IKI SOLARPAYBACK
TRAINING ON SOLAR PROCESS HEAT IN SOUTH AFRICA

Main Components – Solar Collectors and Storage Systems

Dr. Wolfgang Kramer

Fanny Hübner

Fraunhofer Institute for Solar Energy Systems ISE

Online, January 27-28, 2021

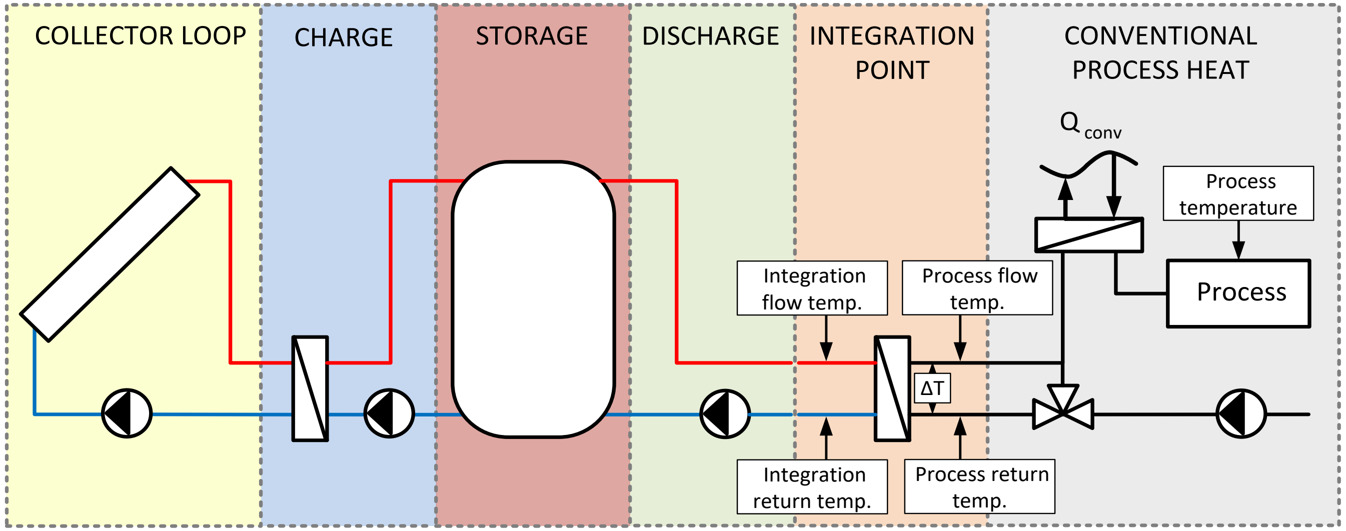
www.ise.fraunhofer.de

Fraunhofer ISE

Content

Main Components of a SHIP system
System components

- Solar irradiation is converted into heat in a solar collector field
- Heat is transported by a Heat Transfer Fluid (HTF)
- Stored in a Thermal Energy Storage (TES)
- Direct or indirect delivery through heat exchangers (HX)
- Pumps, valves and piping
- Control according to an implemented operation strategy



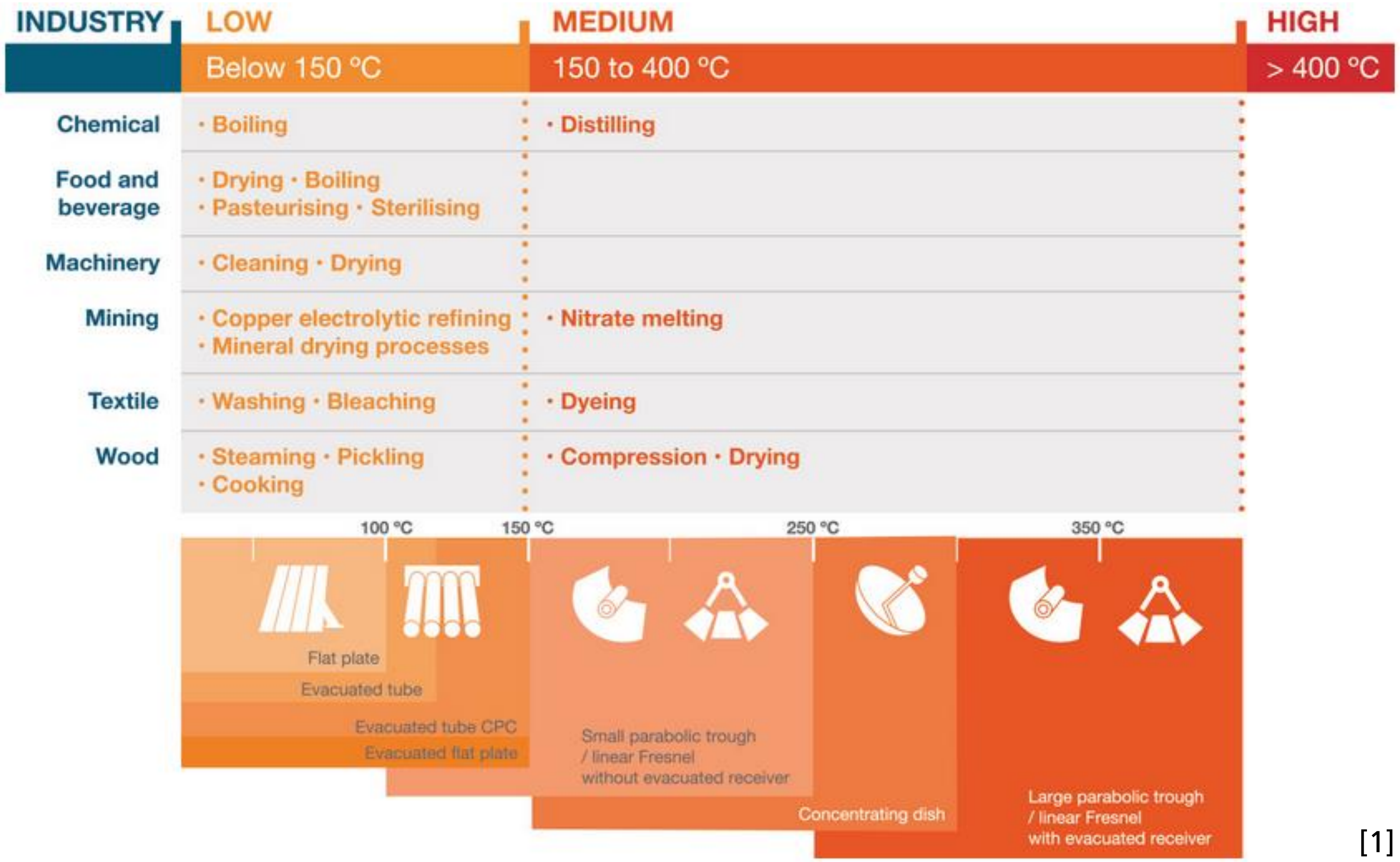
[1]

[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Fraunhofer ISE

Main Components of a SHIP system
Solar Thermal Collectors

- Selection of a specific solar collector technology is intrinsically related to the required temperature at the heat delivery point



[1]

[1] IEA TASK 49, https://www.solar-payback.com/markets/, Accessed October 2019

Fraunhofer ISE

Main Components of a SHIP system
Thermal Energy Storage (TES)

- Heat storage is required for mismatch between thermal energy supply and energy demand
- Commonly used TES are based on water:
  - Relatively inexpensive
  - Inconvenient when large volumes are required (static water pressure)
- Different types of TES are available:
  - Pressurized or non pressurized (atmospheric)
  - With internal or external heat exchanger

Fraunhofer ISE

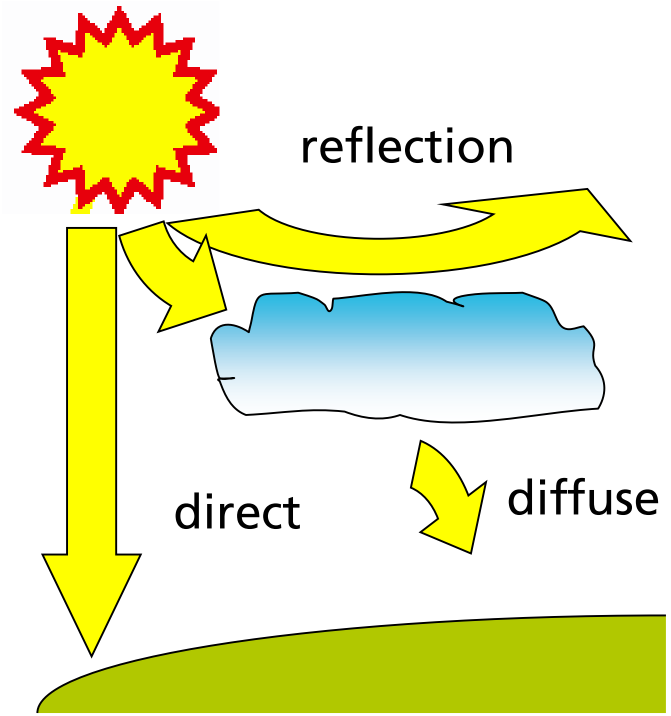
Main Components of a SHIP system
Controller

- Key function:
  - Monitoring and controlling temperatures with pumps and valves
  - Ensuring optimized way of delivering solar energy to the heat system
- Control strategy must be tailored according to the specific heat demand and might include the control of:
  - Mass flow and temperature level at the solar loop side
  - Heat delivery point and rate
  - Standard operation or safety operation modes
- Due to the variety of industrial processes:
  no standardized controllers for SHIP systems

Technologies of Solar Thermal Collectors
General Principles

- On the way through the atmosphere the direct sunlight attenuates
  - Scattering at gas molecules (Rayleigh)
  - Scattering at aerosols, water droplets, dust
  - Absorption at H_2O, CO_2, O_3, other gases
- ➢ Scattering results in diffuse radiation

- Global Radiation = Direct + Diffuse



Direct Normal Radiation DNI

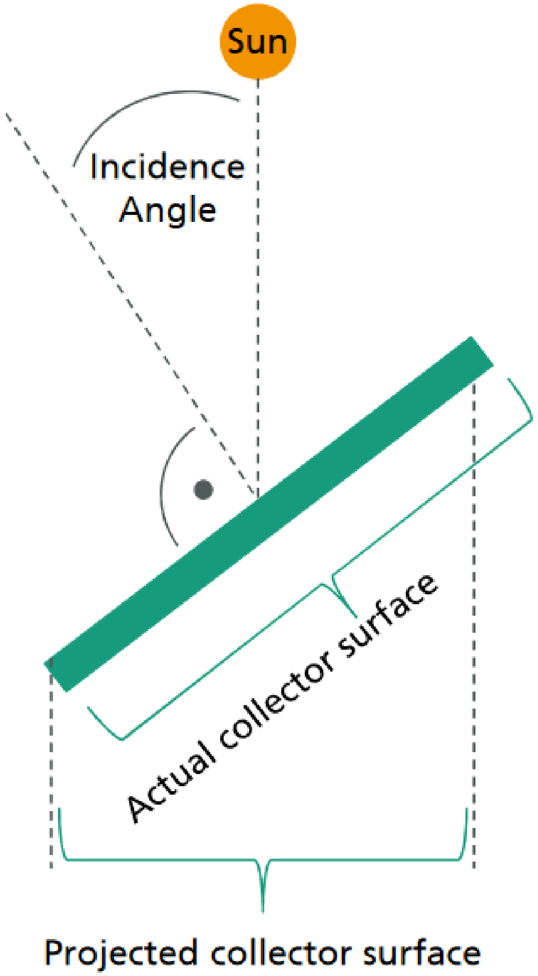
Diffuse Horizontal Radiation DHI

Fraunhofer ISE

Technologies of Solar Thermal Collectors
General Principles

- Optical losses
  - Due to reflectance, transmittance, absorbtance and geometry (Peak optical efficiency)
  - Cosine losses (depending on incidence angle) f = cos (IA)
  - Other optical losses due to surface errors (Incidence Angle Modifier)
  - Shading/Blocking
  - Etc. ...
- Thermal losses
  - Heat transfer to the ambient
  - Defined by absorber surface area and heat transfer coefficient

Cosine losses



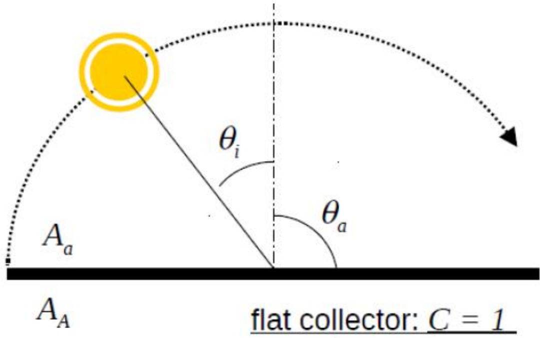
Technologies of Solar Thermal Collectors
General Principles – Stationary System

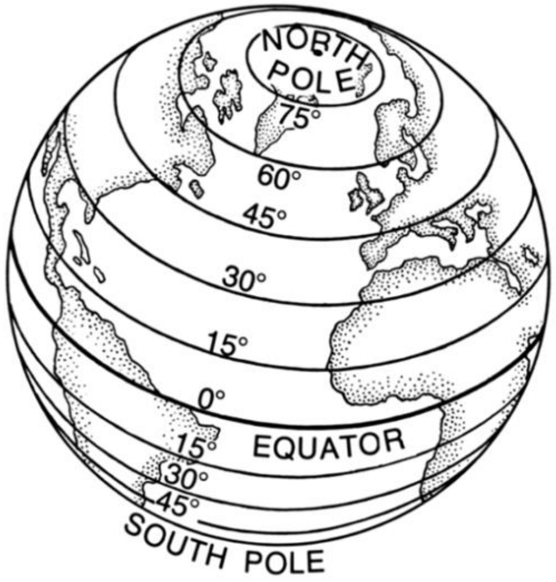
- Tilting the collector surface increases the area able to collect the radiation
- Depending on location, optimal tilt angle for collector increases solar gain
- The higher the latitude the higher the collector slope

- Rule of thumb for slope of stationary collectors:

$$slope[°] = latitude[°] - 10°$$

- In northern hemisphere: south orientation
- In southern hemisphere: north orientation

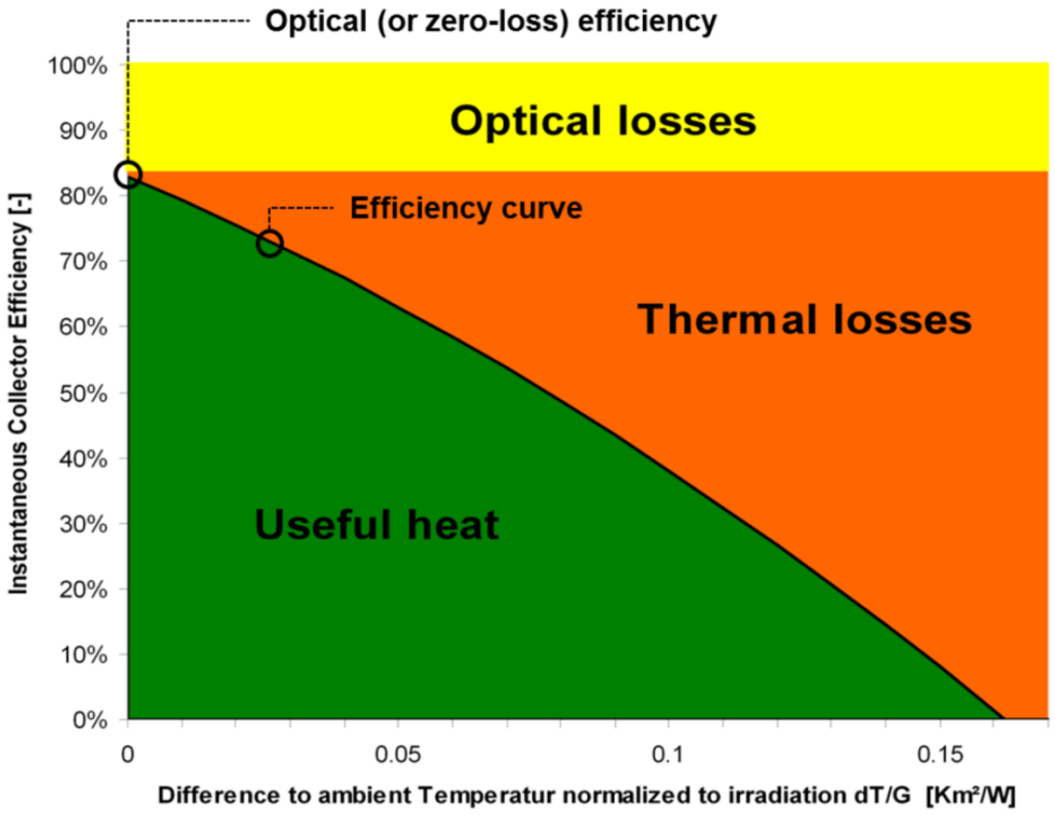




[1]

[1] Scott Foresman, 2007

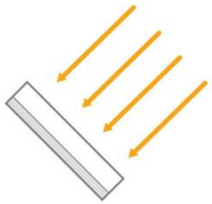
Technologies of Solar Thermal Collectors
General Principles



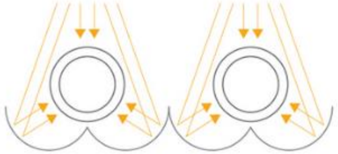
Technologies of Solar Thermal Collectors
General Principles

Stationary collectors (C < 2)

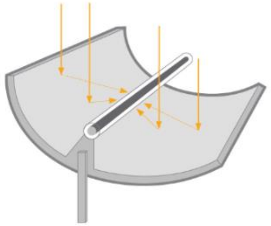
- Flat Plate Collectors FPC
  - (selective) flat absorber with optional flat glazing cover
  - T < 100 °C



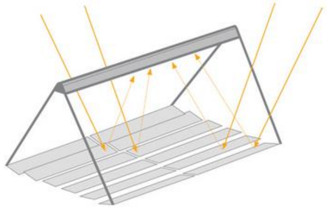
- Evacuated Tube Collectors ETC
  - Vacuum absorber tubes
  - T < 120 °C
- Compound Parabolic Concentrator
  - Stationary line-focus concentrator
  - T < 100-200 °C



Tracking collectors (C > 10)



- Parabolic Trough Collectors PTC
  - Parabolic Mirror
  - Line-focusing concentrator (One-axis tracking)
  - (Non-)evacuated absorber
  - 100 °C < T < 250/550 °C



- Linear Fresnel Reflector
  - Mirror segments
  - Line-focusing concentrator (One-axis tracking)
  - (Non-)evacuated absorber
  - 100 °C < T < 250/550 °C

- Dish Systems
  - Parabolic dish
  - Point-focusing concentrator (Two-axis tracking)
  - 100 °C < T < 300 °C

[1]

[1] Images: Solar collectors, https://www.solar-payback.com/technology/, Accessed October 2019

Fraunhofer ISE

Technologies of Solar Thermal Collectors
Question

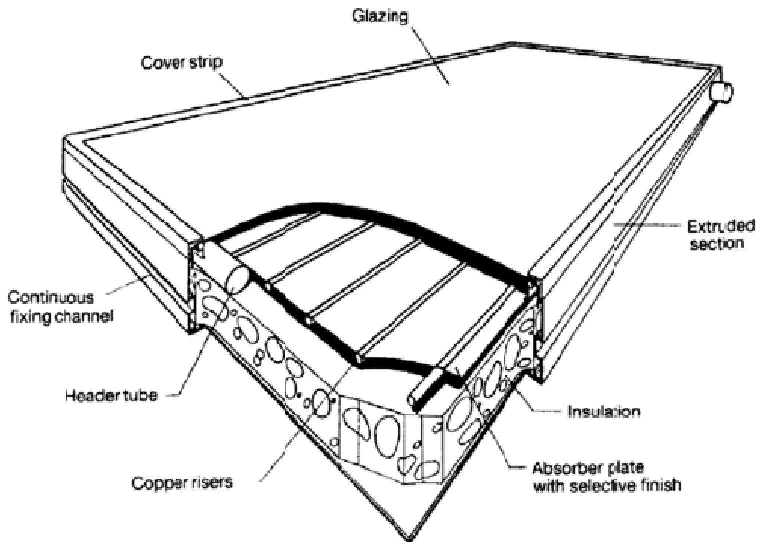
- Which kind of solar collectors have you already seen in reality?

https://forms.gle/oh4mwEpDSBJu8oWu9

Technologies of Solar Thermal Collectors

Flat Plate Collectors

- Commonly used for temperatures in the range of 30 °C to 100 °C

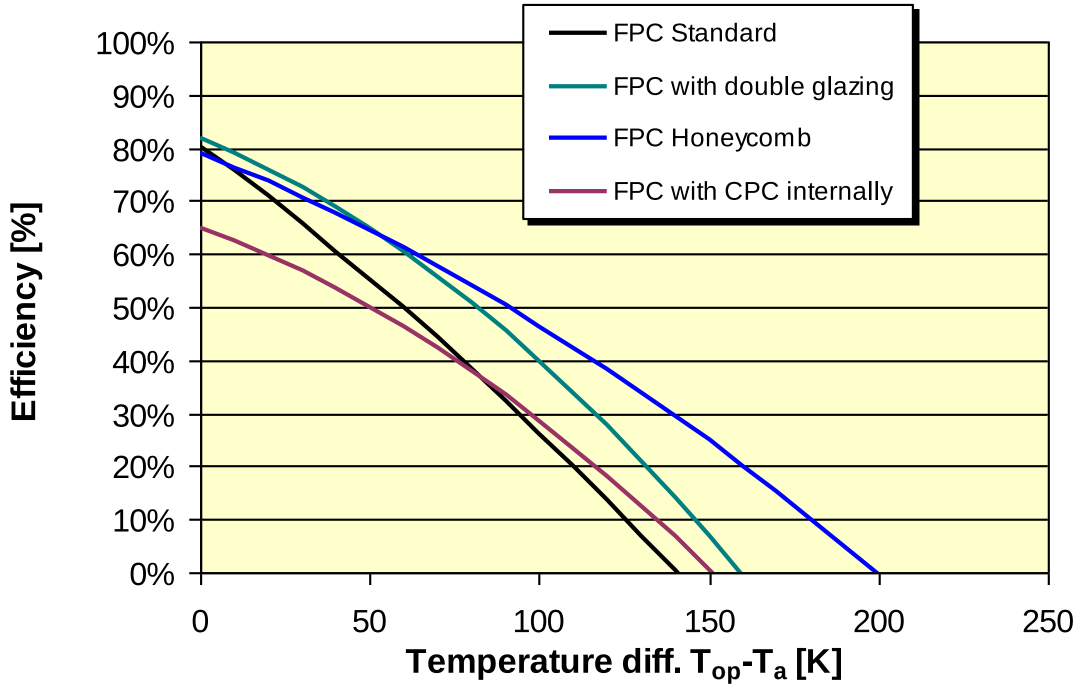


- Absorber tubes through which working fluid flows covered by absorber sheet and a transparent cover
- Coating on the absorber converts the solar irradiation to heat which is transferred to the working fluid in the tubes
- Usual fluid is water/glycol mixture (with some additives) in order to avoid corrosion and frost damages
- Simple to use, little maintenance and relatively cheap

Source: gef, UNEP, ome; Technical Study report on SHIP, State of the art in the Mediterranean region

Technologies of Solar Thermal Collectors
Flat Plate Collectors

- Improved Medium Temperature Flat-Plate Collectors
  - Reduced heat losses
    - double glazed, AR coatings
  - Operation temperature
    - up to 100°C for flat-plate
  - Improvement of optical efficiency difficult



Efficiency for Irradiation 850 W/m², IAM=1

Fraunhofer ISE

Technologies of Solar Thermal Collectors
Flat Plate Collectors

- Double Glazed Flat Plate Collectors → Operating temperatures up to 120°C
- Supplier:
  - Schüco CTE 524 DH 2 double AR-glazing
  - Arcon HT-SA 28/10 AR-glass+ETFE-film
  - Solid „Gluatmugl HT" AR-glass+ETFE-film

Desalination system for capacities up to 2000 l/day, 90 m², Gran Canaria

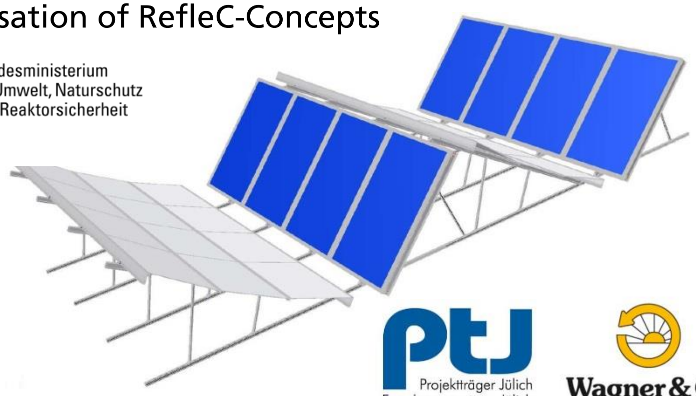
Fraunhofer ISE

Technologies of Solar Thermal Collectors
Flat Plate Collectors

- Development of high efficiency FPC with reduced heat losses
  - External reflector
  - Working temperatures 80 °C to 150 °C (medium temperature range)

Visualisation of RefleC-Concepts

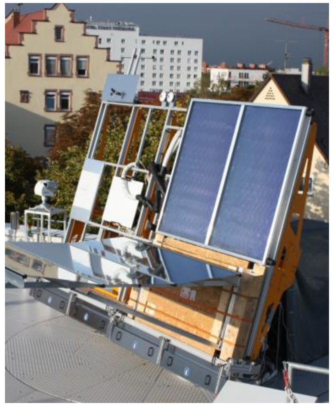
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

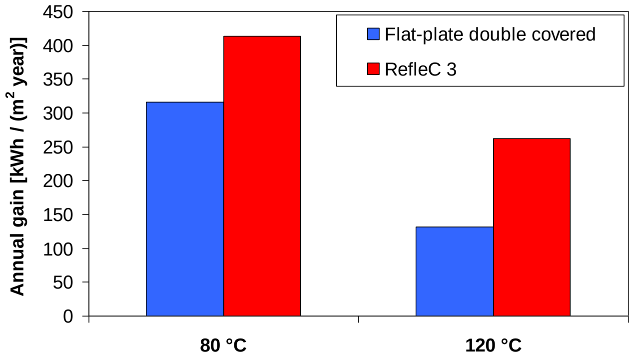


PtJ Projektträger Jülich Forschungszentrum Jülich

Wagner & Co

Prototype on tracker facility at Fraunhofer ISE





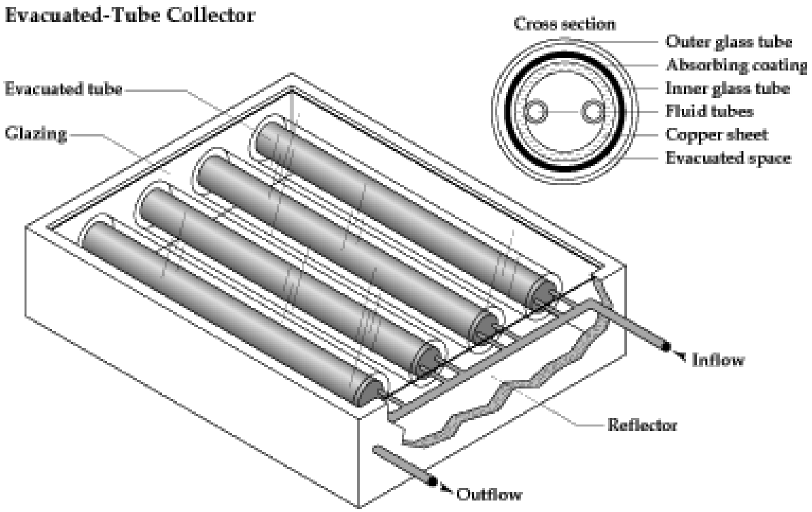
Simulation of collector for Würzburg, Germany. Based on measured thermal efficiency and IAM-values.

Fraunhofer ISE

Technologies of Solar Thermal Collectors

Evacuated Tube Collectors

- ETC can achieve higher temperatures than FPC ranging from 50 to 120°C

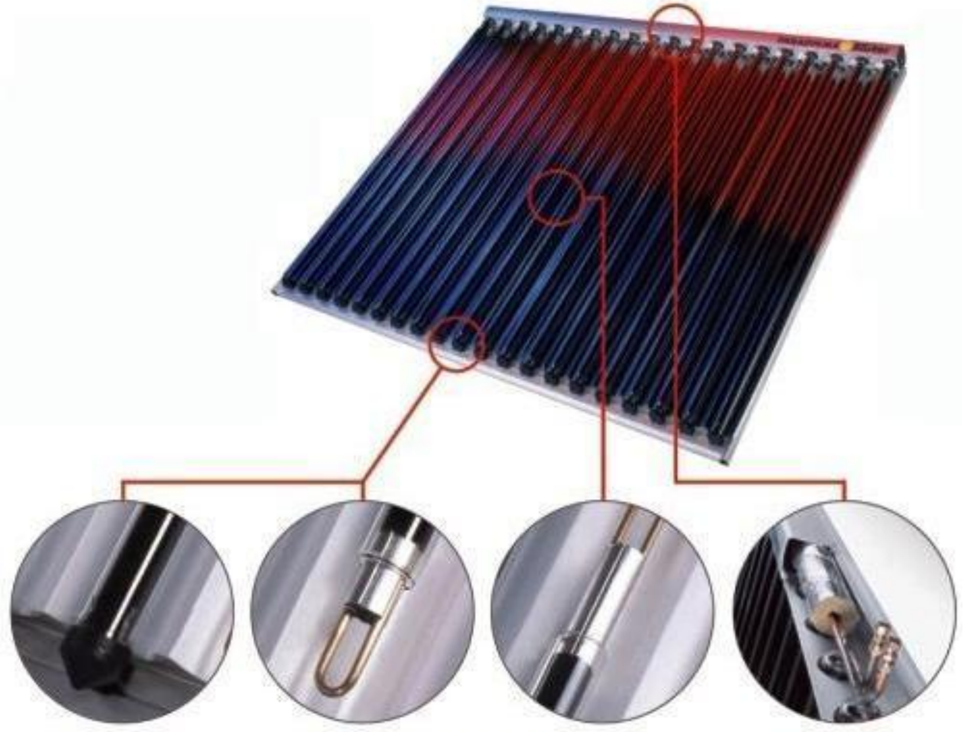


- Consists of a row of parallel vacuum glass tubes
- Absence of air highly reduces convection and conduction losses
- 2 categories of ETC:
  - Direct flow principle: the heat transfer fluid of the collector loop flows directly through the absorber via a co-axial tube
  - Heat pipes principle: the heat of the absorber is transferred to the heat transfer fluid of the collector loop via a heat pipe system (Figure 5 right)

Source: gef, UNEP, ome; Technical Study report on SHIP, State of the art in the Mediterranean region

Technologies of Solar Thermal Collectors
Evacuated Tube Collectors

- Compound Parabolic Concentrator ETC
  - Low concentration CPC (C < 2)
    - Evacuated tubes CPC collectors which can deliver up to 200°C
    - Stationary collector – CPC is designed in a way that all solar positions during a year are accepted by the concentrator
  - Bridges the gap between the lower temperature application FPC (<80°C) to the higher temp. applications of concentrators (T>200°C)


CPC solar collector

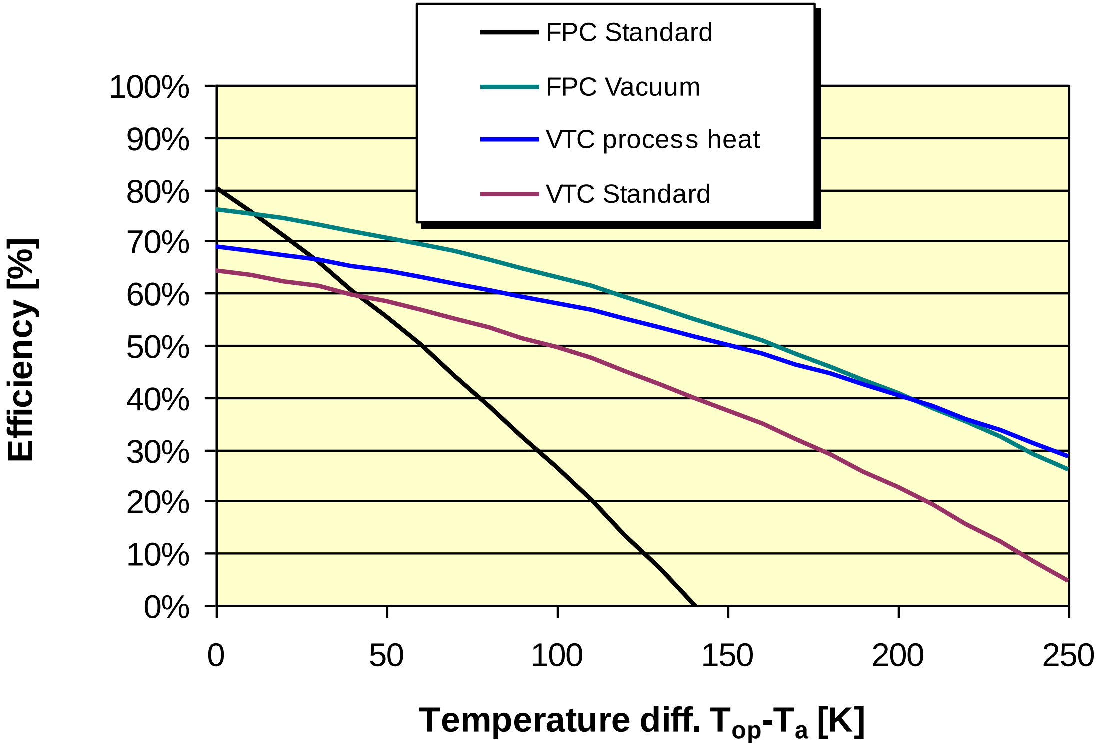
[1]

[1] Figure: http://image.tradevv.com/2010/11/18/linuosolar001_1741789_600/cpc-solar-collector.jpg

Technologies of Solar Thermal Collectors

Comparison ETC vs FPC

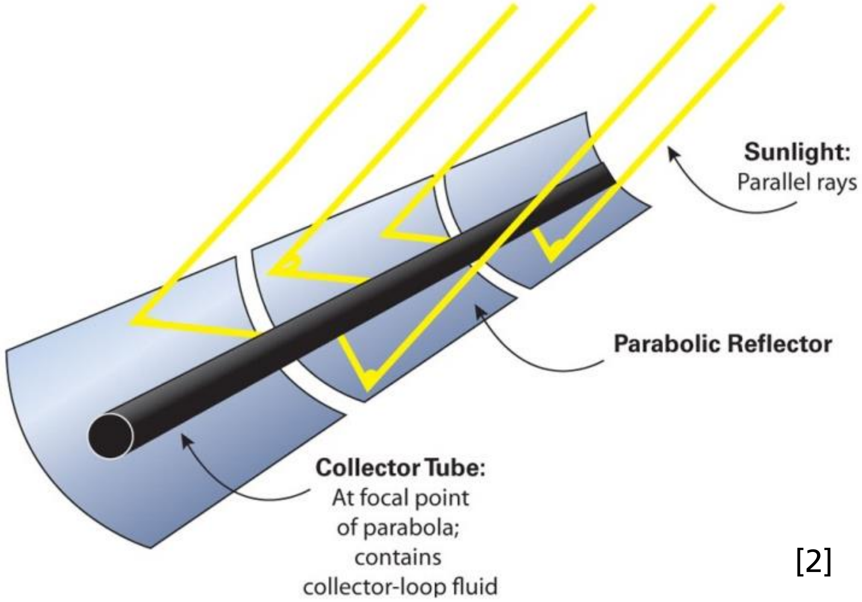
- Flat plate vacuum collector TVP MT-Power
  3rd prize INTERSOLAR 2012
- Vacuum tube collector for process heat
  Paradigma AQUA PLASMA
- Vacuum reduces heat losses substantially
  → operation temperatures
  160°C – 200°C feasible
  dependent on collector



Efficiency for Irradiation 850 W/m², IAM=1
(Values for TVP based on manufacturers data)

Technologies of Solar Thermal Collectors
Parabolic Trough Collectors

- Parabolic mirrors focus only direct sunlight onto an absorber tube



[2]

- Designed to track the sun along one axis oriented in the north-south or east-west direction
- Reflecting surface normally a curved glass mirror or an aluminium sheet
- Water or thermal oil usually used as working fluid
- Receptor consists of an absorber tube of an area usually 25 to 35 times smaller than the aperture

Source: gef, UNEP, ome; Technical Study report on SHIP, State of the art in the Mediterranean region
[2] http://www.homepower.com/sites/default/files/articles/ajax/docs/12_HP133_pg70_Marken-6.jpg

Technologies of Solar Thermal Collectors
Parabolic Trough Collectors

- Project NEP Solar: 230kW Solar Cooling, Australia

[1]

- Aperture: 345m² (PolyTrough 1200)
- Peak Thermal Power: 200kW
- Outlet Temperature: 180°C
- HTF: Water
- Application/End Use: Air conditioning

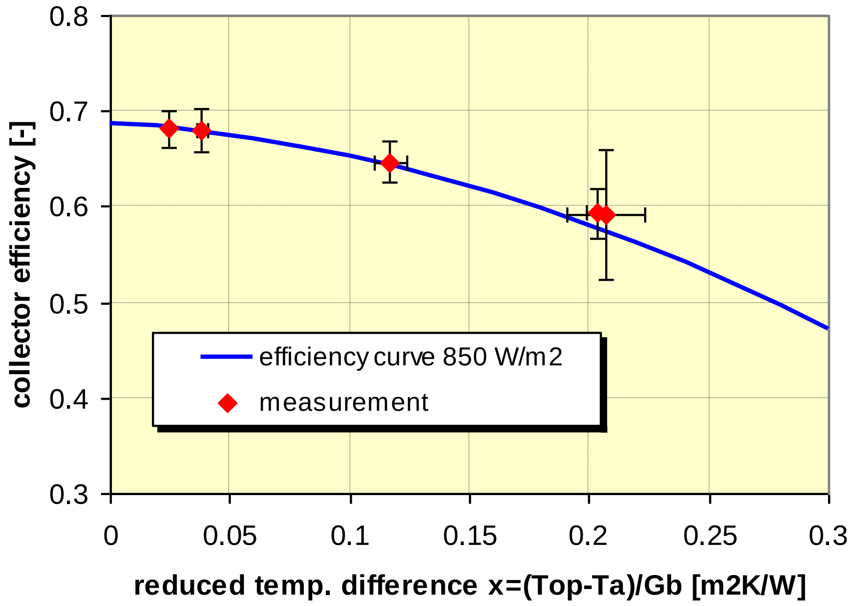
- Commissioning: April 2011

[1] http://www.nep-solar.com/

Technologies of Solar Thermal Collectors
Parabolic Trough Collectors

- Solitem (Germany) – Trough PTC1800

[1]



[1] www.solitem.com

Technologies of Solar Thermal Collectors
Parabolic Trough Collectors

- Soltigua (Italy) - PTM parabolic trough collector
  - Technical features
    - Modular design
    - Surface = 13.5 m²/module
    - Length = 6.2 m/module
    - Cord = 2.4 m
    - Peak power = 570 W/m2 (7.7 kW/module @DNI of 1000 W/m², T_{amb}= 30°C, T_{out} = 200°C)
    - Up to 4 modules driven by the same motor (n.1 PTM24):
    - 25 m long / 54 m² / 31 kWpeak

TECHNOLOGICAL EXCELLENCE

In 2010 PTM has been awarded the **"Towards the A-class building"** prize at the at MCE2010, Europe's largest trade fair for heating and air conditioning.

The prize was given to the best innovations for building energy systems.

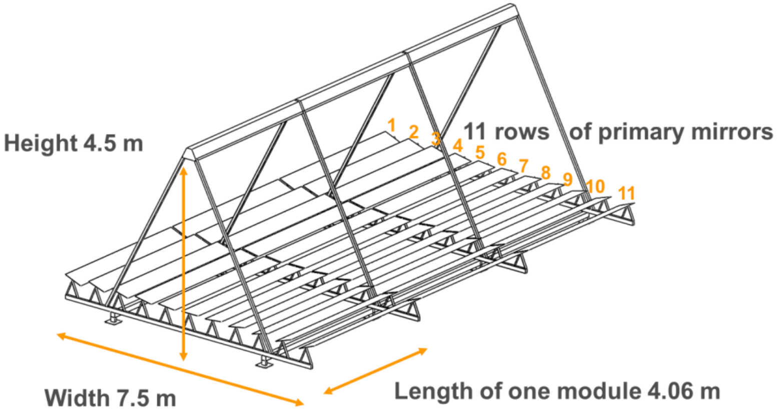
Fraunhofer ISE

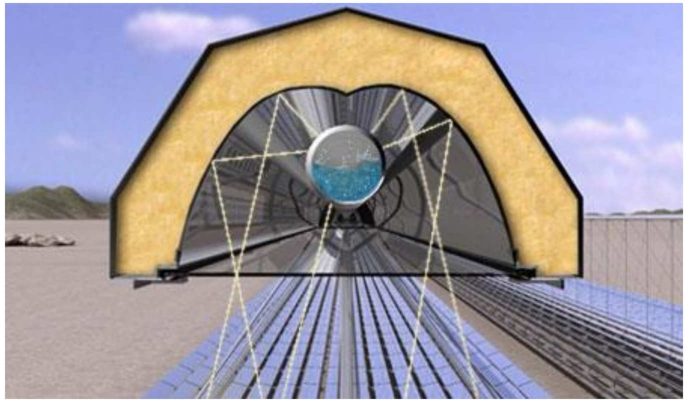
Technologies of Solar Thermal Collectors
Parabolic Trough Collectors

- Solarlite (Germany)
  - Production of PTC collectors
    2300 and 4600 for:
    - process heat
    - concentrated solar thermal power
  - 2.3 m and 4.6 m aperture
  - Operation up to 400°C / 55 bar
  - 12m segment
  - Variable size of plant
  - Costs comparable with larger CSP collectors instead of small plant size

Technologies of Solar Thermal Collectors
Linear Fresnel Collectors

- Many nearly flat mirror facets instead of one parabolic mirror
- Receiver/Absorber is above mirror rows, which track the sun





  - High concentration ratio and temperatures up to 400°C
  - Thermal capacity from 50 kW up to several MW
  - Easy to mount on flat roofs as a result of good weight distribution and high wind resistance
  - Water/steam or thermal oil usually used as working fluid
  - High surface coverage, efficient land use

Source: Industrial Solar Gmbh

Technologies of Solar Thermal Collectors
Linear Fresnel Collectors

- Industrial Solar GmbH (Freiburg, Germany)
  - Geometrical features
    - Length: modular in steps of 4 m
    - Total width: 7.5 m
    - Aperture width: 5.5 m
    - Height: 4 m
  - Weight: 27 kg/m²
  - Peak power: 560 W/m²
  - Max. temp.: 400 °C

INDUSTRIAL SOLAR
thermal solutions

Fraunhofer ISE

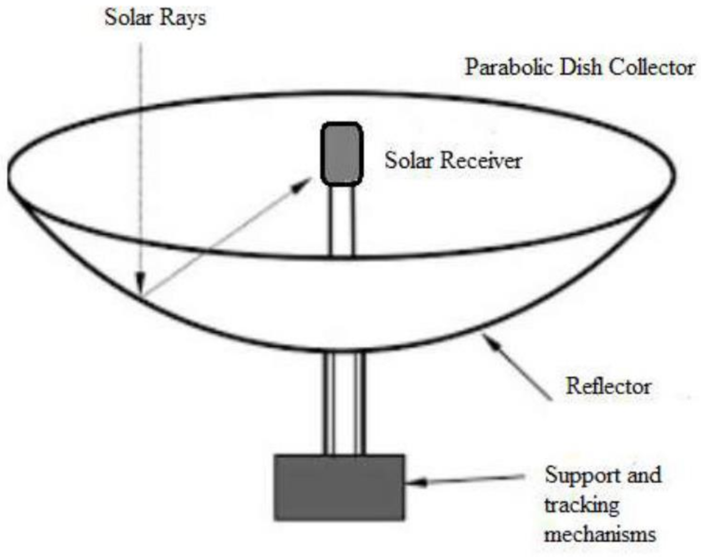
Technologies of Solar Thermal Collectors
Linear Fresnel Collectors

- New developments
  - Further development: Soltigua (Italy), SUNCNIM(France), Thermax (India), Lotus (Egypt), KG Group (India), others…

DSG Pilot Plant in La Seyne Sur Mer, France

Technologies of Solar Thermal Collectors
Dish Systems

- High operating temperatures up to 500 °C

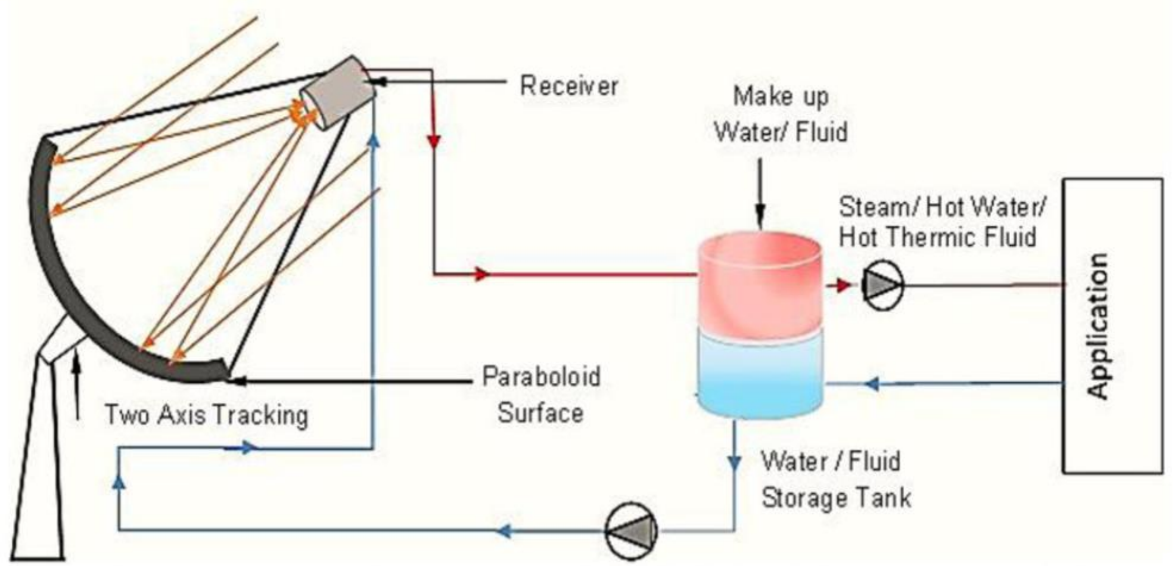


- High optical and thermal efficiency
- Concentration ratio 600 - 2000
- Reflector dish focuses sunlight onto central focal point
- Parabolic mirror or mirrors facets
- Modular collector and receiver
- Wooden, steel or aluminum frames

Source: IRENA-ETSAP Technology Brief, January 2013

Technologies of Solar Thermal Collectors
Parabolic Dish Systems

- Two-axis tracking
- Incidence Angle = 0
- Receiver is tracked



Schematic Diagram of CST System with Paraboloid Dish (Courtesy: CSH India)

Megawatt Solution
(90 m²)

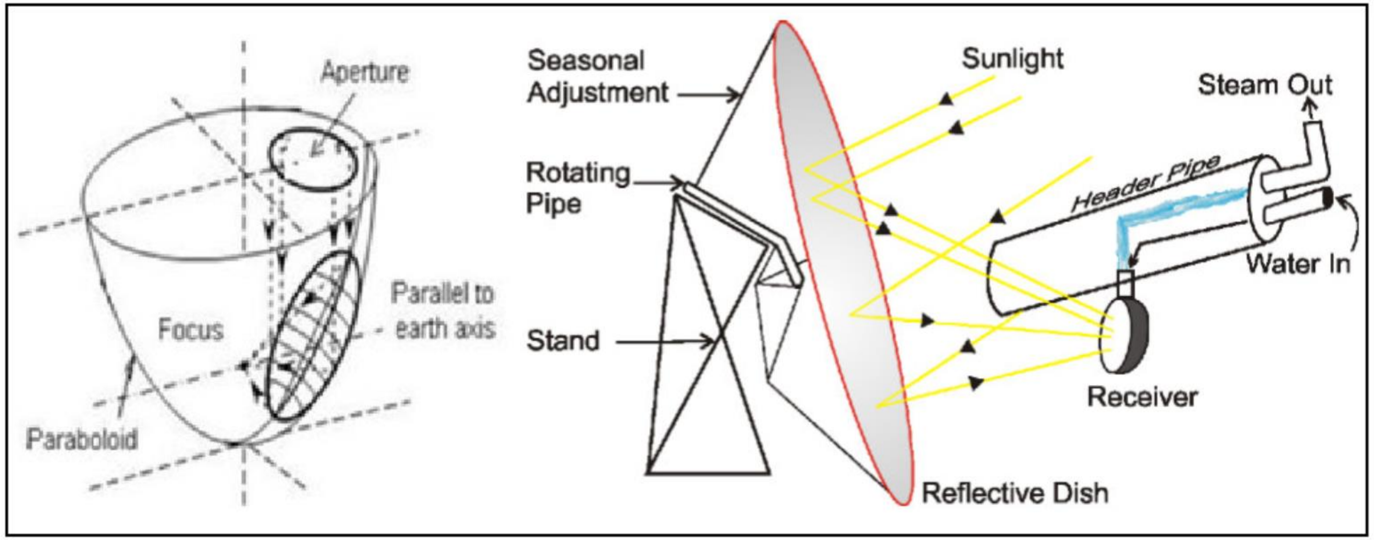
Big Dish at ANU
(482 m²)

Source: https://cecs.anu.edu.au/news/get-close-and-personal-big-dish-anu

Fraunhofer ISE

Technologies of Solar Thermal Collectors
Scheffler Dish Systems

- Application:
  - Low- medium process heat applications
  - Solar cooking
- Scheffler dish
  - Fixed focal point
  - Bending and rotation for efficient tracking



Scheffler Dish [1]

[1] Material and Component Specifications-Fixed Focus Automatically Tracked Elliptical Dish, IT Power India, 2015
[2] Scheffler Dish based Solar System Operations & Maintenance Manual, MNRE, 2014

Technologies of Solar Thermal Collectors
Question

- Which is the appropriate thermal collector technology for the following Temperature
- 50°C ?
- 220° C ?

https://forms.gle/X2EWsQTCZeTVTxjD6

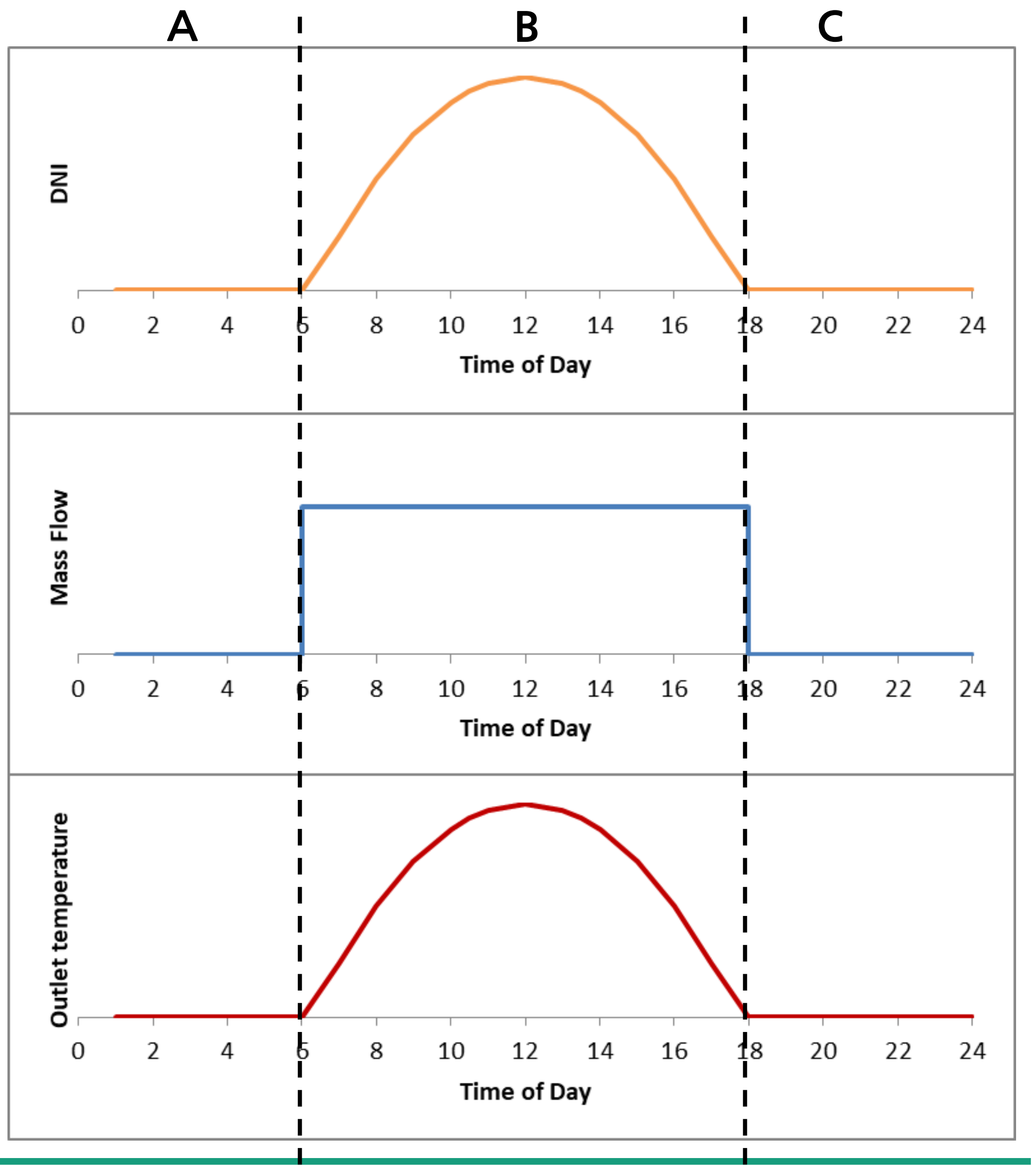
Content

- Main Components of a SHIP System
- Technologies of Solar Thermal Collectors
  - General Principles
  - Types of collectors
- Control
- Thermal Storage
- Summary

Fraunhofer ISE

Mass Flow Control
Fixed Speed Pumps

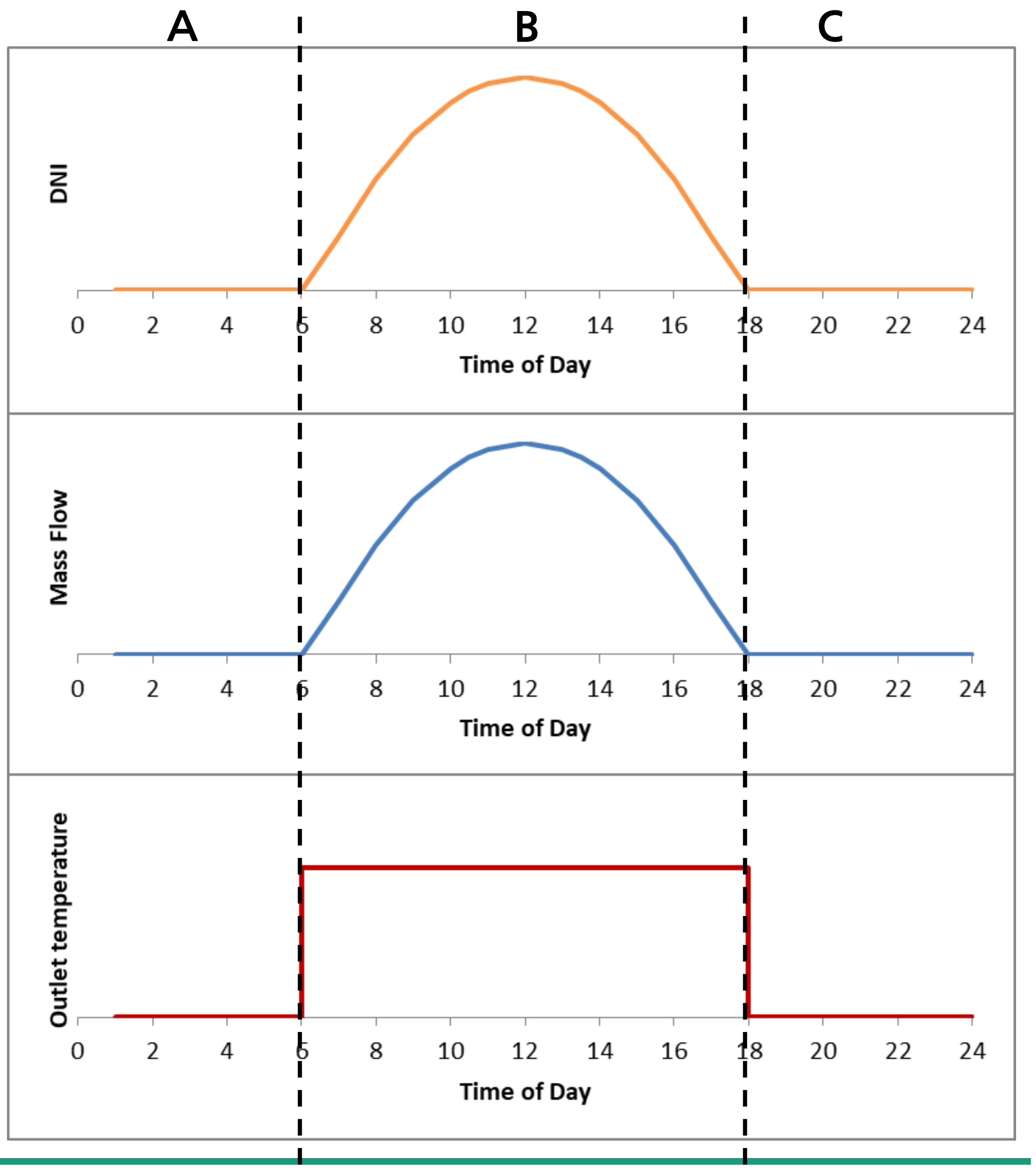
- Phase A:
  No DNI, mass flow = 0
- Phase B:
  DNI, mass flow constant, temperature rises with DNI
- Phase C:
  No DNI, mass flow = 0



Fraunhofer ISE

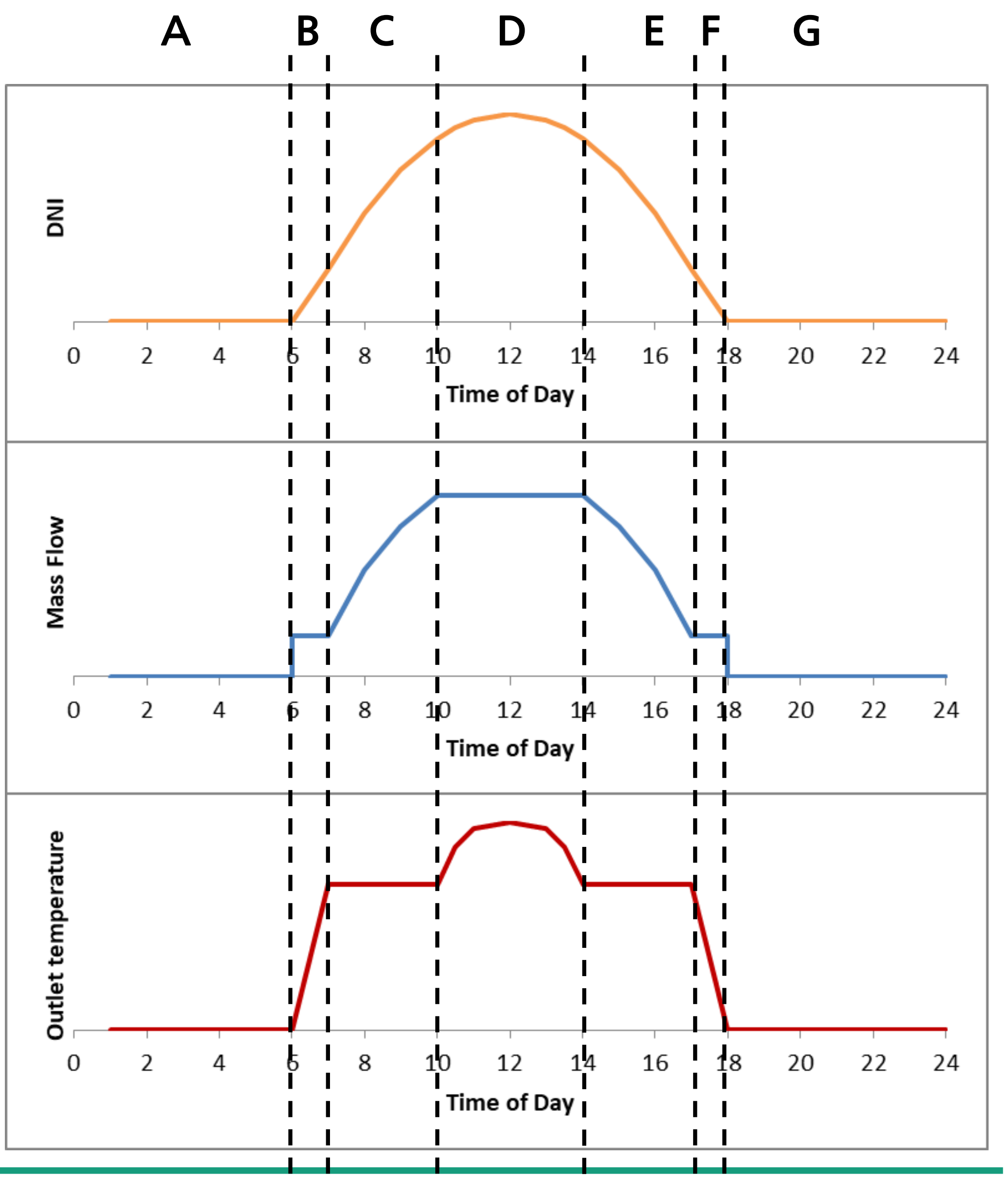
Mass Flow Control
Variable Speed Pump

- Phase A:
  No DNI, mass flow = 0
- Phase B:
  DNI, mass flow controls temperature at set point
- Phase C:
  No DNI, mass flow = 0



Mass Flow Control
Stationary Systems

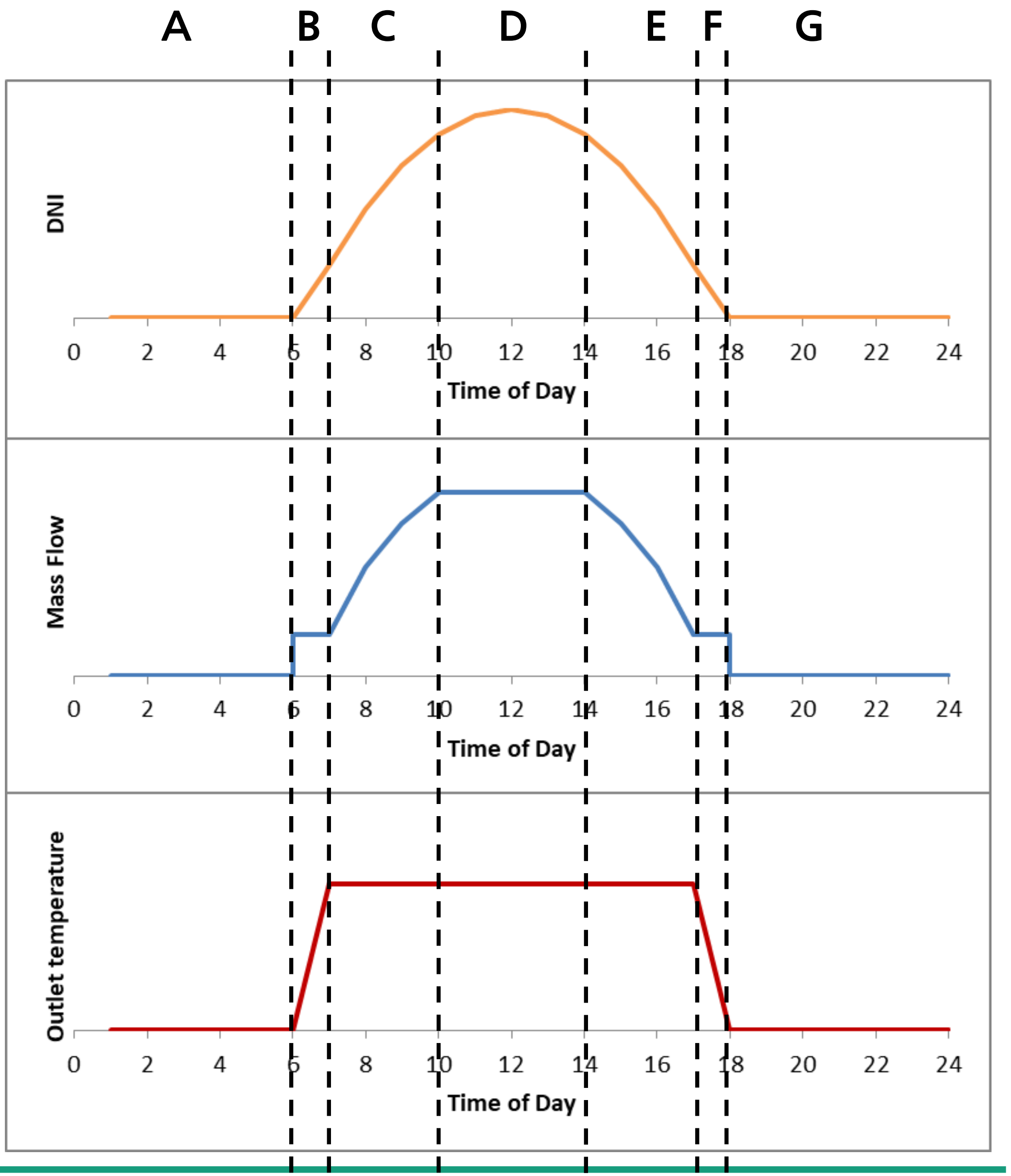
- Phase A:
  No DNI, mass flow = 0
- Phase B:
  Low DNI, minimum mass flow, temperature below set point
- Phase C:
  DNI, mass flow controls temperature at set point
- Phase D:
  DNI, maximum mass flow, temperature above set point, possible stagnation
- Phase E:
  DNI, mass flow controls temperature at set point
- Phase F:
  Low DNI, minimum mass flow, temperature below set point
- Phase G:
  No DNI, mass flow = 0



Fraunhofer ISE

Mass Flow Control
Tracking Systems

- Phase A:
  No DNI, mass flow = 0
- Phase B:
  Low DNI, minimum mass flow, temperature below set point
- Phase C:
  DNI, mass flow controls temperature at set point
- Phase D:
  DNI, maximum mass flow, temperature at set point due to defocusing
- Phase E:
  DNI, mass flow controls temperature at set point
- Phase F:
  Low DNI, minimum mass flow, temperature below set point
- Phase G:
  No DNI, mass flow = 0



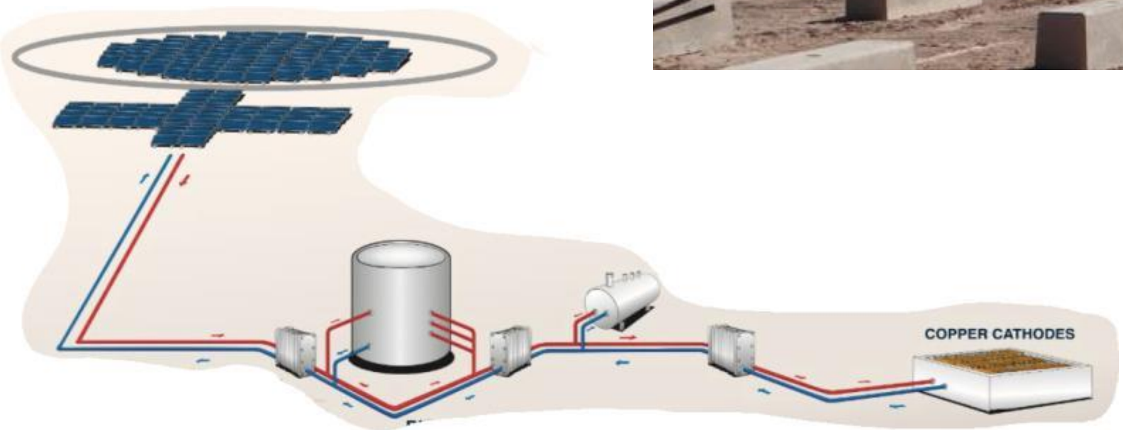
Content

Thermal Storage
Water Storage

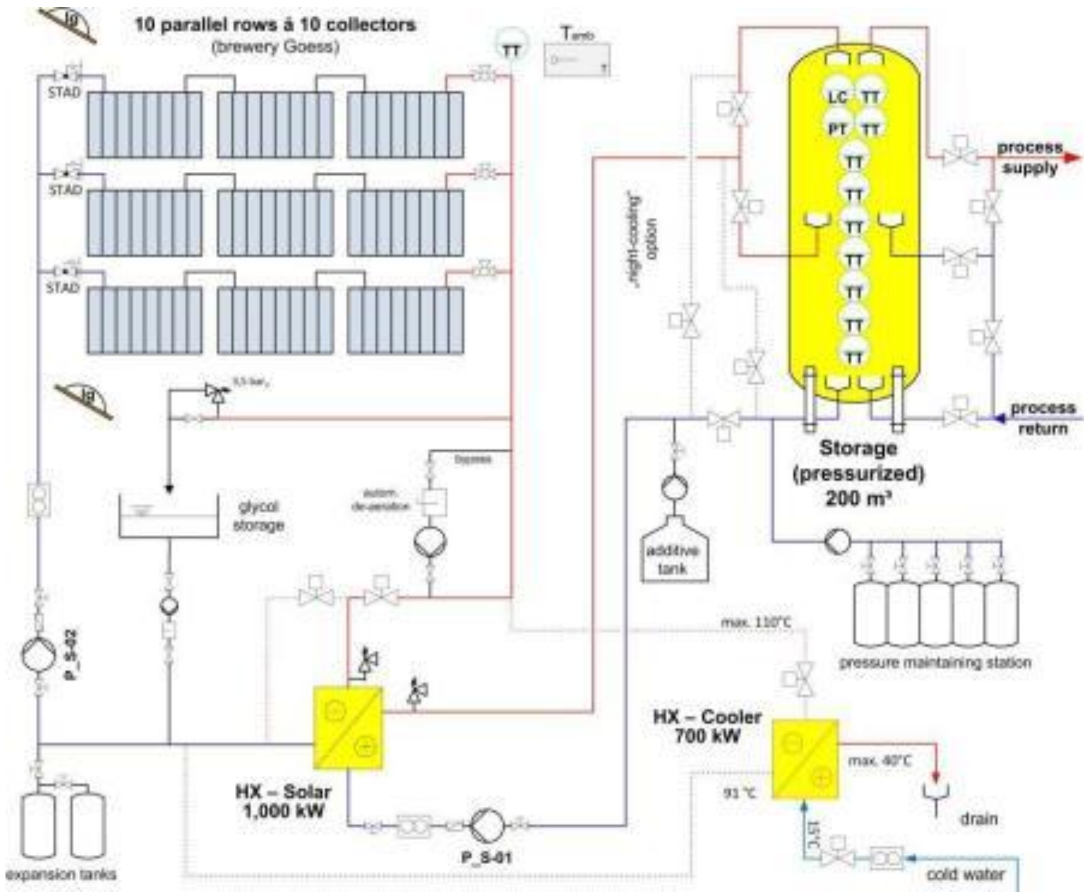
- Unpressurized Tmax < 90°C
- Pressurized Tmax > 90°C
- Steel vessels with insulation
- The standard solution for Solar Process Heat Systems (SPHS) is water storage
- Other fluids are thermal oil and molten salt for higher temperatures

Thermal Storage
Water Storage

- Example: Copper mine "Gabriela Mistral", Chile, non-pressurized water storage
  - Volume: 4300 m³
  - 39,300 m² FPC
  - 85-100% solar fraction
  - electro winning of copper
  - electrolyte kept at 50°C
  - cleaning processes



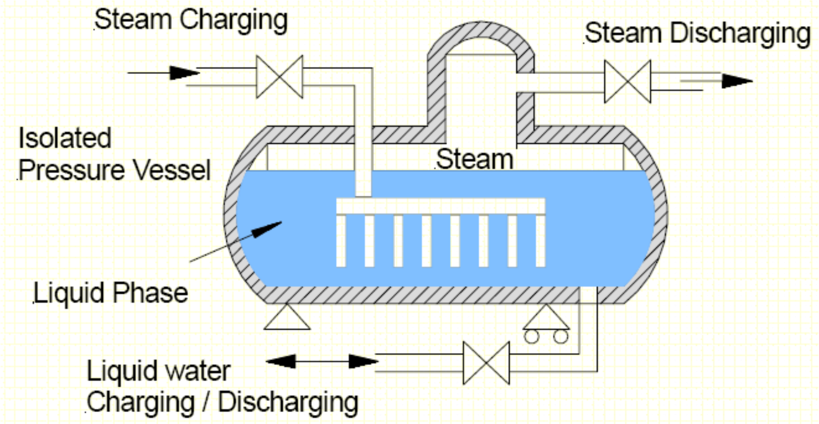
- Example: Brewery Göss, Austria, large pressurized water storage (200 m³)



Fraunhofer ISE

Thermal Storage
Steam Storage

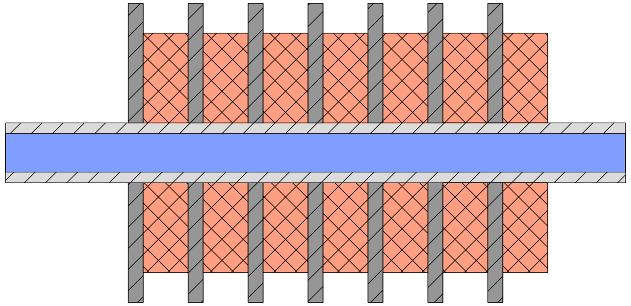
- Ruths Storage
  - Pressurized water for water-steam systems
  - Thermal capacity is proportional to ΔT
  - High investment cost due to expensive pressure vessel
  - No option for large-scale / high-pressure applications



Ruths storage (©DLR)

Thermal Storage
Steam Storage

- Latent heat storage with Phase Change Material PCM
  - Traditional approach: Sandwich configuration
  - Heat transport from HTF into PCM with low conductivity (λ=0,5 W/mK)
  - Lamellae from graphite / aluminum
  - Large heat exchanger area
  - high costs, further R&D necessary

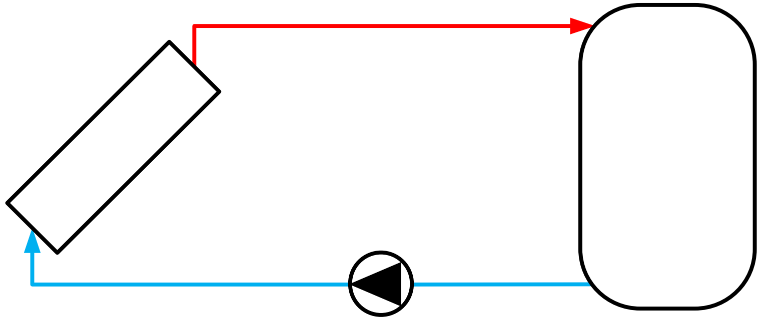


Fraunhofer ISE

Thermal Storage
Charging Concepts

Direct charging without heat exchanger

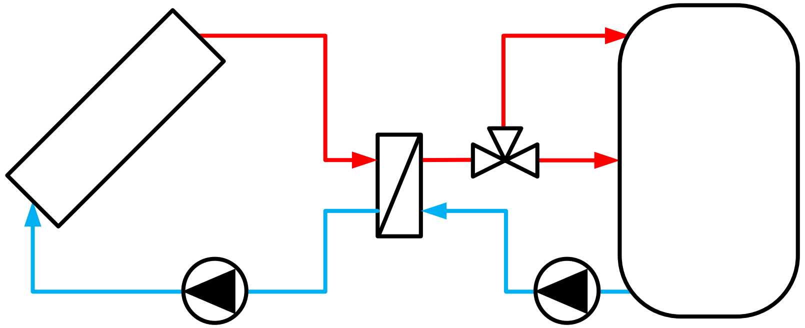
- Cheap and robust
- Collector fluid is storage fluid
- Unwanted discharge of storage by solar loop difficult to avoid



[1]

External heat exchanger with stratification valve

- Different media in collector field and storage
- More complex
- Stratification valve controls storage inlet height by charging flow temperature (optional)



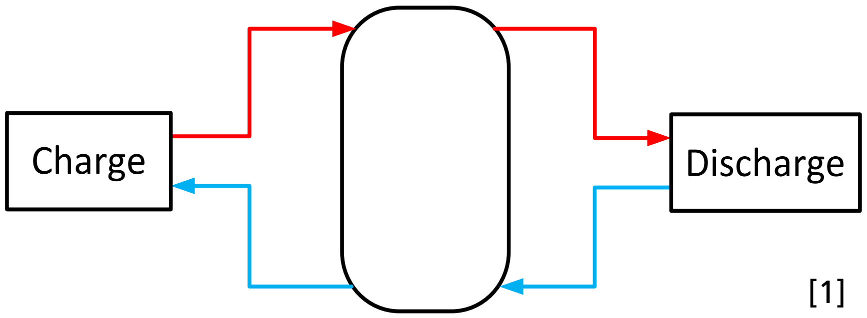
[1]

[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Thermal Storage
Interconnection Concepts

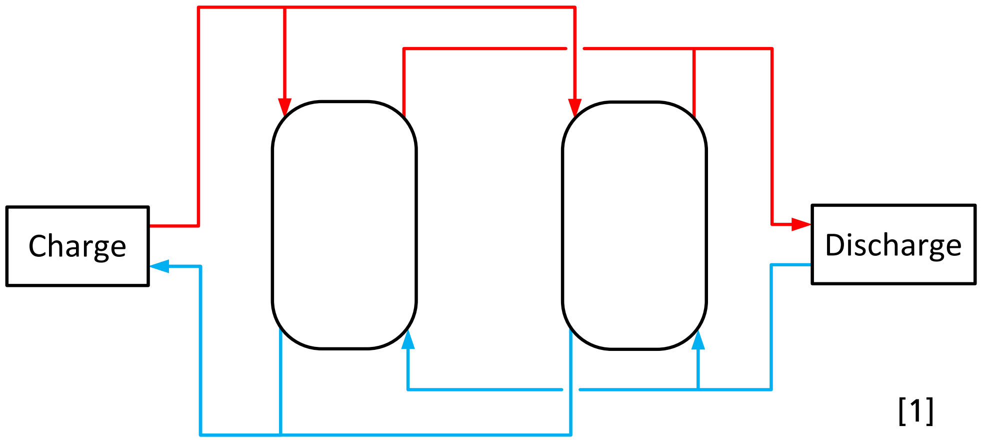
Single buffer storage

- Recommended, if possible
- Low heat losses and piping effort
- Temporal reduction of active storage volume possible, when concepts “mixed charging return flow” and “stratified process return flow” are combined



Parallel storages

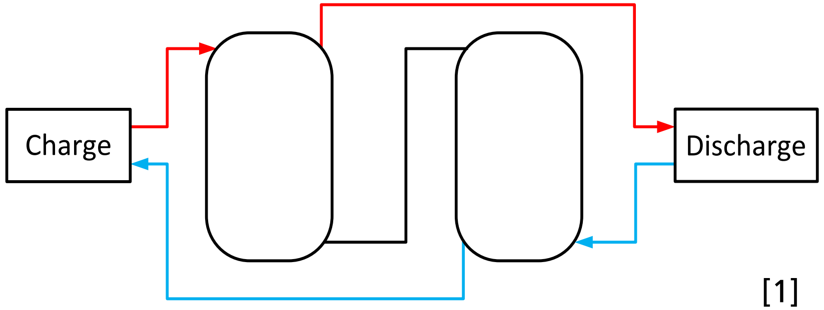
- Only for low ceilings
- Exact hydraulic balance important for uniform flow
- Maximum 2 storages parallel not recommended



[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

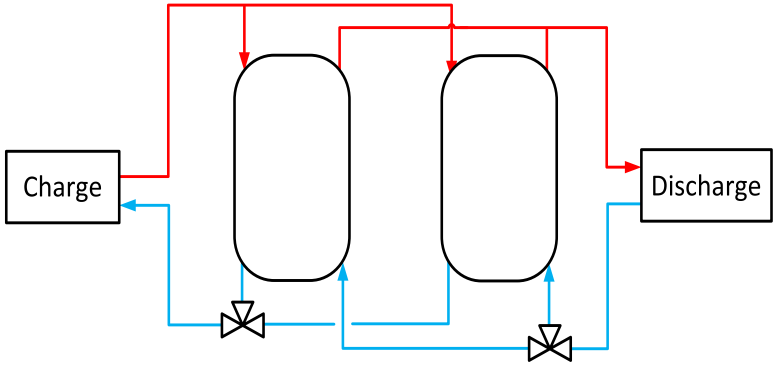
Thermal Storage
Interconnection Concepts

Serial
- Only for low ceilings
- Forced stratification
- Possible destruction of exergy by heat entrainment



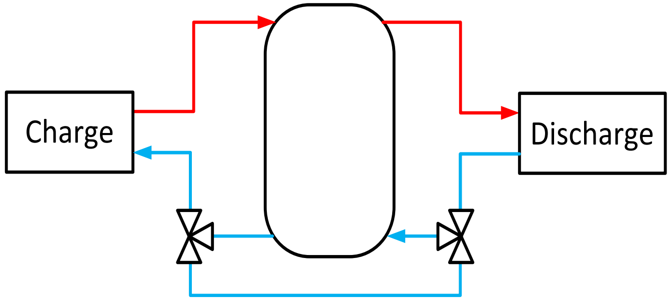
[1]

Priority circuit
- Seasonally adaptable active storage volume
- Separate charge and discharge possible
- Different processes can be supplied at different temperature levels



[1]

Return flow bypass
- Hot process return flow can be bypassed
- Beneficial if process return flow is colder than bottom storage temperature
- Collector loop can operate at process temperature



[1]

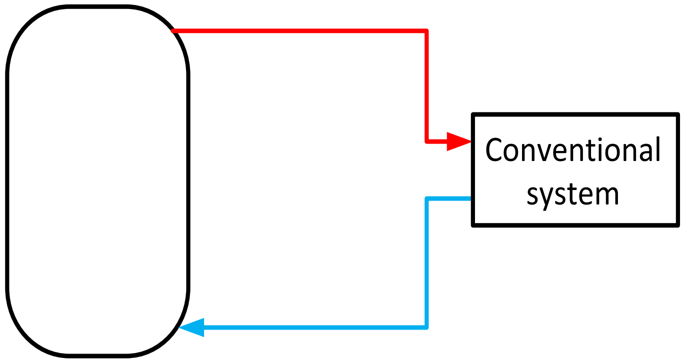
[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Fraunhofer ISE

Thermal Storage
Discharging Concepts

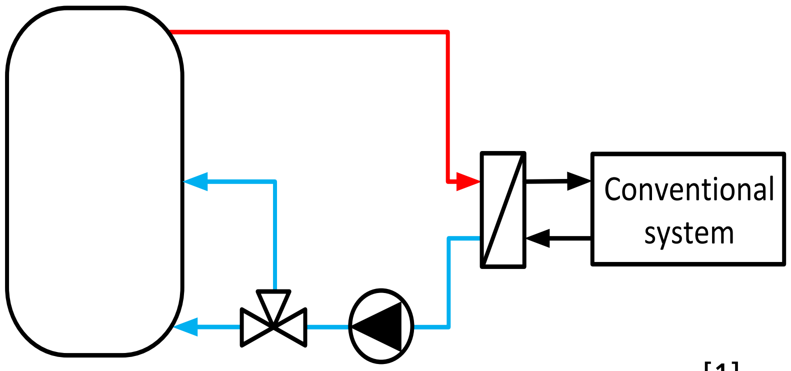
Direct

- Storage medium is process medium
- Storage is integration point



Indirect with stratified process return flow (optional)

- Process medium and storage medium can differ
- Variable heights for discharge flow and return flow possible (stratification for high return flow temperatures indicated)

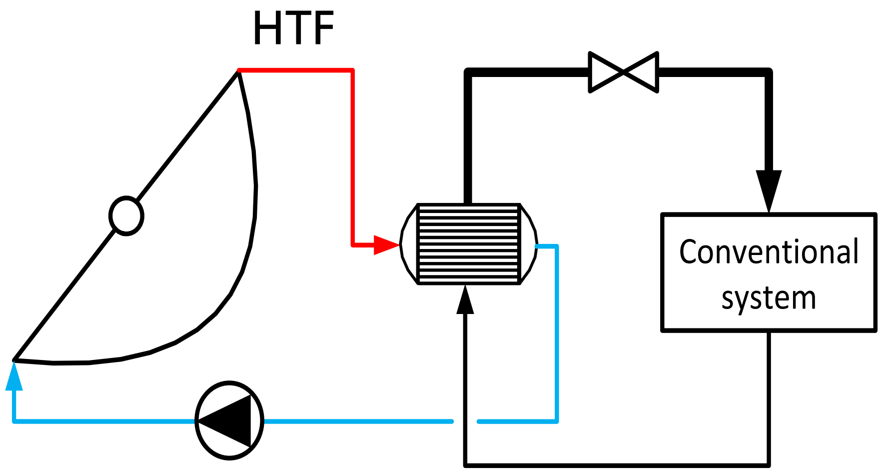


[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Thermal Storage
Steam Generation

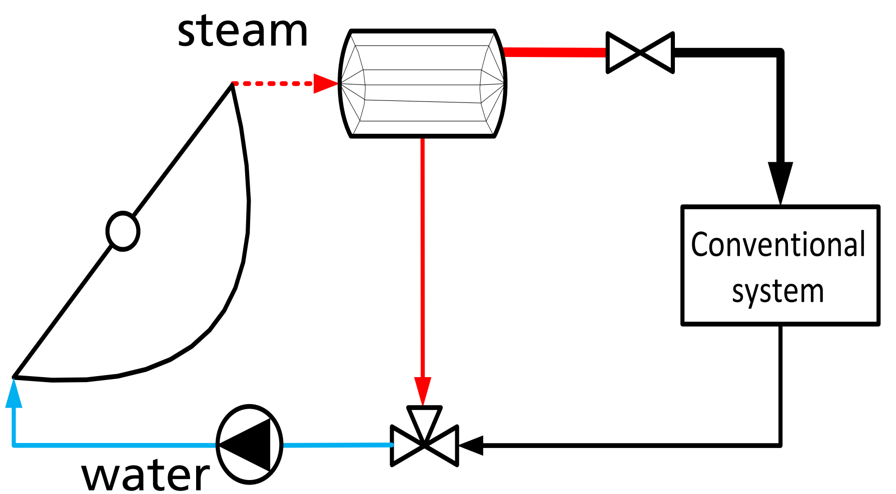
Indirect steam generation

- For collectors with liquid HTF
- Steam generation in kettle type boiler



Direct steam generation

- For steam generating collectors
- Steam drum for phase separation acts as small storage



[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Content

- Main Components of a SHIP System
- Technologies of Solar Thermal Collectors
  - General Principles
  - Types of collectors
- Control
- Thermal Storage
- Summary

Fraunhofer ISE

Main Components of a SHIP system
Overview of main solar components

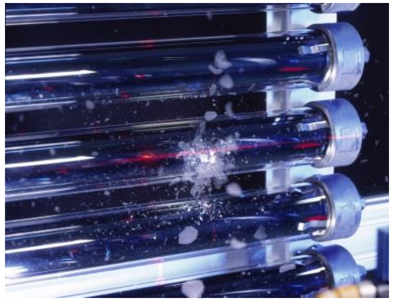
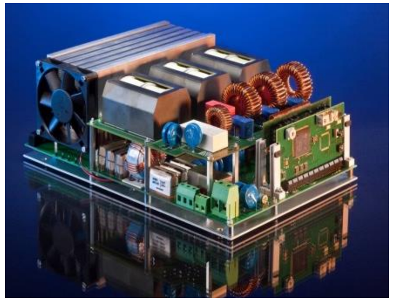
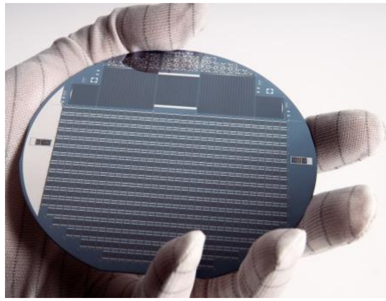
- Solar collectors
  - Flat Plate
  - Evacuated tube
  - Parabolic trough
  - Linear Fresnel
  - Dish systems
- Thermal storage for SHIP
  - Water
  - Steam
  - Phase change materials
- Heat transfer fluid
  - Water / Glycol (up to 120 °C)
  - Oil (up to 390 °C)
  - Molten salt (over 500 °C)
  - Air
  - Steam
- Important auxiliary components
  - Pumps
  - Heat exchanger
  - Valves
  - Pipes
  - Controller and sensors

Summary

- Solar Process Heat is a proven and robust technology
- Collector and system technology is available for a wide range of temperature applications up to 400°C
- Direct steam generation is possible with solar thermal technology
- A cheap energy storage solution is heat storage in water storage tanks
- Intelligent Control Strategy allows to make maximum and adapted use of solar thermal energy

Thank you for your Attention!




Fraunhofer Institute for Solar Energy Systems ISE

Dr. Wolfgang Kramer

Fanny Hübner

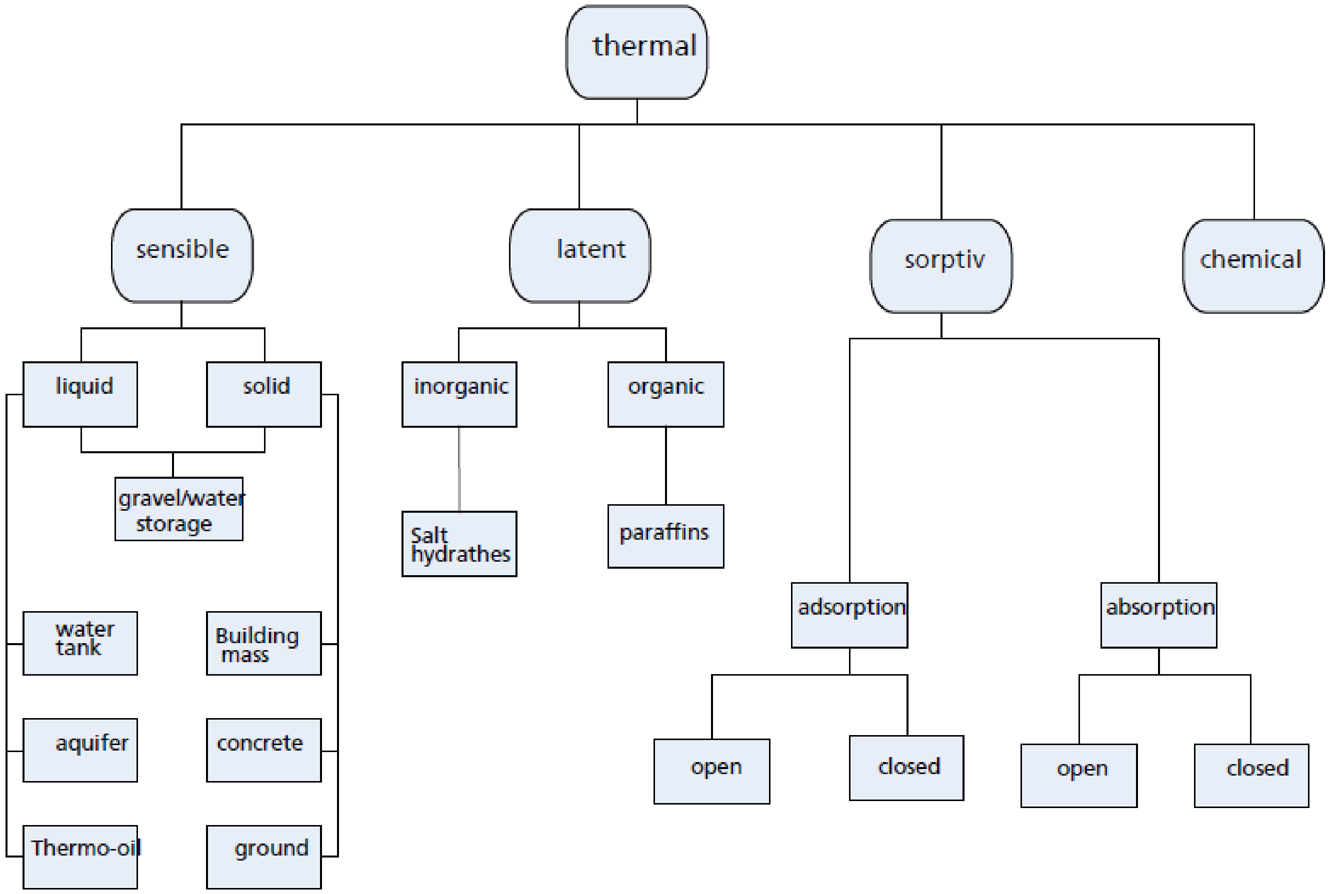
www.ise.fraunhofer.de

wolfgang.kramer@ise.fraunhofer.de
fanny.huebner@ise.fraunhofer.de

Backup

Thermal Storage
Overview

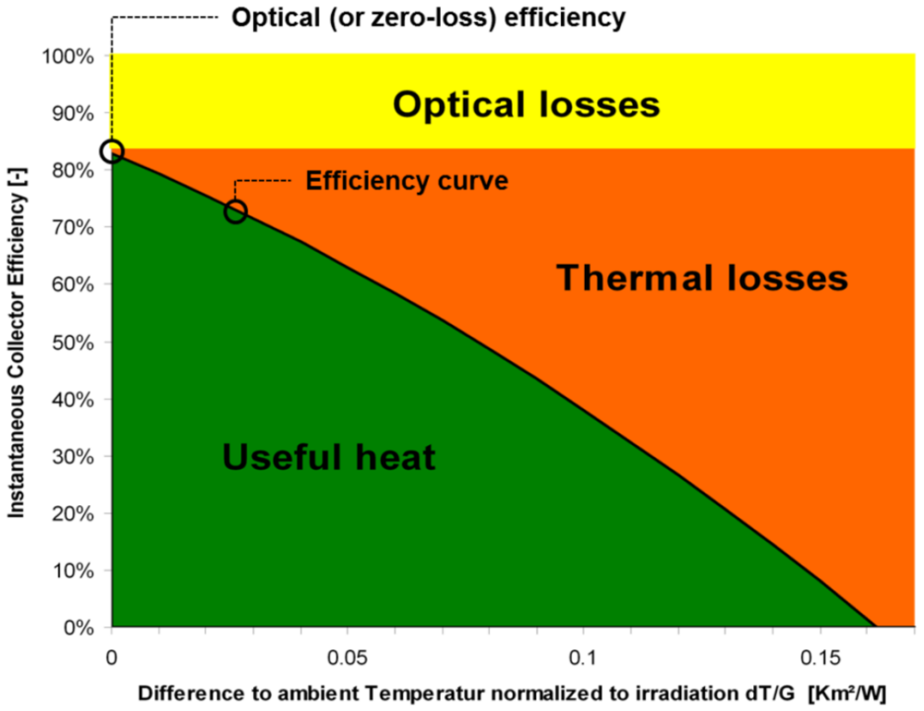
- Available Concepts

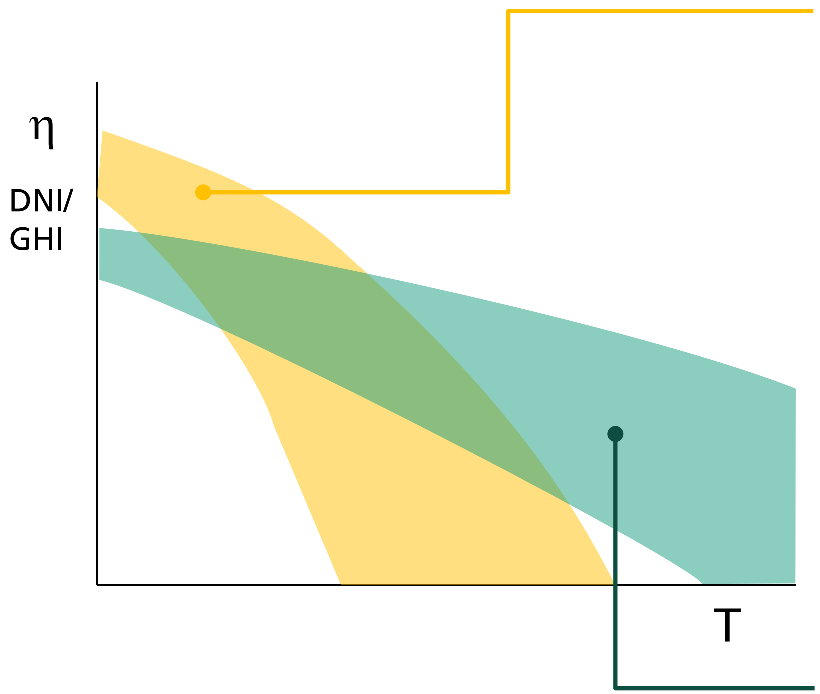


Technologies of Solar Thermal Collectors
Comparison

Motion	Collector type	Absorber type	Concentration	Indicative temperature range (°C)
Stationary	Flat Plate Collector (FPC)	Flat	No	30-80
	Evacuated Tube Collector (ETC)	Tubular	No	50-130
	Compound Parabolic Concentrator (CPC) Collectors	Tubular/ Flat	Yes	80-200
Single axis tracking	Linear Fresnel Reflector (LFR)	Tubular	Yes	60-400
	Parabolic Trough Collector (PTC)	Tubular	Yes	100-450
Two axes tracking	Parabolic dish reflector (PDR)	Point	Yes	100-500
	Heliostats Field collector (HFC)	Point	Yes	150-2000

Technologies of Solar Thermal Collectors
General Principles





Low temperature / Stationary collectors:

- Higher optical efficiency
- Higher thermal losses

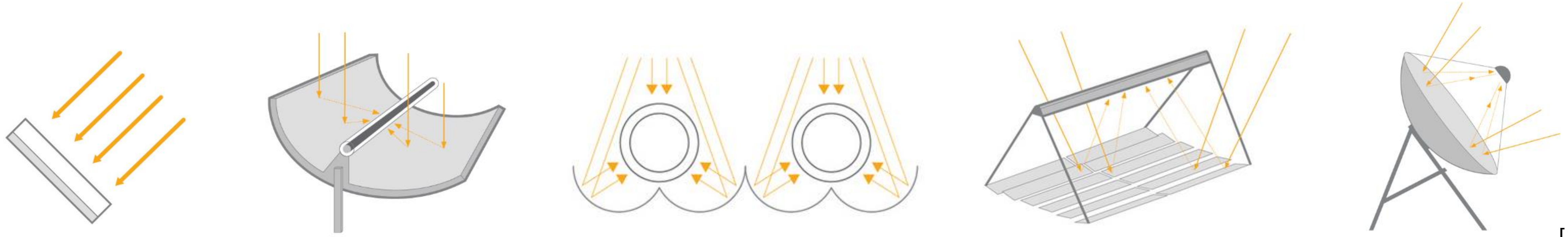
Medium temperature / Tracking collectors:

- Lower optical efficiency
- Lower thermal losses

Fraunhofer ISE

Main Components of a SHIP system
Solar Collector

- "Heat exchanger" which convert solar irradiation into heat
- Surface absorbing irradiation is called *absorber*
- Collected solar energy is carried from *heat transfer fluid* (HTF) to the process or to an energy storage tank to be used later
- Heat is transferred to the *working fluid* (air, water, or oil) circulating through the process system
- Different technologies for different operating temperature levels



[1]

[1] Solar collectors, https://www.solar-payback.com/technology/, Accessed October 2019

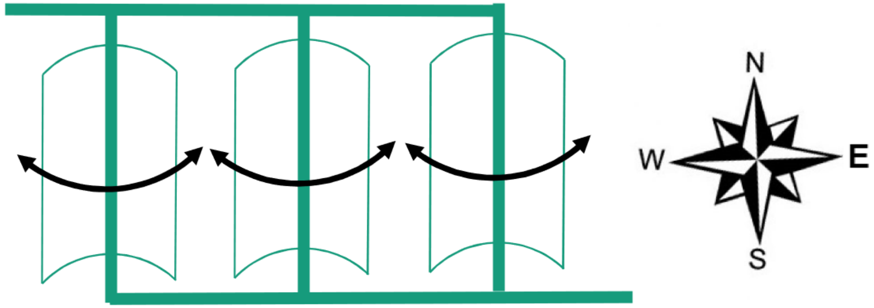
Fraunhofer ISE

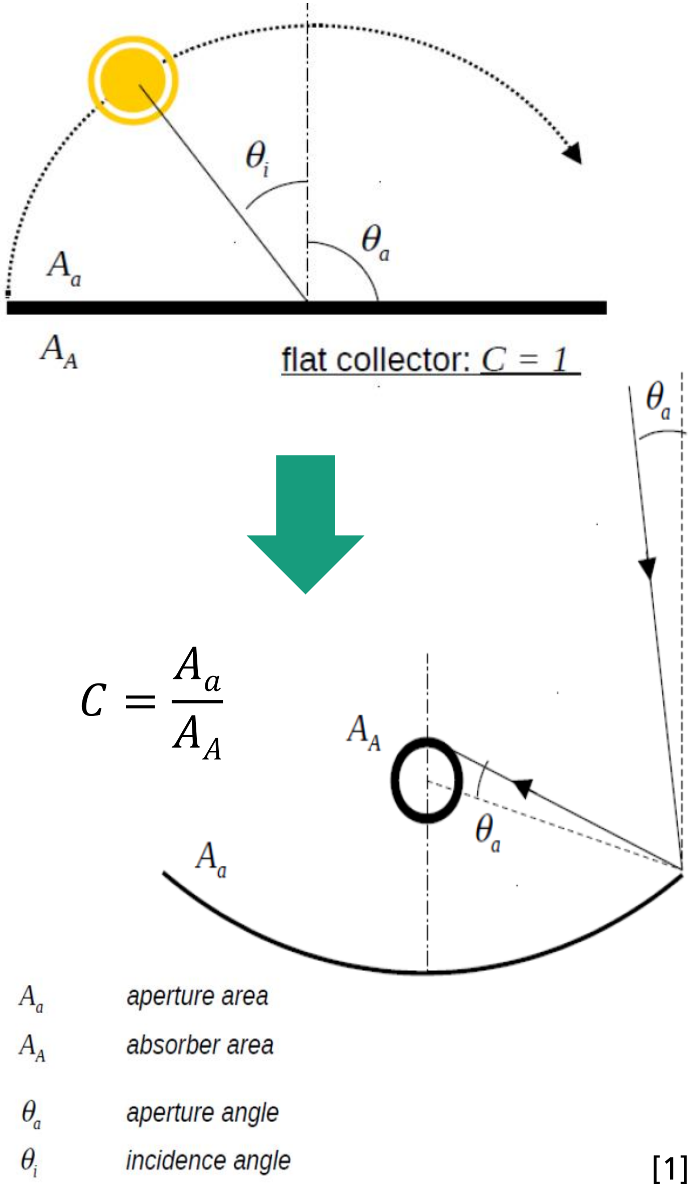
Main Components of a SHIP system
Heat Exchangers

- Heat exchangers as heat transfer surfaces between two independent hydraulic circuits (often with different HTF)
- Plate heat exchangers (especially 2 fluids) and tube-shell heat exchangers (fluid–air or fluid–steam) are widely used
- Characterizing parameters are:
  - Heat transfer coefficient UA [W/K]
  - Heat exchanger efficiency depends on:
    - Mass flows (cold and hot side)
    - Geometry and fluid properties
    - Flow principle (parallel flow, cross flow, counter flow)

Technologies of Solar Thermal Collectors
General Principles – Tracking Technologies

- At radiative balance, the temperature of an ideal absorber surface (black body) would rise by maximum of 91.3 K (neglecting convection and conduction)
- In order to rise the temperature, heat flux must be increased -> Concentration
- However: increase of concentration reduces the acceptance angle
- Need of tracking systems with solar concentrators
- Most common: North-South orientation for East-West tracking



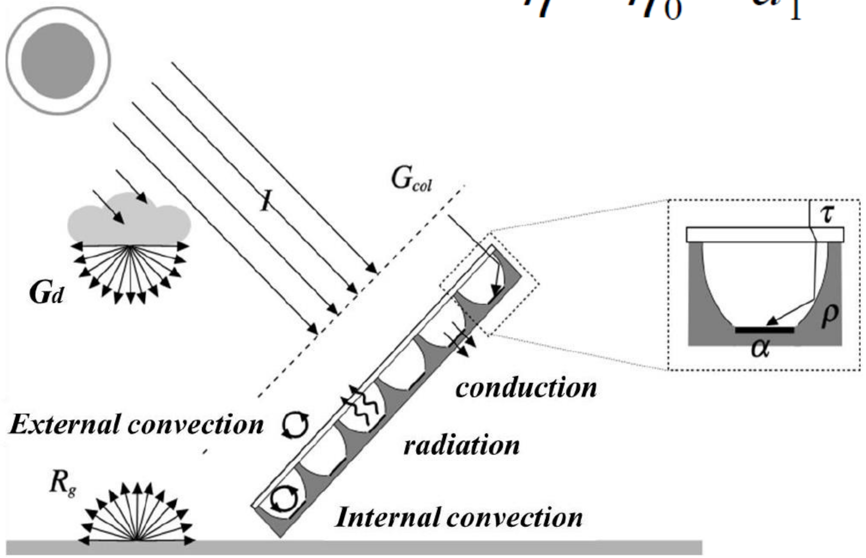


[1] Horta P. (2015): State of the Art of process heat collectors, IEA/SHC TASK 49 Technical Report A.1.3.

Technologies of Solar Thermal Collectors
General Principles

- Collector efficiency depends on:
  - Optical losses depending on incidence angle
  - Thermal losses depending on operating temperature

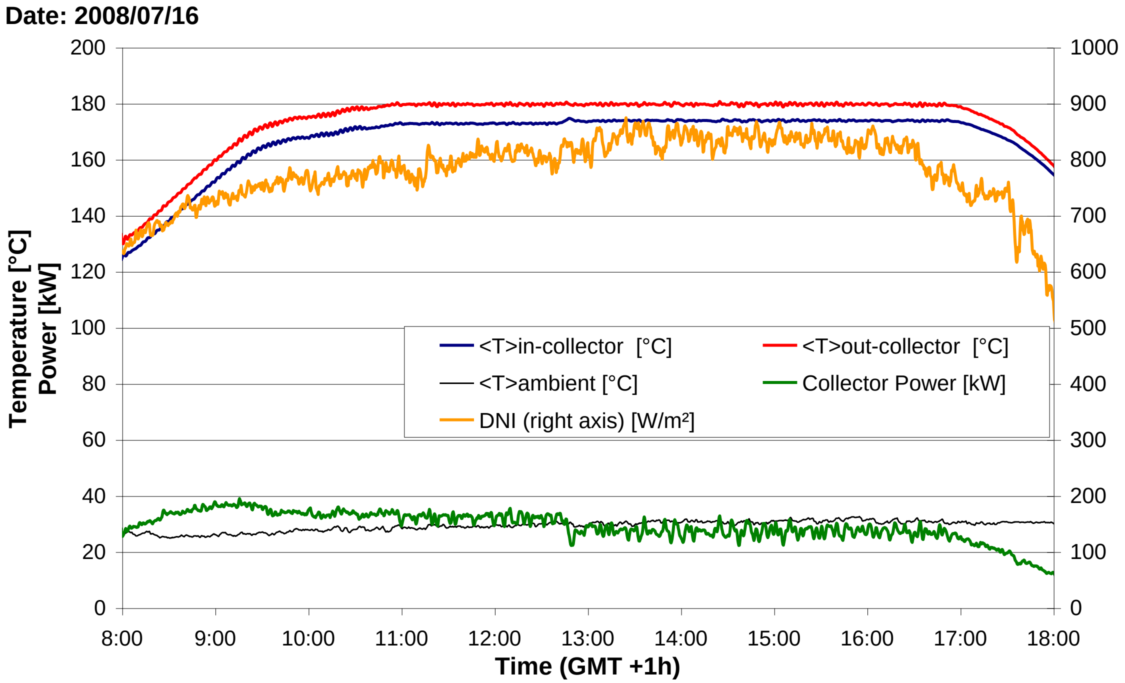
$$\eta = \eta_0 - a_1 \cdot \frac{(T_m - T_a)}{G} - a_2 \cdot \frac{(T_m - T_a)^2}{G}$$



- η [-] collector efficiency
- η_0 [-] zero-loss efficiency
- a_1 / a_2 [W/m² K] heat loss coefficients
- T_m [°C] mean fluid temperature
- T_a [°C] ambient temperature
- G [W/m²] total solar irradiance on collector plane

Technologies of Solar Thermal Collectors
Linear Fresnel Collectors

- Industrial Solar GmbH (Freiburg, Germany)
- Monitoring of collector field: Precise temperature control



Fraunhofer ISE

Technologies of Solar Thermal Collectors
General Principles

- Measures to increase the efficiency of solar thermal collectors:

Selective Absorber Surfaces

- Spectrally selective absorber surfaces
- Development of special coating materials
  → Shifting of absorptivity and emissivity spectral distributions
- Aim: Achieve high absorptivity and low emissivity
- Emittance: 0.05 – 0.15
- Absorptance: 0.9 – 0.95

Vacuum

- Notable enhancement of thermal performance of solar collectors
- Evacuation of volume between absorber surface and surrounding glass
- Thus, limitation or elimination of thermal losses by means of convection
- Nowadays also available for flat plate collectors

Content

- Main Components of a SHIP System
- Technologies of Solar Thermal Collectors
  - General Principles
  - Types of collectors
- Control
- Thermal Storage
- Summary

Fraunhofer ISE