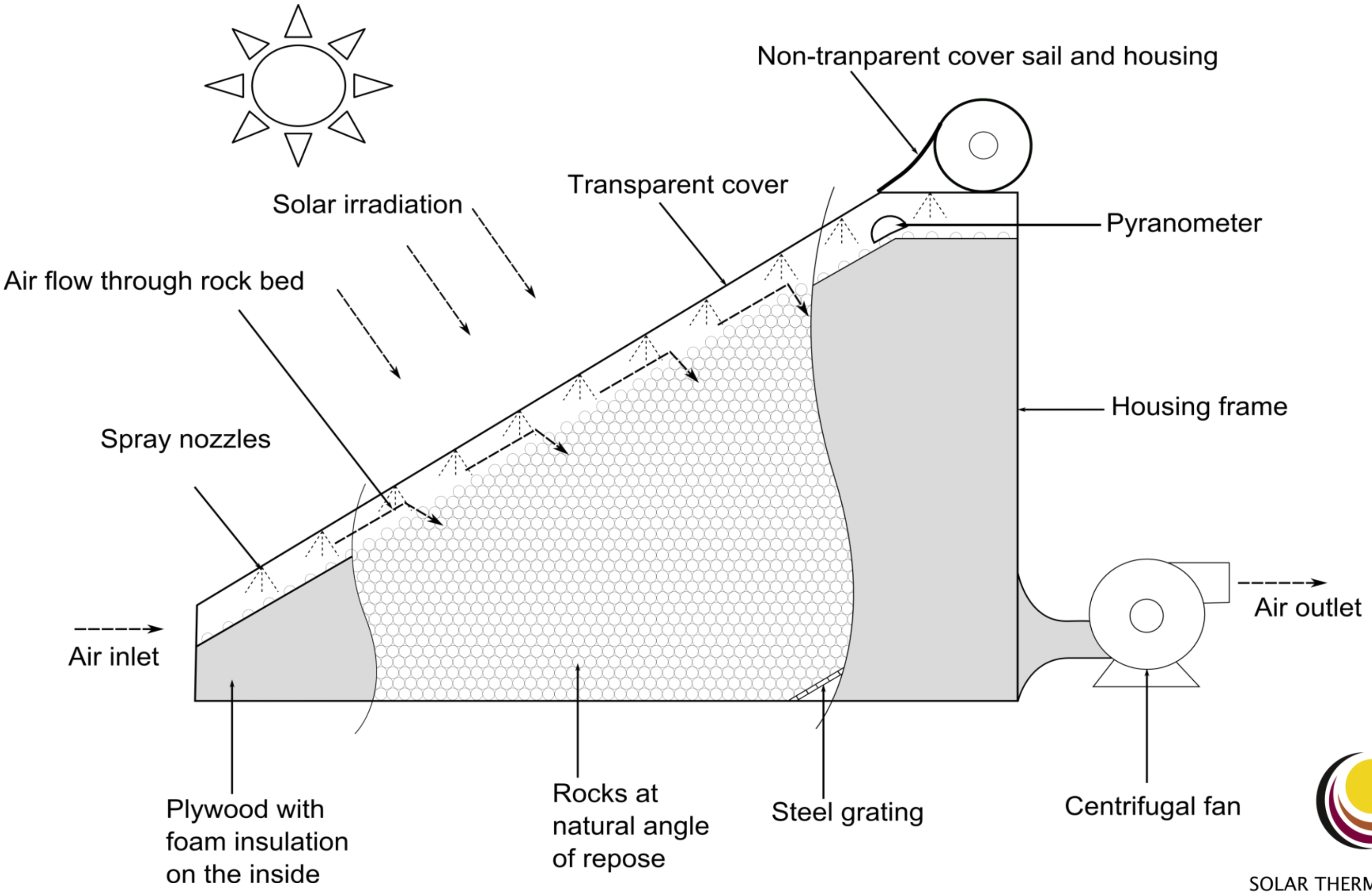
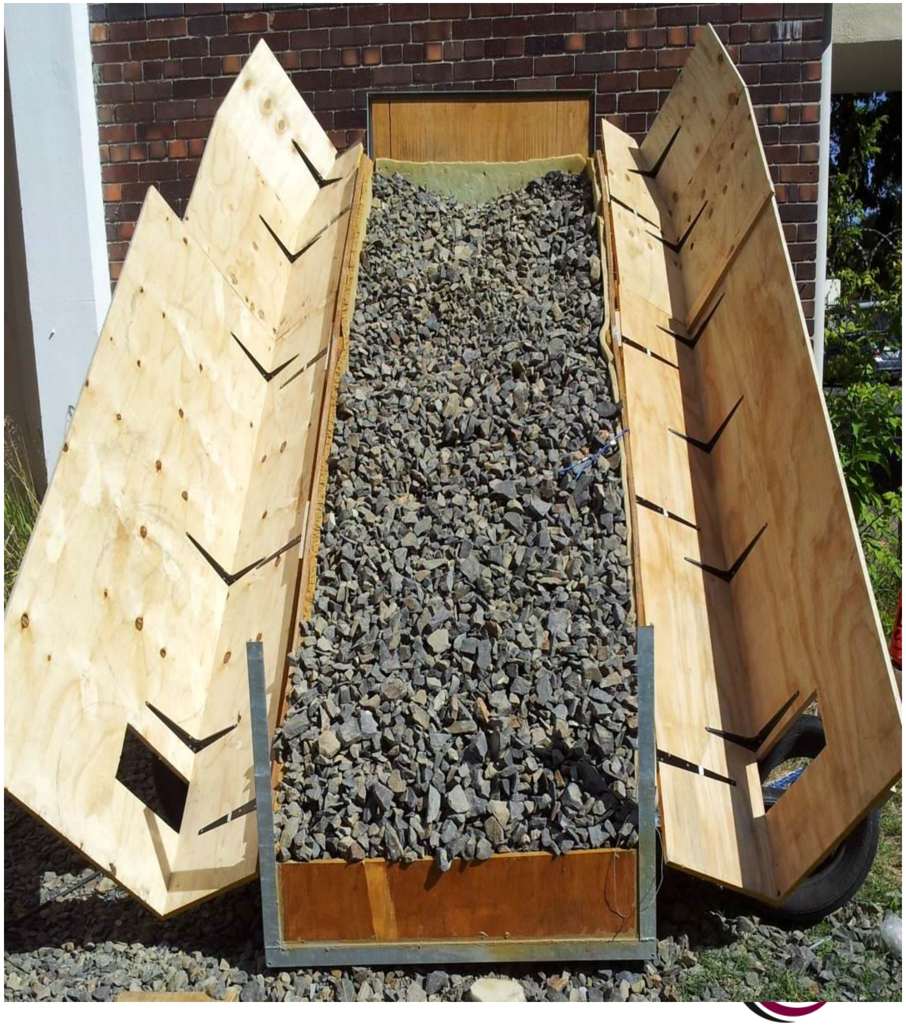
System design

- Scale model



System design

- Scale model concept



Design parameters

- Rocks modelled as spheres with volume-equivalent diameter

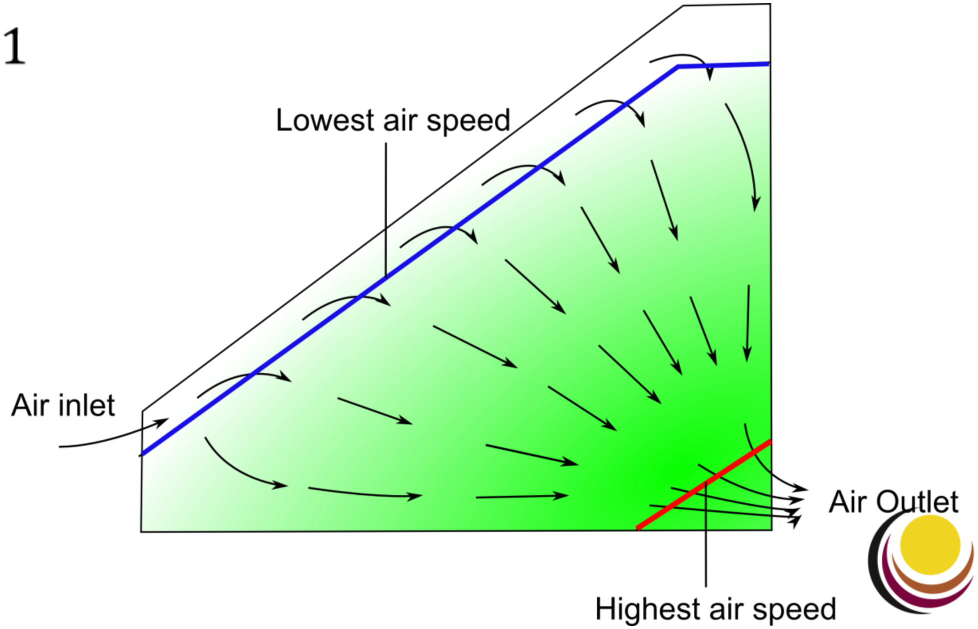
$$D_v = \left[\frac{6}{\pi}\left(\frac{1}{n}\sum_{i=1}^{n} V_{pi}\right)\right]^{1/3}$$

- Internal particle resistance neglected at small Biot numbers

$$Bi = \frac{hD_v}{2k_p} < 0.1$$

- Mass flow rate of air

$$m = \rho A_{cs} v_s$$



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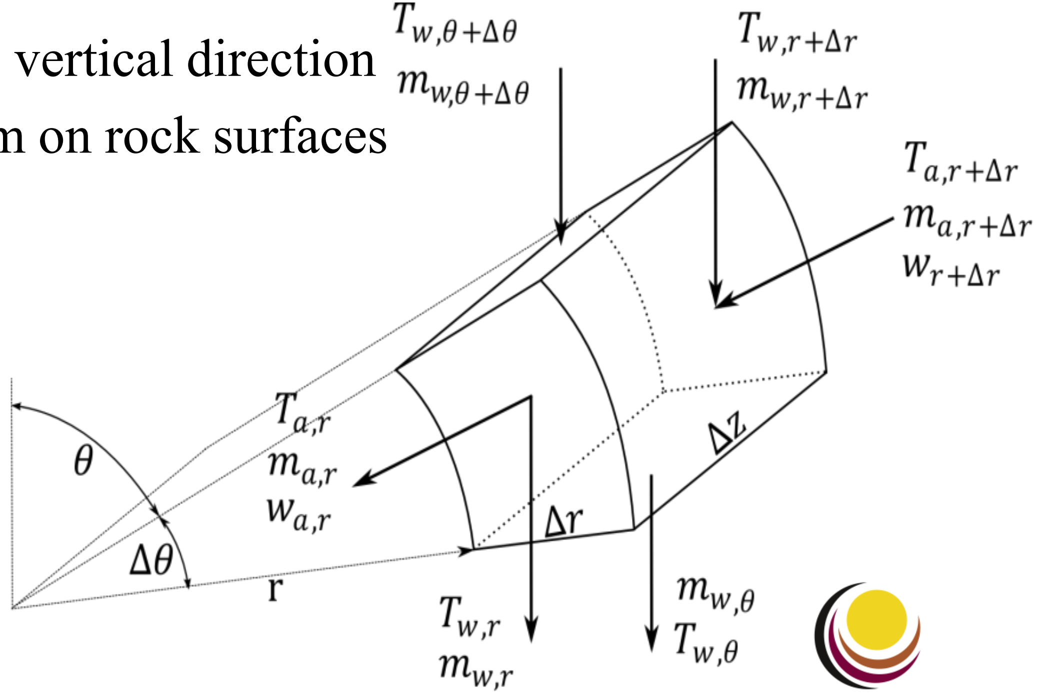
Model assumptions

- Rock bed modelled as a quarter annulus
- Wall effects neglected
- Radiation & conduction between particles are neglected
- No temperature gradient within solid particles
- Air flows only in the radial direction
- Water flows only in the vertical direction
- Infinitely thin water film on rock surfaces



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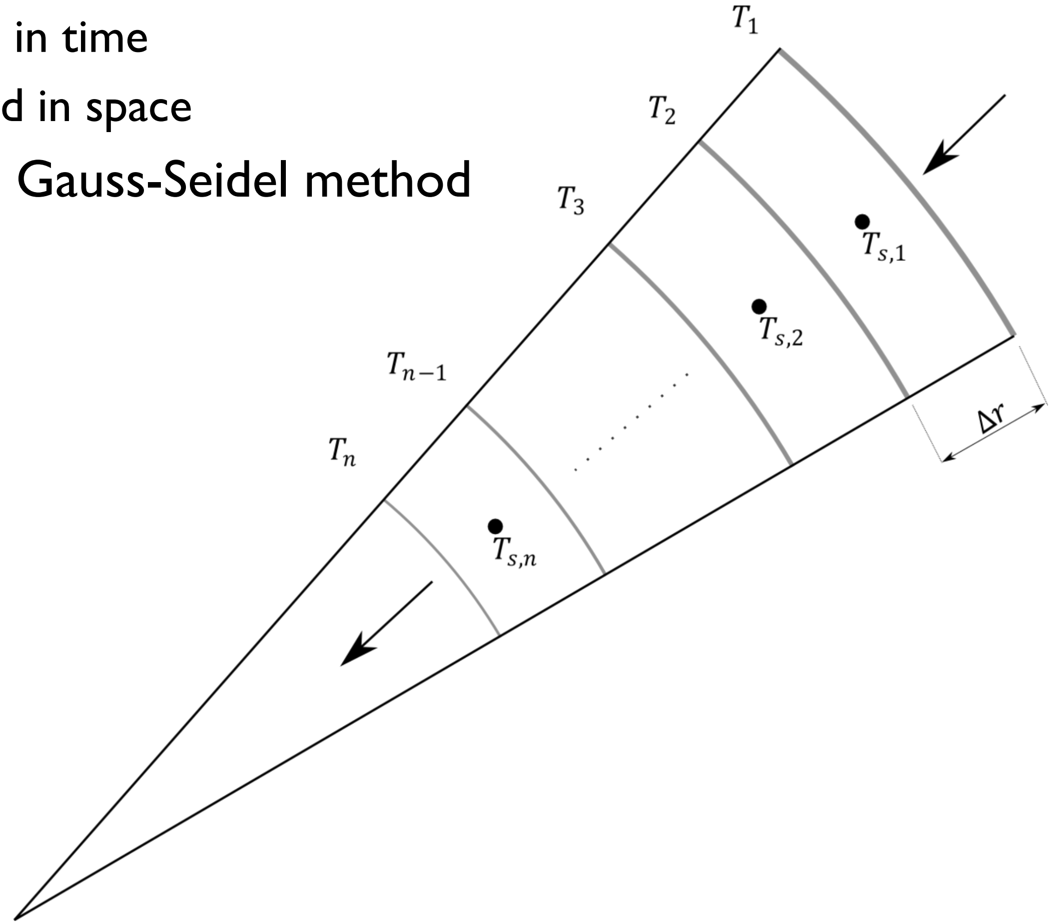
Numerical Approach

- First order upwind scheme
  - Forward in time
  - Backward in space
- Solved with Gauss-Seidel method

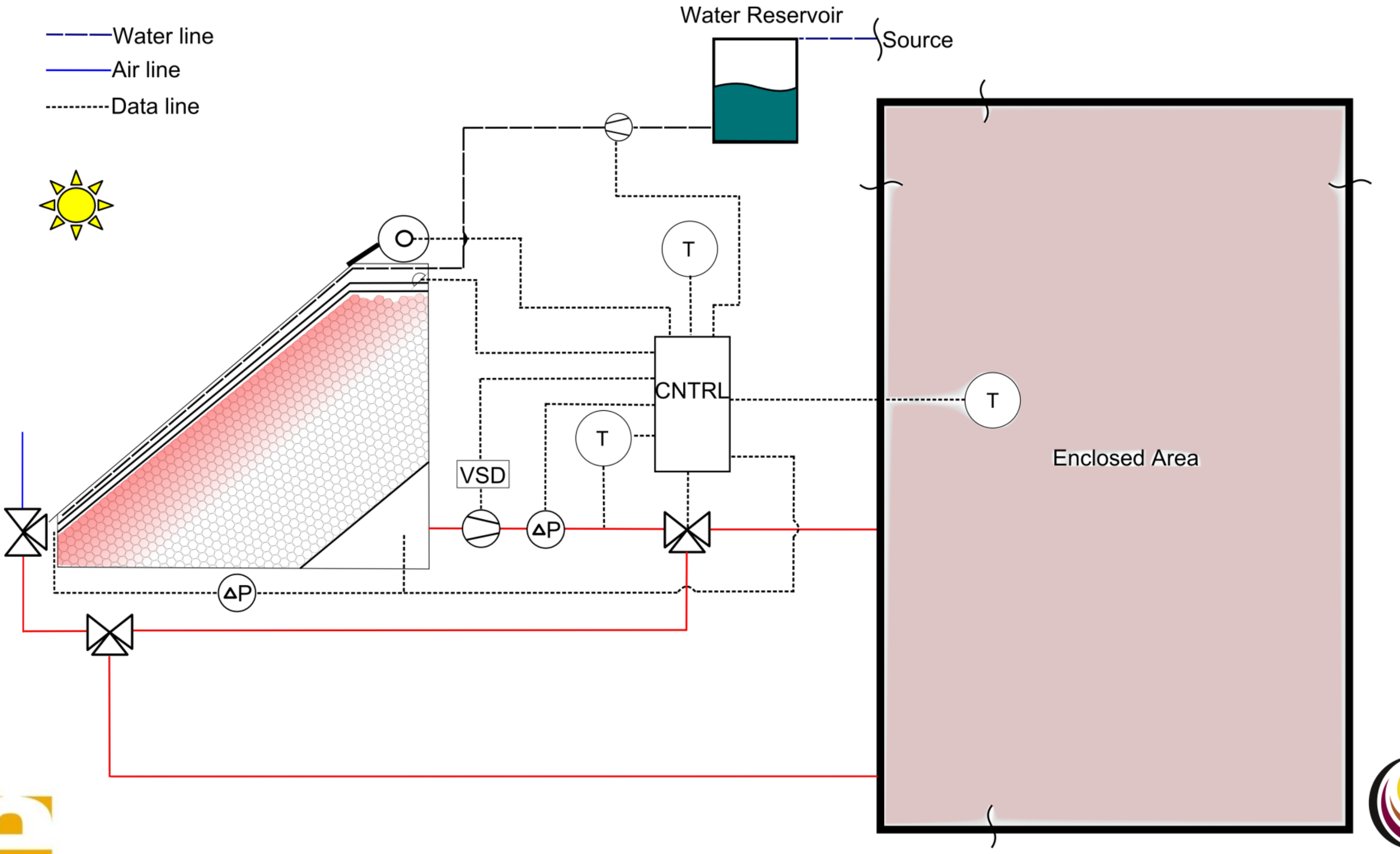


System operation

- Three basic modes of operation
  - Heating (solar)
  - Cooling (convective)
  - Cooling (evaporative/convective)

System operation

- Heating (solar)



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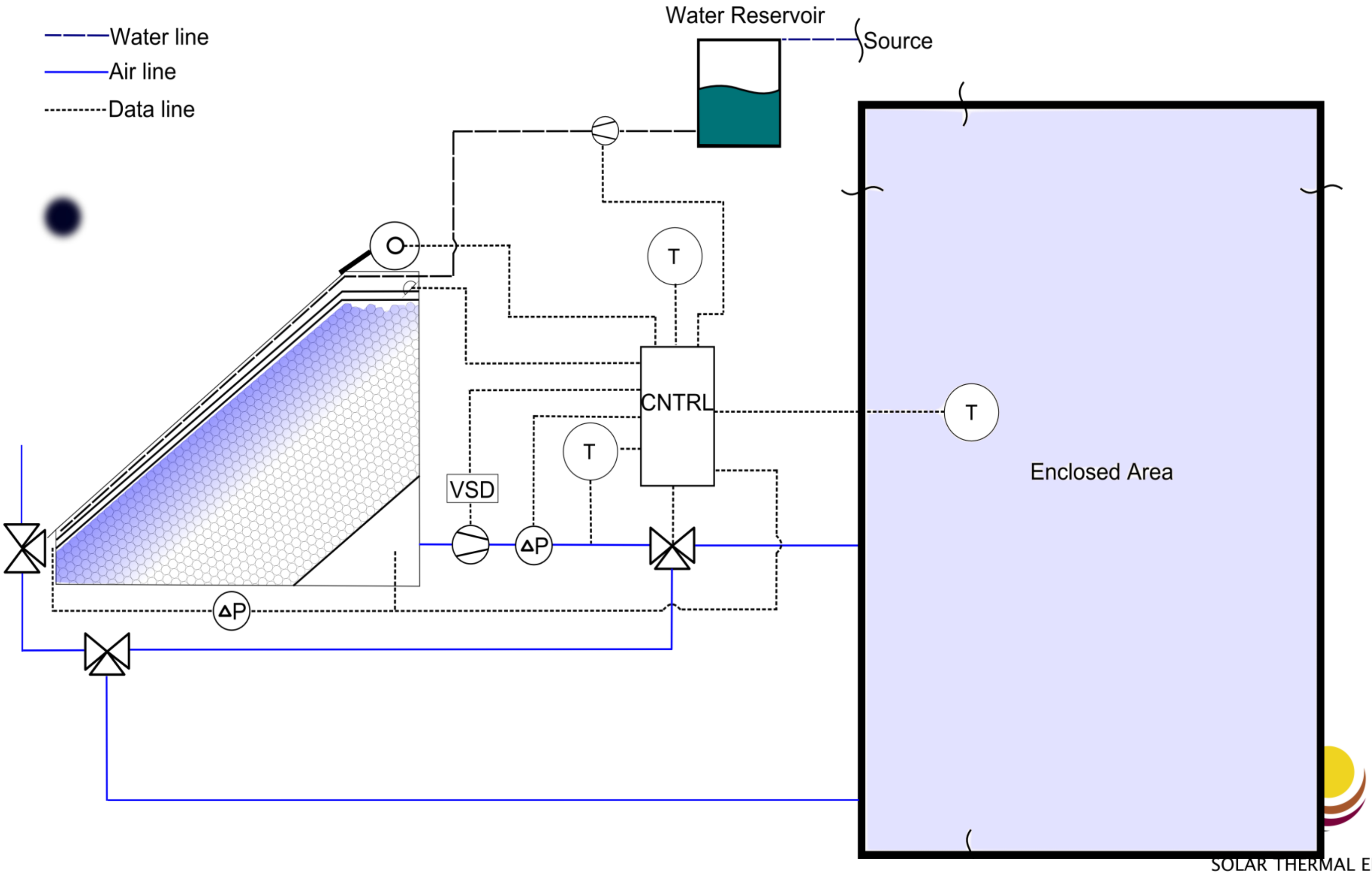
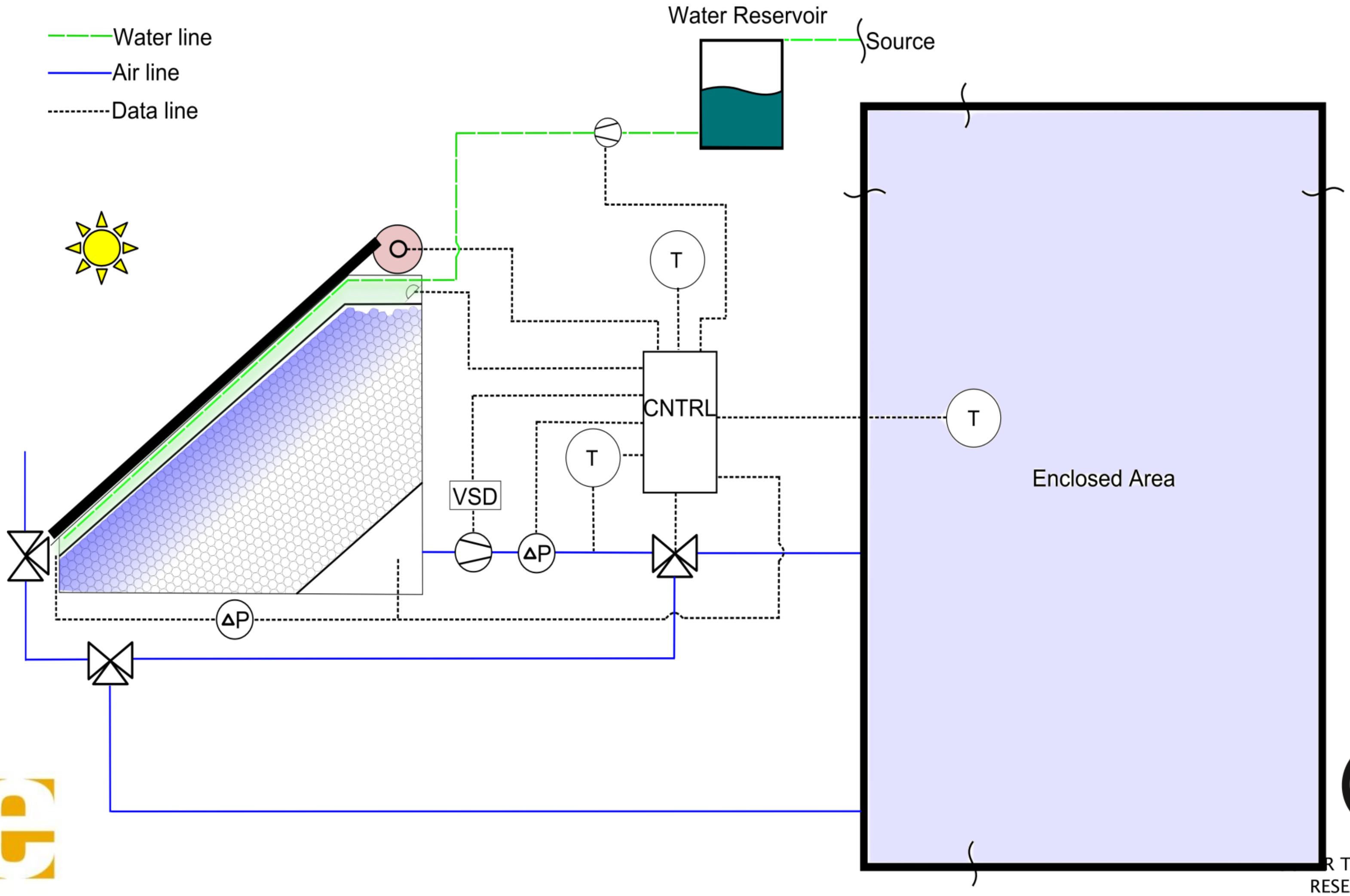
System operation

- Cooling (convective)



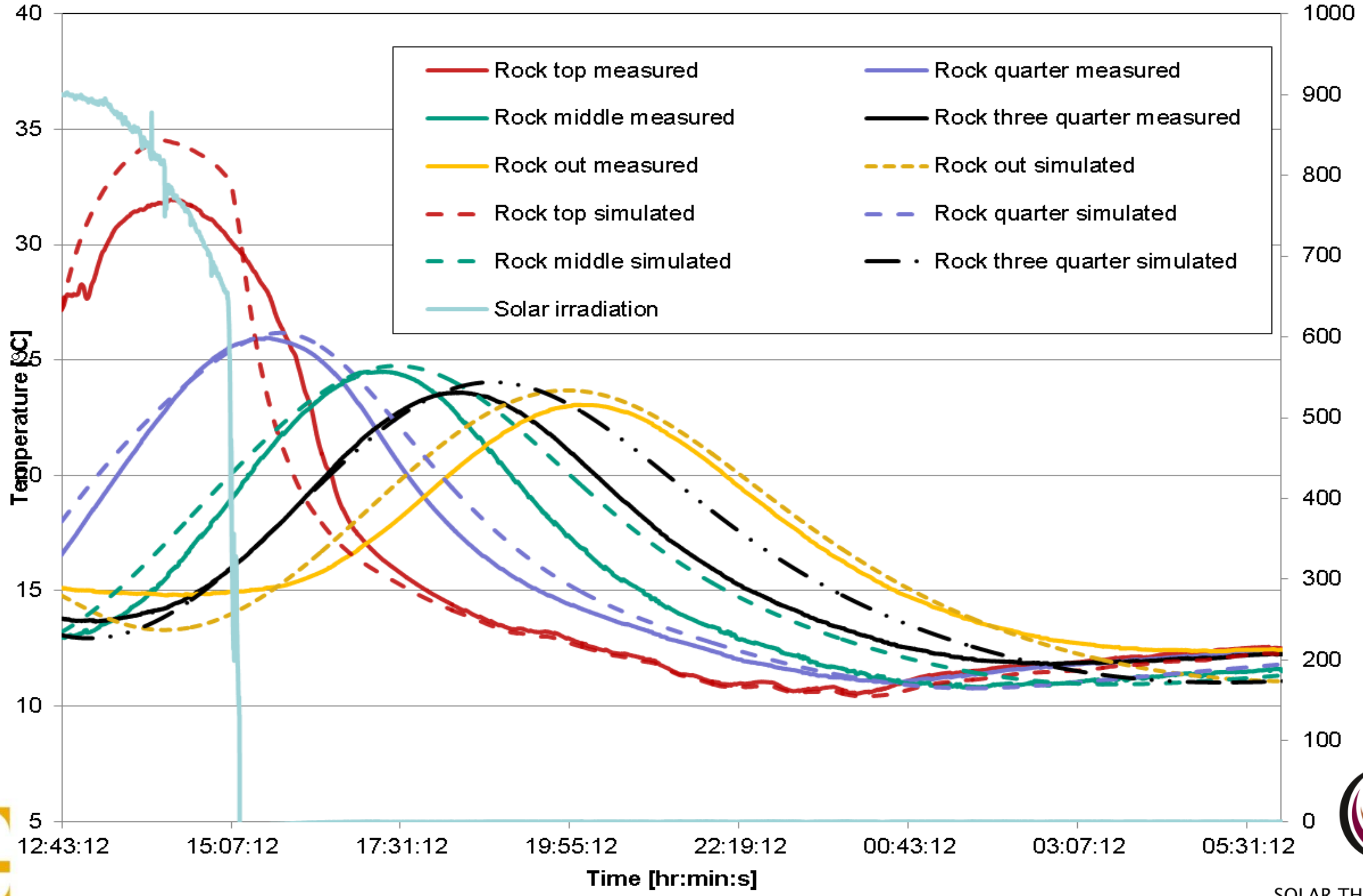
System operation

- Cooling (evaporative/convective)



Preliminary results

- Comparison between predicted and measured rock temperatures



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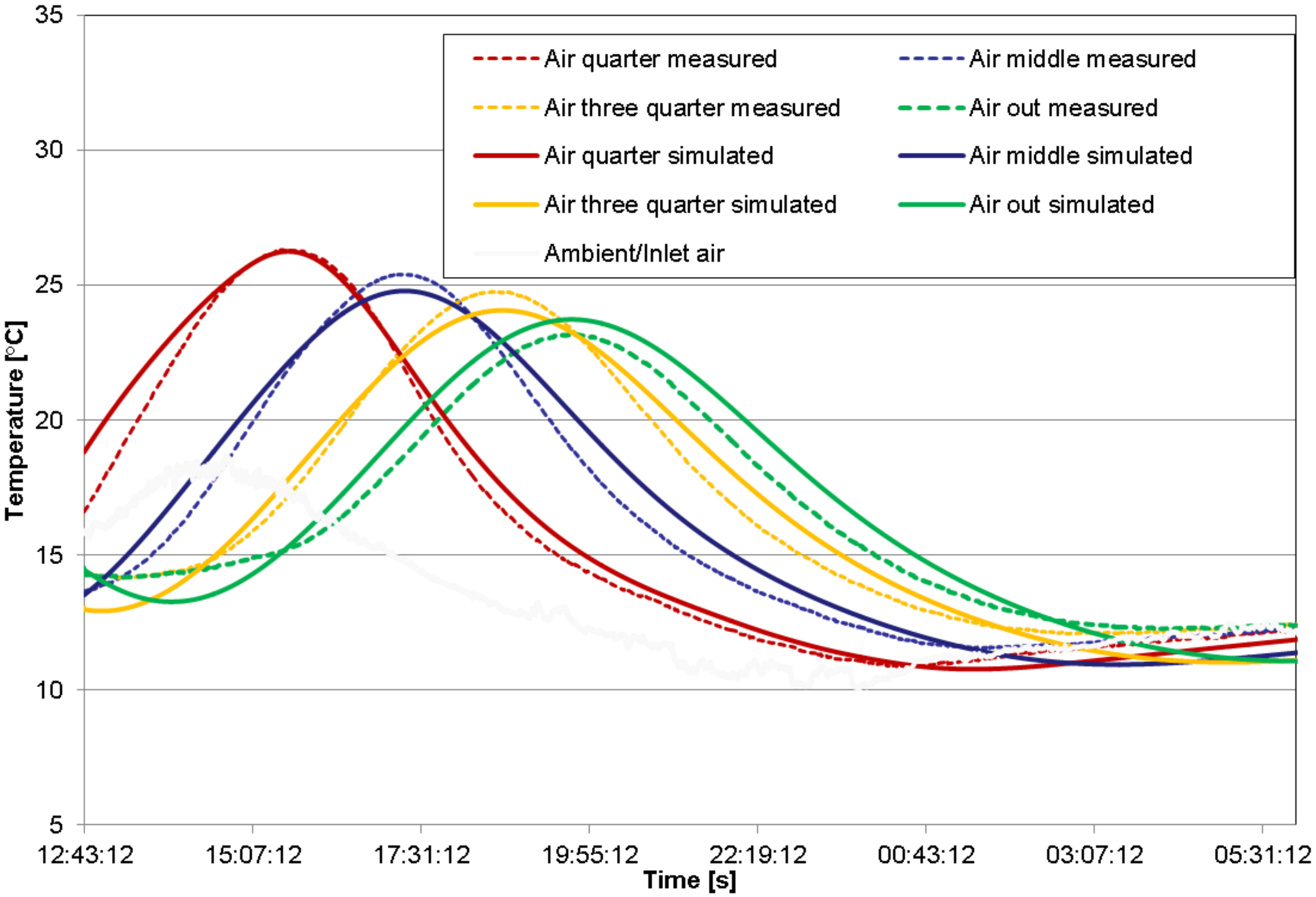
Preliminary results

- Comparison between predicted and measured air temperatures



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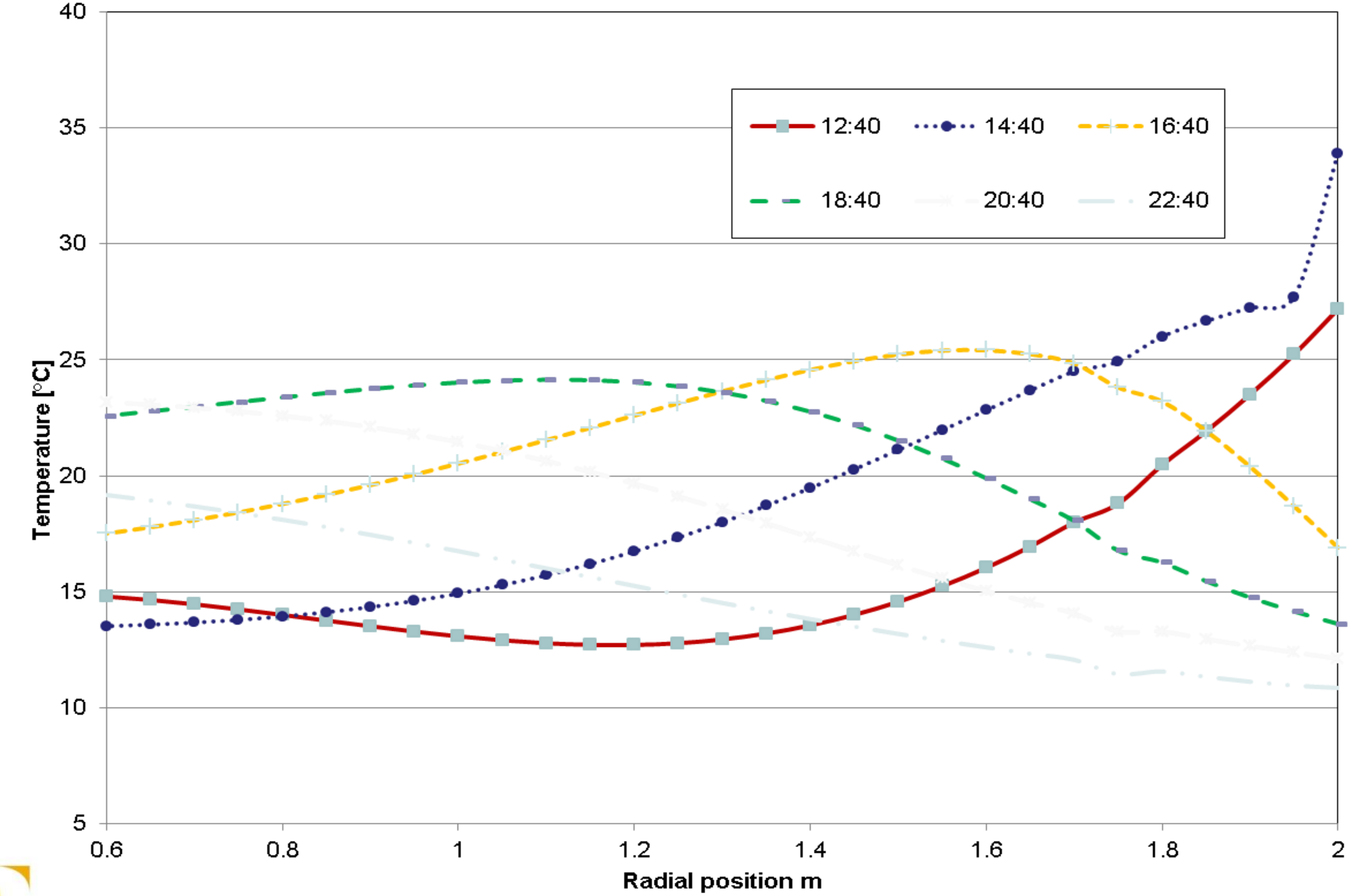
Preliminary results

- Radial temperature distribution of rock



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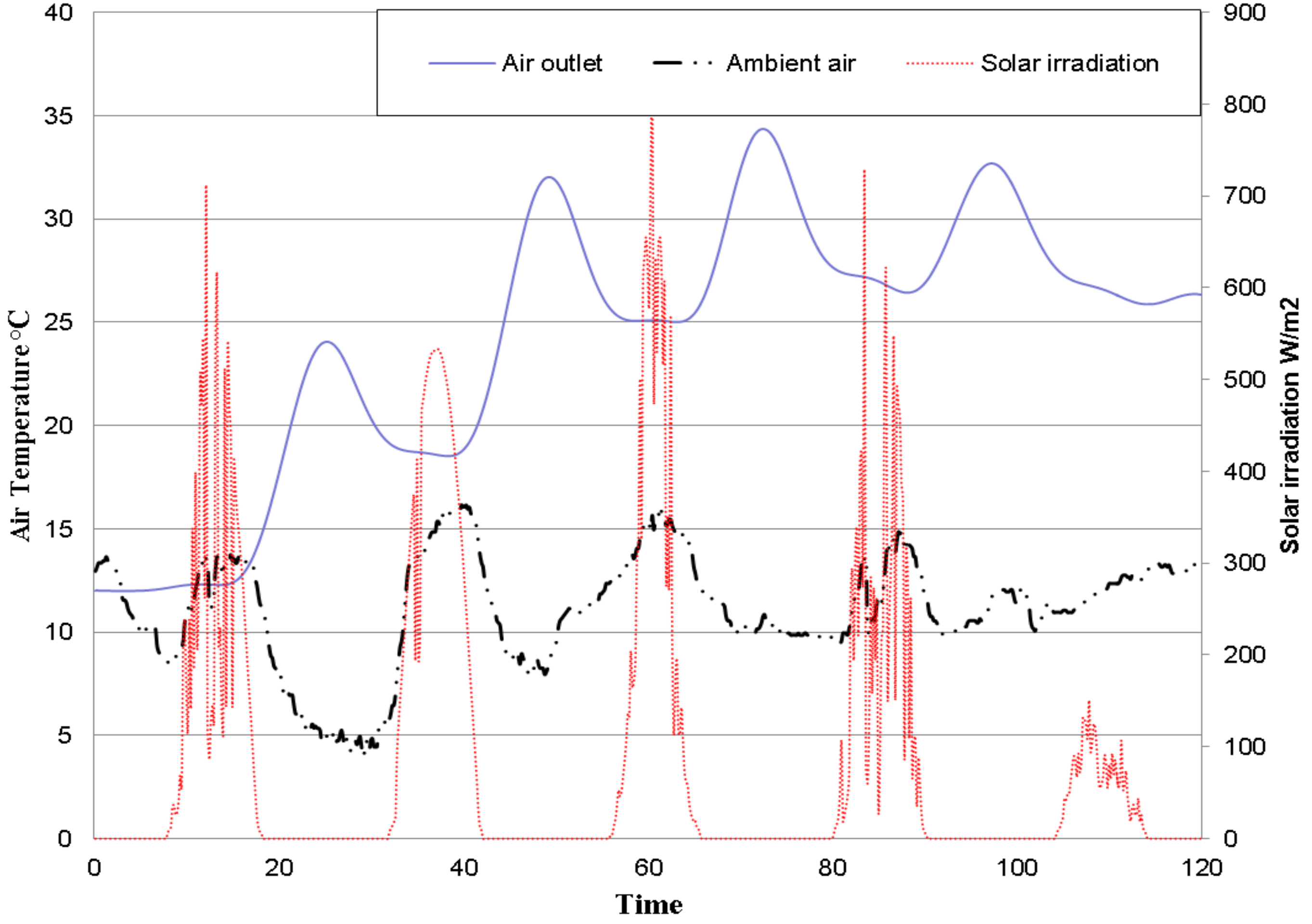
Preliminary results

- 100% Positive charge during winter



Conclusion

- Preliminary results look promising
- Trends between measurements and predictions correlate fairly well
- Prototype for heating cycle was successfully built while modifications for wet cooling still needs to be implemented
- Testing still in progress!

Acknowledgements:

CRSES

University of Stellenbosch

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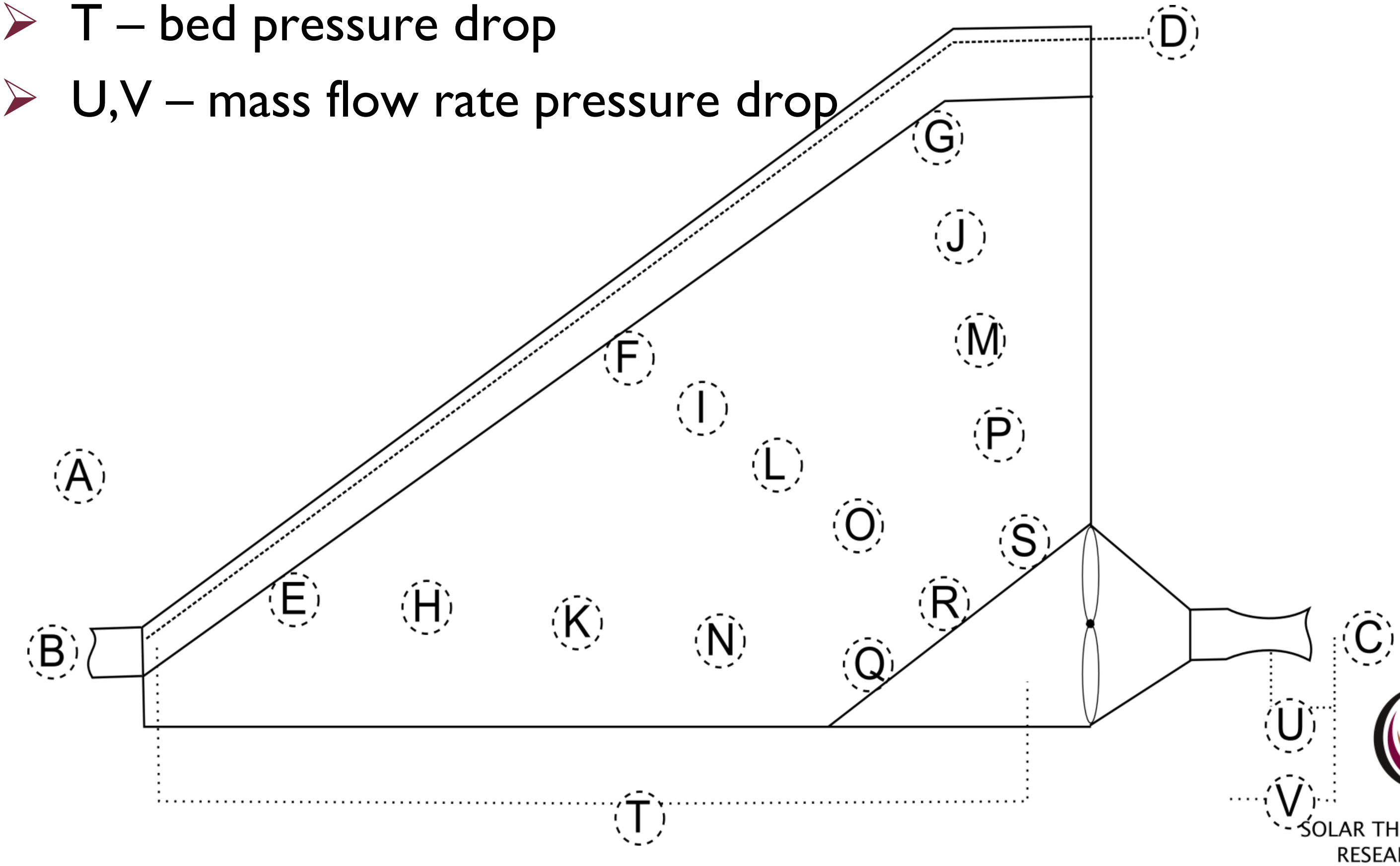
Appendix

- A,B,C – 2x wet-bulb, 2x dry-bulb temperature
- D – water temperature
- E-S – 2x solid-, 2x air temperature
- T – bed pressure drop
- U,V – mass flow rate pressure drop



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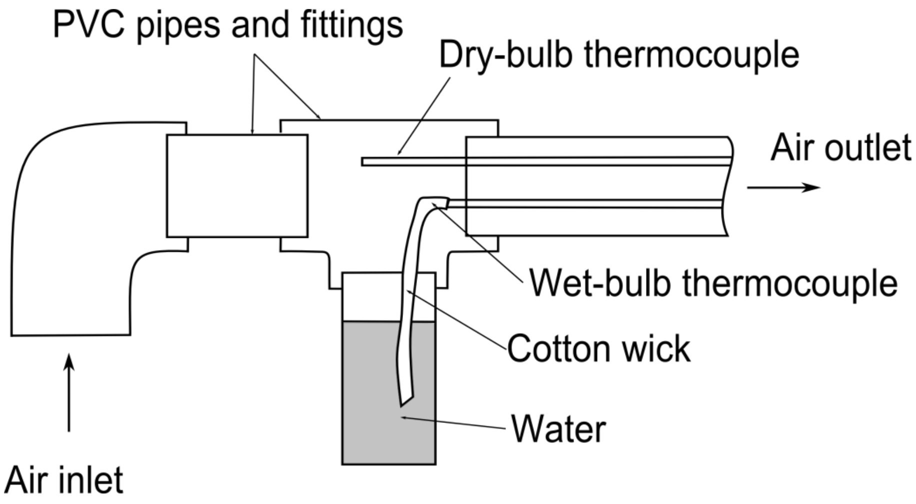
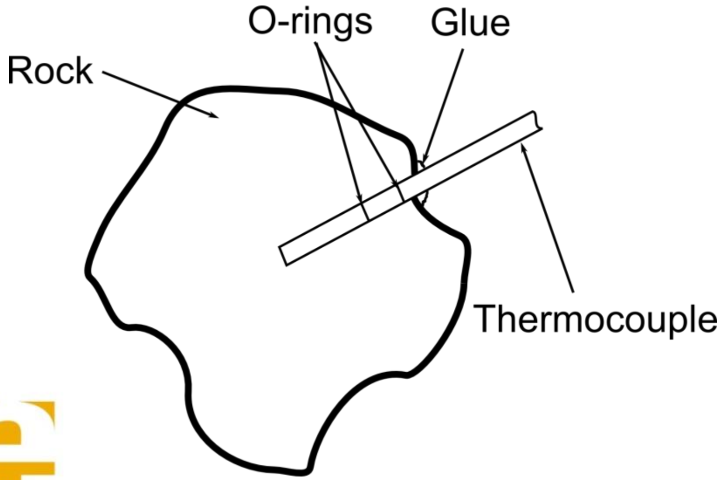
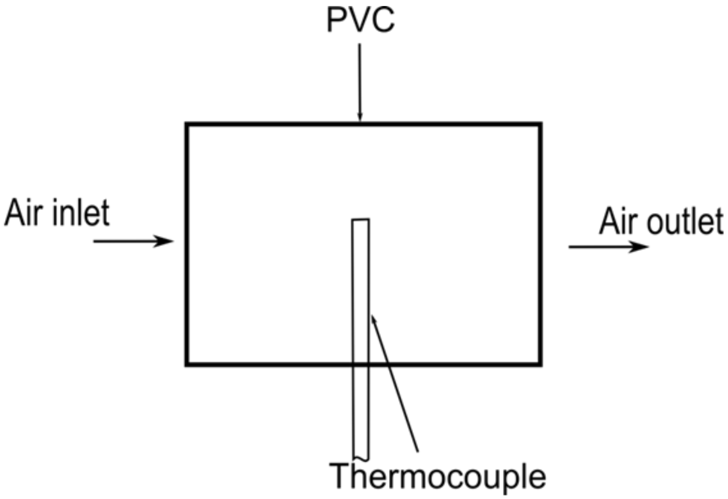
Appendix


PVC pipes and fittings
Dry-bulb thermocouple
Air outlet
Wet-bulb thermocouple
Cotton wick
Water
Air inlet


O-rings
Glue
Rock
Thermocouple

Appendix



PVC

Air inlet

Air outlet

Thermocouple

$$\dot{m}_f = C_n \phi_g Y A_n \left(2\rho_n \Delta p_n\right)^{0.5}$$

A_n – *nozzle cross sectional area*
Δp_n – *pressure drop over nozzle*
ϕ_g – *gas expansion factor*
C_n – *discharge coefficient*

Appendix

- Rock bed specifications
  - Air tight
  - Natural angle of repose
  - Sides, bottom and back insulated
  - Foam inside walls to reduce wall effects
  - Bed dimensions 2.5 x 2 x 1.22 m (Length x Height x Width)

Rock hornfells		**Cover**	
Density	2495 kg/m^3	Material	PETG
Void fraction	0.4	Transmis-sivity	0.87
Specific heat	820 J/kgK		

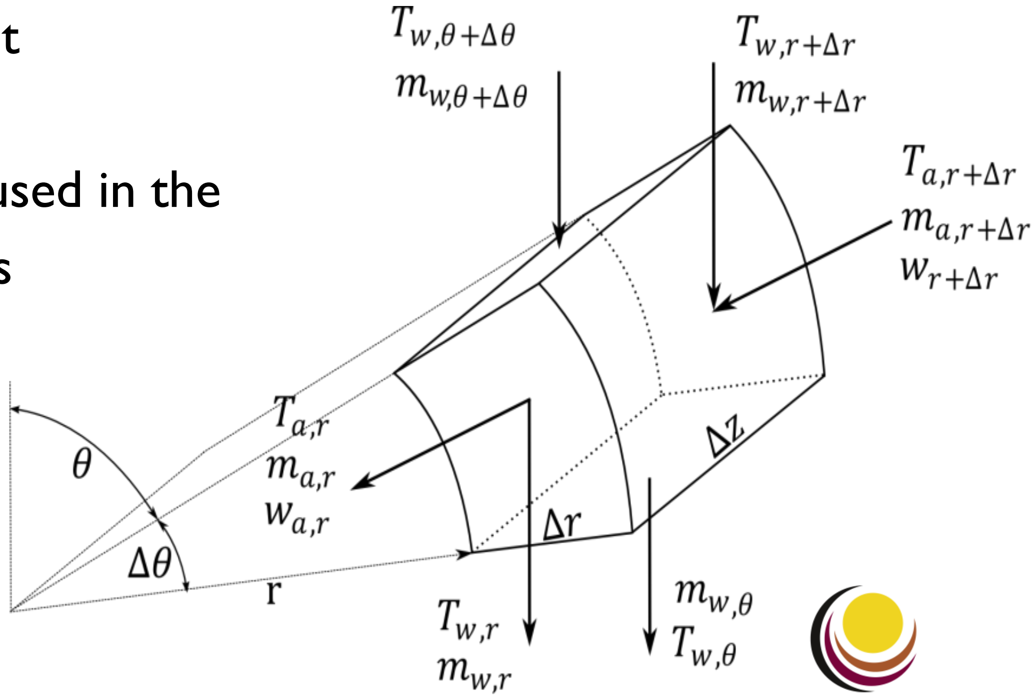
Design parameters

- Wakao et al. (1979) present appropriate correlation for heat transfer coefficient

$$h = 2 + 1.1Re_{pv}^{0.6}Pr^{1/3}$$

- Analogy between heat and mass transfer used to determine mass transfer coefficient

- These parameters are used in the the governing equations



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Design parameters

- Rocks modelled as spheres with volume-equivalent diameters

$$D_v = \left[\frac{6}{\pi}\left(\frac{1}{n}\sum_{i=1}^{n} V_{pi}\ \right)\right]^{1/3}$$

- Particle Reynolds number defined with this diameter

$$Re_{pv} = Re_v(1-\epsilon) = \frac{\rho v_s D_v}{\mu}$$

- Internal particle resistance neglected at small Biot numbers

$$Bi = \frac{hD_v}{2k_p} < 0.1$$