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UNIVERSITY OF PRETORIA

Solar thermal power generation using the Brayton cycle

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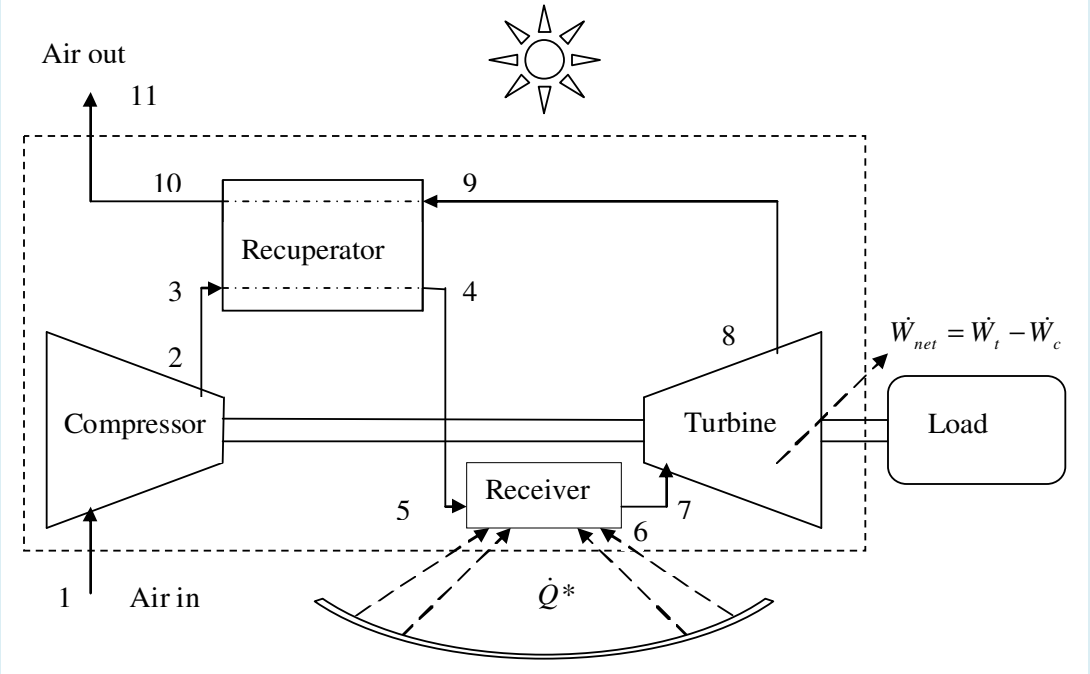
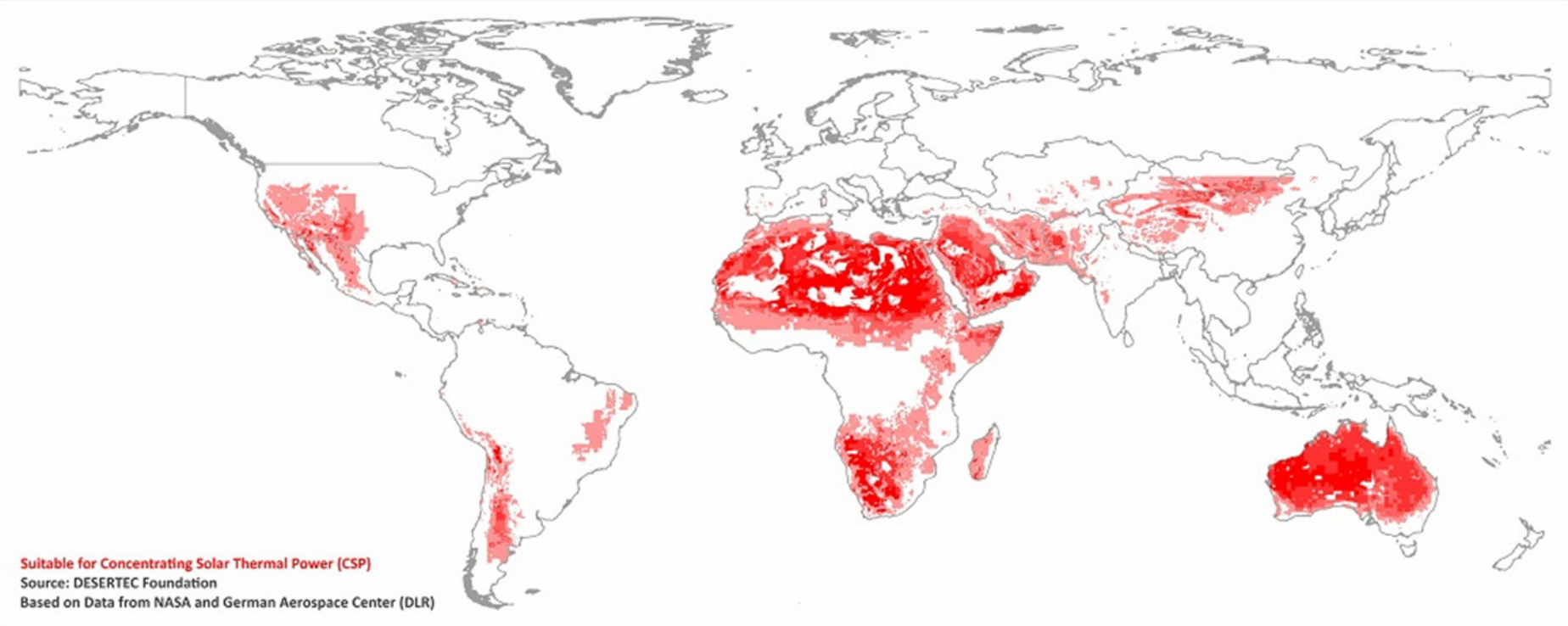
Scope of research – Thermodynamic optimisation

- Open and direct solar thermal Brayton cycle
- Second Law of Thermodynamics
- Entropy Generation Minimisation
- Maximise net power output
- Optimise geometry of recuperator and receiver
- Heat Transfer & Fluid Flow Irreversibilities
- Prof. J.P. Meyer (Head of Department) and prof. Bello-Ochende as study leaders

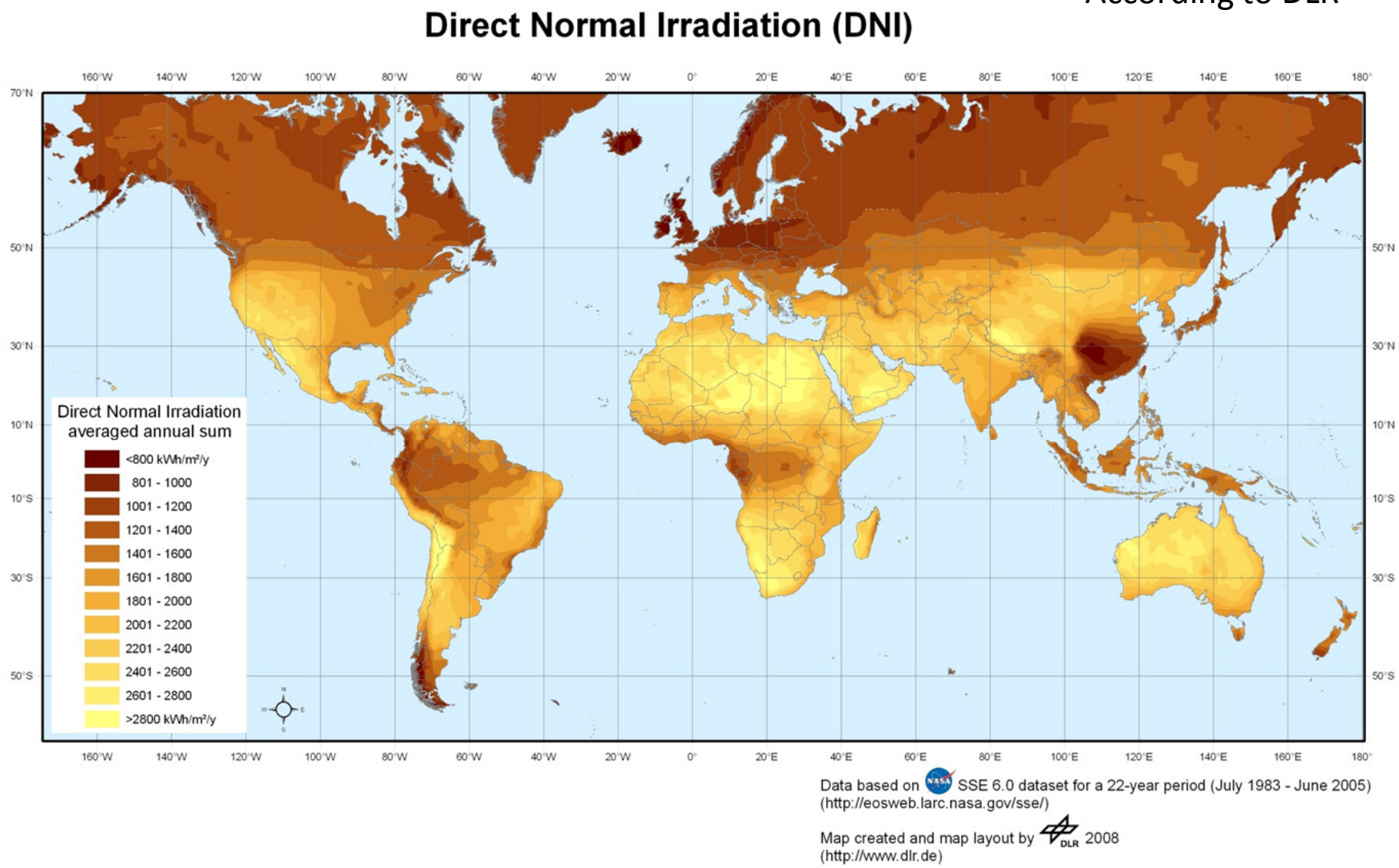


Solar resource – South Africa
Why Solar?

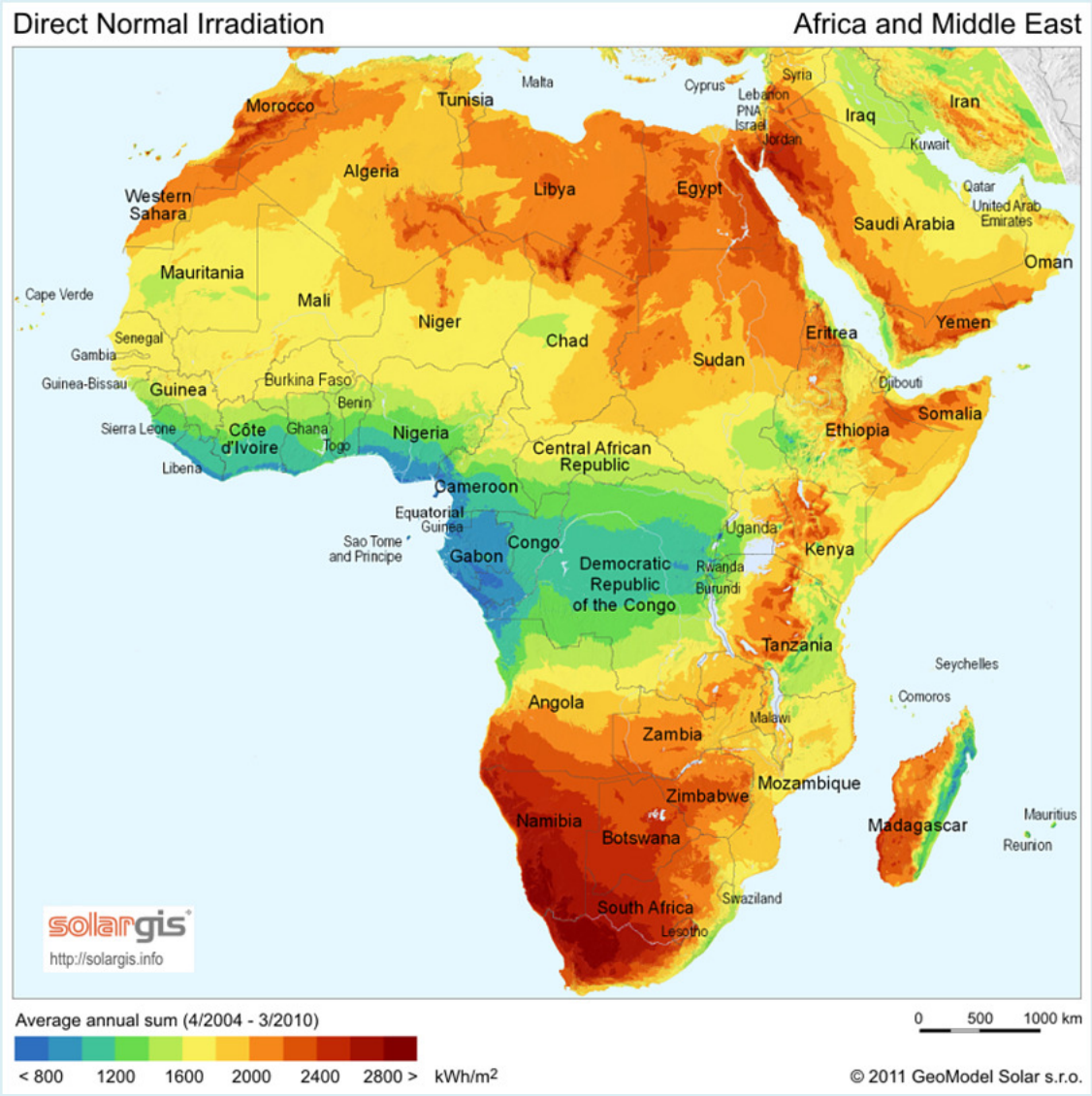


Solar resource - World

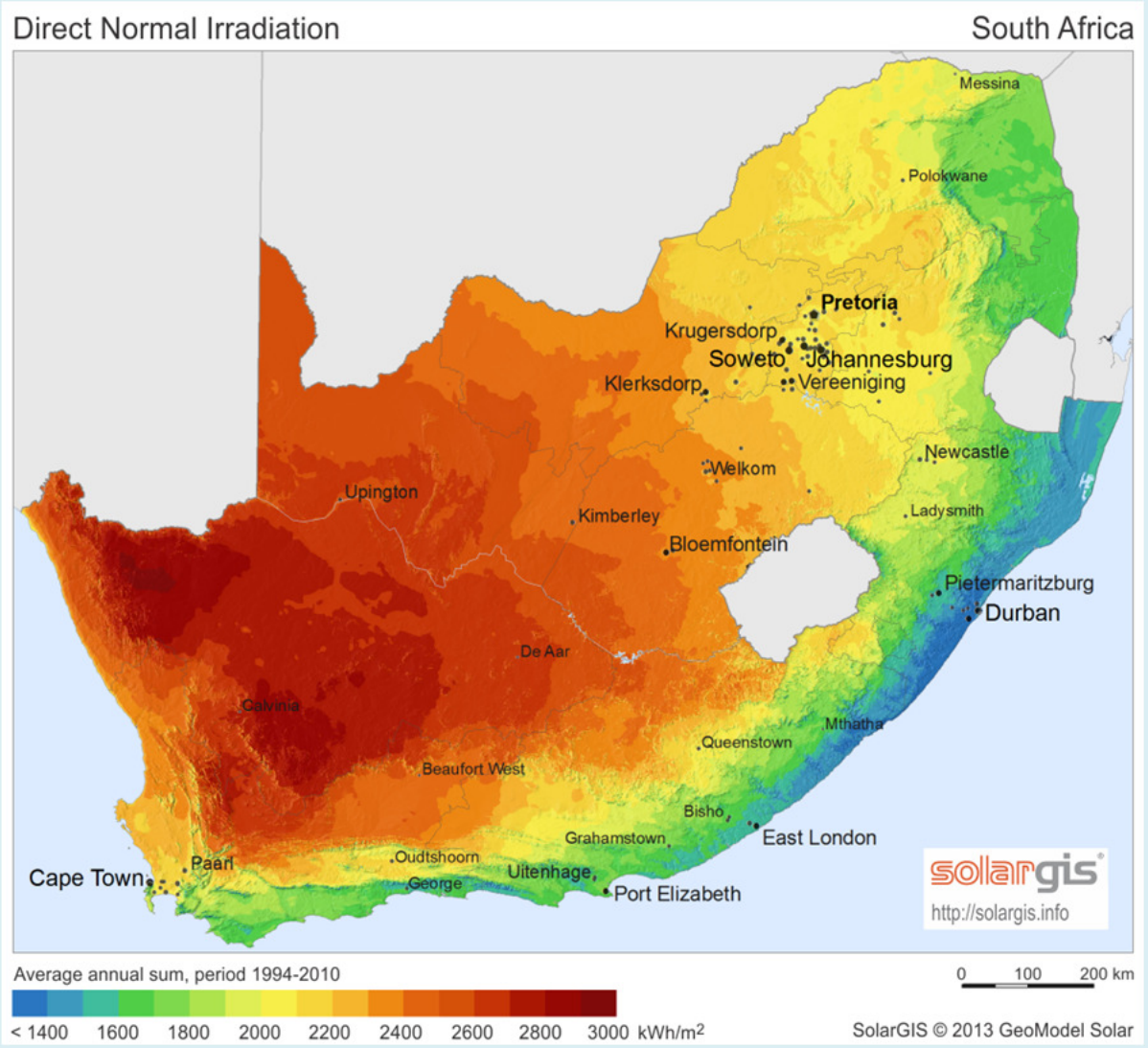
- According to DLR



Solar resource – South Africa
Why Solar?

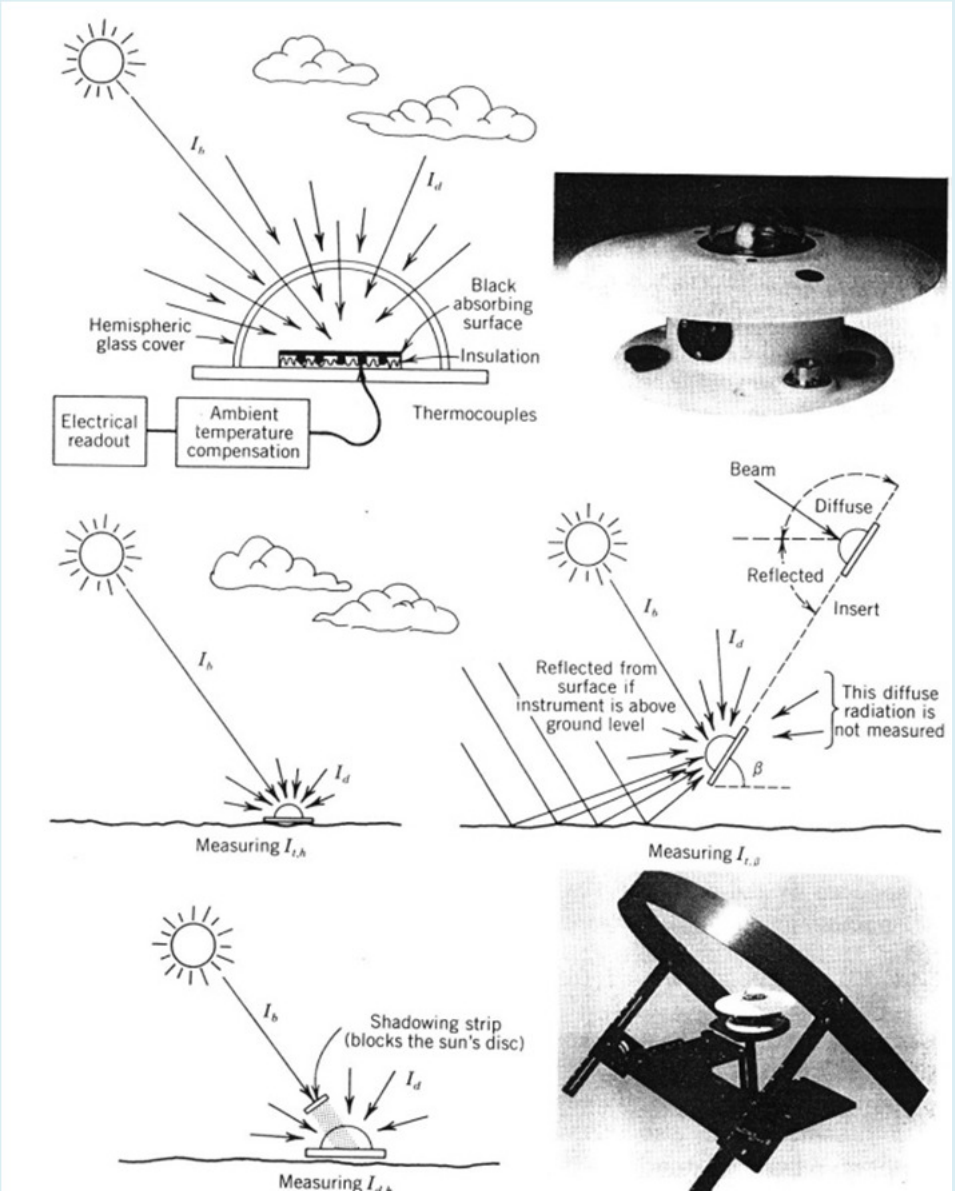


The Department of Minerals and Energy places South Africa's annual direct normal irradiation (DNI) between 2 500kWh/m2 and 2 900 kWh/m2 with an average of almost 300 days of sunshine per year.

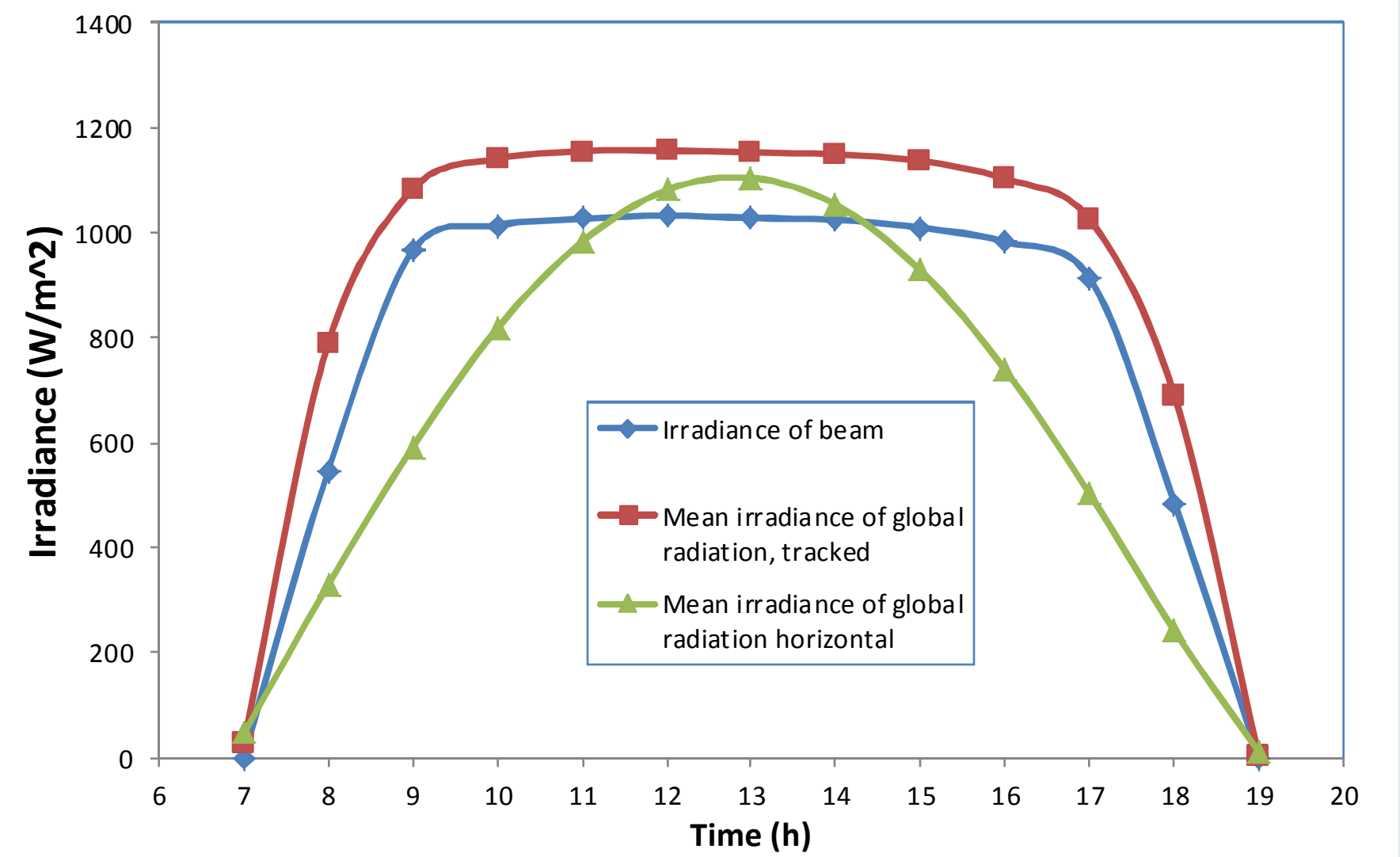


Solar resource - Pyranometer

- According to Stine and Geyer (2001)
- Global horisontal irradiance
- Pyrheliometer measures DNI



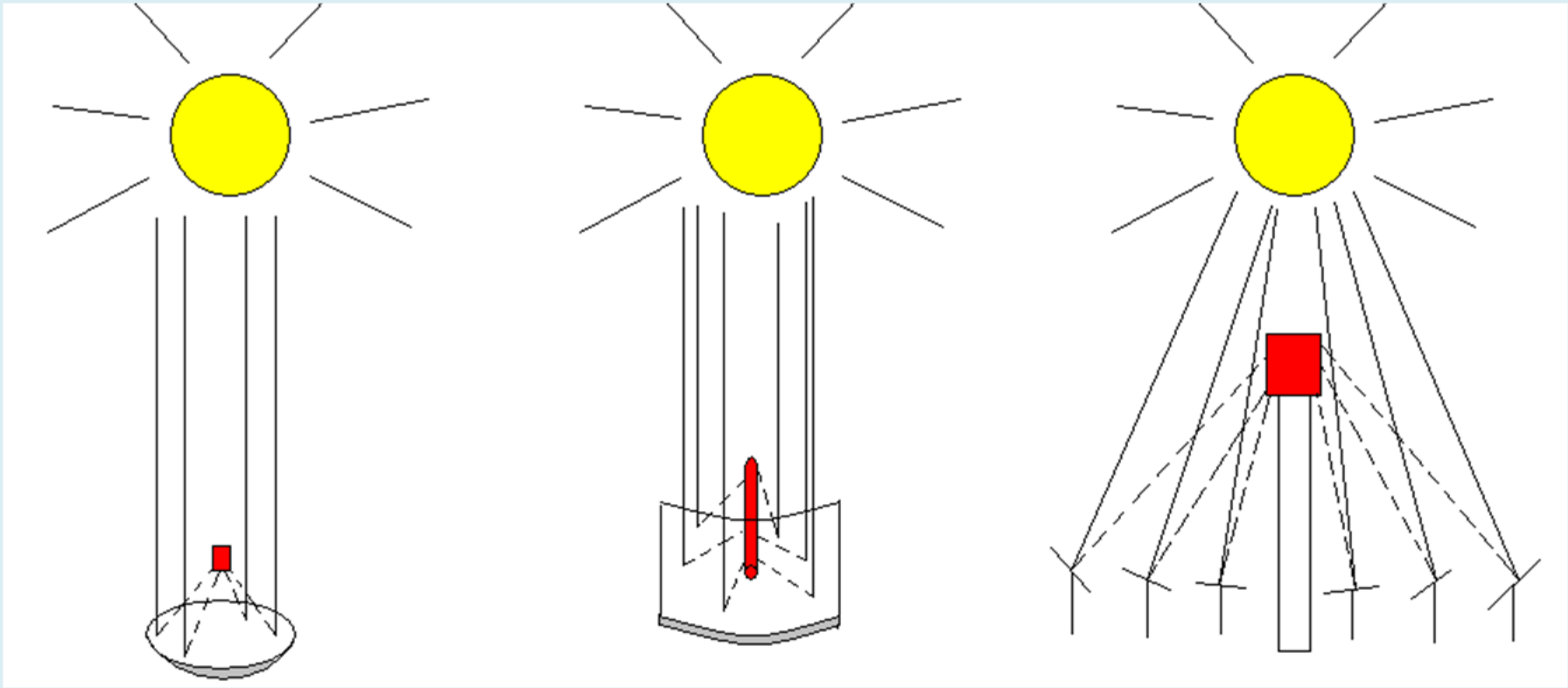
Solar resource – South Africa, Pretoria Meteonorm

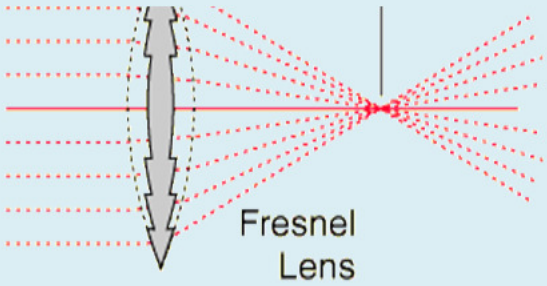


Solar power

- Photovoltaics
- CSP
- Solar water heaters

CSP - Concentrating methods





Solar Tower

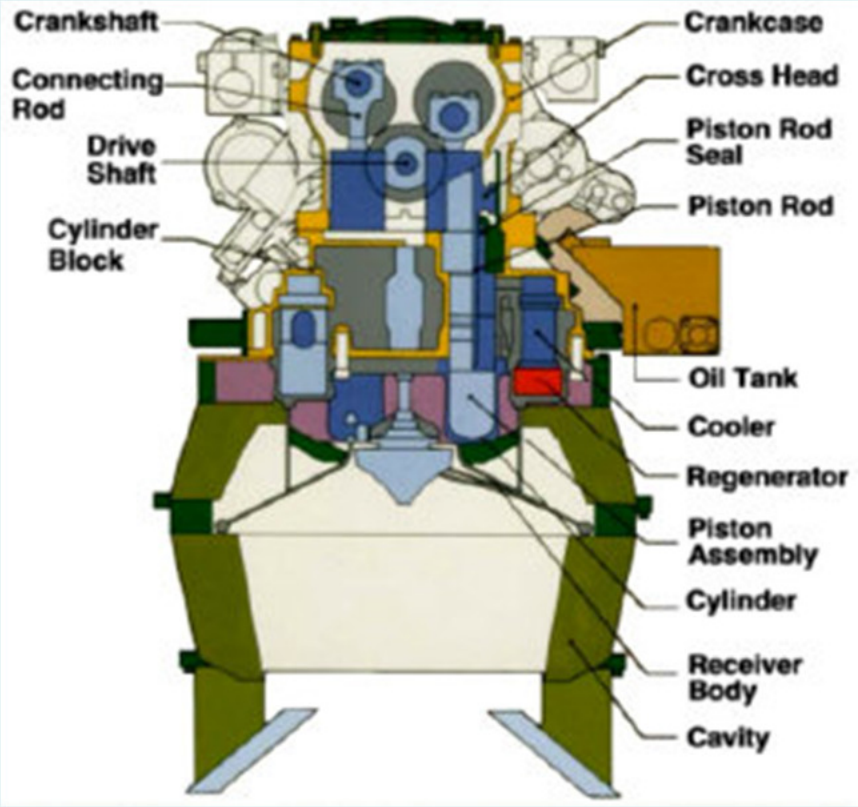
CSP (Concentrated solar power)

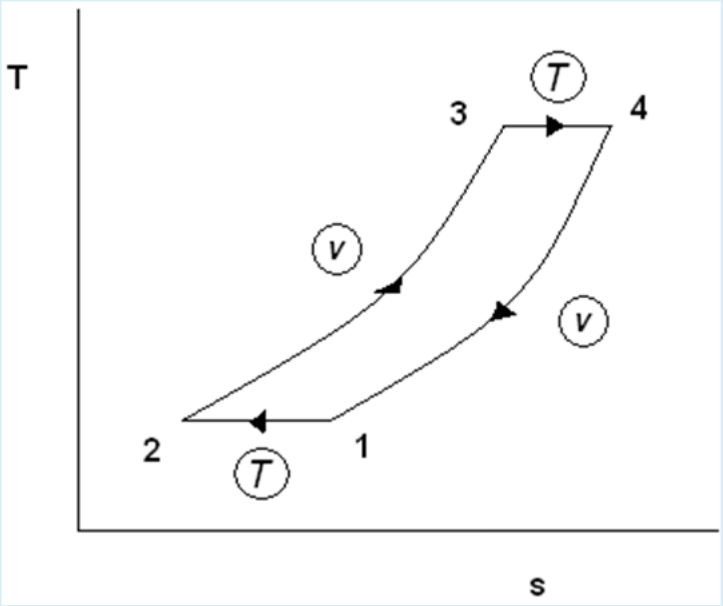
Power conversion cycles:

- Stirling Dish
- Steam Rankine Cycle
- Brayton cycle

Stirling Dish

Stirling Engine



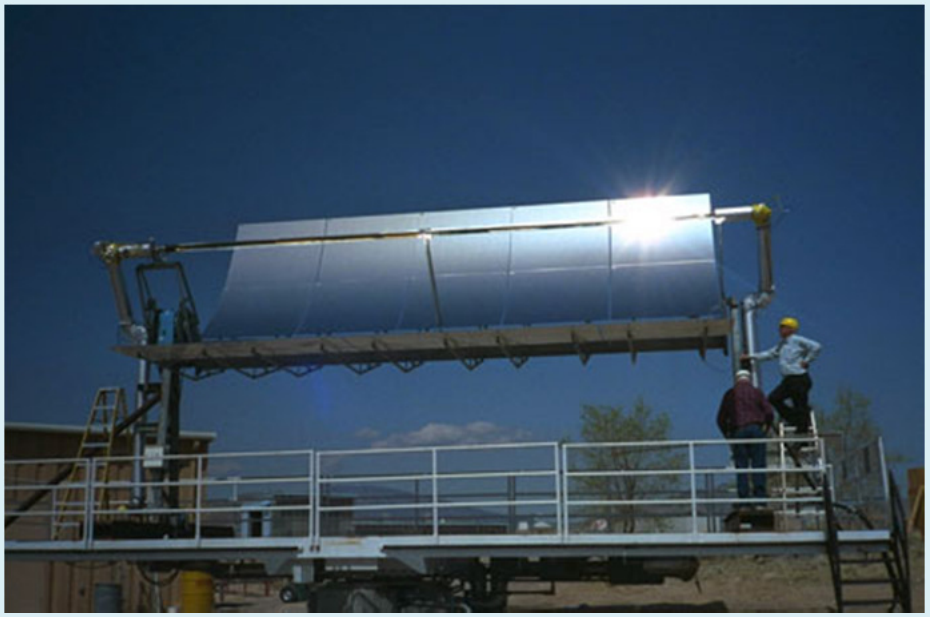


Stirling Dish

- Ripasso Energy, a solar technology provider based in Sweden, has commissioned the first units of their Concentrated Solar Power (CSP) installation in Upington, South Africa.

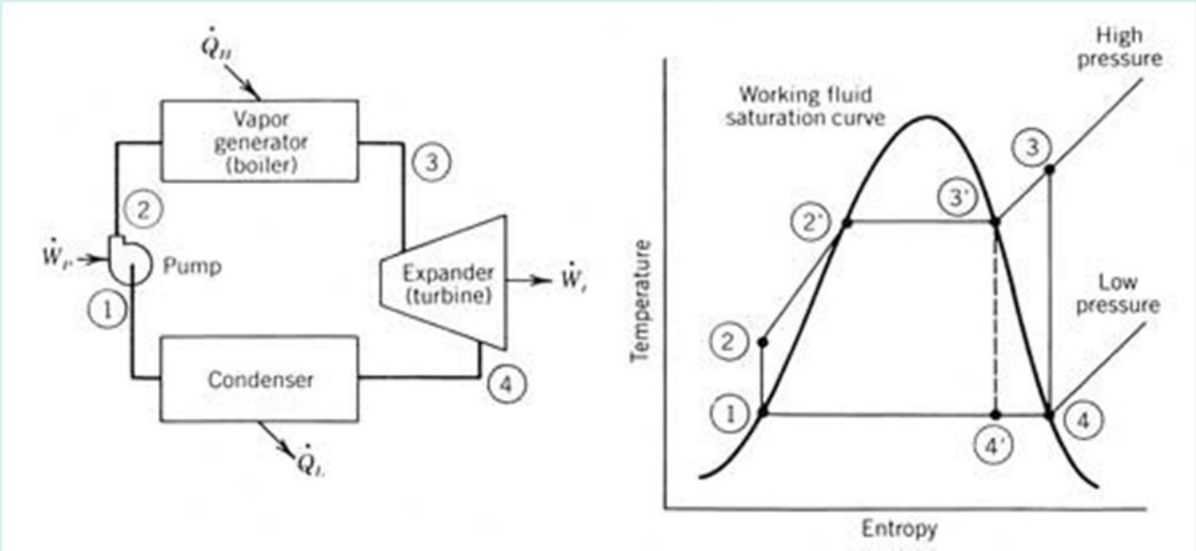
- The technology is based on parabolic mirrors and Stirling Power Converters (SPC). During the initial operation a new solar-to-grid-quality-electricity efficiency world record of 32 % has been achieved.

Rankine cycle

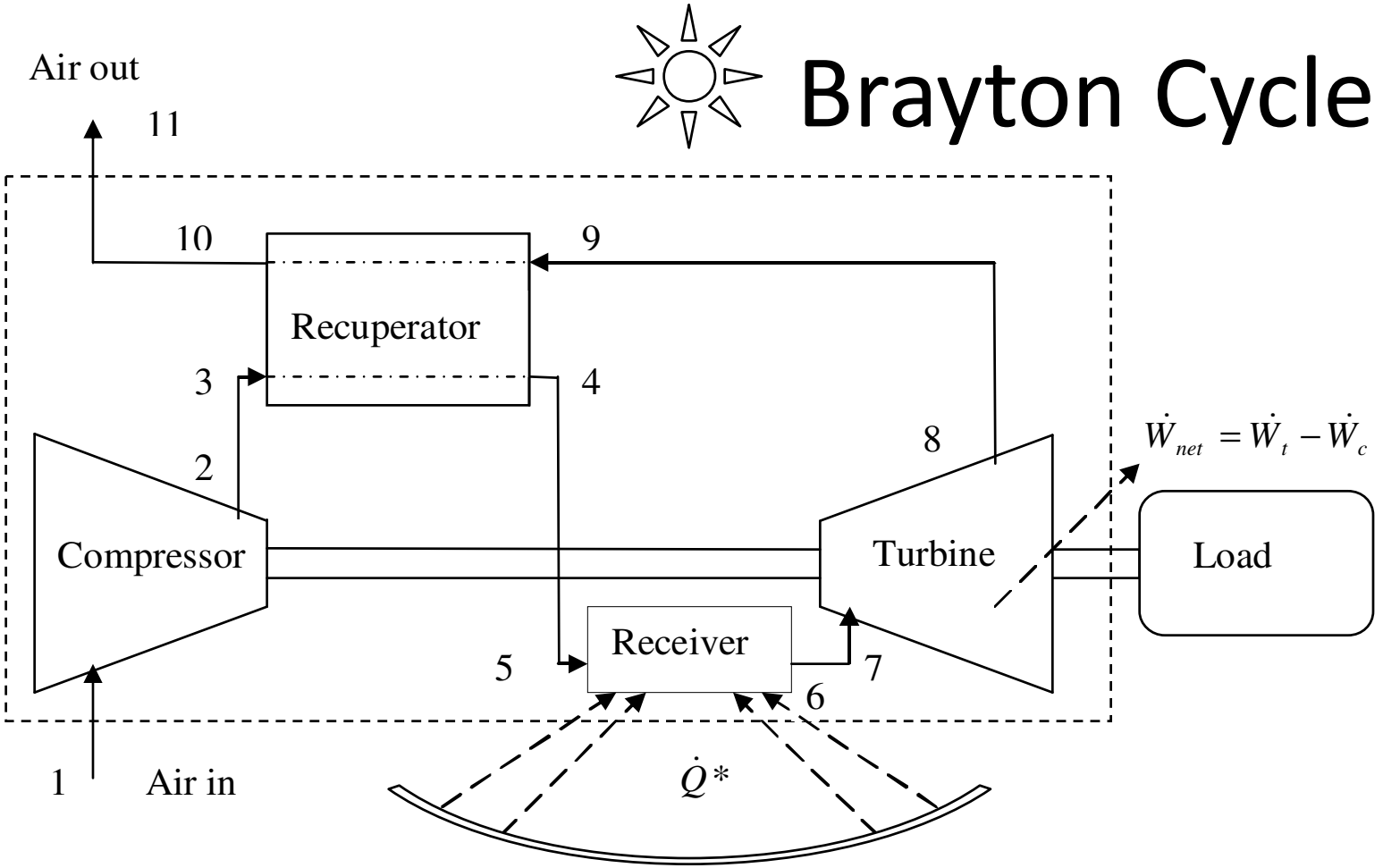


- Sandia National laboratories

- Fluid – water
- Lower temperatures
- Trough



Brayton Cycle

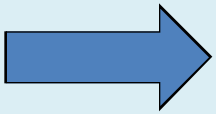


- Air/Gas
- High temperatures
- Dish/Tower

Small-scale open and direct solar thermal Brayton cycle with recuperator

- Advantages
  - High recommendation [1, 2] (cost, efficiency)
  - Air as working fluid
  - Hot air exhaust
    - Water heating
    - Space heating
    - Absorpsion refrigeration
  - Recuperator
    - high efficiency and
    - low compressor pressure ratios

- Disadvantages
  - recuperator and receiver pressure losses
  - turbo-machine efficiencies
  - recuperator effectiveness [3]
  - Heat losses



irreversibilities

[1] Chen L., Zhang, W. and Sun, F., 2007; [2] Mills, D., 2004; [3] Stine and Harrigan, 1985

Why small-scale?

Advantages of micro-grid

- Smaller financial commitment
- No municipality or larger corporation

Disadvantage of micro-grid

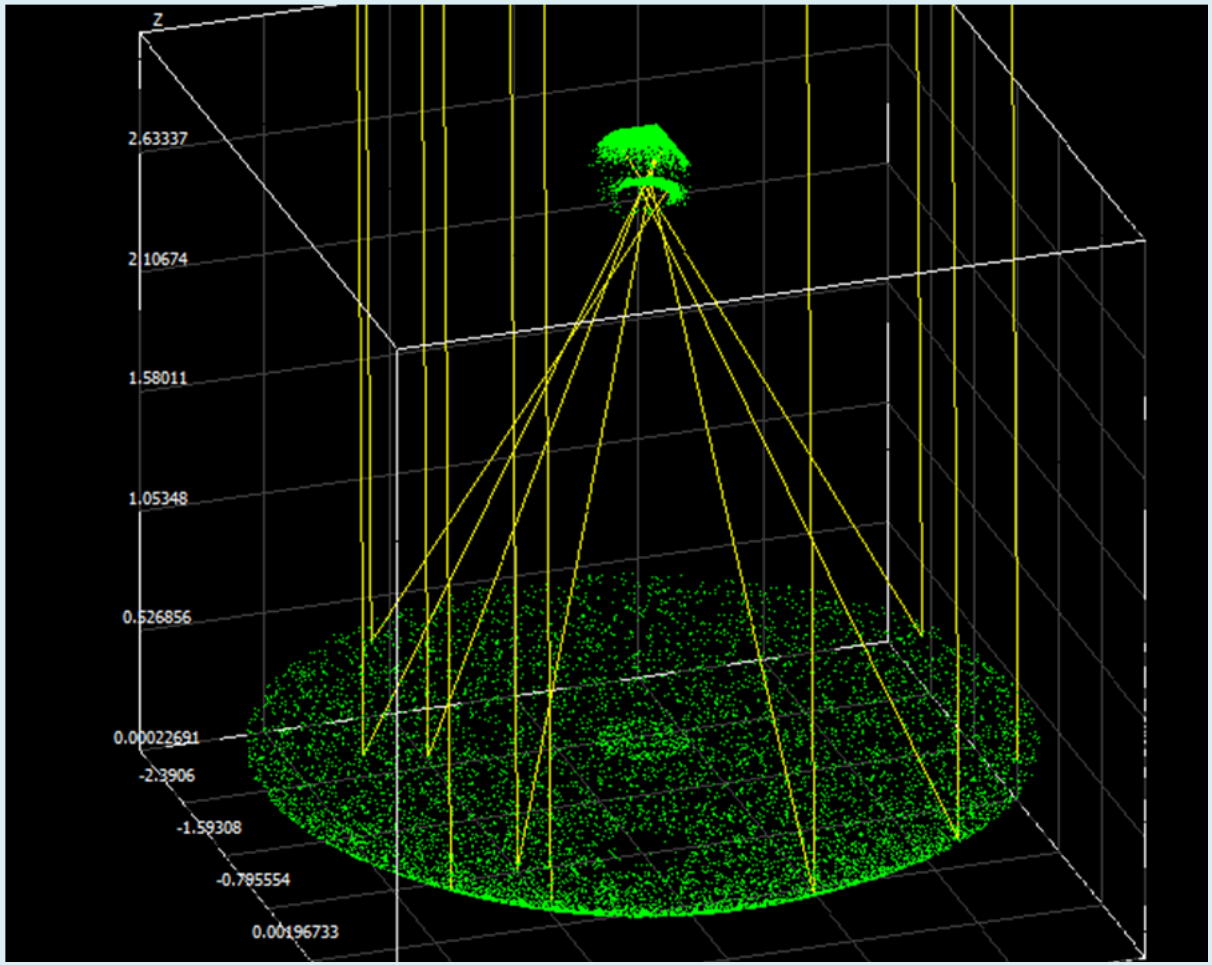
- Grid management

Small-scale solar thermal Brayton cycle – design considerations

- Dish
- Tracking
- Sensors
- Receiver
- Recuperator
- Heat loss, pressure loss
- Micro-turbine

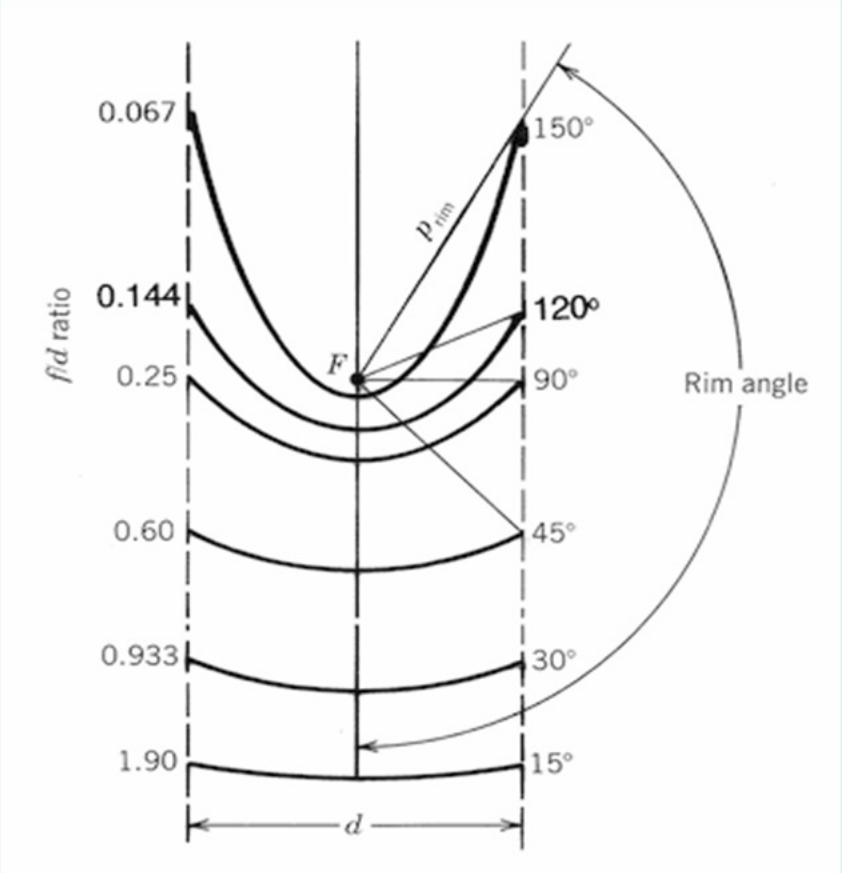
Solar Brayton - Dish

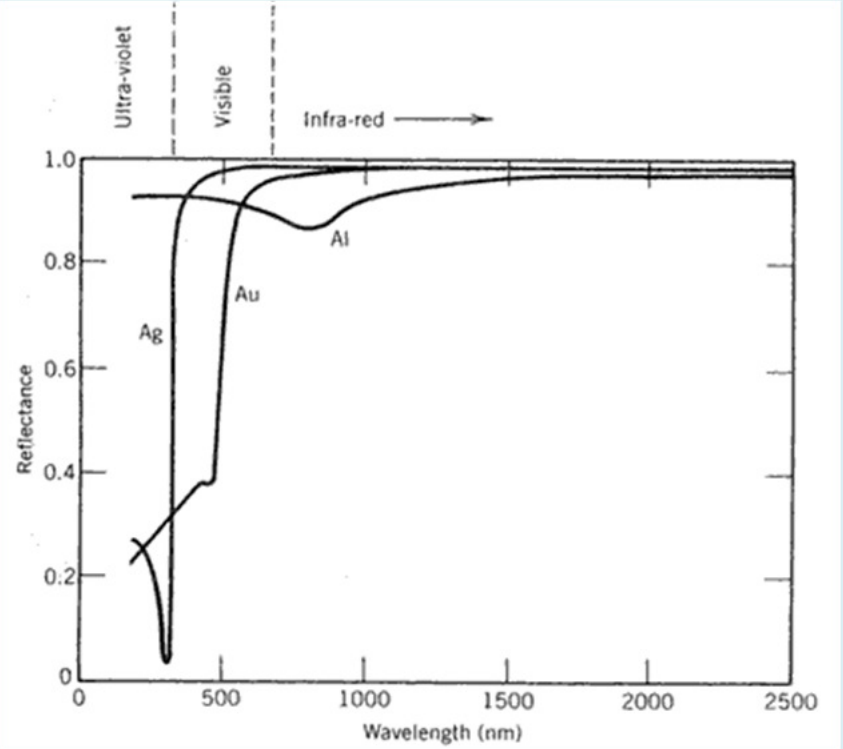
- Soltrace
- Reflectance
- Shape



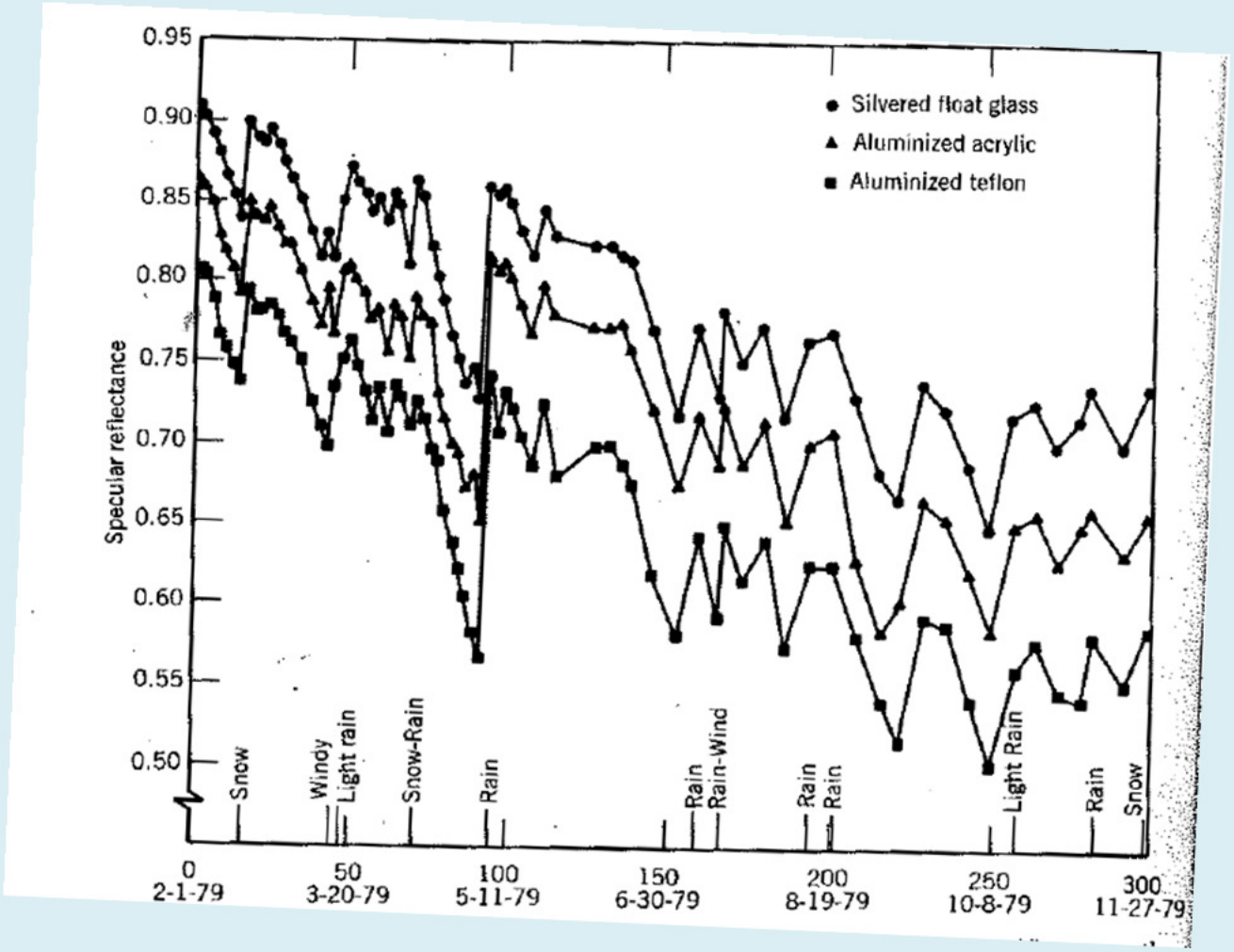
Reflectance of aluminium - 79% to 86%.
Polished aluminium - 91% specular reflectance.

Solar Brayton – Dish

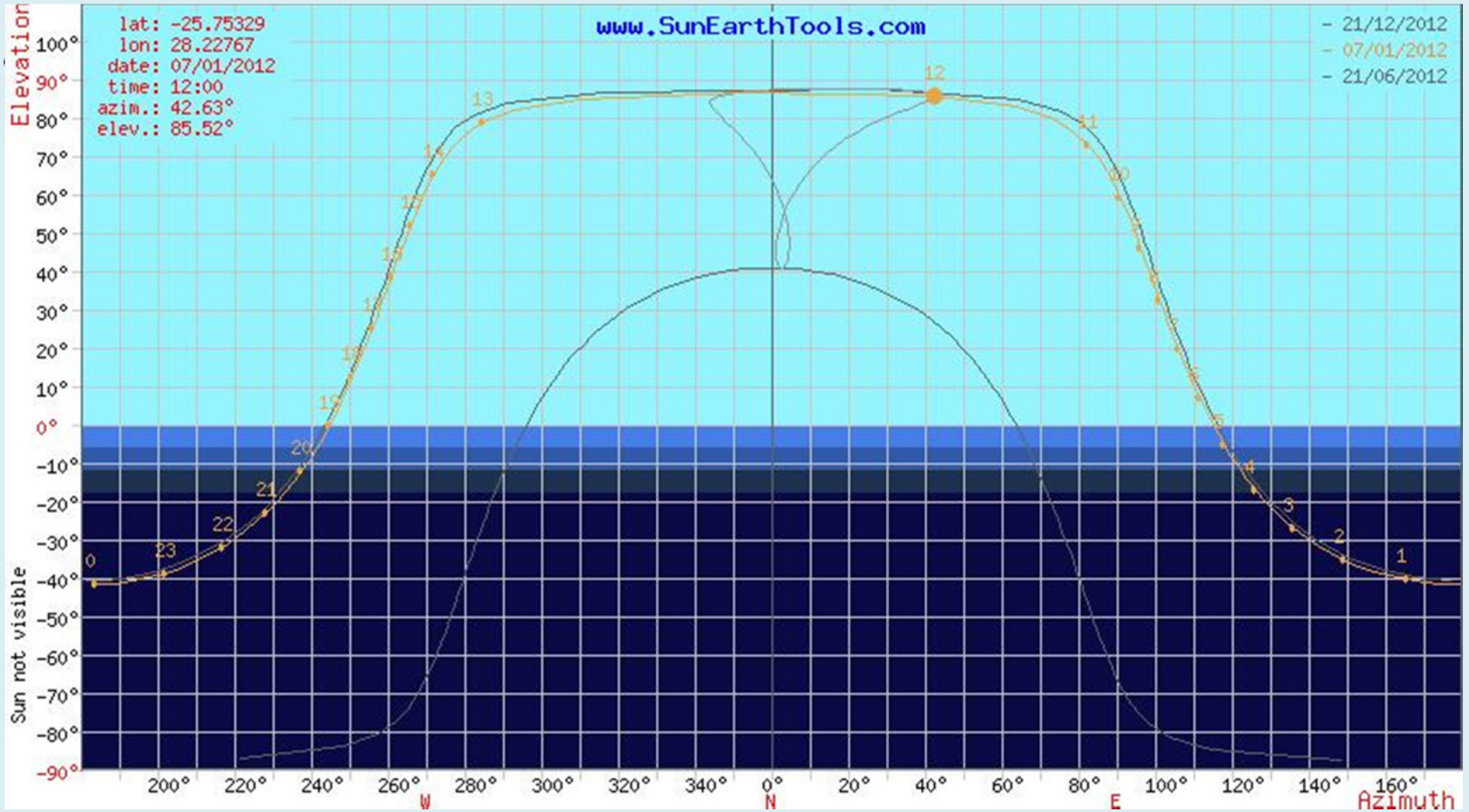




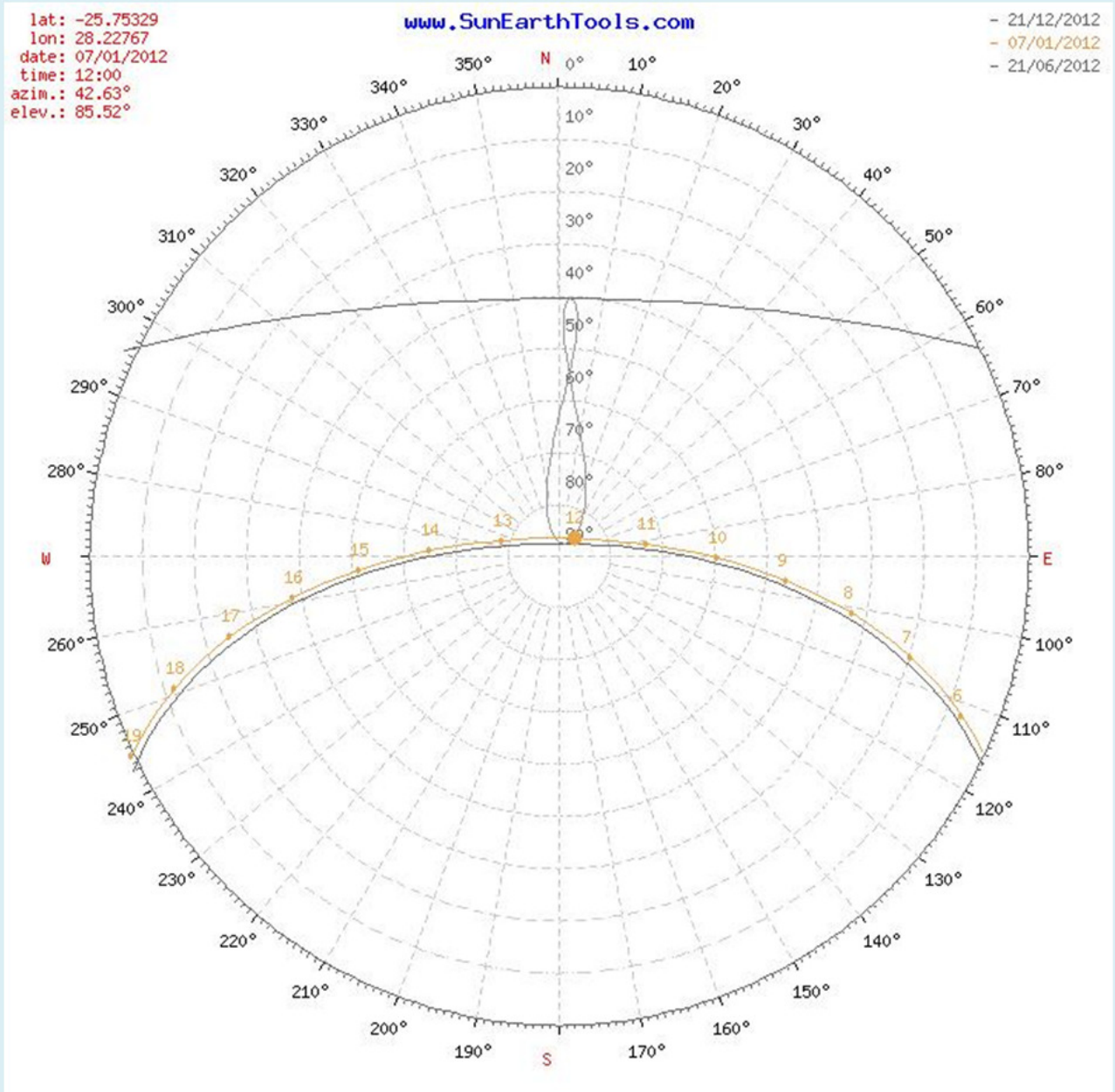
Solar Brayton – Dish Reflectivity vs time



Tracking - Elevation



Tracking - Azimuth



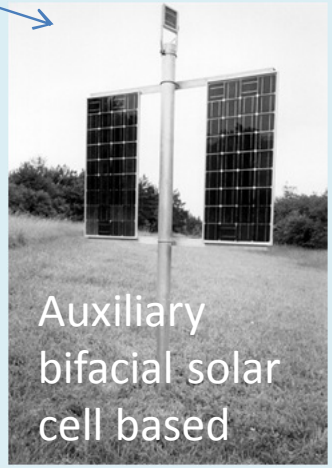
Two-axis solar tracking required

Solar tracking

Active

Micro-processor and electro-optical sensor based

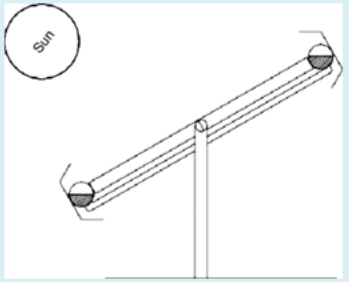
Date and time based or a combination of sensor and date/time based

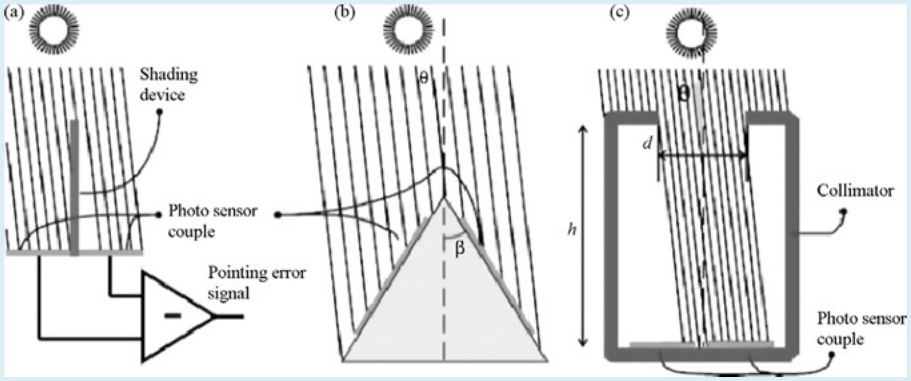


Passive

Bi-metallic strips

Fluid





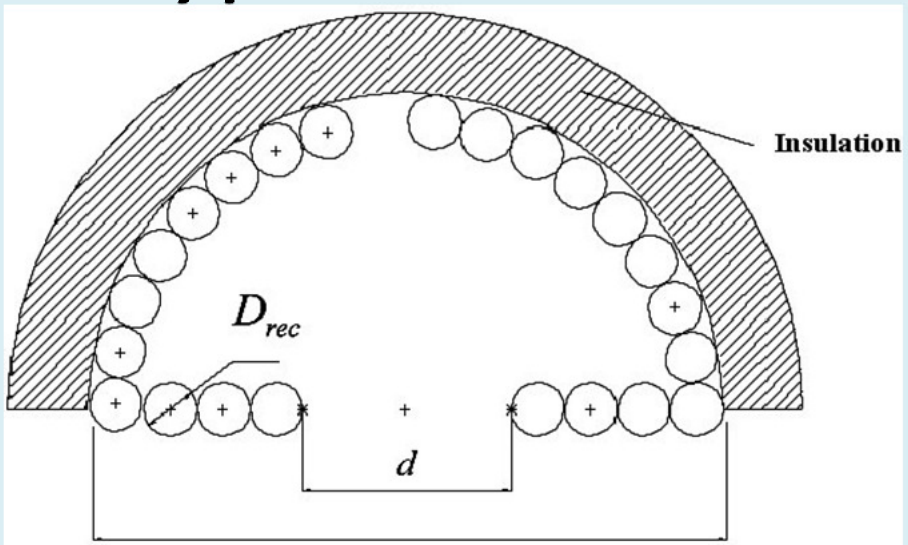
Mousazadeh et al. (2004), Poulek and Libra (2000)

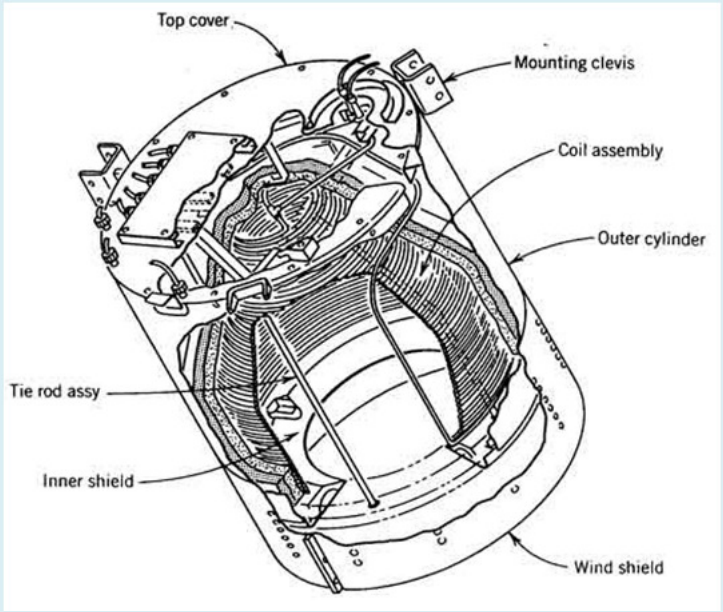
Solar thermal Brayton - Receiver

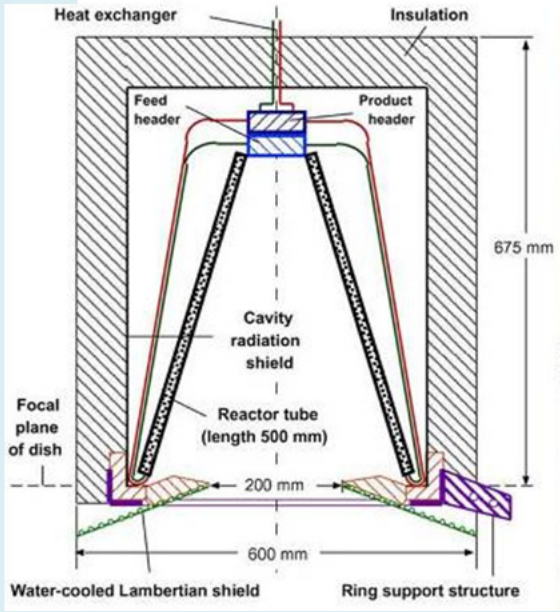
- Receiver types
  - Pressurised tube receiver (cavity) – air/water/oil/salt
  - Open volumetric pressurised receivers (sucks air in through a fan)
  - Closed volumetric receiver (sucks pressurised air in, using quartz glass cover)
  - Solar particle receivers (air particle mixture absorbs solar radiation)

Receiver types

- Pressurised tube receiver (cavity) – air/water/oil/salt

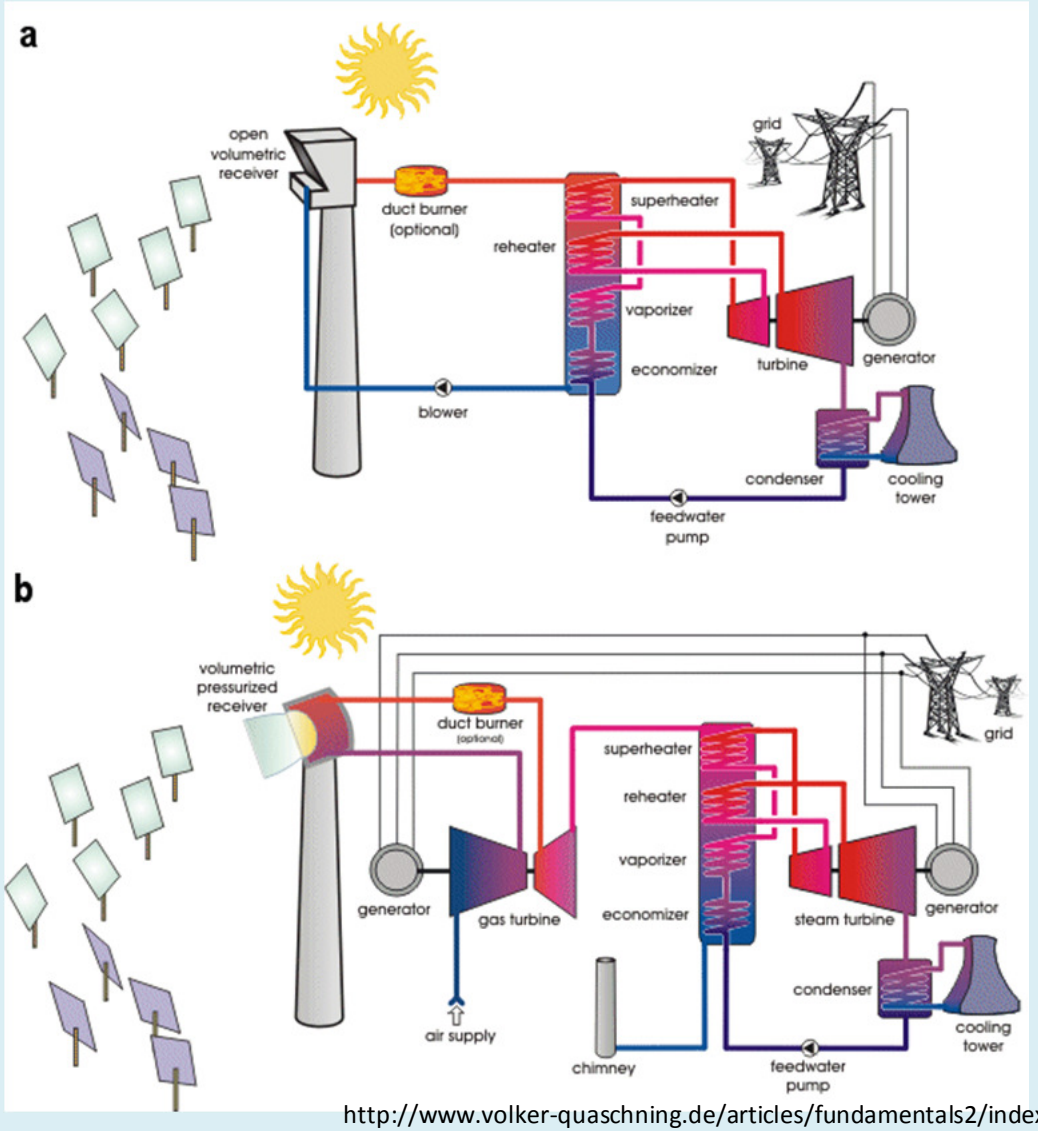






Solar thermal Brayton - Receiver

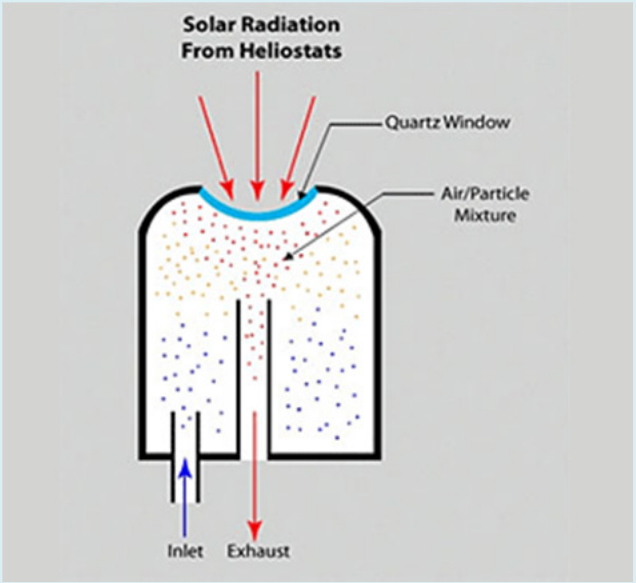
- Open/closed volumetric receiver

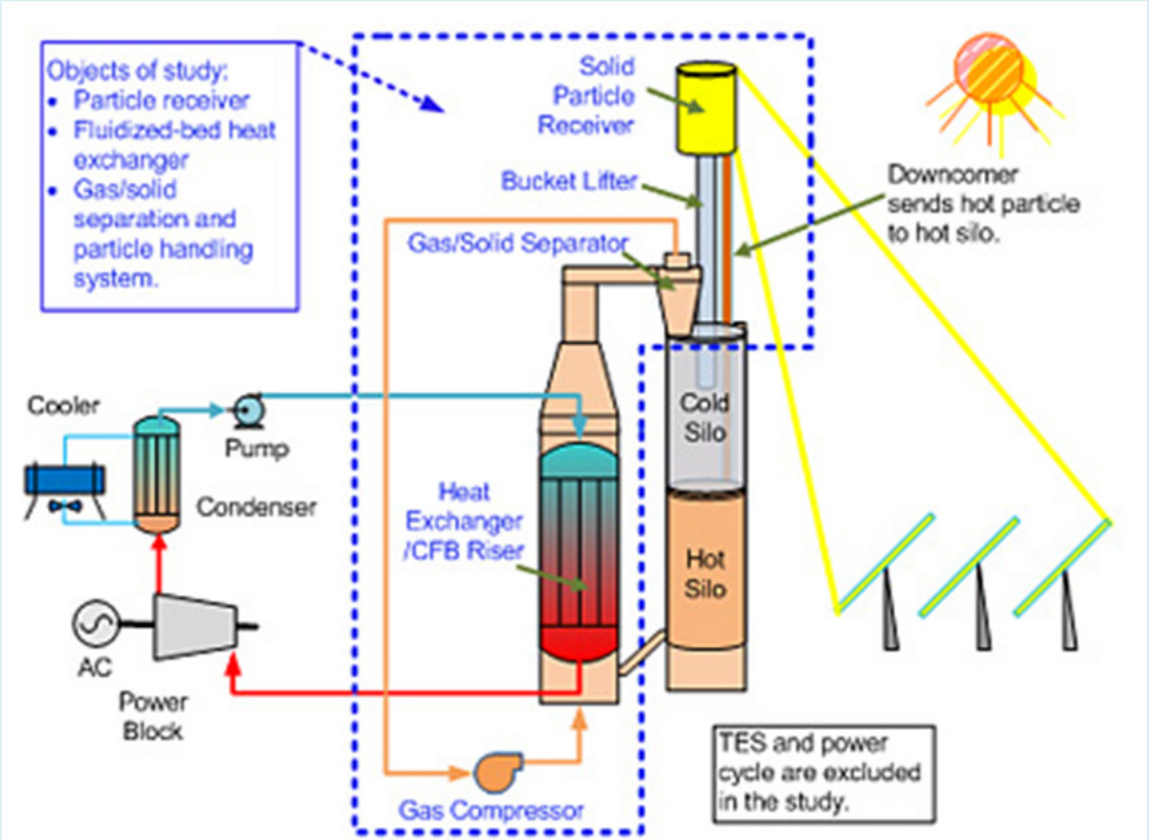


http://www.volker-quaschning.de/articles/fundamentals2/index.php

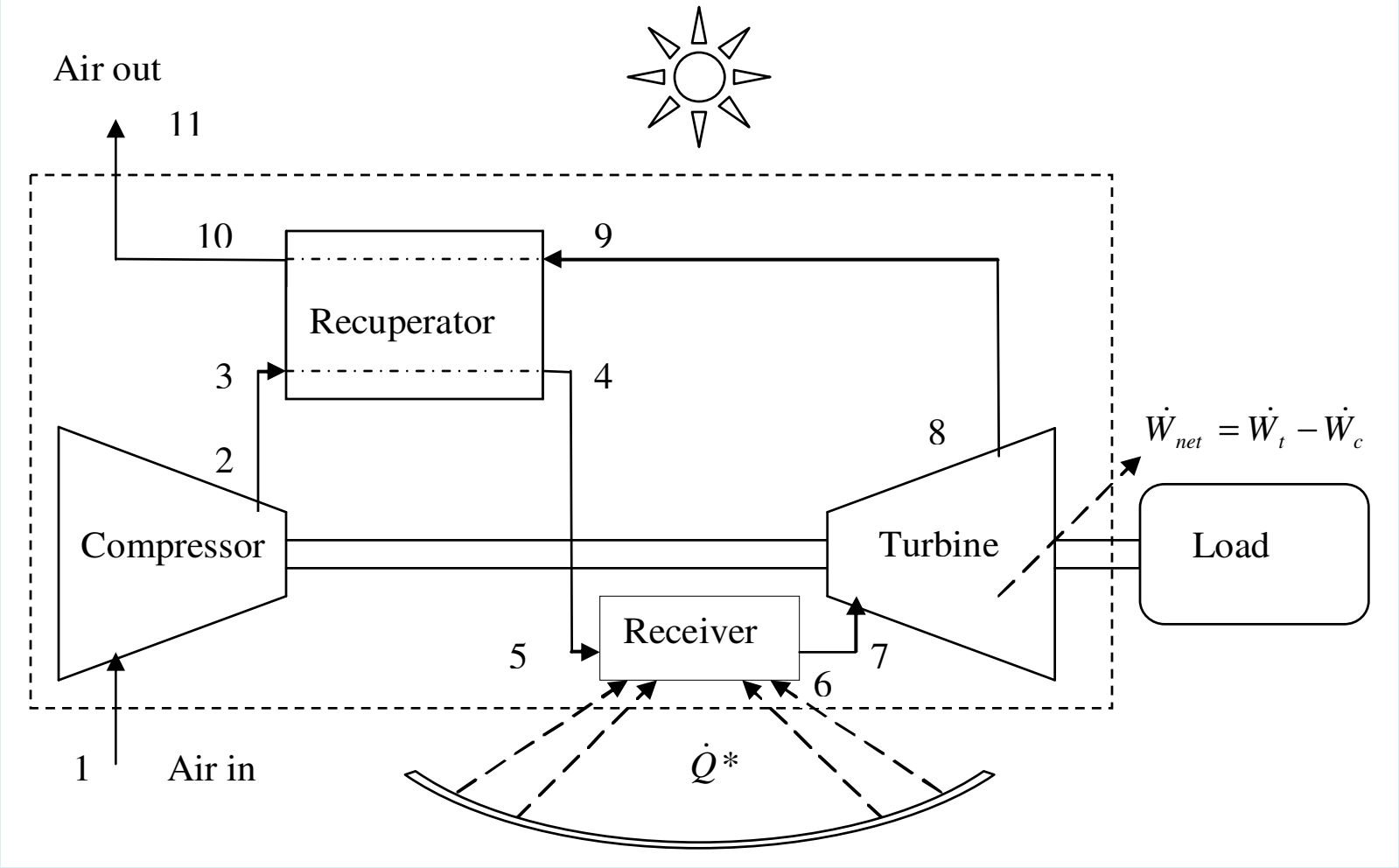
Solar thermal Brayton - Receiver

- Particle receiver (air-particle mixture absorbs sunlight)

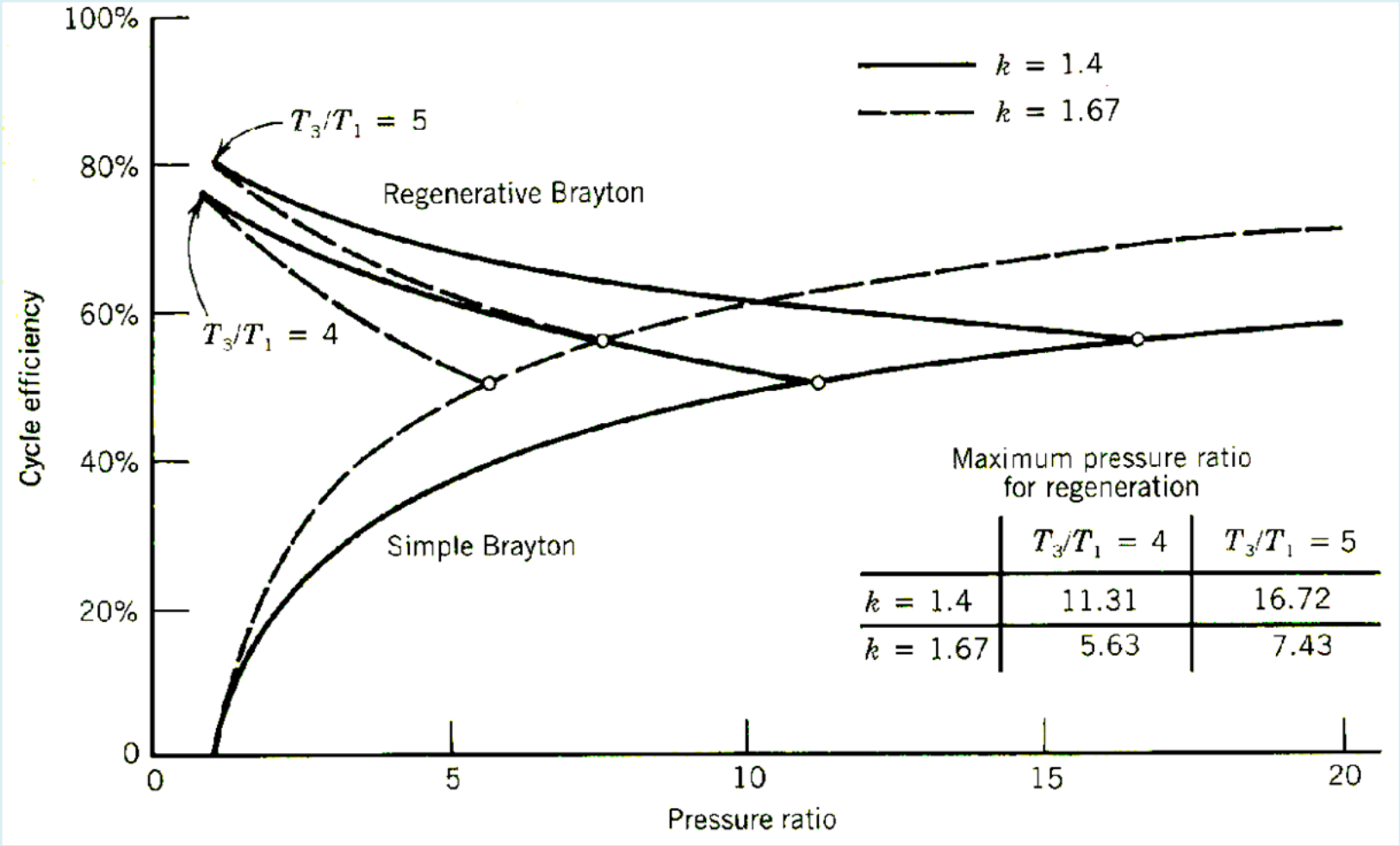




Solar thermal Brayton - Recuperator



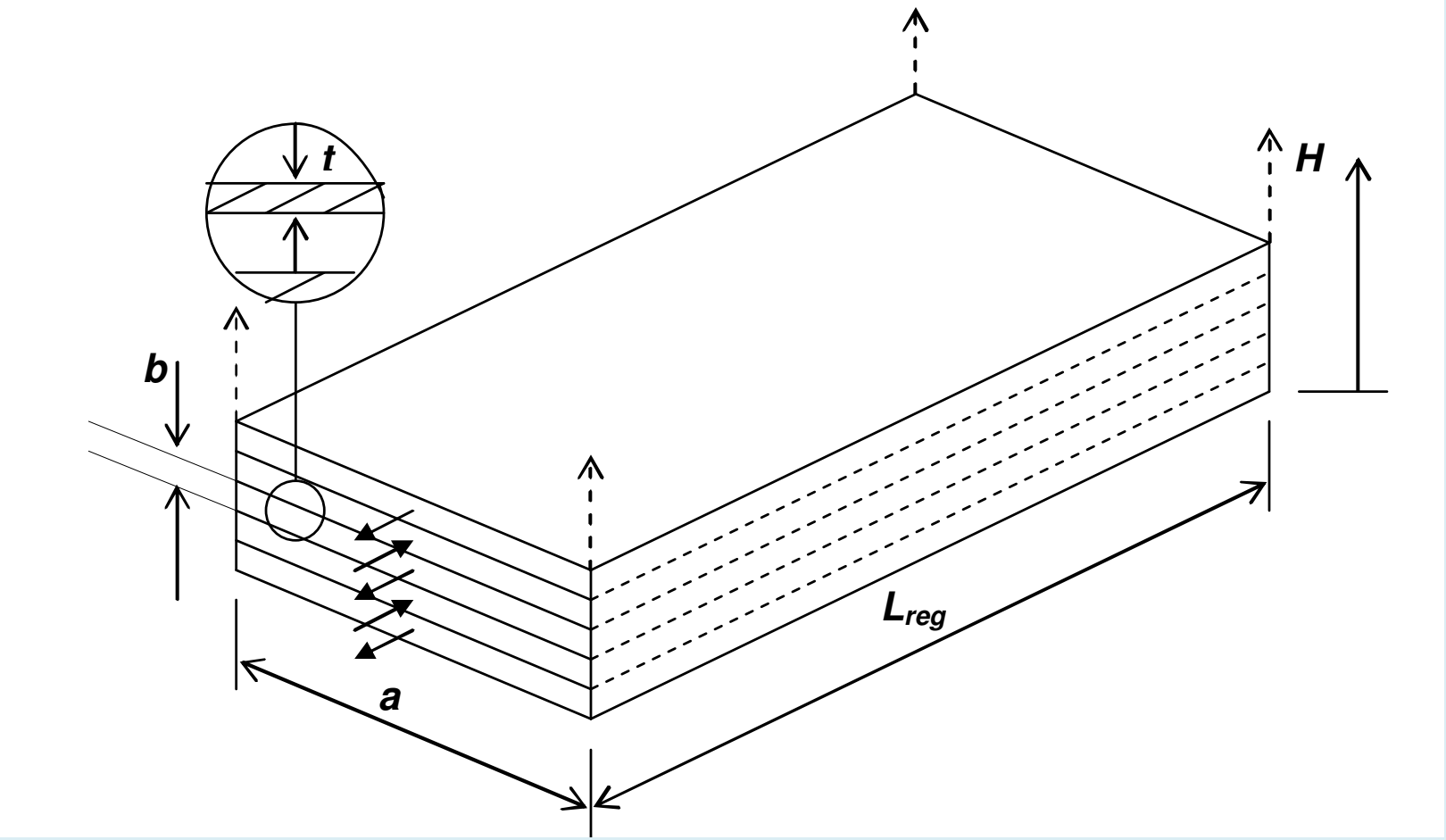
Solar thermal Brayton - Recuperator



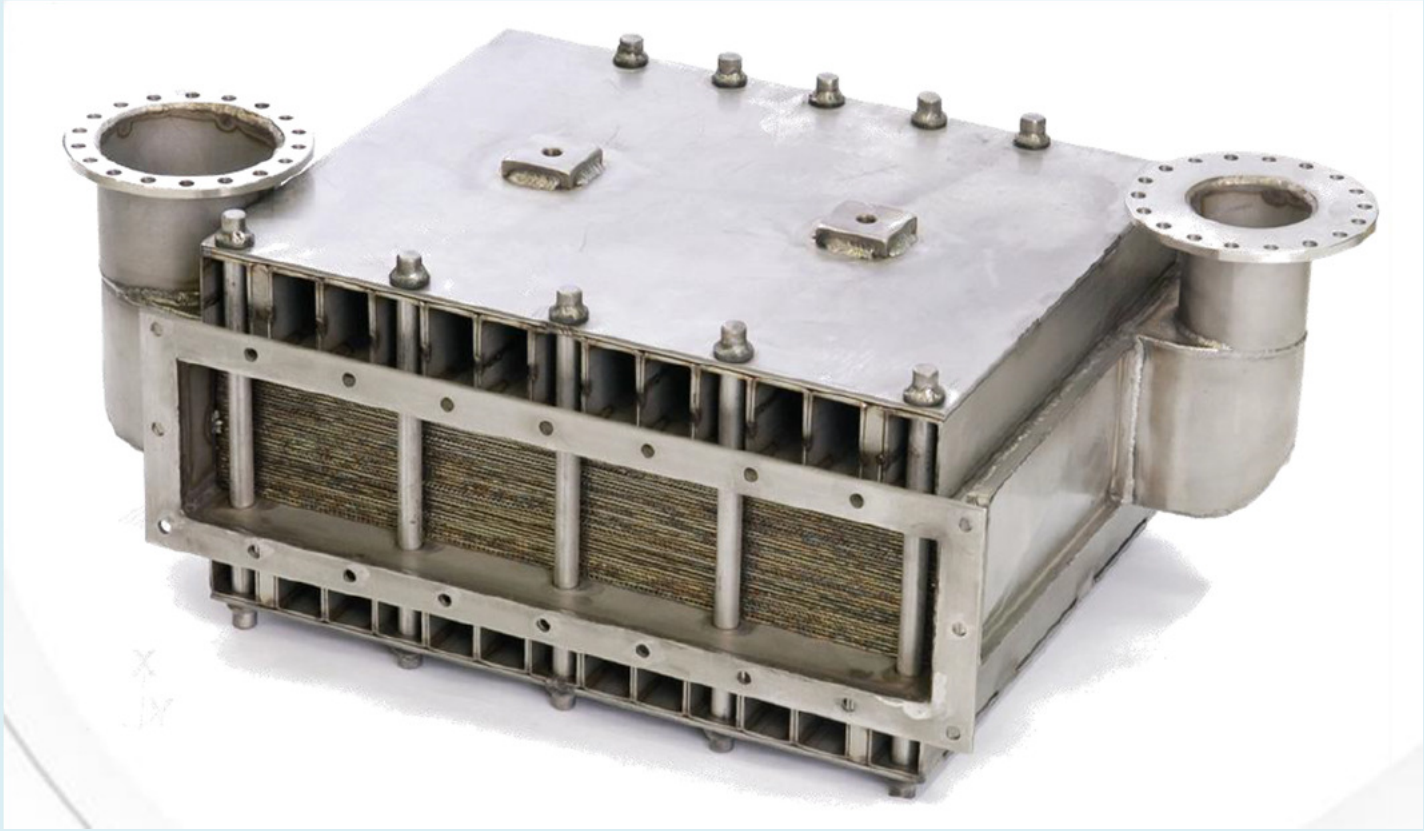
Maximum pressure ratio for regeneration

	$T_3/T_1 = 4$	$T_3/T_1 = 5$
$k = 1.4$	11.31	16.72
$k = 1.67$	5.63	7.43

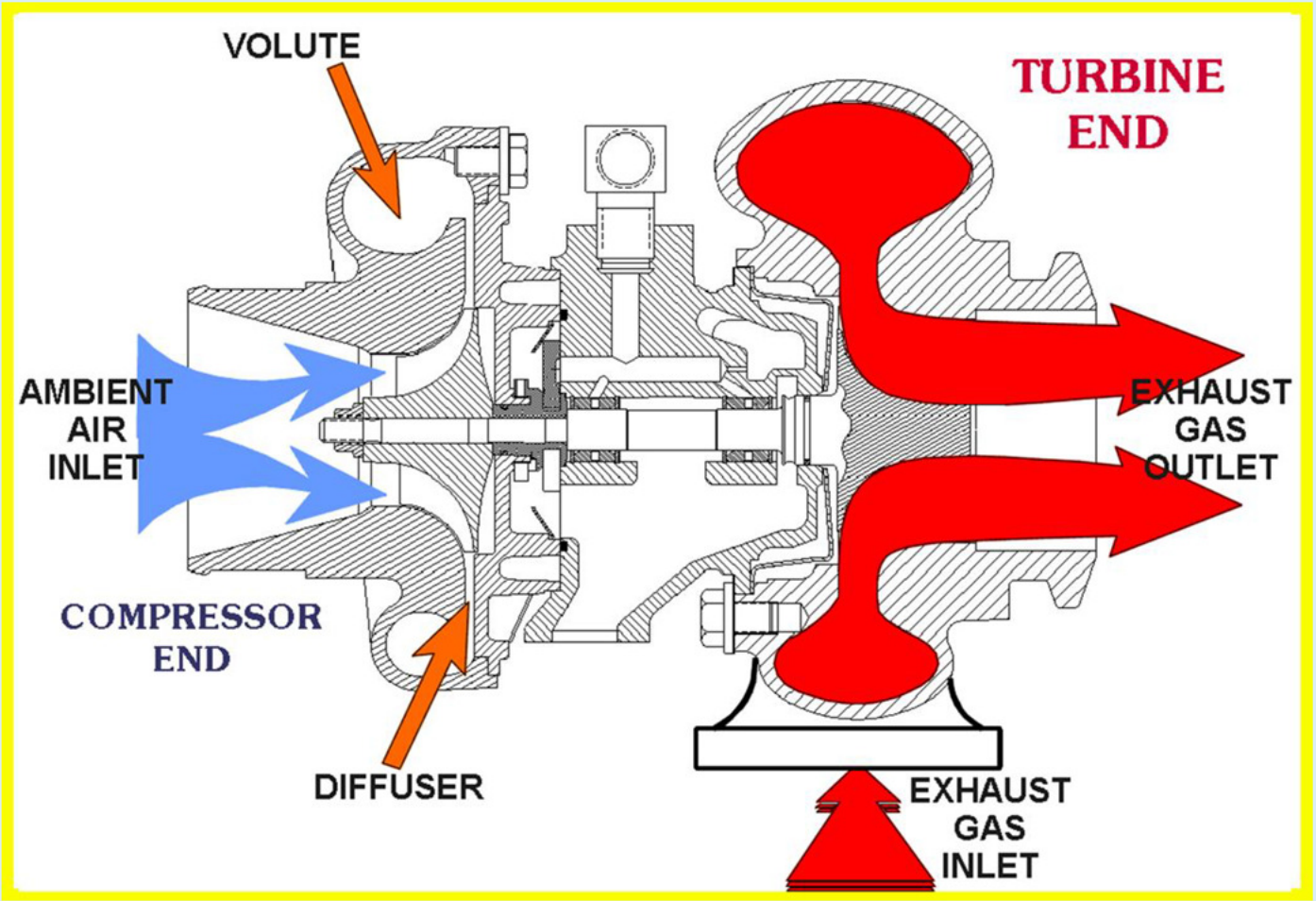
Solar thermal Brayton – plate type recuperator



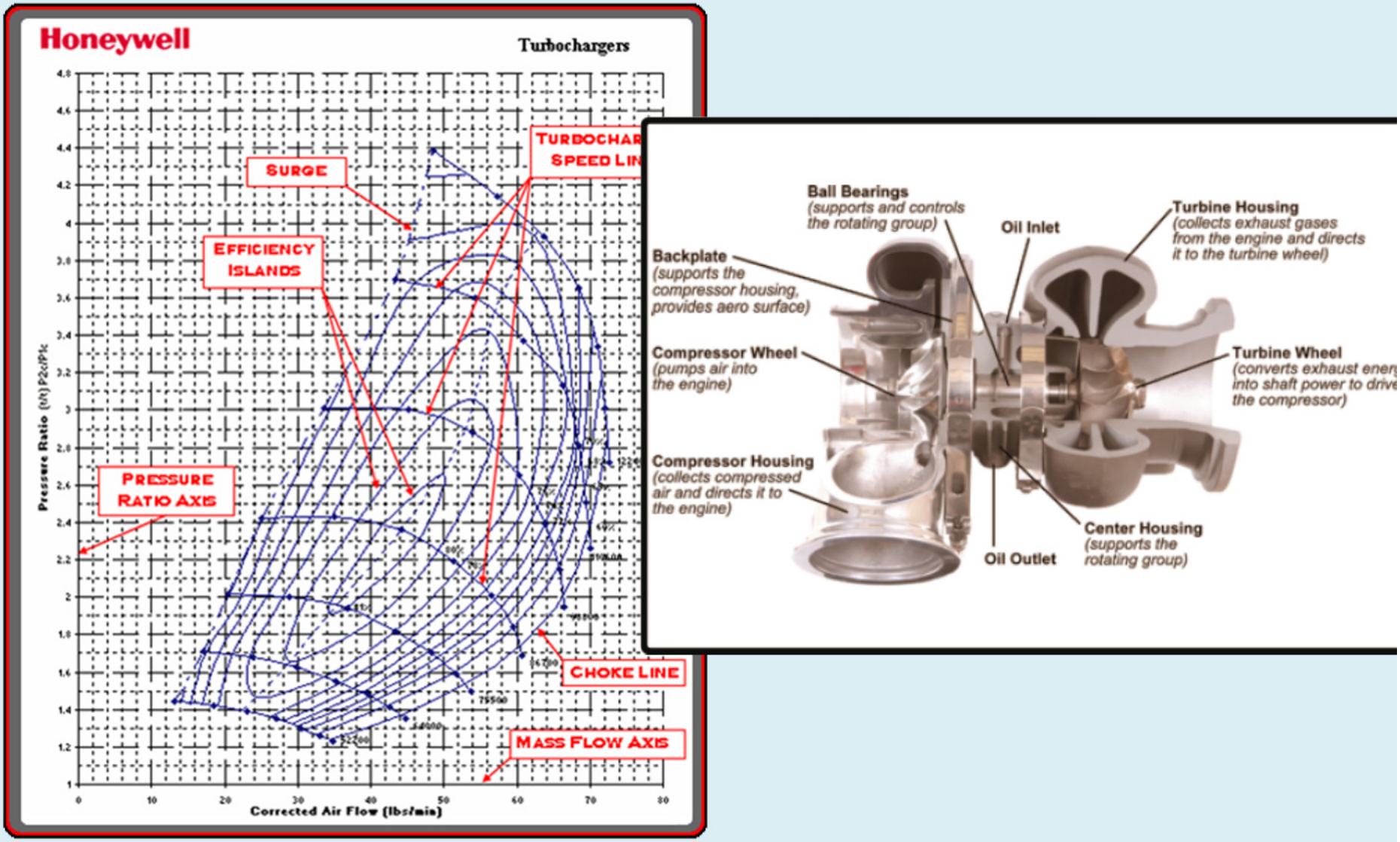
Solar thermal Brayton – plate type recuperator



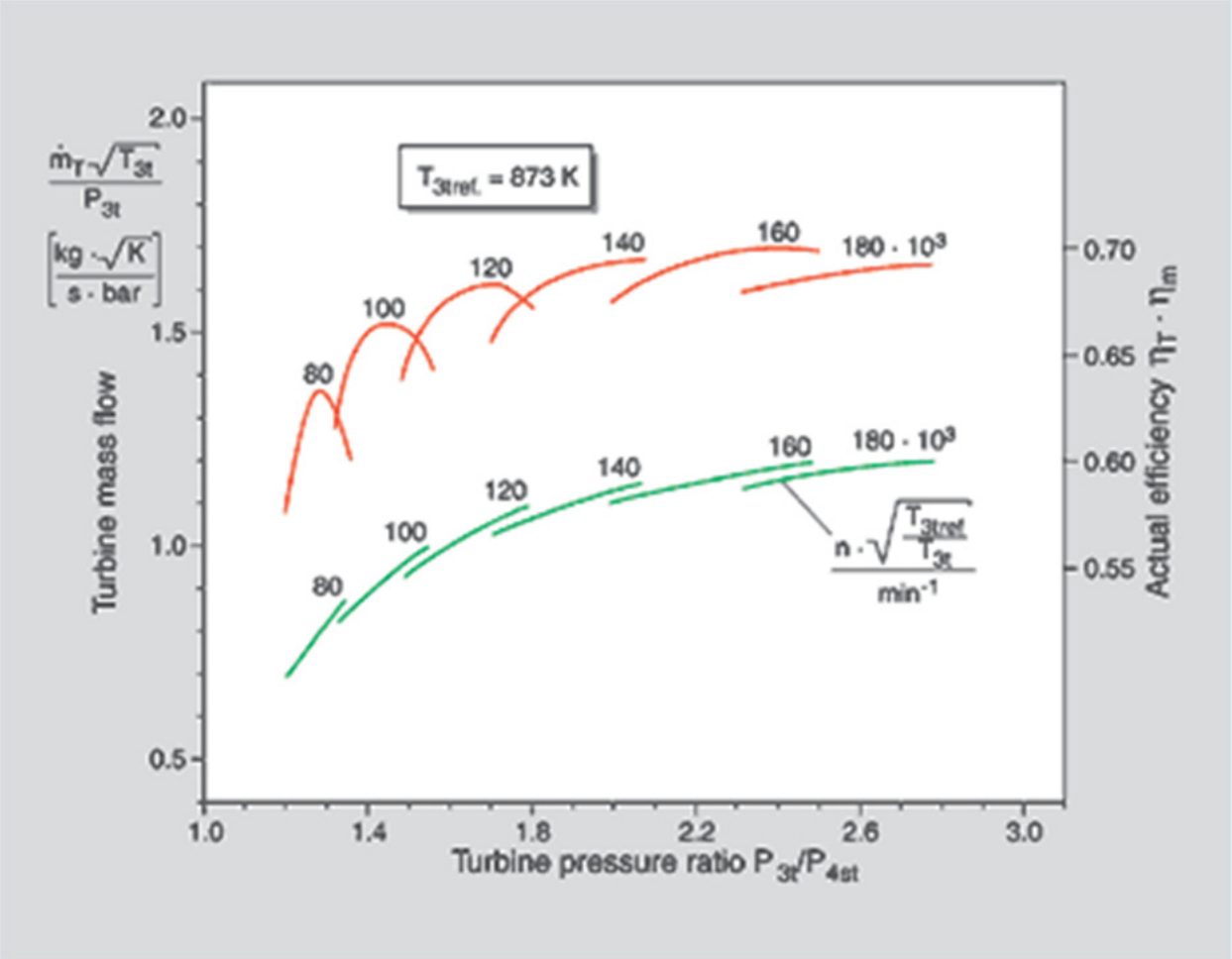
Micro-turbine, coupling



Micro-turbine – compressor map

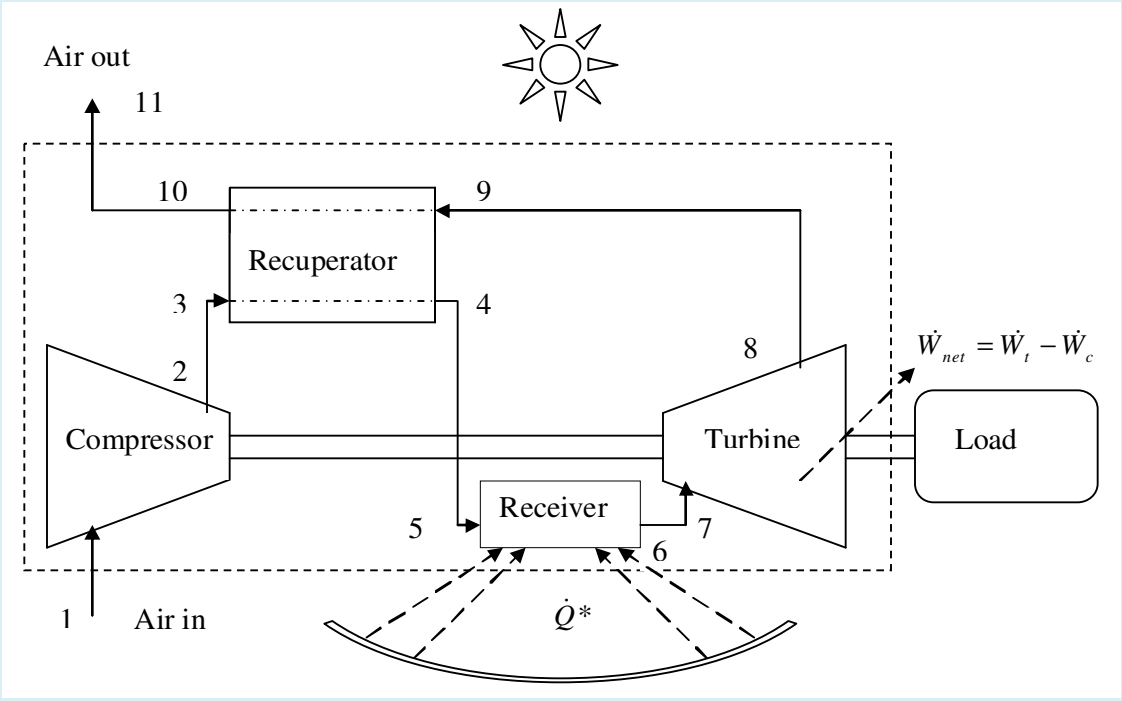


Micro-turbine – turbine map

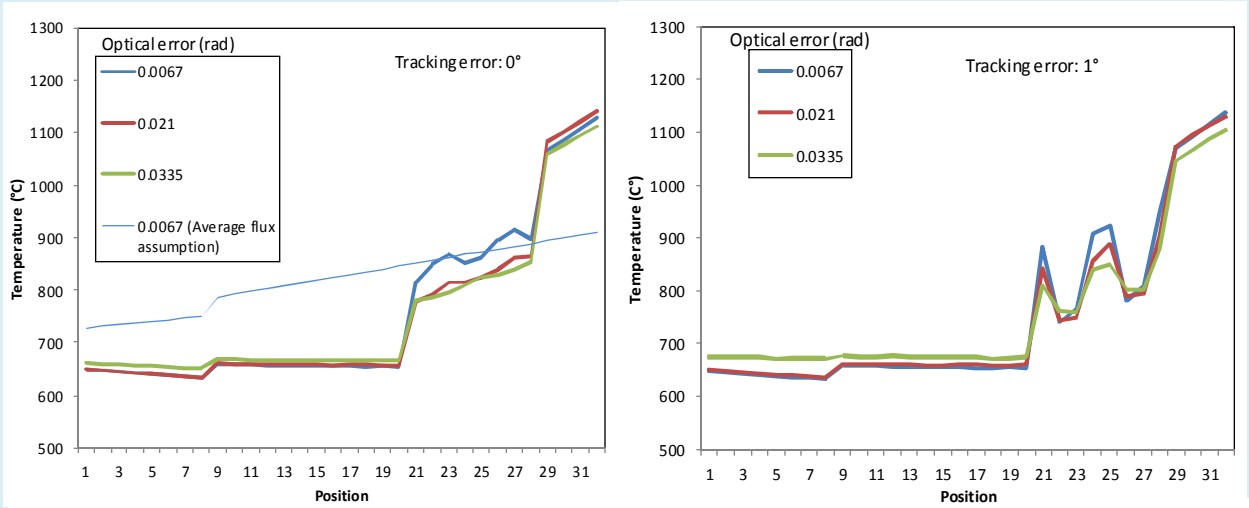


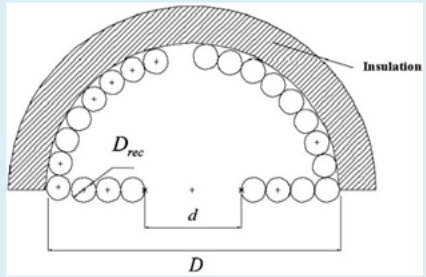
Research

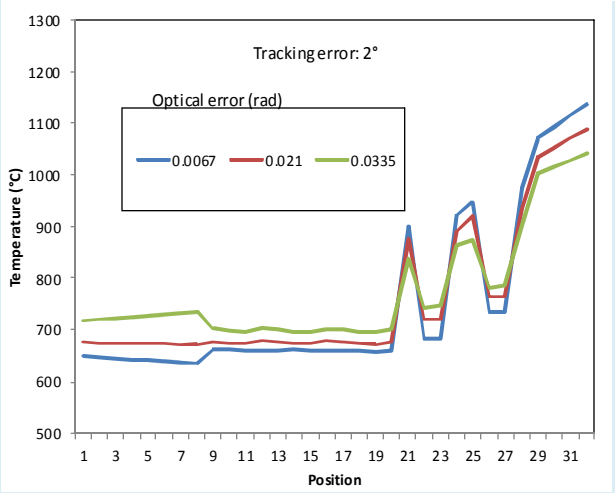
- Determination of cavity receiver wall temperatures – effects of tracking errors, slope errors, specularity errors
- Modelling – Matlab (steady), Flownex (time)
- Determining maximum net power output – total entropy generation minimisation (optimising components)
- Experimental setup

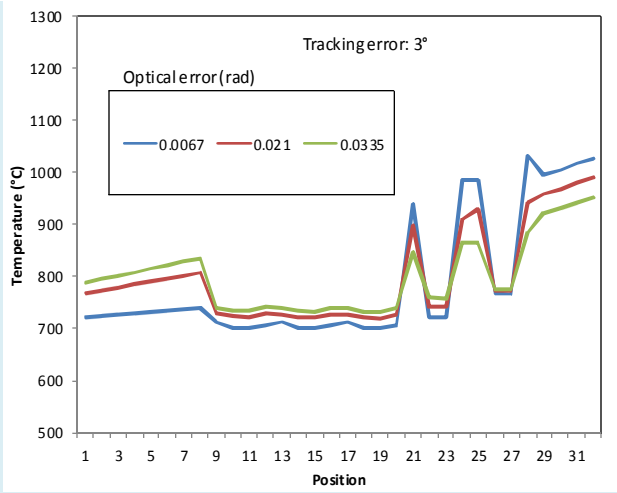


Research results – cavity receiver temperatures as function of errors

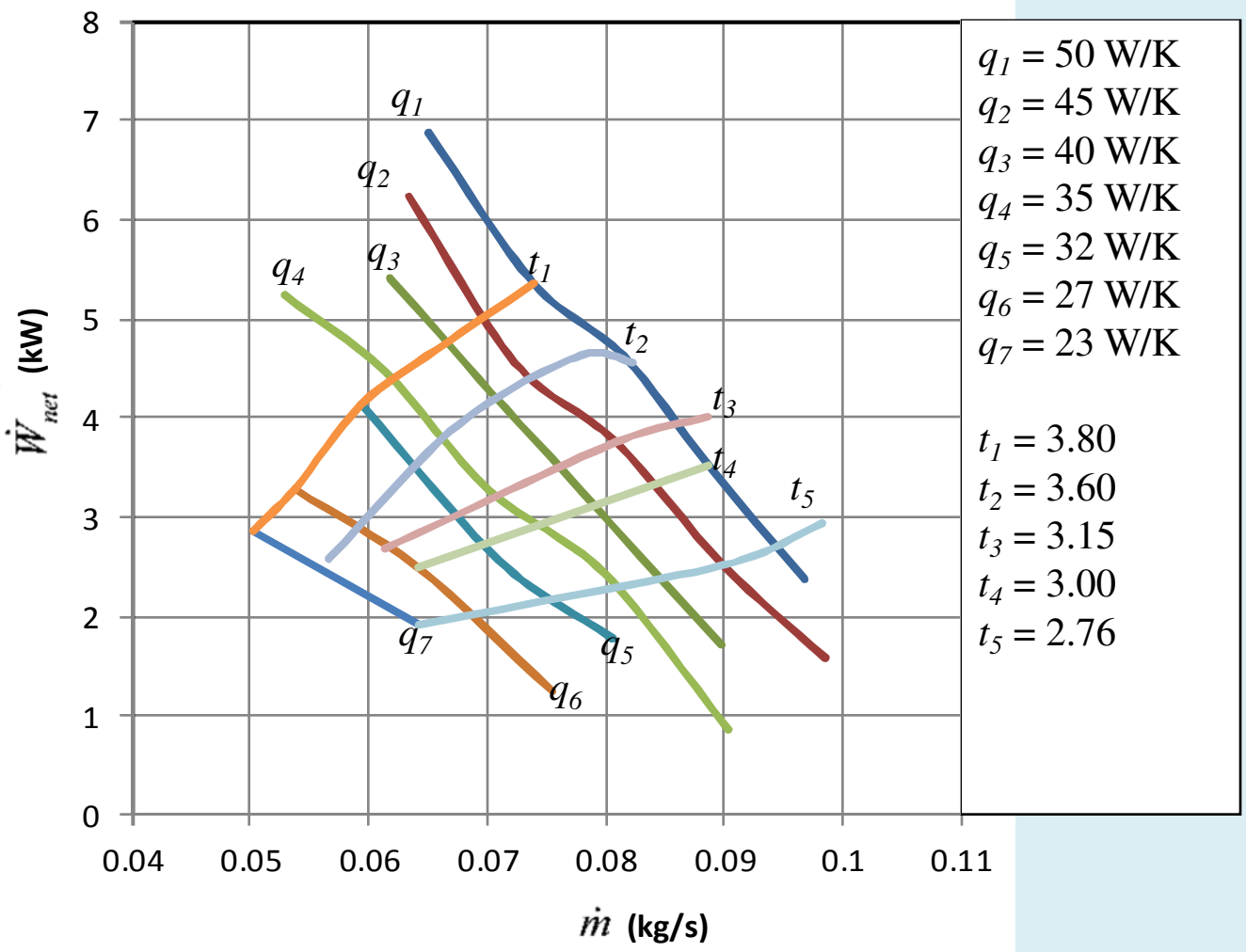




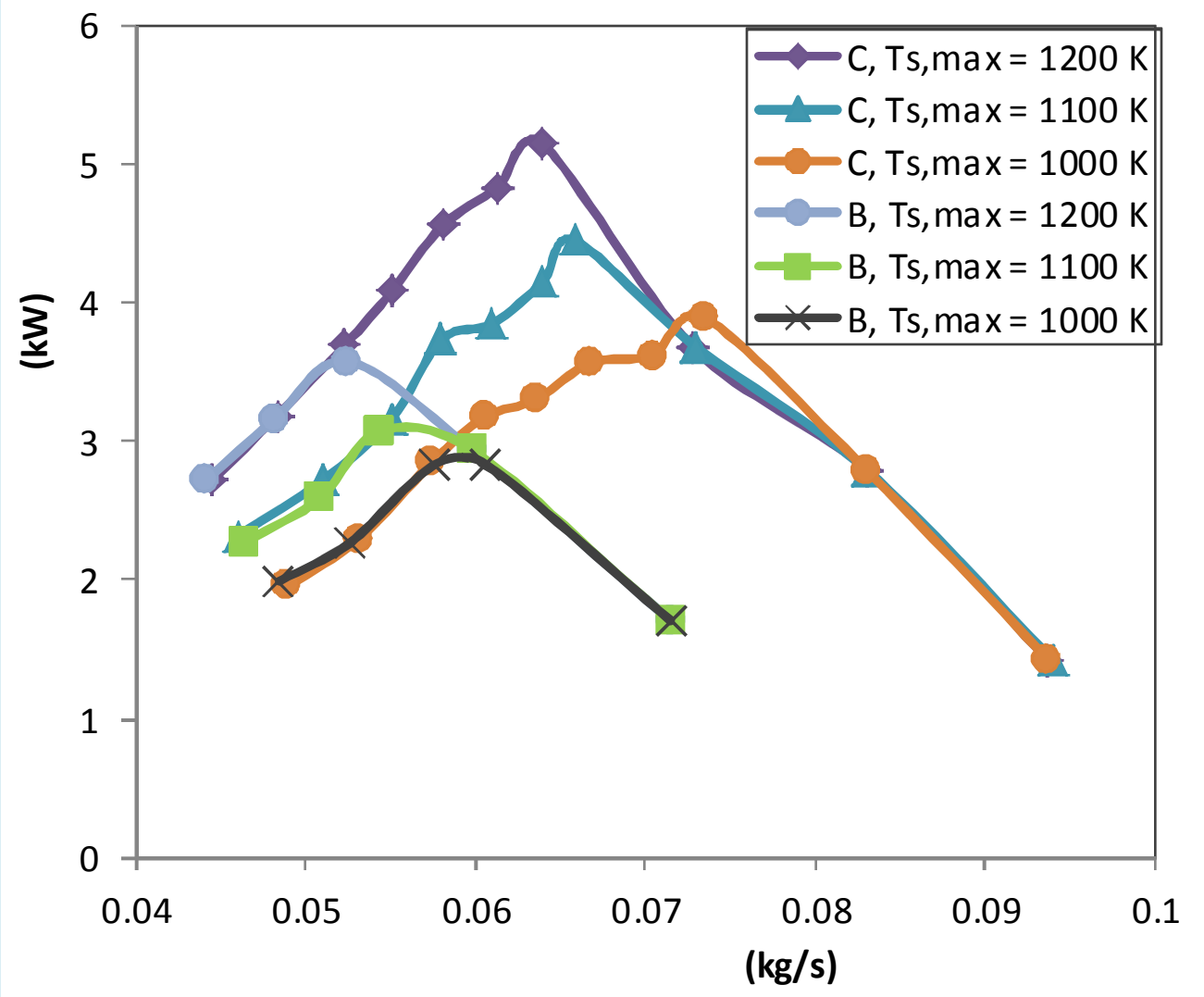


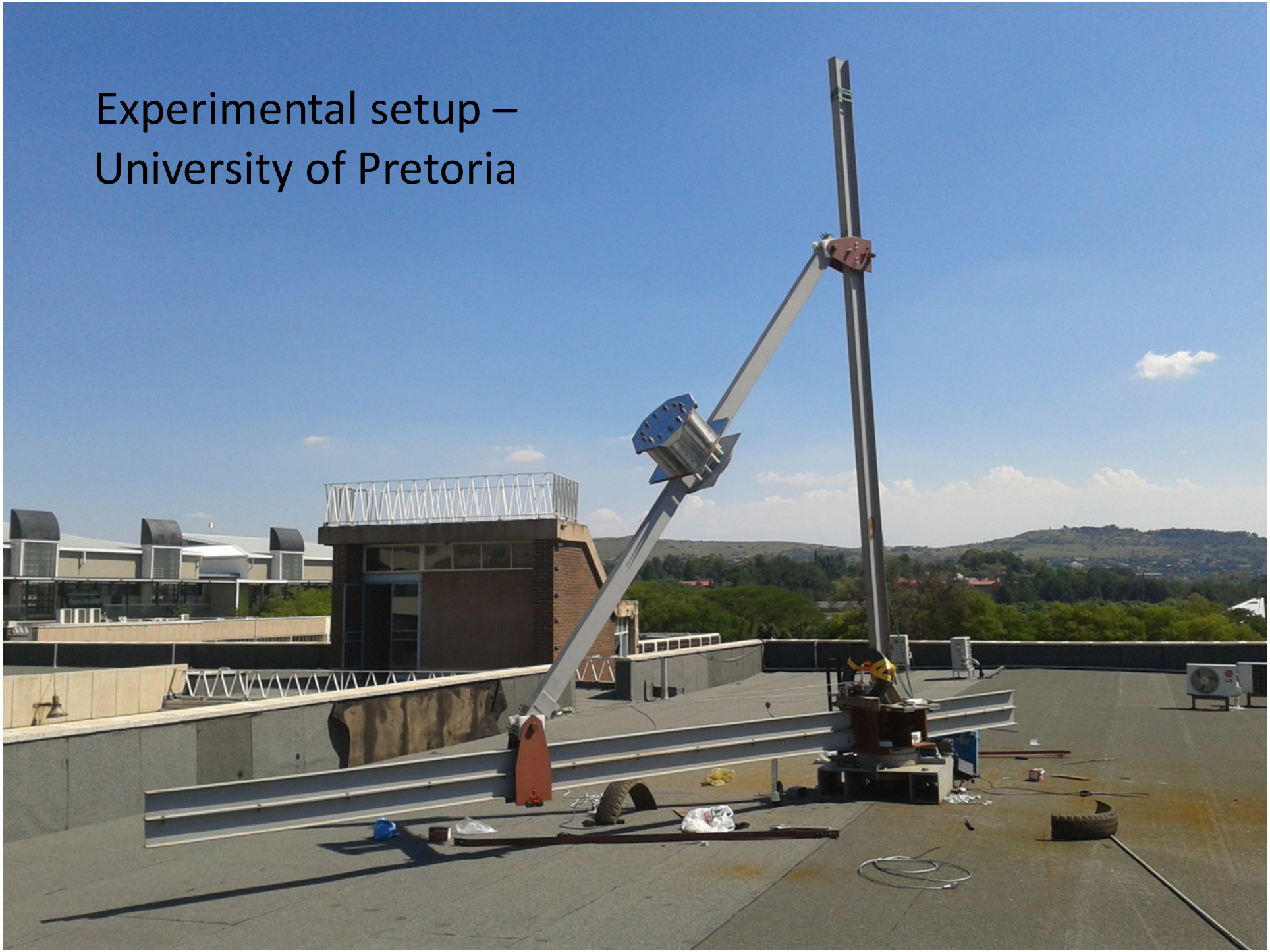


Research results – Maximum net power output as function of solar power and maximum receiver surface temperature



Research results – Maximum net power output as function of weather condition and maximum receiver surface temperature

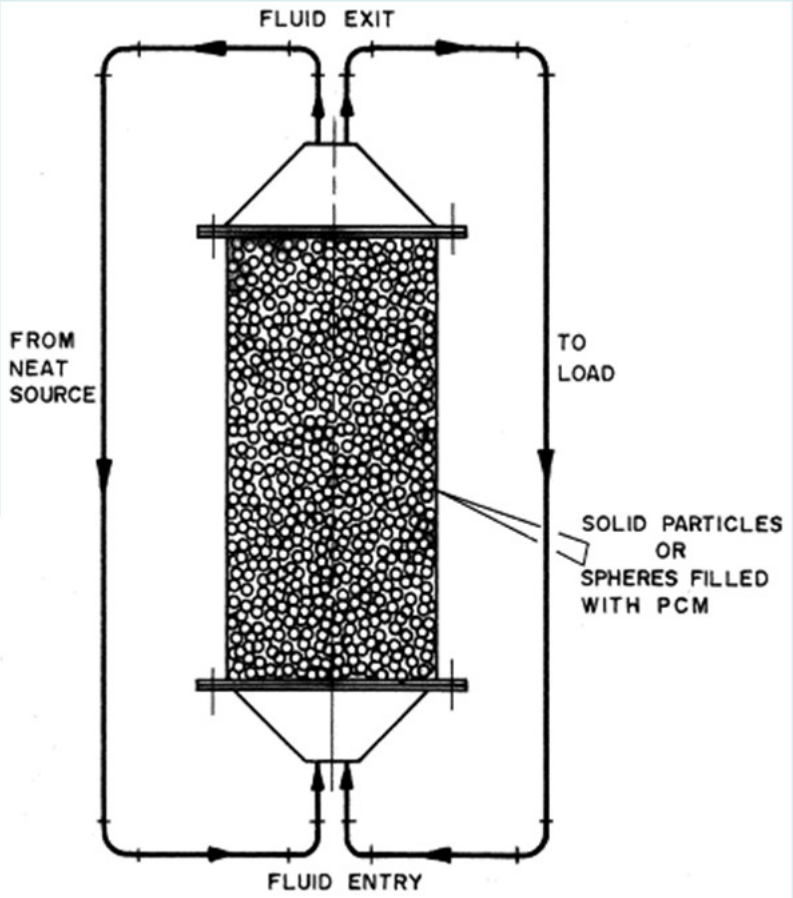


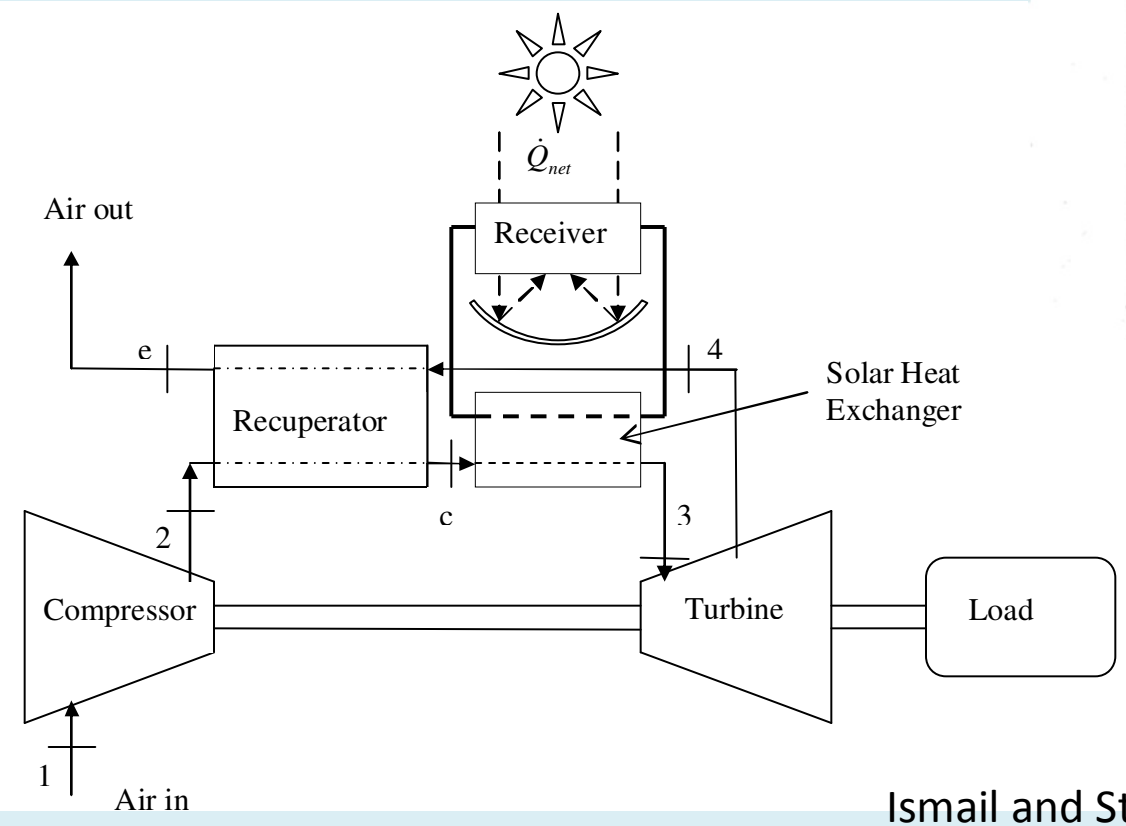

Experimental setup –
University of Pretoria

Experimental setup – University of Pretoria

For interest - Storage

- Batteries
- Rock storage
- Molten Salt





Ismail and Stuginsky (1999), Applied Thermal Engineering

For interest –
Large scale solar in South Africa

According to SASTELA

- Abengoa:
  - KaXu Solar One, a 100 MW parabolic trough plant with three hours of storage, close to Pofadder;
  - Khi Solar One, a 50 MW solar power tower with storage capacity of two hours, in Upington.

- Bokpoort CSP, a 50 MW parabolic trough power station with nine hours of storage, located near Groblershoop, by the Saudi group, ACWA, in partnership with South African solar and investment groups

- Eskom is developing a 100MW power tower plant with nine hours of storage in Upington; and

- The Department of Energy is investigating the feasibility of establishing solar power plants with capacity of up to 5 000MW in the Northern Cape.

Brayton – oversees – Solar CAT, Brayton Energy, Google

Questions?

- willemleroux@gmail.com