LowTEMP

Large scale solar thermal

Requirements, opportunities, integration into DH-networks

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

LowTEMP training package - OVERVIEW

Introduction

- Intro Climate Protection Policy and Goals
- Intro Energy Supply Systems and LTDH
- Energy Supply Systems in Baltic Sea Region

Energy Strategies and Pilot Projects

- Methodology of Development of Energy Strategies
- Pilot Energy Strategies – Aims and Conditions
- Pilot Energy Strategy – Examples
- Pilot Testing Measures
- CO_2 emission calculation
- LCA calculation

Financial Aspects

- Life cycle costs of LTDH projects
- Economic efficiency and funding gaps
- Contracting and payment models
- Business models and innovative funding structures

Technical Aspects

- Pipe Systems
- Combined heat and power (CHP)
- Large Scale Solar Thermal
- Waste & Surplus Heat
- Large Scale Heat Pumps
- Power-2-Heat and Power-2-X
- Thermal, Solar Ice and PCM Storages
- Heat Pump Systems
- LT and Floor heating
- Tap water production
- Ventilation Systems

Best Practice

- Best Practice I
- Best Practice II

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Overview

- **Solar radiation and heat production**
- **Overview - Solar thermal systems & operating modes**
  - General principle of flat plate collectors
  - General principle of evacuated tube collectors
    - Indirect-flow evacuated tube collectors / heat-pipe principle
    - Direct-flow evacuated tube collectors / Compound Parabolic Concentrator (CPCs)
  - Characteristics of the heat medium
- **Installation & planning requirements**
  - Collector orientation / tilt & efficiency
  - Collector arrangement / Collector circuitry
  - Tichelmann-Principle
  - Stagnation handling

Overview

- **Technical & economic efficiency**
  - Difference betweeen collector & system yield
  - Annual cover ratio
  - Increasing annual solar coverage through storage
  - Key questions regarding investment costs & economic efficiency
- **Feed-in principles**
  - Hydraulic integration of solar thermal feed-in
  - Solar heat combined with other fuels
- **ANNEX & Overview about Pilot Projects**

Solar radiation & heat production

- **approximate solar radiation in Central Europe at midday :** +/- 1000 watts / m^2 (under perfect weather conditions)
- **annual average of solar radiation in Central Europe:** +/- 125 W/ m^2

(about 1/8 of perfect conditions)

- **approx. average solar radiation on collector:**

1/8 x 24h (3h per day)

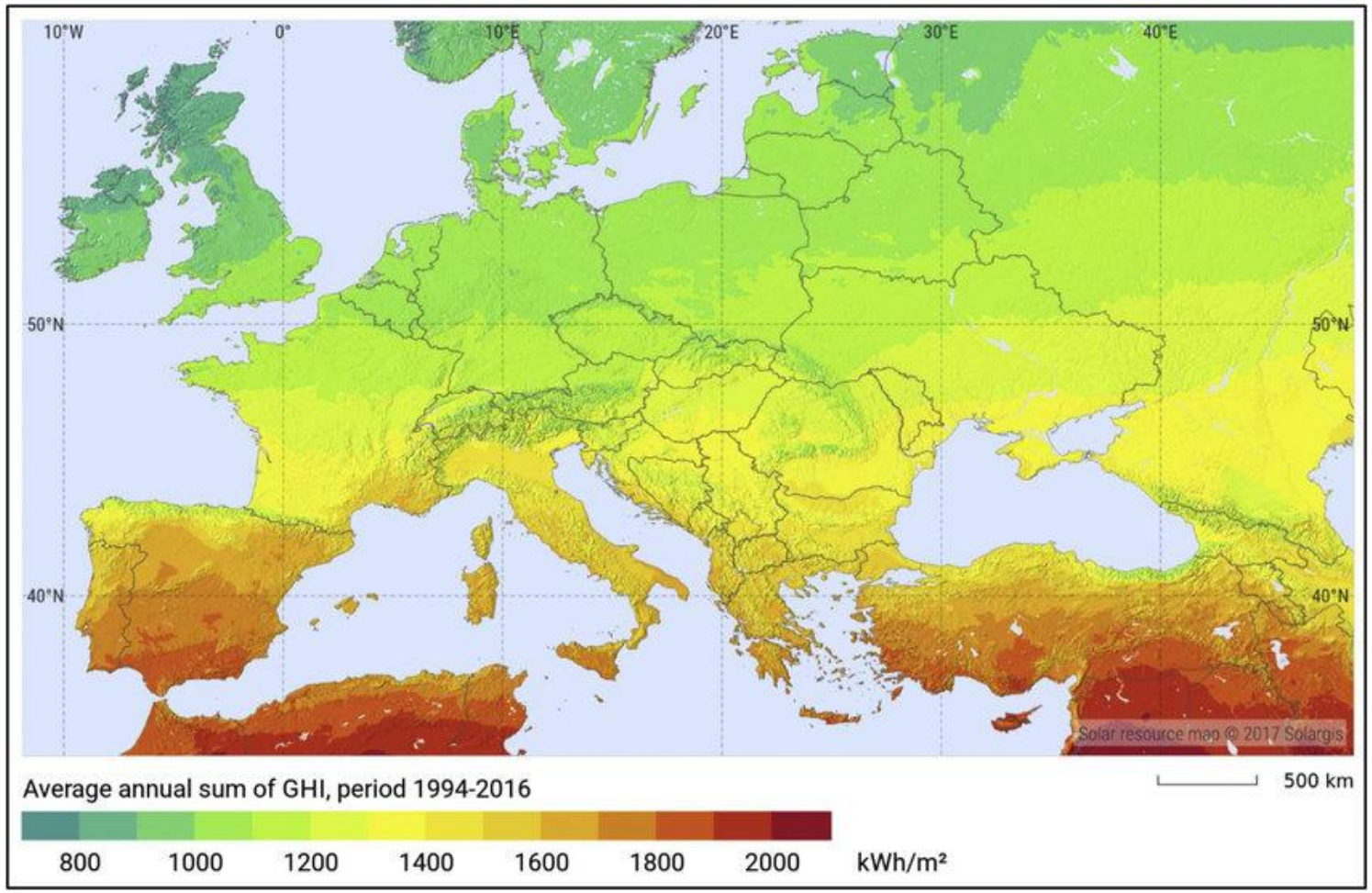
or 1/8 x 8760 h/a = +/- 1100 operating hours /a

→ +/- **1100 kW/h per m^2a**

Source: pixabay

Source of example: Arbeitsgemeinschaft QM Fernwärme [1]

Solar radiation & heat production



- Annual yield depends on many factors
  - weather
  - collector type
  - site specifications
  - plant dimensioning and energy utilization
  - installation angle
  - etc…

Source: Gholami & Røstvik. 2020 [2]

Overview - Solar thermal systems & operating modes

- **Where to place solar heat collectors?**
  - Ground mounted solar collectors

    (cheapest solution; depending on land prices, distance to the existing pipe system or consumer, general heat utilization, storage & many other parameters)
  - Roof mounted solar collectors (interesting for large and flat rooftop areas)

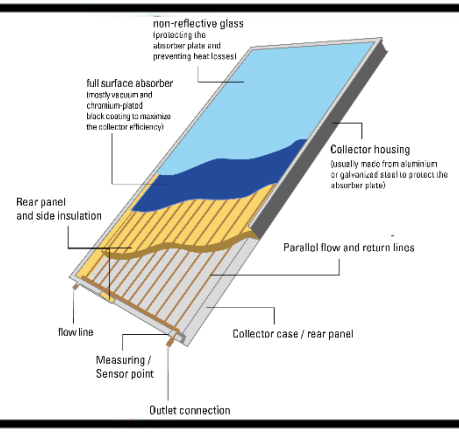
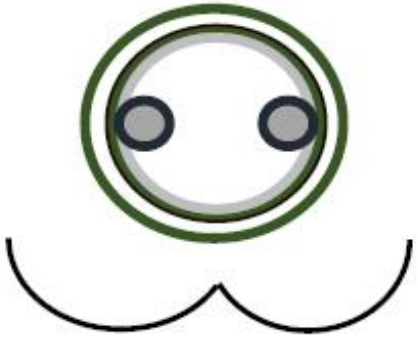
- **Most common collector types on the market?**
  - Flat plate collectors
  - Evacuated tube collectors

Source: Ritter XL Solar [3]

Source: Ritter XL Solar [3]

Source & copyright: LowTEMP. Stefan Simonides [4]

Overview - Solar thermal systems & operating modes

types	flat plate collectors	evacuated tube collectors		
	conventional / high performance collectors	indrect flow	direct flow	
		heat-pipe principle	evacuated tube	Compound Parabolic Concentrator
		Source: baunetz_wissen		

Source: AGFW & baunetz_wissen ; adjusted by AGFW-Project GmbH [5]

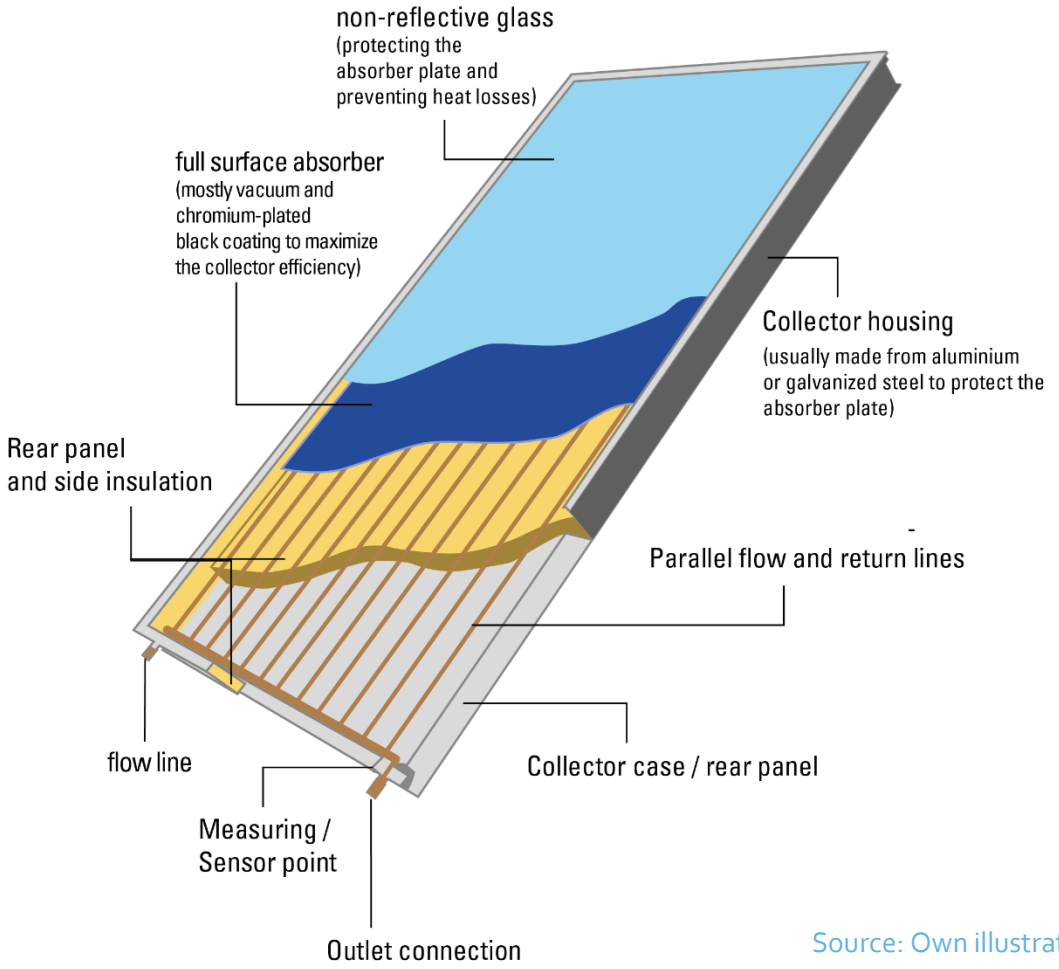
General principle of flat plate collectors

- Flat plate collectors are using a flat absorber plate that is isolated with mineral wool, polyurethane foam or other materials
- This isolation is less efficient than the vacuum isolation of evacuated tube collectors
- High performance flat plate collectors are operating with copper absorbers

Source & copyright: Stefan Simonides

General principle of flat plate collectors

- approx. production of 500-550 kWh annual yield per gross collector surface
- Reach operating temperatures from 30 to 80 °C
- If well planned, can reach stagnation temperatures from 150-200 °C
- Can be installed in series or parallel connection
- Installation angle variable
- FPCs usually work with a medium from water and antifreeze fluid



Source: Own illustrations AGFW-Project GmbH

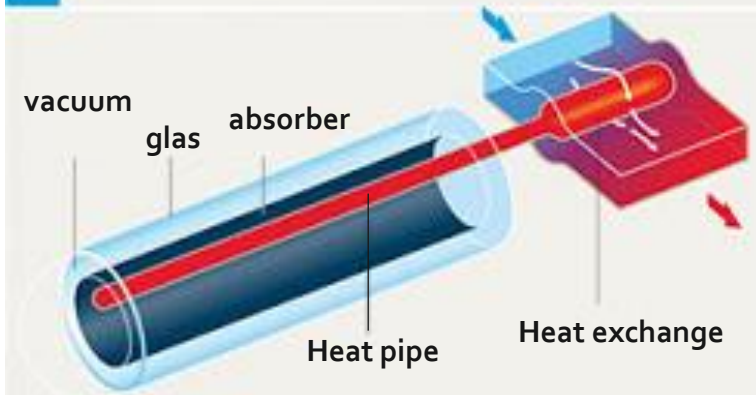
General principle of evacuated tube collectors

- Evacuated tube collectors are typically designed with parallel rows of double-hulled glas tubes
- The very high thermal insulation can be reached by the vacuum in the outer tube
- Heat pipes are transmitting the heat to the heat medium (indirect flow) **or** direct flow lines transport the heat medium in an „U-shape" through the inner glass tube
- Higher temperature levels can be achieved (above 200 °C up to 350°C)
- higher heat extraction efficiency compared with FPCs in the temperature range above 80°C
- Efficiency levels are also higher than flat plate collectors
- Higher investment costs then flat plate collectors

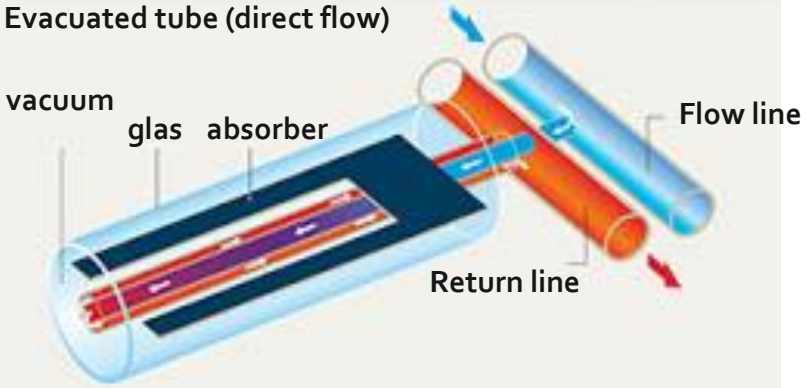
Source: Ritter-XL-Solar [6]

General principle of evacuated tube collectors

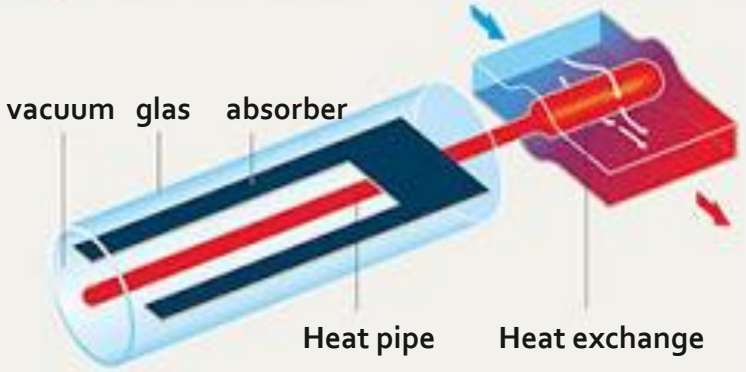
Sydney tube with heat pipe (indirect flow)



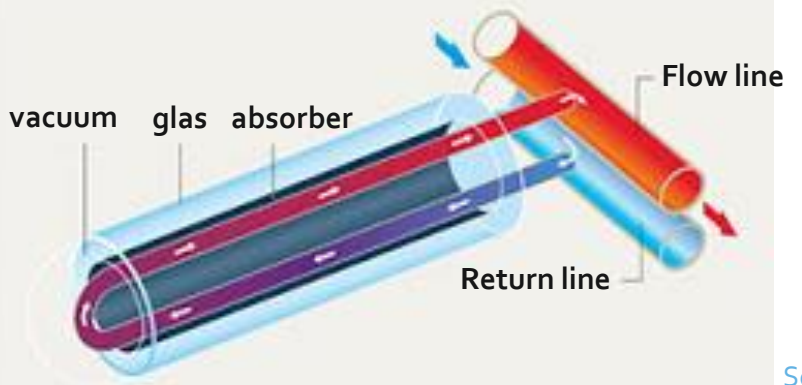
Evacuated tube (direct flow)



Evacuated tube & heat pipe principle (indirect flow)



Evacuated tube or Sydney tube (direct flow)



Source: Solarwärme (2014); translated & adjusted [7]

Indirect-flow evacuated tube collectors or heat-pipe principle

- Heat transfer tube is installed on the backside of an absorber panel
- The tube is filled with a heat medium (mostly water or alcohol under negative pressure)
- The heat transfer takes place at the top of the tube

(condensation of heat medium → released heat is transferred to the collector pipe system

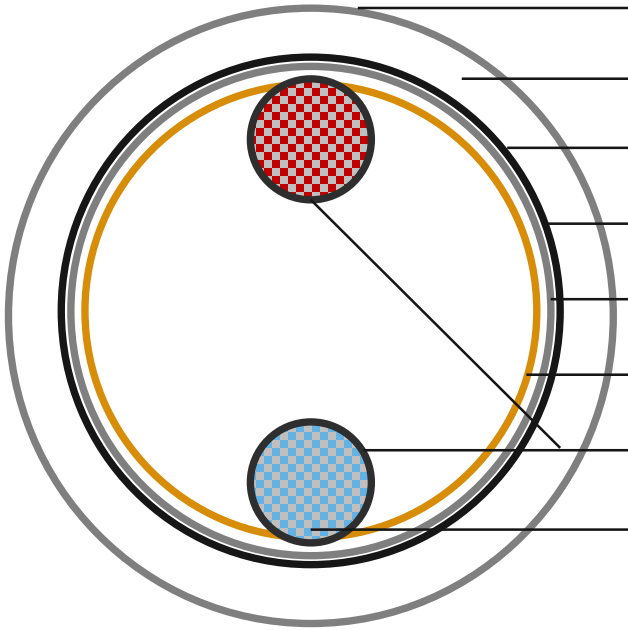
→ condensate of heat medium returns to the bottom of the glass tube and heats up again)

→Works also at days with low solar radiation, because condensate

evaporates already at low temperatures of about 25 °C (collector temperature)

→ Less pressure loss due to direct heat exchange at the flow line

Evacuated tube collectors



outer glass tube

vacuum

Coating (e.g. black-chrome or black-nickel)

inner glass tube

inner glass tube

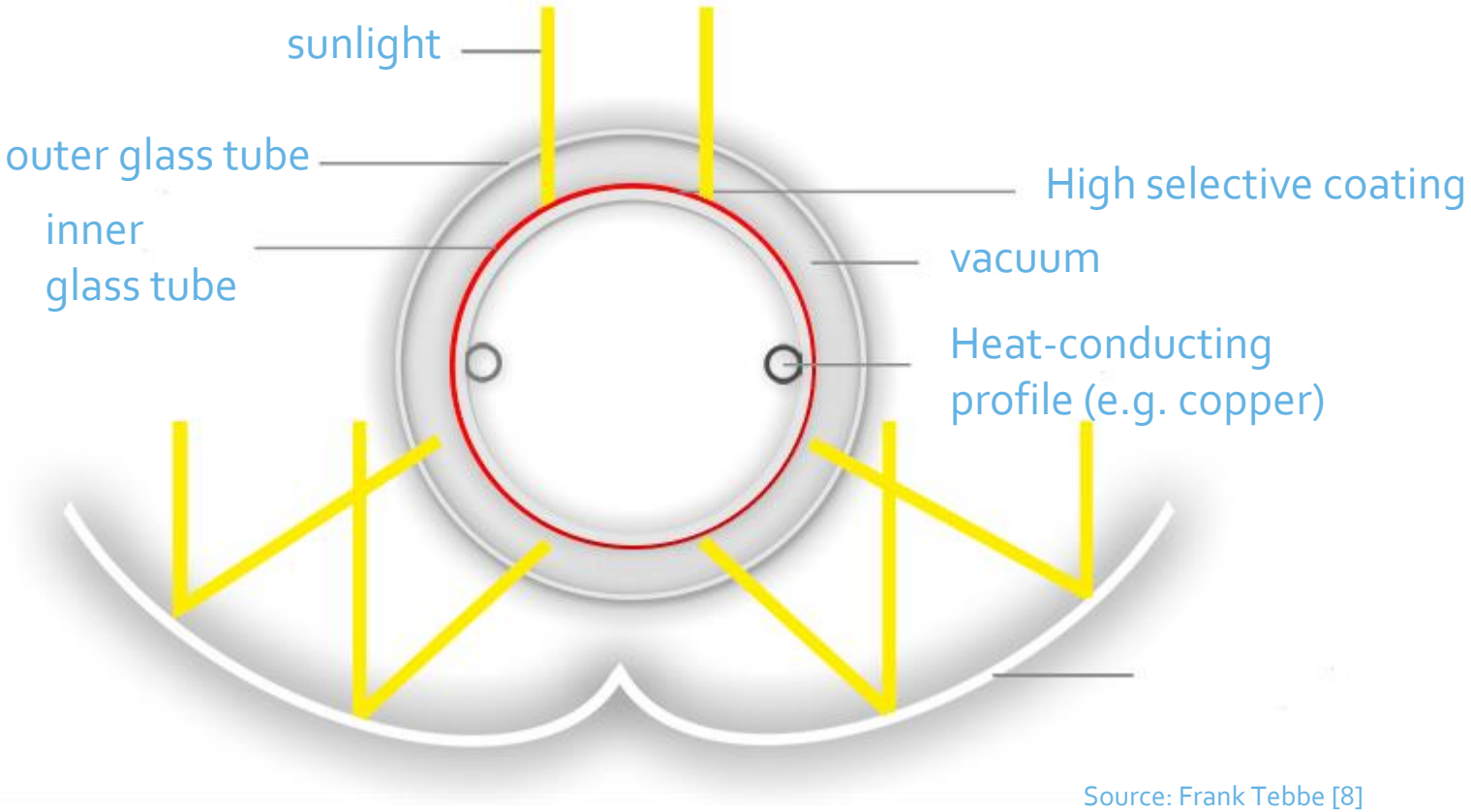
copper tubes

heat transfer medium

Compound Parabolic Concentrator (CPCs)

- Capability of **reflecting** to the absorber **all** of the incident radiation within **wide limits**
- changing solar orientation can be **reduced** by using a trough with two sections of a parabola facing each other
- By using **multiple internal reflections**, any radiation entering the aperture within the collector acceptance angle finds its way to the absorber surface

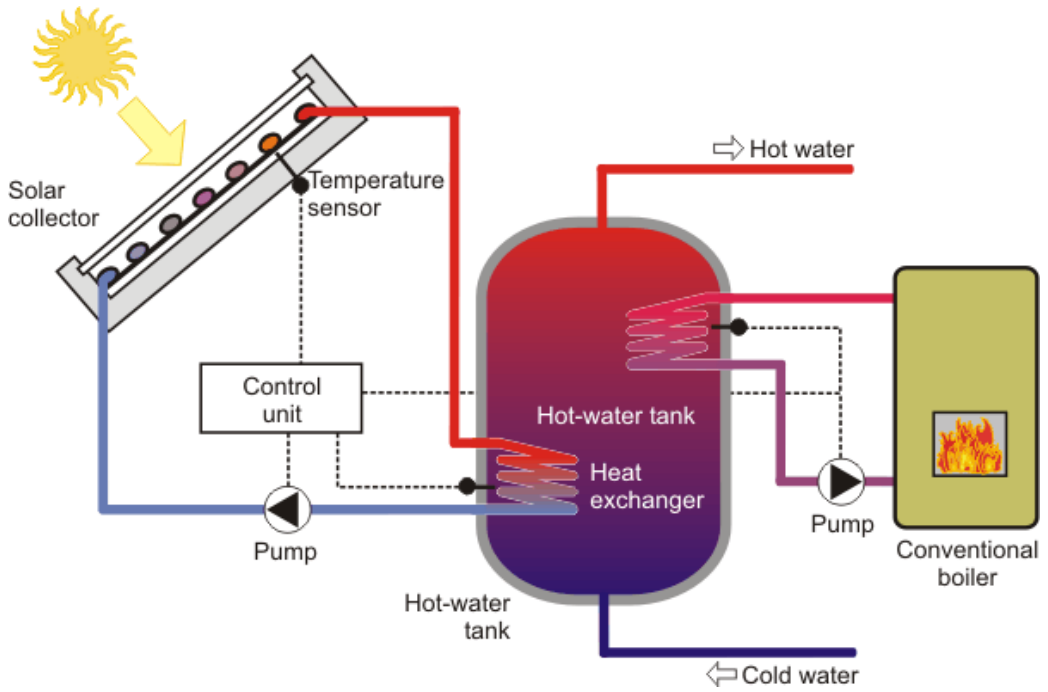
→ High investment costs



Source: Frank Tebbe [8]

Characteristics of the heat medium

- SDH-Heat medium ≠ district heating water
- Heat is exchanged at the heating station / storage tank via heat exchangers
- Heat is exchanged at the top of evacuated tube-collectors operating with indirect flow



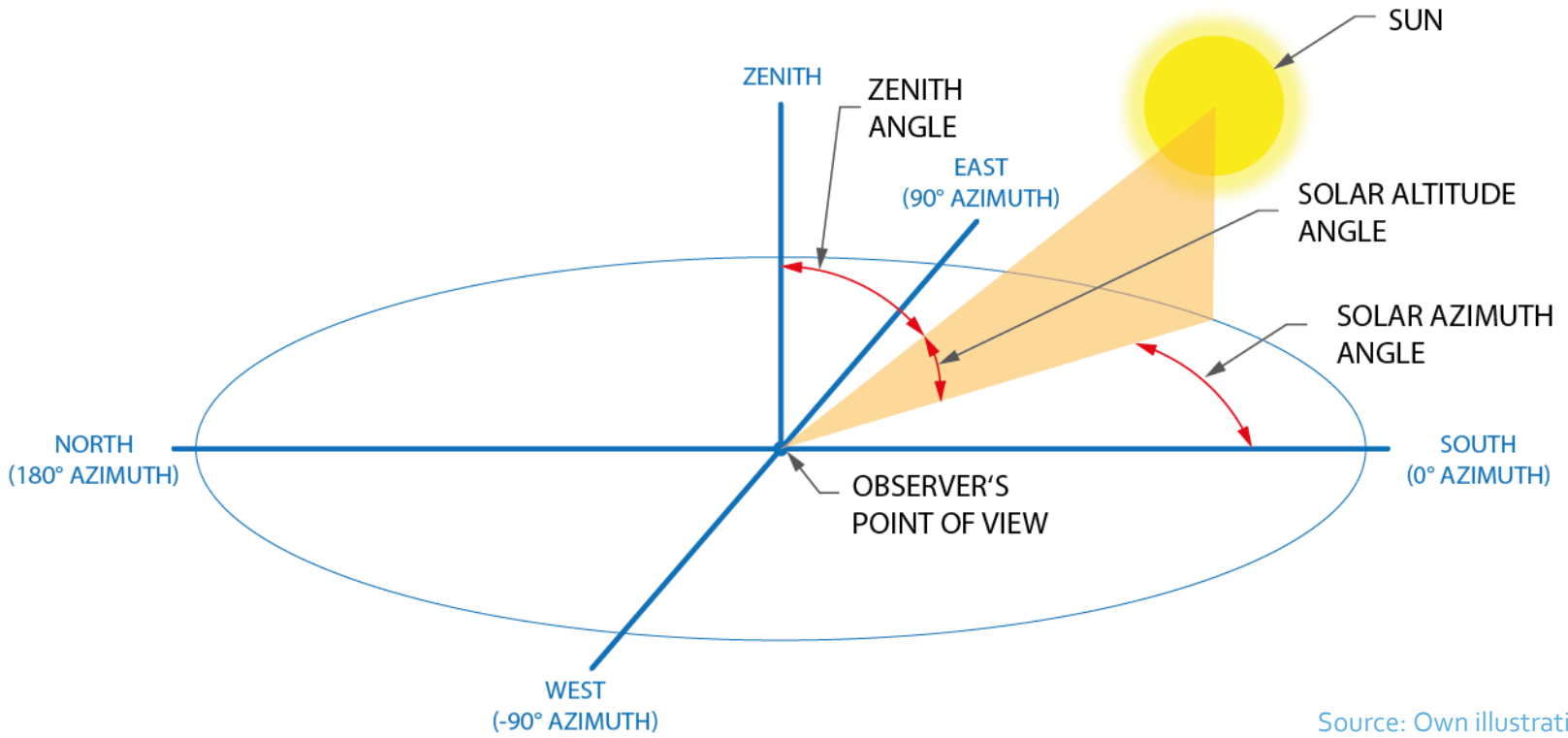
Source: Volker Quaschning [9]

Important characteristics for SDH heat medium:

- High temperature stability
- Low viscosity (due to heat capacity)
- High heat capacity
- Environmental compatibility
- Corrision protection (demineralised water etc.)
- Frost protection (usually mixture of water and alcohol used; e.g Propylene Glycol)

Installation & planning requirements

Collector orientation / tilt (set-up angle) & efficiency



Source: Own illustrations AGFW-Project GmbH

Installation & planning requirements

Collector orientation / tilt & efficiency

- absorber gets the most efficient energy when collector axis is absolute vertical to the sun rays

  → change related to hour and season

  →hence the collectors must be oriented in the latitude right angle and slope

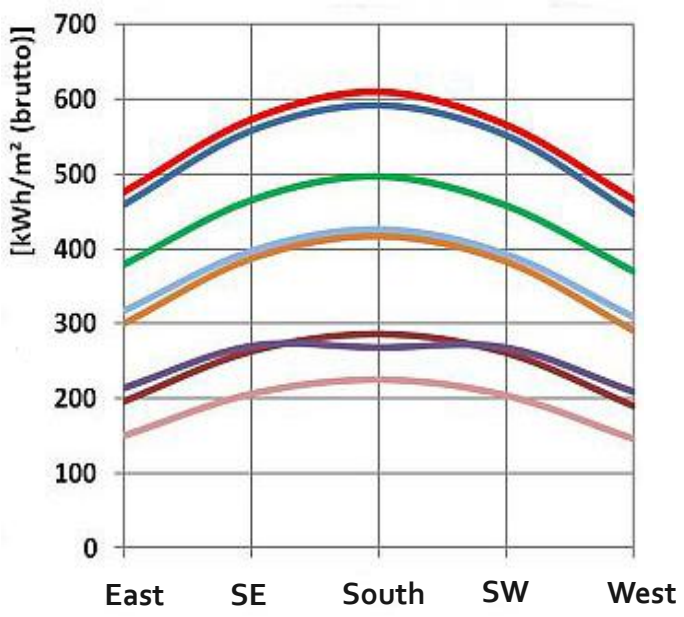
- For Europe usually 25° to 45° is the most ideal "solar altitude angle" to mount, but also angles up to 60° e.g. on rooftops can be found
- The higher the tilt the higher the collector yield during winter times / days with low solar radiation

  → high tilts minimize peaks and thermal stagnation in summer, but also the temperature level

→ **Orientation generally always depends on the site specific operation / planned heat utilization** (space heating / domestic hot water preparation / both / with or without seasonal storage) **/ heat demand etc.**

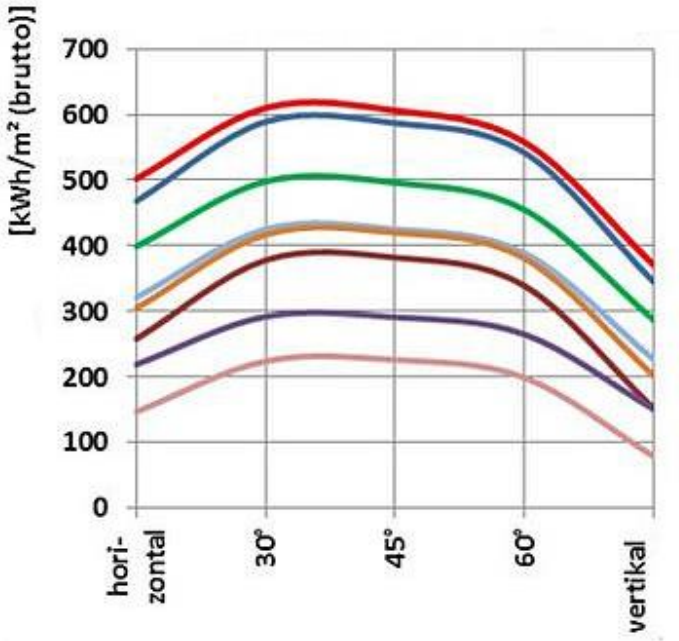
Installation & planning requirements

Collector orientation / set-up angle & efficiency



Calculative <u>EXAMPLE</u> for different varieties of solar thermal collectors.

- Location: Würzburg, Germany
- Set-up angle: 75° orientation: varying
- Average collector temp.: 75 C°



Calculative <u>EXAMPLE</u> for different varieties of solar thermal collectors.

- Location: Würzburg, Germany
- Orientation: South; tilt: varying
- Average collector temp.: 75 C°

Source of example: Paradigma (translated and adjusted) [10]

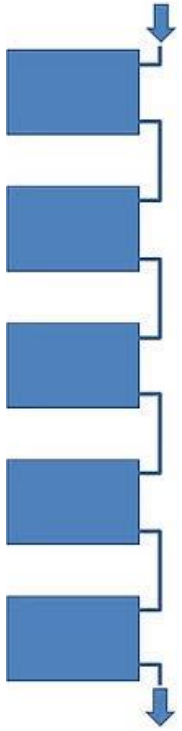
Installation & planning requirements

Collector arrangement & circuitry

- large scale solar-thermal plants can be designed in series and/or parallel connections

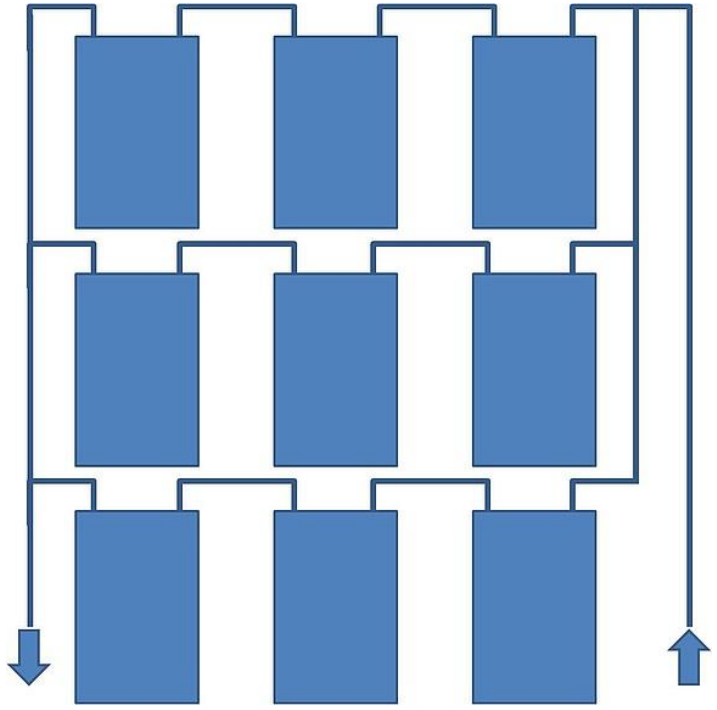
Series connection

- high pressure losses
- high pump capacity
- even flow rates
- High
- Less piping installation / lower investment costs



Parallel connection

- low pressure losses
- less pump capacity
- **Tichelmann principle** necessary for even flow rates
- Lower flow rates
- ΔT depends on collectors in series connection
- for large scale SDH-plants



Series & parallel connection. Own illustrations AGFW-Project GmbH

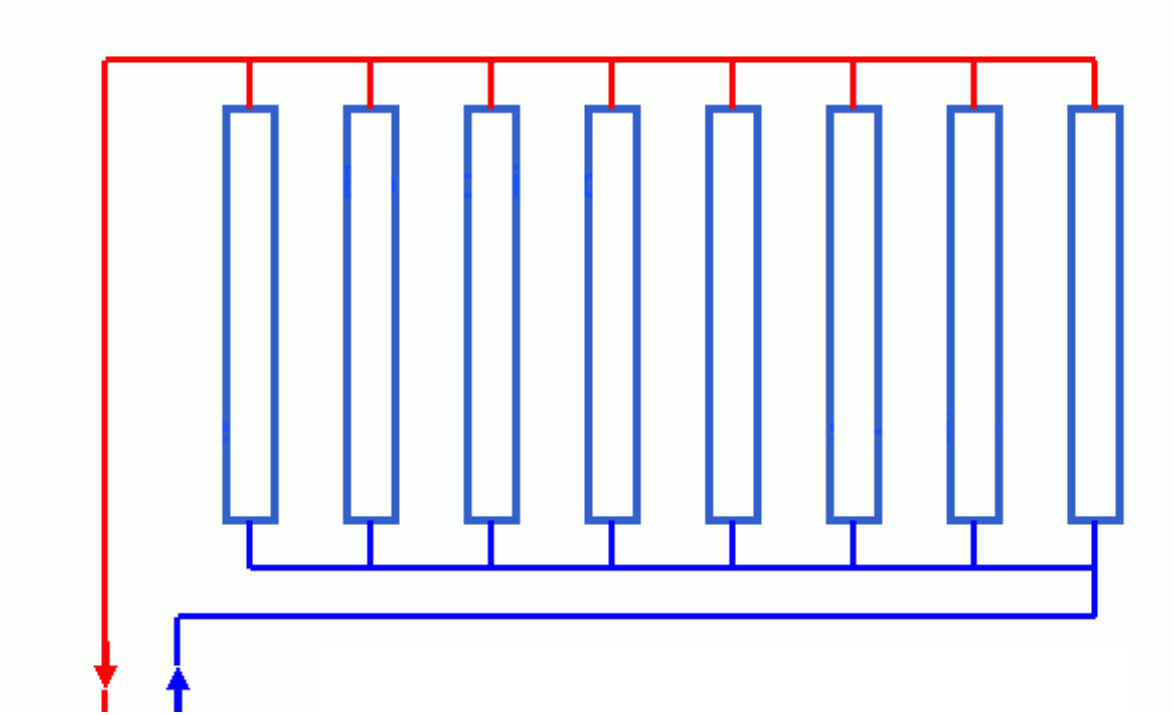
Installation & planning requirements

„Tichelmann-principle“:

- equal length ratio between flow line & return line
- Heat medium always covers same distance
- Equal pressure losses within the system
- Equal mass flux distribution

→ Higher piping needed

→ Fewer regulation effort needed e.g. through control valves



Tichelmann-principle. Own illustrations AGFW-Project GmbH

Stagnation handling

Design Temperature

Design temperature is the maximum temperature a solar thermal collector or collector loop part can stand without being damaged. The design temperature of the entire solar loop is determined by the collector loop component with the lowest design temperature.

Operation temperature

Operation temperature is defined as the maximum temperature of a solar thermal collector or the collector loop where "normal" operation shall be pursued.

→ **determined by maximum storage temperature**

→ **determined by heat demand of the connected DH-system**

Stagnation

Stagnation describes the state of a solar thermal system in which (by any reason) the flow in the collector loop is interrupted although sufficient solar irradiance is available for operation of the collector loop.

→ the fluid in the solar thermal collector is heated up to a temperature where the absorbed energy equals the losses

(Source: Frank, E., Mauthner, F., & Fischer, S. (2015). [11]

Stagnation handling

„Stagnation handling…

…if stagnation is an accepted operation mode!"

„Overheating prevention…

… If stagnation is not an accepted operation mode!"

Keymark-Certificates: http://www.estif.org/solarkeymarknew/

TÜVRheinland®
DIN CERTCO

itw

Page 1/2

Summary of EN 12975 Test Results, annex to Solar KEYMARK Certificate	Licence Number	
	Issued	2015-11-30

Stagnation temperature - Weather conditions see note 2	Tstg	301	°C
Effective thermal capacity	ceff = C/Ag	9.18	kJ/(m²K)
Max. intende operation temperature - see note 3	Tmax,op	160	°C
Max. operation pressure - see note 3	pmax,op	1000	kPa

(Example of a keymark-certificate. Source: www.estif.org)

Constructional precautions, security concept with regard to plant-dimensioning have to be THE important aspects in the planing phase!

(Quoted from Frank, E., Mauthner, F., & Fischer, S. (2015). [11]

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Stagnation handling

Effects of stagnation:

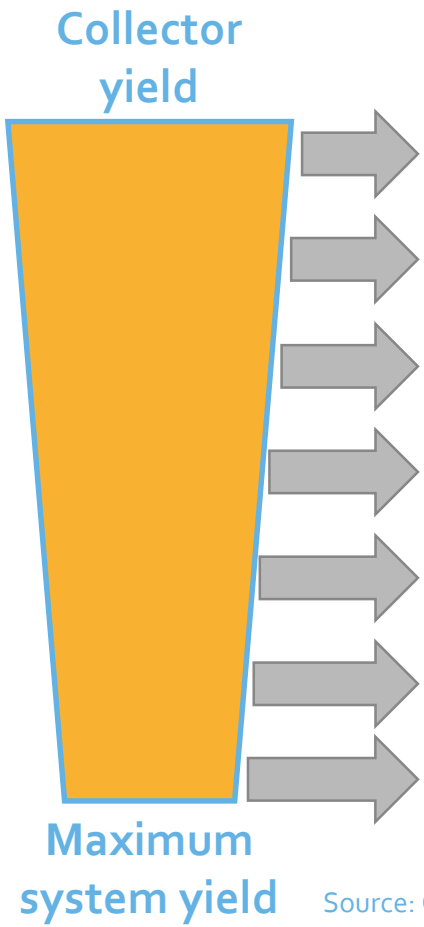
- Pressure increase and steam formation in the collector
- Steam development in the solar circuit
- High stress on the system components (e.g. pump gaskets)
- Possible cracking of glycol in the heat transfer fluid

Handling stagnation:

- Drainage of the solar fluid (especially necessary for glycol medium before stagnation state)
- Disable pumps & overpressure management
- Active cooling e.g. with groundwater and a second heat exchanger (extra well and absorption well will be needed)

→ Accepting stagnation as operation mode needs to considered and planned within the planning and implementation phase

Technical & economic efficiency



Source: Own illustration AGFW-Project GmbH

Difference betweeen Collector & system yield

Difference occurs…

- … due to warming up in the morning and cooling down at night
- … in pipes and valves
- … due to storage
- … due to stagnation
- … due to active frost protection
- … due to antifreeze fluid
- … due to heat exchangers

The difference between collector yield and maximum system yield can be roughly estimated by taking 10 % of the annual radiation

Annual cover ratio

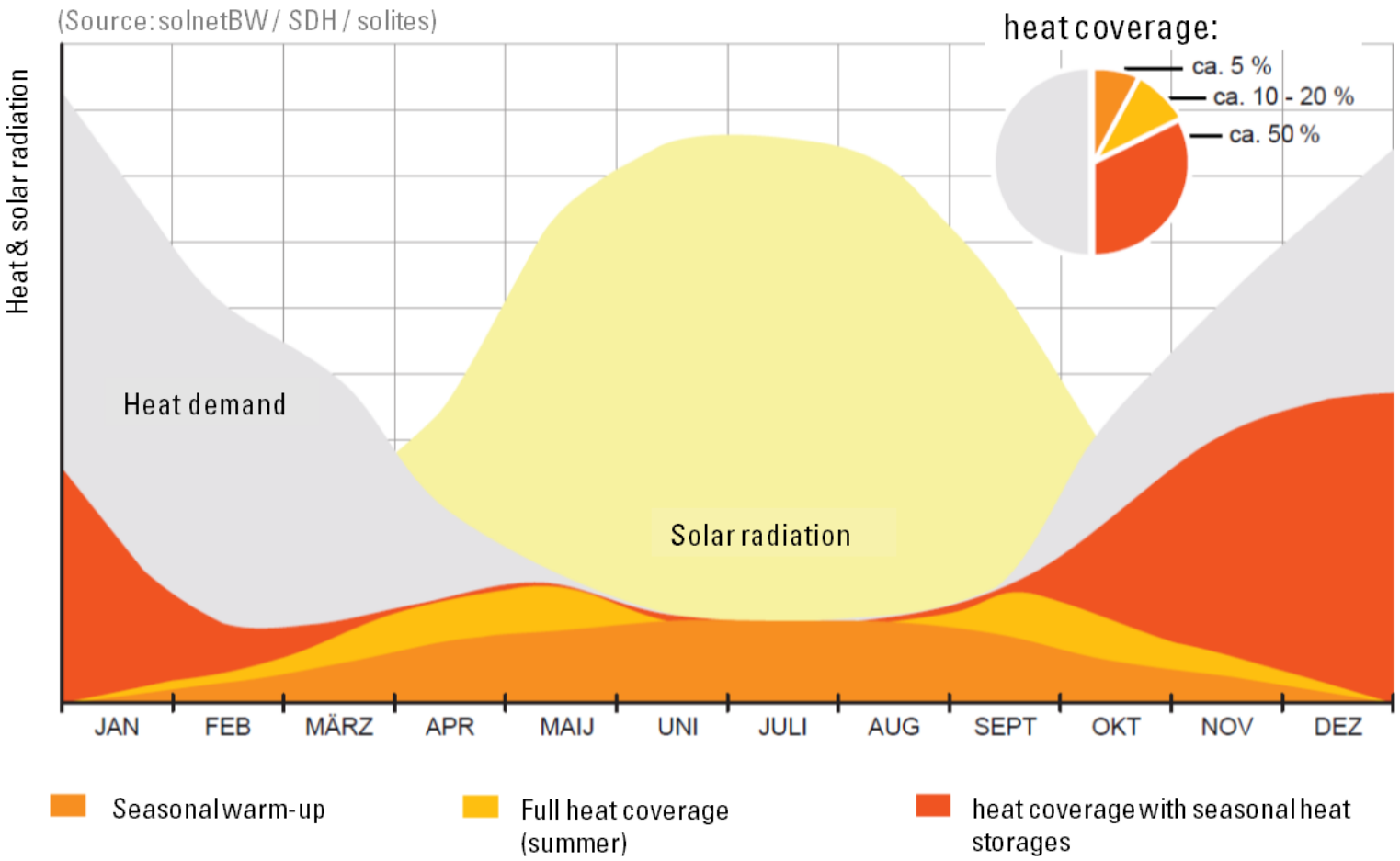
Cover ration depends on:

- Integration of solar heat production in DH-systems (feed-in point: flow line / return flow)
- Planned heat utilization and operating temperature level

  (Domestic hot water preparation, space heating, floor heating, etc.)
- Building structure (development area, existing building structure)
- Structure of the solar system (buffer storage, seasonal storage or direct integration)
- Direct or indirect feed-in

→ **No determined reference values!** (cover ratio needs to be estimated for each specific project)
→ SDH-plant can approx. reach between 30-60 % of the annual demand of domestic hot water preparation (complete coverage in summer)
→ Seasonal storage can increase the annual solar cover ratio by boosting stored water e.g. with a heat pump in transition periods

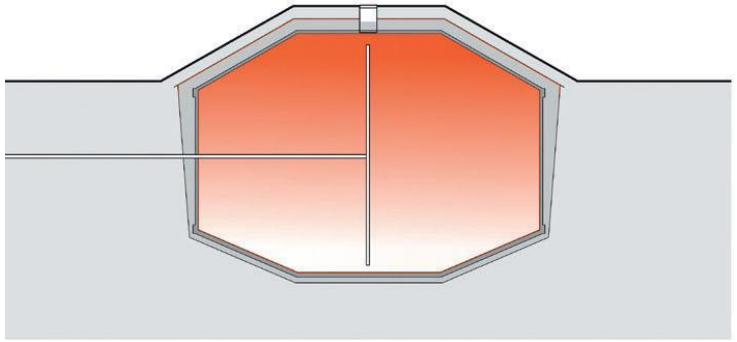
Increasing annual solar coverage through storages



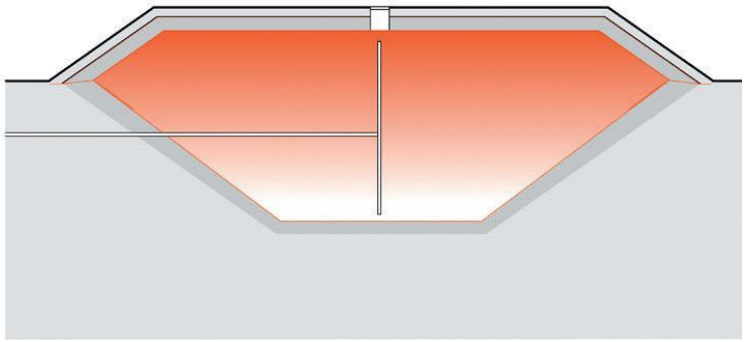
Source: Mathilde Kolbe [12]

Increasing annual solar coverage through storages

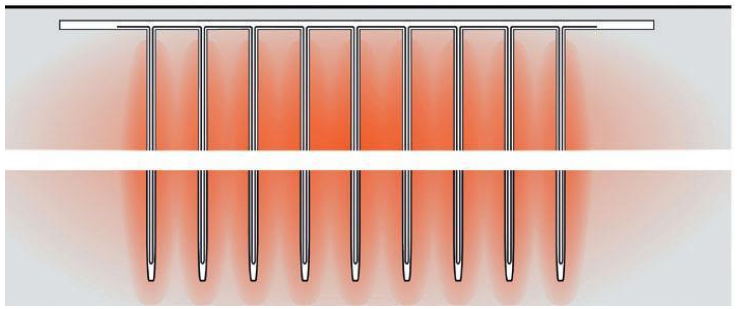
Heat storage (tank)
(60 to 80 kWh/m³)



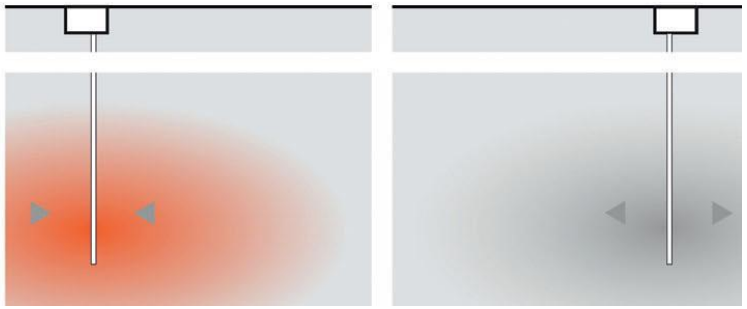
Pit store
(30 to 80 kWh/m³)



Pie store (geothermal probe)
(15 to 30 kWh/m³)



Aquifer storage
(30 to 40 kWh/m³)



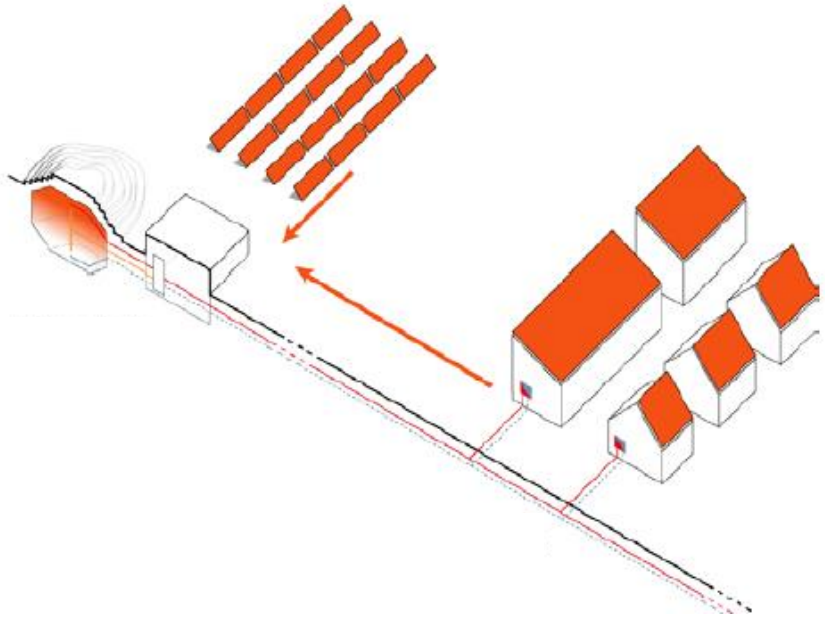
Storages options:

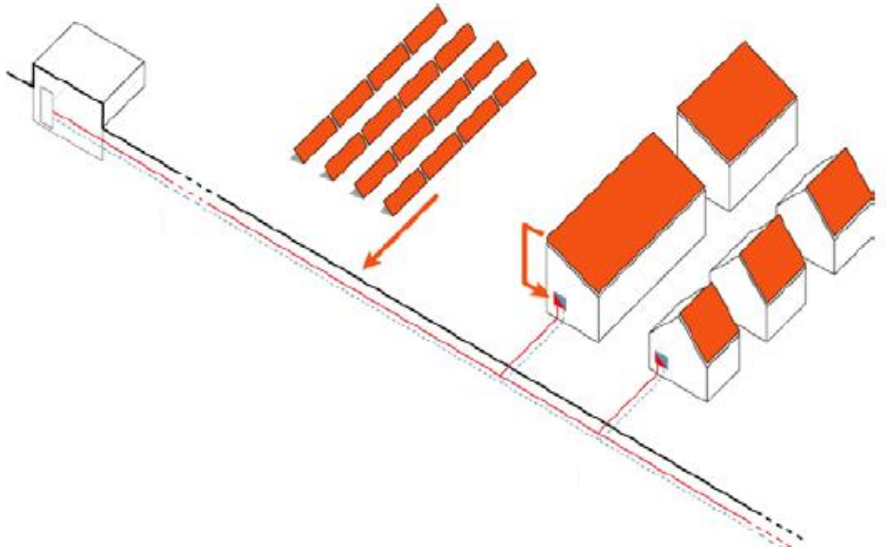
- Buffer storages (daywise storage)
- Seasonal storages (on the left)

Source:ikz.de (translated) [13]

Feed-in principles – decentral / central

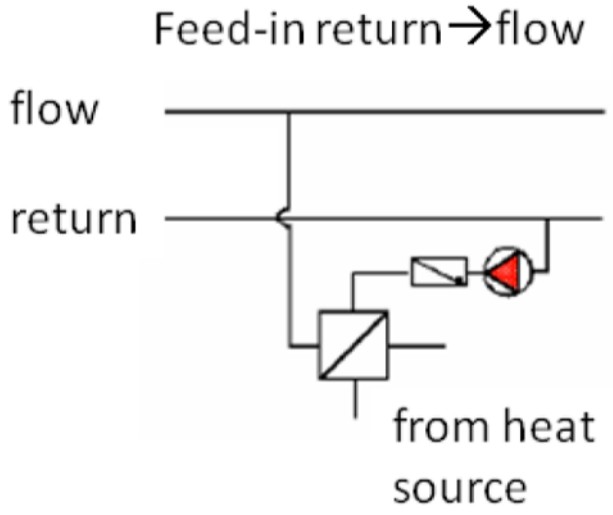
- „Decentral“: solar thermal plant is not close located to another major heat generator
- Central: feed-in point can be a transfer station (Solarthermal plant is located next to another heat generator e.g. heat plant / cogeneration unit)





Source: Solites (translated) [14]

Feed-in principles – decentral



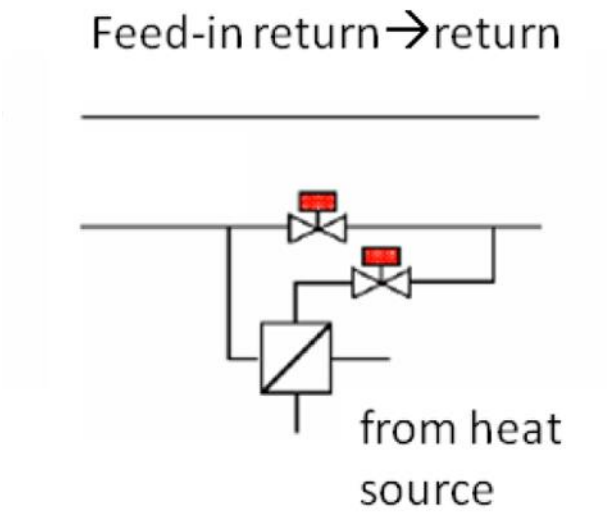
- Required temperature hub in the heat generator is defined by flow and return line of the heating grid
- Solar plant has to be operated at matched flow volumes, adjusted to the required flow temperature
- Feed-in pump has to overcome pressure differences between return and flow (could come to several bar)

  \+ no change in return temperatures

  \- high pump capacities needed

(Figure & Quoted from Solar District Heating (SDH) (2012) [15].

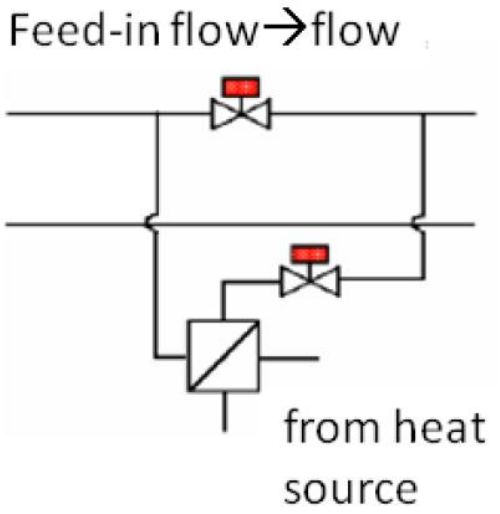
Feed-in principles – decentral



- Operating temperatures of solar plant lowest compared to other feed-in modes
- High solar yields can be expected
- No pumping energy required
- Constant mass flow in collectors
- Grid operators need to install a flow resistance to control feed-in by solar plant
- High return temperatures are not favourable

(Figure & Quoted from Solar District Heating (SDH) (2012). [18]

Feed-in principles – decentral

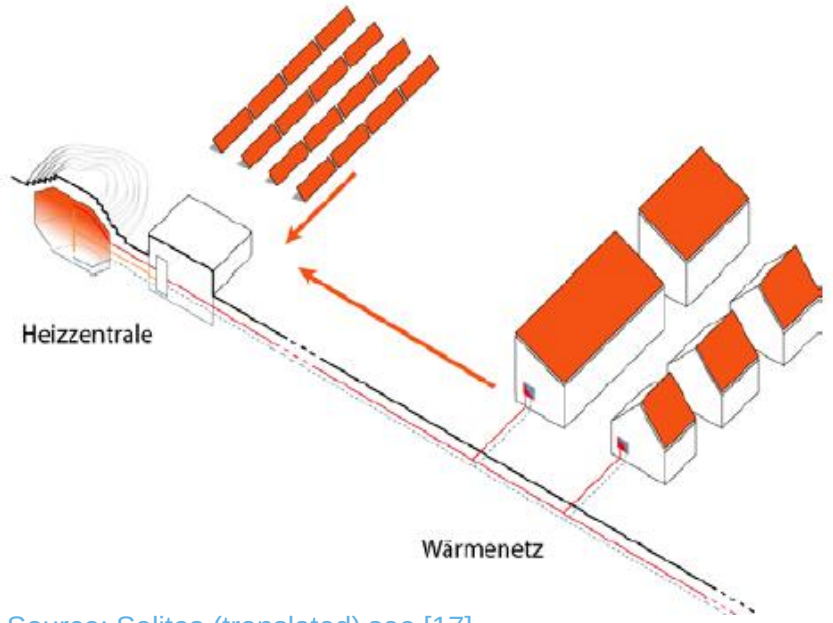


- High collector operating temperatures needed
- Low solar thermal efficiency and yields due to high temperature level

(Figure & Quoted from Solar District Heating (SDH) (2012). [18]

Feed-in principles – central

- Heat transfer takes place with heat exchangers at the central heating station
- clear distinction between solar cycle and DH-systems
- Feasible combination of solarthermal plant with other heat generating technologies possible



Source: Solites (translated) see [17]

SDH combined with other heat generating technologies

- Technically solar heat can be combined with any other energy source

→**The economical and environmental feasibility relies on multiple factors and needs to be estimated for each case!**

Few examples:

- **Increase of Return-flow**
  - **Saving primary energy:** increase of return flow temperature / coverage of domestic hot water preparation in summer)
  - High return flow temperatures not always wanted by grid operators
- **In combination with a cogeneration plant**
  - Solar thermal plants could lower output for electricty production

Key points regarding investment & operating costs

- Cost of land
- Collectors
- Collector field installation including piping in the field
- Anti-freeze fluid
- Transmission piping (collector field to heat exchanger unit)
- Heat exchanger (HX) unit (including pumps, expansion vessels, control, etc.)
- Connection to existing DH-systems
- Storage
- Control system
- Design & optimization
- Miscellaneous (e.g. building, ground shaping, fence, plant management etc.)

(Quoted from Solar District Heating (SDH) (2012). [16]

Key points regarding investment costs & economic efficiency

- Heat demand & dimension of the plant
- Storage size / seasonal storage needed (if, which other heat source e.g. heat pump will be needed?)
- Required landsize & price need to be evaluated with legal issues and construction law
- Which solar thermal system is needed? / Which temperature level is necessary?
- What are the existing structures of heat generation? What will be the future solar feed-in scenario?

  → piping expenses
- How much should be the estimated solar thermal heat coverage / annual duration?

  → Flow pipe / return pipe feed-in or both?
- What are the energy savings by other integrated/existing heat sources (e.g. (bio)gas / biomass etc.)?
- How much funding is possible?
- What are the financing costs (term, interest rate)?
- Development of energy costs within the next few years?

Contact

AGFW-Project GmbH
Project company for rationalisation,
information & standardisation

Stresemannallee 30
60596 Frankfurt am Main
Germany

E-mail: info@agfw.de
Tel: +49 69 6304 - 247
www.agfw.de

ANNEX I: Possible Scenario:
Requirements for DH-supplier / Solar power plant operator

- Solar-DH is a volatile energy production
- Check at the feeding point, if the intended thermal load can be fed into the DH-network
- **Scenario:** loading condition "summer" - least thermal load, but the highest solar heat supply
- **Following principles are important to be considered:**
  - **Solar thermal load in the course of the day << thermal grid load summer**

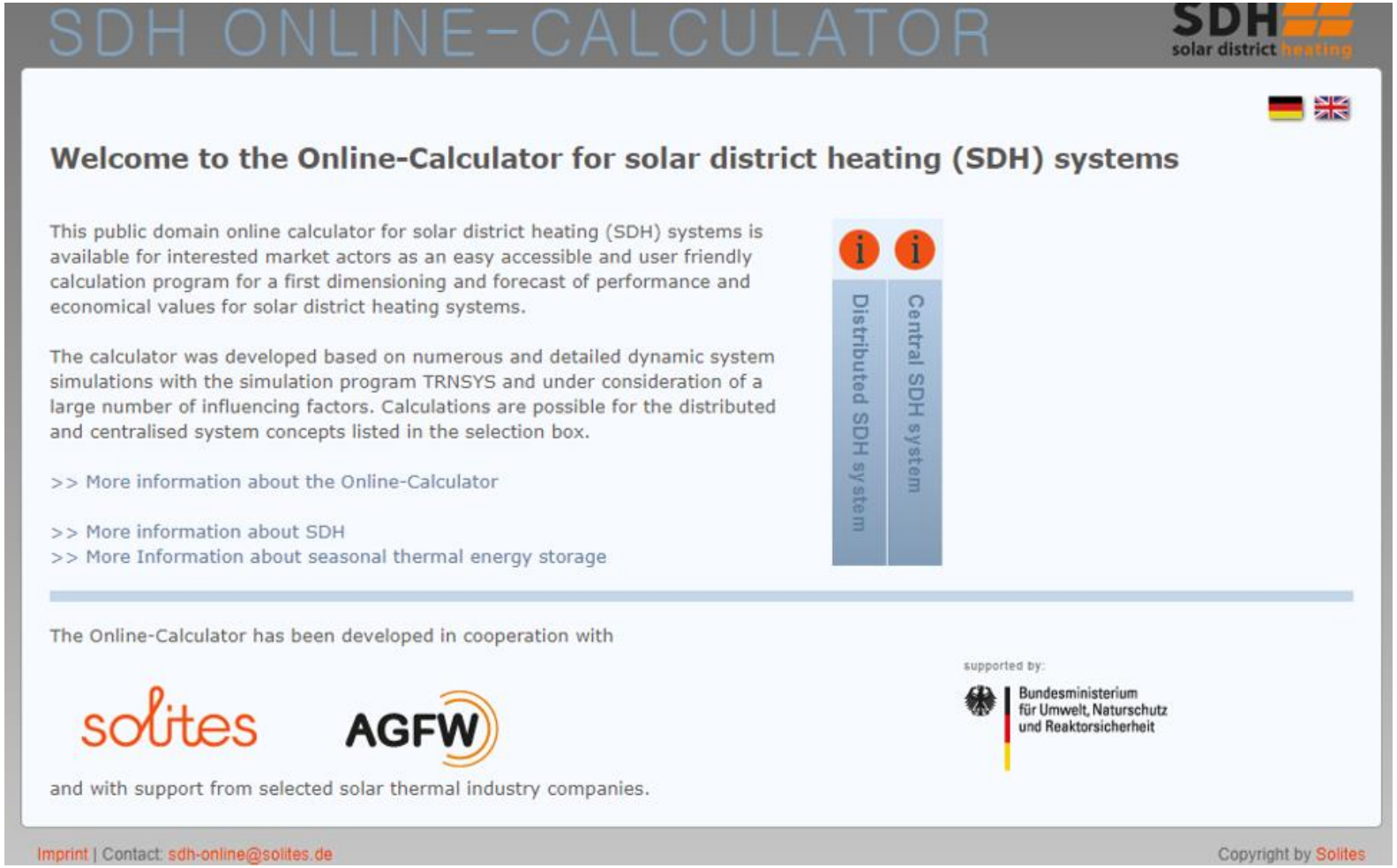
    → heat absorption possible at any time as flow into the grid stays low
  - **Solar thermal load in the course of the day < or = thermal grid load summer**

    → heat absorption temporarily not possible → buffer storage might be useful
  - **Solar thermal load in the course of the day > thermal grid load summer**

    → buffer storage necessary for feeding in the solar heat load with a time lag (if appropriate on demand)
  - Plant size is depending on the maximum transportable heat

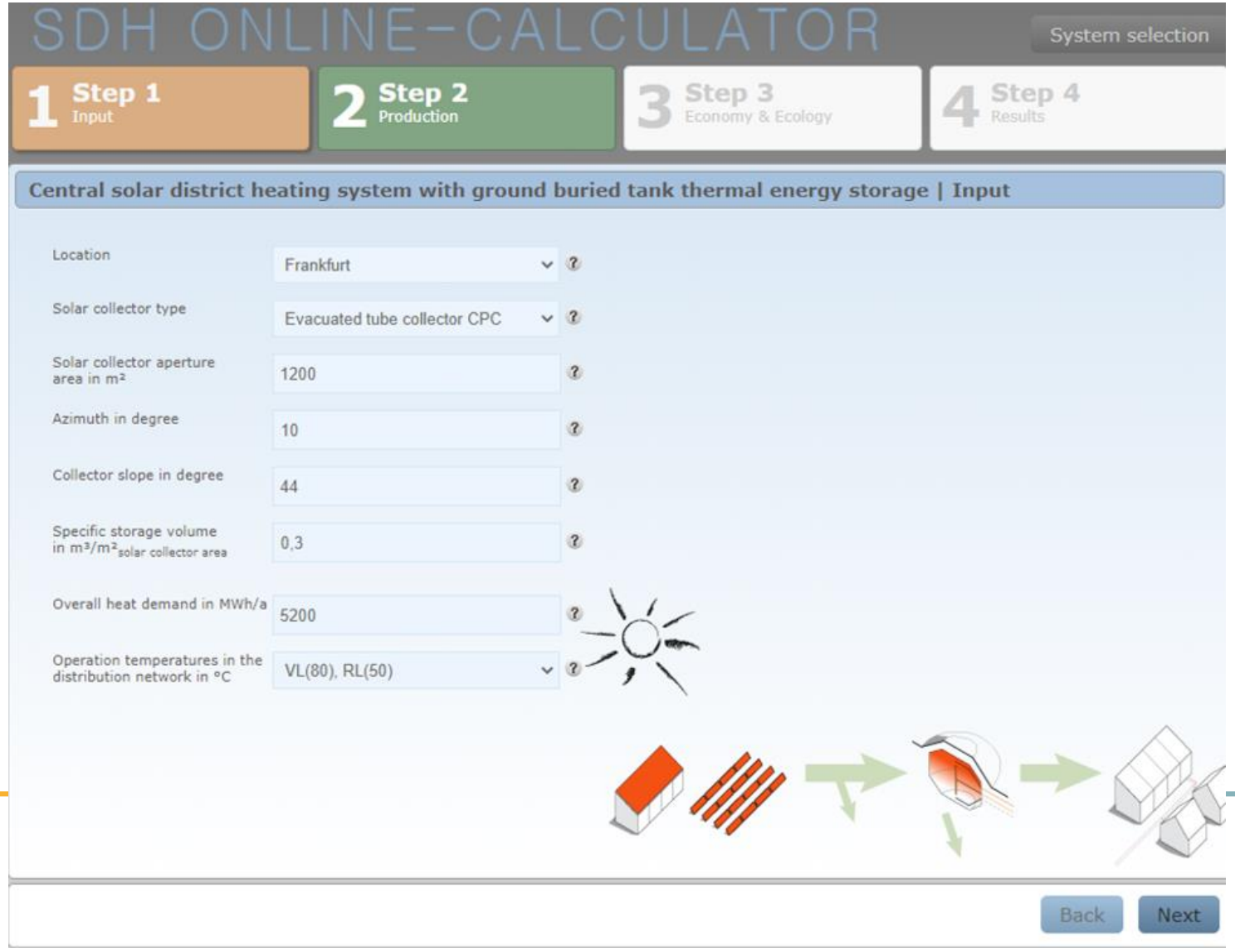
ANNEX II: SDH Online-Calculator – EXAMPLE

http://www.sdh-online.solites.de/?lang=en-US



SDH Online-Calculator

http://www.sdh-online.solites.de/?lang=en-US



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SDH Online-Calculator

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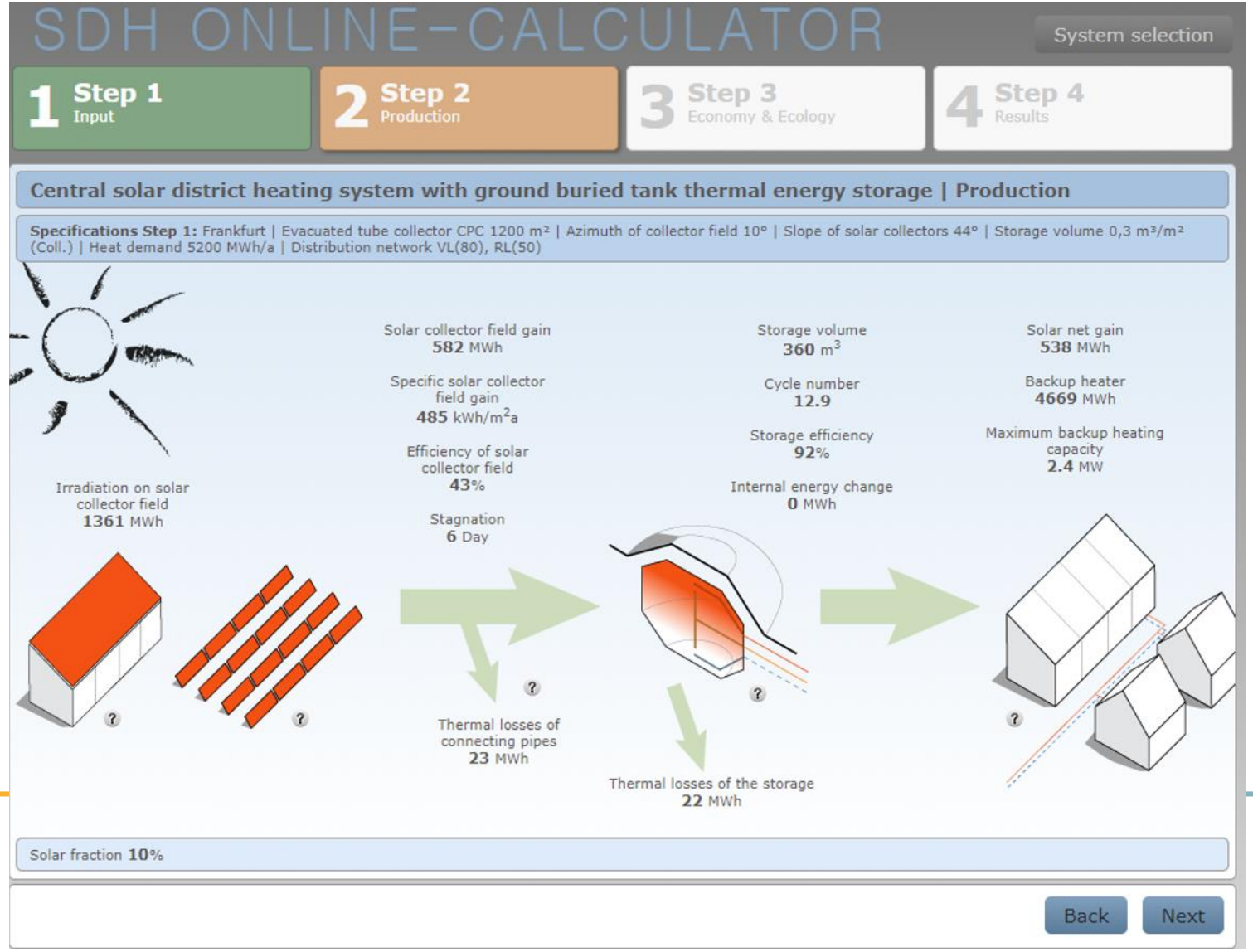


SDH Online-Calculator

http://www.sdh-online.solites.de/?lang=en-US

LowTEMP

SDH ONLINE-CALCULATOR

System selection

1 Step 1 Input | 2 Step 2 Production | 3 Step 3 Economy & Ecology | 4 Step 4 Results

Central solar district heating system with ground buried tank thermal energy storage | Economy & Ecology

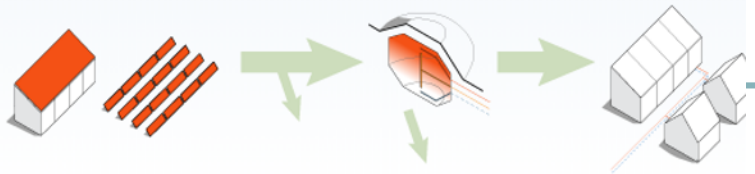
The economic calculation is simplified for the main components on the basis of the German VDI 2067

Economy

Specific solar collector field cost in €/m²	392
Funding rate for solar collector field in %	40
Specific cost for the thermal storage in €/m³	372
Funding rate for the thermal storage in %	40
Interest rate in %	4
Fuel cost in €/MWh	50
Electricity cost in €/Mwh	50

Ecology

Energy source of the backup heater	Biomass
Efficiency of the backup heater in %	90
Energy source of the reference heater	Gas
Efficiency of the reference heater in %	90



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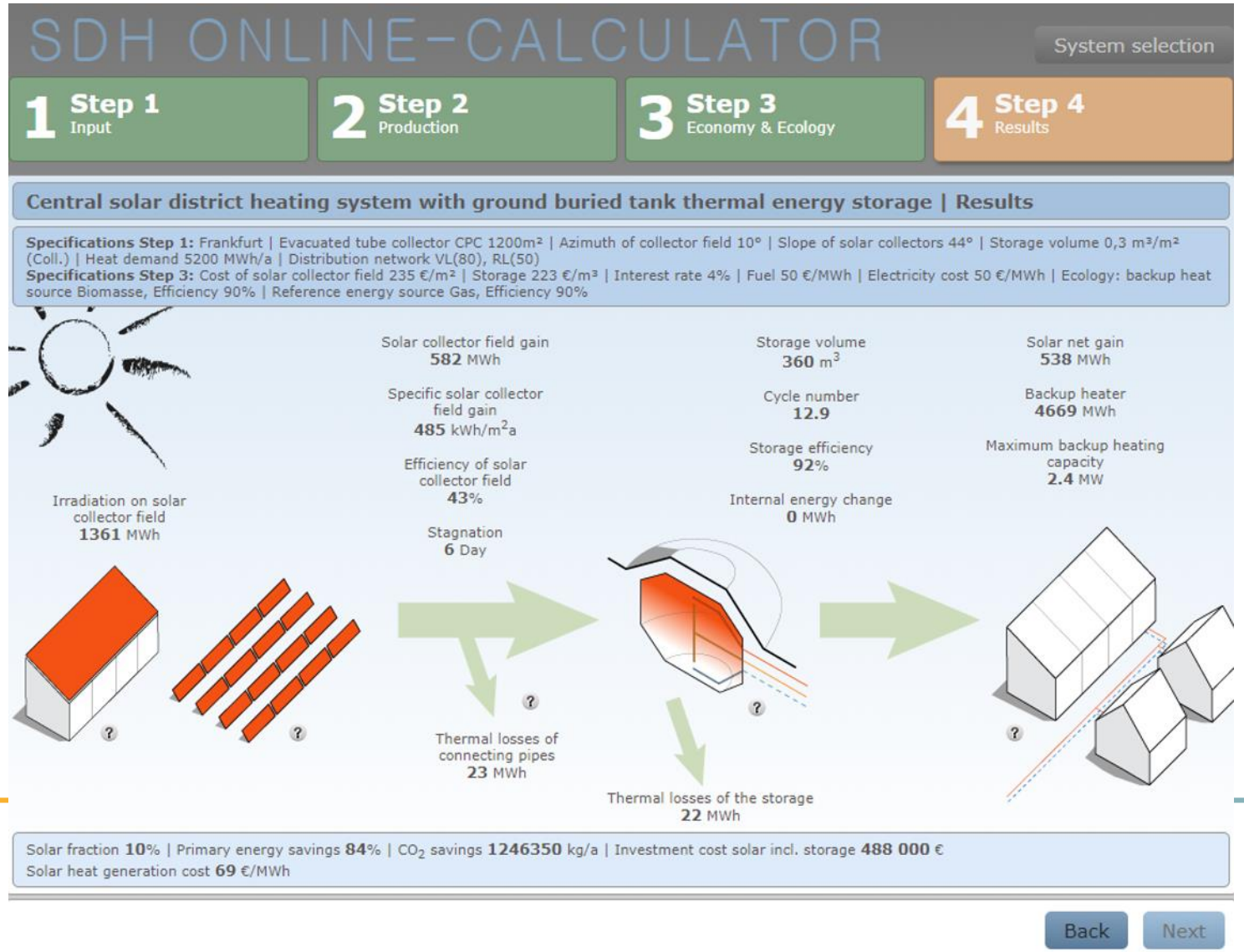

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