Solar storage

- water storage
- PCM stores
- volume design
- stratification
- heat losses

Heat storage for solar thermal systems

irregular heat supply

irregular heat load

- during a day
- during a year

HEAT STORE = HEART OF SOLAR SYSTEM

highly efficient solar collector + inefficient store = inefficient system

Criteria

- storage density (capacity)
- size of storage (space demand)
- efficiency (loss, usability of storage - exergy)
- price
- lifetime
- safety
- ekology

Possibilities

on the market

- **storage of sensible heat**
  - stored energy proportional to temperature change
  - storage density: **100 to 300 MJ/m^3**
- **storage of latent heat**
  - use of phase change + sensible heat
  - storage density: **200 to 500 MJ/m^3**

under development

- **sorption storage**
  - storage of water (humidity) in solid (**ad**sorption) or liquid (**ab**sorption) component, sorption process = heat rejection, regeneration = heat supply
  - storage density: **500 to 1000 MJ/m^3**
- **storage with chemical reactions**
  - reversible chemical reaction with heat absorption and rejection
  - storage density: **1000 to 3000 MJ/m^3**

Sensible heat storage

$$Q = \int_{t_1}^{t_2} V \cdot \rho \cdot c \cdot dt = V \cdot \rho \cdot c \cdot (t_1 - t_2)$$

Working medium	Temperature range [°C]	Specific heat *c* [Wh/kg.K]	Density ρ [kg/m³]	Thermal capacity ρ.*c* [Wh/m³.K]
water	**0-100**	**1,16**	**998**	**1160**
air	-50-1000	0,28	1,1	0,31
oil	0-400	0,44-0,5	800-900	350-450
gravel, sand	0-800	0,2	1800-2000	360-390
granit	0-801	0,21	2750	570
concrete	0-500	0,24	1900-2300	460-560
brick	0-1000	0,23	1400-1900	330-440
iron	0-800	0,13	7860	1000
gravek-water (37% water)	0-100	0,37	2200	810

Water as a storage medium

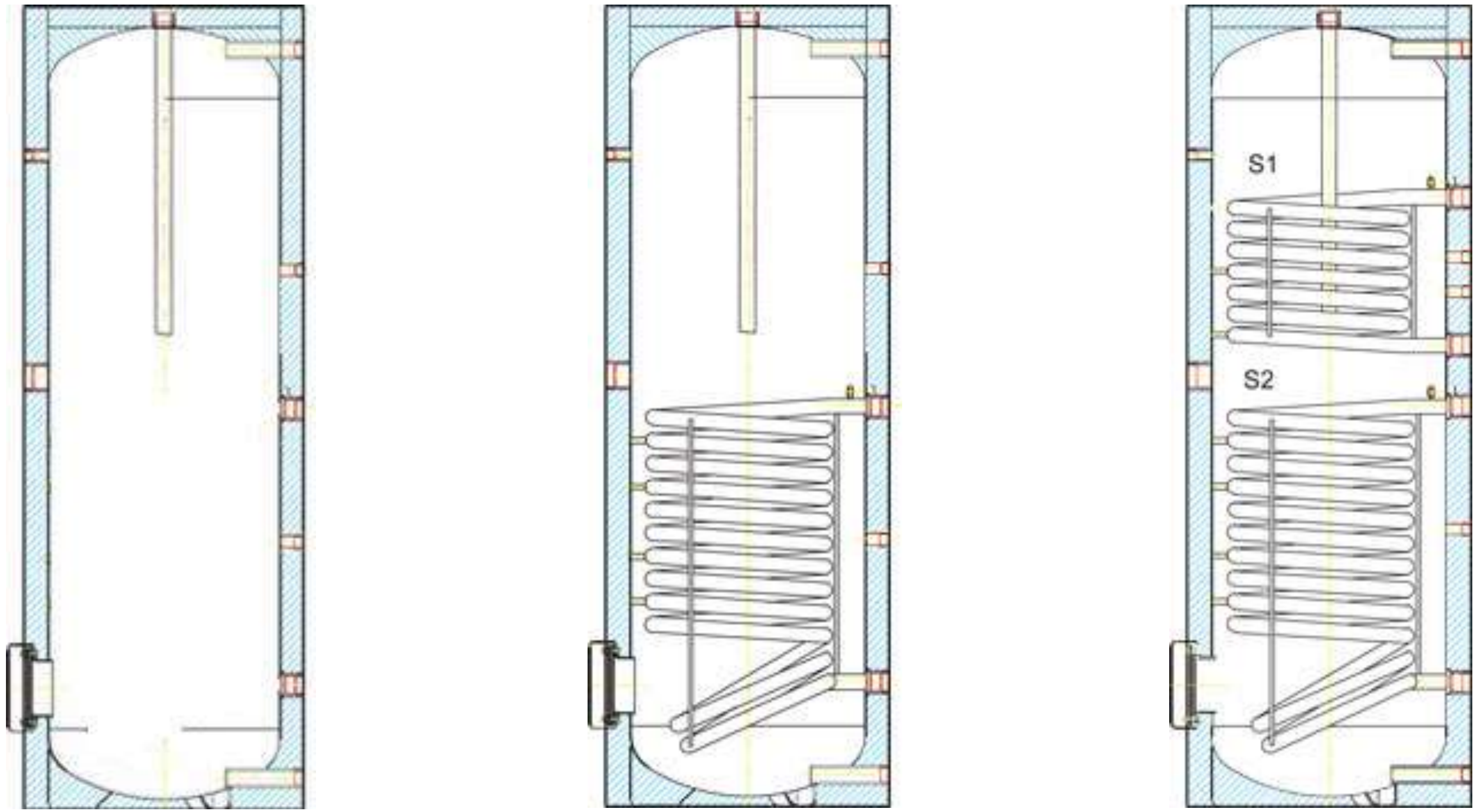
- available
- cheap
- non-toxic
- non-flammable
- good heat transfer (conductivity)
- high thermal capacity

- limited temperature range (0 to 100 °C)
- small surface tension (leaks)
- corrosivity

Water storage types

- **application**
  - hot water stores
  - heating water stores, heat stores, combistores
- **number of heat exchangers**
  - vessels (0), monovalent (1), bivalent (2), multivalent (...)
- **pressure**
  - pressurized
  - non-pressurized (free water level)
- **storage period**
  - short-term (daily)
  - long-term (seasonal)

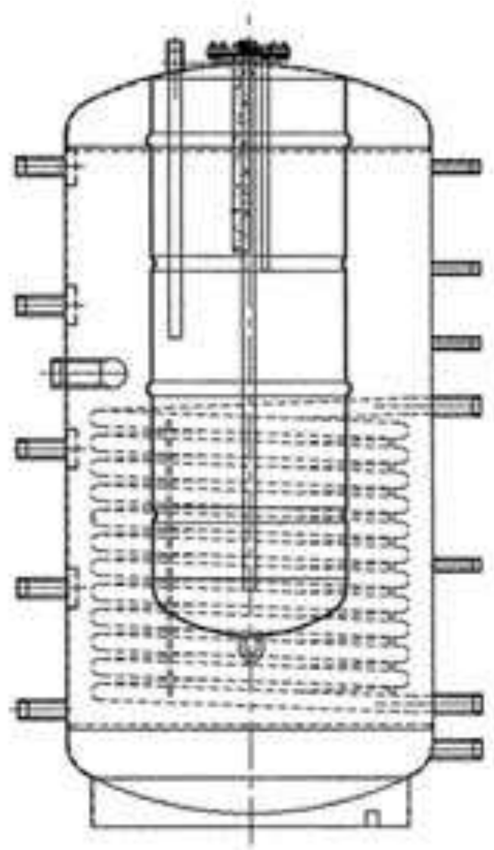
Hot water stores – heat exchangers



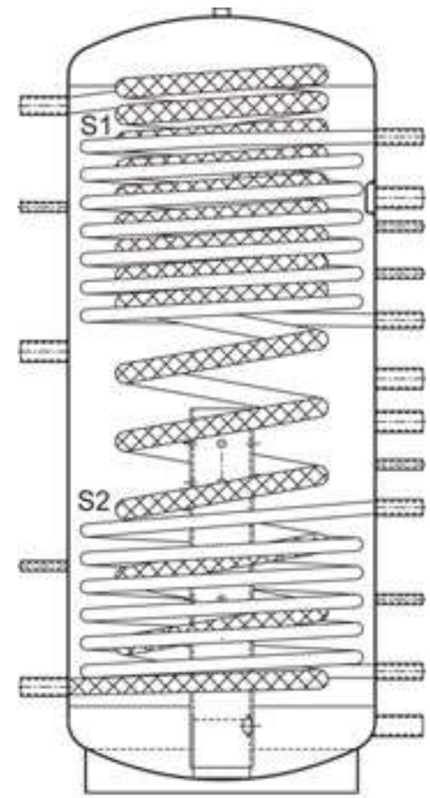
vessel monovalent bivalent

Combined tanks (HW + SH)

flow heat exchanger

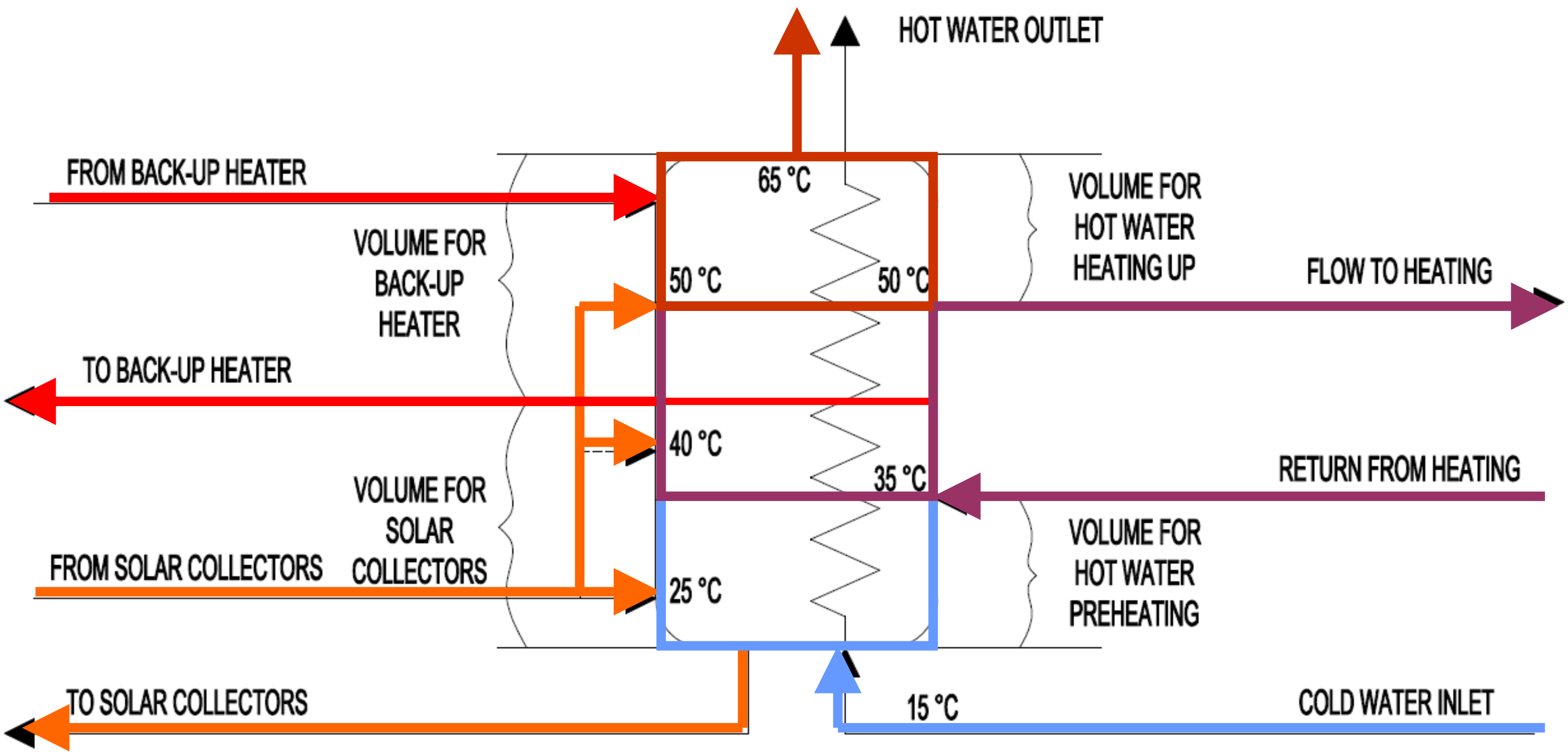


tank in tank



flow-tank heat exchanger

Combined tanks (HW + SH)

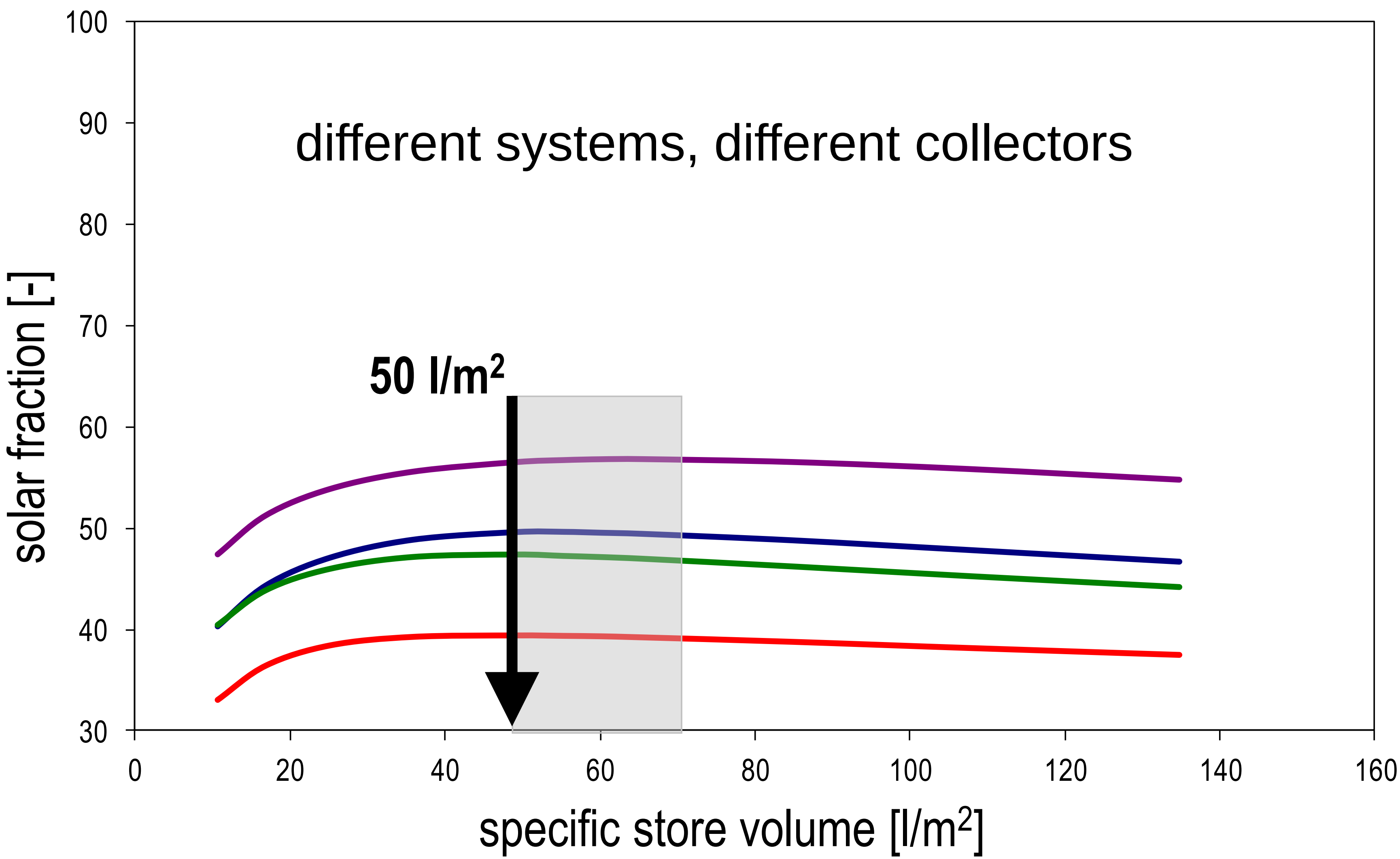


What size ?

- **domestic hot water**
  - **50 l/m²** collector aperture area

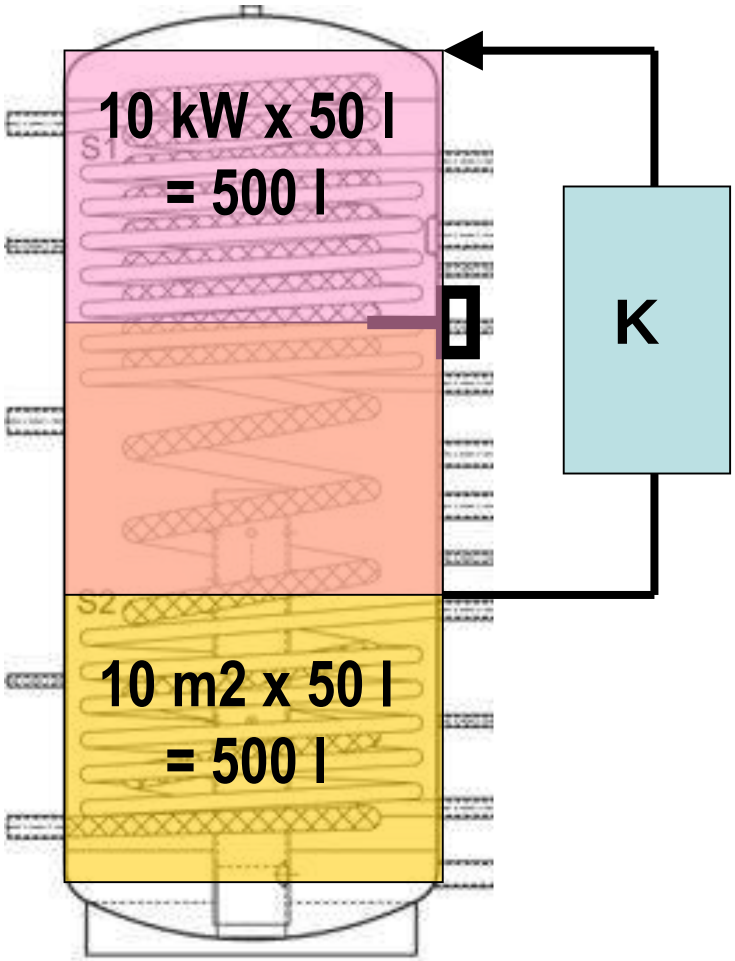
- **combined with heating**
  - **50 to 70 l/m²** collector aperture area
  - larger if backup heater supply heat into store
    - biomass boiler (logs) 50 l/kW
    - automatic biomass boiler (pellets) 25 l/kW
    - heat pump 15 to 30 l/kW
    - gas boilers 25 l/kW

Comparison of volumes

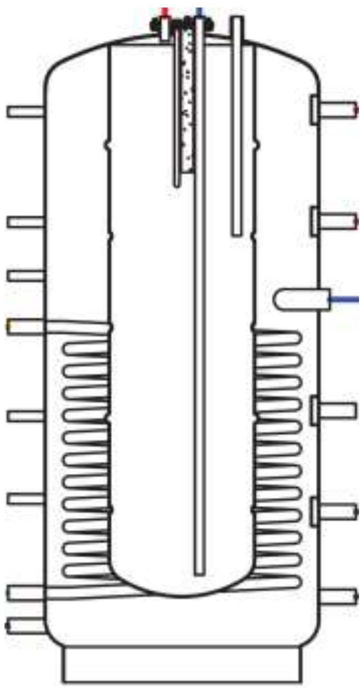
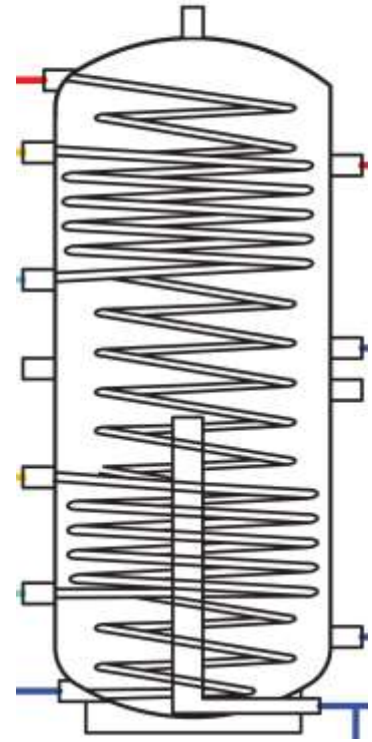


What size ?

- **solar combitank**
  - one for solar system and back-up
  - one for DHW and SH
- **example**
  - solar system 10 m^2
  - biomass boiler 10 kW
  - **2/3 volume = cca 500 l**
  - **storage size 750 l**



Which solar store ?

tank in tank	flow HX
	
small heat transfer area	more than 2x larger area
small loads	larger loads
1 – 2 persons	3 - 4 persons

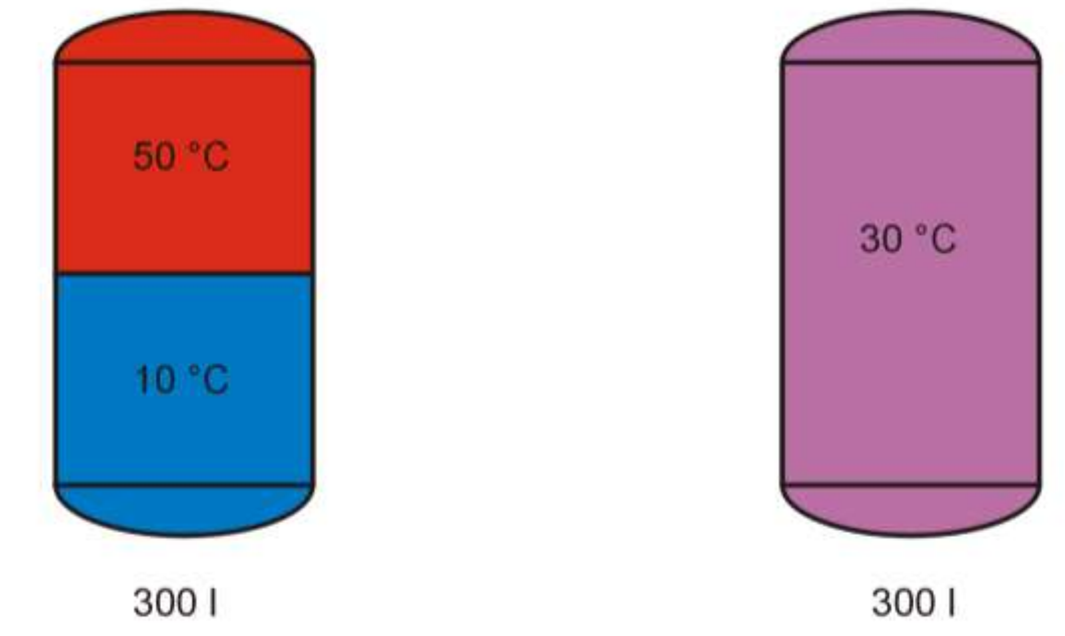
Exergy = usable energy (temperature)

stratified

mixed

150 l at 50 °C

150 l at 30 °C



thermal stratification = high efficiency, high solar fraction

Factors influencing stratification

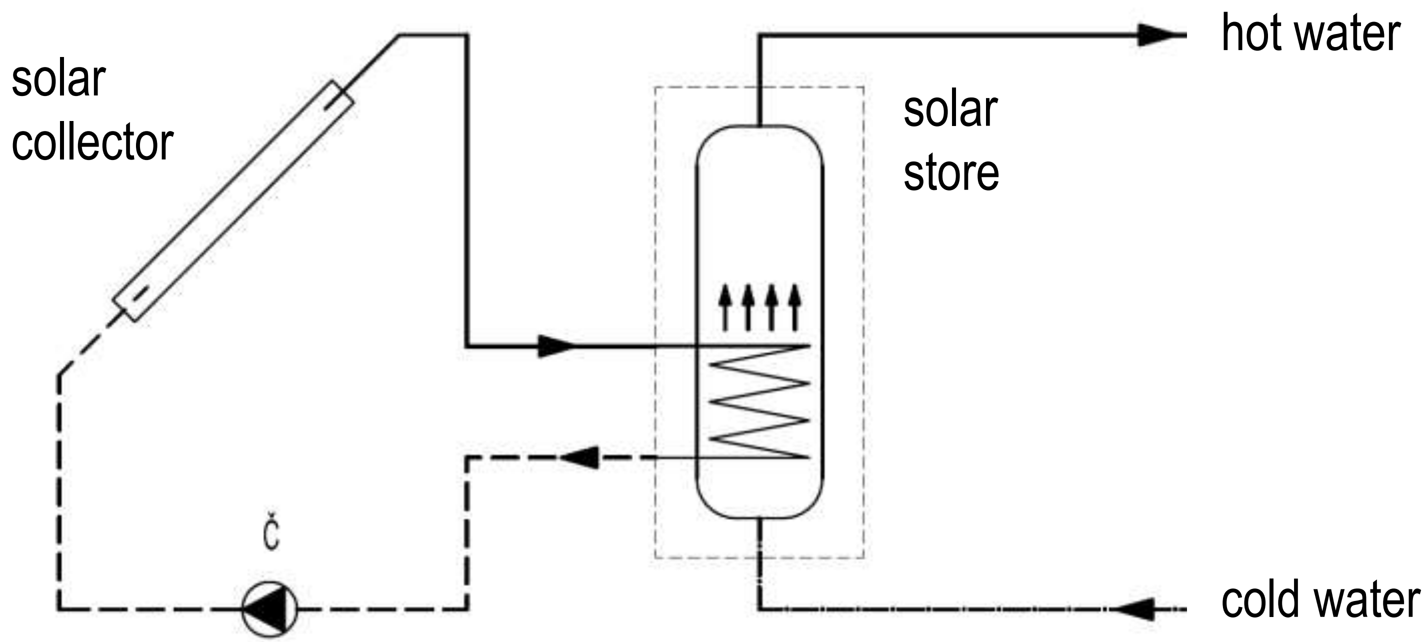
- aspect ratio: height / diameter
- heated water inlet
- hot water load
- cold water inlet
- heat losses
- vertical conduction in storage wall
- vertical conduction in water content

Influence of supply and load

indirect charge – direct discharge

small solar systems for hot water

heat exchanger in bottom part – collector efficiency, use of volume

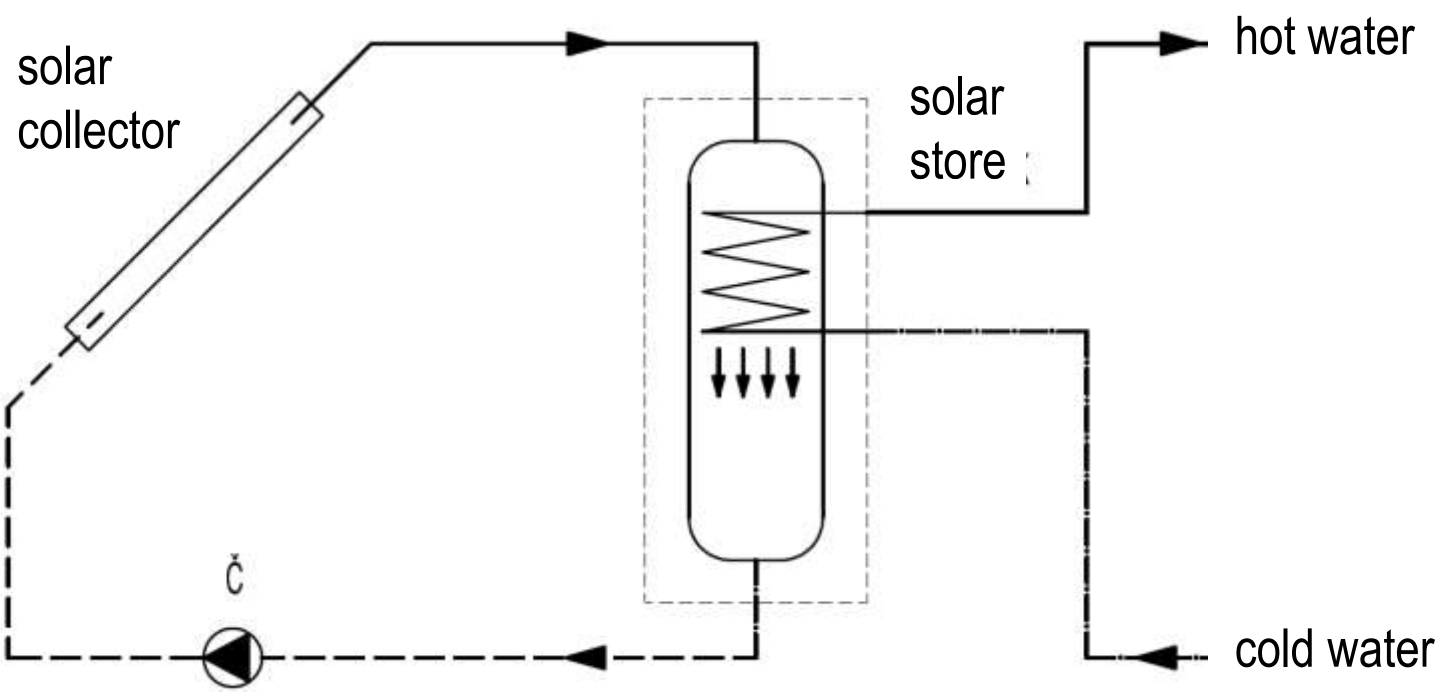


Influence of supply and load

direct charge – indirect discharge

larger solar systems with external heat exchanger (combisystems)

Fig: bad location of HW HX (obr), better to use full heigth

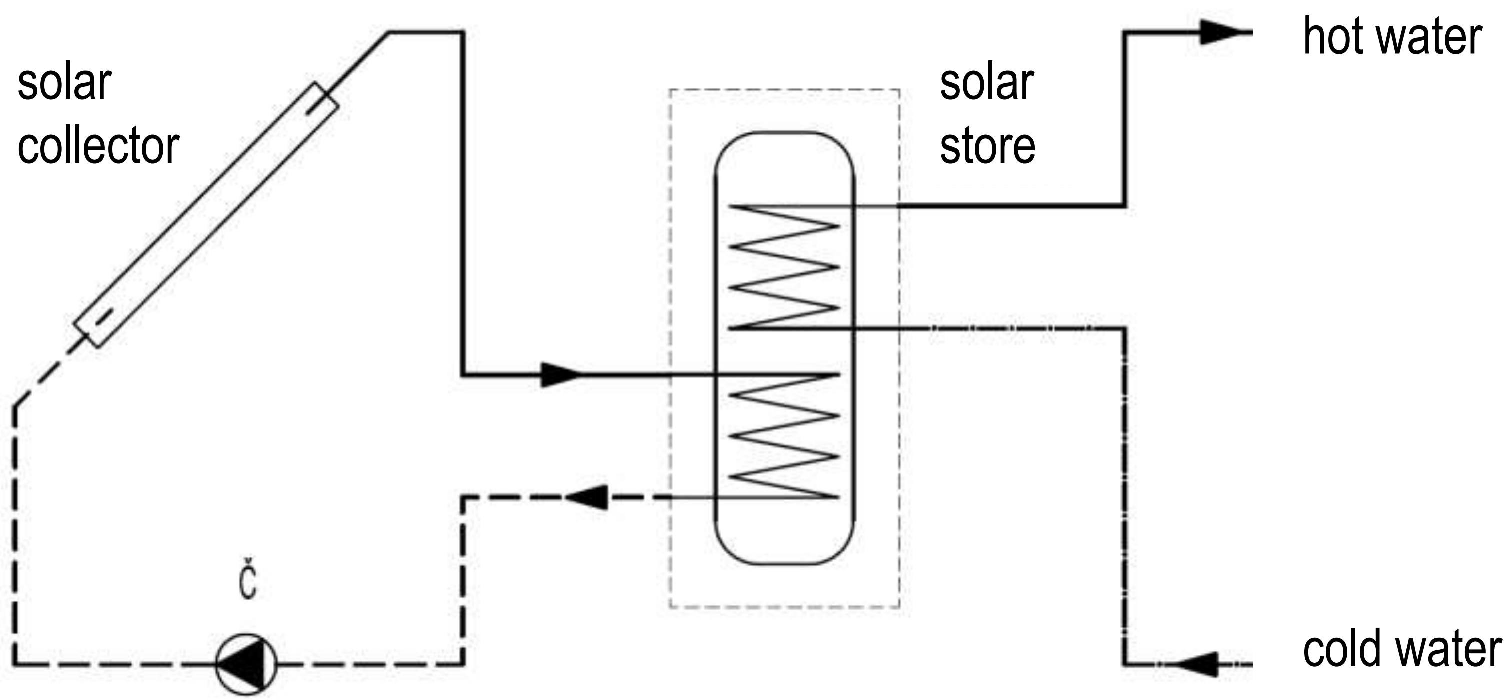


Influence of supply and load

indirect charge – indirect discharge

simple combisystems

large mixing effects

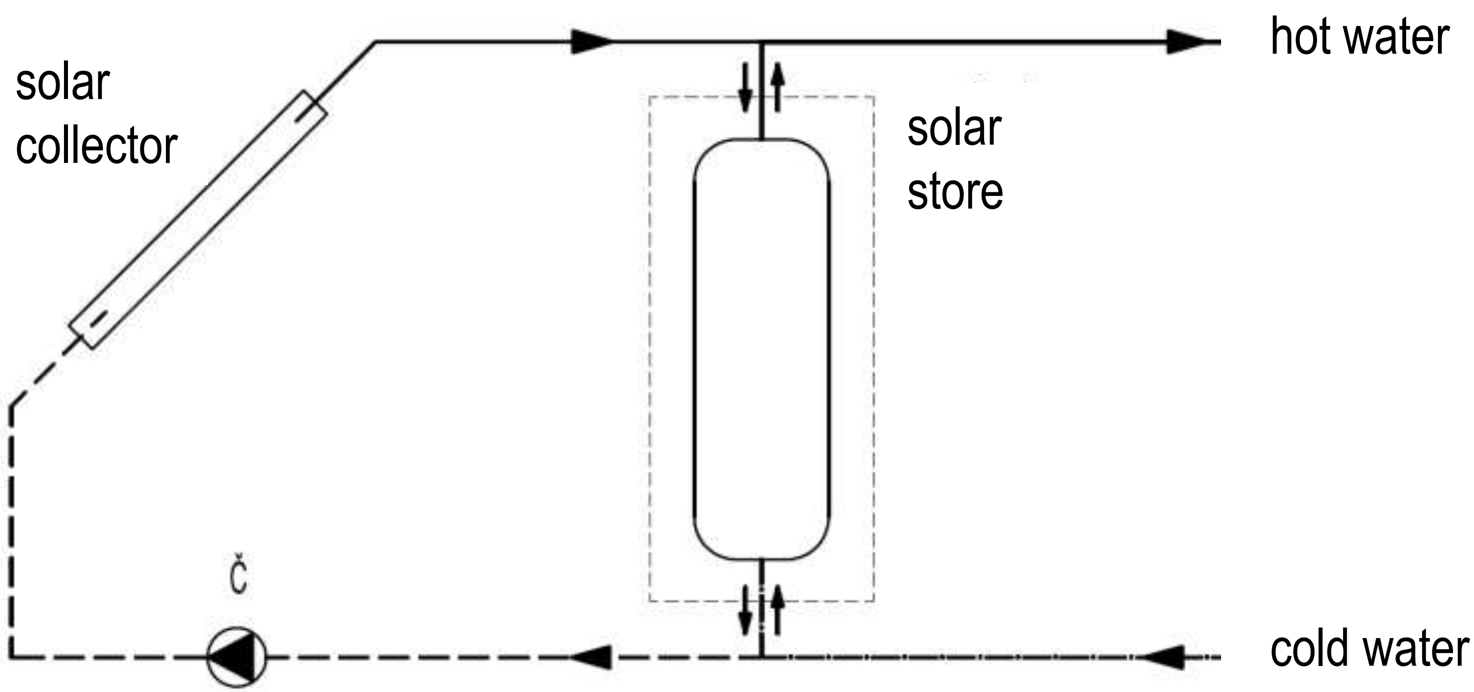


Influence of supply and load

direct charge – direct discharge

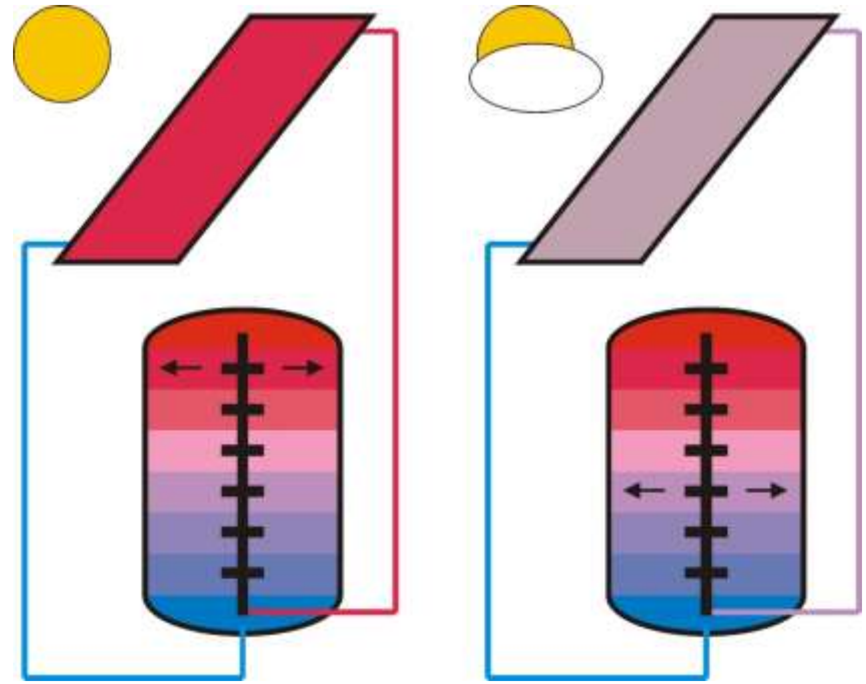
advanced storages with stratification devices

charging and discharging at layers (piston effect)



Heat storage with stratification

- **stratification** (thermal layering) of storage volume – heat storage to layers with same or similar temperature
- upper part with significantly higher temperatures than bottom part (cold until fully charged)
- reduction of back-up heating



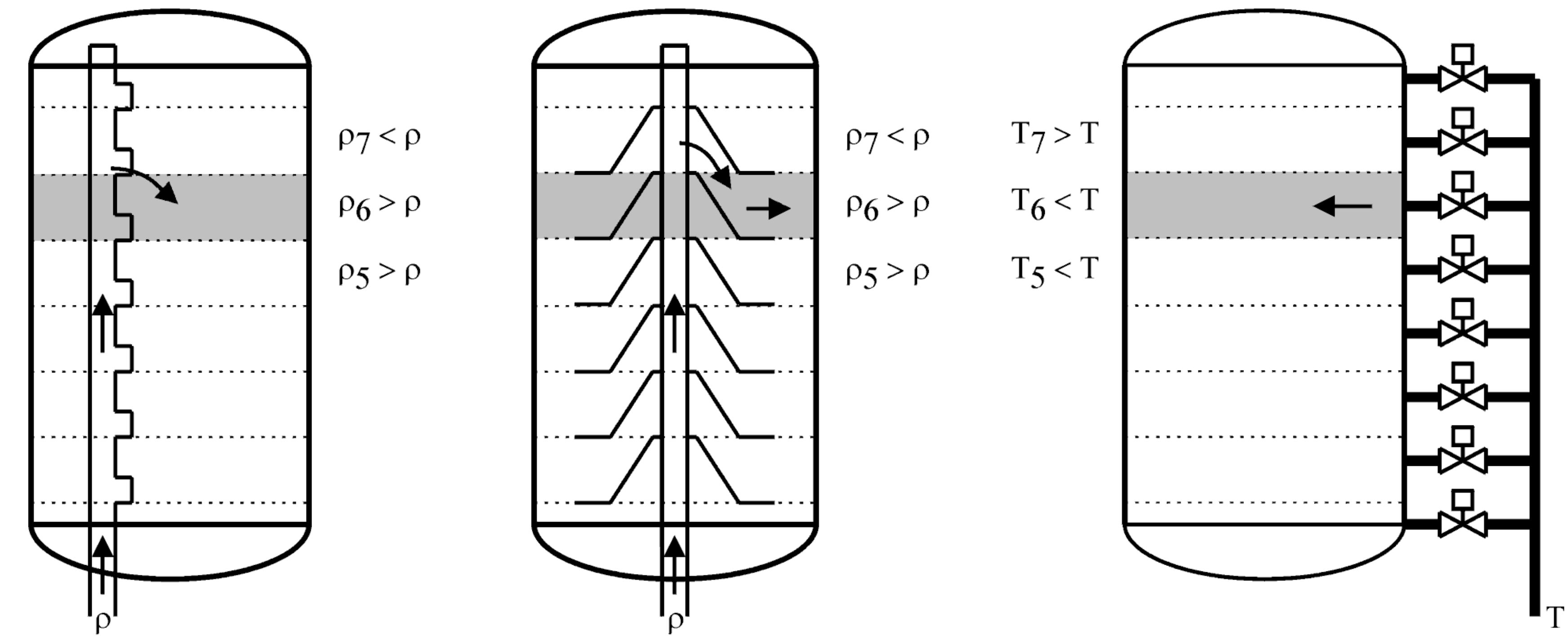
- increase of usable gains

increase of solar fraction

Stratified storage

- assumption: **low flow** to achieve higher temperature difference at solar collector (30 to 40 K)
- e.g. solar system control to constant collector output temperature, „once – through“ mode
- stratification devices
  - passive
  - active

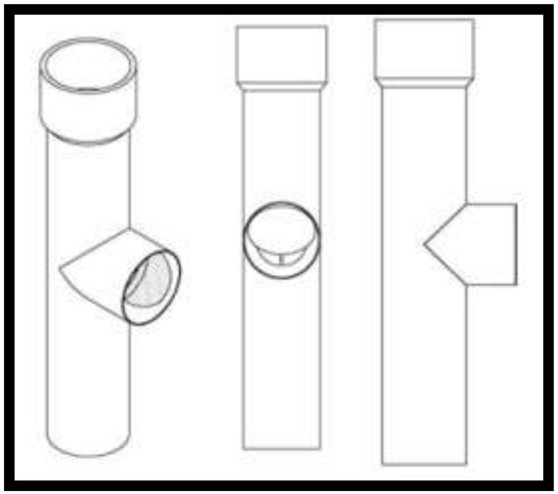
Controlled thermal stratification

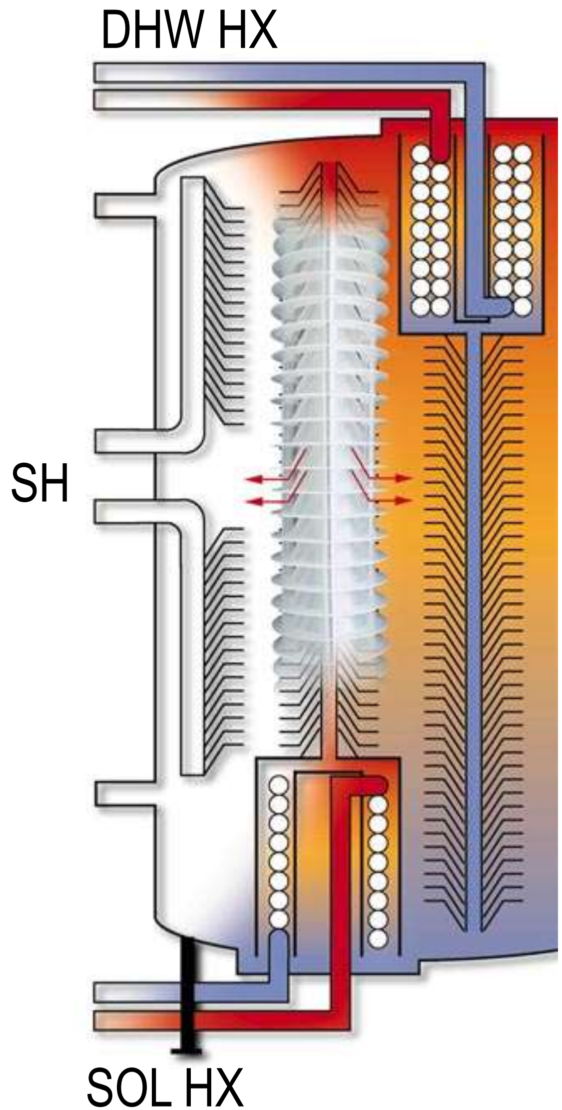


water enters the layer with similar density = similar temperature (passive)

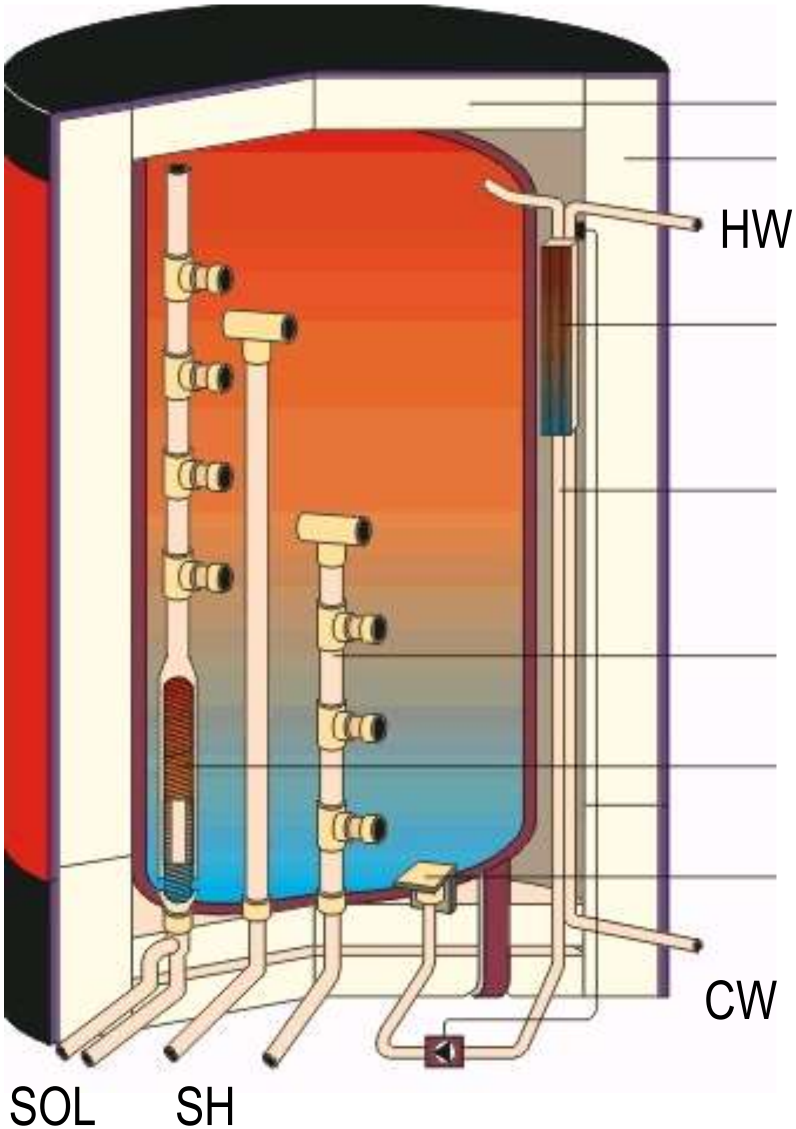
advanced control (active)

Stratification devices





Stratification devices



insulation

DHW heat exchanger

pipes

return water stratified (SH)

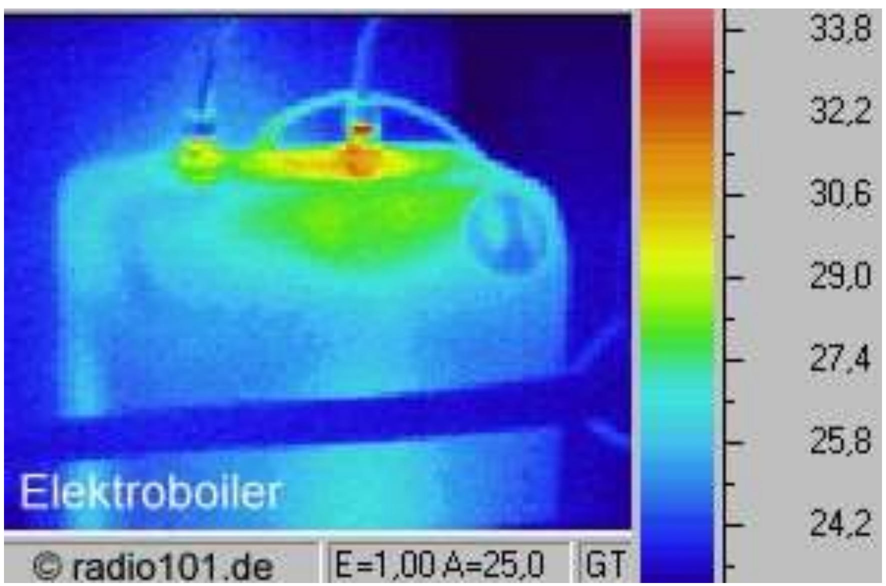
stratification device for solar collector loop integrating HX

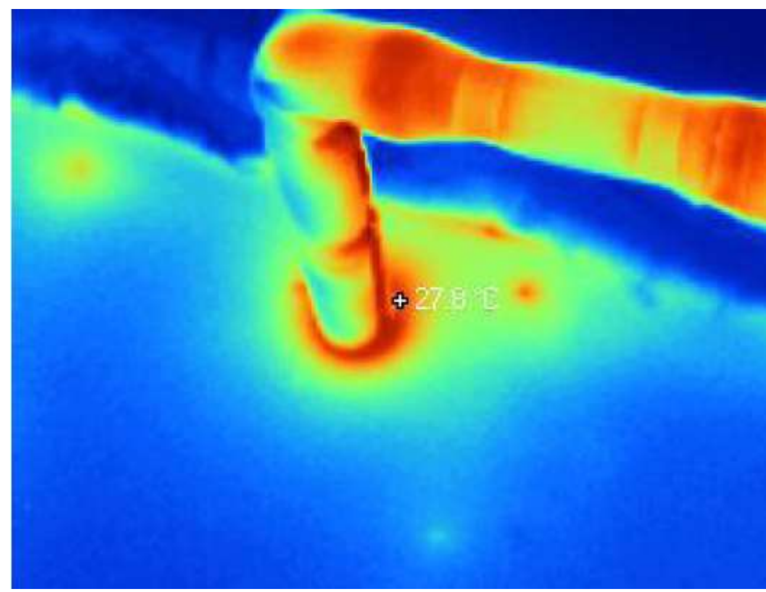
inlet of cooled water from DHW heat exchanger

source: Solvis

Heat losses

- influence storage effectivity
- thermal insulation
- pipe connections
  - thermal bridges, degradation of stratification





Heat loss of storage

- specific heat loss of cylindric storage tank *U.A* [W/K]

$$UA = \boxed{\frac{\pi\cdot(D_e+2\cdot s_{ins})\cdot(L+2\cdot s_{ins})}{\cancel{\frac{1}{\alpha_i}}+\frac{s_{ins}}{\lambda_{ins}}+\cancel{\frac{s_w}{\lambda_w}}+\frac{1}{\alpha_e}}} + \boxed{2\cdot\frac{\pi\cdot(D_e+2\cdot s_{ins})^2}{\cancel{\frac{1}{\alpha_i}}+\frac{s_{ins}}{\lambda_{ins}}+\cancel{\frac{s_w}{\lambda_w}}+\frac{1}{\alpha_e}}}$$

wall **2 x bottom**

D_e storage diameter (no ins); $D_e + 2.s_{ins}$ (with ins), L height

s_{ins} insulation thickness

λ_{ins} insulation conductivity

s_w wall thickness

λ_w wall conductivity

α_i heat transfer coefficient (liquid)

α_e heat transfer coefficient (ambient)

Heat loss of storage

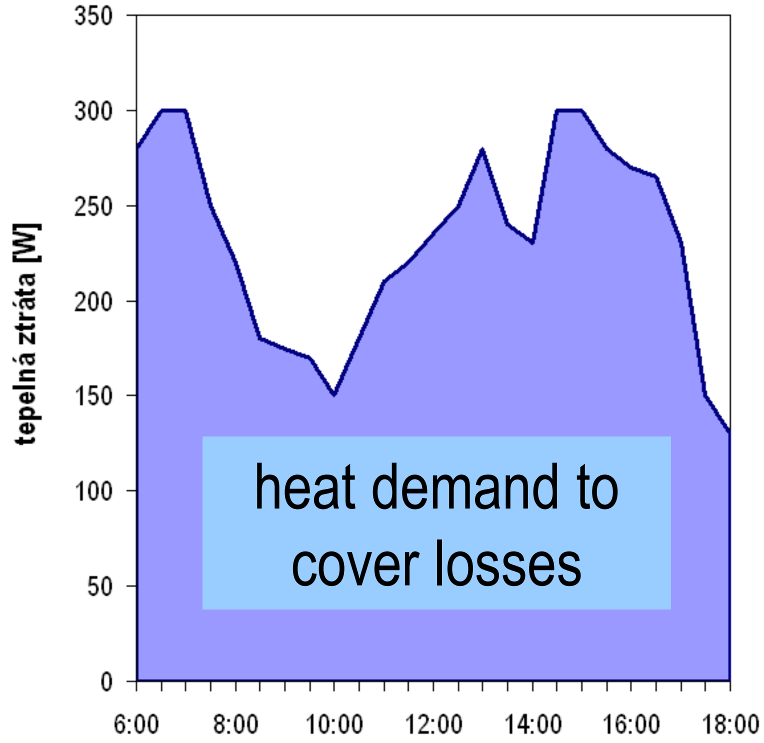
- heat loss of storage (power)

$$\dot{Q}_{l,st} = U \cdot A \cdot (t_{st} - t_a) \qquad \text{[W]}$$

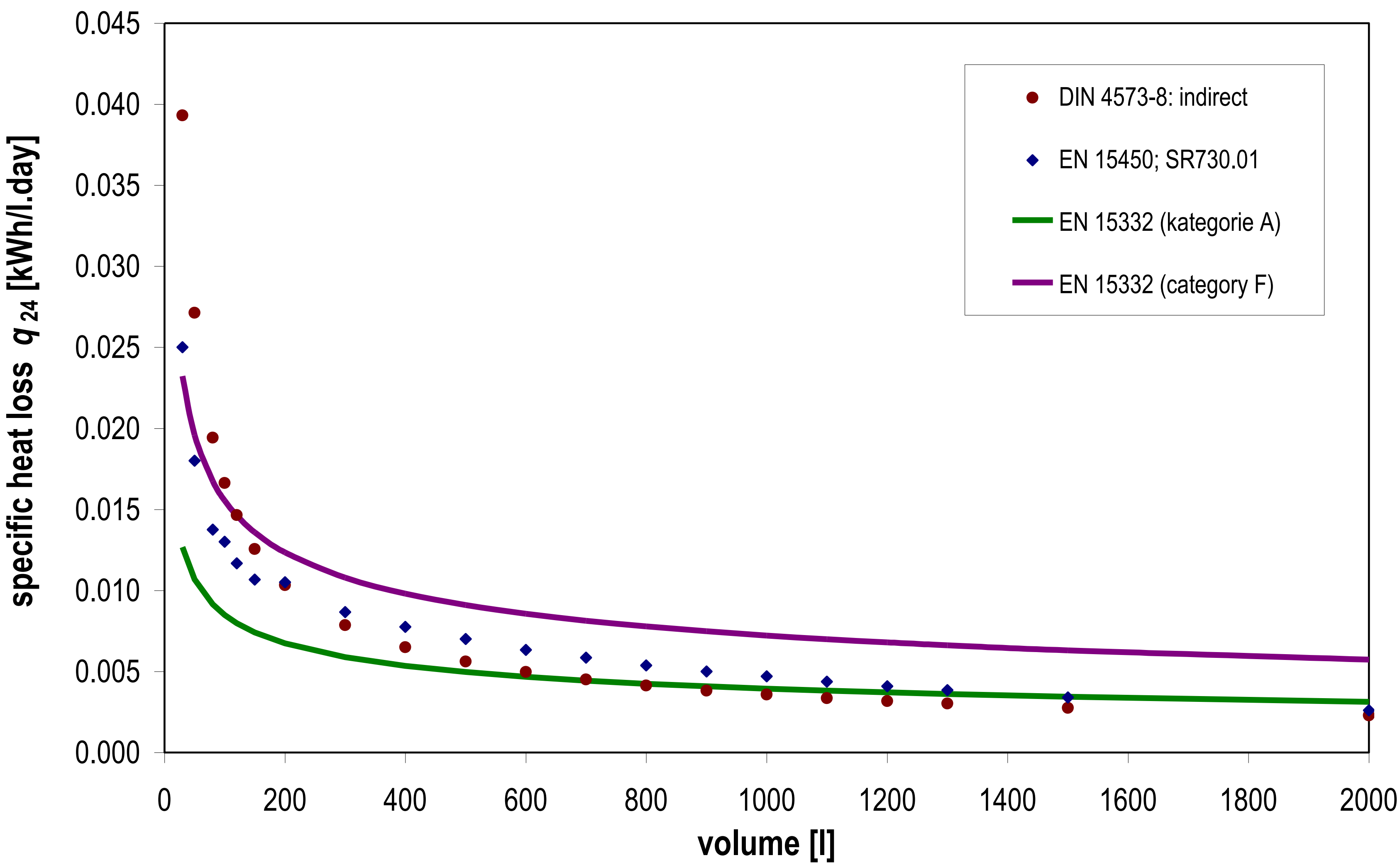
- heat loss of storage (energy)

$$Q_{l,st} = \int \dot{Q}_{l,st} \, d\tau \qquad \text{[MJ, kWh]}$$

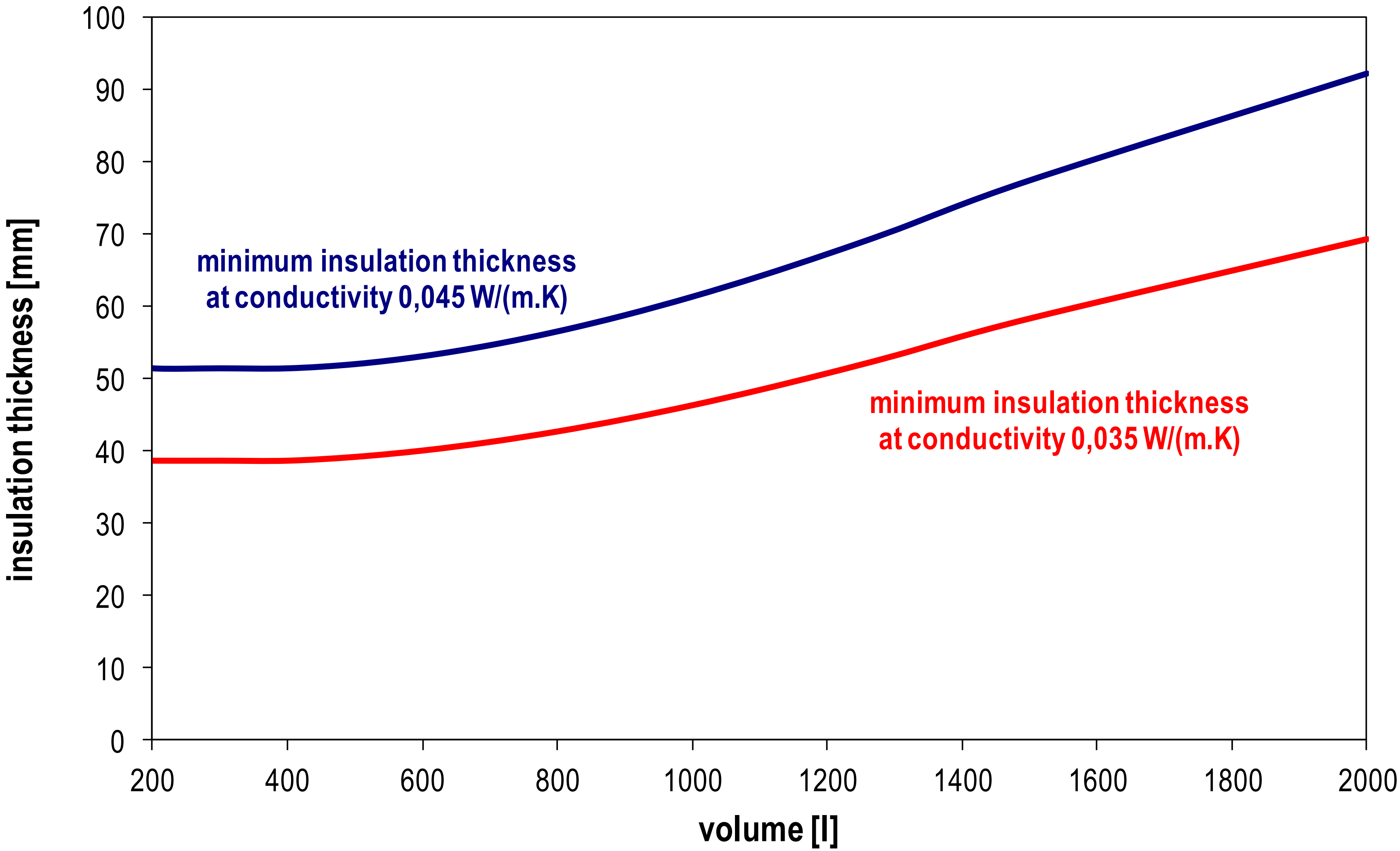
$$Q_{l,st} = \sum_{i=1}^{n} U \cdot A \cdot (t_{st,i} - t_{a,i}) \cdot \Delta\tau_i$$



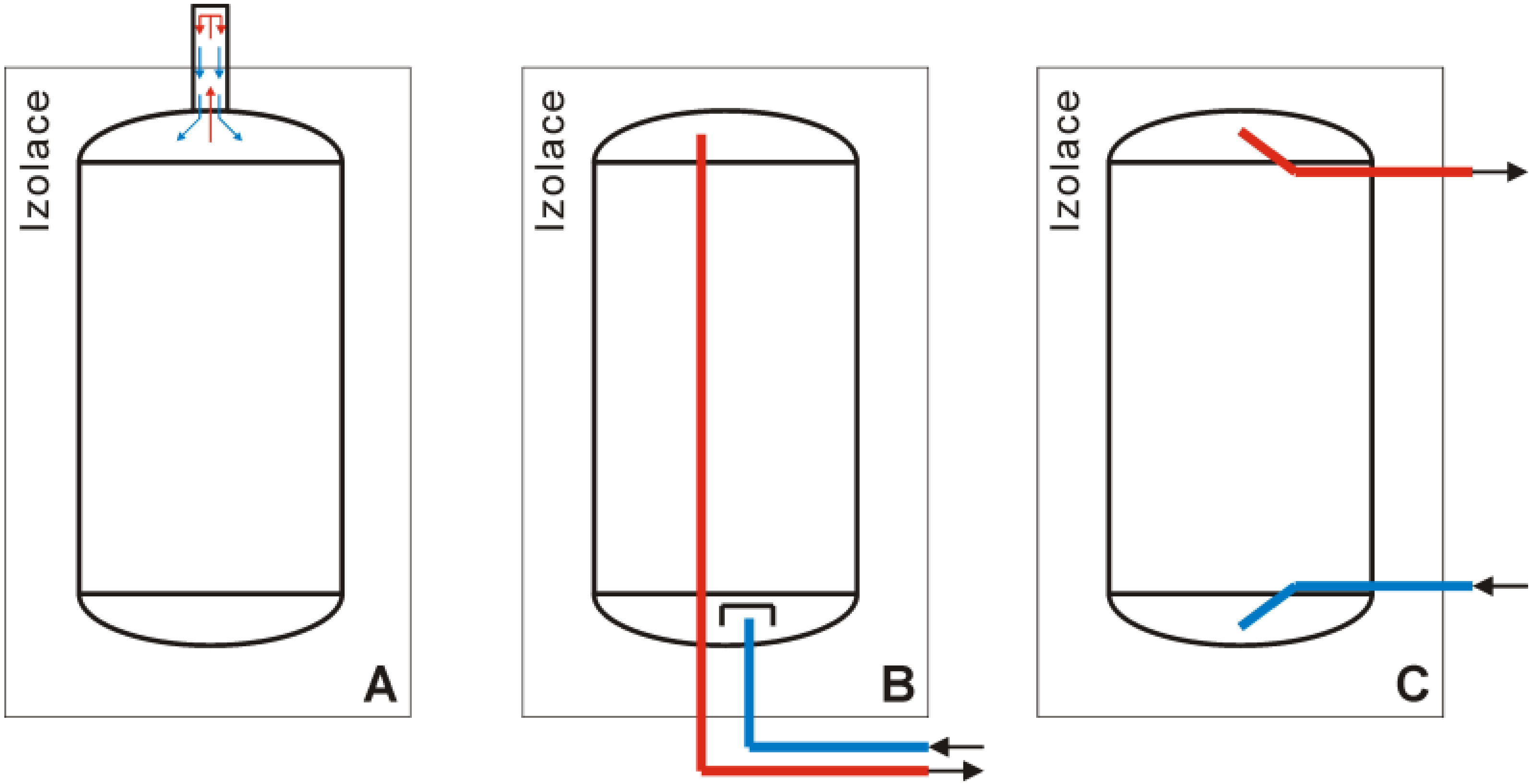
Requirements (standard, legislation)



Minimum insulation thickness

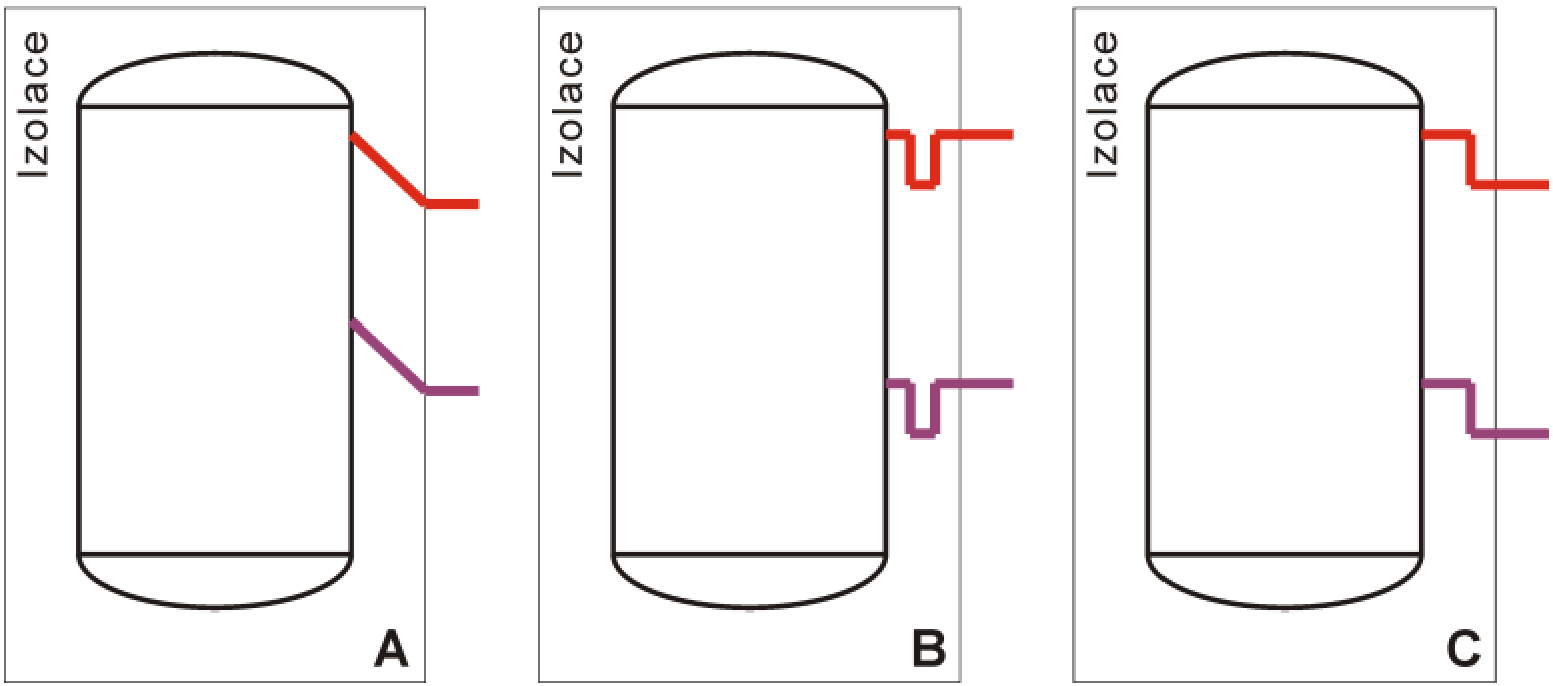


Influence of pipe connection

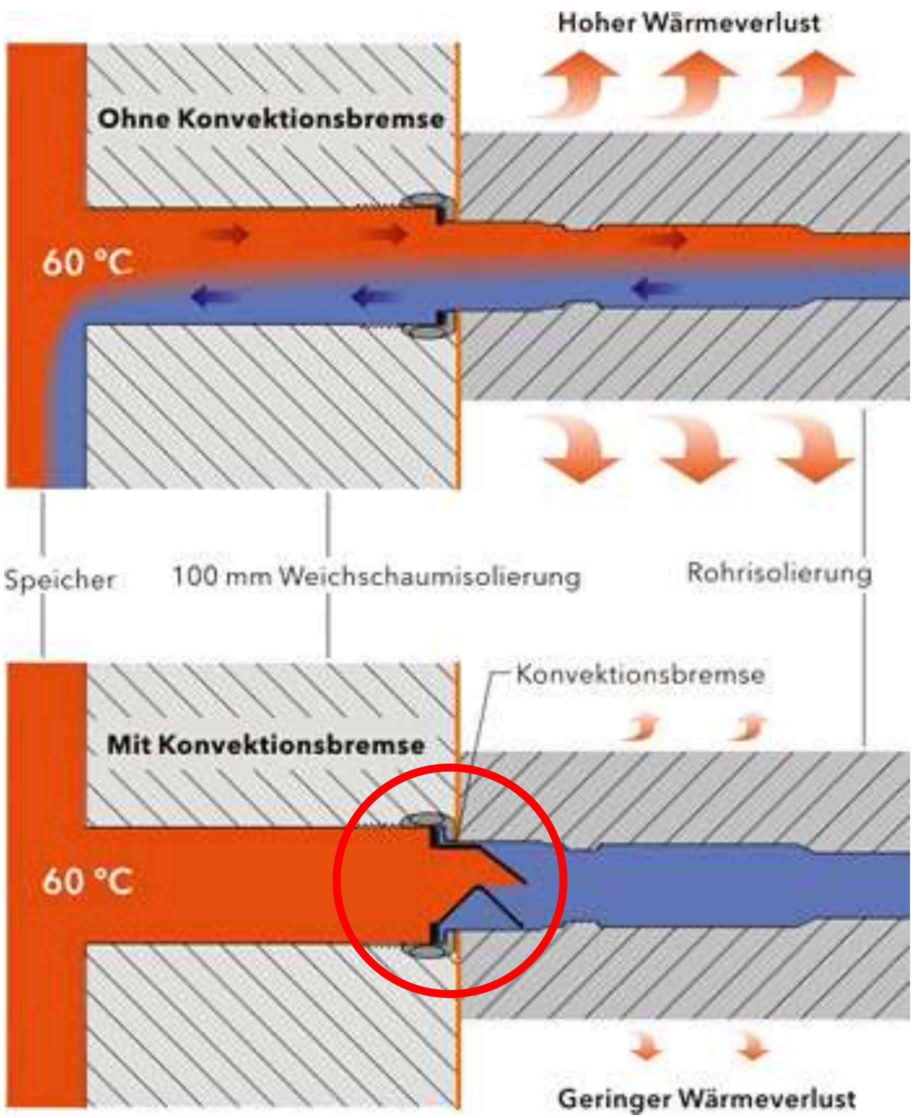


Influence of pipe connection

thermosiphon (convection) brakes – natural check-valve, elimination of losses by in-pipe convection



Influence of pipe connection

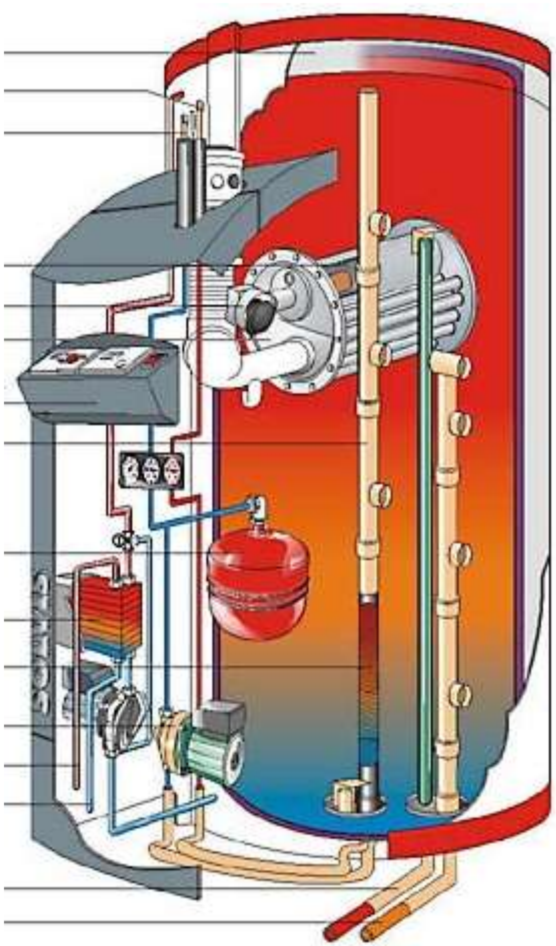


convection
brake

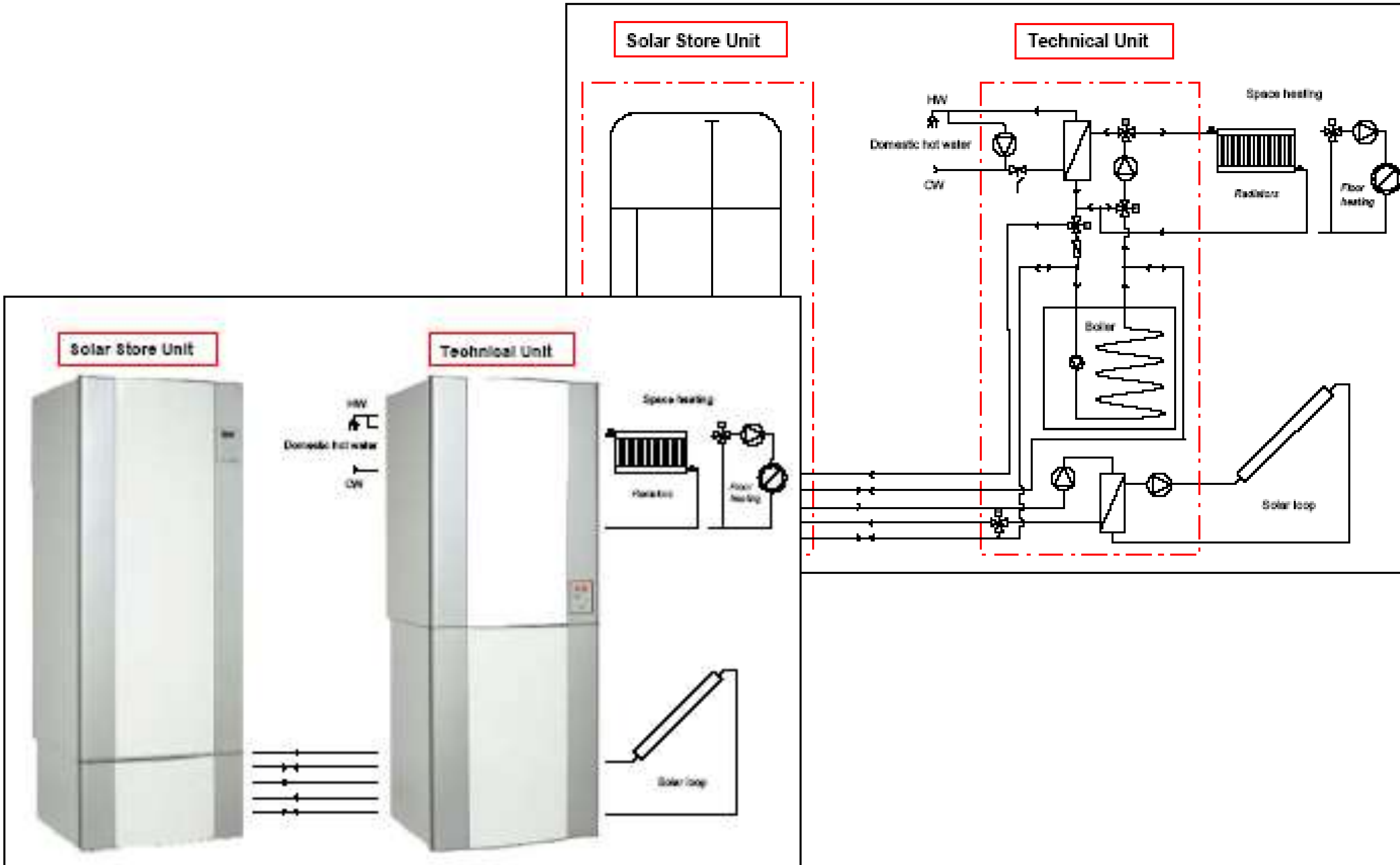
Trends

compact (integrated) solution

- minimizing of installation defects
- optimized hydraulics
- efficiency
- space savings
- placement into residential rooms



Trends


Solar Store Unit
Technical Unit
HW
Domestic hot water
CW
Space heating
Radiators
Floor heating
Boiler
Solar loop
Solar Store Unit
Technical Unit
HW
Domestic hot water
CW
Space heating
Solar loop

Heat storage with phase change

- phase change accompanied with heat absorption / heat rejection
- liquid – gas: undesirable change of volume
- **liquid – solid:** suitable (melting – solidification)

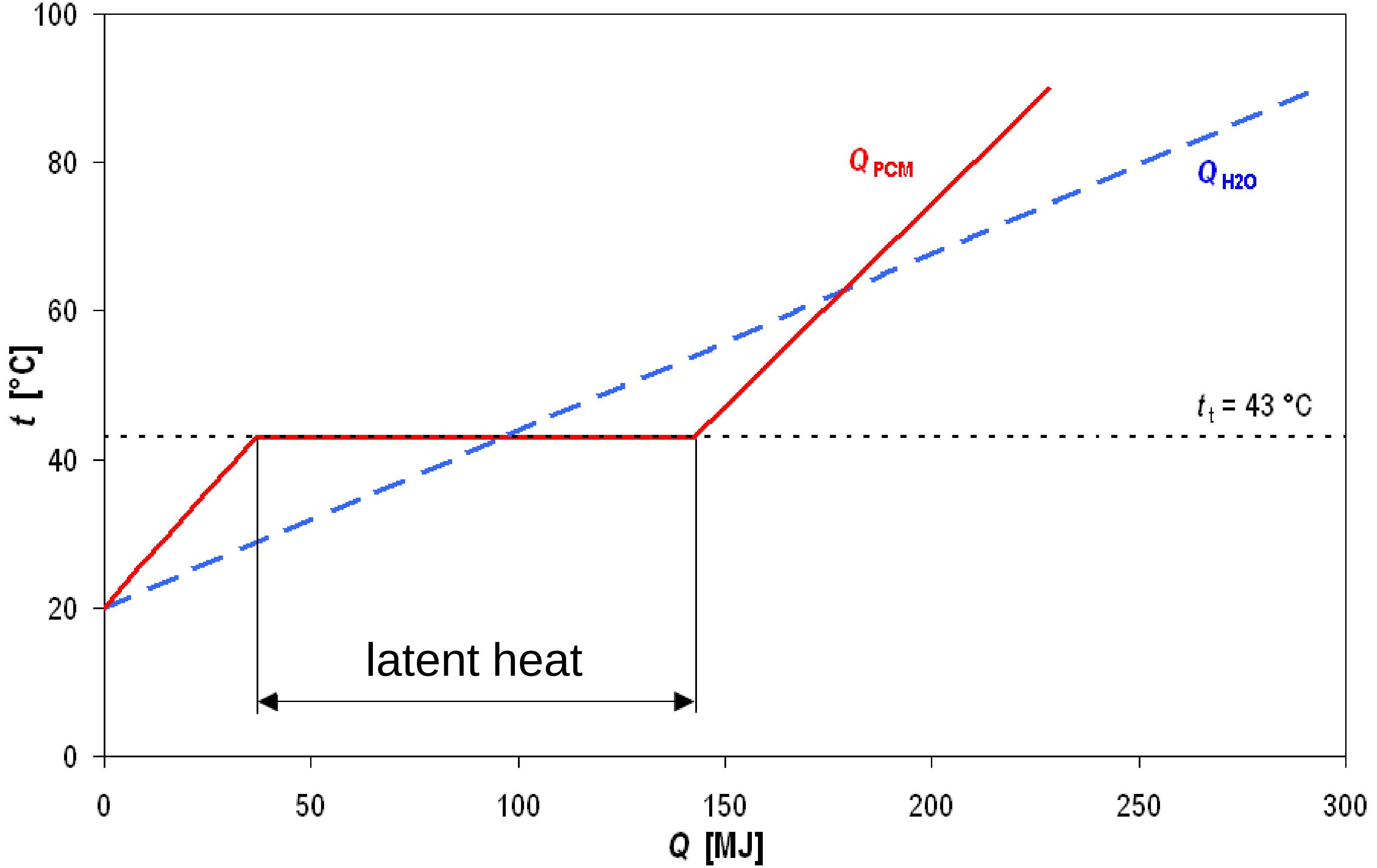
$$Q = V \cdot \left[\boxed{\rho_s \cdot c_s (t_m - t_1)} + \boxed{\rho_m \cdot l_m} + \boxed{\rho_l \cdot c_l (t_2 - t_m)} \right]$$

sensible heat solid phase — latent heat — sensible heat liquid phase

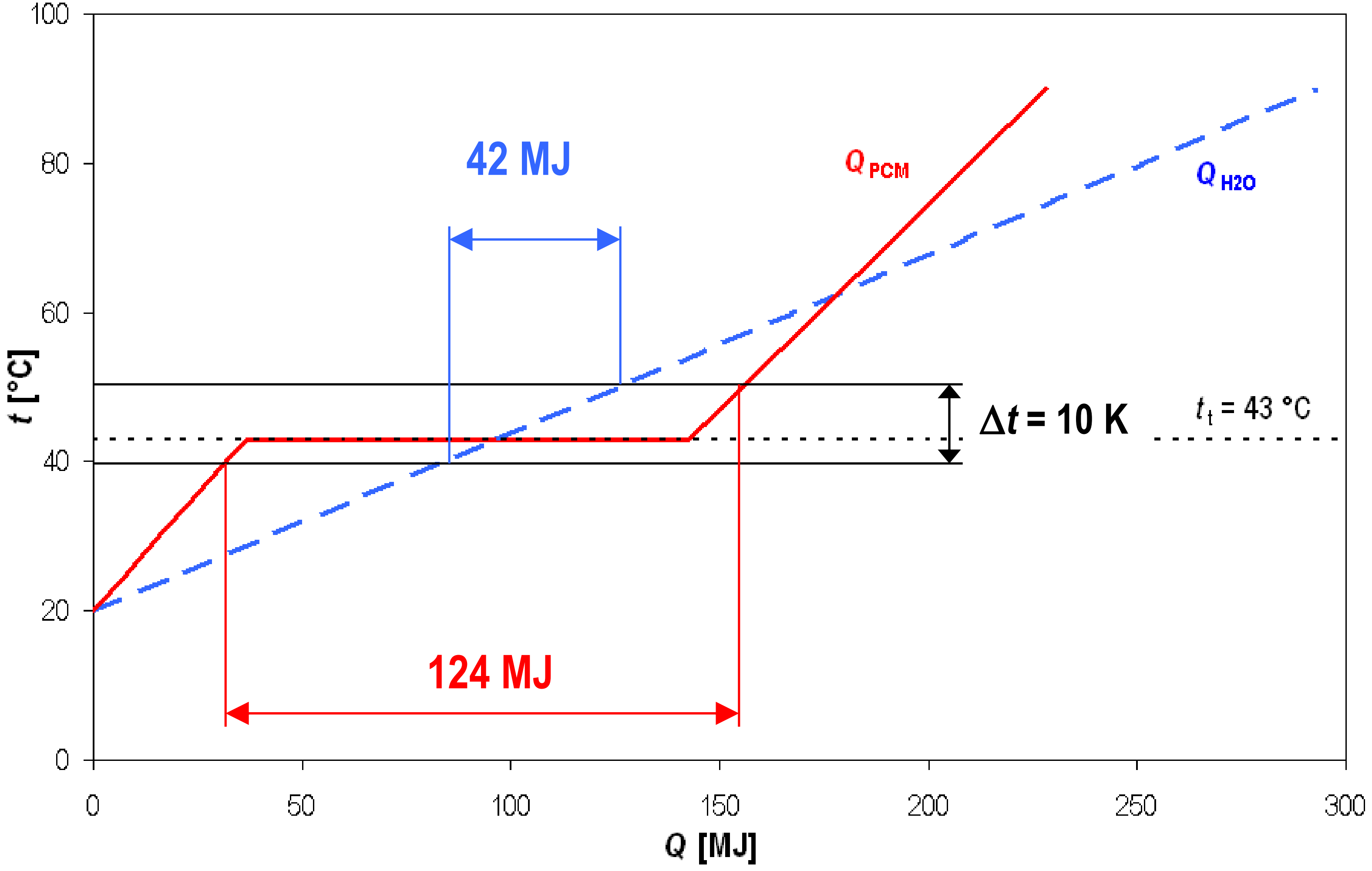
where t_m ... phase change temperature $t_1 < t_m < t_2$

l_t ... latent heat of melting - solidification

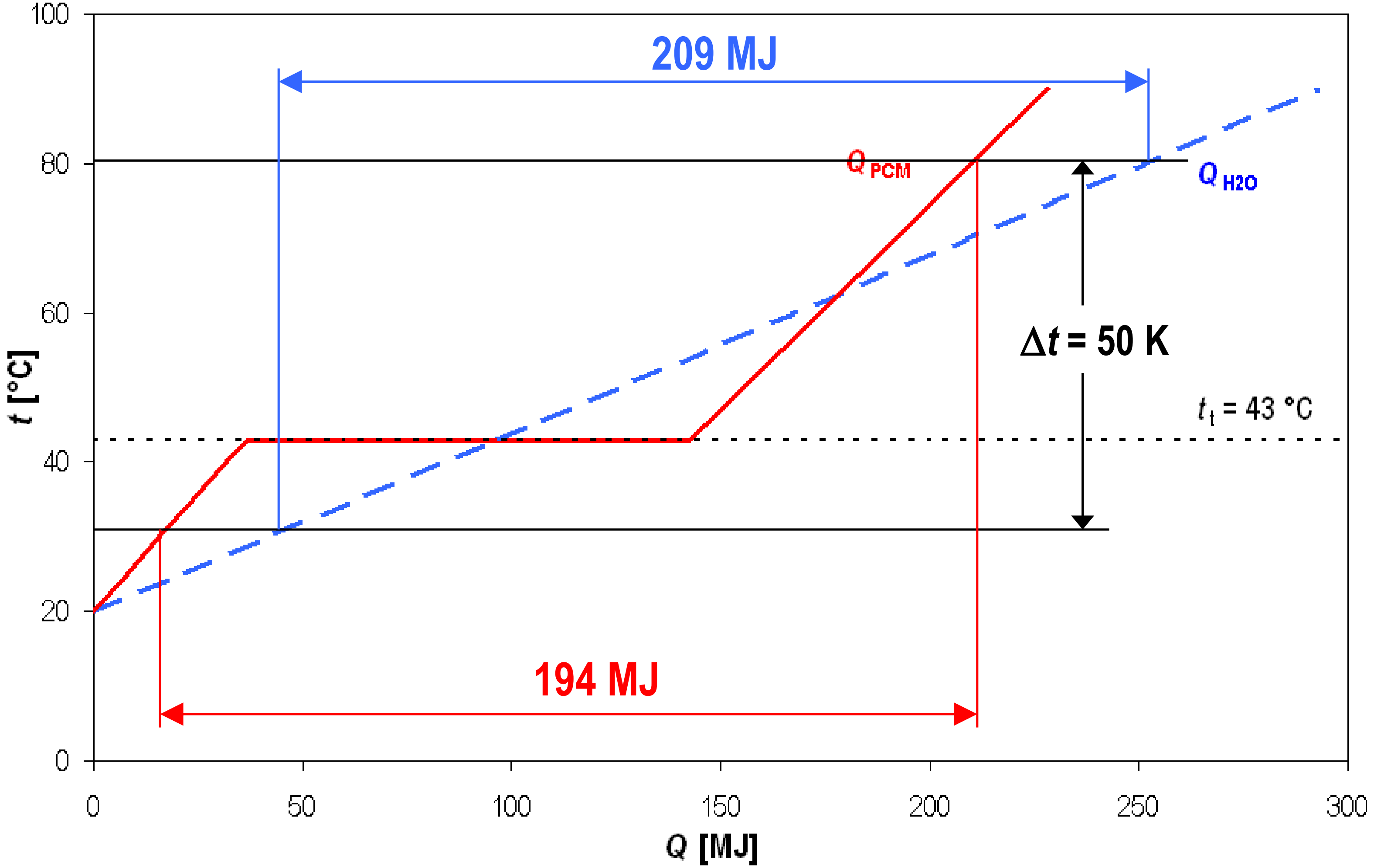
Heat storage with phase change



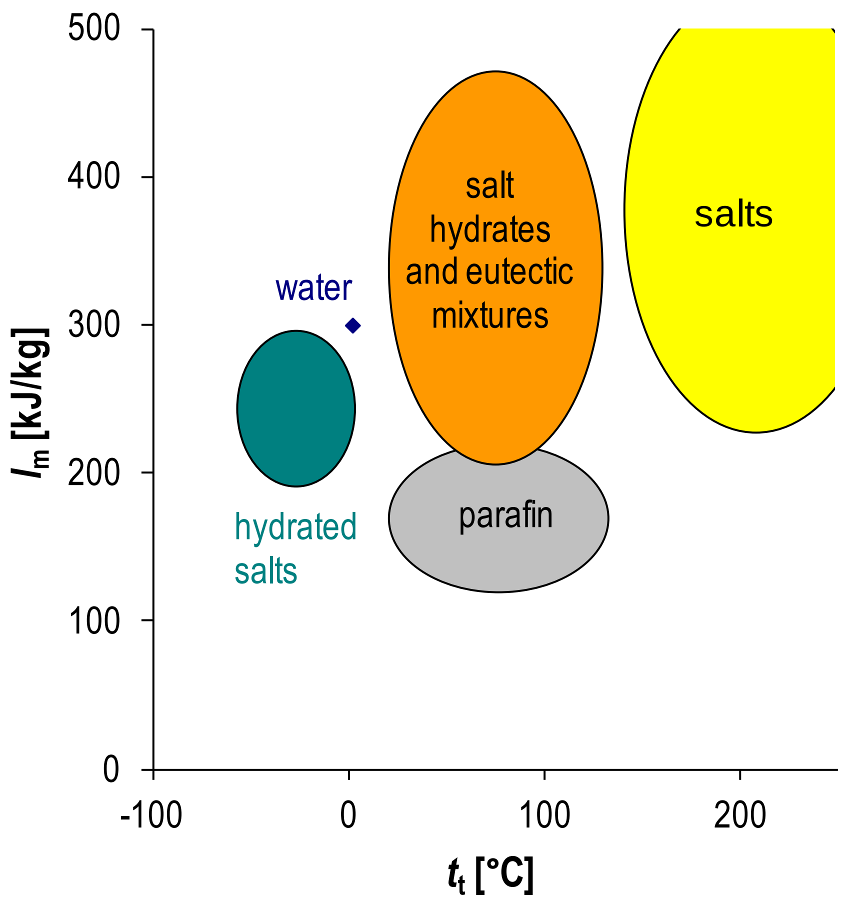
Heat storage with phase change



Heat storage with phase change



Phase change materials (PCM)



anorganic PCM:

salt hydrates (Glauber salt)

+ high latent heat

+ high thermal conductivity

- corrosive

- subcooling

- phase segregation

organic PCM:

wax, parafin, fatty acids

+ chemically, thermally stable

+ noncorrosive

- low thermal conductivity

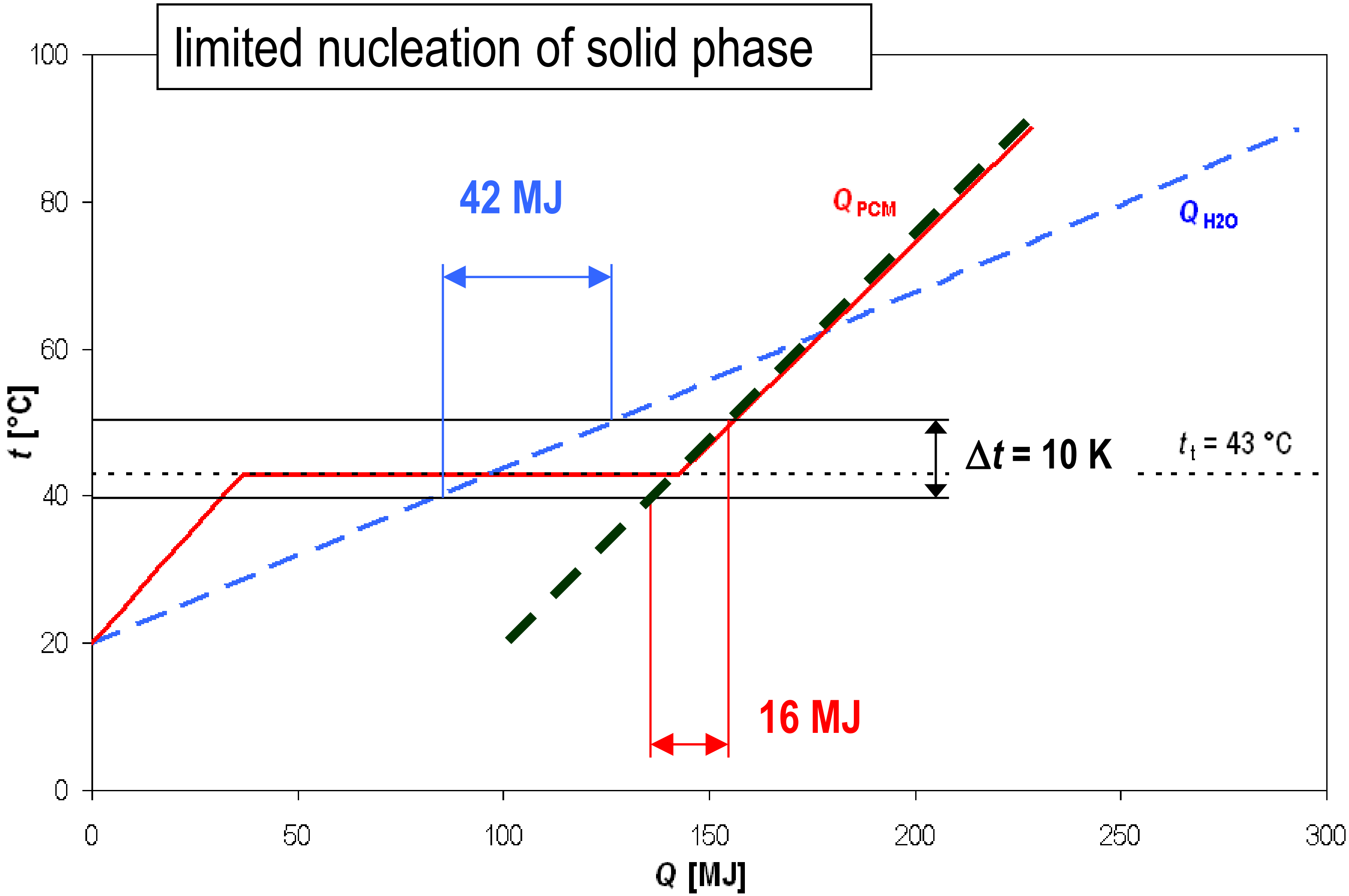
- low latent heat

Phase change materials (PCM)

required properties

- suitable temperature of phase change
  - for solar systems: 35 – 70 °C, choice of temperature
- low thermal conductivity (parafins) – irregular melting, reduction of storage capacity
  - use of conductive matrix, composite materials (carbon fibres)
- change of volume at phase change – not critical (up to 15 %)
- corrosion (salts)
- need for longterm stability (cyclic change of phase)
- subcooling: to use it or not?

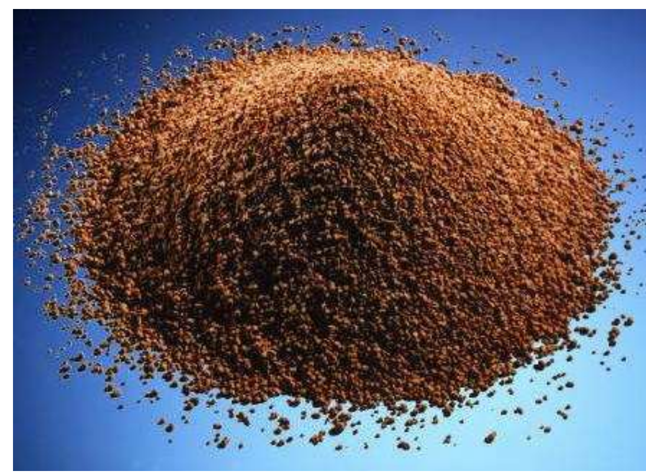
Subcooling



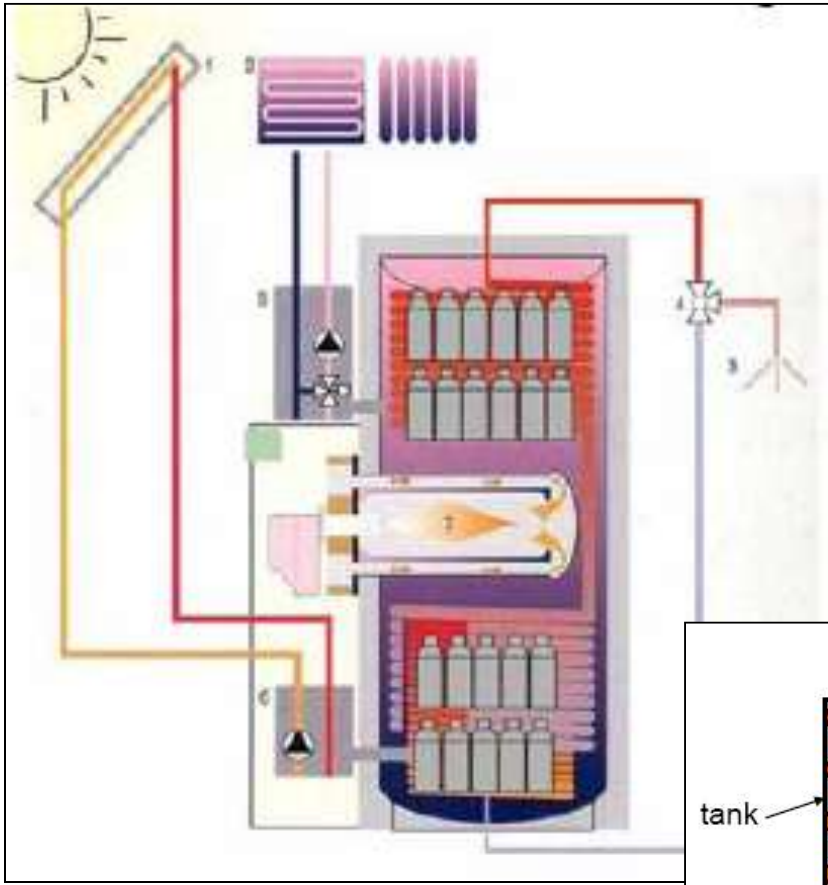
limited nucleation of solid phase
42 MJ
16 MJ
Q PCM
Q H2O
Δt = 10 K
t_t = 43 °C
t [°C]
Q [MJ]
0
20
40
60
80
100
0
50
100
150
200
250
300

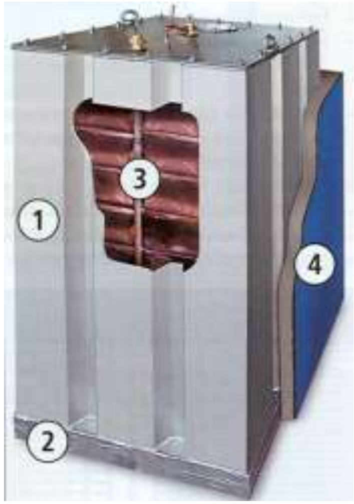
Parafins

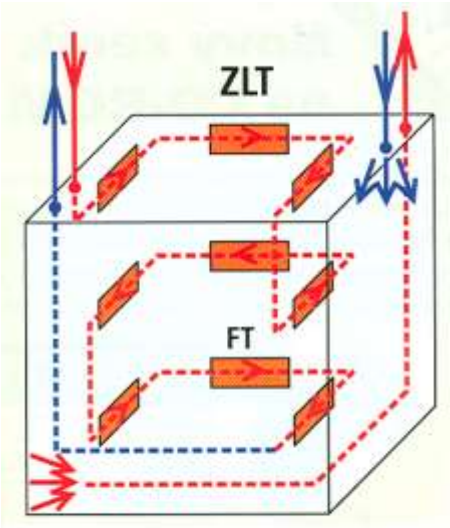
Product	Melting point[1]	Heat storage capacity[2]
	[°C]	[kJ/kg]
RT -4	-4	179
RT 3	4	198
RT 4	4	182
RT 5	5	198
RT 6	6	175
RT 21	21	134
RT 27	27	179
RT 31	29	169
RT 42	41	174
RT 50	49	168
RT 52	52	173
RT 55	55	172
RT 58	58	178
RT 60	60	144
RT 62	61	146
RT 65	65	152
RT 82	82	176
RT 100	100	124

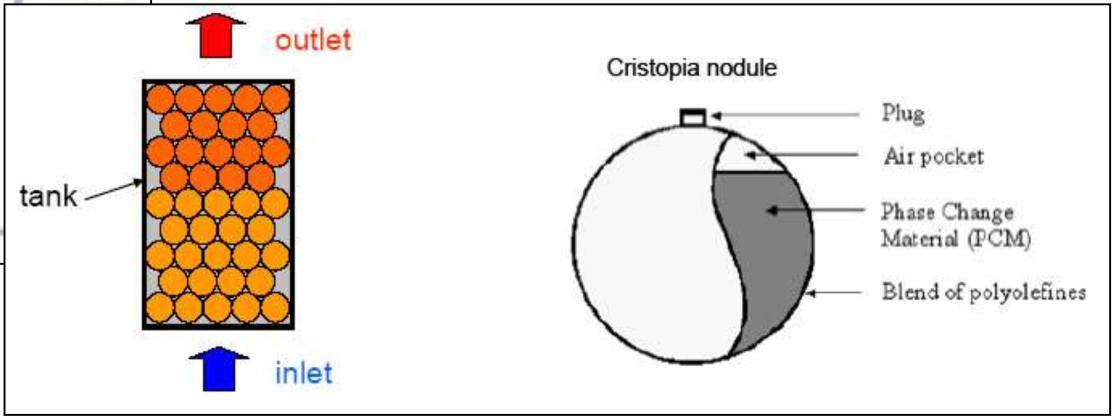


Applications - macrocapsules

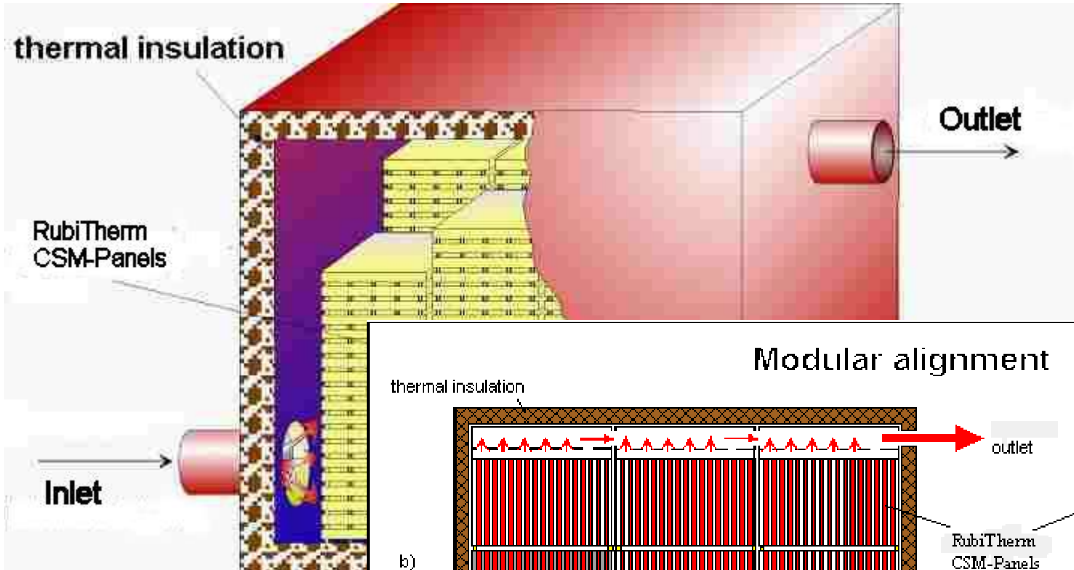


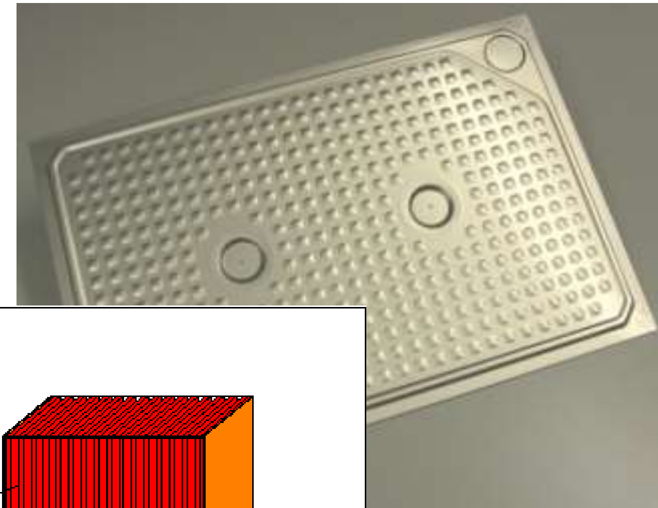


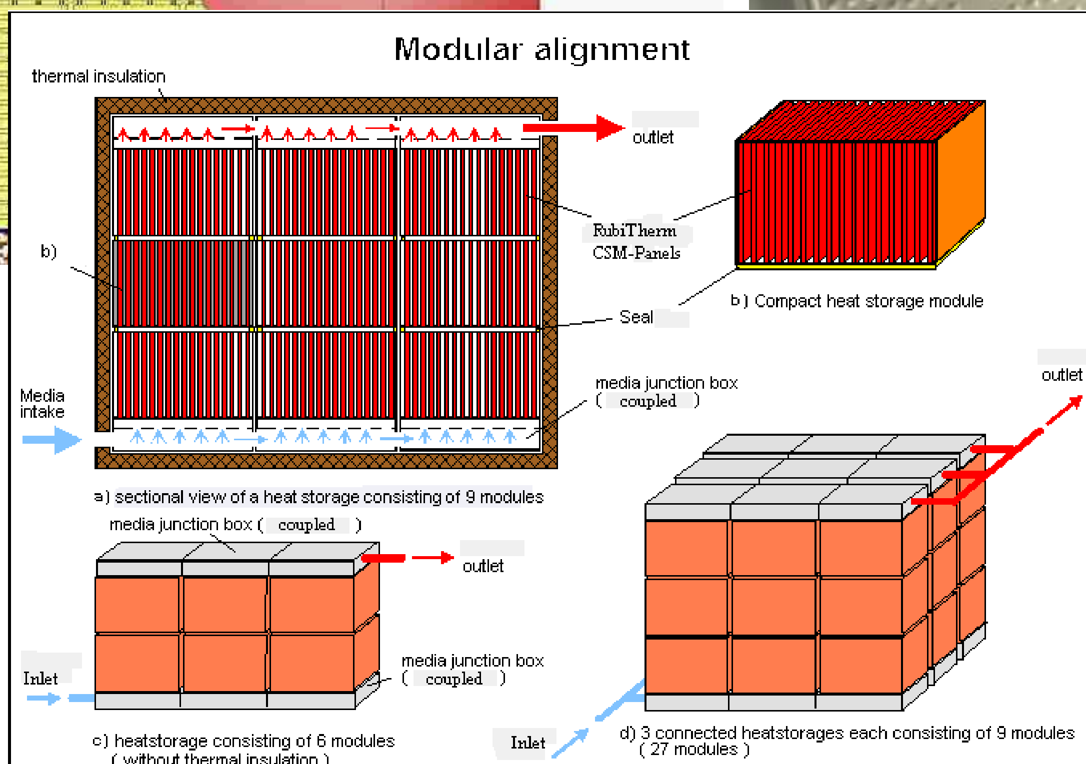




Applications - macrocapsules

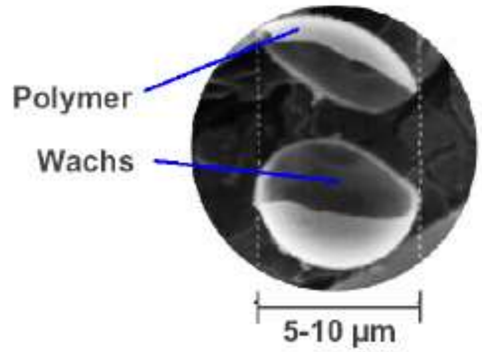


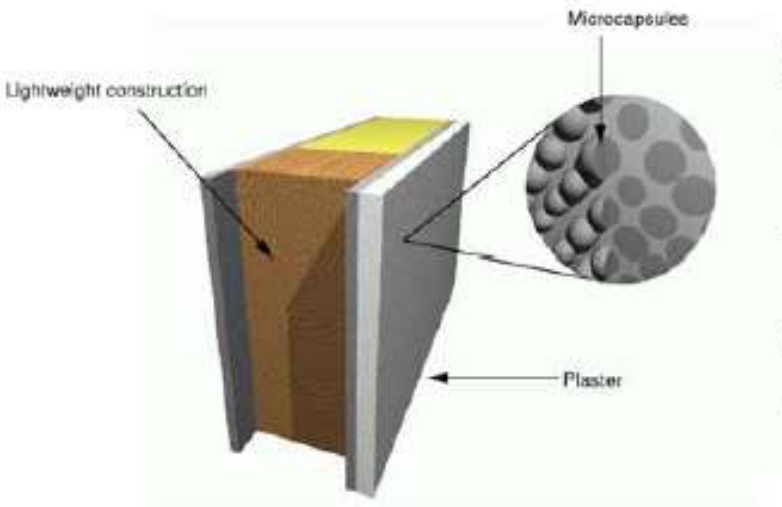


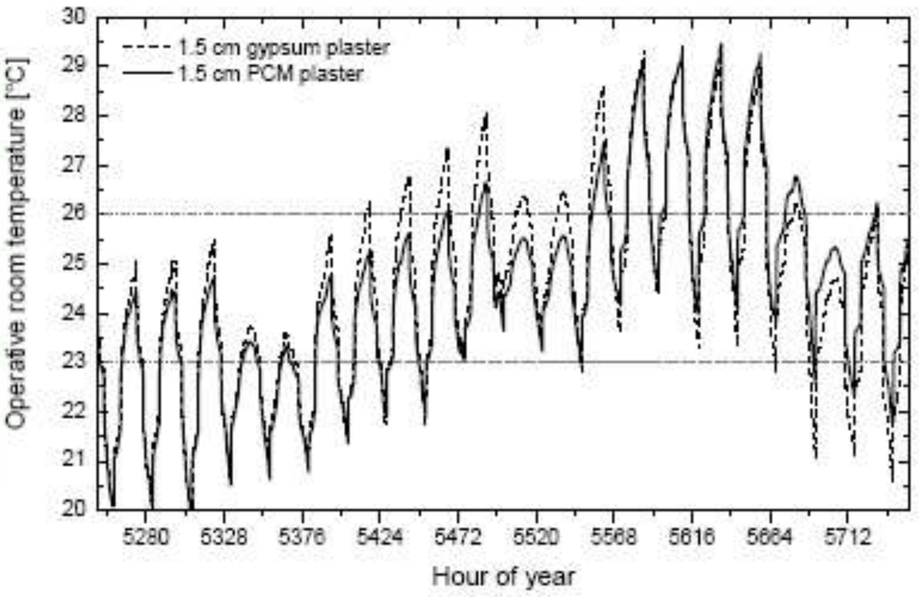


Applications - microcapsules

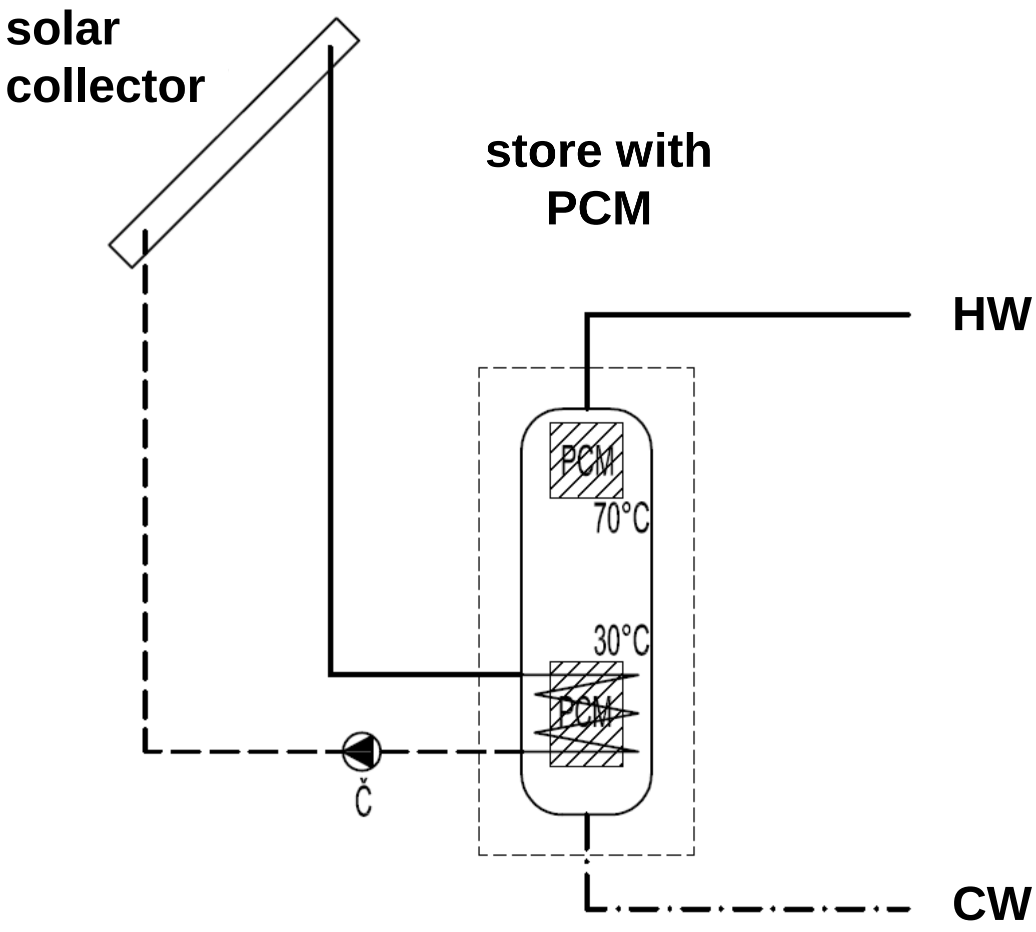
PCM slurries

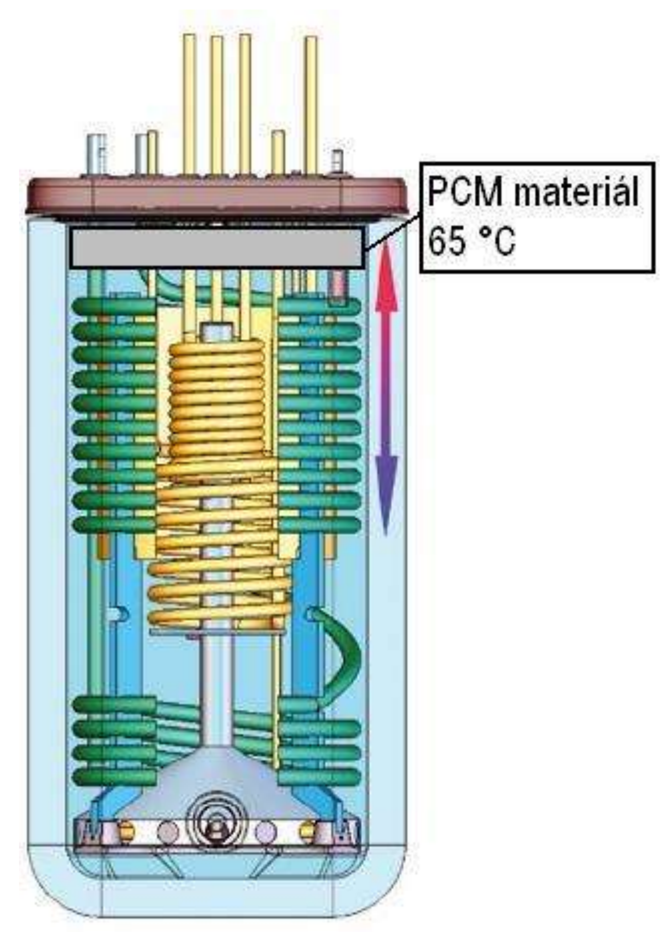






Use of PCM in solar systems





Use of PCM in solar systems