DIMENSIONING EXPANSION VESSELS HEAT EXCHANGER

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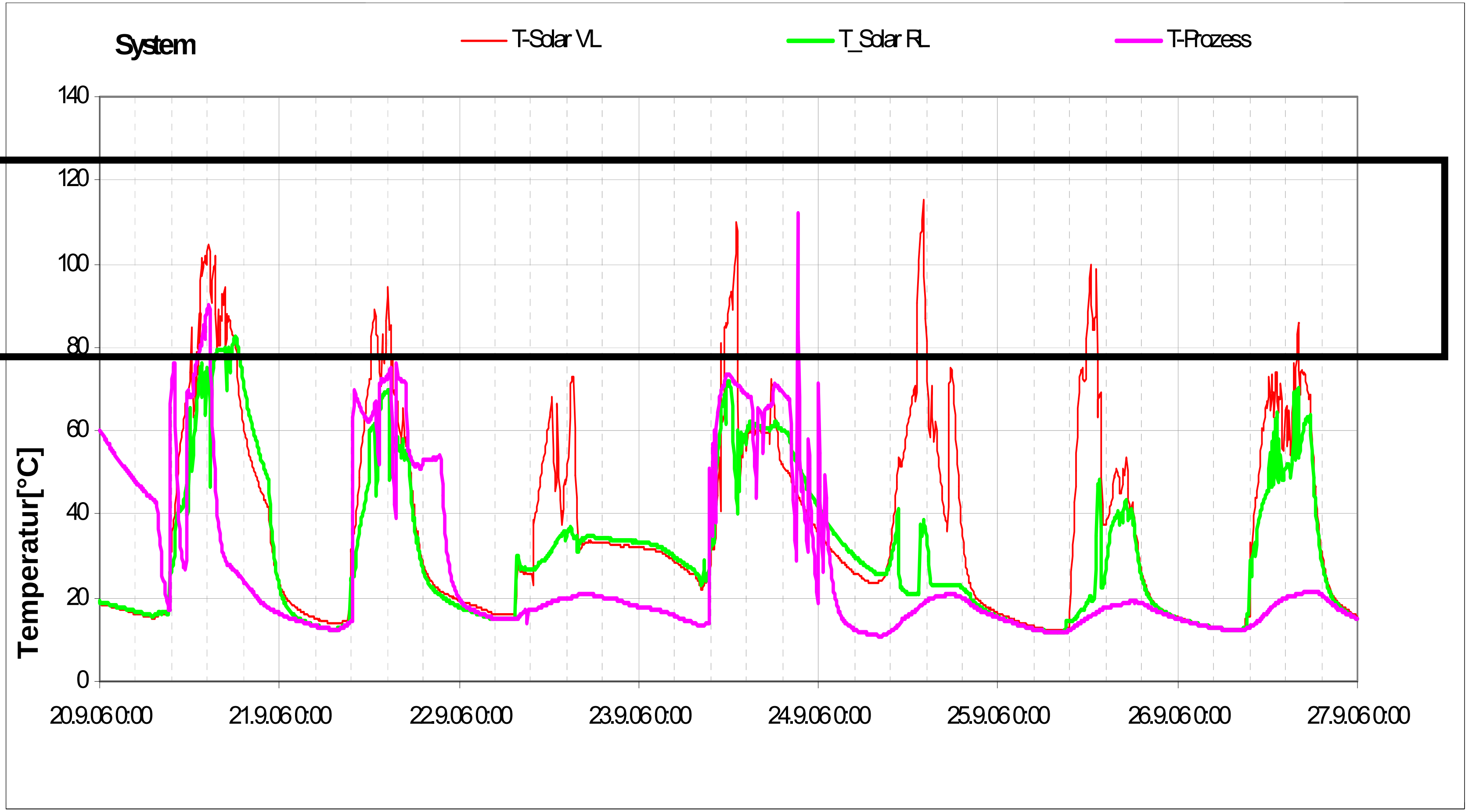
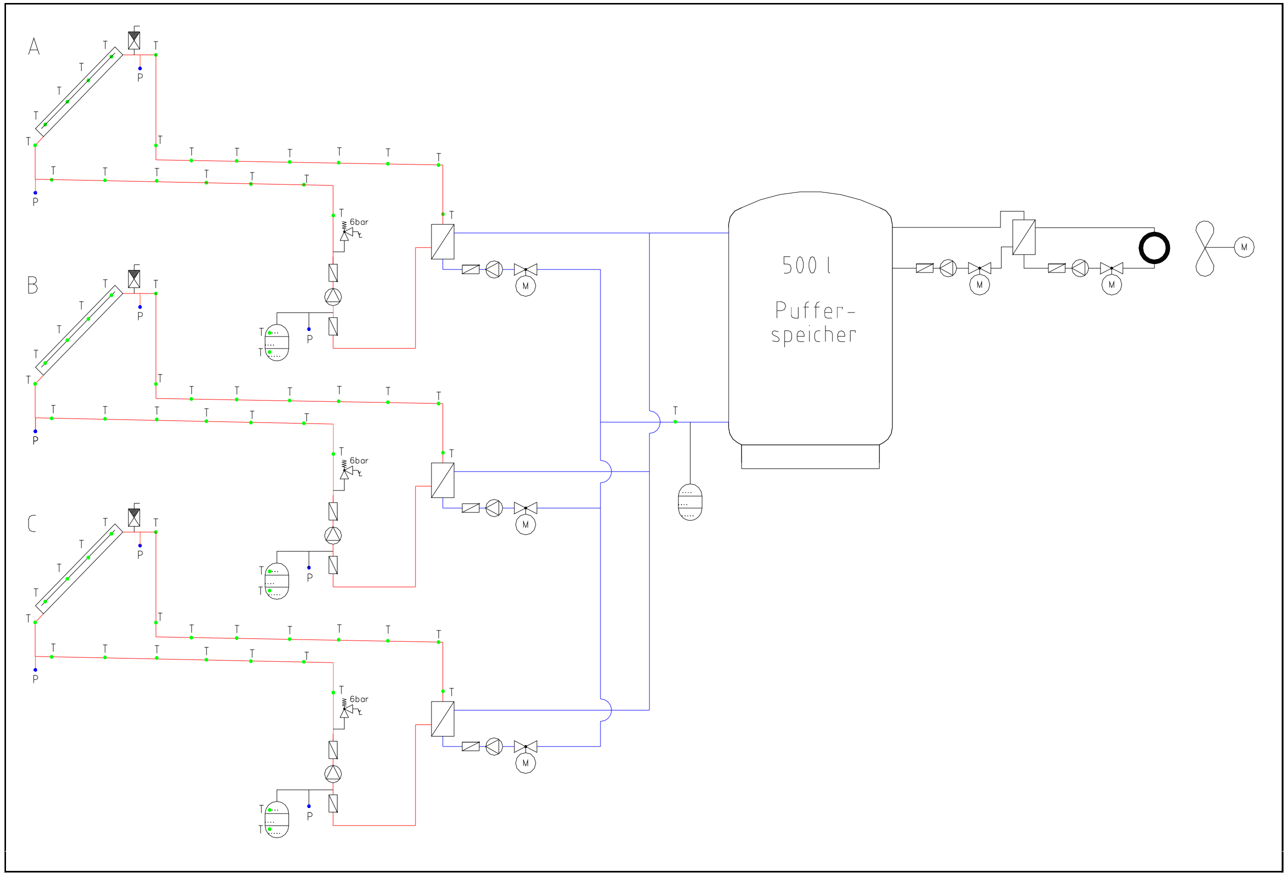
Monitoring Results – Collector Temperatures



Stagnation behaviour – Test lab

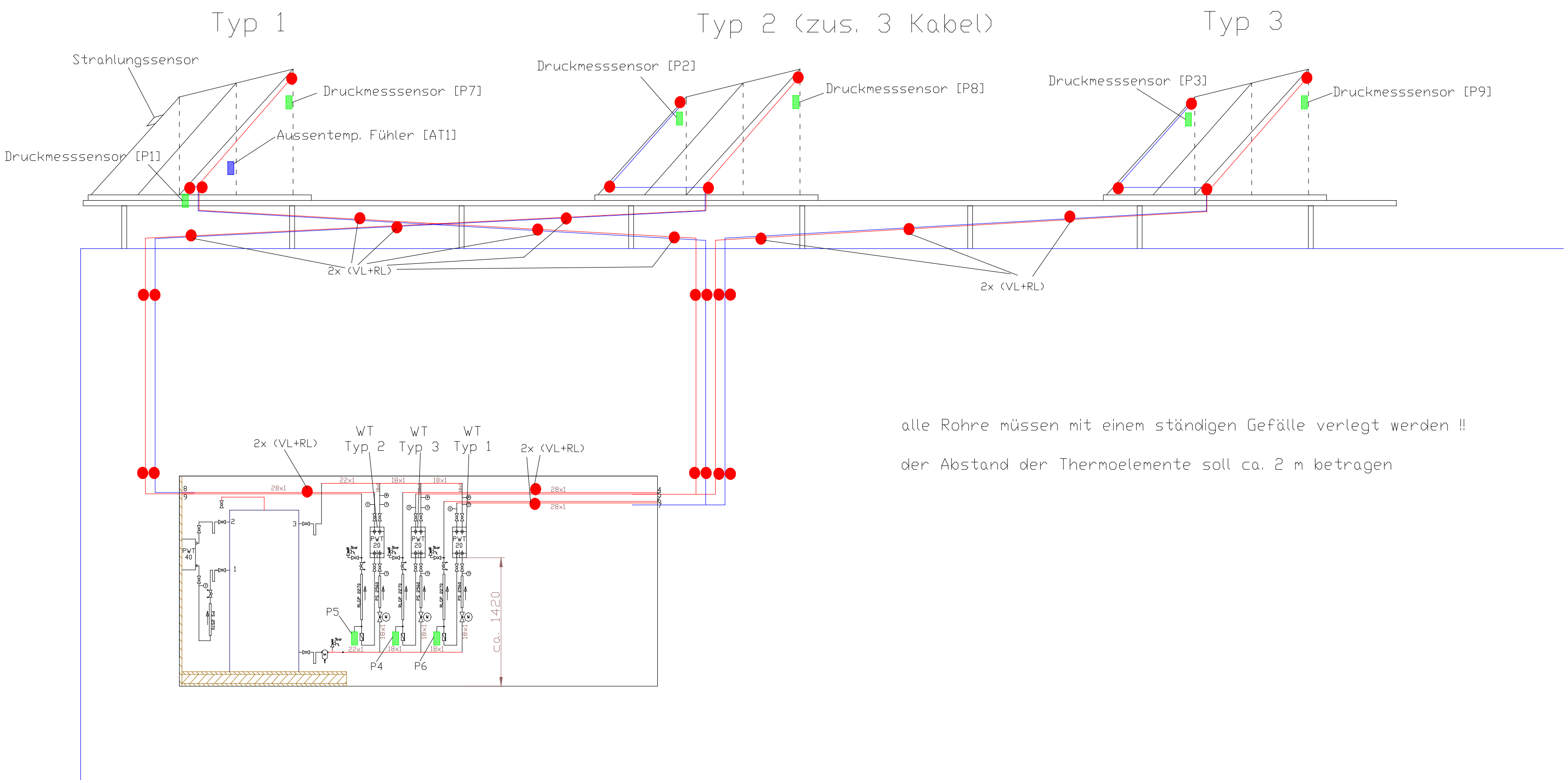
Test- und Versuchssystem mit eingezeichneten Messstellen



Geplanter Aufbau des Versuchs- und Testsystems

Stagnation behaviour – Test lab

Test system setup and positions of the sensors



Stagnation behaviour – Test lab

Test system: collectors

Stagnation behaviour – Test lab

Test system: Overall system

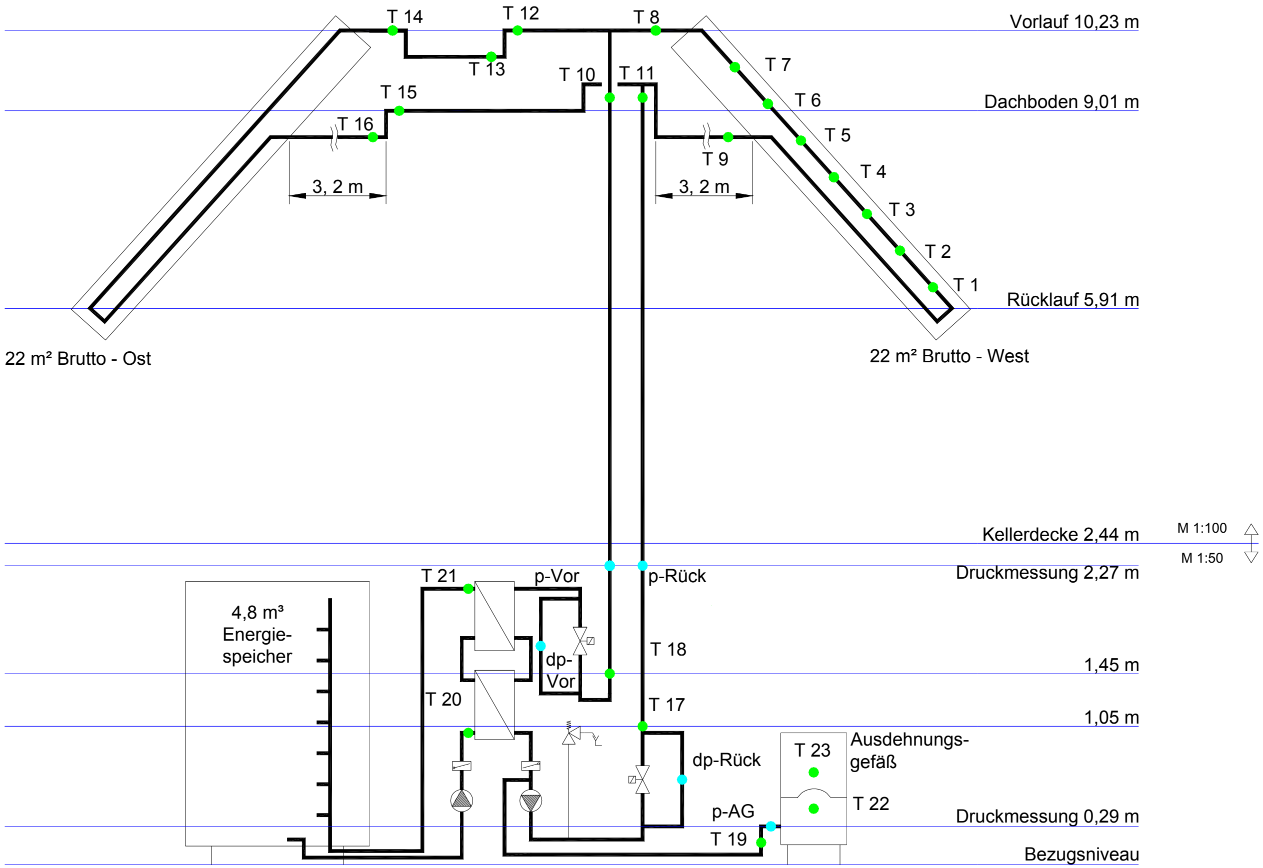
Stagnation behaviour – Test lab

Test system: Heat Exchangers and Expansion Vessels

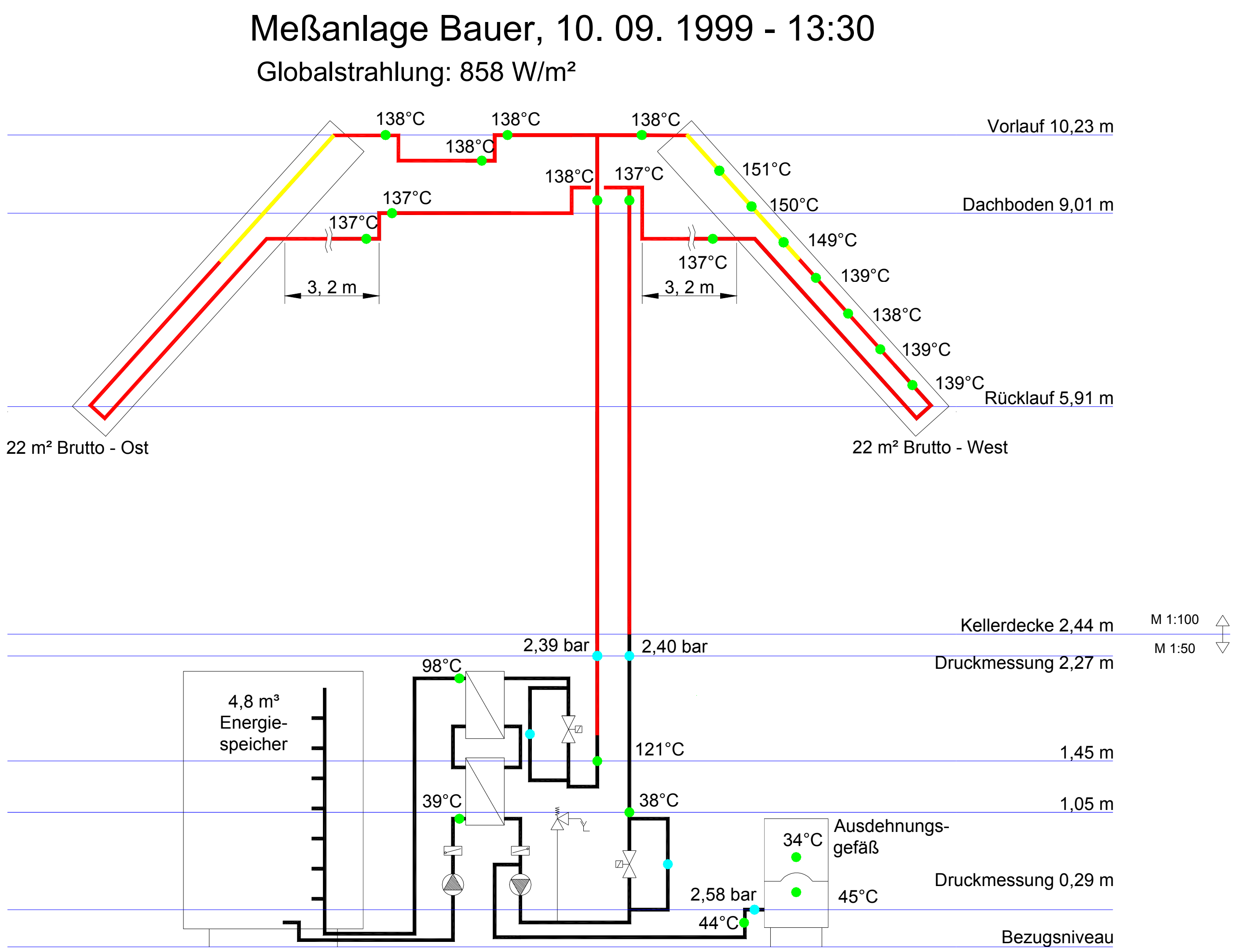
Stagnation behaviour – In situ Monitoring

Stagnation behaviour – In situ Monitoring

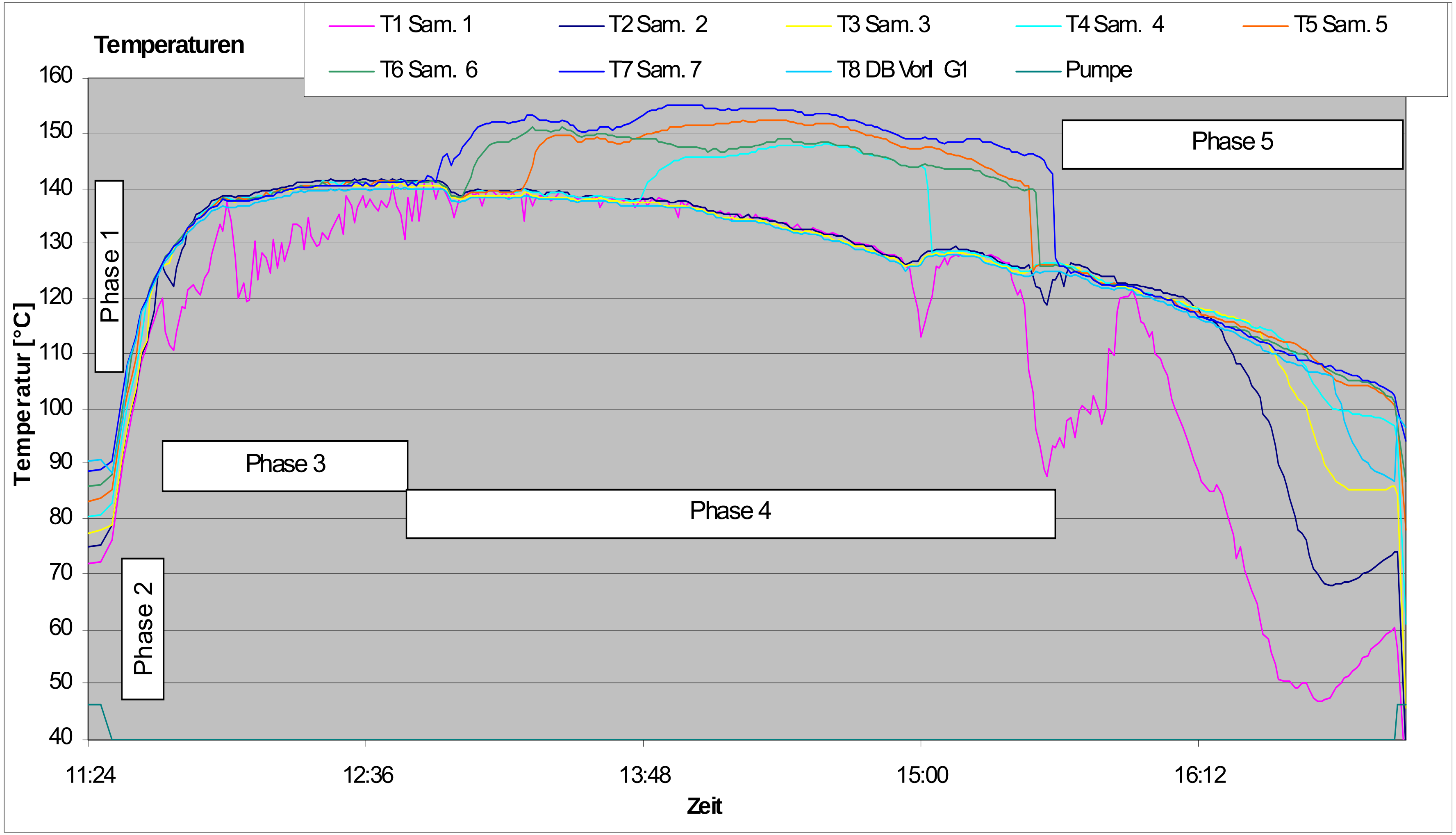
Meßanlage Bauer



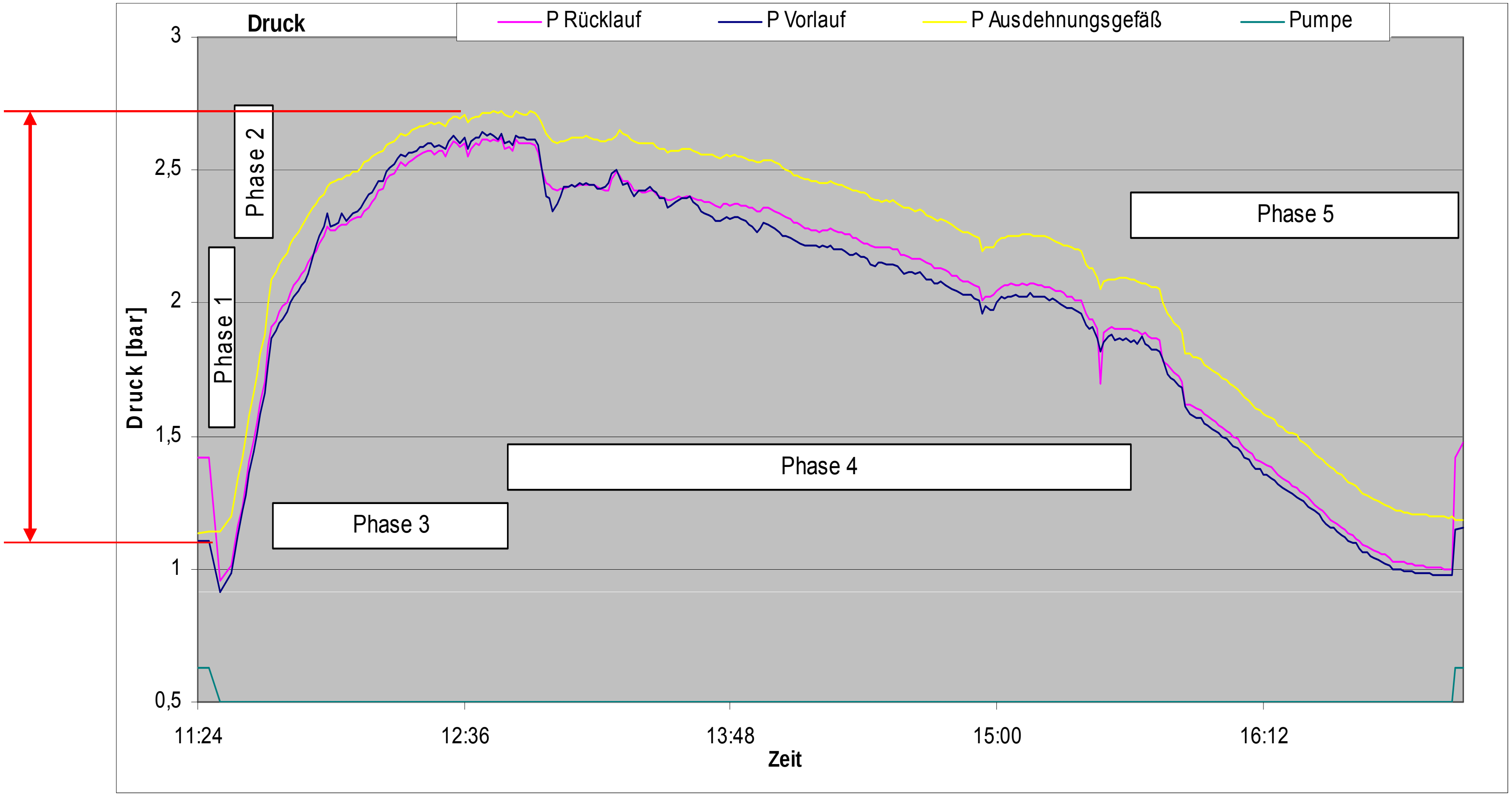
Stagnation behaviour – In situ Monitoring



Stagnation behaviour

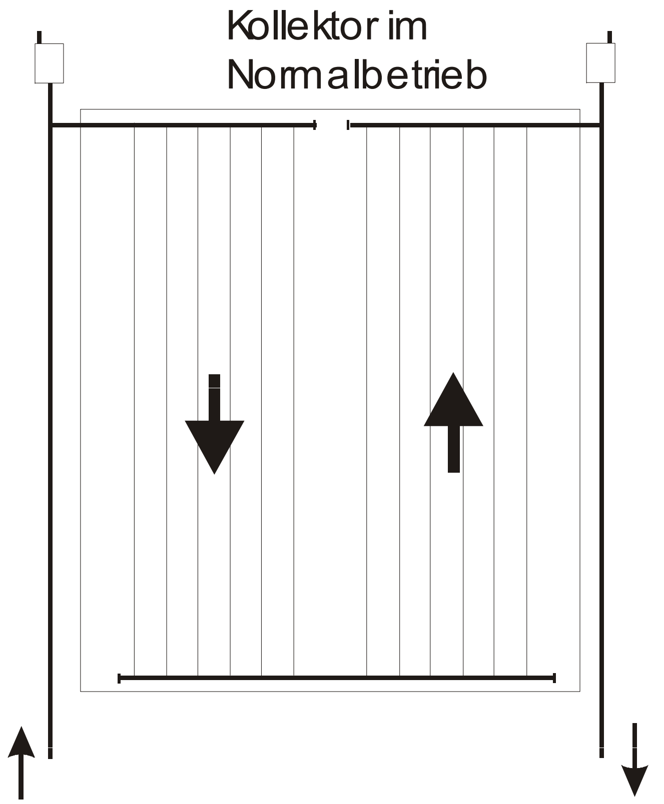


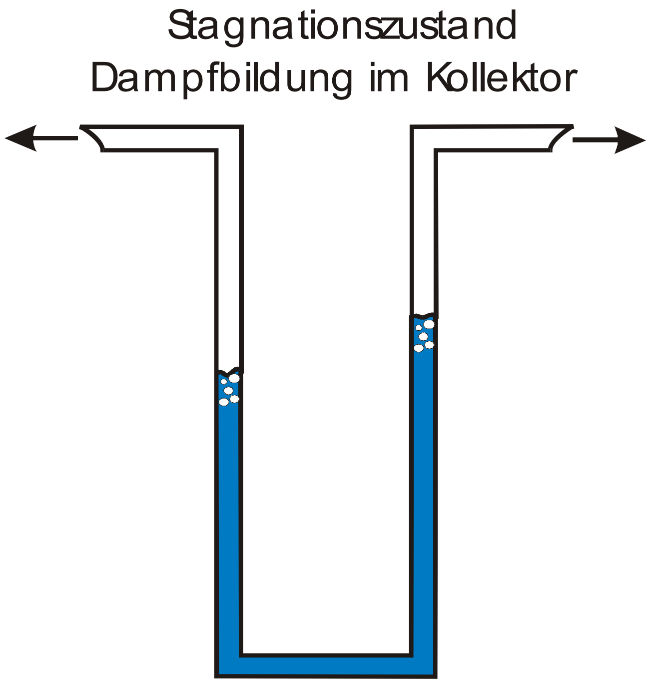
Stagnation behaviour



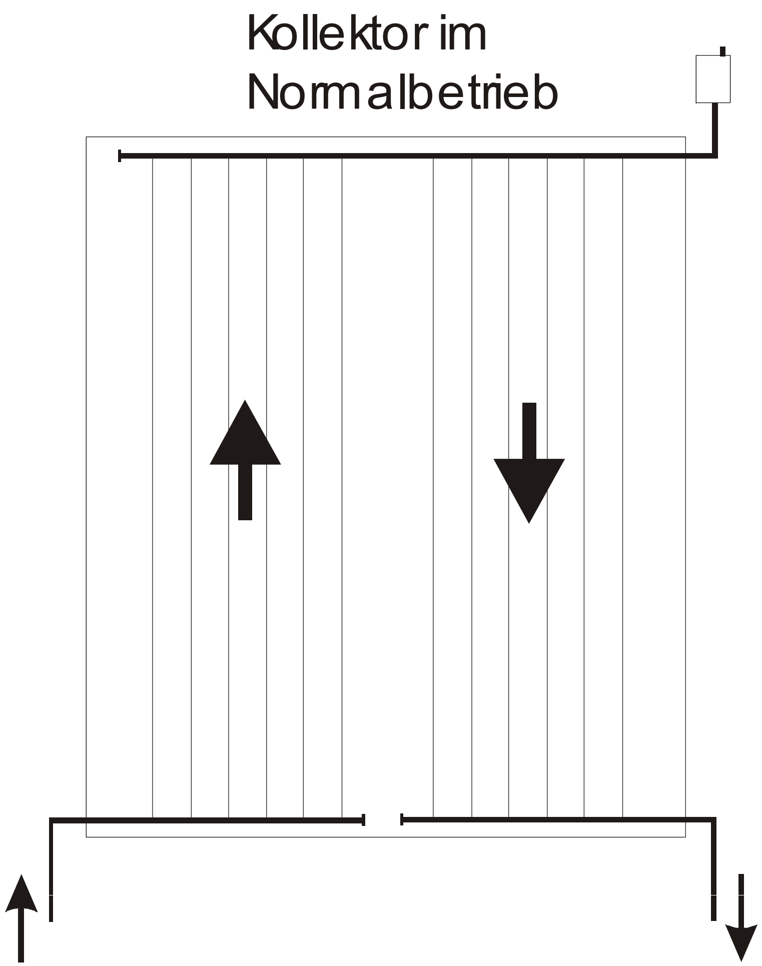
Collector with bad emptying behaviour

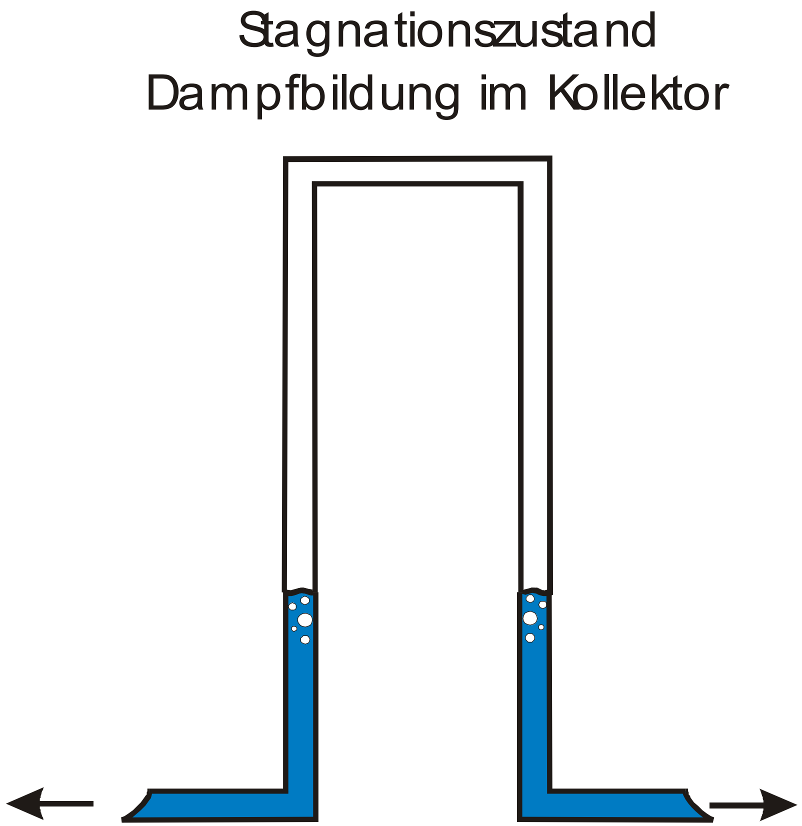
Kollektorverschaltung mit ungünstigem Entleerungsverhalten:



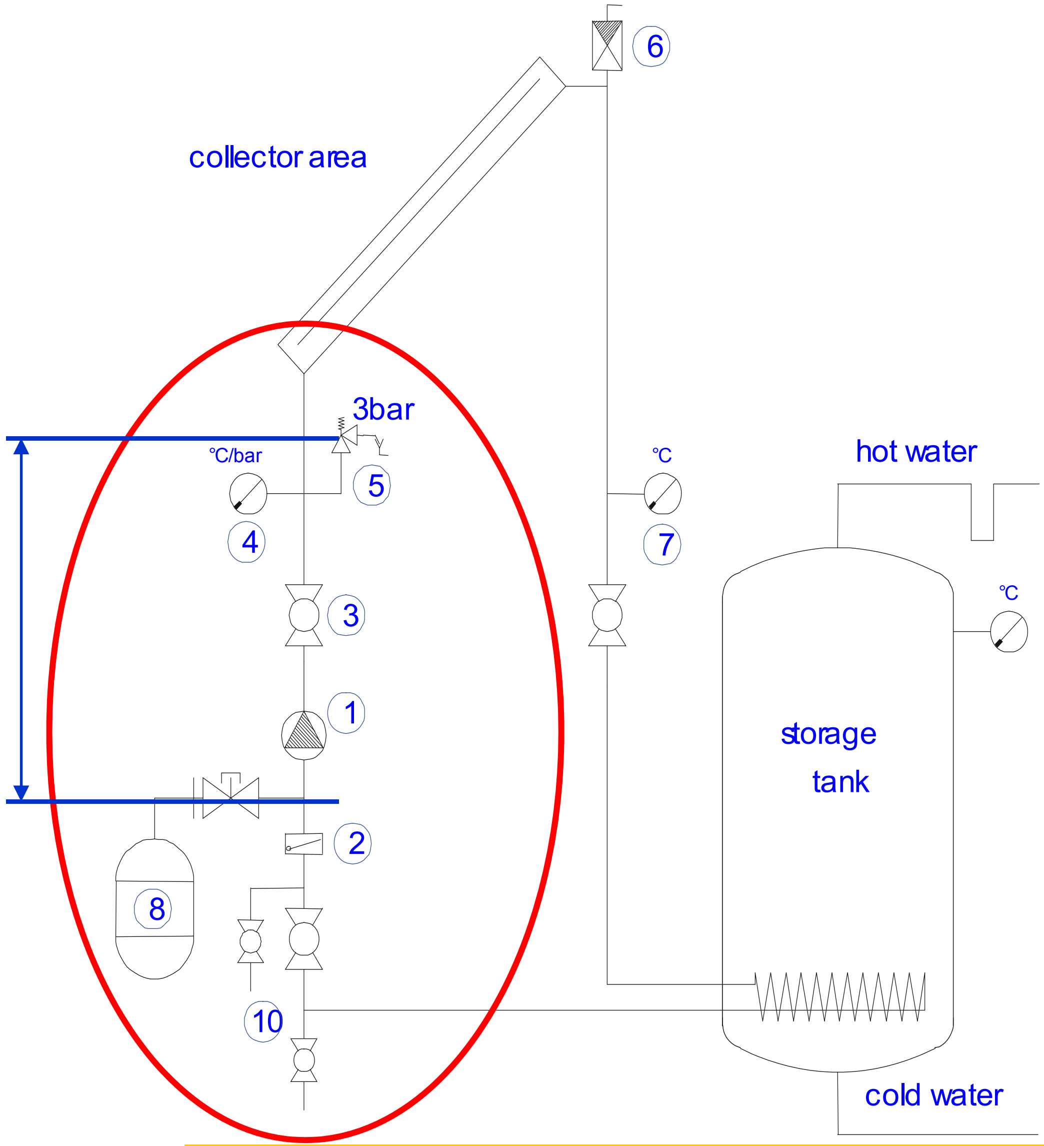


Collector with good emptying behaviour



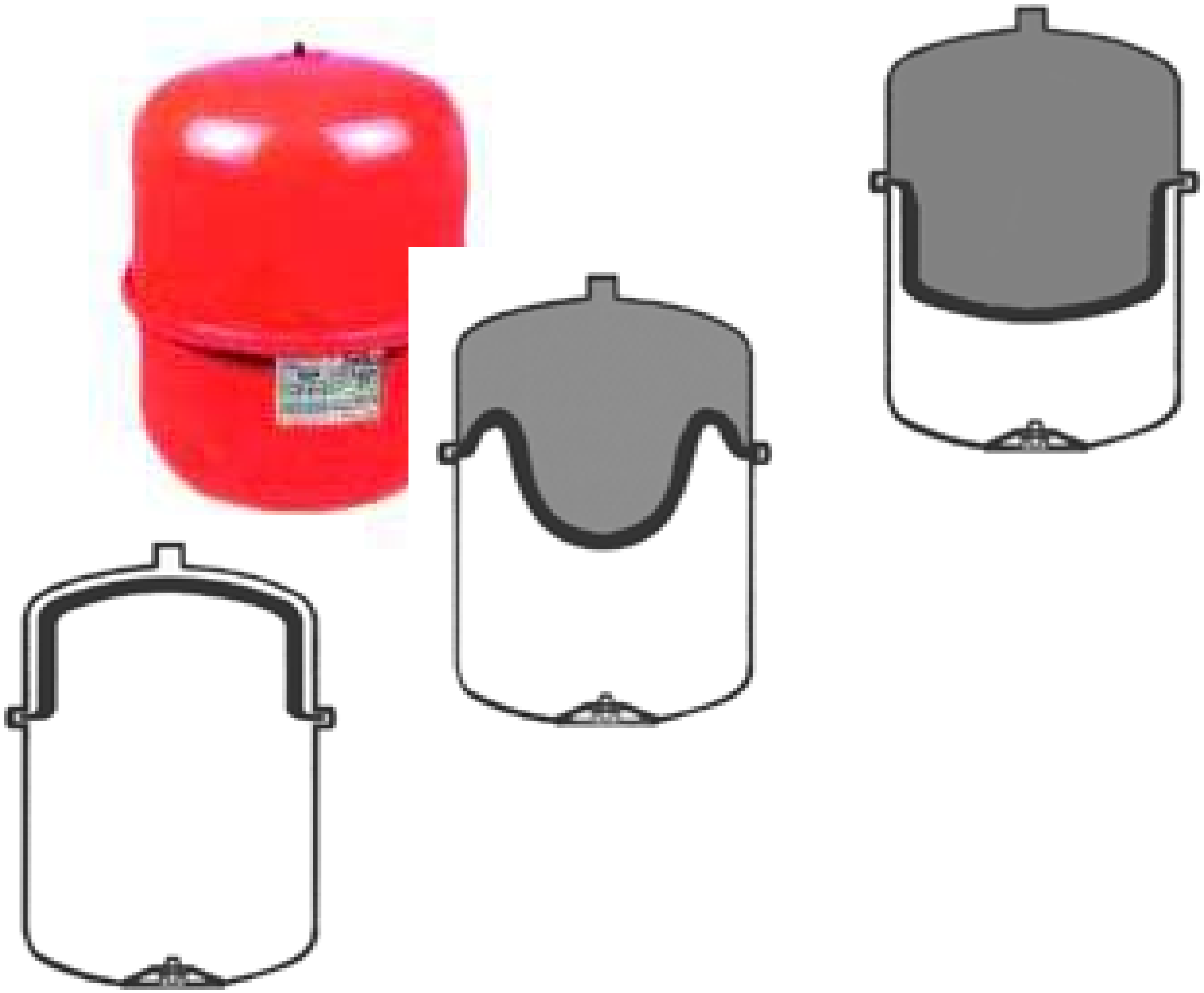


HYDRAULIC SCHEME OF A SOLAR HOT WATER SYSTEM

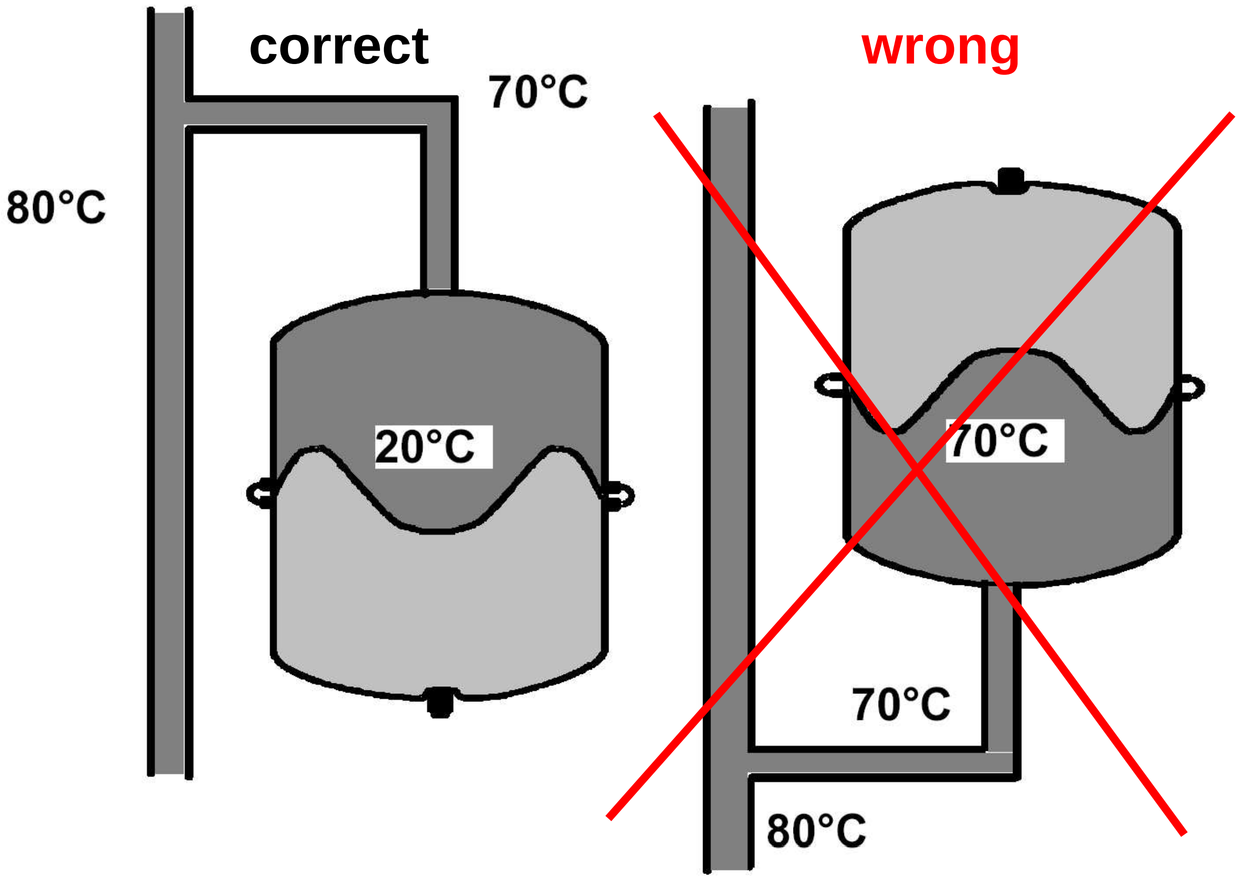


1. circulation pump
2. gravity brake
3. lock valve
4. thermometer and pressure gauge
5. pressure relief valve
6. escape valve
7. thermometer
8. expansion tank
9. fill and empty valve

EXPANSION VESSEL



EXPANSION VESSEL



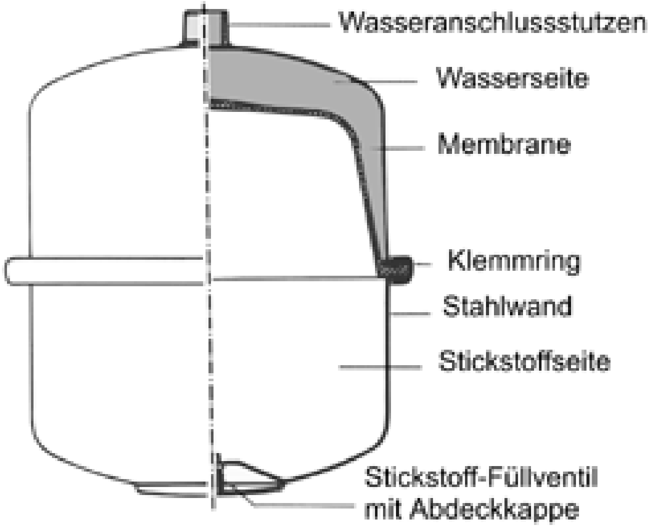
EXPANSION VESSEL

Mode of operation

In order to keep the increase in pressure in all cases of operation at least 20% below the responding pressure of the security valve the expansion vessel has to contain

1. the expansion volume of the heat transfer fluid
2. the overall vapour volume (VD) at the state of stagnation

General - MEV



Adjustment of the Nitrogen-pre-pressure

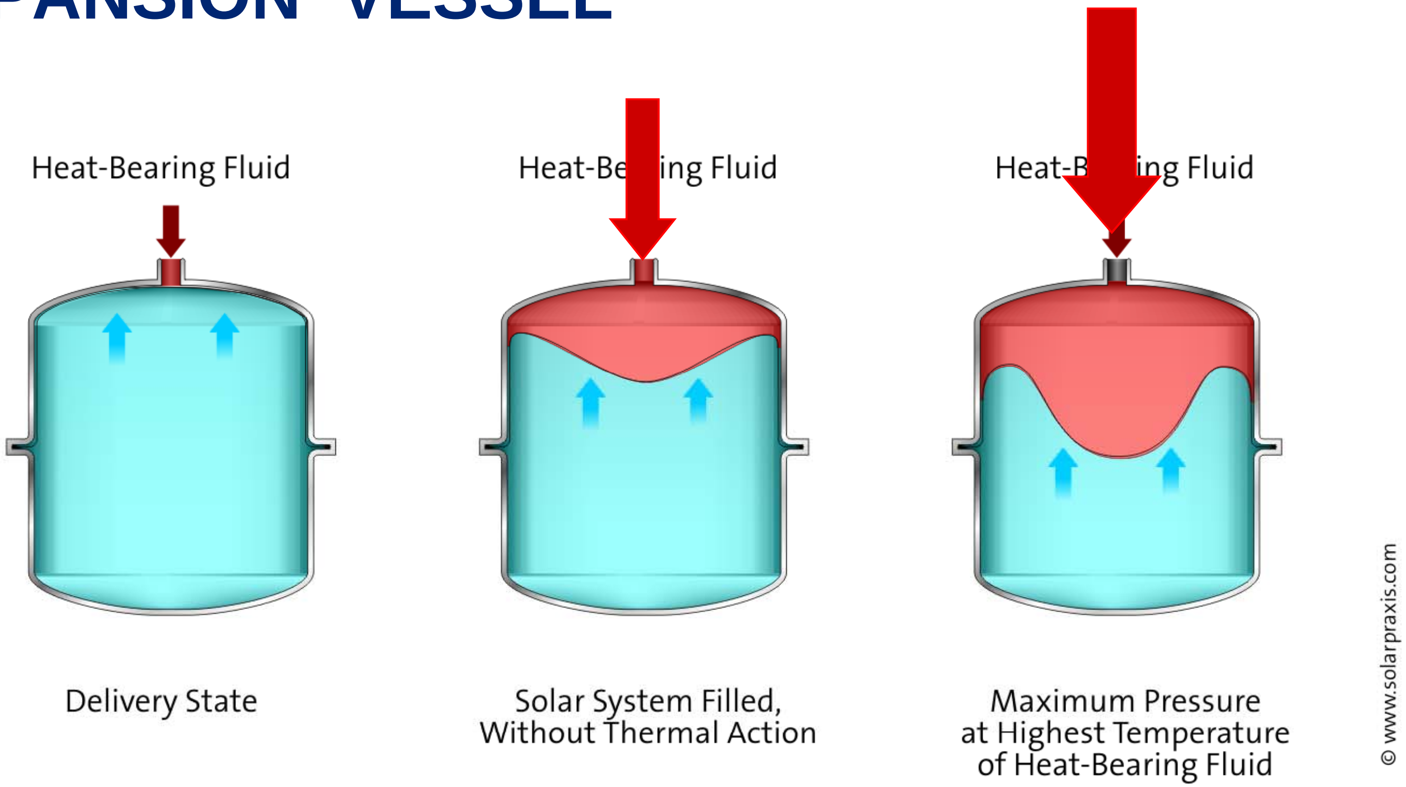
Annual check of the pressure

Hanging installation with not insulted copper pipe

Installation before the pump and after the non-return valve

Membrane has to be resistant against glycol (anti-freeze fluid)

EXPANSION VESSEL

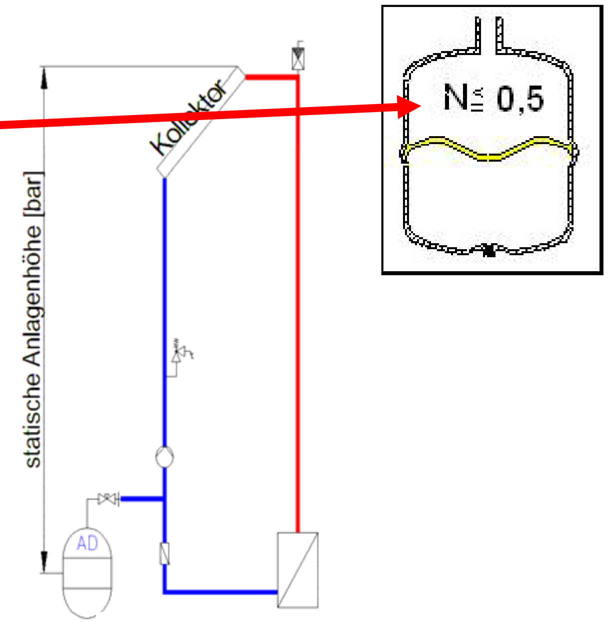


1) Delivery state
2) Normal working condition
3) Max. pressure (3 – 6 bar)

Terms for dimensioning

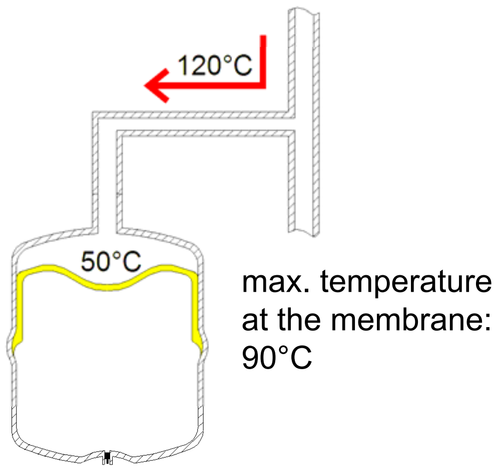
Efficiency (Nutzeffekt) **N**

Capacity of the MEV, which can be used without damage (over expansion) of the membrane



Primary pressure in the vessel P_0

Static height of the system plus 0.5 - 1 bar over pressure at the highest point of the system



Primary fluid (Gefäßvorlage) **V_V**

Reserve of fluid in case of a slight loss of pressure during air release

Dimensioning

Difference pressure P_{diff} [bar]
$H_{diff} = H_{MEV} - H_{SV}$ [m]
ρ Density of the heat transfer fluid [kg/m³]

$$P_{diff} = \frac{-H_{diff} \cdot \rho_{kalt} \cdot 9{,}81}{100.000}$$

MEV Efficiency N [-]
P_e = Pressure of the system [bar]
P_0 = Primary pressure in the MEV [bar]

$$N = \frac{P_e + P_{diff} + 1 - \frac{(P_0 + 1)}{0{,}9}}{P_e + P_{diff} + 1}$$

Coefficient of expansion n [1]

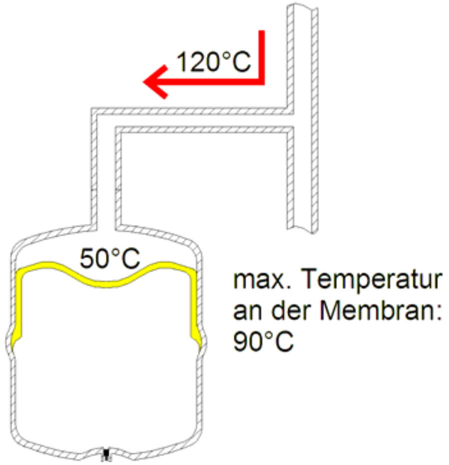
$$n = \frac{\rho_{kalt}}{\rho_{warm}} - 1 \approx 0{,}09$$

MEV Nominal volume V_N [l]
V_D = max. volume of vapour [l]
V_G = Total volume of the heat transfer fuid [l]
V_V = Primary fluid (Gefäßvorlage) [l]

$$V_N > \frac{V_G \cdot n + V_V + V_D}{N}$$

Calculation of the Primary Fluid

$$V_V \geq V_K \cdot \frac{T_K - T_{max}}{T_{max} - T_V}$$



V_V	Primary fluid [l]
V_K	Volume of the collector [l]
T_K	Temperature of the collector fluid at the expansion vessel [°C]
T_V	Origin temperature of the primary fluid in the MEV [°C]
T_{max}	Max. permissible temperature in the MEV [°C] z.B. 90 °

!

Result: The volume of the primary fluid should correspond to the volume of the collector.

Example of calculation

Conditions:

- 10 m² collector area
- flow pipe V_L: 15 m Cu pipe 18x1
- return pipe V_L: 15 m Cu pipe 18x1
- safety valve: 6 bar
- pressure of the system: 2.5 bar
- primary pressure in the expansion vessel: 2.0 bar

1^{st} step : volume of the expansion vessel

$$V_N > \frac{V_G \cdot n + V_V + V_D}{N}$$

MEV	nominal volume V_N	litre
V_D	maximum vapour volume	litre
V_G	total volume of the heat transfer fluid	litre
V_V	primary fluid	litre
N	MEV efficiency	
n	coefficient of expansion of the heat transfer fluid	

2^{nd} step: Calculation of the MEV efficiency

$$N = \frac{P_e + P_{diff} + 1 - \dfrac{(P_0 + 1)}{0.9}}{P_e + P_{diff} + 1}$$

N	MEV efficiency	
Pe	nominal pressure of safety valve	bar
P_0	primary pressure	bar

3^{rd} step: Calculation of the MEV efficiency

$$P_{diff} = \frac{-H_{diff} \cdot \rho_{cold} \cdot 9.81}{100{,}000}$$

P_{diff}	pressure difference		bar
H_{diff}	H_{MEV}–H_{SV}		m
r	density of the heat transfer fluid	kg/m³	~1051 kg/m³

3rd step: Calculation of the MEV efficiency

$$P_{diff} = \frac{0.5 \cdot 1051 \cdot 9.81}{100,000} = 0.052 bar$$

	P_{diff}	pressure difference	bar
	H_{diff}	$H_{MEV} – H_{SV}$	m
r		density of the heat transfer fluid kg/m³	~1051 kg/m³

3rd step: Calculation of the MEV efficiency

$$N = \frac{P_e + P_{diff} + 1 - \frac{(P_0 + 1)}{0.9}}{P_e + P_{diff} + 1} = \frac{4.8 + 0.052 + 1 - \frac{(2.0 + 1)}{0.9}}{4.8 + 0.052 + 1} = 0.43$$

P_e = nominal pressure of safety valve – tolerance of respond (20 %)

P_e = 6 bar – 20 % = 4.8 bar

Pressure difference P_{diff} = 0.052 bar

Nominal pressure of safety valve P_e = 4.8 bar

P_o = 2.0 bar

4^{th} step: Calculation of the heat transfer fluid

$$V_G = V_{pipe} + V_{coll} + V_{heat\ exchanger} \qquad \text{litre}$$

Factor of expansion n

$$n = \frac{\rho_{cold}}{\rho_{hot}} - 1 \approx 0.99$$

0.45 l/ m²

$$V_G = \frac{0.16^2 \cdot \pi}{4} \cdot 300 + 4.5 + 2.0 = 12.5$$

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5^{th} step: Calculation of the primary fluid V_V

The volume of the primary fluid is more or less equivalent to the volume of the collector.

-> $V_V = V_{coll} = 4.5$ litre

6^{th} step: Calculation of the volume of vapour V_D

$V_D = V_{coll} + V_{pipe-vapor}$ litre

$V_{coll} = 4.5$ litre

Calculation of the volume of vapour in the pipes

Maximum vapour power = 10 m² * 50 W/m² = 500 W

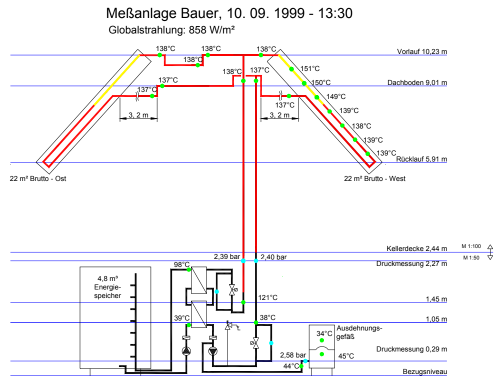
Vapour Power:

Good draining collectors: 50 W/m²

Bad draining collector: 120 W/m²

6th step: Calculation of the volume of vapour V_D

Calculation of the reach of the vapour in the solar pipes $V_{pipe\text{-}vapor}$ (calculation through the thermal power loss of the pipes):



thermal power loss of the pipe: 25 W/m

(reach of vapour in the pipe) =
(max. vapour power)/(thermal power loss of the pipe per meter of pipe)

(reach of vapour in the pipe) = 500/25 = 20 meter
16er Cu pipe

6th step: Calculation of the volume of vapour V_D

$$V_{pipe-vapour} = \frac{0.16^2 \cdot \pi}{4} \cdot 200 = 4.0$$

V_D = 4.5 + 4.0 = 8.5 litre

6th step: Volume of the expansion vessel

$$V_N > \frac{V_G \cdot n + V_V + V_D}{N} = \frac{12.5 \cdot 0.09 + 4.5 + 8.5}{0.43} = 32.8\,litre$$

Rule of Thumb

Nominal volume of expansion vessel [ltr.] = collector area x 3.5

$$V_N = a_{coll} \times 3.5$$

$$V_N = 10 \times 3.5 = 35 \text{ litre}$$

Heat Exchanger

Flat plate heat exchanger

Possibility of high pressures at operation

Principle of counter current

The high grades of turbulence leads to a self cleaning effect and subsequently to a minimization of costs and a longer lifetime

One plate heat exchanger can be used to load more than one heat storage tank

Disadvantages:

Like at all other external heat exchangers an additional pump is necessary on the secondary side of the heat exchanger

Flat plate heat exchanger

They are very compact compared with ordinary coil heat exchangers. They save about 85 to 90 % in volume and weight.

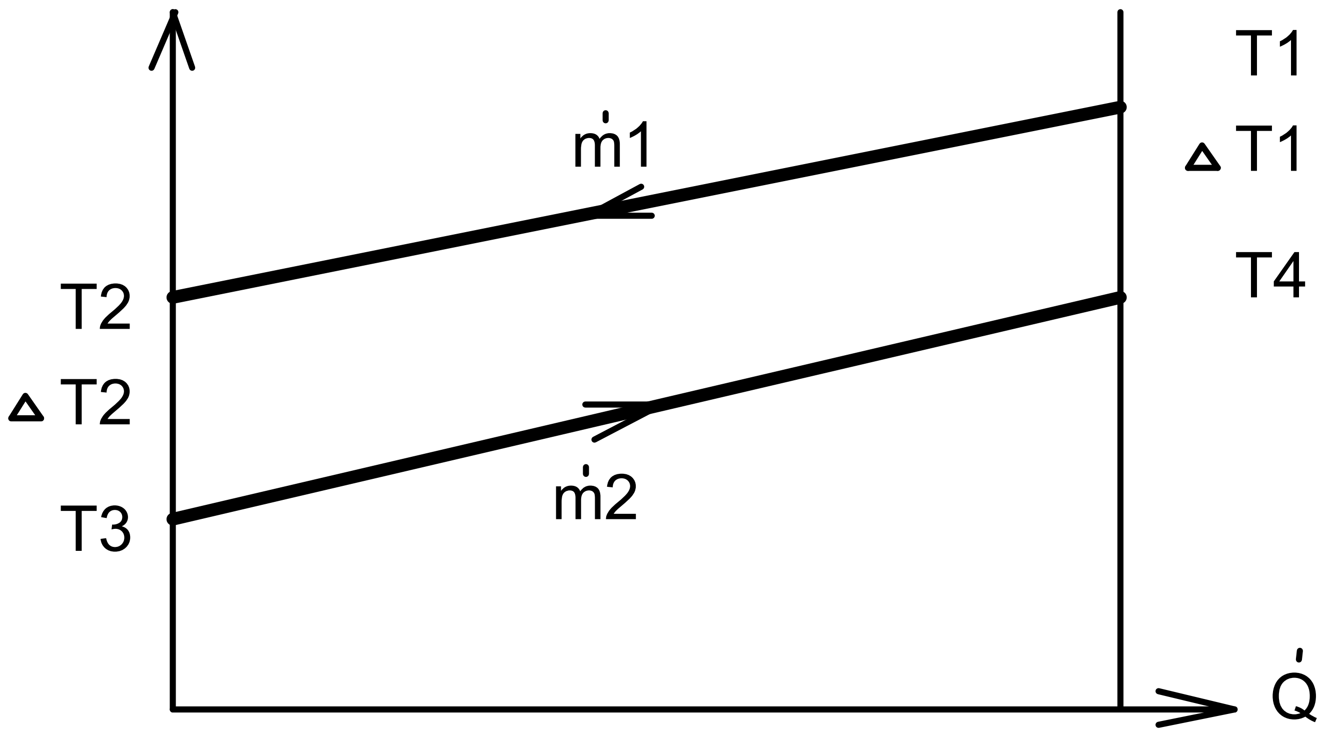
Maximum exploitation of the material: the capacity is 25 % higher as the capacity of screwed plate heat exchangers. The capacity is 10 times higher as the capacity of coil heat exchangers.

Less use of energy because of a better heat transfer coefficient and subsequently a better temperature difference

Heat transfer still at a temperature difference of 1 K

Design of Flat plate heat exchanger

Temperature difference of a heat exchanger shown in a -T-diagram

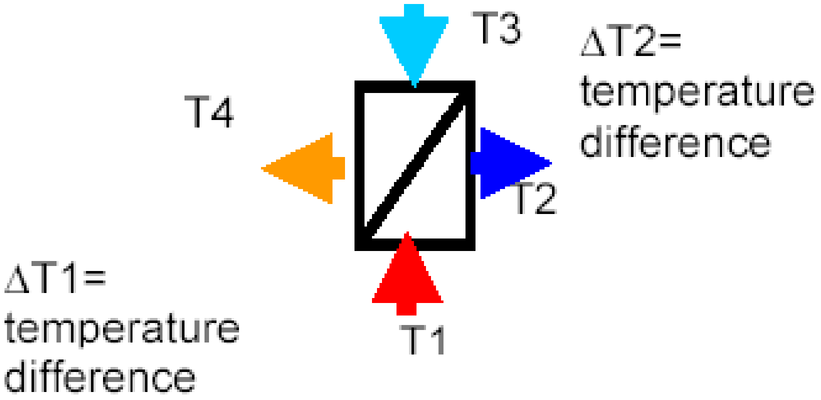


Design of Flat plate heat exchanger

$$\dot{Q} = \dot{m}_1 \cdot cp_1 \cdot (T_1 - T_2) = \dot{m}_2 \cdot cp_2 \cdot (T_4 - T_3)$$

$$\dot{Q} = U \cdot A \cdot \Delta T_{log}$$

$$\Delta T_{log} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$



Design of Flat plate heat exchanger

$\dot{Q}$	transferred power	W
$\dot{m}_1, \dot{m}_2$	mass flow per second	kg/s
c_{p1}, c_{p2}	specific heat capacity	kJ/kgK
T_i	temperature of the media	°C
U	heat transmission coefficient of the heat exchanger W/m²K	
A	heat transfer area	m²
DT_{log}	logarithmic temperature difference	K

Design of Flat plate heat exchanger

Plate heat exchangers reach u-values between 1000 and 2000 W/m²K (high power, low volume). Table 1 gives the necessary values in order to design a heat exchanger.

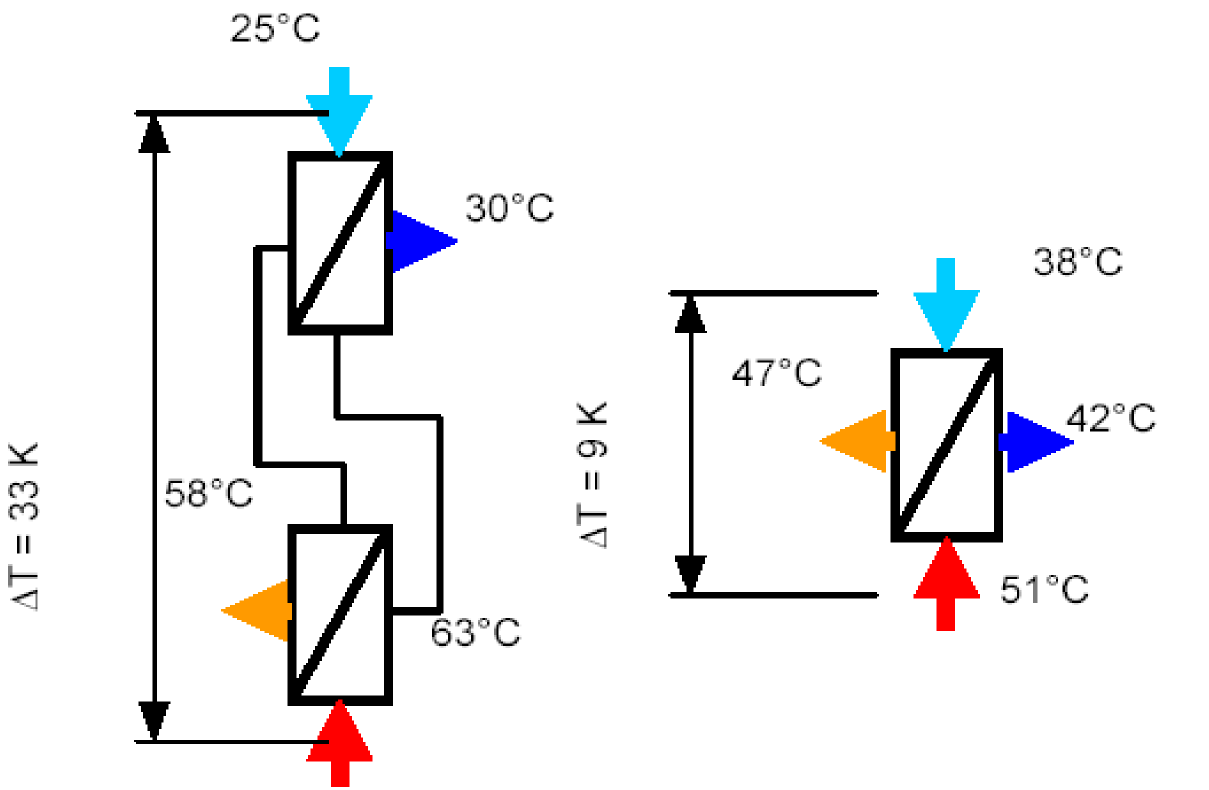
Data for design of heat exchangers

		Primary circuit	Secondary circuit
Media		propylenglycol/water	water
Concentration of the fluid	%	40	0
Temperature at entrance	°C	65	25
Temperature at exit	°C	32	60
Mass flow	kg/s	0.25	– *

*results from assumed data

Design of Flat plate heat exchanger

Low Flow | conventional



Secundary side: $\dot{m} = 1915 \frac{kg}{h}$ | $\dot{m} = 521 \frac{kg}{h}$

Design of plate heat exchanger

$P = \dot{Q} \cdot \eta_{coll} \cdot A_{coll}$	$= 0.8 \cdot 0.63 \cdot 40 = 20.2$ kW	kW
P	power of the collector	kW
$\dot{Q}$	maximum irradiance, assumed to 0.8 kW/m²	kW/m²
η_{coll}	collector efficiency, assumed to 0.63	
A_{coll}	gross collector area, 40 m²	m²

Design of coil heat exchangers

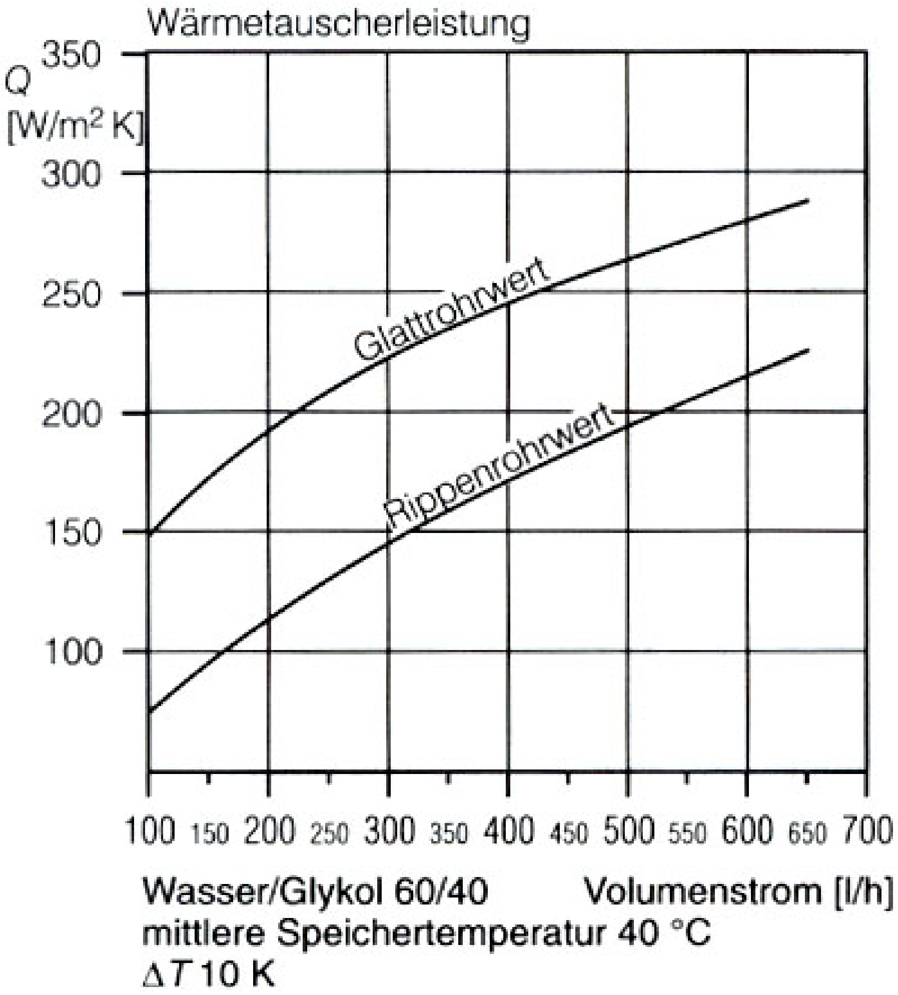
Smooth pipe heat exchanger:

approx. 0.2 m² heat exchanger surface per m² collector area

Finned tubes heat exchanger:

approx. 0.3 – 0.4 m² heat exchanger surface per m² collector area

Design of coil heat exchangers



General rules of thumb

Collector Area

1 m² collector area per person (bed, s…

Storage Capacity

70 litre storage cap… …ea

Heat Exch…

0.… …ea for smooth tube HX

0.… m² collector area for finned tube HX

80 – 90% annual solar fraction

Southern African conditions

Expansion Vessel

V_N = collector area x 3.5