Integration of Solar Thermal Systems

(Czech-Austrian Winter/Summer School)

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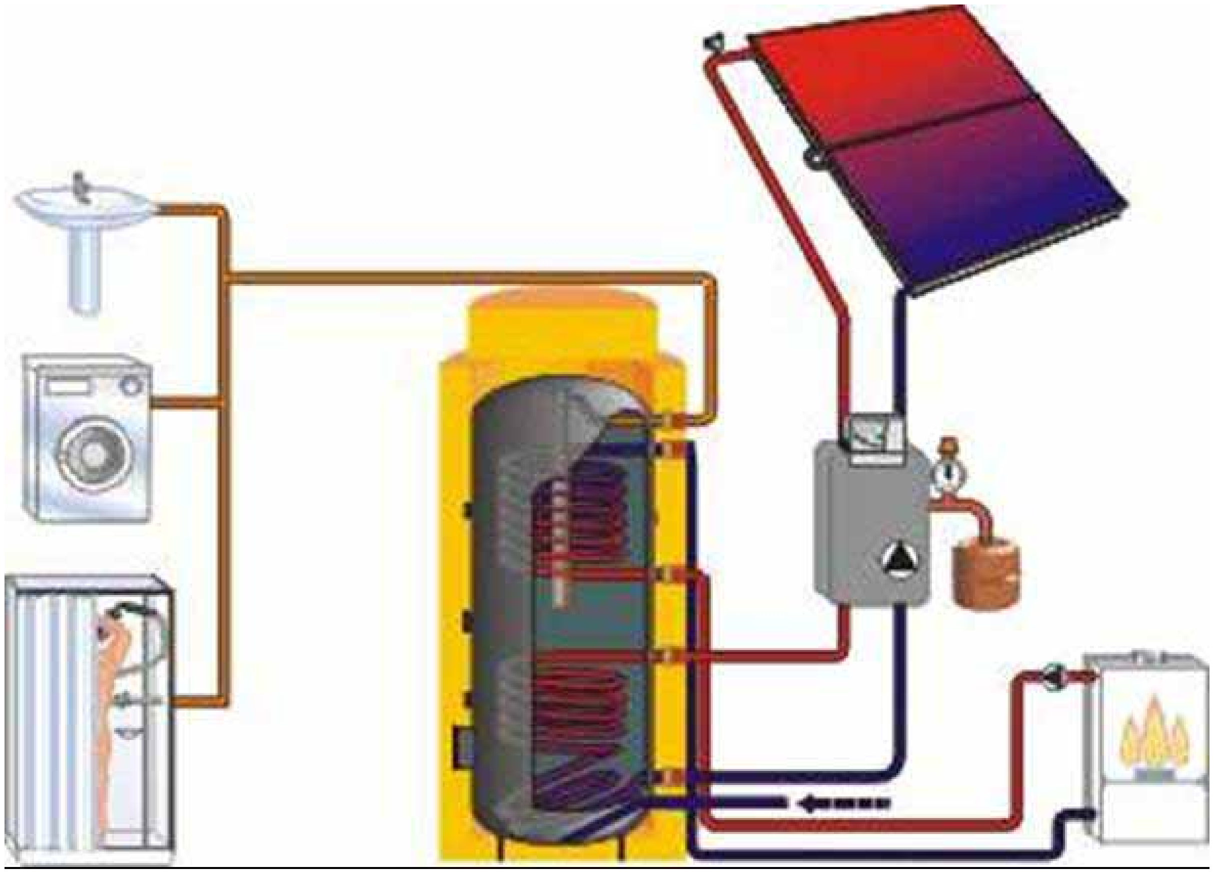
Content

- Where to Use Solar Thermal Energy
- DHW and Space Heating Demand
- Demand District Heating Systems

Content

- Hydraulic integration of solar thermal systems
  - Basics
  - Domestic hot water (DHW) plants
  - Combisystems (DHW space heating)
  - District heating systems
  - Swimming pools
- Dimensioning
  - DHW-plants
  - Basic definitions (frational energy savings etc.)
  - Sensitivity analysis
    - Slope, azimuth, collector area ,strorage volume and store paramters
    - Type of collector, characteristic of spaceheating system, control, hydraulics

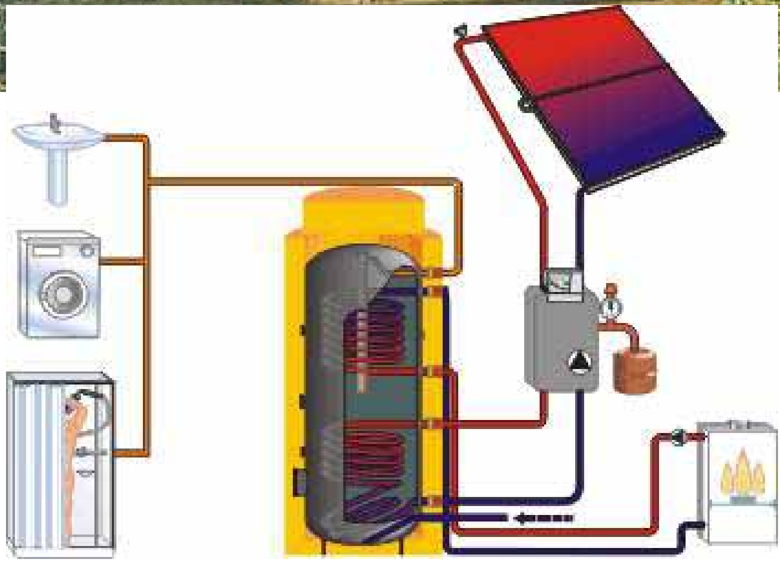
Principle of Solar Thermal Energy Use



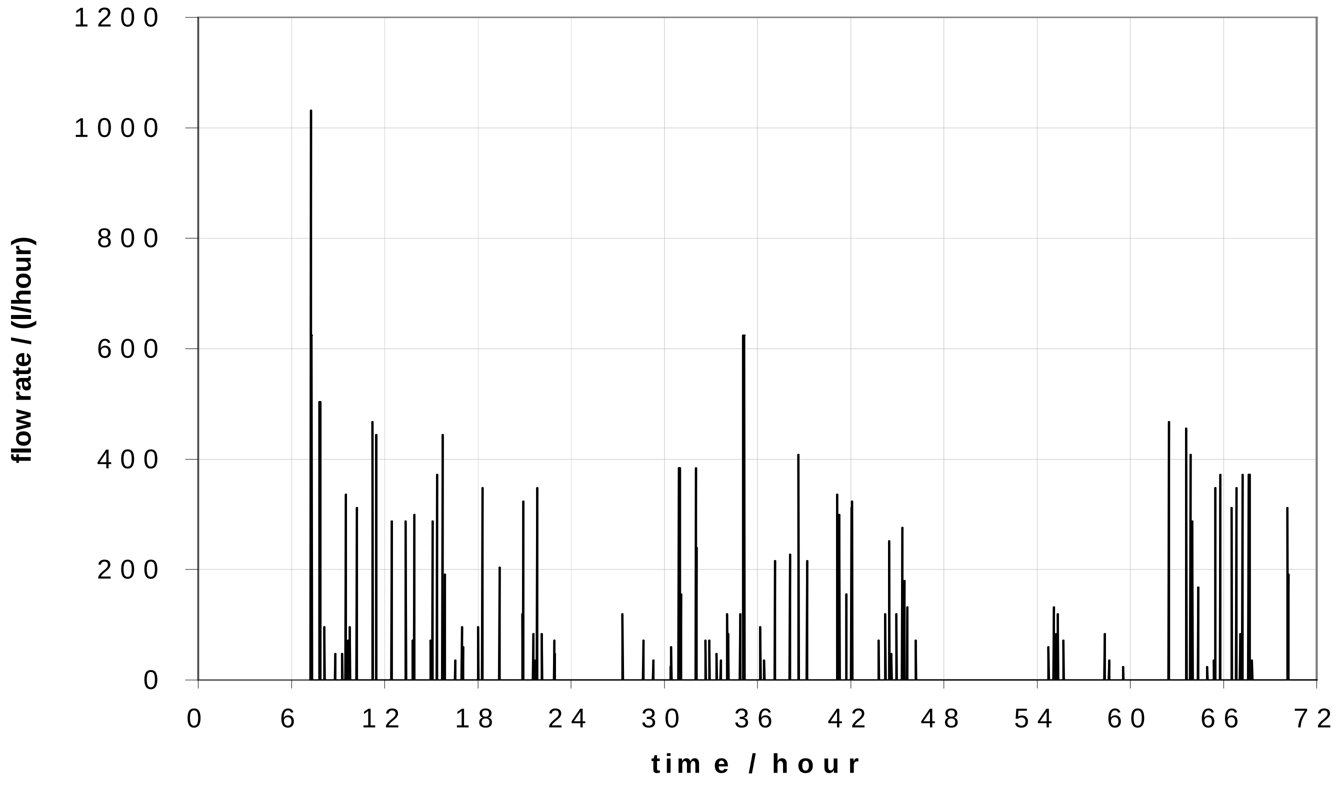
Where to use solar thermal

- Domestic hot water (DHW)
- Space heating + DHW
- District heating networks
- Swimming pools
- Cooling
- Process Heat
- Electricity production

Domestic hot water production



Domestic hot water demand



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Solar Combisystems

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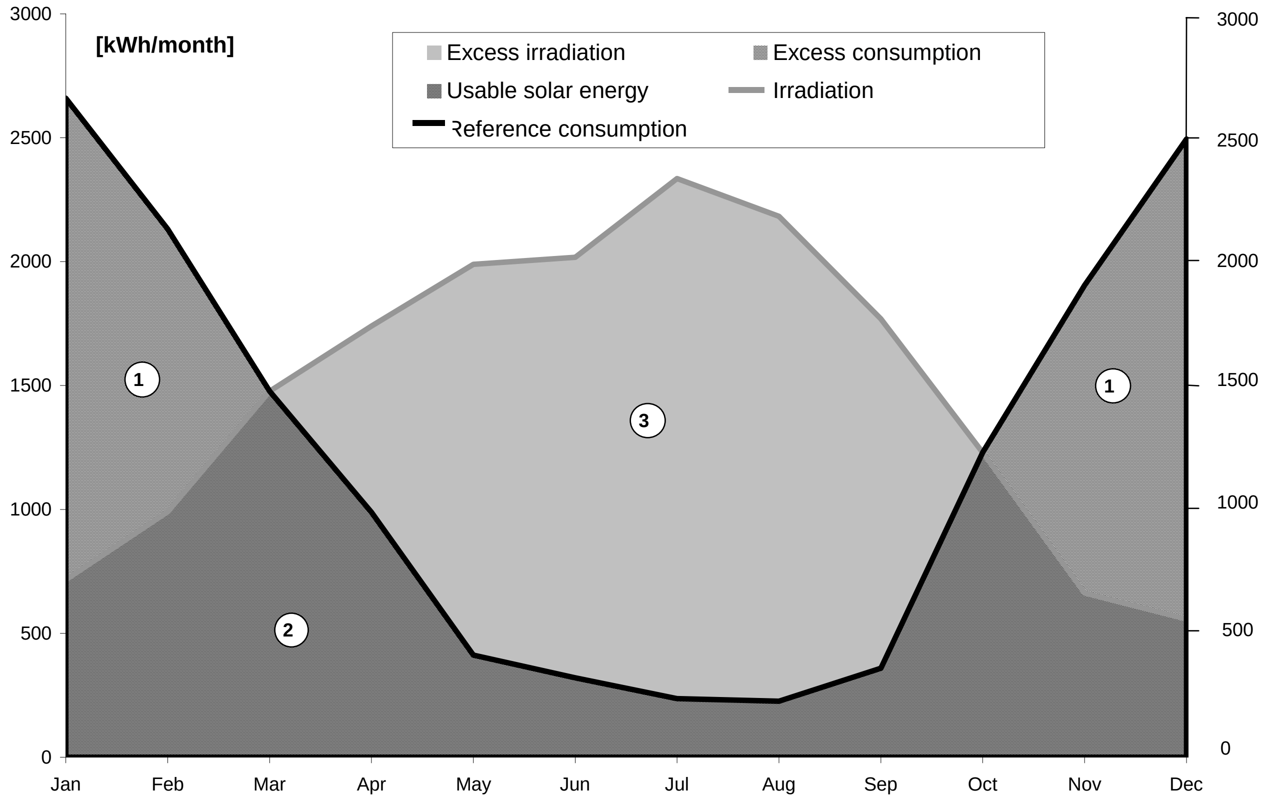
Solar Combisystems
space heating demand



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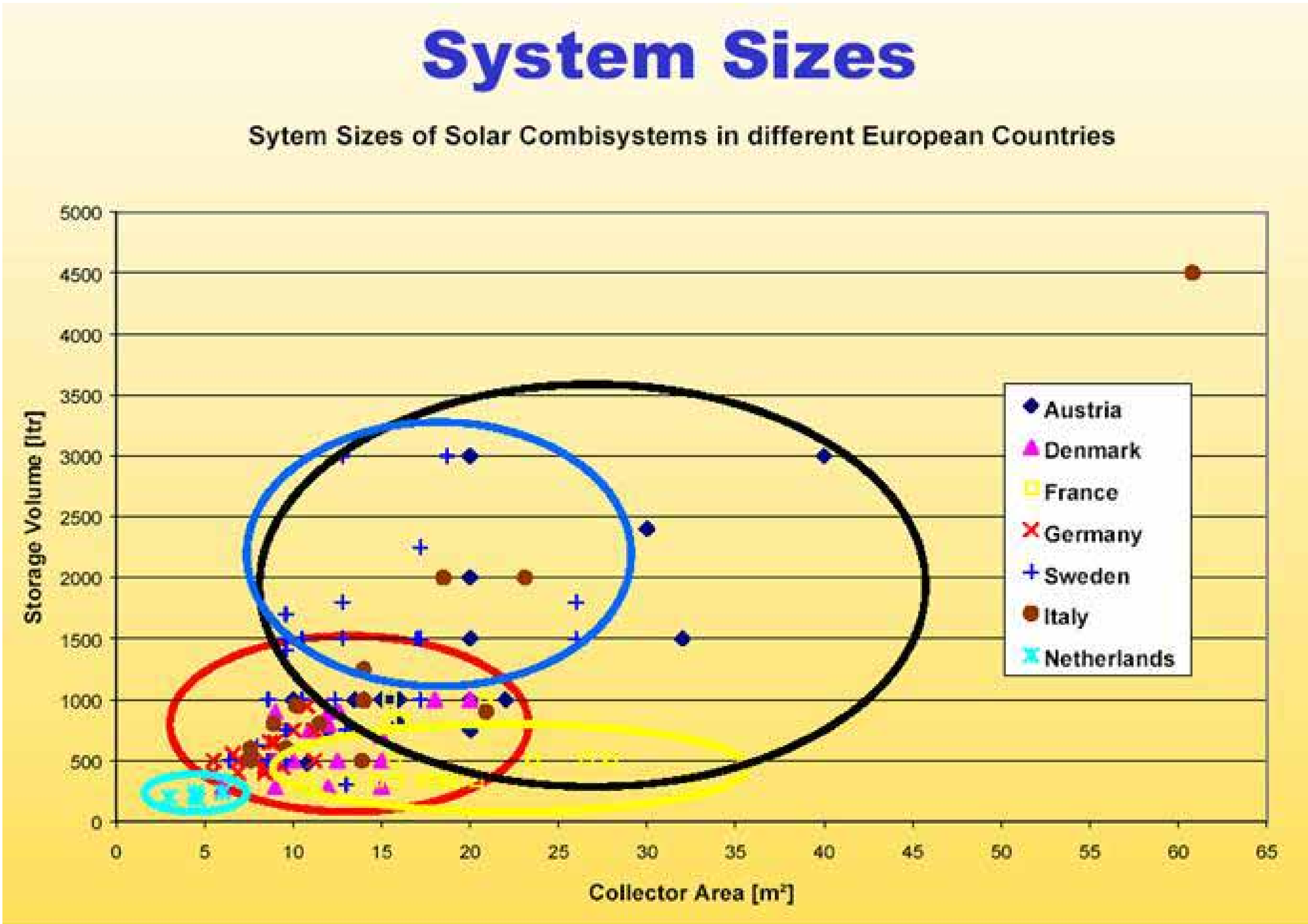
Sizes of Solar Combisystems
Source: AEE-Intec



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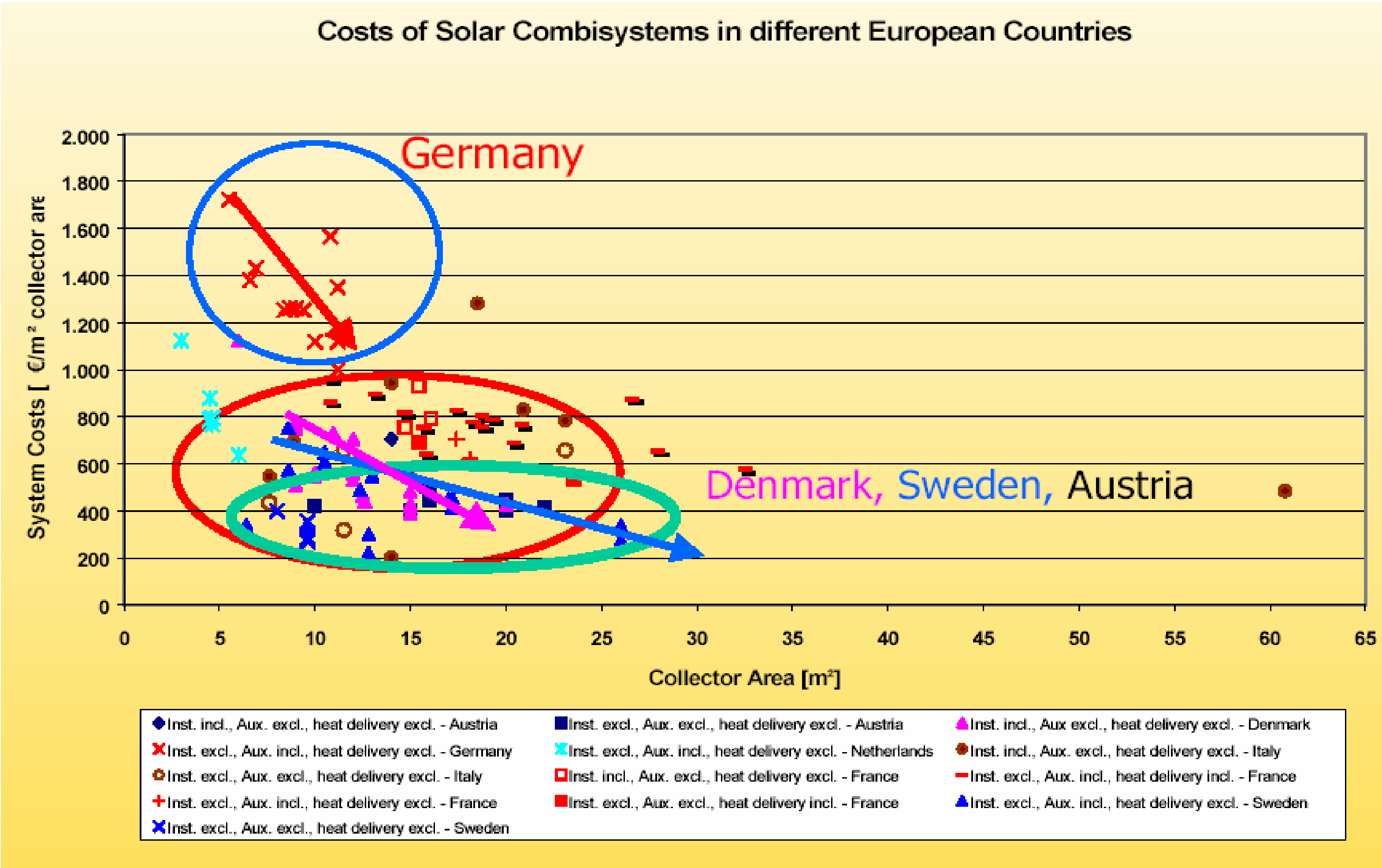
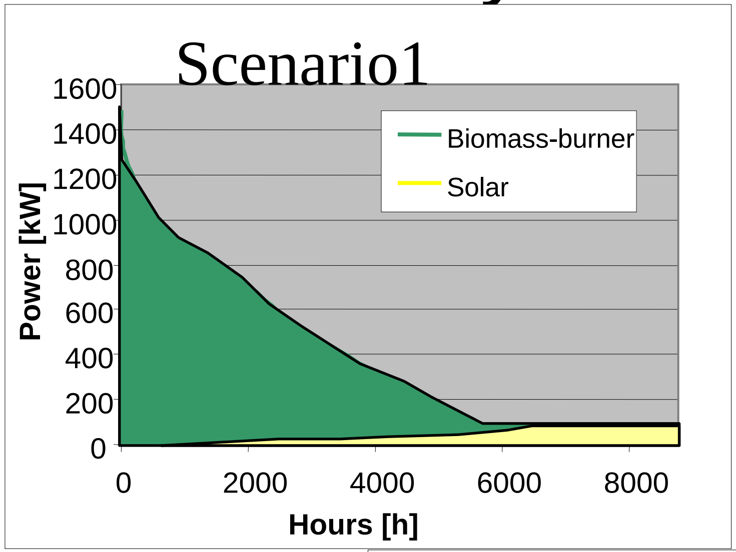
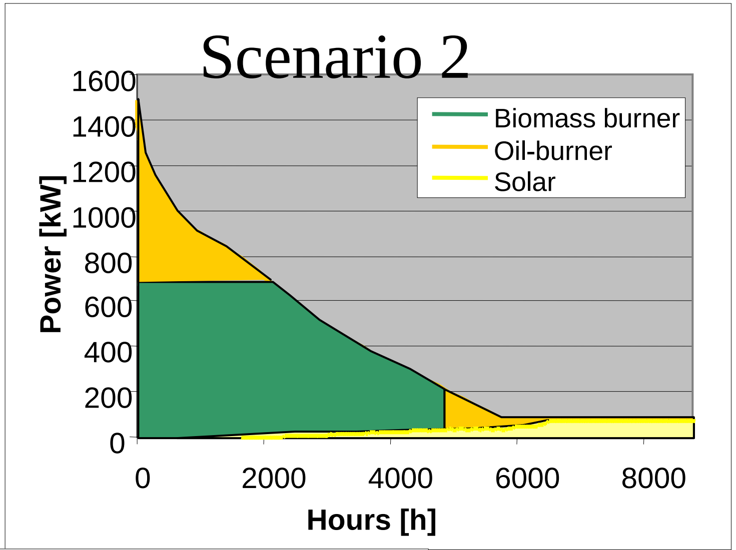
Cost of Solar Combisystems
Source: AEE-Intec

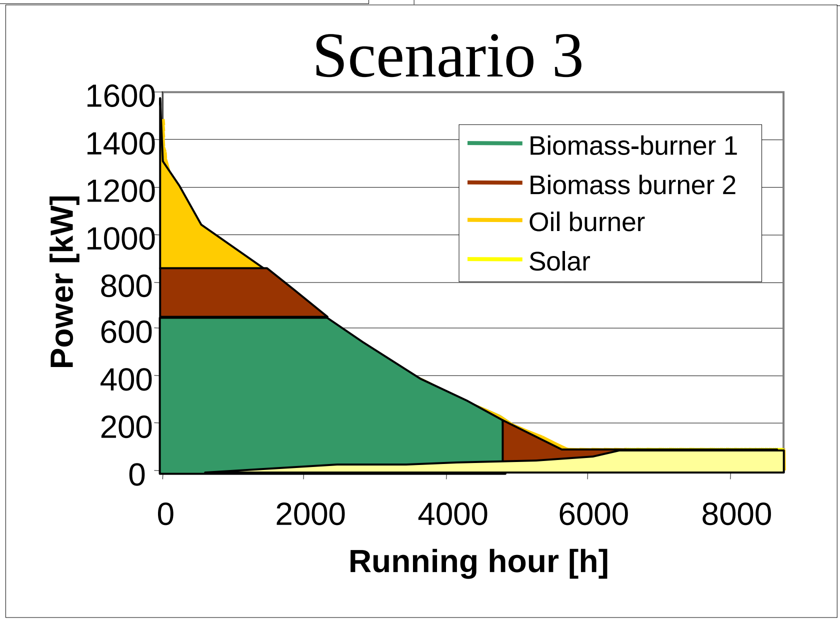


District heating networks

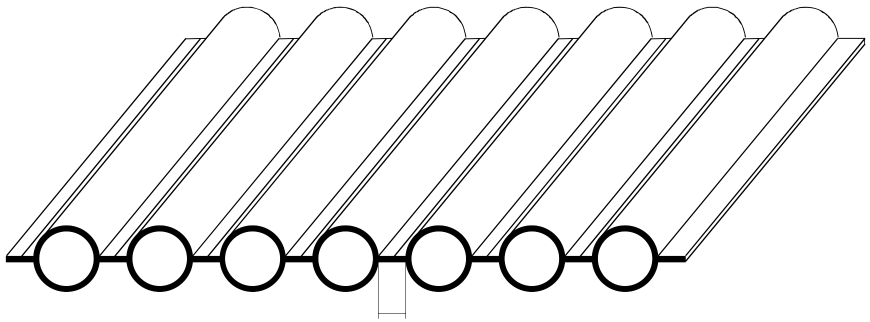
Demand for district heating systems
Layout of Boilers and Solar







Solar heated swimming pools



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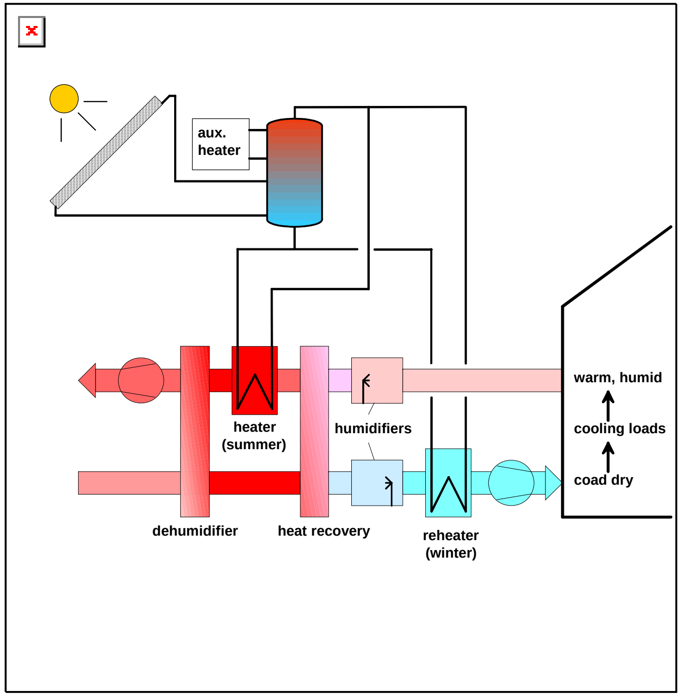
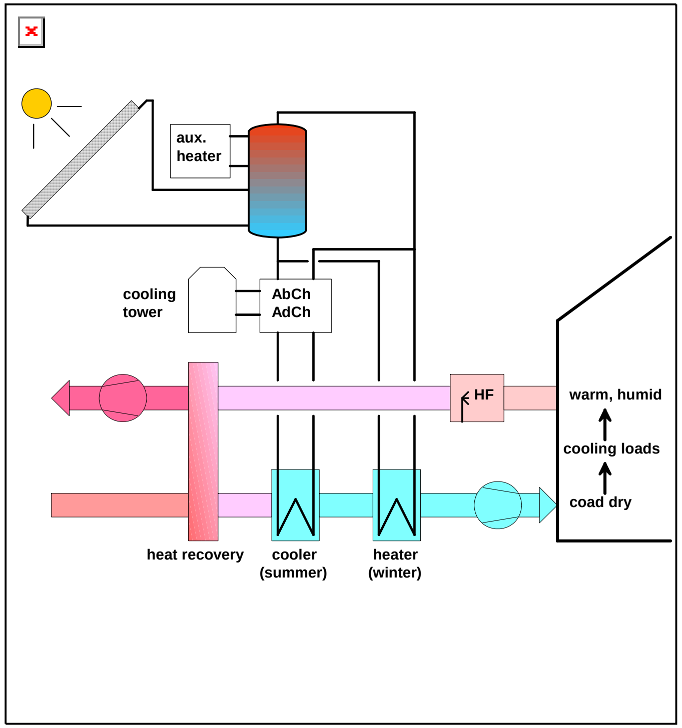
Solar assisted cooling

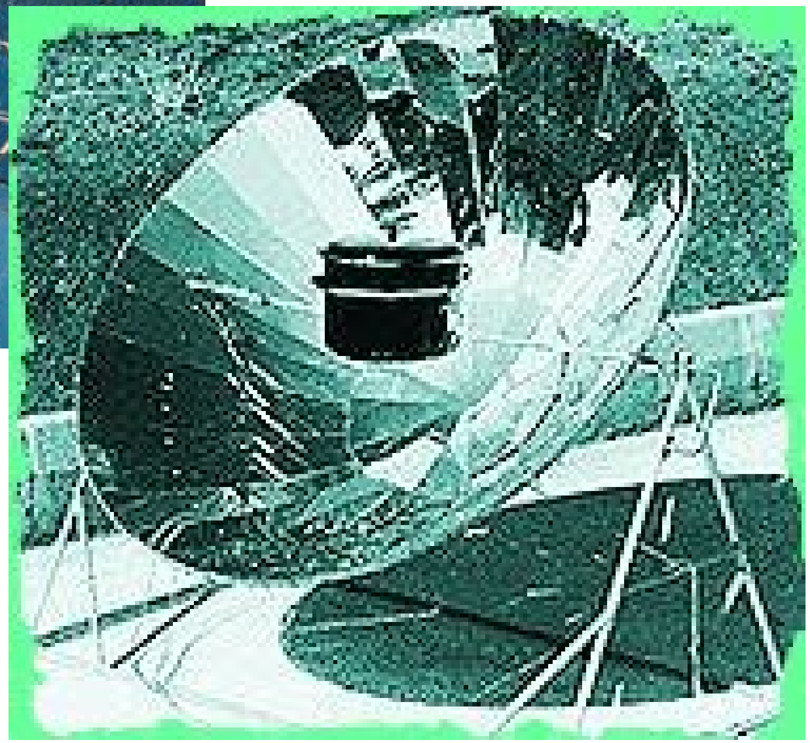


Deccicant system

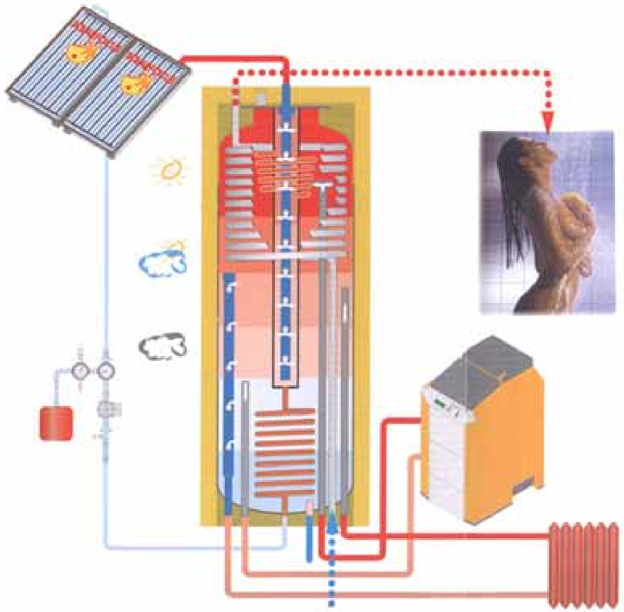


Ab/Adsorption system

Process heat



Hydraulics of Solar Thermal Systems

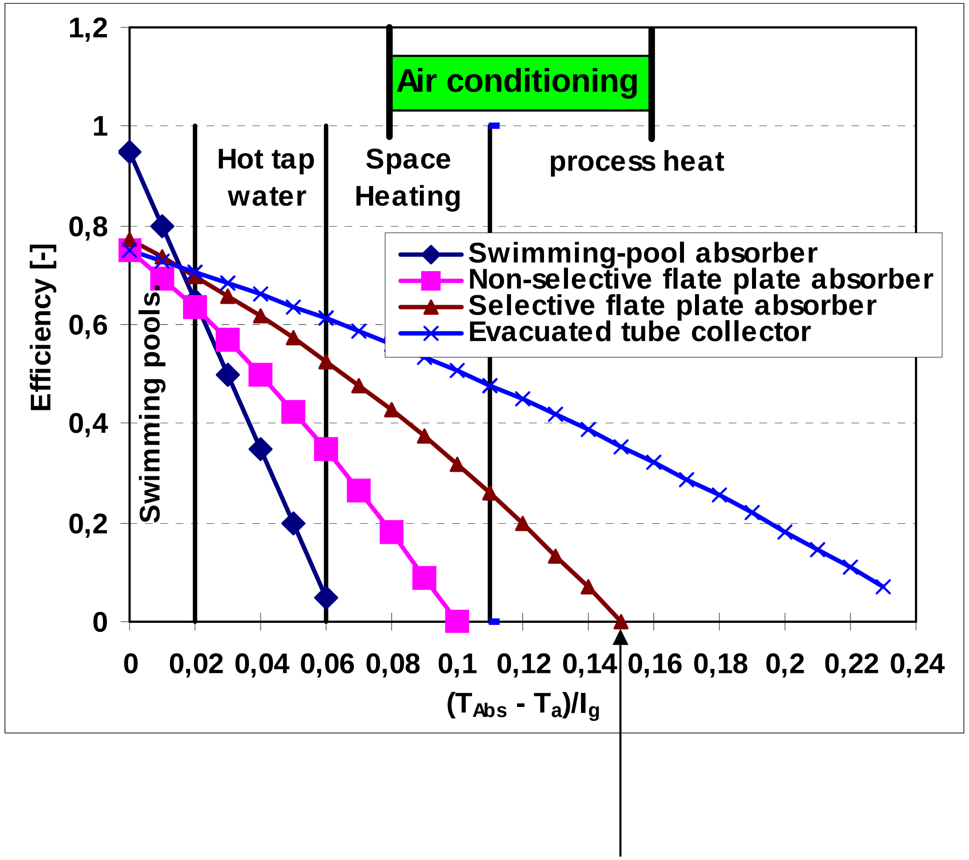


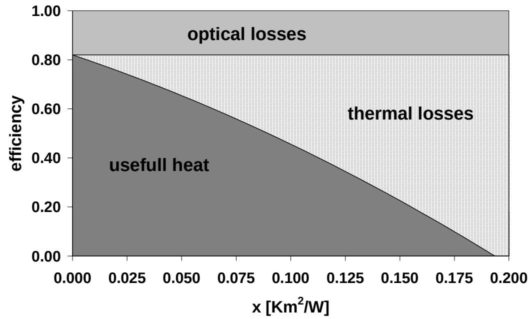
Hydraulics of Solar Thermal Systems

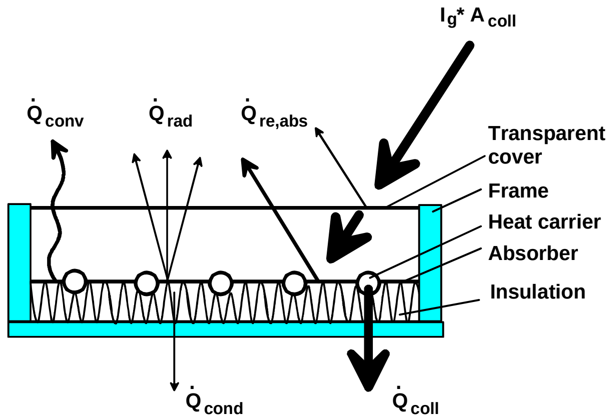
The hydraulic layout of a solar system has to fulfil several tasks:

- Deliver as much solar gain as possible into the stores (or the heat sinks) without exergy (temperature) loss.
- Have as low as possible thermal losses
- Distribute all heat needed to the heat sinks (space heating and DHW).
- Reserve enough store volume to be heated up for the auxiliary heater in order to guarantee enough running time (smaller for gas burners, larger for wood burners).
- Low investment costs.
- Low space demand.
- Easy and failure safe installation, (as simpler as better).

Collector characteristics

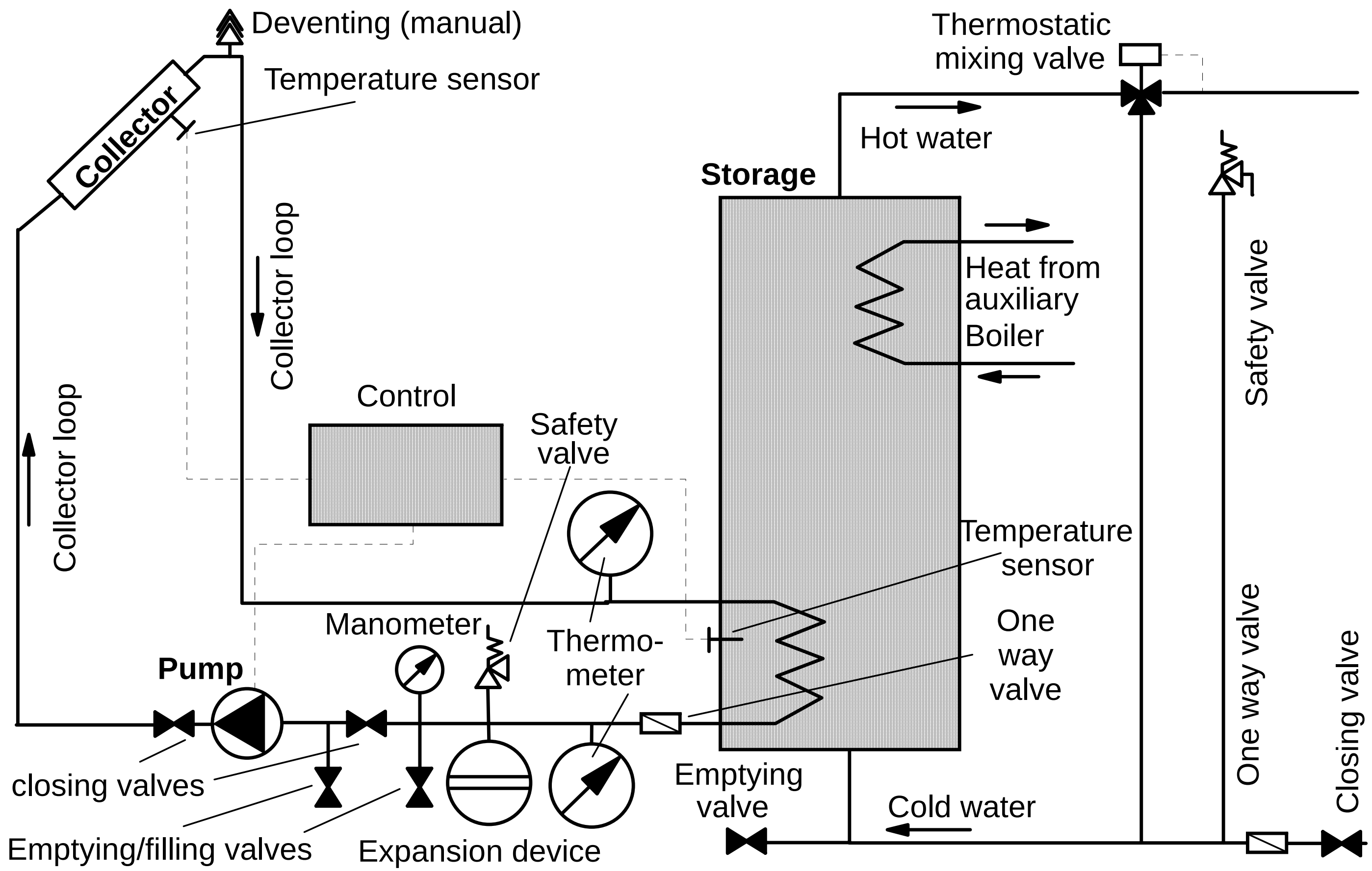






Note : Maximum collector standstill temperature at 1000 W/m² irradiance and 30 °C ambient temperature: Tabs = (0,14*1000)+30 = 170 °C

Domestic hot water hydraulics



Hydraulics of solar DHW systems, control strategy

Two temperature sensors

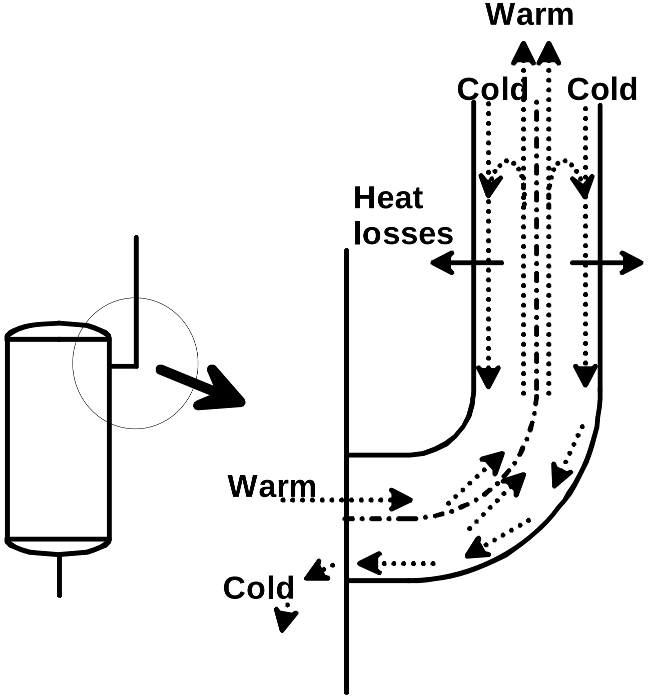
- In collector (near collector outlet)
- In store (near outlet to collector)

If T_{col} > (Tstore + 5 - 10°C) => Start

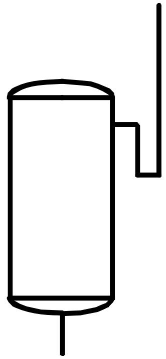
If T_{col} > (Tstore + 2 - 3°C) => Stop

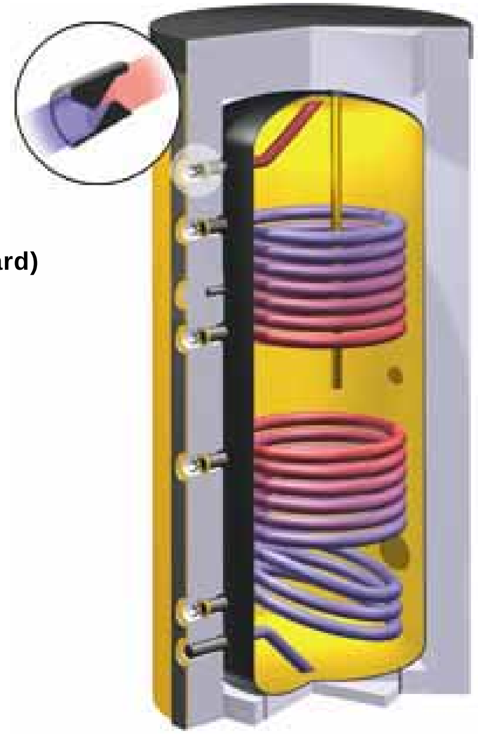
Dead band to avoid cycling at startup

Hot water storages, measures to enhance stratification



Solution:
THERMOSYPHON
(about 10 * tube diameter downward)





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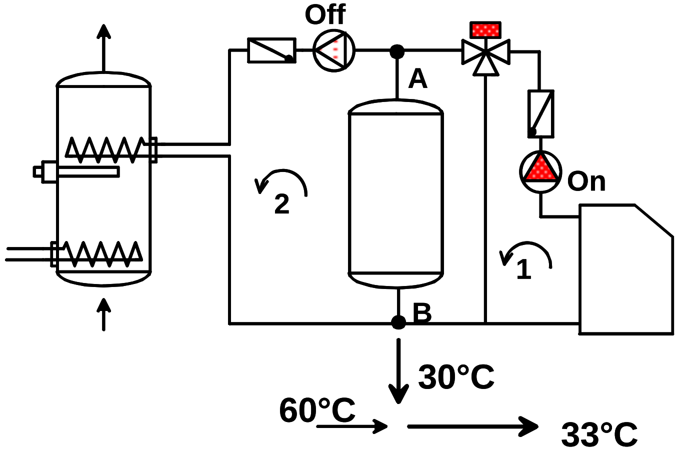
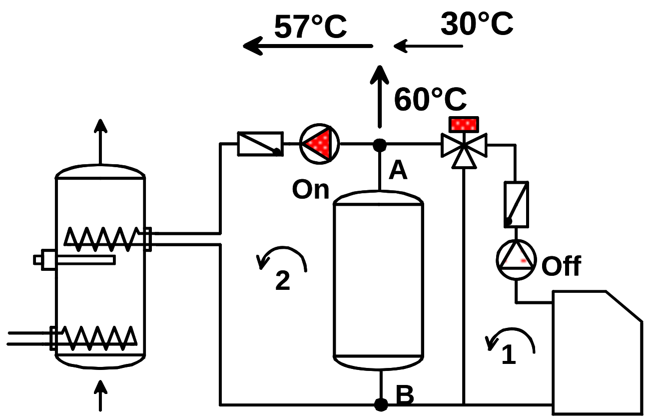
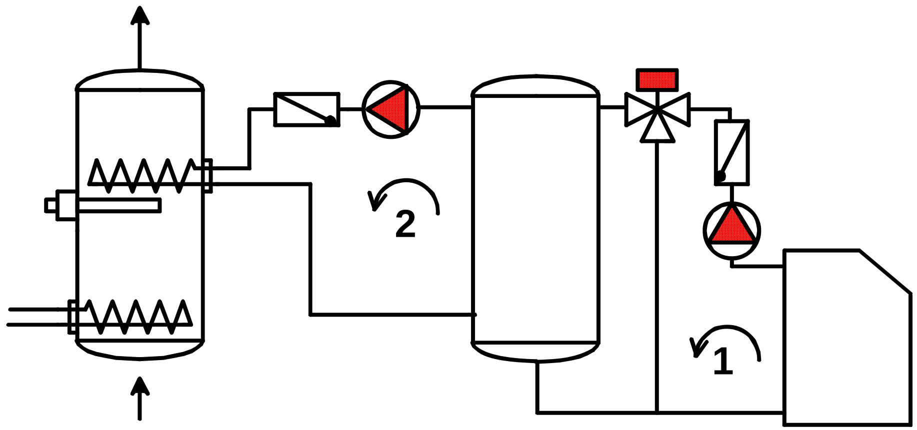
Hydraulics of solar thermal collector plants, general, decoupling of circuits

$$\frac{\dot{M}_2}{\dot{M}_{Puffer}} = \sqrt{\frac{\sum \zeta_{Puffer}}{\sum \zeta_2}}$$

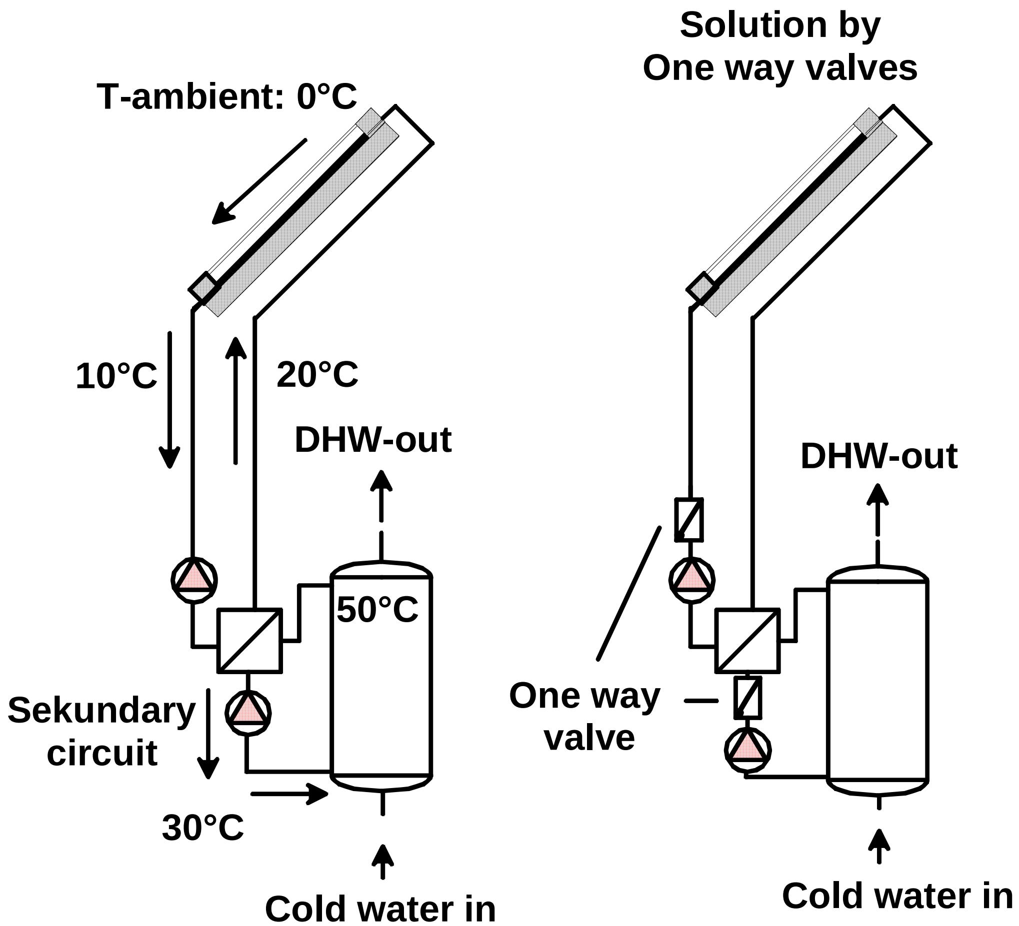




Solution =>



Hydraulics of solar thermal collector plants, general, one-way valves in collector circuit



Hydraulics of solar thermal collector plants, collector stagnation

Reasons for collector stagnation

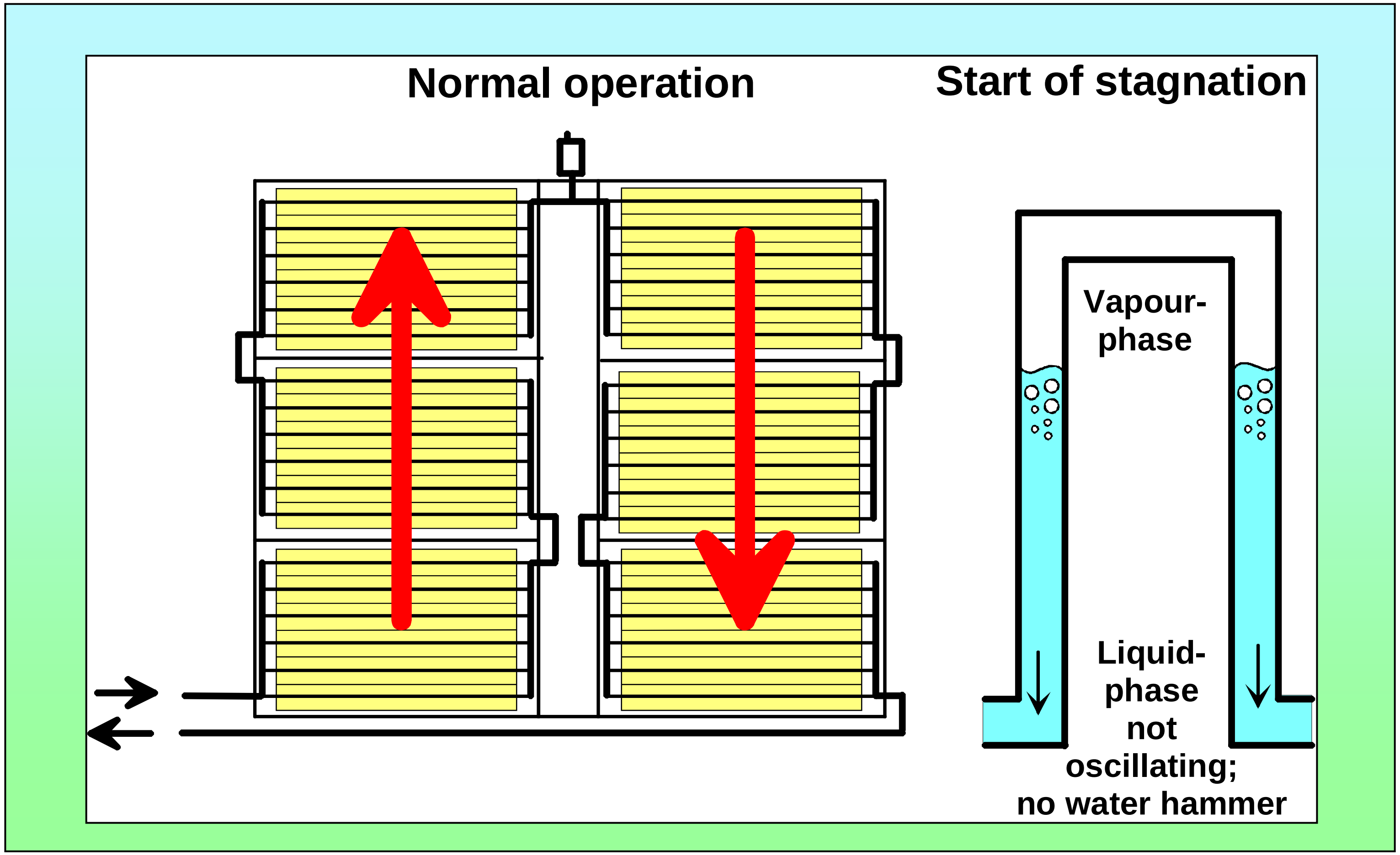
- Heat demand of all available heat sinks is already satisfied
- Electricity break down
- Some collectors circuits in parallel collector circuits tubes are not in operation due to “blocking” air

Hydraulics of solar thermal collector plants, collector stagnation temperatures

	Stagnation temperature	Saturated steam pressure	
		Water	Water/Glykol (70%/30%)
	[°C]	[bar]	[bar]
Swimming pool collector (no cover)	90	0.,7	0.6
Non selective abosrber (single glass cover)	120 - 150	2.0 – 4.8	1.7 – 4.2
Selective absorber (single glass cover)	160 - 200	6.2 – 15.6	5.4 – 14.1
Evacuated heat pipe collector	90	0.7	0.6
Evacuated tube- and evacuated flate plate collector	250 - 300	40 - 86	> 25

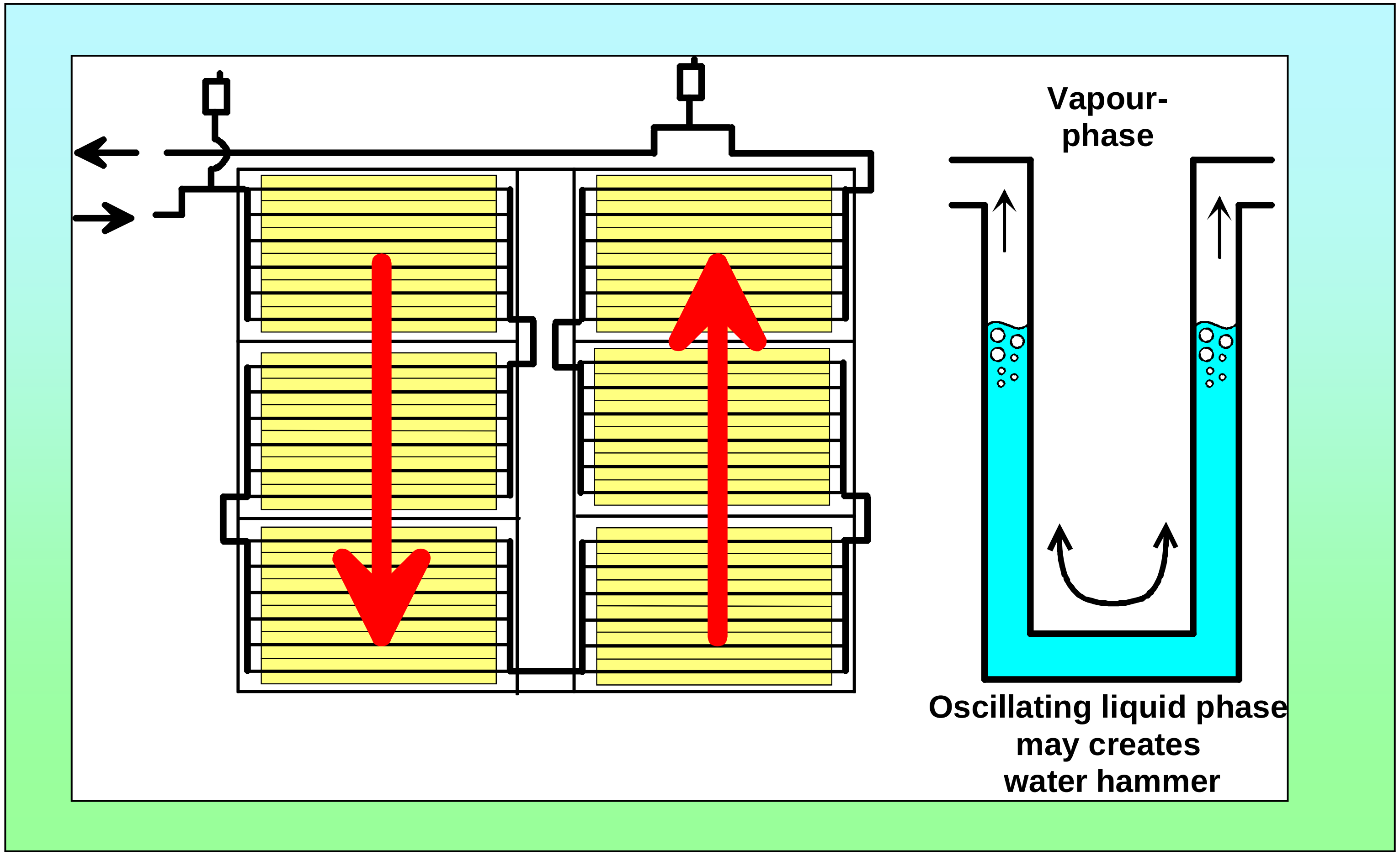
Collector stagnation

Hydraulic collector flow scheme pressing liquid out of the collector during evaporation (case 1)



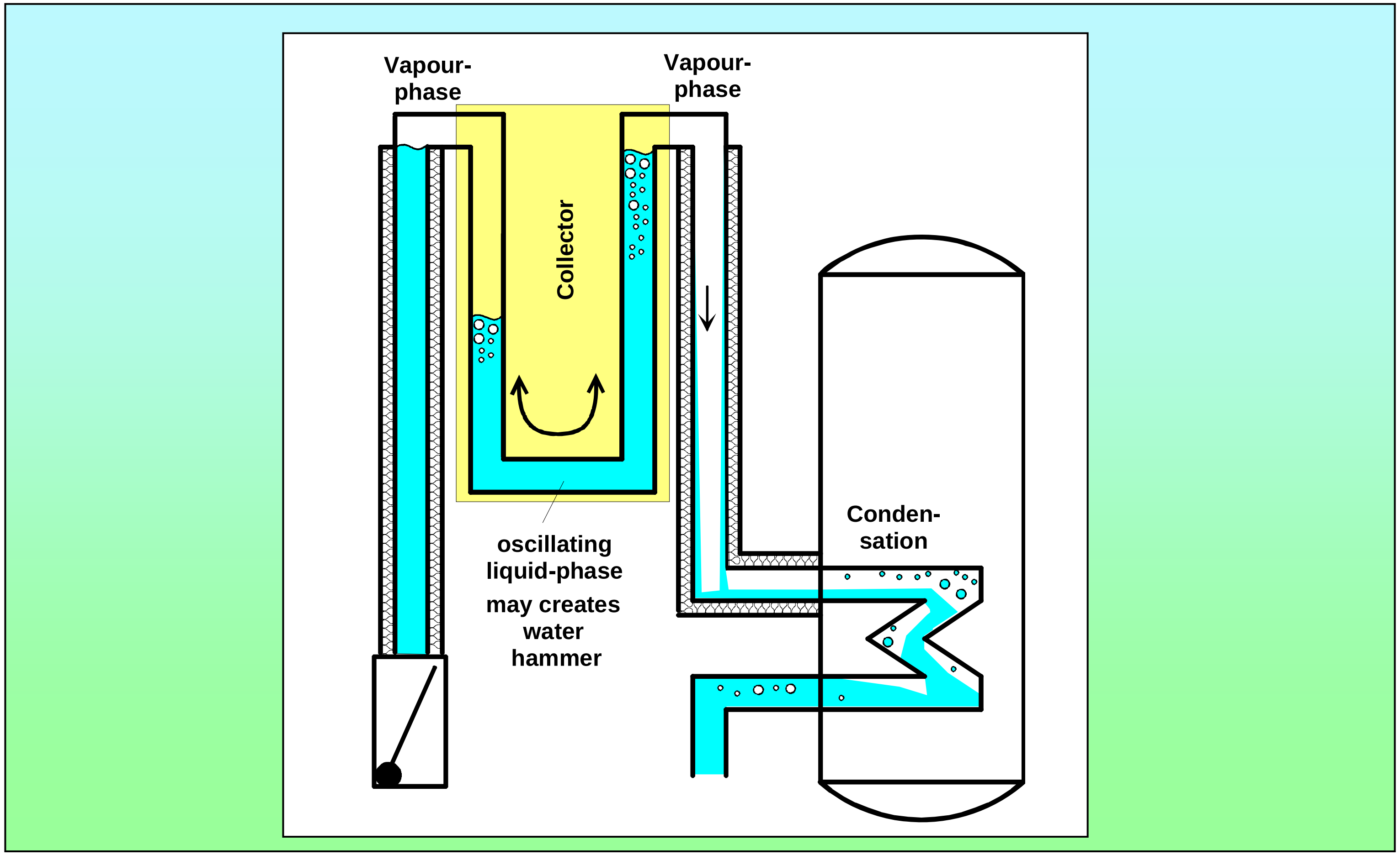
Collector stagnation

Hydraulic collector flow scheme pressing steam out of the collector during evaporation (case 2)



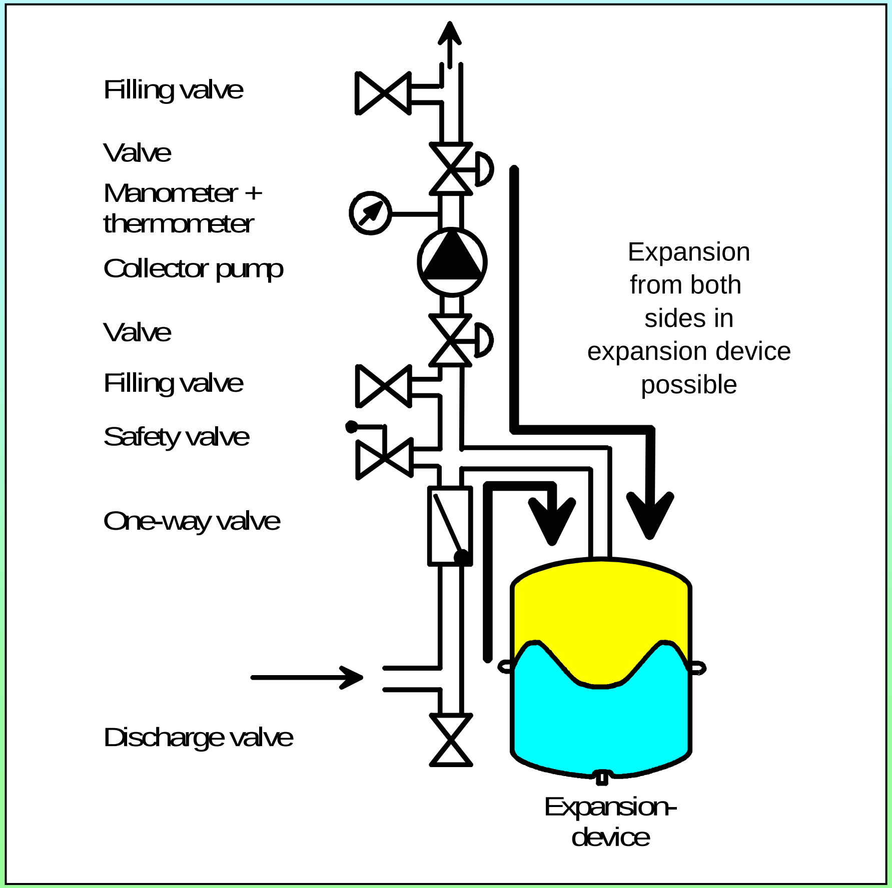
Collector stagnation

Hydraulic collector flow scheme of a tubing that is blocked on one side case 3)



Collector stagnation

Hydraulic flow scheme of pump, one-way valve and expansion device allowing the flow from both collector sides



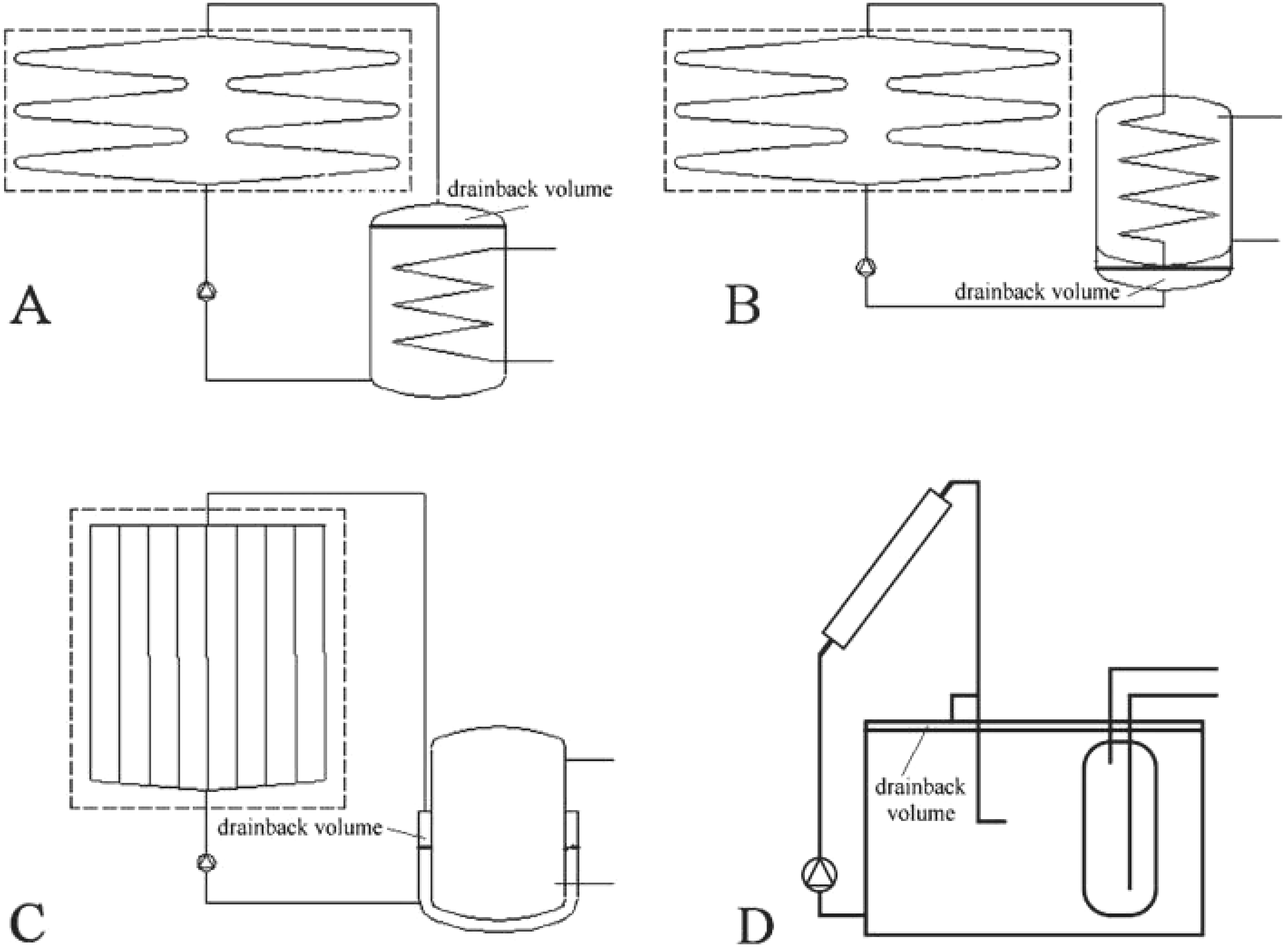
Collector stagnation Conclusion

- During stagnation several phases occur
- More or less steam is produced in different hydraulic collector layouts
- As more steam is produced as higher is the risqué of water hammer
- Preferable is the collector layout with U-shape open to bottom (minimum steam production)
- Collector fluid should not be heated above 130 °C

Methods to avoid collector stagnation or its problems

- Additional heat sink (like swimming pool, boiler as HX to chimney)
- Layout only for summer demand (small plants, vacation ??)
- Cool down during night (weather of next day)
- Drain back systems

Drain back systems



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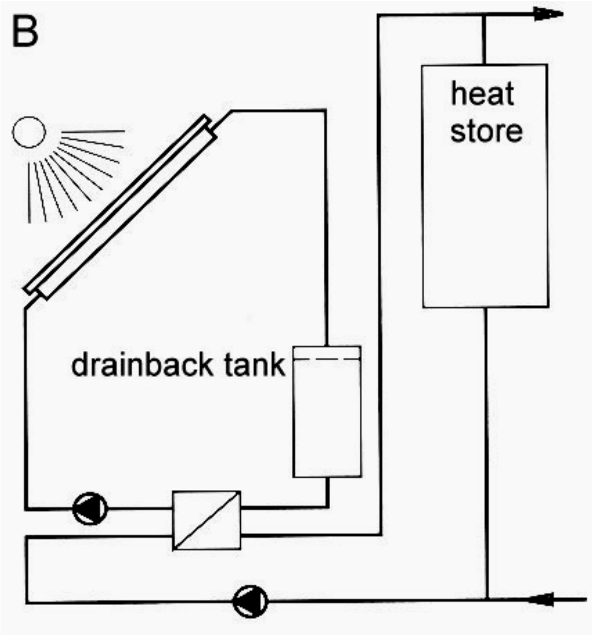
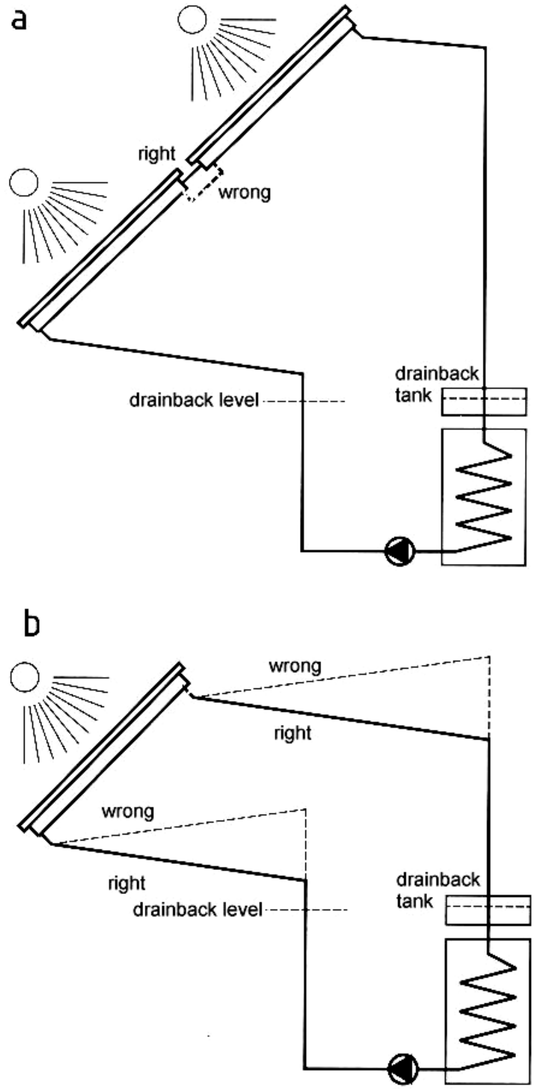
Drain back systems





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Drain back systems

Advantages

- No overheating of collector fluid
- Integrated expansion device
- Antifreeze can be skipped (if draining is fast enough)
- Draining is also needed for collector stagnation with evaporation

Disadvantages

- Geometry of collector tubing is crucial to assure correct fast draining (difficult to be reached on site)

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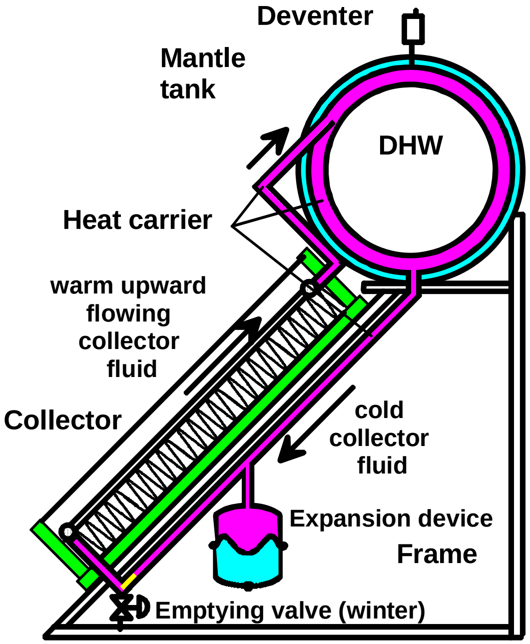
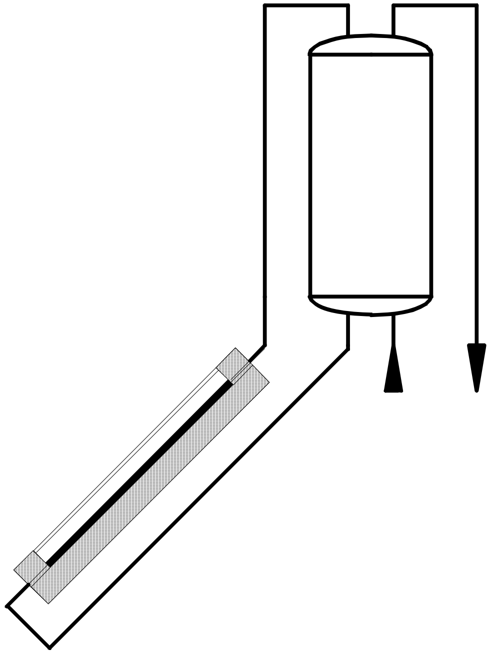
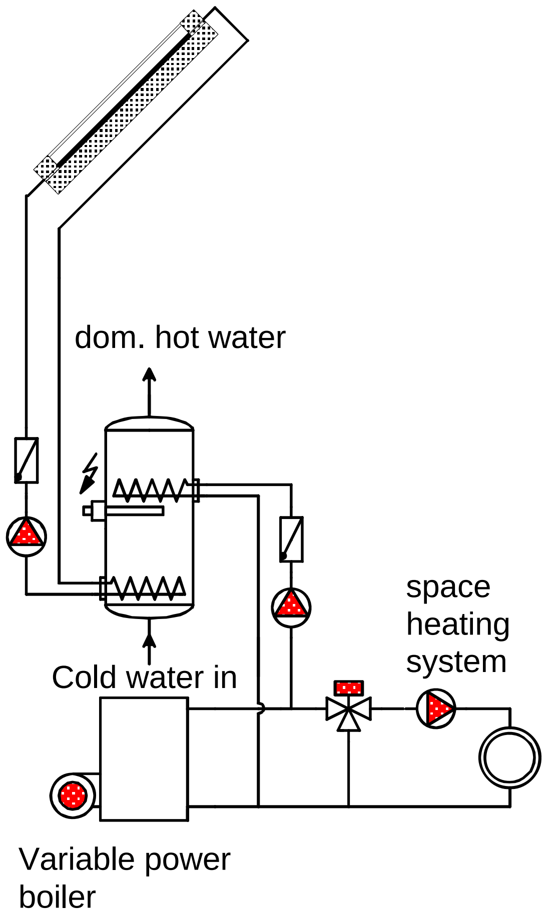
Hydraulics of solar DHW systems, natural circulation systems





Hydraulics of solar DHW systems, forced circulation systems



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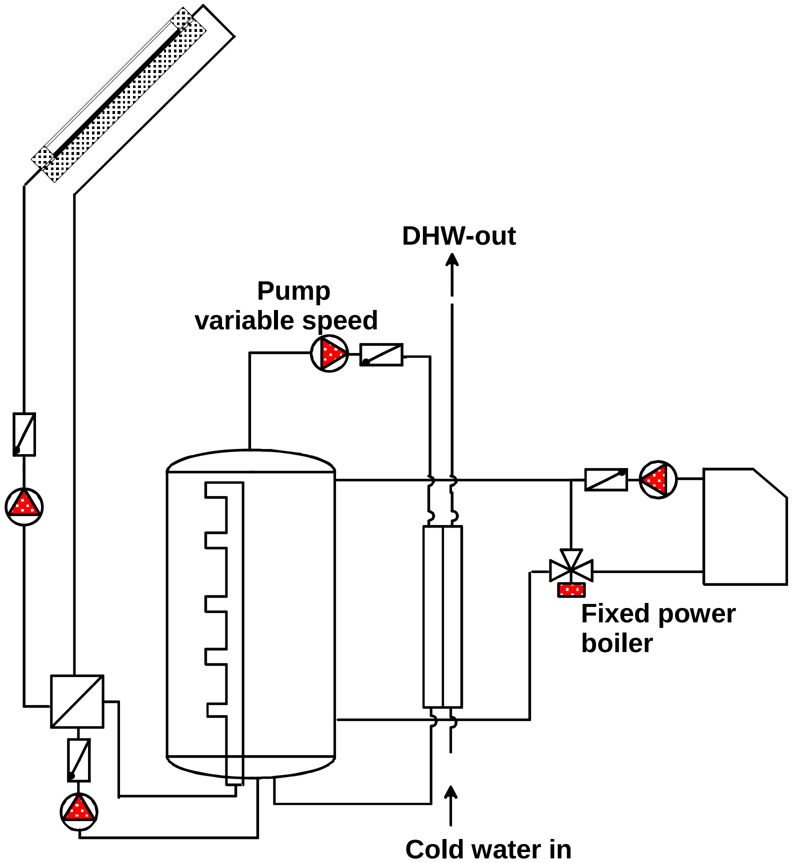
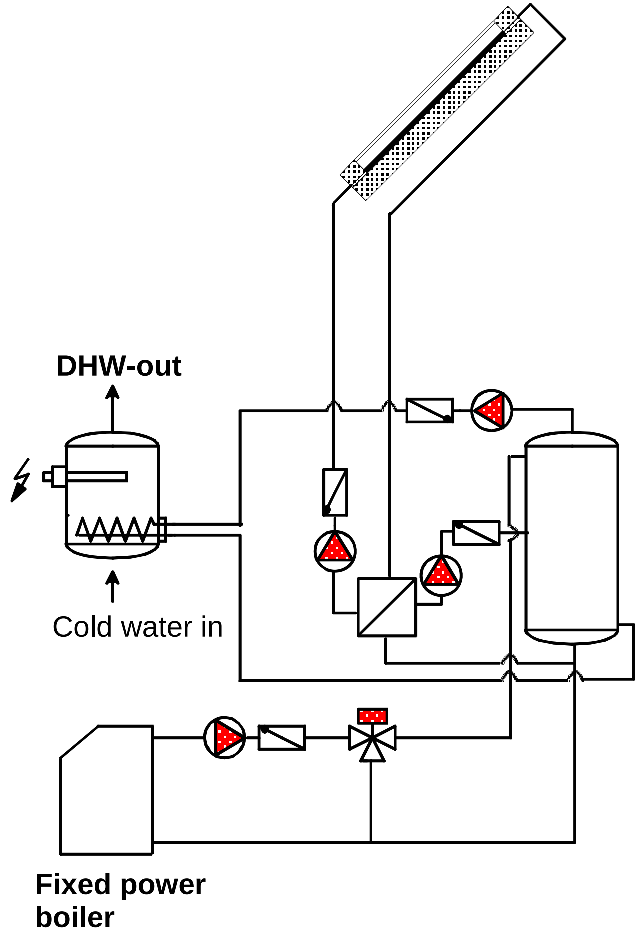
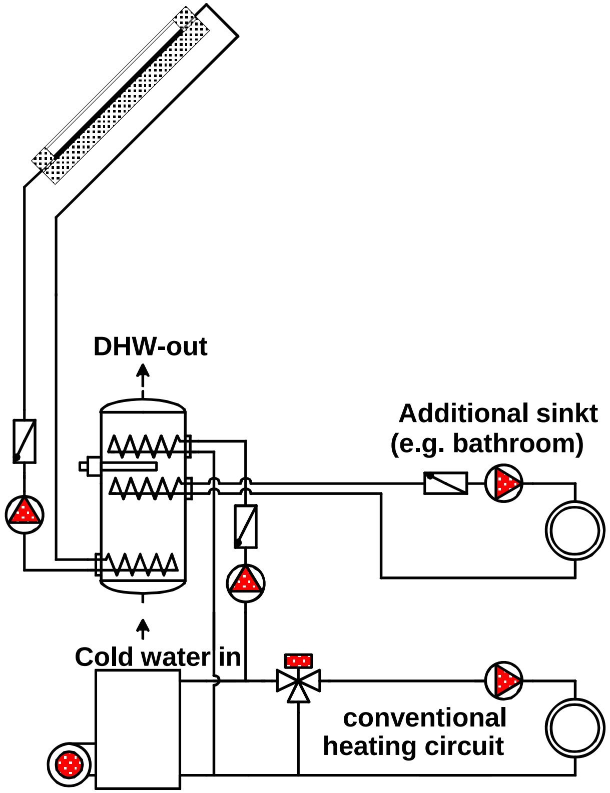
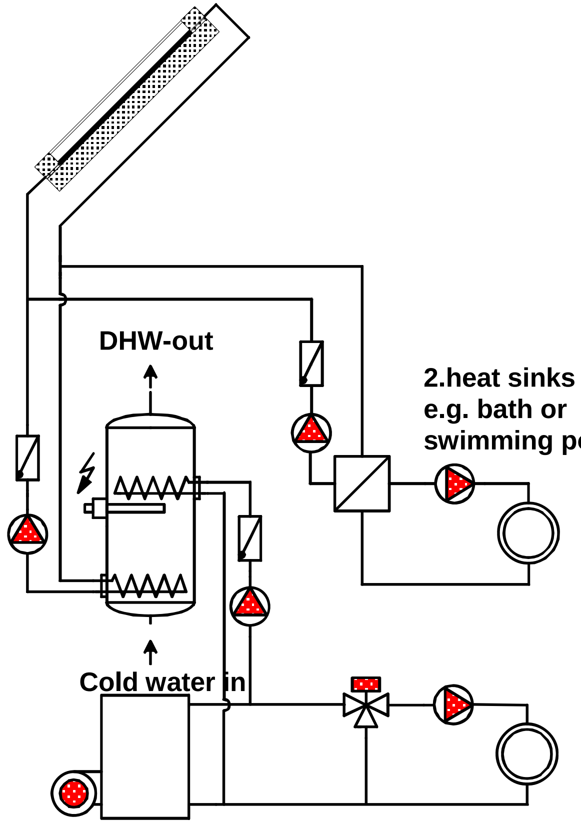
Hydraulics of solar DHW systems, avoiding legionella



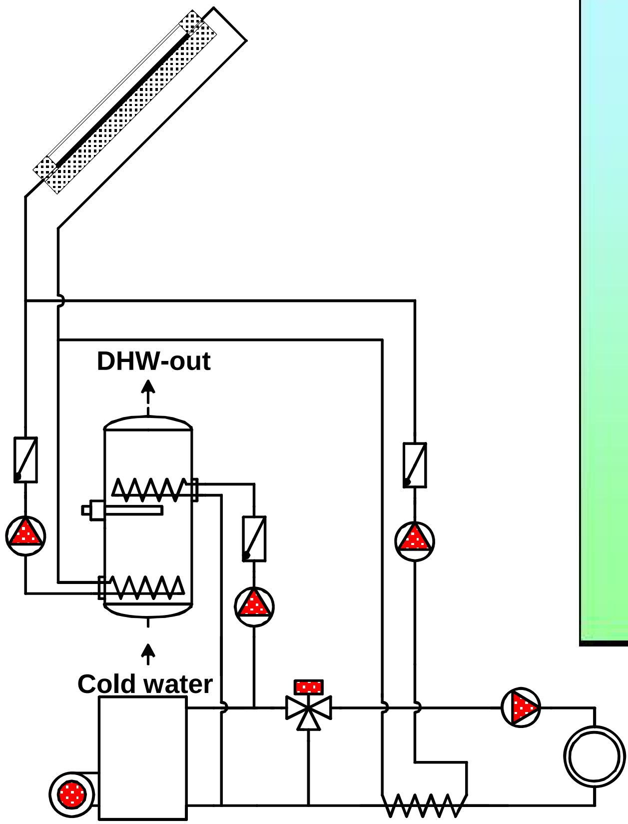


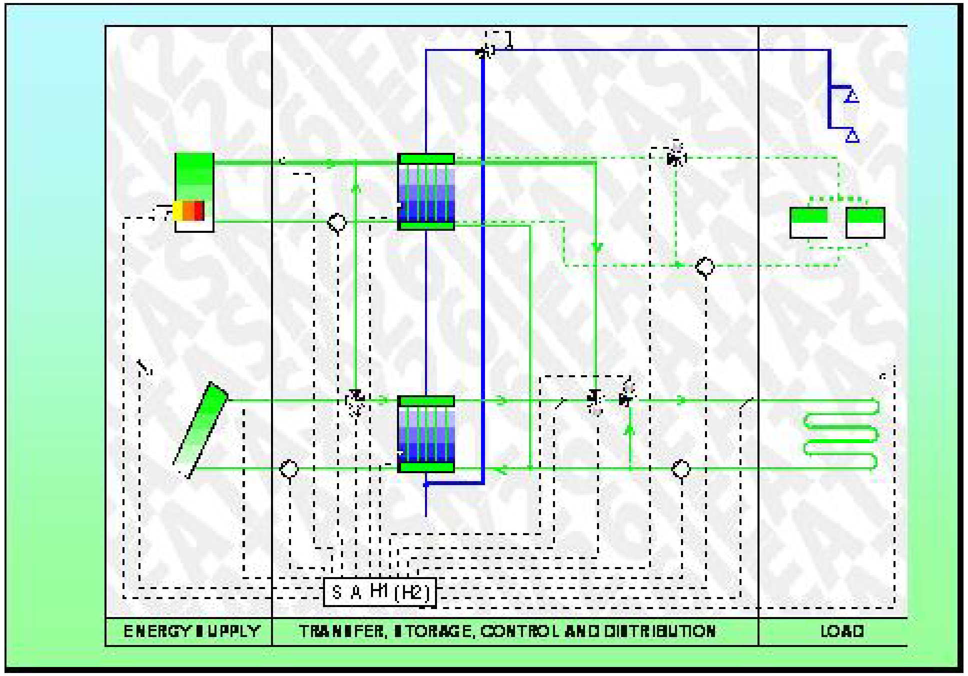
Hydraulics of solar combisystems (small solar plants and fractional saving)



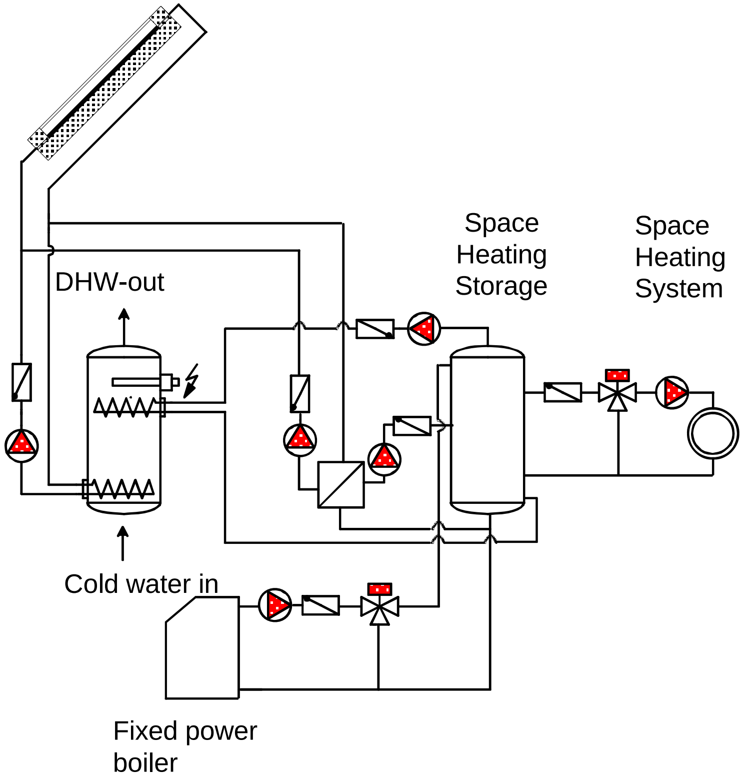


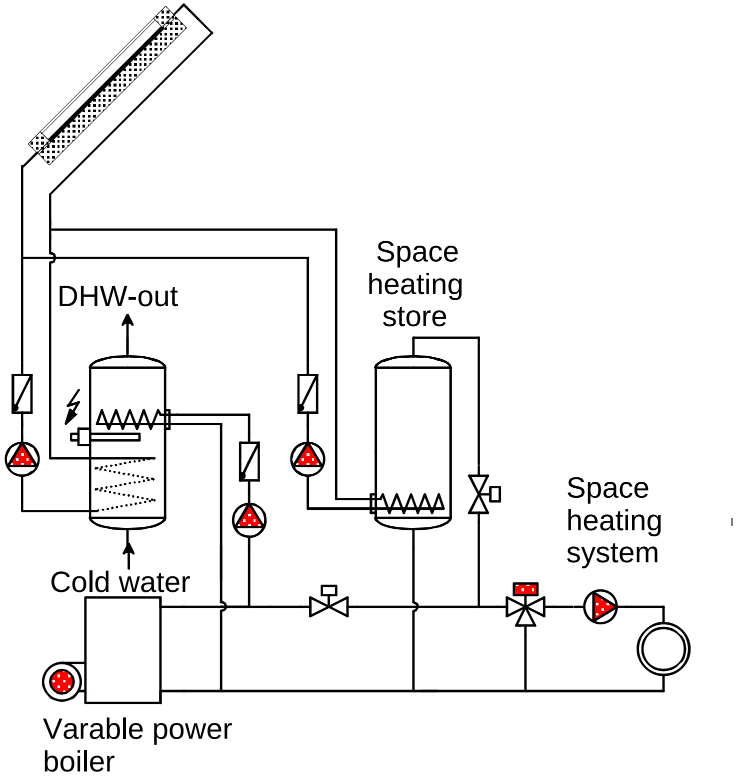
Hydraulics of solar combisystems (floor heating system as storage)





Hydraulics of solar combisystems (two store systems)





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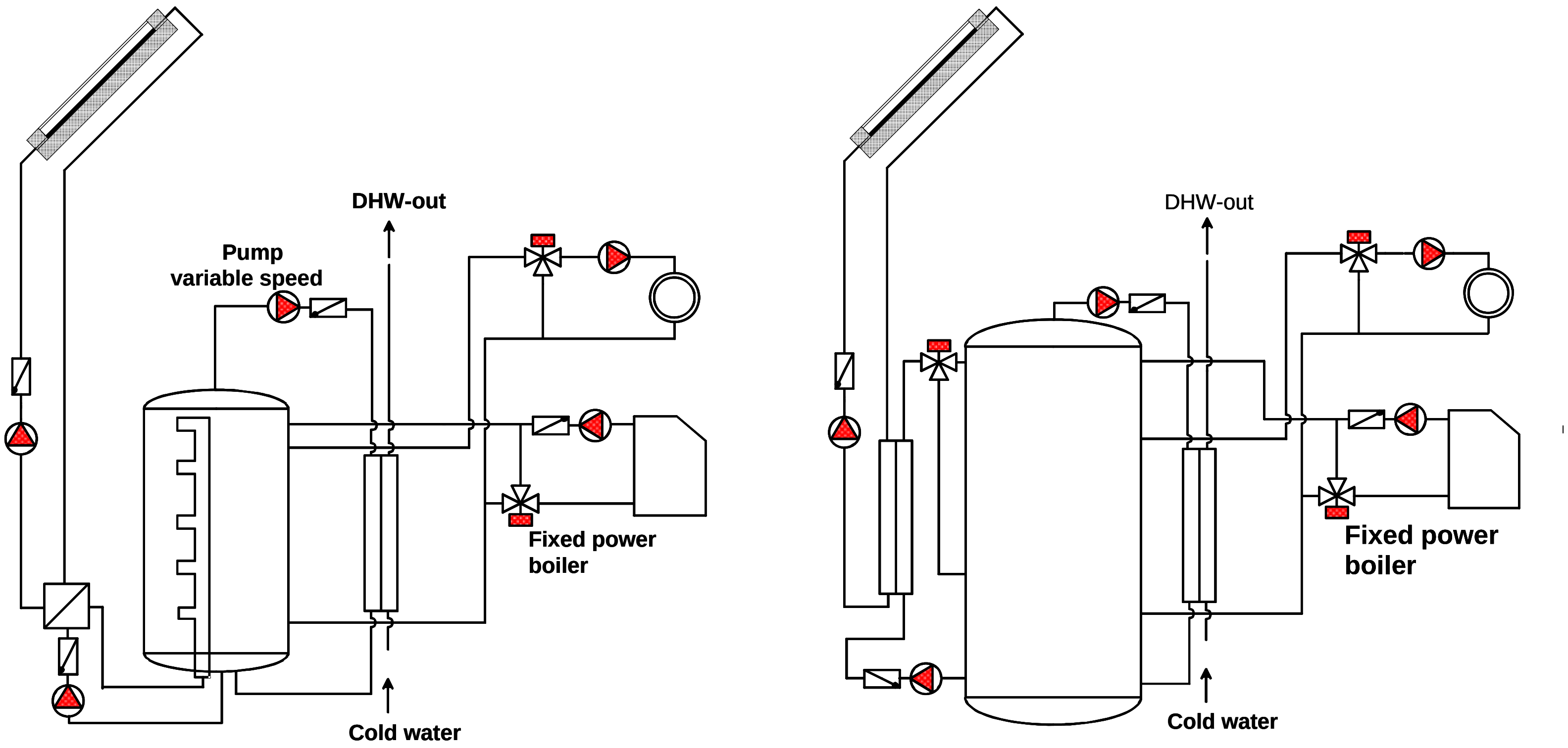
Hydraulics of solar combisystems (one store systems with external DHW once through HX)



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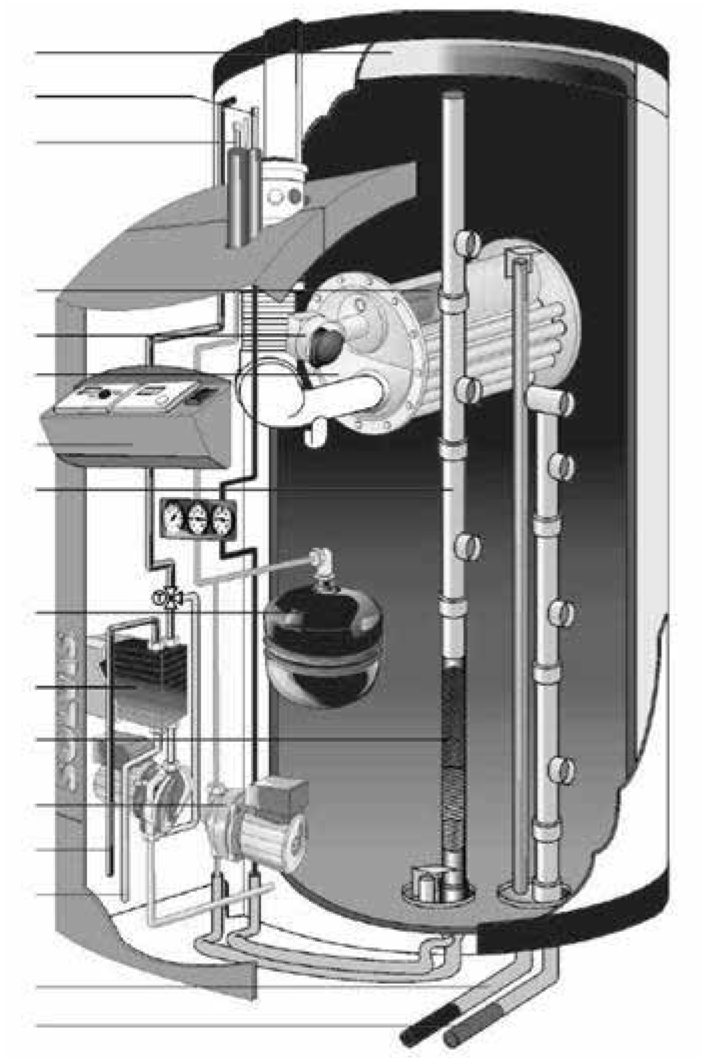
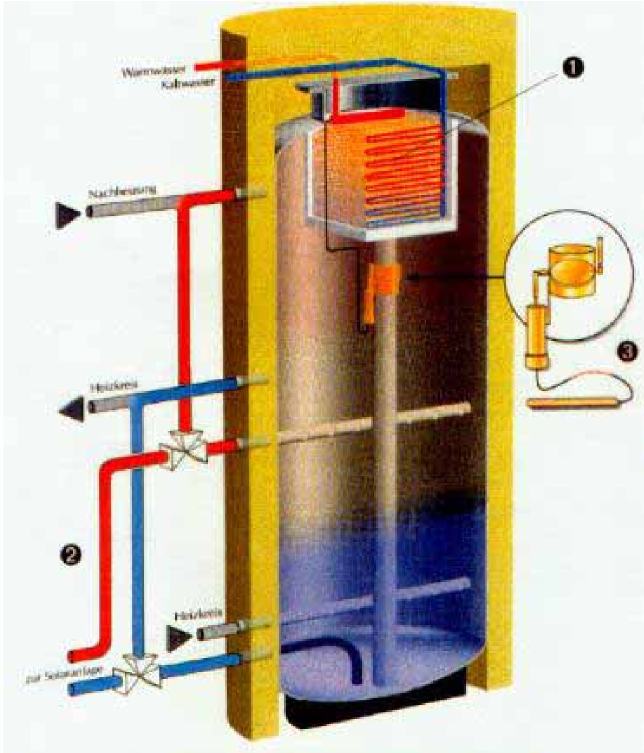
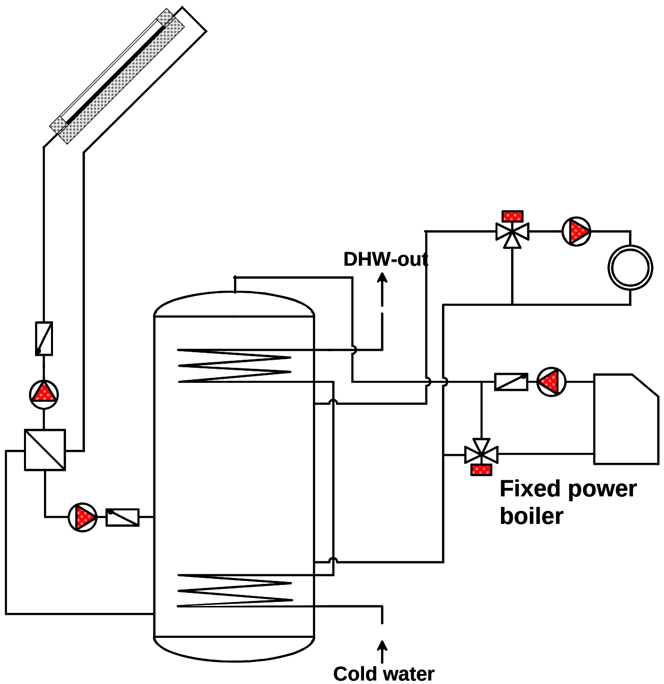
Built examples

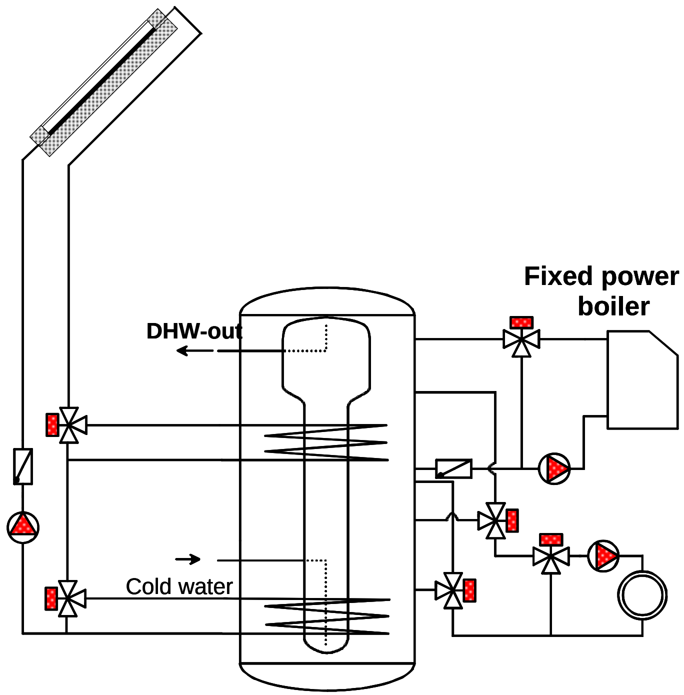




❶ Hochleistungs-Wärmetauscher für eine gleichmäßig hohe Zapftemperatur
❷ Zwei-Zonen-Beladesystem zur optimalen Nutzung der Sonnenwärme
❸ Flow-Control-System zur stabilen Wärmeschichtung

Hydraulics of solar combisystems (one store tank in tank or internal once through HX)





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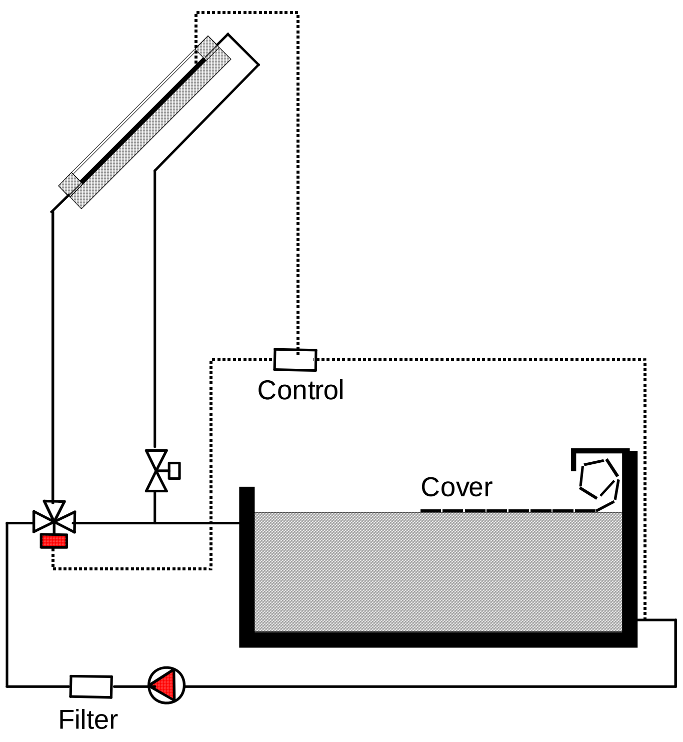
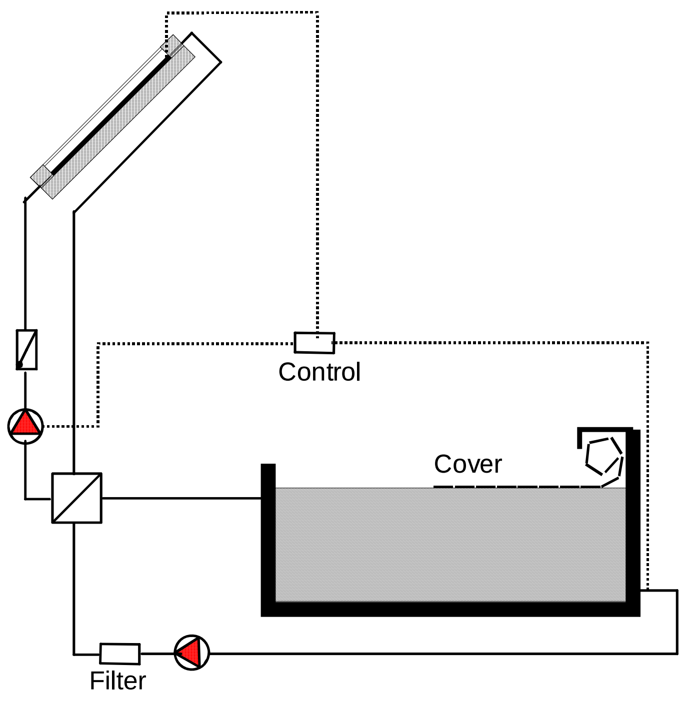
Solar heated swimming pools





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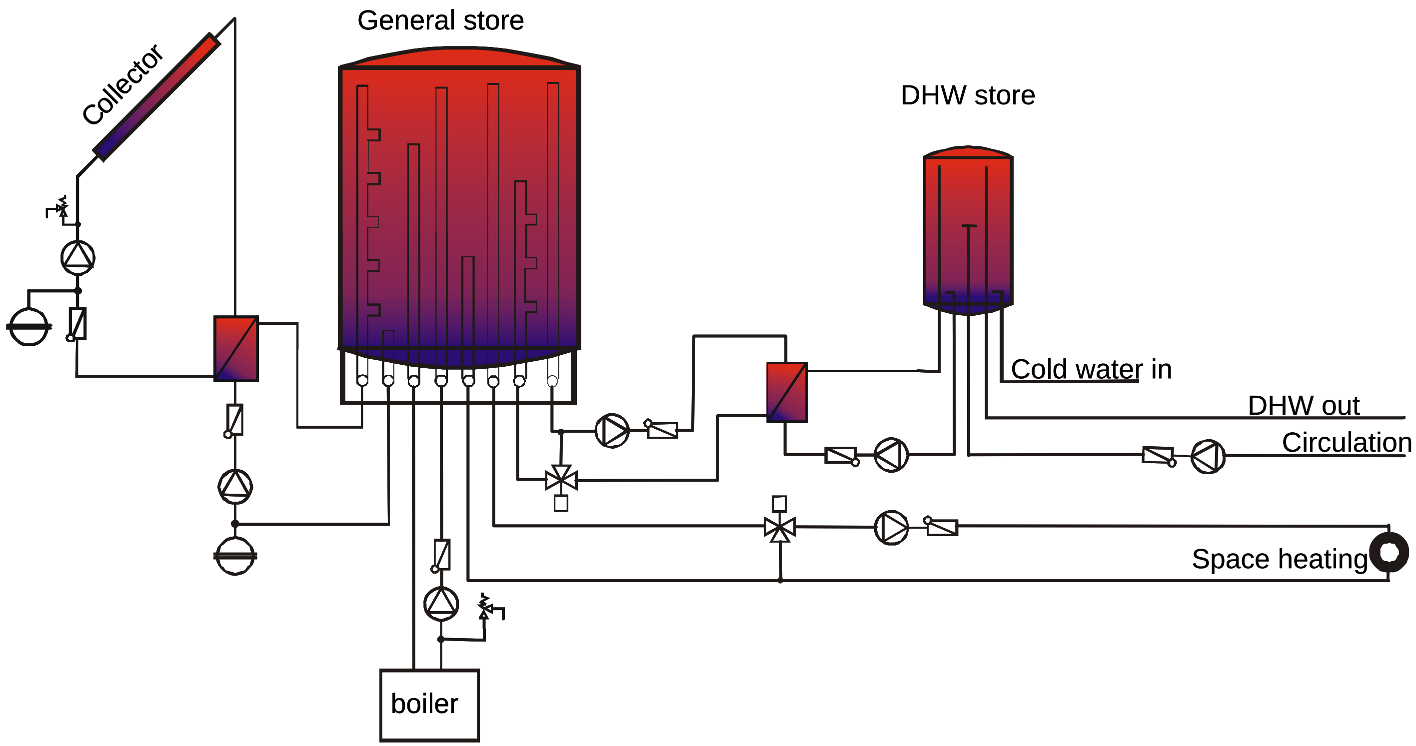
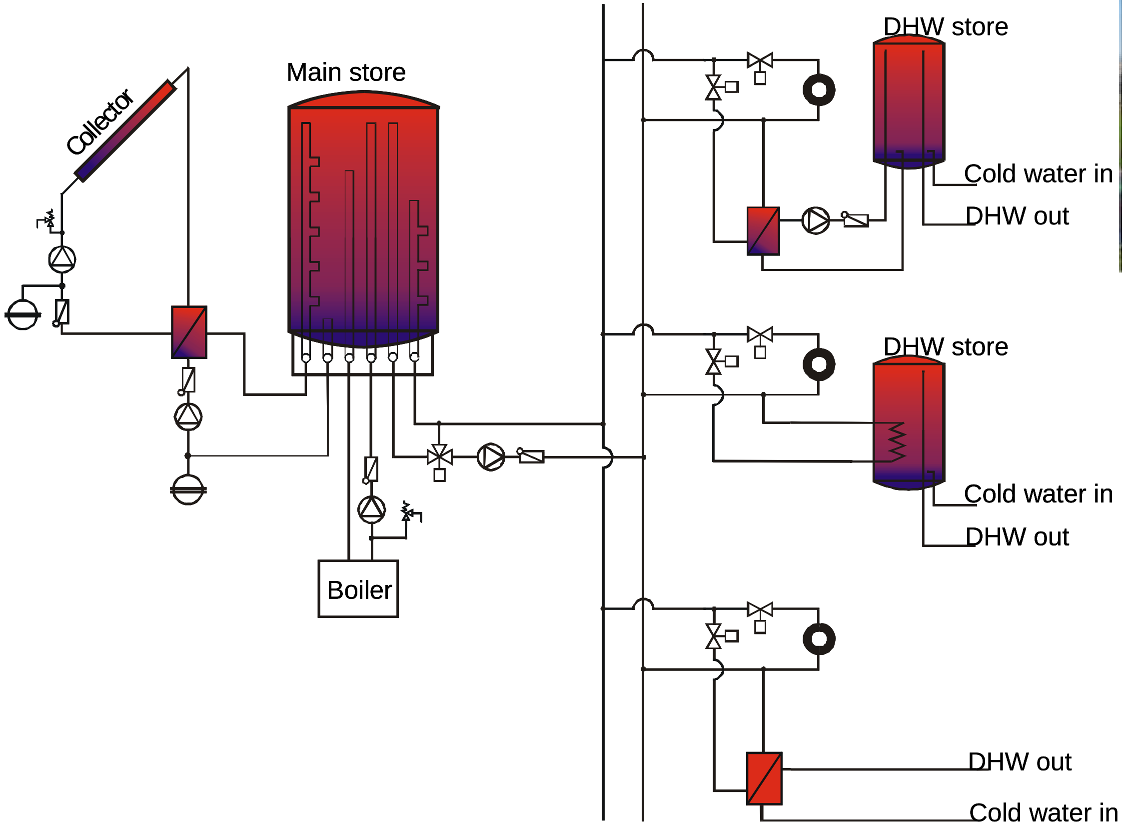
Hydraulics of solar combisystems (solar plants for multi family houses 4 pipe system)

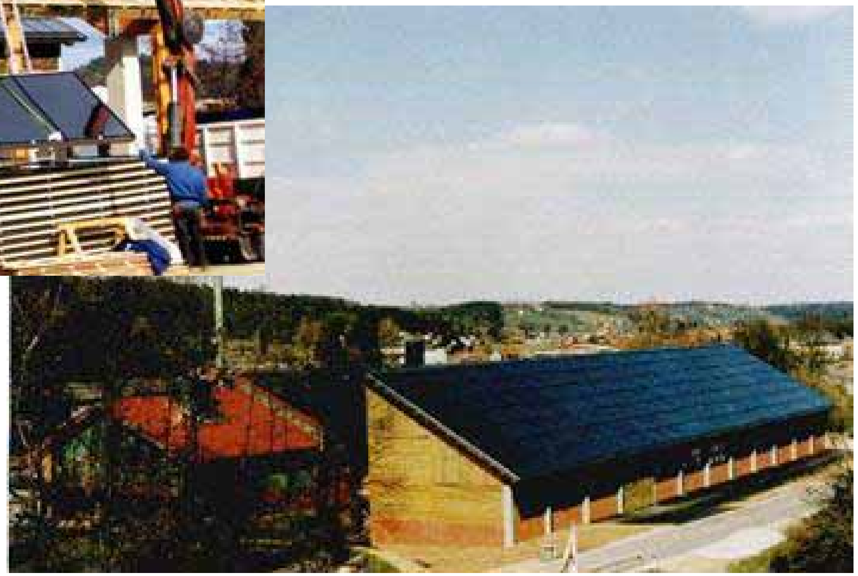


Hydraulics of solar combisystems (solar plants for multi family houses, 2 pipe system)



http:\\www.gswb.at

Solar plants for district heating networks



When small storage:

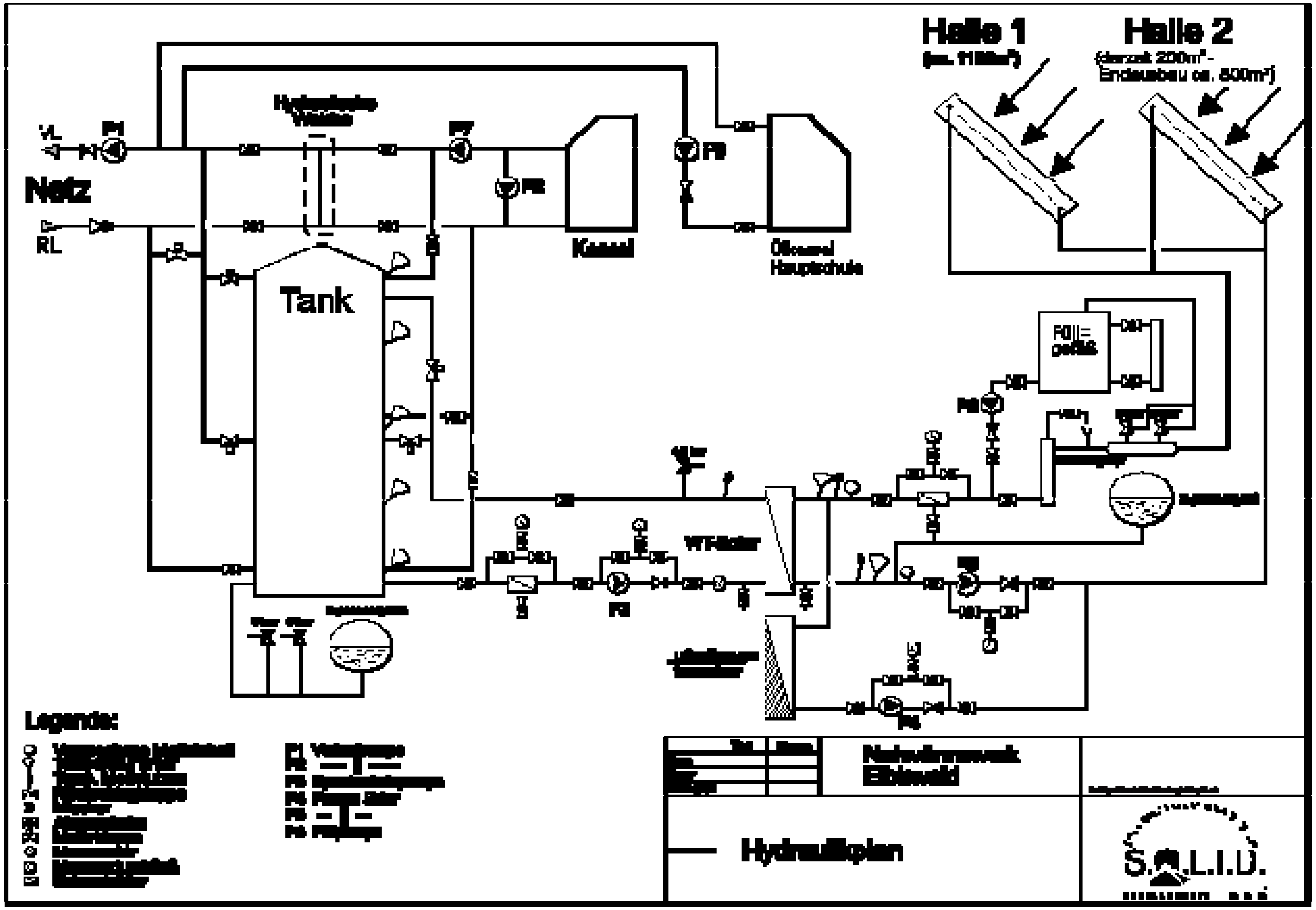
Layout only for summer load to prevent stagnation

Solar assisted biomass-district heating system Eibiswald (Austria)

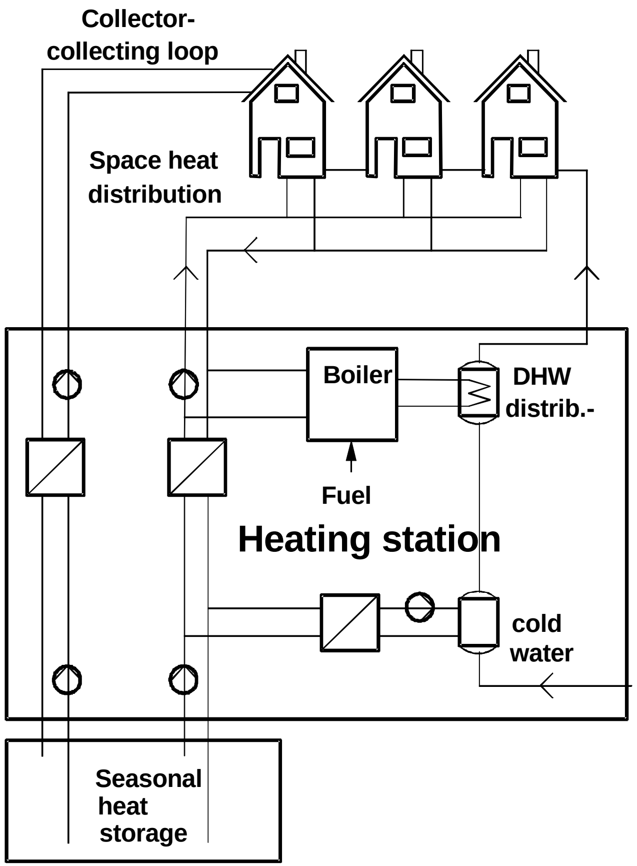
Technical data:

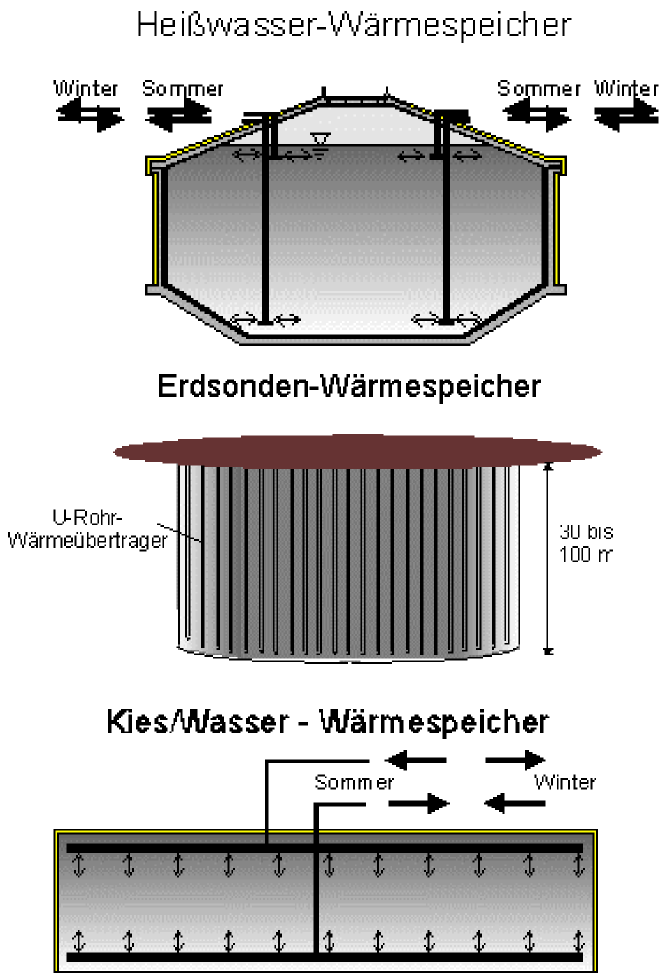
- Set into use 1994
- Farmers association
- Biomas boiler: 2000 kW
- Whole year operation ab 1997
- Storage: 105 m^3
- Solar plant (1997): 1250 m^2
- Wood chips store: 4000 Srm
- District heat net length incl. houses): 4000 m
- Σ user heating capac.: 3000 kW
- 31 users

Hydraulics of solar combisystems (solar plants district heating networks)



District heating systems, seasonal storage





Control of solar combisystems

- Max. temperature from auxiliary as low as possible (user demand)
- DHW store max. < 65°C (if limestone problem)
- DHW store greater 400 l: temperature daily above 60°C (german legionella standard)
- Heating store solar max. < 95°C (to prevent boiling)

- When stratifiers are used => Low flow system
- When internal solar heat exchangers are used => High flow systems

- 2-store systems: control has to decide which store should be loaded first from solar: best way:
  off heating season: DHW store primarily
  heating season: store with lowest temperature primarily

Dimensioning of Solar Systems

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Fractional energy savings

$$SF_a = \frac{Q_{solar\ heat\ delivered}}{Q_{total\ heat\ demand}}$$

store heat losses are assigned to boiler

$$SF_b = \frac{Q_{solar\ heat\ delivered}}{Q_{solar\ heat\ delivered} + Q_{auxiliary\ heat\ delivered}}$$

store heat losses are assigned equally

$$SF_c = 1 - \frac{Q_{conventional\ heat\ delivered}}{Q_{total\ heat\ demand}}$$

store heat losses are assigned to solar plant

Example

$Q_{DHW} + Q_{SH}$ = 15000 kWh
Q_{solar} = 9000 kWh
Q_{Boiler} = 8000 kWh

SF_a = 60 %, SF_b = 53 %, SF_c = 47%

SF_c is used for further calculations

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Fractional energy savings of Task 26, IEA using reference system

$$\text{Fractional Savings thermal (FSAVtherm)} = 1 - \frac{Fuel_{Combi}}{Fuel_{Referenz}}$$

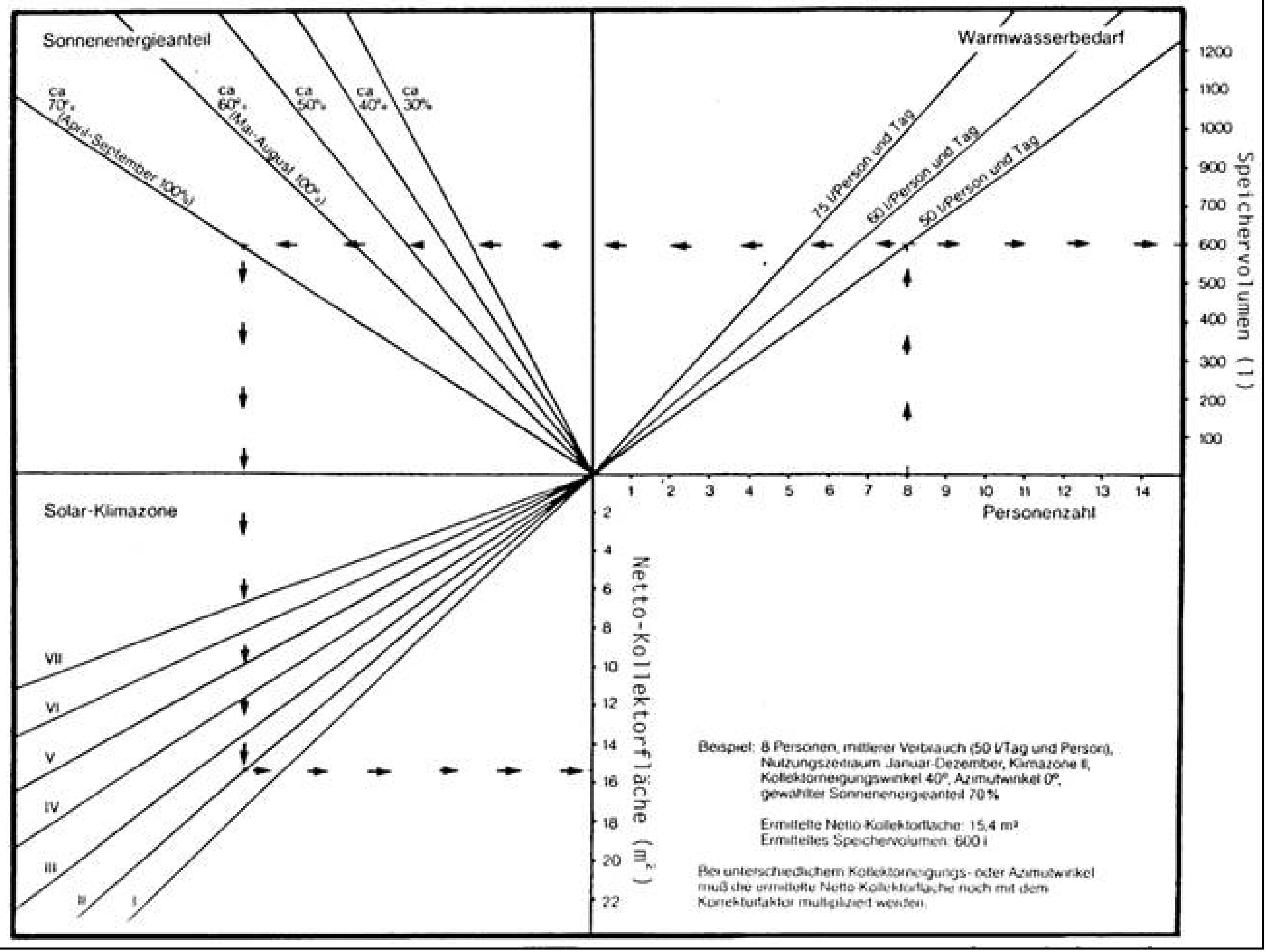
$$\text{Fractional Saving extended (FSAVext)} = 1 - \frac{Fuel_{Combi} + El_{pri,Combi}}{Fuel_{Referenz} + El_{pri,Referenz}}$$

$$\text{Fractional Saving indicator (Fsi)} = 1 - \frac{Fuel_{Combi} + El_{pri,Combi} + Penalty_{Combi}}{Fuel_{Referenz} + El_{pri,Referenz}}$$

Note:

Comparing to a reference system and using the fuel demand rather than final energy, the boiler efficiency of reference system compared to the solar system becomes significant

Simple dimensioning of solar DHW systems



Simple dimensioning of solar DHW systems

Solar-climate-zone	Hours of sunshine	Global iradiation	
	[h/year]	kWh/m²,day	kWh/m²,year
I	< 1500	ca. 2.5	ca. 920
II	1500 - 1700	ca. 2.8	ca. 1030
III	1700 - 1900	ca. 3.1	ca. 1115
IV	1900 - 2100	ca. 3.4	ca. 1230
V	2100 - 2300	ca. 3.7	ca. 1370
VI	2300 - 2500	ca. 4.1	ca. 1490
VII	> 2500	ca. 4.4	ca. 1610

Sensitivity analysis of reference combisystem reference conditions

Location Graz, standard year

Building

- Design heat load : 8 kW
- Internal gains: 0,5 kW
- Design temperature: -12 °C
- Design flow/return temperature of heating system: 40/30 °C

DHW demand (45°C) 200 l/Tag

Collector (selctive absorber)

- Area: 30 m^2
- Azimuth: Süd
- Slope: 45 °
- Tube length collector storage 15 m

DHW store

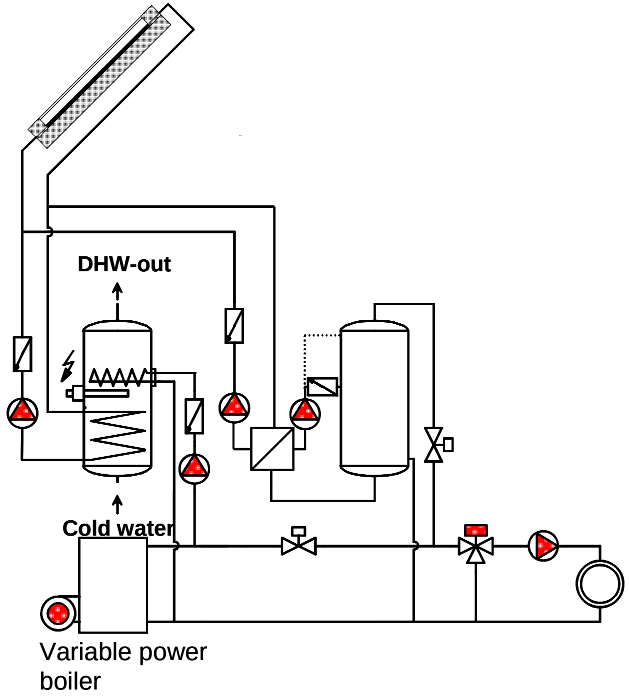
- Volume: 500 l
- Insulation: 10 cm, λ = 0,05 W/mK

Space heating store

- Volume: 2000 l
- Insulation: 15 cm, λ = 0,05 W/mK

Control

- Max. temp. DHW store solar: 70 °C
- Max. temp DHW store auxiliary: 60 °C
- Max temp. SH store solar: 100 °C



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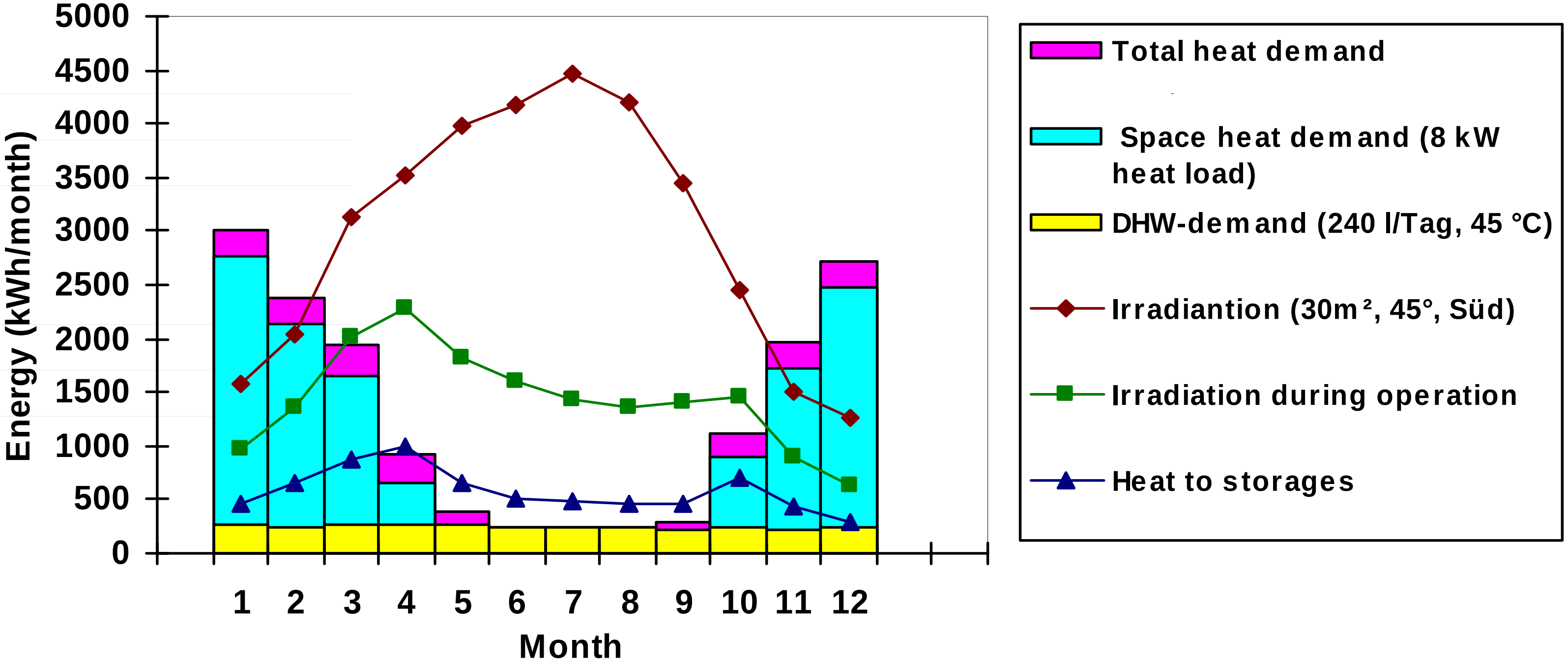
Sensitivity analysis of reference combisystem energy balance of reference conditions



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$SF_c = 34\ \%$

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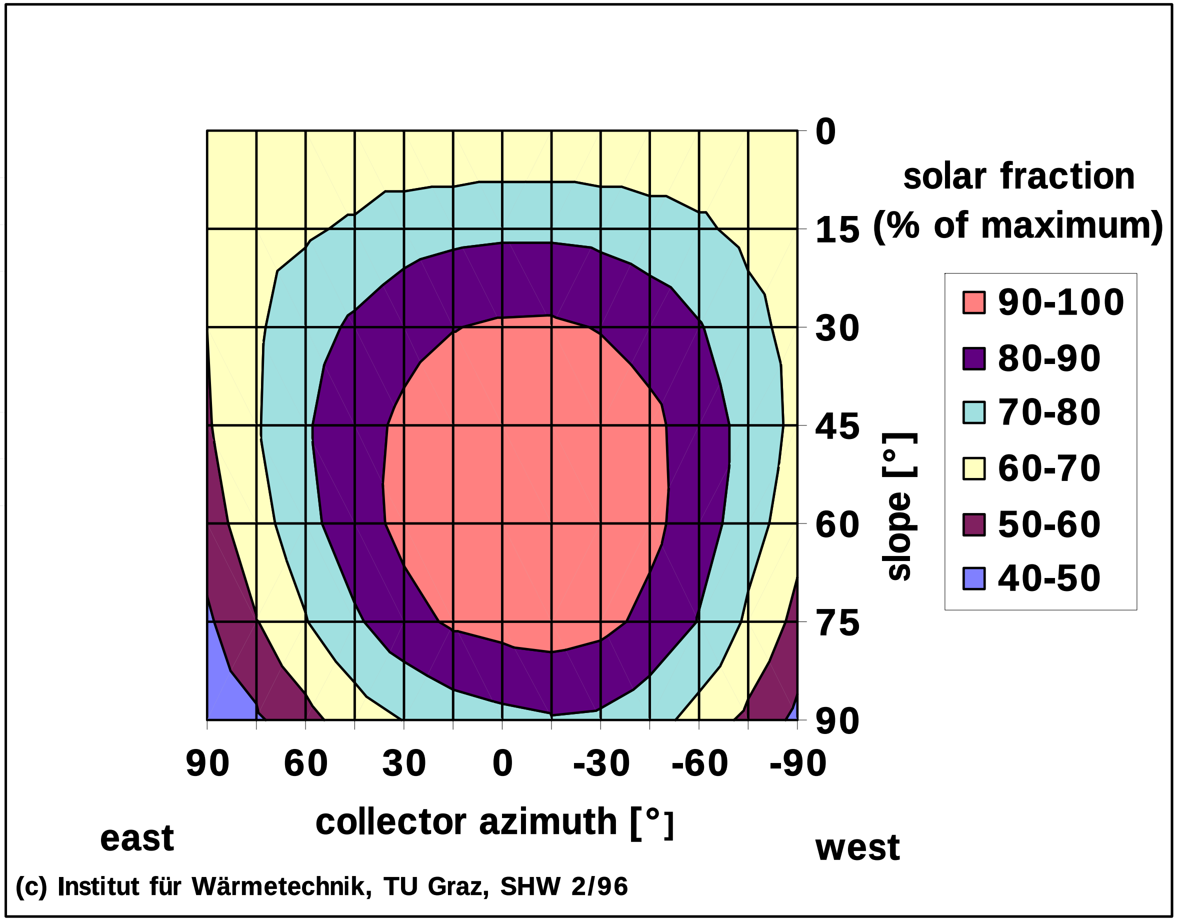
Sensitivity analysis of reference combisystem
SF_c dependency on slope and azimuth



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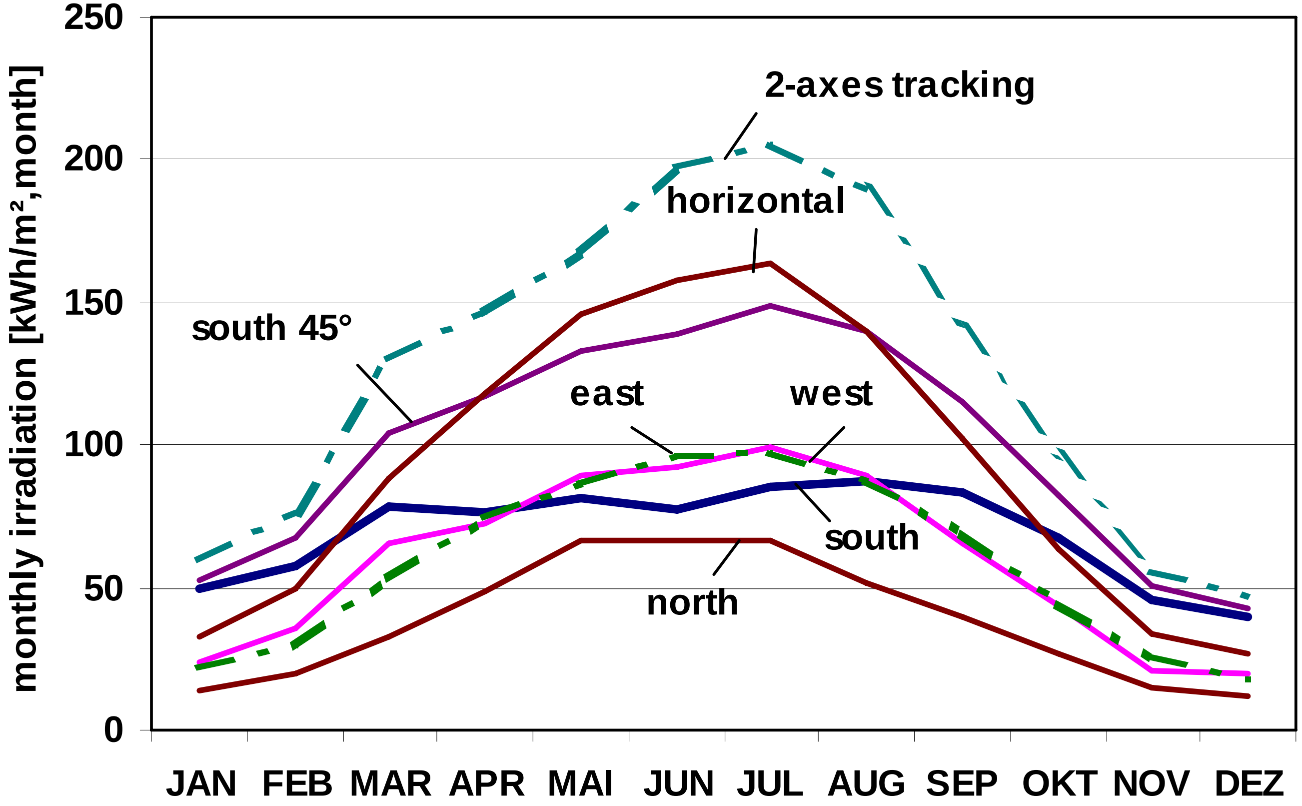
Hemispherical irradiation on surfaces of different orientations for a middle European climate



Sensitivity analysis of reference combisystem SF_c dependency on slope and azimuth

- Optimal slope equals to lattitude of loaction
- Optimal orientation about 5° west (northern hemisphere)
- Little decrease of SF_c by opt. slope ± 25°
- Little decrease of SF_c by opt. azimuth ± 30°
- Slope of 90° south is far better than horizontal collector (wall collector)

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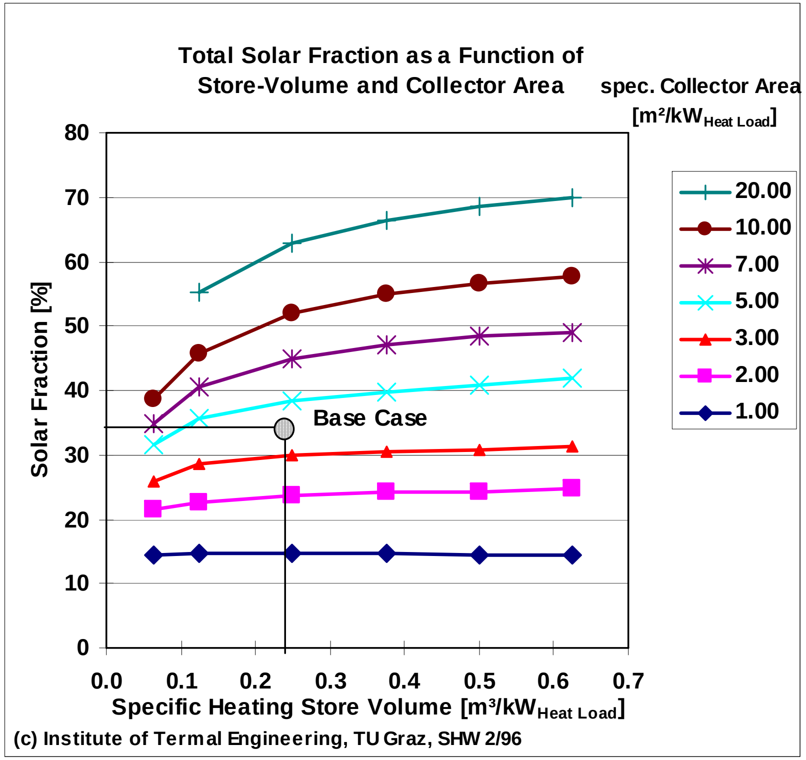
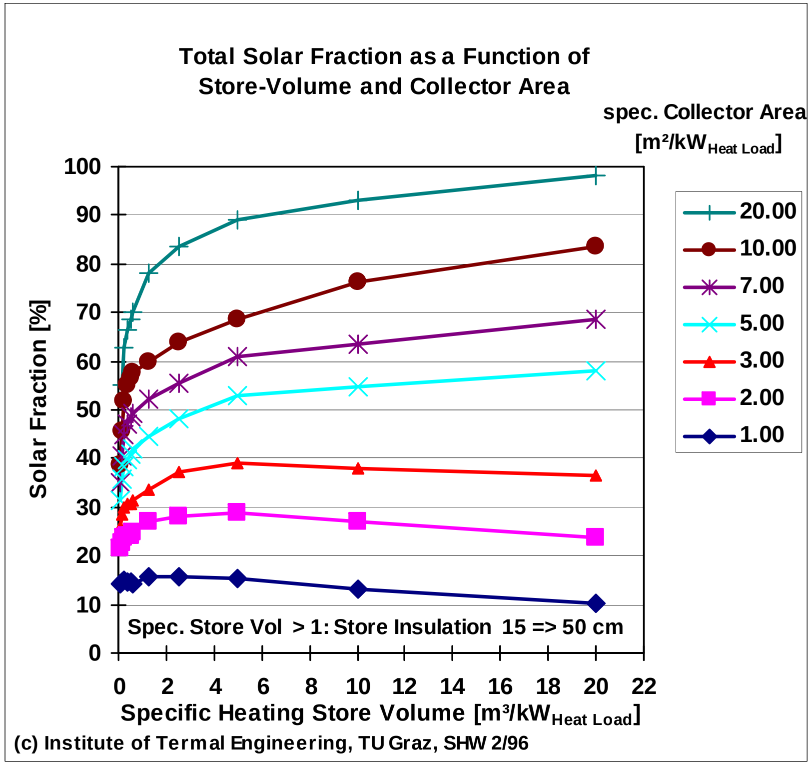
Sensitivity analysis of reference combisystem
SF_c dependency on store volume and collector area





$$A_{coll\_p} = A_{coll} / \dot{Q}_{load}$$ and

$$V_{store\_p} = V_{store} / \dot{Q}_{load}$$

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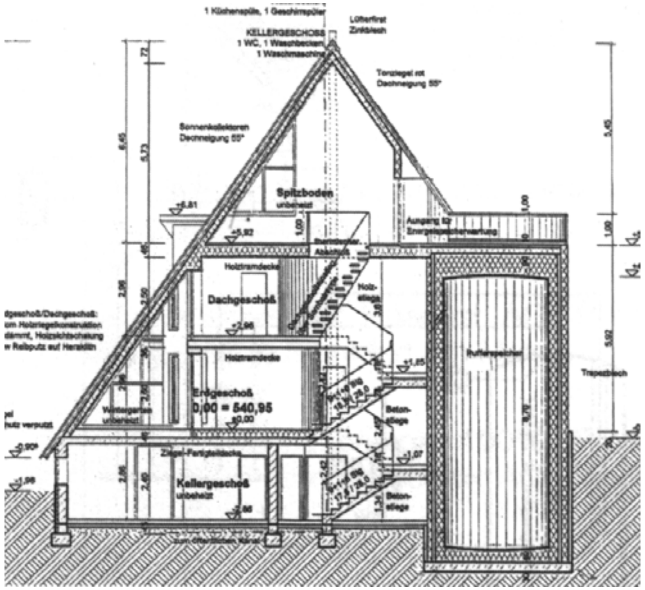
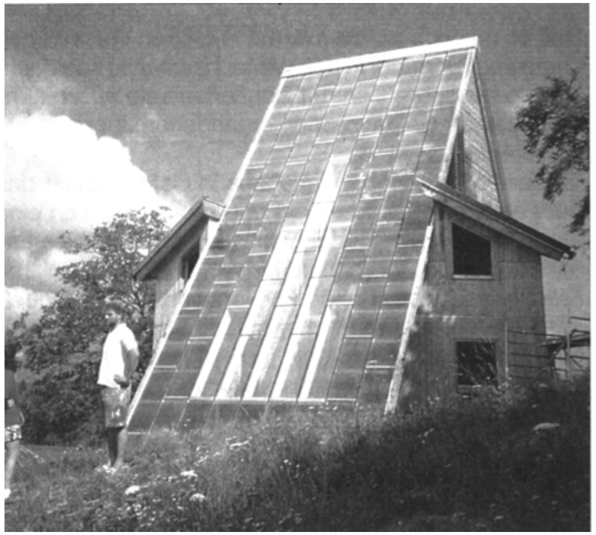
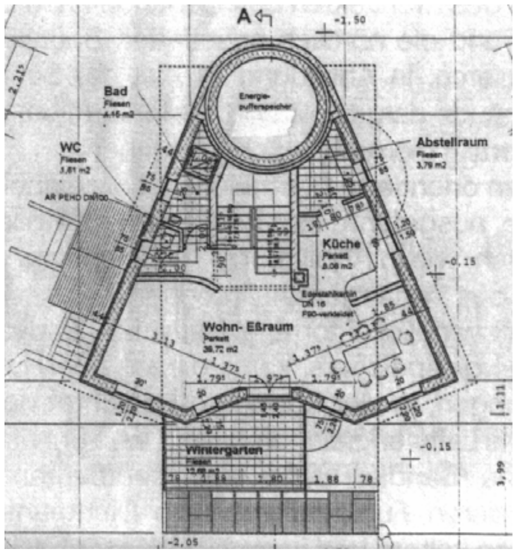
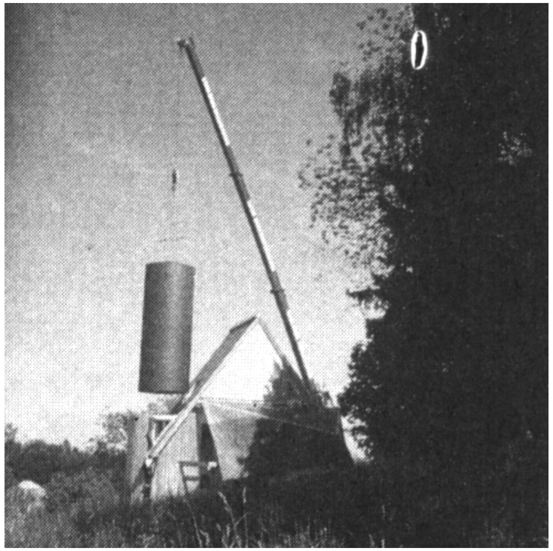
Example of purely solar heated house





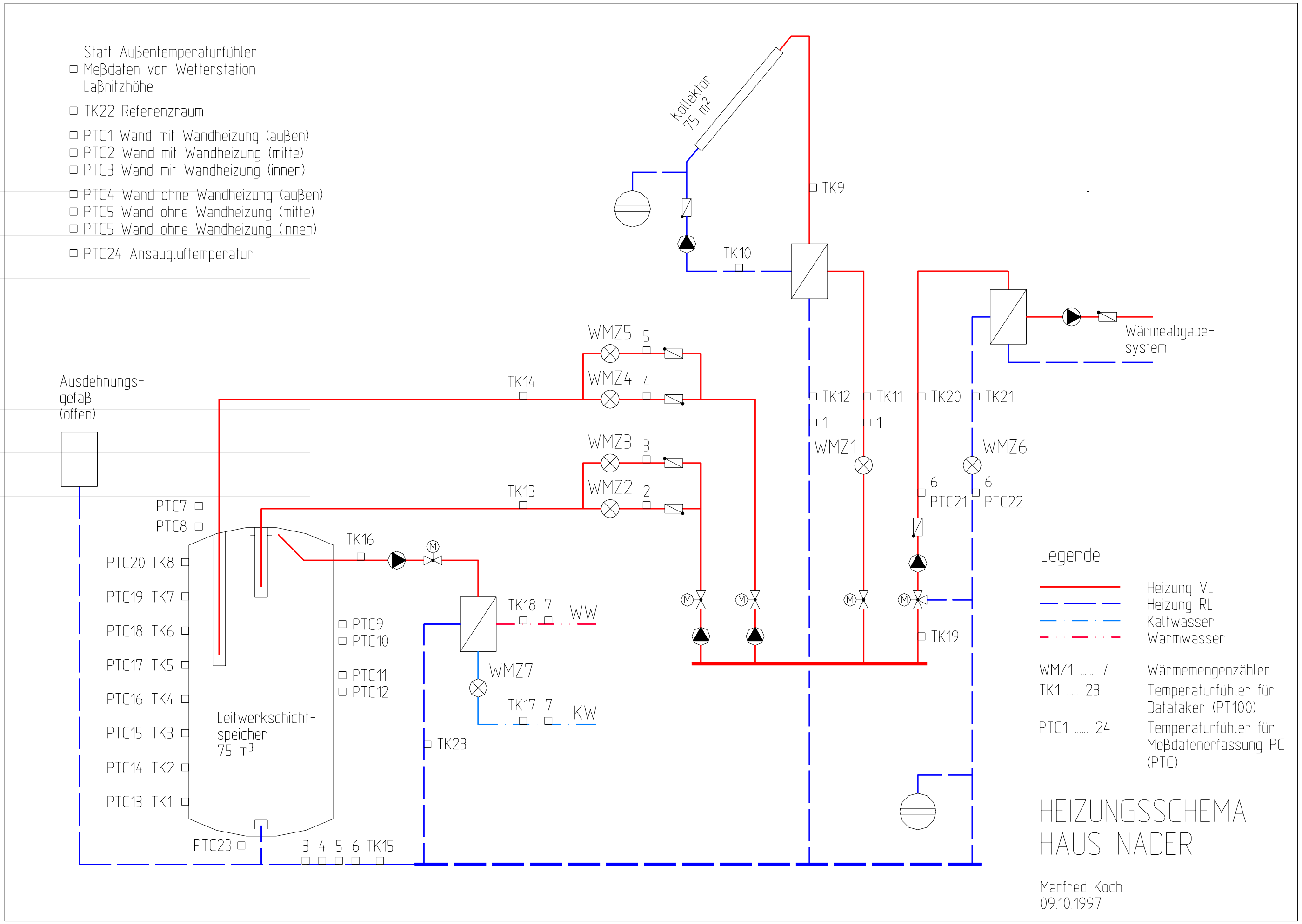




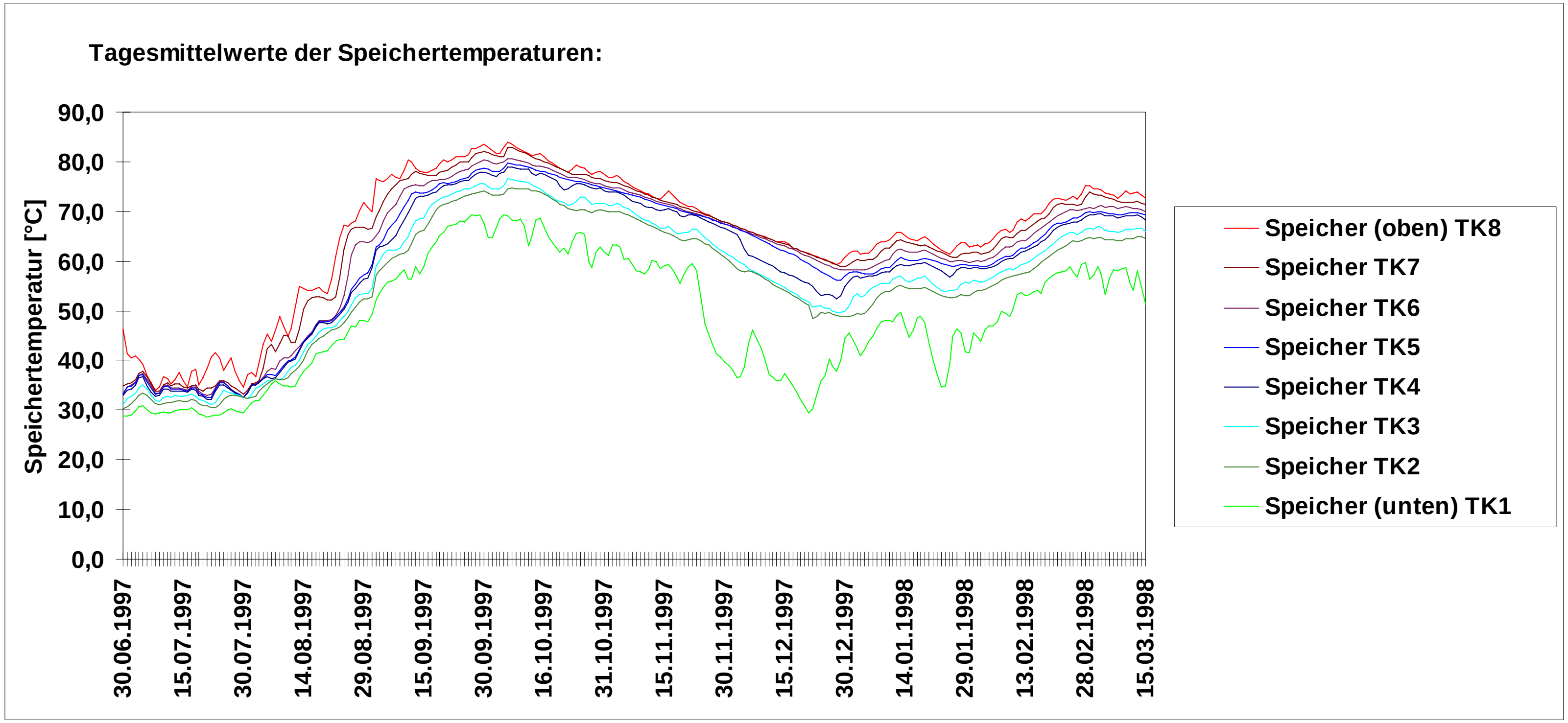
Example of purely solar heated house (No 10)

• **Living area**	**124 m²**
• **Persons**	**4 (1 Baby, 1 small kid)**
• **Heated volume**	**520 m³**
• **Design heat load**	**4,1 kW (ÖNORM B8135)**
• **Heat distribution system**	**Wall/floor 33/28**
• **Collector (absorber)**	**75 m² Agena Azur, south, 55°**
• **Store volume**	**75 m³ water**
• **DHW production**	**external once through HX**
• **Auxiliary boile**	**NONE**

Example of purely solar heated house (No 10)



Example of purely solar heated house (No 10) store temperatures first year



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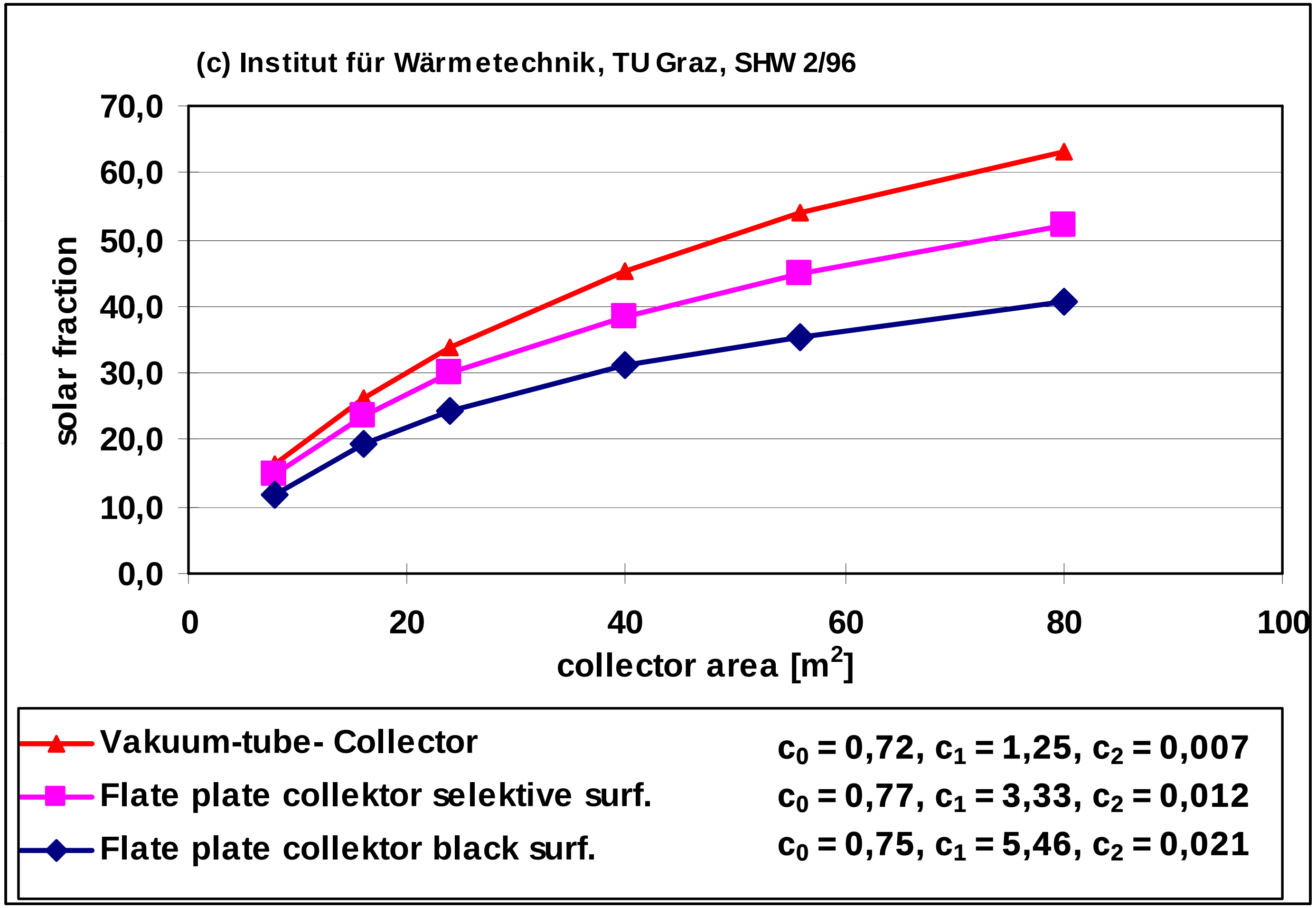
Example of purely solar heated house (No 10) one year energy balance (June 97 – March 98)

Collectorer yield	**16.700 kWh (220 kWh/m²)**
Heat to store top	**2150 kWh**
Heat to store middle	**14280 kWh**
Σ Heat to store	**16430 kWh**
Heat delivered top	**145 kWh**
Heat delivered middle	**728 kWh**
Heat to space heating	**1090 kWh (is it worth this ???)**
Heat fo DHW	**520 kWh (50 l/d ???)**

Sensitivity analysis of reference combisystem
SF_c dependency on collector type



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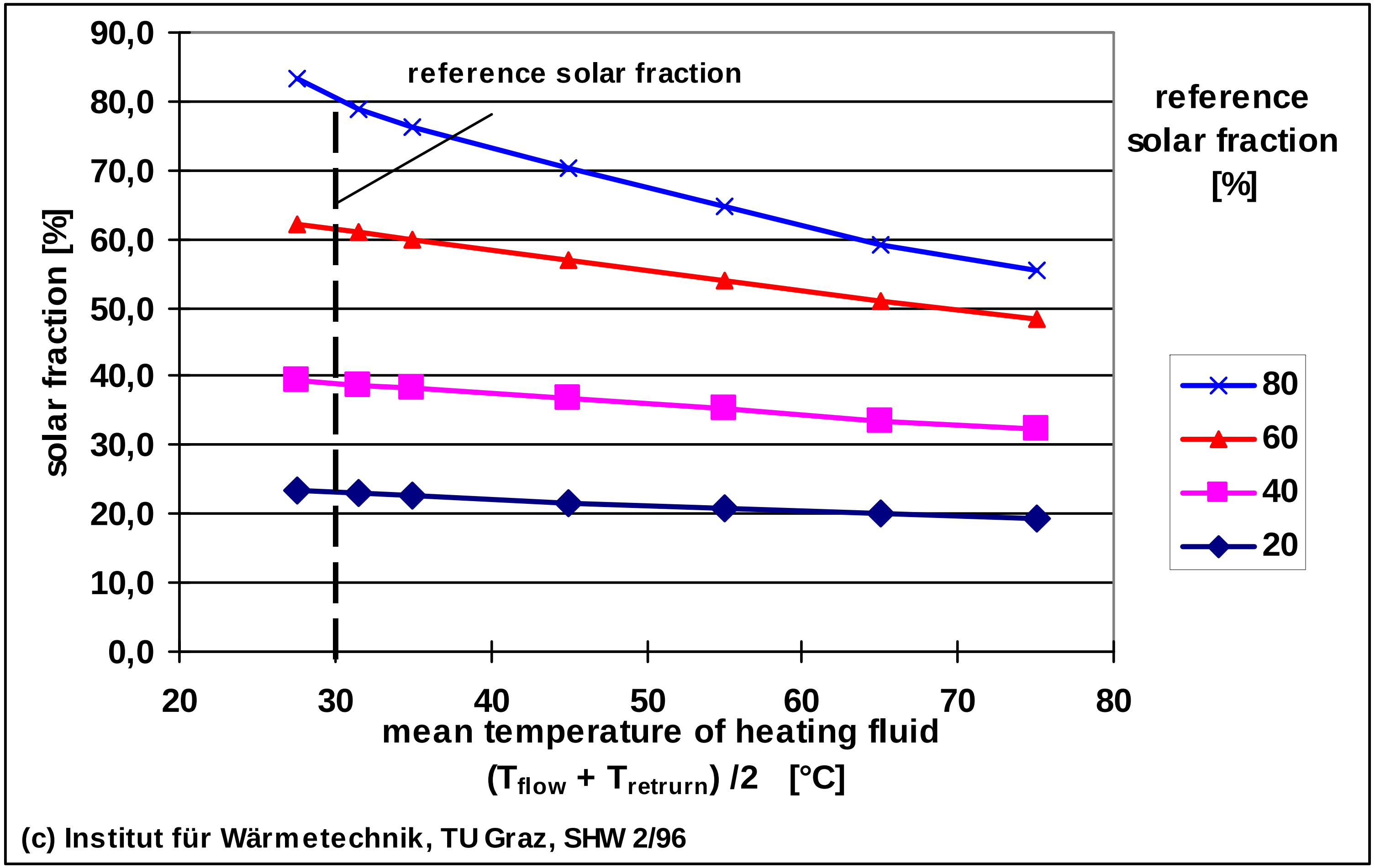
Sensitivity analysis of reference combisystem SF_c dependency on design temperature of the heating system



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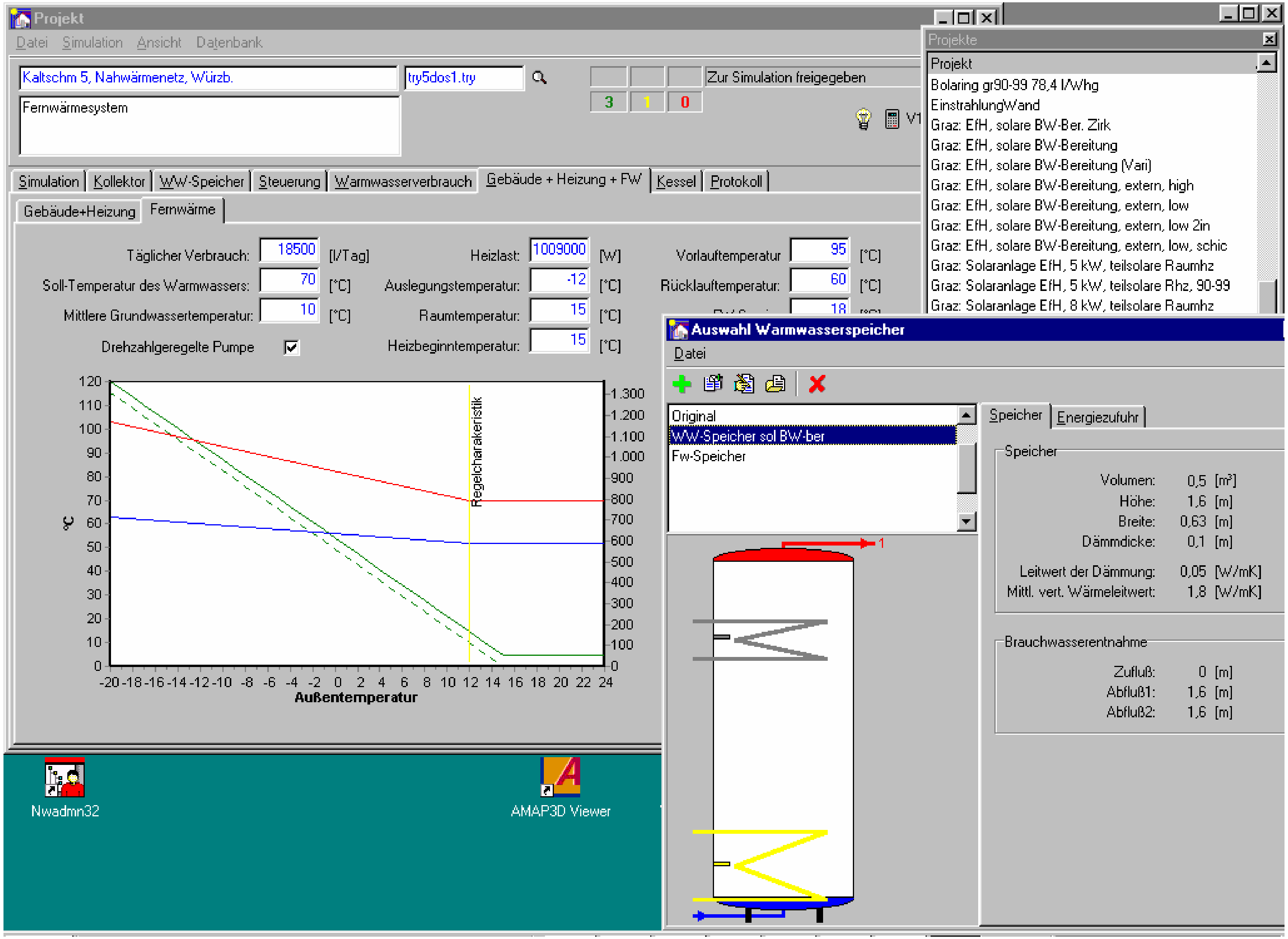
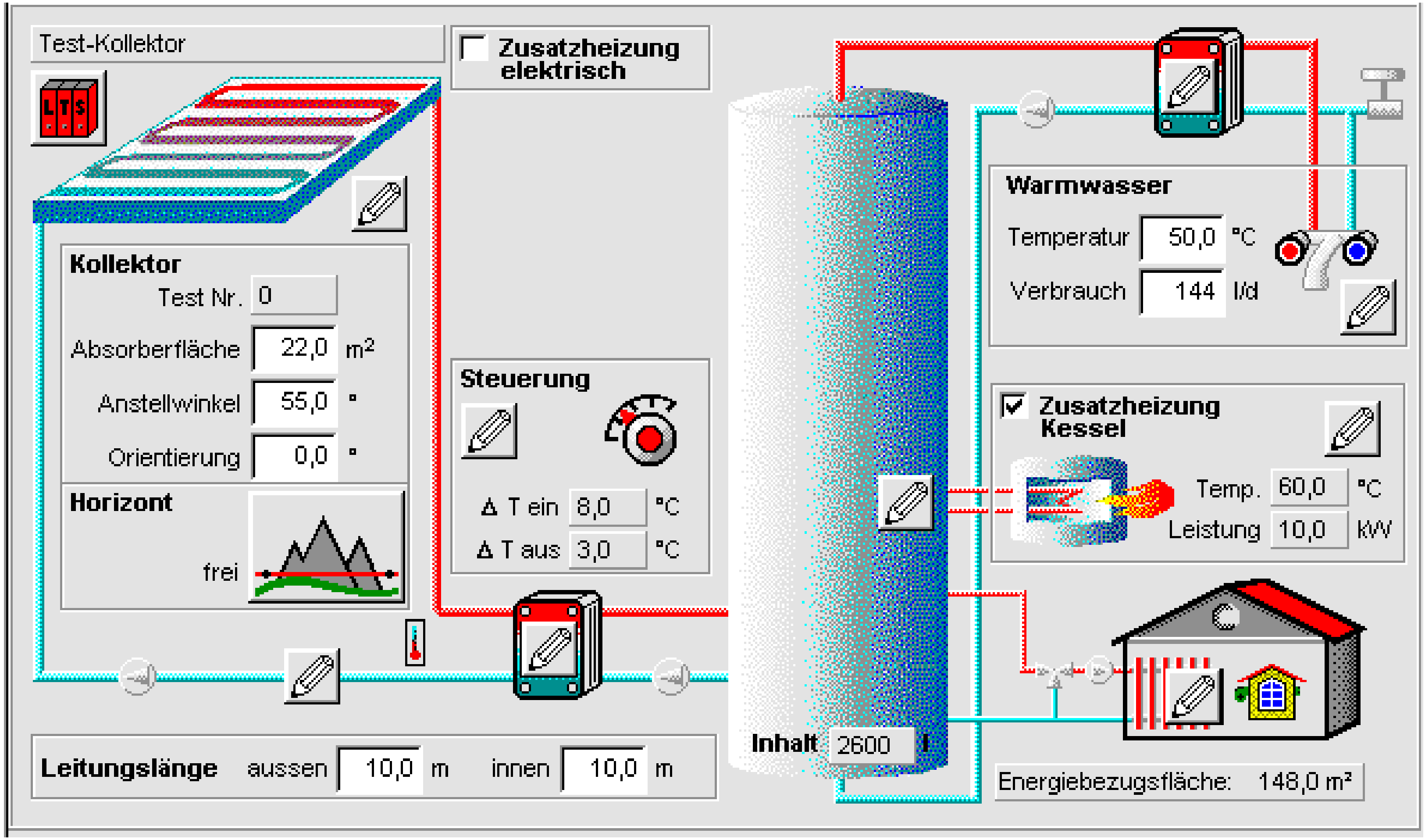
Simulation programs for solar thermal systems: SHWwin



Simulation programs for solar thermal systems
Polysun



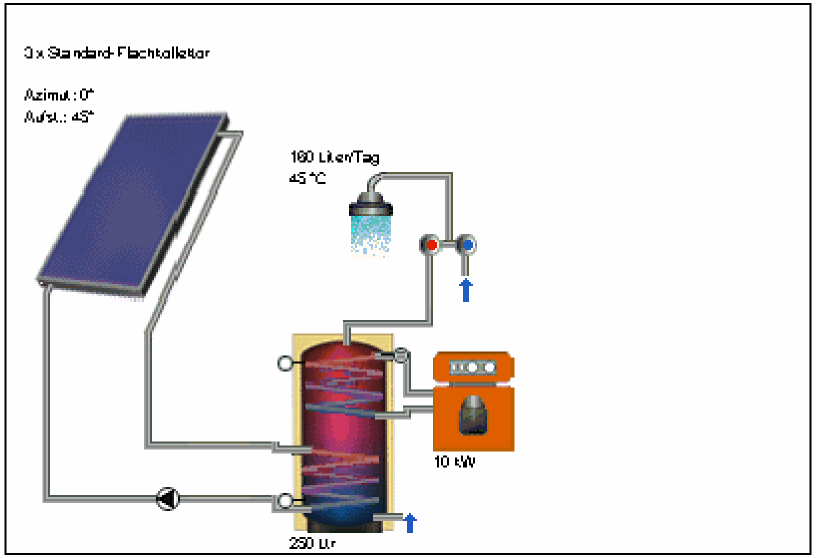
Simulation programs for solar thermal systems: TSOL

Dr.-Ing.G.Valentin+Partner GbR
VALENTIN Energiesoftware

Variante 1 **T*SOL 4.0 Demo**

Projekt: Projekt 1 Datum: 06.09.02

Solaranlage mit biv. WW-Speicher



Ergebnisse der Jahressimulation

Einstrahlung Kollektorfläche:	3,36 MWh	1119,59 kWh/m²
Abgegebene Energie Kollektoren:	1646,64 kWh	548,88 kWh/m²
Abgegebene Energie Kollektorkreis:	1425,84 kWh	475,28 kWh/m²
Energielieferung Trinkwarmwassererwärmung:	2380,71 kWh	
Energie Solarsystem an Warmwasser:	1425,84 kWh	
Zugeführte Energie Zusatzheizung:	1128,79 kWh	

Brennstoffeinsparung:	214,2 l
Vermiedene CO2-Emissionen:	576,4 kg
Deckungsanteil Warmwasser:	55,8 %
Systemnutzungsgrad:	42,5 %

Simulation programs for solar thermal systems: TRNSYS