SHIP Egypt

SHIP Design Guideline

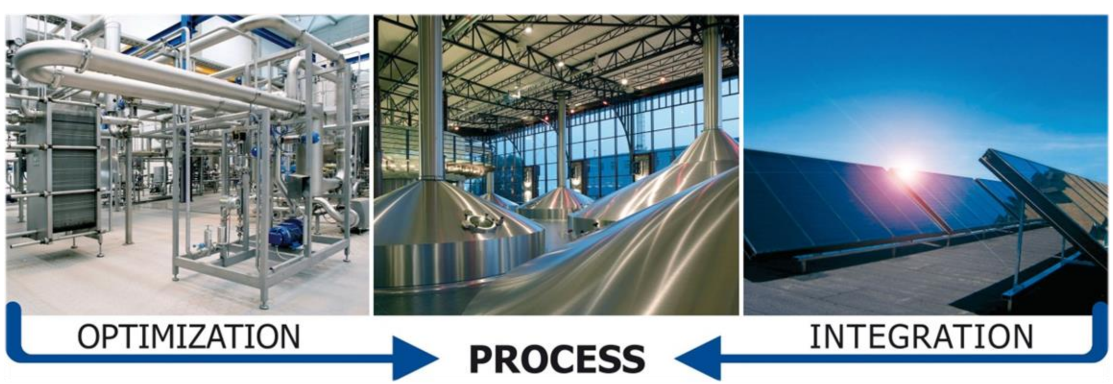
Wolfgang Glatzl & Josef Buchinger

AEE INTEC & ConPlusUltra

Aim of the session (part II)

- **Basic design of a solar thermal process heat system based on the outcomes of the process optimization session (part I) and following the approach for efficient energy planning in industry:**

1. Avoid energy losses (e.g. efficient boilers and process technologies. insulation. etc.)
2. Increase efficiency of the existing system (e.g. exploit heat recovery potential. etc.)
3. Design and implementation of sustainable energy supply technologies to further decrease fossil fuel demand



Outline

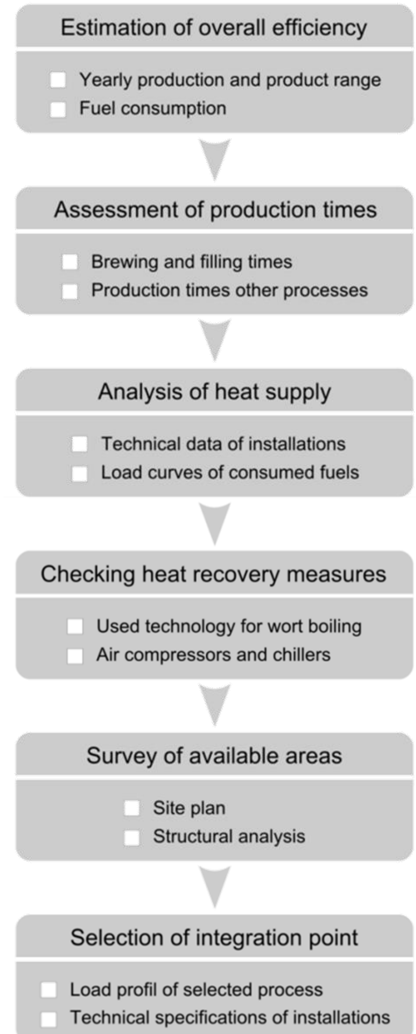
- **Assessment methodology for solar thermal integration**

- **1-0 Process integration**
  - 1.1) Solar thermal integration point
  - 1.2) Solar thermal integration concept
  - 1.3) Characteristic annual / weekly / daily load profile

- **2-0 Solar thermal system design**
  - 2.1) Choice of an appropriate solar thermal collector technology
  - 2.2) Collector field placement
  - 2.3) Hydraulic diagram solar loop + process loop
  - 2.4) Basic engineering of collector loop and loop components
  - 2.5) Simulation of the annual solar energy gains
- **3-0 Techno-economic comparison of results**

Assessment methodology

- Energy audit on-site (basic data acquisition. company visit)
- Assessment of production times and still-stands (daily. weekly. annually)
- Analysis of heat supply and evaluation of representative load profiles
- **Identifying process optimization and energy efficiency measures**
- Survey of available areas (ground or roof) for solar thermal system installation
- Selection of solar thermal integration point and hydraulic integration concept
- **Detail engineering of the solar thermal system**



Source: IEA SHC Task 49 / IV 2013 / B. Schmitt

Methodology

Industry data

- Process suitable for SHIP
- Solar concept
- Load profile

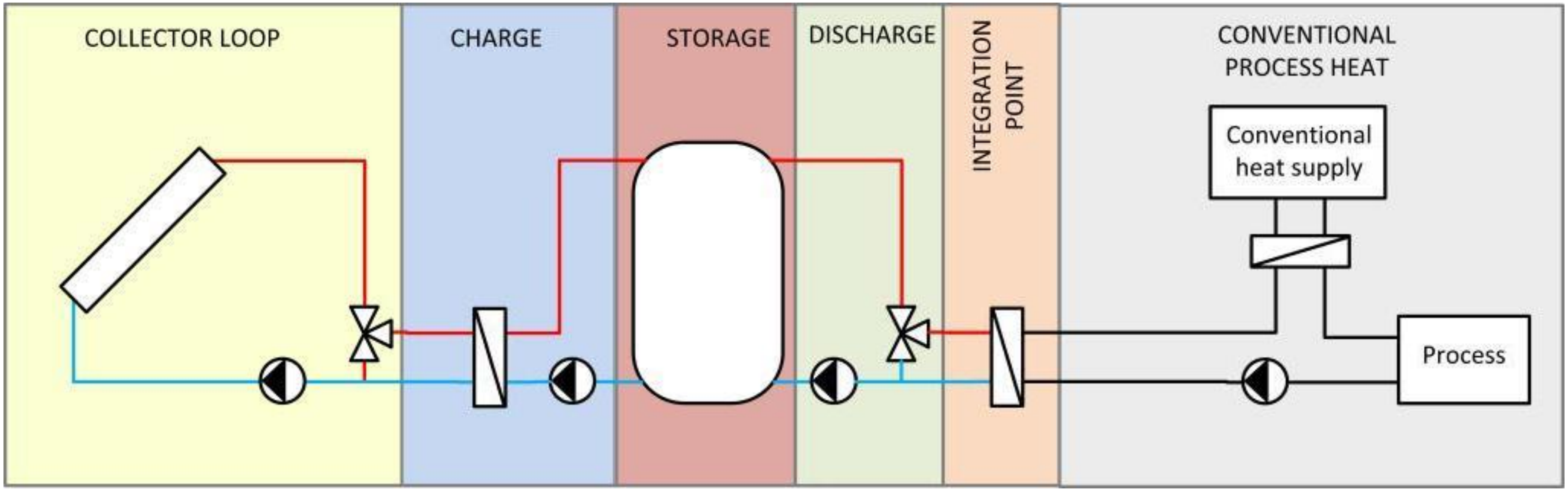
Solar concept

- Selection of the appropriate collector
- Placement
- Hydraulic concept
- Collector design
- Selection and design of components
- Simulation
- Economic evaluation

Part of the solar concept

What components are needed?

DISCUSSION!



Solar thermal design

- **Process integration**
  - Process suitable for SHIP
  - Solar concept
  - Load profile

- **Solar concept**
  - Selection of the appropriate collector
  - Placement
  - Hydraulic concept
  - Collector design
  - Selection and design of components
  - Simulation

- **Economic evaluation**

Solar thermal design

- **Process integration**
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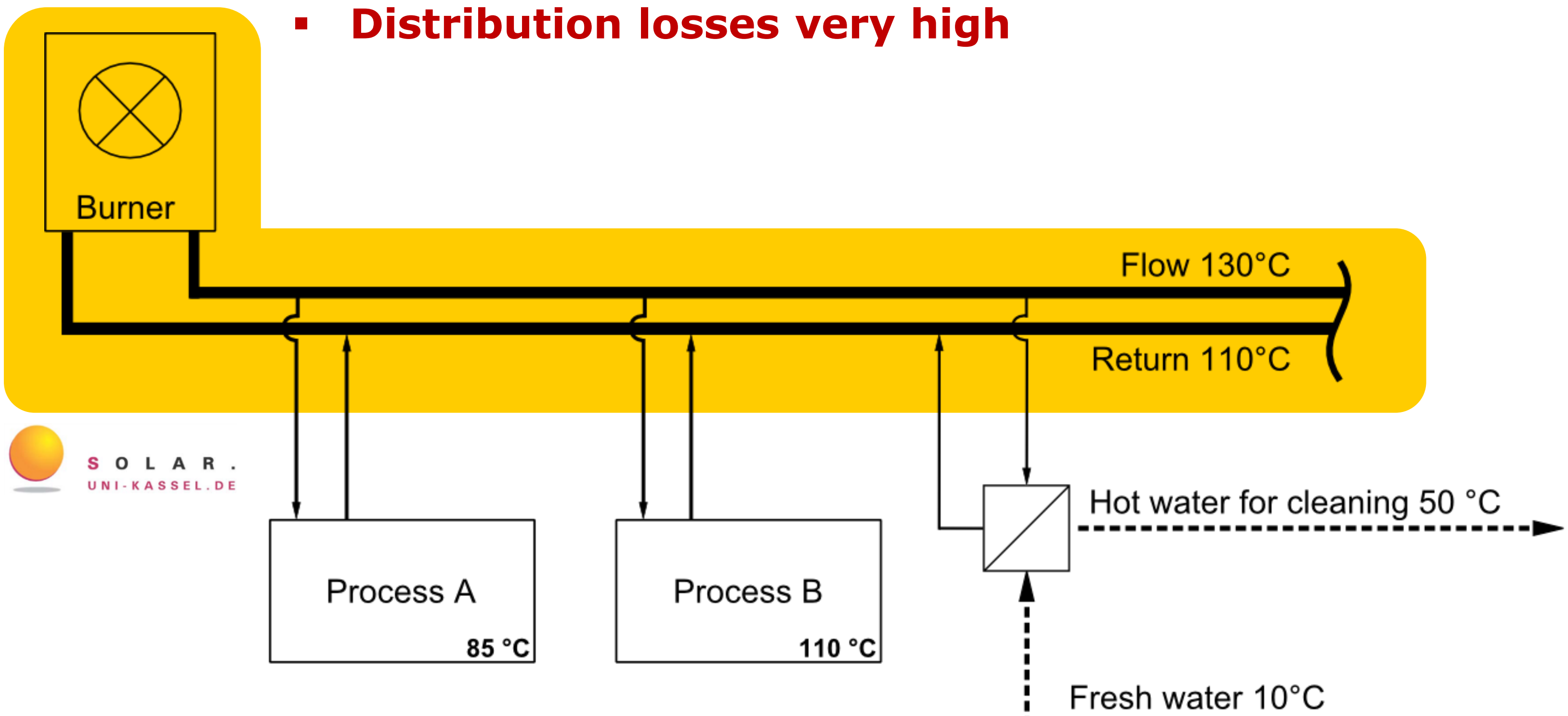
  - Simulation
- **Economic evaluation**

1-0 Process integration

1.1) Solar thermal integration point

- Option 1: Integration on **supply** level
  - **"easy" hydraulic system integration**
  - **solar supply temperature > process temperature**
  - **Distribution losses very high**

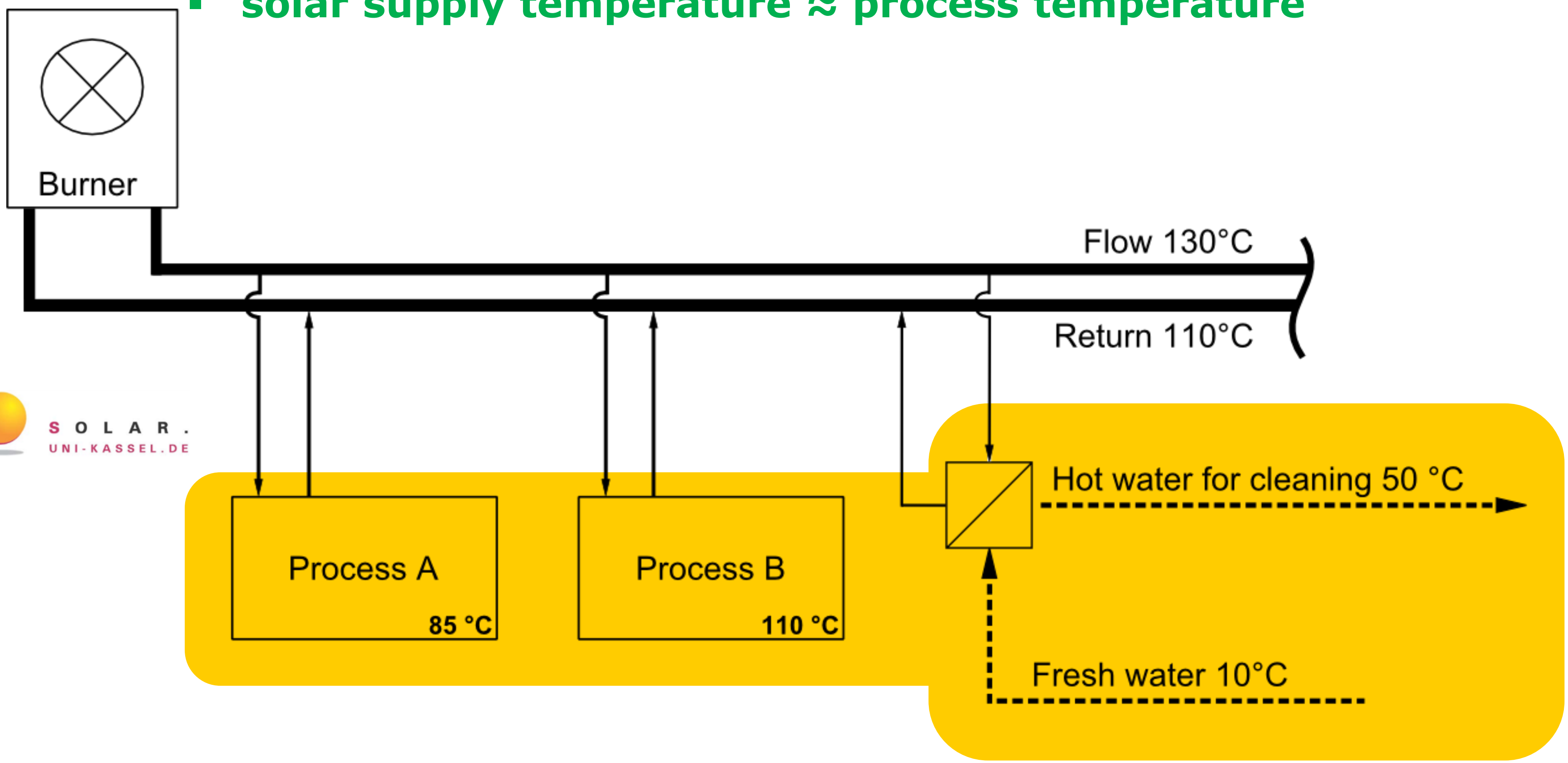


SOLAR.
UNI-KASSEL.DE

1-0 Process integration

1.1) Solar thermal integration point

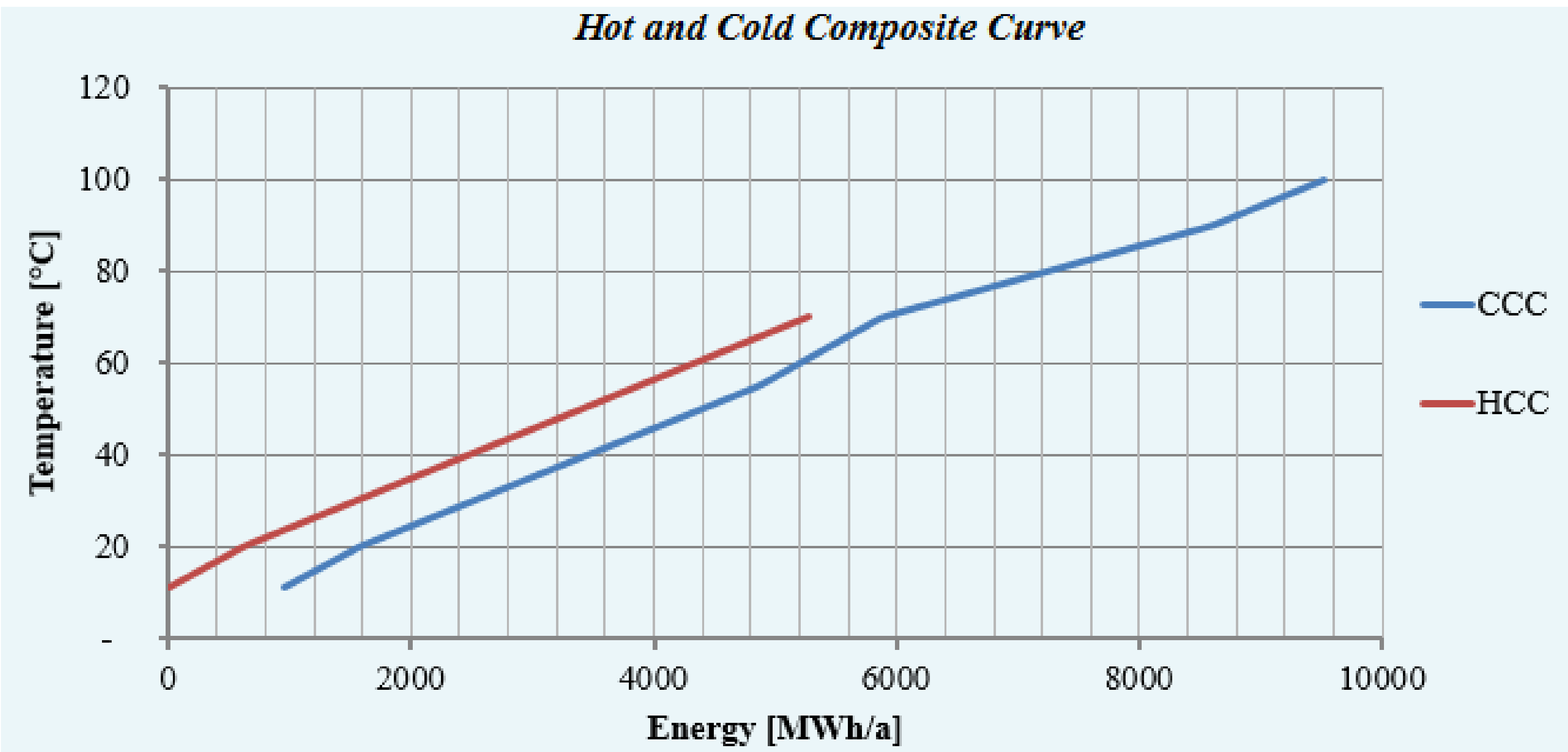
- Option 2: Integration on **process** level
  - **“complex” hydraulic system integration**
  - **solar supply temperature ≈ process temperature**



1-0 Process integration

1.1) Solar thermal integration point

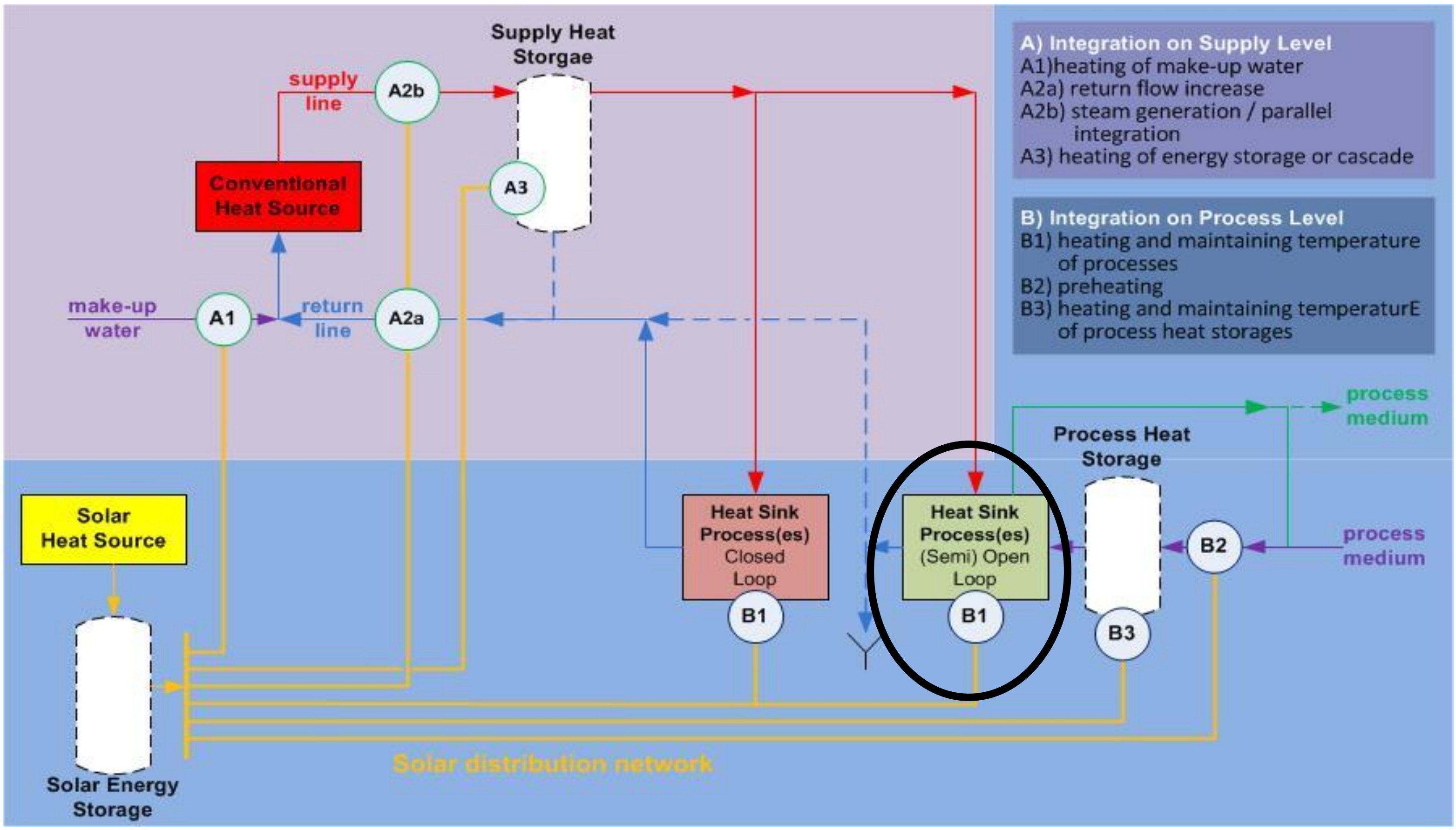
- Pinch analysis considerations
  - Pinch rule: No heating below the Pinch point!
- Pinch curves for test case:



1-0 Process integration

1.1) Solar thermal integration point

- Possible integration points for solar process heat applications



Source: IEA SHC Task 49 / IV 2013

Solar thermal design

- **Process integration**
  - Process suitable for SHIP
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  - Load profile
- **Solar concept**
  - Selection of the appropriate collector
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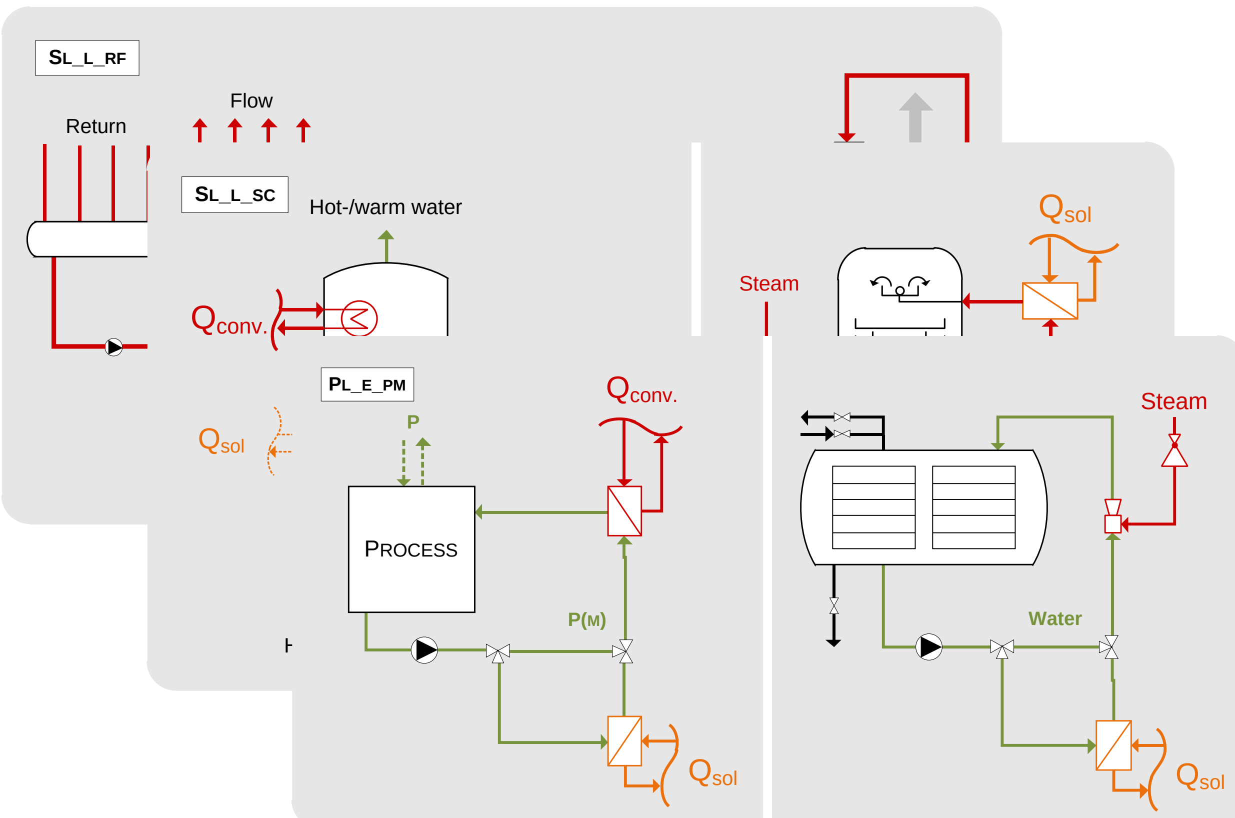
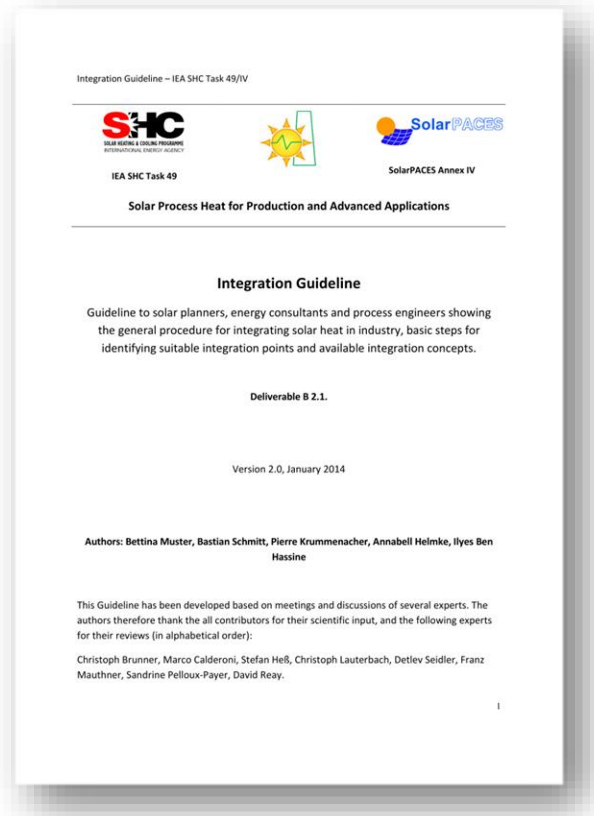
  - Simulation
- **Economic evaluation**

1-0 Process integration

1.2) Solar thermal integration concept

– IEA-SHC Task 49 / Annex IV integration guideline
  - **Available here: http://task49.iea-shc.org/**




Integration Guideline – IEA SHC Task 49/IV

IEA SHC Task 49

SolarPACES Annex IV

Solar Process Heat for Production and Advanced Applications

Integration Guideline

Guideline to solar planners, energy consultants and process engineers showing the general procedure for integrating solar heat in industry, basic steps for identifying suitable integration points and available integration concepts.

Deliverable B 2.1.

Version 2.0, January 2014

Authors: Bettina Muster, Bastian Schmitt, Pierre Krummenacher, Annabell Helmke, Ilyes Ben Hassine

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Christoph Brunner, Marco Calderoni, Stefan Heß, Christoph Lauterbach, Detlev Seidler, Franz Mauthner, Sandrine Pelloux-Payer, David Reay.

Design study (Part I)

1.2) Solar thermal integration concept

- Task 1.1: Characterize solar process heat integration point and integration concept
- Task 1.2: Draw basic hydraulic process integration scheme
  - Calculate heat exchanger capacity
  - Calculate piping dimensions
    - Velocity in pipes

Group work

Solar thermal design

- **Process integration**
  - Process suitable for SHIP
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- **Solar concept**
  - Selection of the appropriate collector
  - Placement
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  - Selection and design of components
  - Simulation

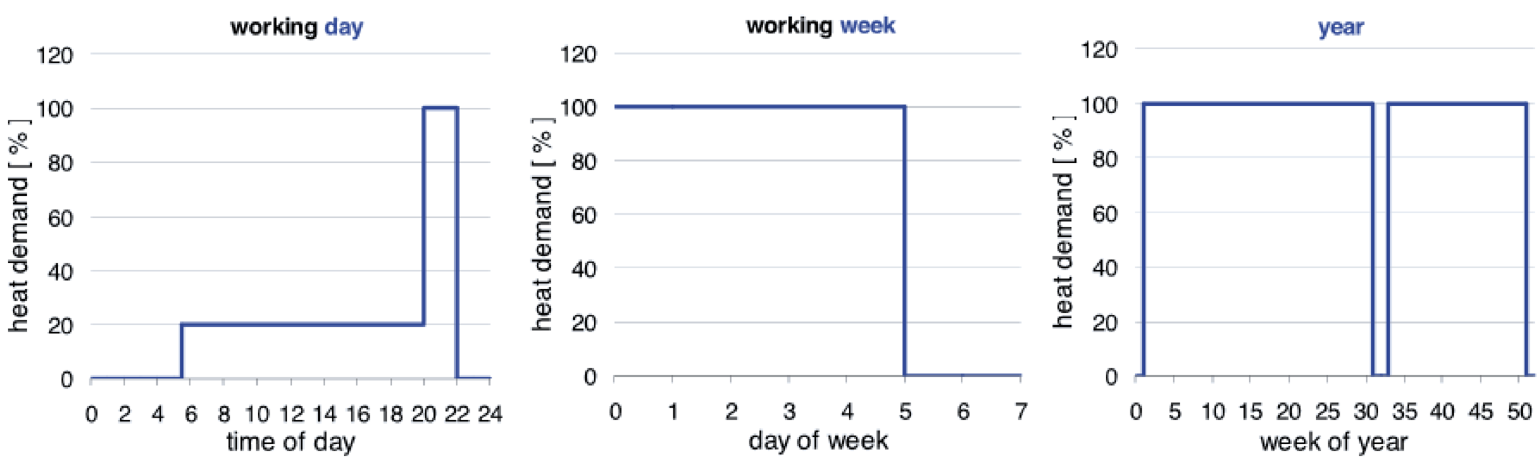
- **Economic evaluation**

1-0 Process integration

1.3) Characteristic load profile on an hourly basis

- Daily load profile: dimensioning of collector field and heat storage. simulation of solar thermal system yield
- Weekly load profile: dimensioning of heat storage and simulation of solar thermal system yield
- Annual load profile: simulation of solar thermal system yield

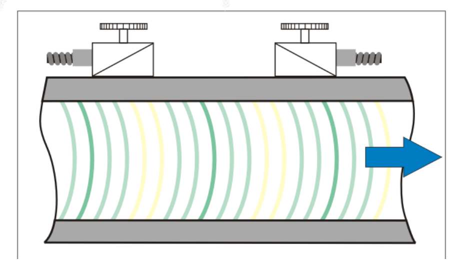
  - EXAMPLE: : non-continuous demand(e.g. cleaning water demand)



1-0 Process integration

1.3) Characteristic load profile

- If no data on the thermal heat demand available representative measurements should be taken
- E.g.: Ultrasonic Flow Measurement of Liquids



Flow sensor	
range flow velocity	0.01 bis 25 m/s
accuracy (@ v>0.15m/s with standard calibration)	± 1.6% of reading ± 0.01 m/s
Temperature sensor Pt 1000 4-wire	
range temperature	-150° C bis +560° C
accuracy	± 0.01% of reading ± 0.03 K

Technical Specification FLUXUS® F601 (www.flexim.com)

Calculation of Volumetric Flow Rate

$\dot{V} = k_{Re} \cdot A \cdot k_a \cdot \Delta t/(2 \cdot t_{fl})$

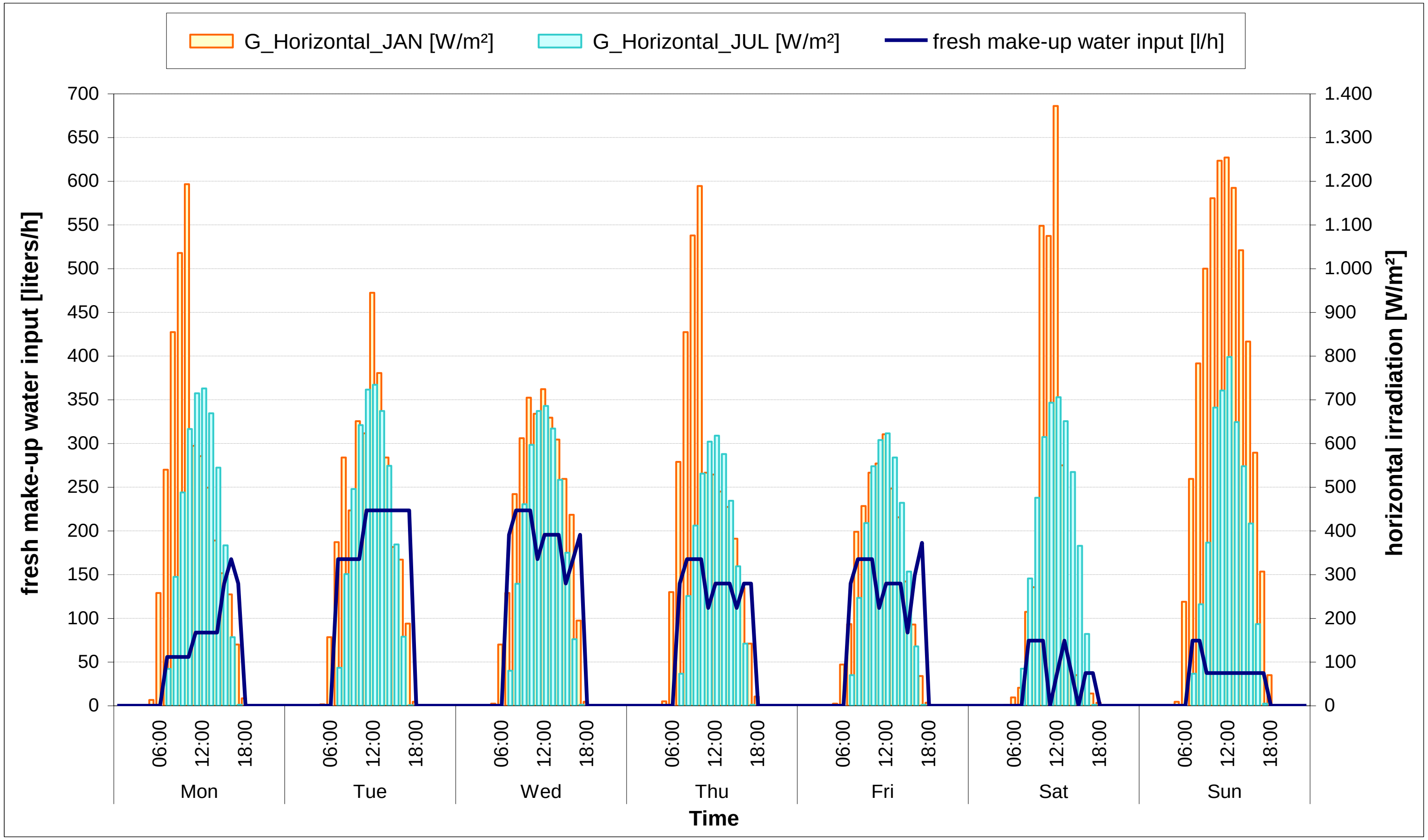
where

$\dot{V}$	-	volumetric flow rate
k_{Re}	-	fluid mechanics calibration factor
A	-	cross-sectional pipe area
k_a	-	acoustical calibration factor
Δt	-	transit time difference
t_{fl}	-	transit time in the medium

1-0 Process integration

1.3) Characteristic load profile

– example: measured make-up water demand for steam boiler at a brewery in Polokwane



1-0 Process integration

1.3) Characteristic load profile

– Task 1.3: Generate annual process load profile on an hourly basis (= 8,760 values)

Group work

Solar thermal design

- **Process integration**
  - Process suitable for SHIP
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  - Load profile

- **Solar concept**
  - Selection of the appropriate collector
  - Placement
  - Hydraulic concept
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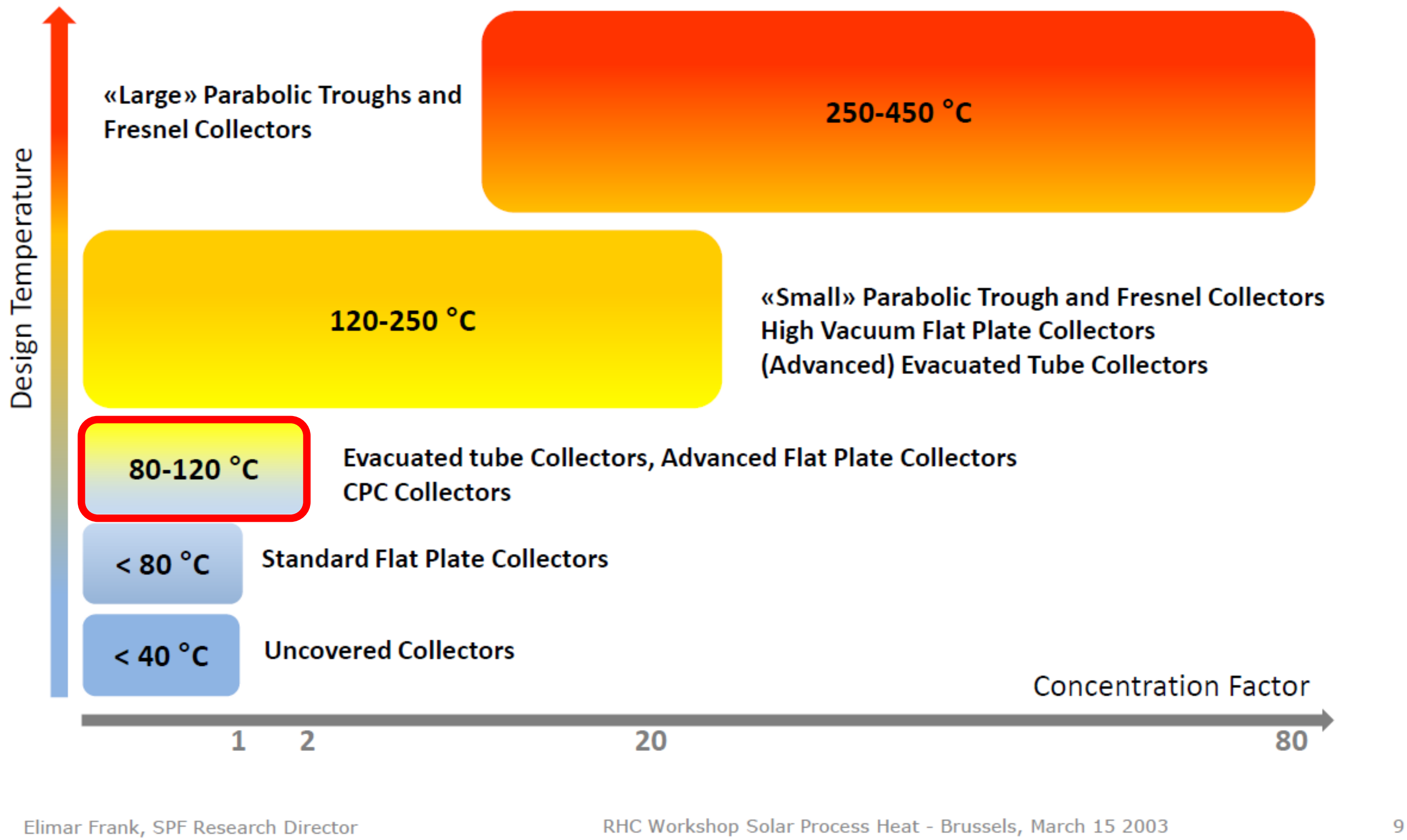
- **Economic evaluation**

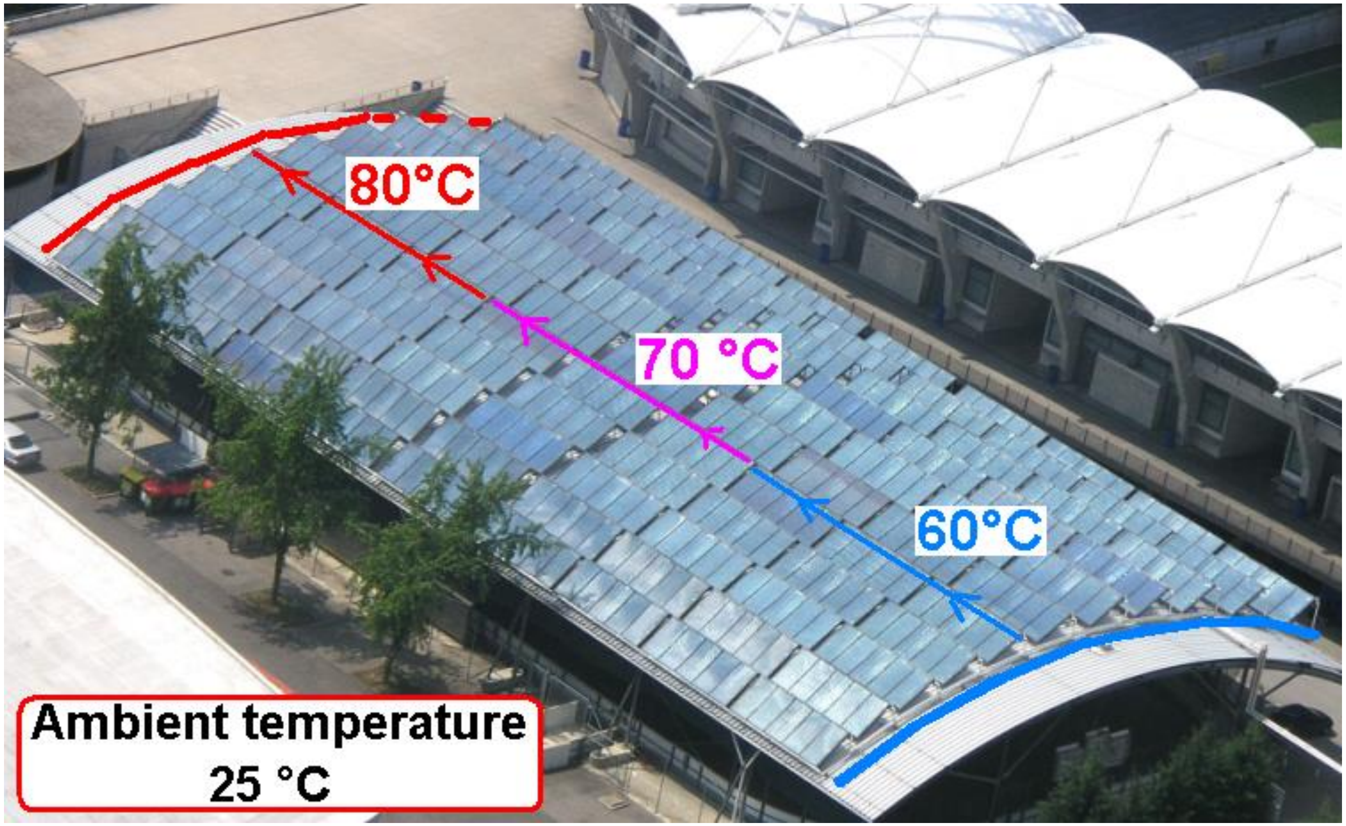
2-0 Solar thermal system design

2.1) Solar thermal collector technologies

- Different collectors for different design temperatures



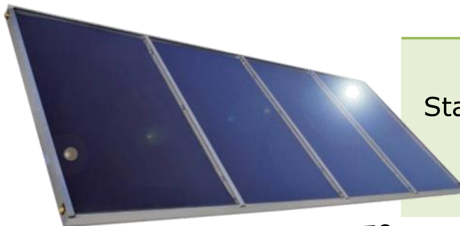
What‘s ‚ΔT‘ ?



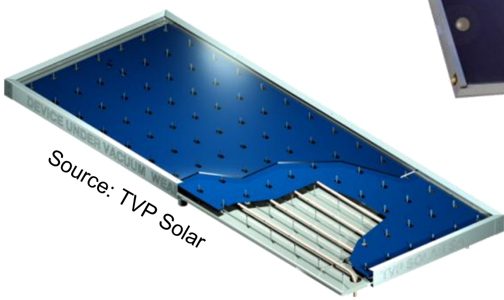
delta T (= $T_{\text{Collector mean temp}} - T_{\text{ambient}}$)

(70° C – 25 ° C) = ΔT 45° C

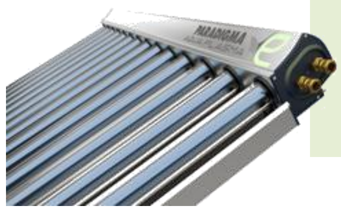
2-0 Solar thermal system design



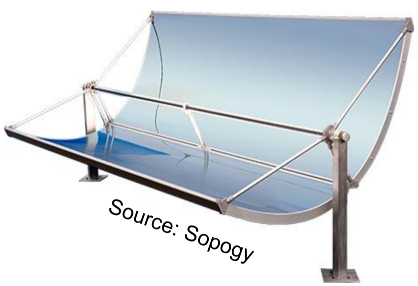
Source: GREENoneTEC



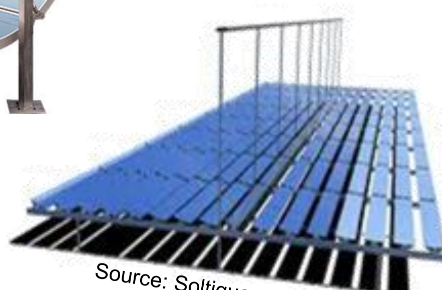
Source: TVP Solar



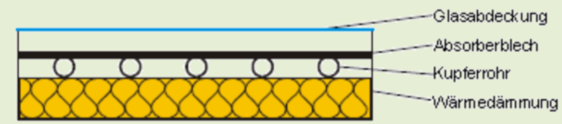
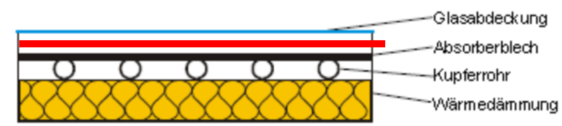
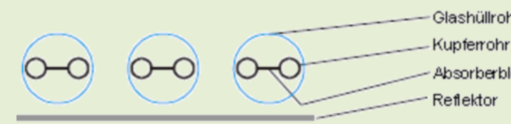
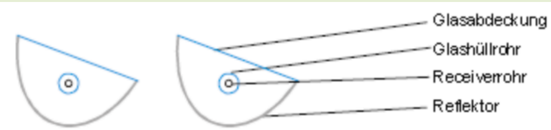
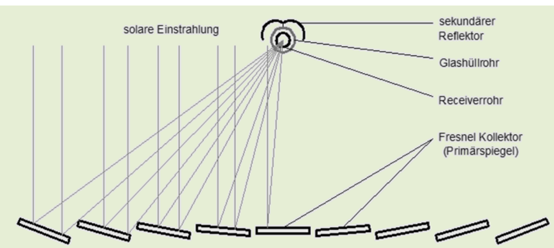
Source: Ritter Solar XL



Source: Sopogy



Source: Soltigua

TYPE	SKETCH (cross-section)	Design temperature
Standard flat plate collectors		**20 – 80 °C**
Advanced flat plate collector (vacuum filled, multiple covers, etc.)		**60 – 120 °C** up to 160 °C
Evacuated tubular collector		**60 – 120 °C** up to 160 °C
Parabolic trough collectors		**120 – 250 °C** up to 400 °C
Fresnel collectors		**120 – 250 °C** up to 400 °C

2-0 Solar thermal system design

2.1) Solar thermal collector technologies

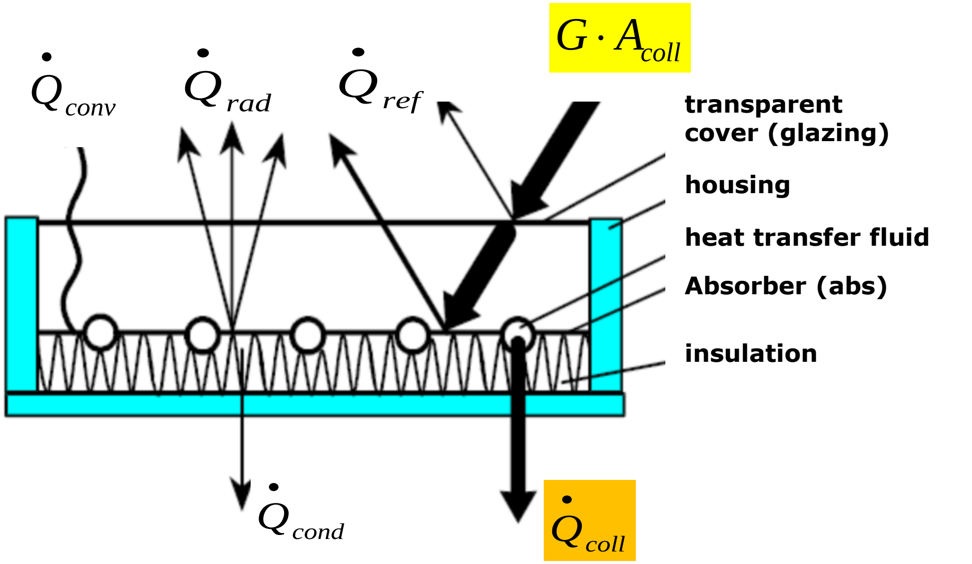
- Solar thermal collector efficiency curve

$$\dot{Q}_{coll} = G \cdot A_{coll} - \dot{Q}_{ref} - \dot{Q}_{rad} - \dot{Q}_{konv} - \dot{Q}_{cond}$$

$$\dot{Q}_{ref} = G \cdot A_{coll} \cdot \left(1 - \tau_{glazing} \cdot \alpha_{abs}\right)$$

$$\dot{Q}_{rad} = A_{coll} \cdot \varepsilon_{abs} \cdot \sigma \cdot \left(T_{m,coll}^4 - T_a^{\,4}\right)$$

$$\dot{Q}_{conv} + \dot{Q}_{cond} = A_{coll} \cdot U_{coll} \cdot \left(T_{m,coll} - T_a\right)$$



$$\eta_{coll} = \frac{\dot{Q}_{coll}}{G \cdot A_{coll}} = \underbrace{\tau_{glazing} \cdot \alpha_{abs}}_{c_0} - \underbrace{\frac{U_{coll}}{G}}_{c_1} \cdot \left(T_{m,coll} - T_a\right) - \underbrace{\frac{\varepsilon_{abs} \cdot \sigma}{I_g}}_{c_2} \cdot \left(T_{m,coll}^4 - T_a^{\,4}\right)$$

2-0 Solar thermal system design

2.1) Solar thermal collector technologies

- Solar thermal collector efficiency curve

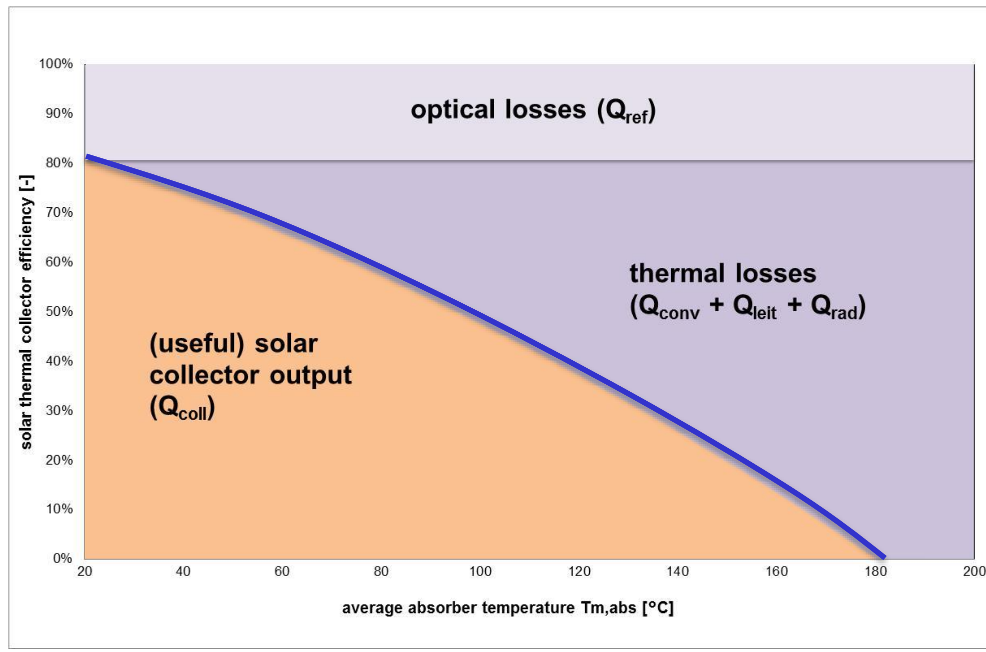
$$\eta_{coll} = c_0 - c_1 \cdot \frac{T_{m,coll} - T_a}{G} - c_2 \cdot \frac{(T_{m,coll} - T_a)^2}{G}$$

Symbols:

c_0 = maximum efficiency
= efficiency at (t_m = t_a) [-]

c_1 = linear heat loss coefficient [$W \cdot m^{-2} \cdot K^{-1}$]

c_2 = quadratic heat loss coefficient [$W \cdot m^{-2} \cdot K^{-2}$]



2-0 Solar thermal system design

2.1) Solar thermal collector technologies

- Solar thermal collector efficiency curve

$$\eta_{coll} = c_0 - c_1 \cdot \frac{T_{m,coll} - T_a}{G} - c_2 \cdot \frac{(T_{m,coll} - T_a)^2}{G}$$

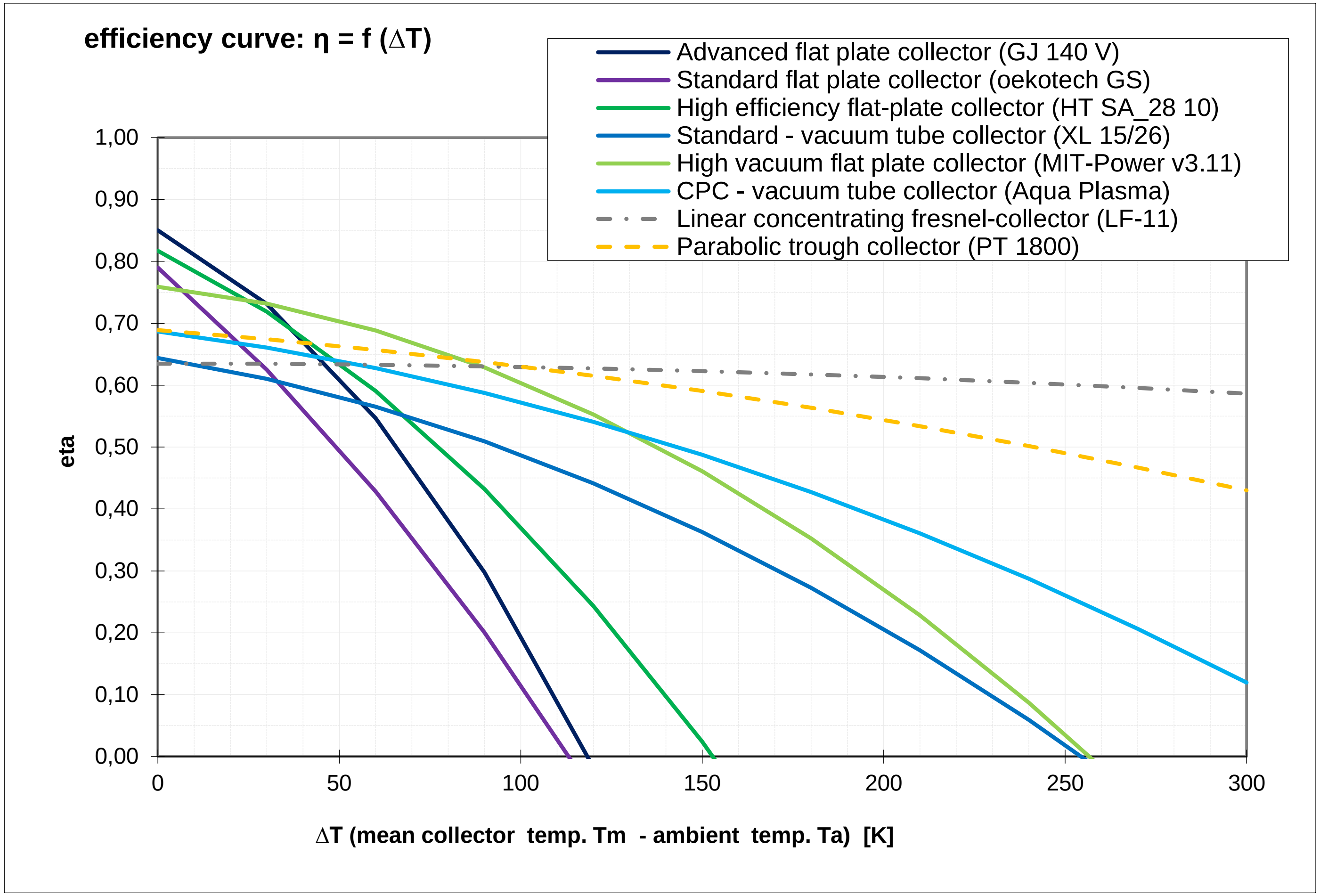
Type of collector			
Source:	c_0	c_1	c_2
Standard flat plate collector (oekotech GS)	0.79	3.979	0.014
Advanced flat plate collector (GJ 140 V)	0.85	2.30	0.029
High efficiency flat-plate collector (HT SA_28 10)	0.817	2.205	0.0135
Standard - vacuum tube collector (XL 15/26)	0.644	0.749	0.005
CPC - high efficiency vacuum tube collector (Aqua Plasma)	0.687	0.613	0.003
High vacuum flat plate collector (MIT-Power v3.11)	0.76	0.51	0.007
Linear concentrating fresnel collector (LF-11)	0.635	0.000	0.0004
Parabolic trough collector (PT 1800)	0.689	0.36	0.0011

- for collector data sheets go to: http://solarkey.dk/

2-0 Solar thermal system design

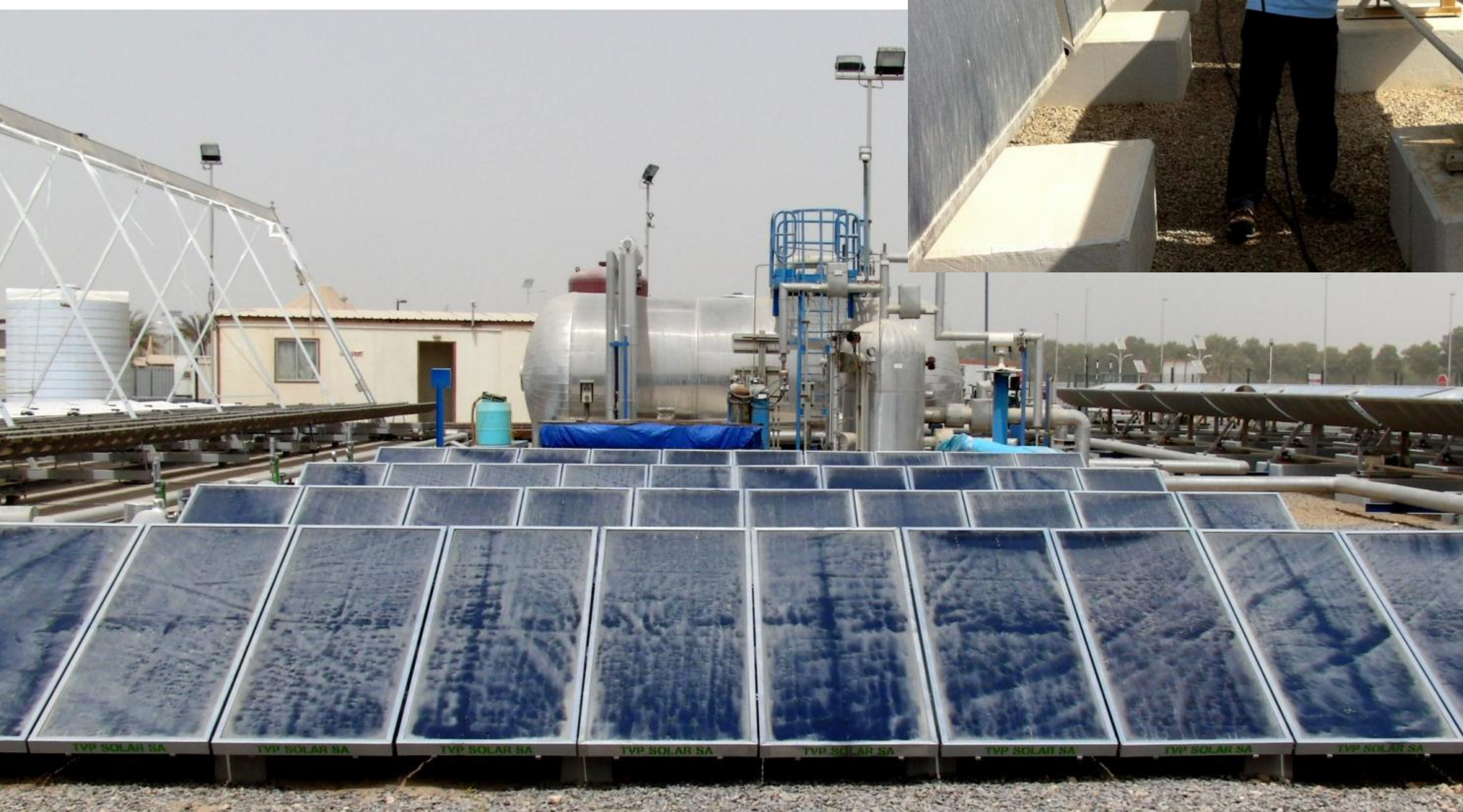
2.1) Solar thermal collector technologies

- Efficiency curves for G=800 W/m² and T_a= 20°C



Cleaning of collectors in Masdar

Cleaning of collectors in Masdar



2-0 Solar thermal system design

2.1) Solar thermal collector technologies

– Task 2.1: Choose appropriate solar thermal collector technology based on process characteristics

- Pre-define suitable collector technologies based on the temperature level needed
- Use efficiency curve template and information from the solar thermal collector data sheet for detailed efficiency curve analysis
- Link Solar Keymark

Group work

Solar thermal design

- **Process integration**
  - ⇨ Process suitable for SHIP
  - ⇨ Solar concept
  - ⇨ Load profile

- **Solar concept**
  - ⇨ Selection of the appropriate collector
  - ⇨ Placement
  - ⇨ Hydraulic concept
  - ⇨ Collector design
  - ⇨ Selection and design of components
  - ⇨ Simulation

- **Economic evaluation**

2-0 Solar thermal system design

2.2) Collector field placement

- Availability of suitable space for a solar thermal collector field installation is often a bottleneck at industrial sites
  - **Get site plans. pictures. Google maps images. GIS data. etc.**
  - **Discuss with responsible people on site regarding appropriate roof or ground areas**
  - **In case of roof mounting it is often necessary to ask for a structural analysis of the roof beforehand**

- In case there is space available optimum inclination and orientation of the single solar thermal collectors can be determined
- Based on the available space a maximum possible collector field size can be estimated beforehand

2-0 Solar thermal system design

2.2) Collector field placement

– Mounting options for flat and evacuated tube collectors

Ground mounted systems

Collectors with ballast blocks, waterworks, Graz, Austria [SOLID]

Post mounted system, Oberzeiring, Austria [SOLID]

- area utilization ratio: 0.5-0.6 (ground, flat roof) / 0.8-0.9 (in roof)

2-0 Solar thermal system design

2.2) Collector field placement

– Mounting options for Fresnel or parabolic through collectors

- area utilization ratio: 0.4-0.5

- area utilization ratio: 0.8-0.9

2-0 Solar thermal system design

2.2) Collector field placement

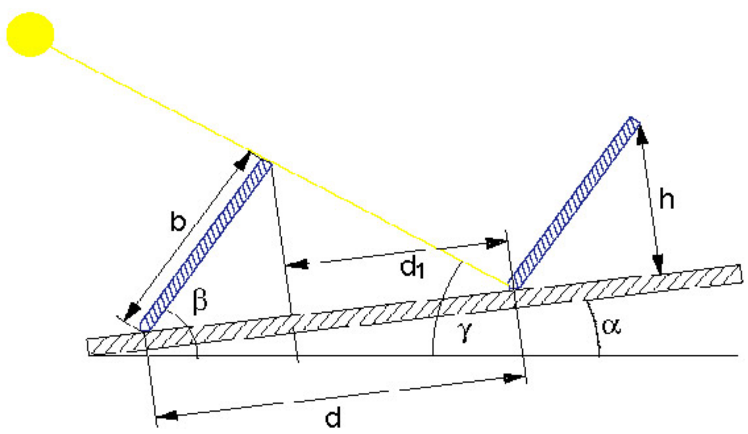
– How to choose the right inclination and orientation of the collectors?

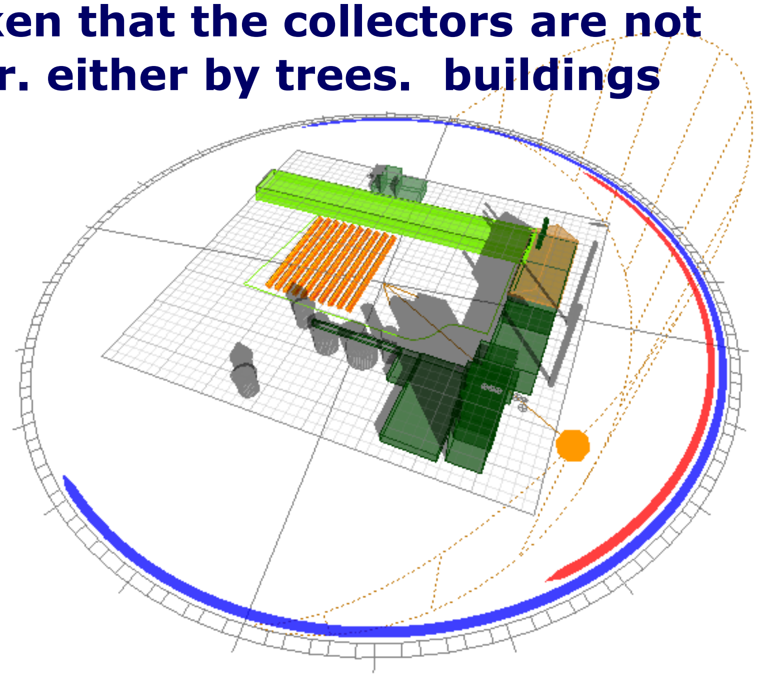
2-0 Solar thermal system design

2.2) Collector field placement

– How to choose the right inclination and orientation of the collectors?

  - **As a general rule. the collector should be facing the equator. That means in the southern hemisphere facing north and in the northern hemisphere facing south.**
  - **In addition care should be taken that the collectors are not shaded at any time of the year. either by trees. buildings or other collectors.**





2-0 Solar thermal system design

2.2) Collector field placement

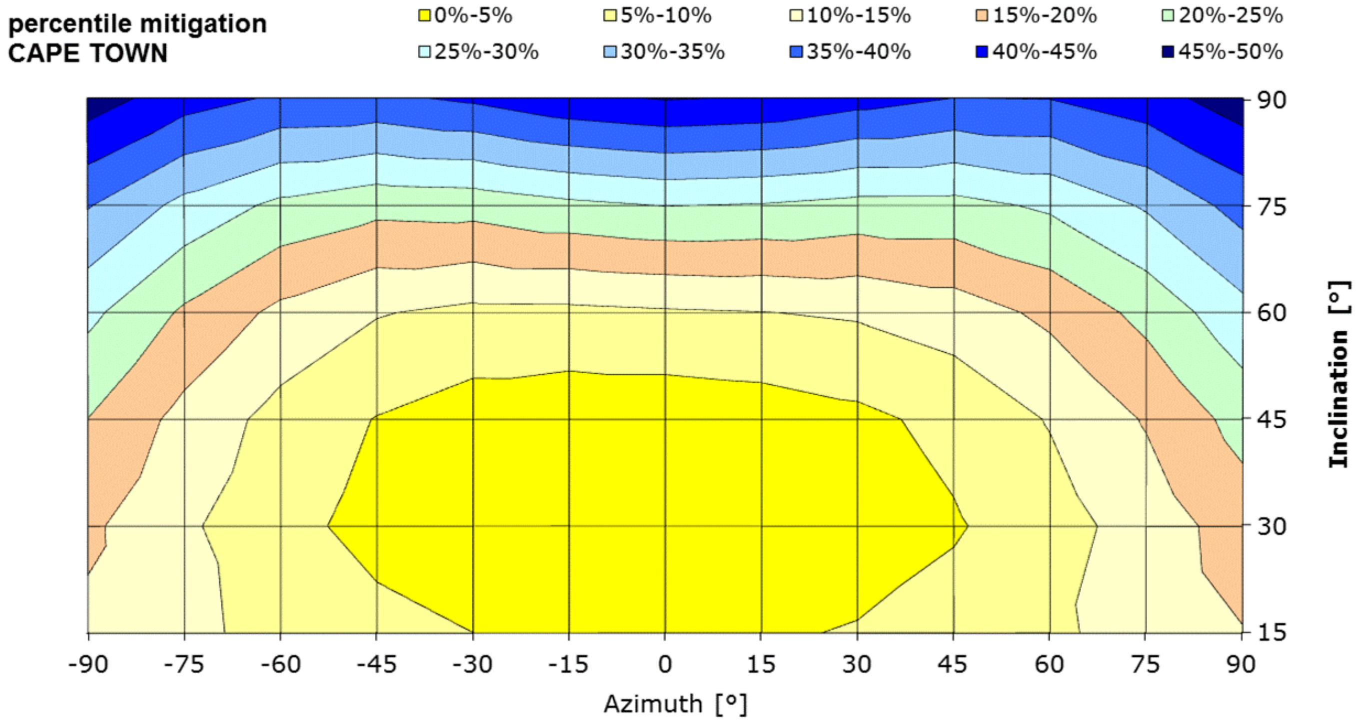
- How to choose the right inclination angle (slope angle of tilt)?
  - **The largest yield is obtained when the collector is always orientated perpendicular to the sun. However. the optimal tilt angle for the collectors varies according to the season. as the sun is higher in the sky in summer than in winter.**
  - **As a general rule. the optimum angle of tilt is (almost) equal to the degree of latitude of the site. e.g.:**
    - Latitude Cairo: 30.1° South → opt. tilt angle: 28°

- To determine optimum annual tilt angle use: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=africa

2-0 Solar thermal system design

2.2) Collector field placement

- Collector orientation can vary ±40° from equator and from 15° to 45° in slope with less than a 5% reduction in energy savings
- Within this range it is generally easy to compensate with a slightly larger collector area



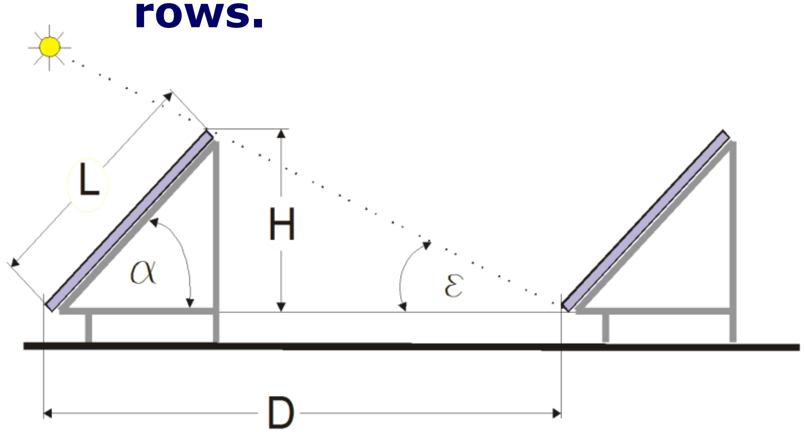
Source: AEE INTEC based on Meteonorm climate data

2-0 Solar thermal system design

2.2) Collector field placement

– Minimum row distance to avoid overshadowing

- **Variables influencing the distance. D between the collector rows.**



$$H = L \cdot \sin\alpha$$

$$D = \frac{L \cdot \sin[180 - (\alpha + \varepsilon)]}{\sin\varepsilon}$$

Symbols:

D	Distance between the rows of collectors [m]
L	Collector length [m]
H	Collector height [m]
α (a)	Collector inclination angle [°]
ε (e)	Incident solar radiation angle **in winter** [°]

2-0 Solar thermal system design

2.2) Collector field placement

– Task 2.4:
  - What is the **maximum** collector field size for a given ground area?
  - What inclination and azimuth angle do you propose?
  - Make a first draft of the ground mounted collector field (no. of rows, no. of collectors per row)

Group work

Solar thermal design

- **Process integration**
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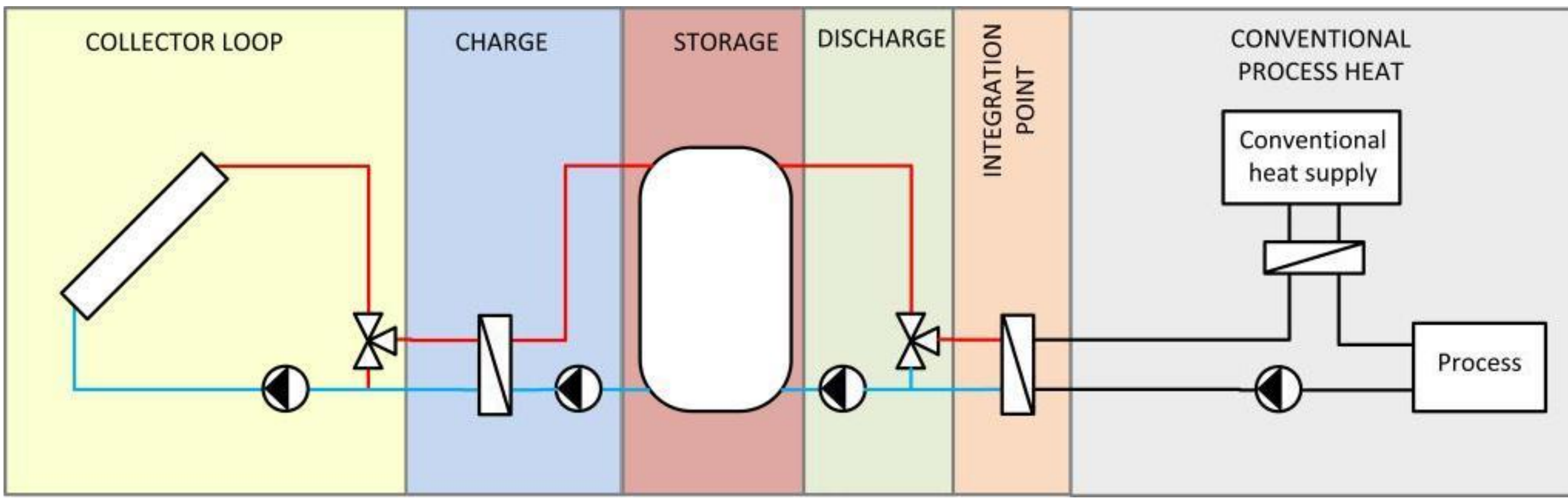
- **Solar concept**
  - Selection of the appropriate collector
  - Placement
  - Hydraulic concept
  - Collector design
  - Selection and design of components
  - Simulation

- **Economic evaluation**

2-0 Solar thermal system design

2.3) Hydraulic diagram of solar loop + process loop

- Schematic diagram of solar process heat application



2-0 Solar thermal system design

2.3) Hydraulic diagram of solar loop + process loop

– Task 2.3: Draw basic hydraulic diagram of solar loop + process loop

Group work

Solar thermal design

- **Process integration**
  - Process suitable for SHIP
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- **Solar concept**
  - Selection of the appropriate collector
  - Placement
  - Hydraulic concept
  - Collector design
  - Selection and design of components
  - Simulation

- **Economic evaluation**

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

- Collector loop (solar primary loop)
  - **Size of the solar thermal collector field**
  - **Dimensioning of solar primary loop pipes and pump**
  - **Introduction: Expansion and safety devices**
  - **Introduction: collector field hydraulics**
- Charge (solar secondary loop)
  - **Dimensioning of solar loop heat exchanger**
  - **Dimensioning of solar secondary loop pump and pipes**
- Dimensioning of the solar energy storage volume
- Discharge (solar process heat supply loop)
  - **Dimensioning of solar process heat supply loop heat exchanger**
  - **Dimensioning of solar process heat supply loop pump and pipes**

2-0 Solar thermal system design

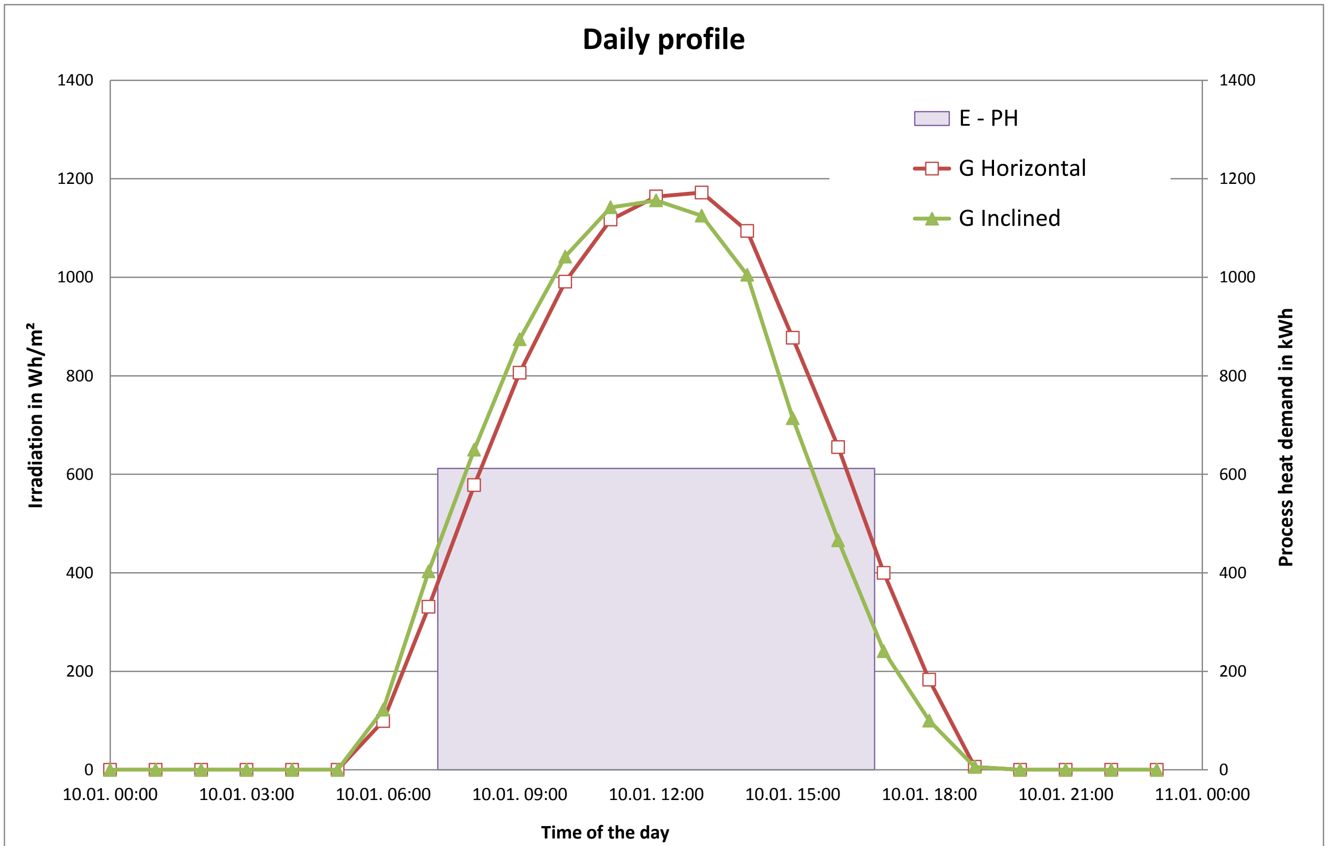
2.4) Basic (detail) engineering of the solar thermal system

– Dimensioning of the collector field
  - **Collector field size is designed in a way to cover daily process heat demand to 100% at the hottest day**
  - **This ensures that the solar thermal system is not over-dimensioned**
  - **For this calculation hourly climate data for the site are needed for the hottest day in the year**
    - e.g.: Meteonorm, T-SOL, Polysun, GIS data bases (commercial)
    - e.g.: PV-GIS: http://re.jrc.ec.europa.eu/ (**free**)

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Dimensioning of the collector field based on “hottest” day



specific max. daily **horizontal** irradiation

$$G_{hor.max} = 9.5\ \mathrm{kWh/(m^2 \cdot day)}$$

specific max. daily **inclined** irradiation

$$G_{incl.max} = 9.0\ \mathrm{kWh/(m^2 \cdot day)}$$

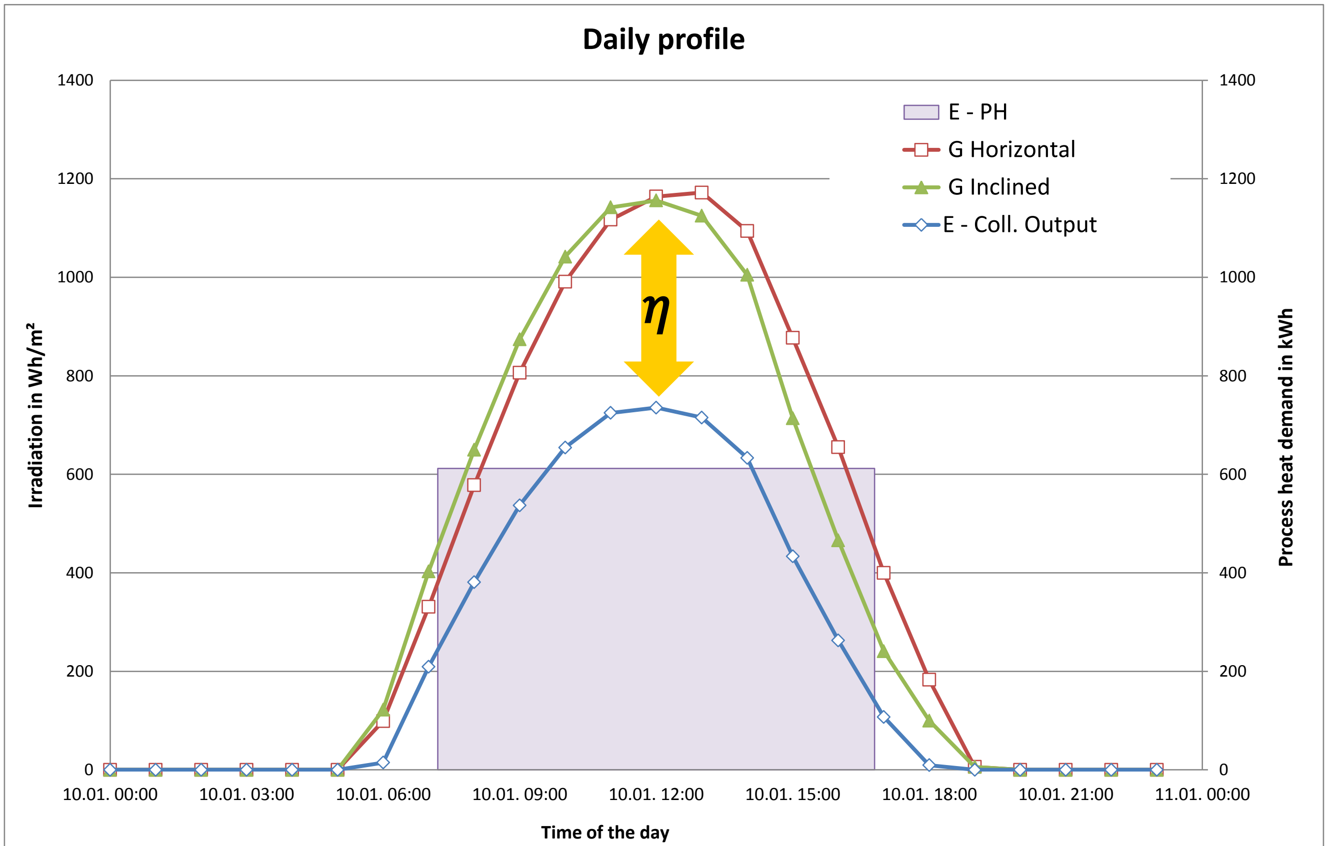
daily process heat demand

$$E_{PH} = 9{,}800\ \mathrm{kWh/day}$$

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Dimensioning of the collector field



specific max. daily collector output

$$E_{coll,max} = 5.4\ \mathrm{kWh/(m^2 \cdot day)}$$

max. daily utilization ratio:

$$\eta_{coll,day} = \frac{E_{coll,max}}{G_{incl,max}}\ [-]$$

max. collector area:

$$A_{coll,max} = \frac{E_{PH}}{E_{coll,max}}\ [m^2]$$

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Dimensioning of storage tank size

- **Storage tank should be dimensioned in a way that energy produced by the collector field can be stored during weekend still-stands (this example: for one day)**

$$Q_{storage}\,[kWh] = E_{coll,max} \cdot A_{coll,max}$$

$$V_{storage}\,[m^3] = \frac{Q_{storage} \cdot 3600}{\rho \cdot cp \cdot \left(T_{Storage,max} - T_{Storage,avg}\right)}$$

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Calculation of solar loop heat exchanger

- **The capacity of the solar loop heat exchanger $P_{HX\text{-}Solar}$ [kW] equals the max. hourly collector field power $P_{coll,max}$ @ design mean collector temperature (this case: 110/80 → Tm=95°C).**

$$P_{HX-Solar} = P_{coll,max}\,[kW] = \dot{G}_{incl,max} \cdot \eta_{coll,max}\,(95°C)$$

- **$G_{incl,max}$ [W/m²] is in the range of 1,100 – 1,200 W/m² all over the world**
- **$\eta_{coll,max}$ need to be calculated according to the efficiency curve with max. hourly irradiation on inclined surface and mean design collector temperatures**

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Calculation of solar loop cooler (water / water HEX)

- **For large scale solar process heat applications it might be necessary to install an active cooling device to avoid overheating resp. stagnation.**
- **→ pros: less temperature and pressure stress of the solar lop components**
- **→ pros: small expansion devices (only to absorb liquid expansion)**
- **→ cons: uninterruptable power supply to run the control and the pumps in case of power outages needed**
- **The capacity of the primary loop cooler $P_{HX\text{-}Cooler}$ [kW] equals the max. hourly collector field power $P_{coll,max}$ @ max. mean collector temperature (this case: 150/120 → Tm=135°C).**

$$P_{HX-Cooler}\,[kW] = \dot{G}_{incl,max} \cdot \eta_{coll,max}\,(135°C)$$

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

- Dimensioning of expansion vessels in solar primary and secondary loop
  - **If an active cooling device for stagnation prevention is used expansion vessels only need to be designed to absorb liquid expansion**

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

– Dimensioning of pumps in the solar primary loop

- **Max. pump mass flow is calculated from the max. hourly collector field power P coll,max [kW] and the design collector loop supply and return temperatures**

$$\dot{m}_{solar} = \frac{P_{coll,max}}{cp \cdot (T_{supply} - T_{return})}$$

- **Pressure loss in the system need to be calculated from losses in the collector field. piping. fittings. heat exchanger. etc.**

$$\Delta p_{system} = \lambda \cdot \frac{l}{d} \cdot \frac{\rho}{2} \cdot v^2 + \sum \zeta \cdot \frac{\rho}{2} \cdot v^2$$

- **E.g.:** Grundfos WebCABS – Pump design software

2-0 Solar thermal system design

2.4) Basic (detail) engineering of the solar thermal system

- Task 2.4:
  - Define suitable collector field size considering load, collector and radiation
  - Calculate heat exchanger capacity in solar loop
  - Design appropriate solar energy storage volume
  - Dimensioning of pipes and pumps
  - Dimensioning of expansion and safety devices
  - Draw hydraulic diagram of the collector field (considering hydraulic balancing of the system)

Group work

Solar thermal design

- **Process integration**
  - ⇨ Process suitable for SHIP
  - ⇨ Solar concept
  - ⇨ Load profile

- **Solar concept**
  - ⇨ Selection of the appropriate collector
  - ⇨ Placement
  - ⇨ Hydraulic concept
  - ⇨ Collector design
  - ⇨ Selection and design of components
  - ⇨ Simulation / Yearly analysis

- **Economic evaluation**

2-0 Solar thermal system design

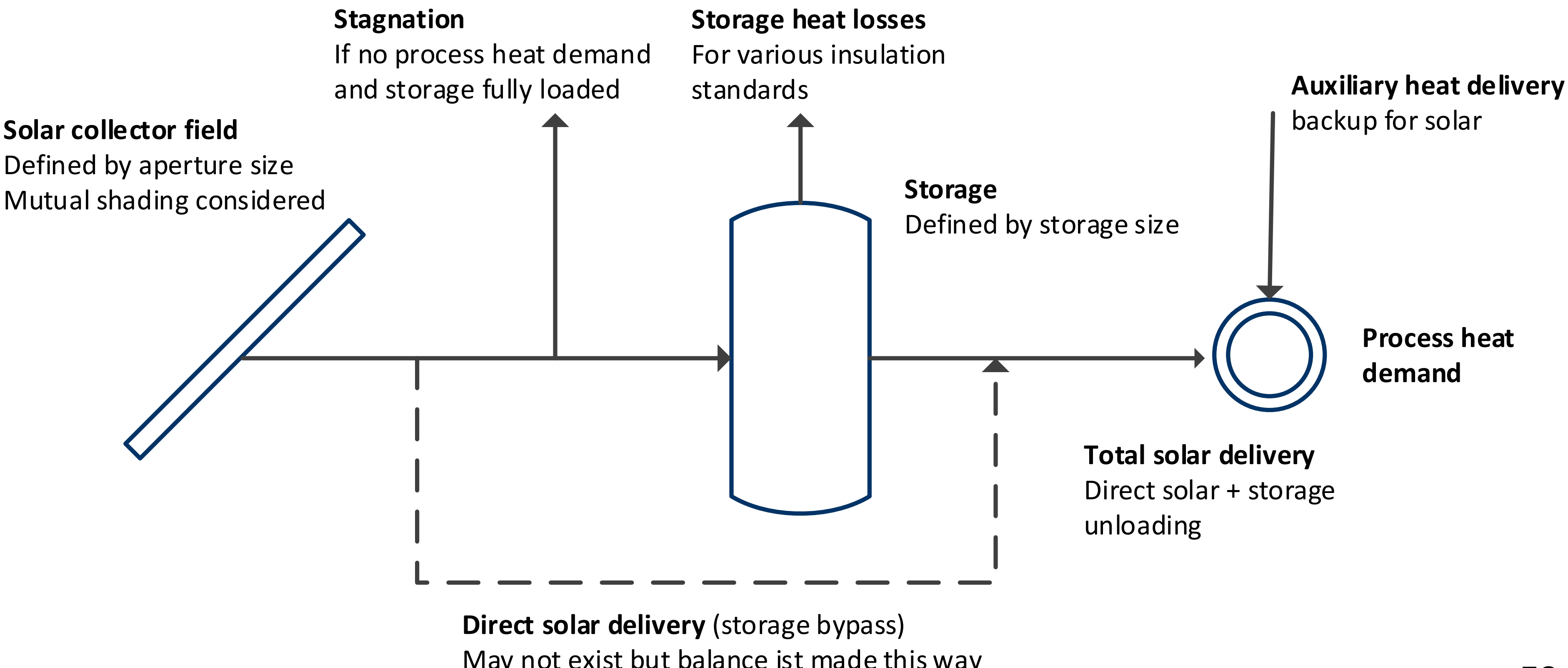
2.5) Simulation of annual energy gains

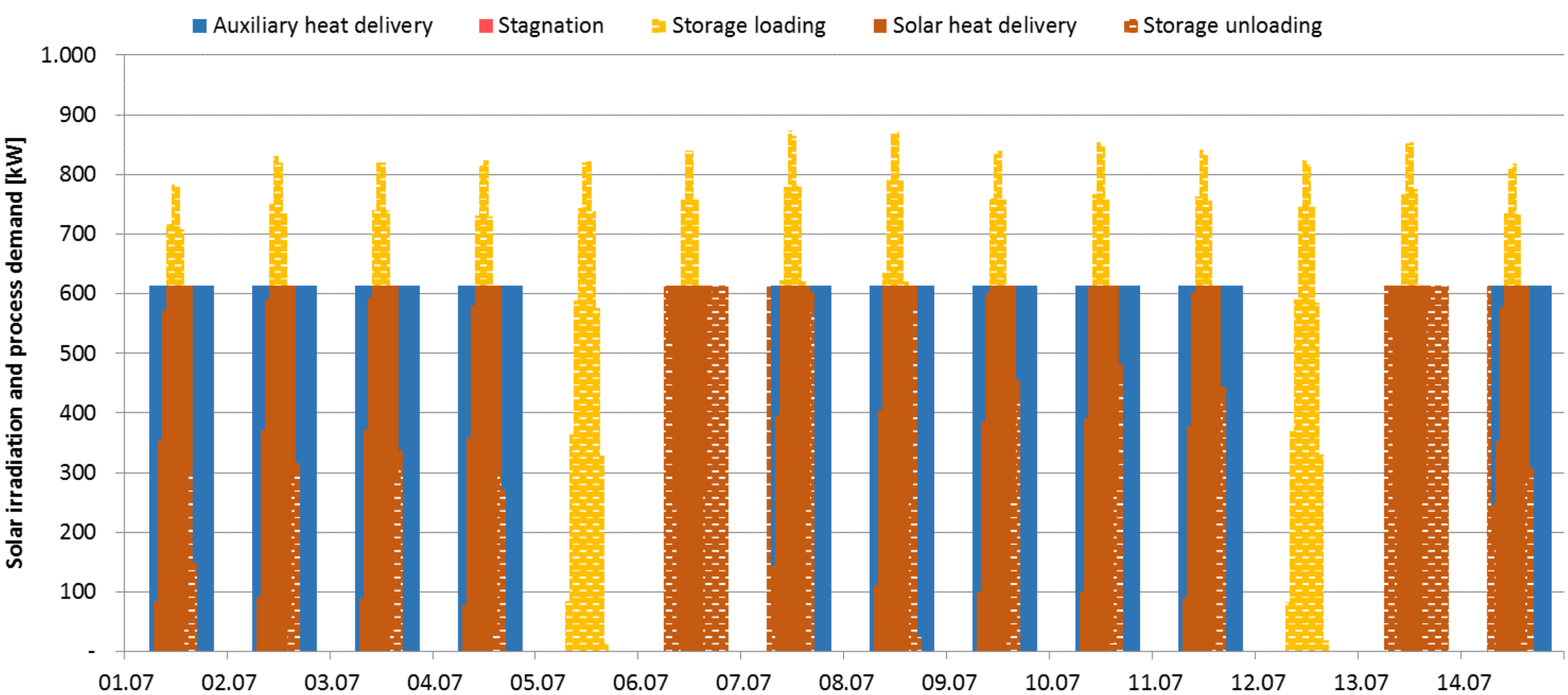
– Simulation studies are necessary to

- **determine annual energy gains, final energy savings, etc. of the solar thermal system (MWh/a)**
- **determine annual CO_2 reductions (tons of CO_2 equiv./a)**
- **compare different system concepts and / or collector types**
- **optimize system parameters (e.g. insulation thickness, control strategy, storage size, etc.)**
- **→ basis for techno-economic comparison of different variants (resp. cases)**

Simulation tools

- PolySun, TSOL and others are commercial tools for simulating solar thermal ystems
- The SHIP TOOL 2-0 incorporates a yearly analysis of the solar thermal system





Auxiliary heat delivery
Stagnation
Storage loading
Solar heat delivery
Storage unloading
Solar irradiation and process demand [kW]
1.000
900
800
700
600
500
400
300
200
100
-
01.07
02.07
03.07
04.07
05.07
06.07
07.07
08.07
09.07
10.07
11.07
12.07
13.07
14.07

2-0 Solar thermal system design

2.5) Simulation of annual energy gains

- Task 2.5:
  - What is the annual heat output (MWh/a) of the solar thermal system designed?
  - How much final energy can be saved?
  - Comparison of several cases
    - Variation of aperture size
    - Variation of collector row distance
    - Variation of storage size
    - Variation of storage insulation standards

Solar thermal design

- **Process integration**
  - Process suitable for SHIP
  - Solar concept
  - Load profile

- **Solar concept**
  - Selection of the appropriate collector
  - Placement
  - Hydraulic concept
  - Collector design
  - Selection and design of components
  - Simulation

- **Economic evaluation**

3-0) Techno-economic comparison

Based on the outcomes of the simulation case studies several cases can be compared in terms of

- **Levelized cost of heat (LCOH) of solar thermal heat produced [€/kWh]**
- **Return on investment - ROI**
- **Net present value over system life-time**
- **Etc.**

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{th}}{(1+i)^t}}$$

LCOH	Levelised cost of heat in €/kWh
I_0	initial capital cost in €
A_t	annual operating cost in €/a
M_{th}	(useful) annual solar yield in kWh/a
i	discount rate in %
n	project life time in years
t	year (1,2, …n)

3-0) Techno-economic comparison

- Task 3-0:
  - Based on techno-economic consideration:
    - which collector technology should be used?
    - which row distance should be used?

Group work

Solar thermal design

- **Process integration**
  - ⇨ Process suitable for SHIP
  - ⇨ Solar concept
  - ⇨ Load profile

- **Solar concept**
  - ⇨ Selection of the appropriate collector
  - ⇨ Placement
  - ⇨ Hydraulic concept
  - ⇨ Collector design
  - ⇨ Selection and design of components
  - ⇨ Simulation
  - ⇨ Economic evaluation

Summary of results (project report)

Summarize the results in a project report

SHIP Egypt

SHIP Design Guideline

Wolfgang Glatzl & Josef Buchinger

AEE INTEC & ConPlusUltra