Thermal storage

Dr. Herena Torio

Outline

Characteristics

- Aims
- Types

Water tanks

- Heat transfer processes: losses and self-discharge
- Stratification
- Sizing guidelines
- System performance

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Seasonal storage tanks
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Characteristics

Main purposes:

- Overcome mismatching between demand and solar resource

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- Decouple mass flows (and energy transfer) between heat sources and heat sinks

- Reduces required capacity (power) of auxiliary heating devices

- Store at appropriate temperature level (avoiding mixing – irreversibilities)

Characteristics

Main thermal storage types:

- Water tanks

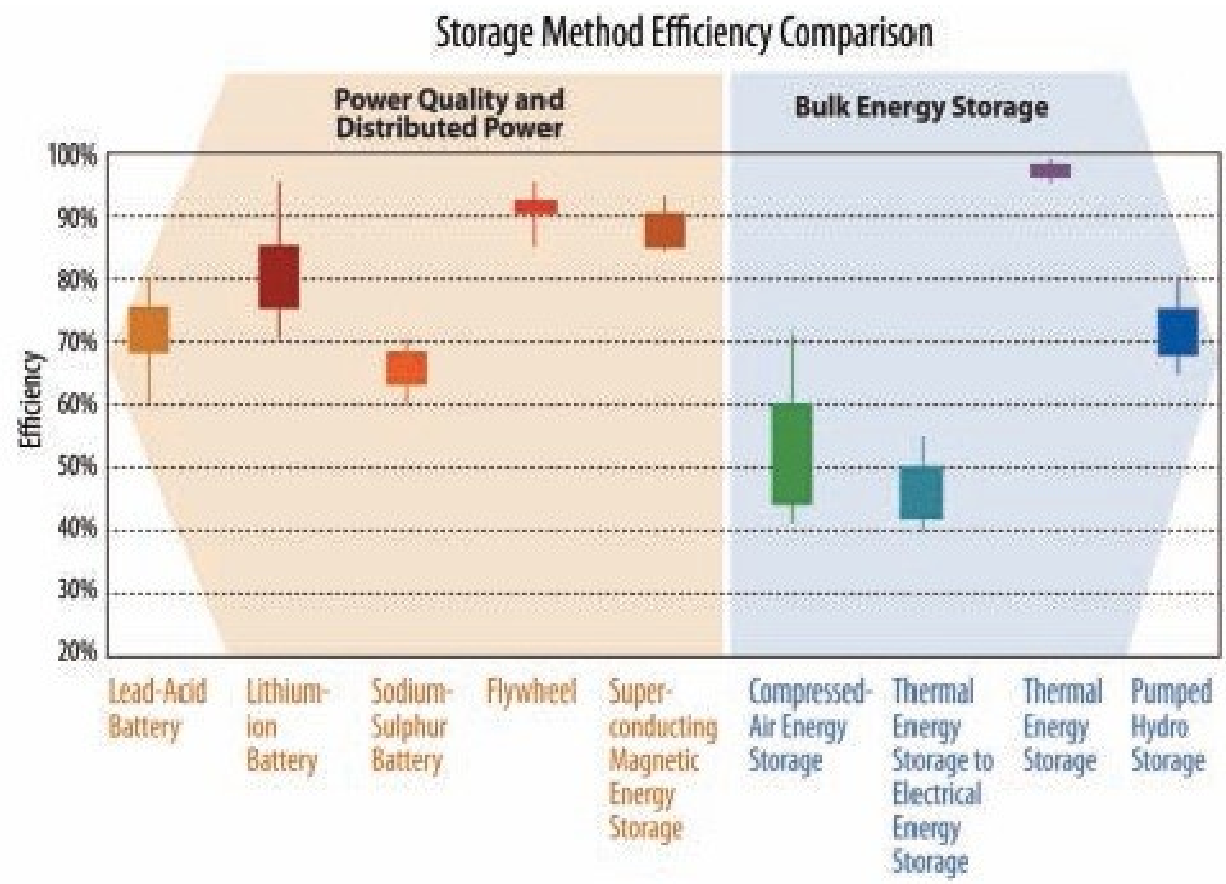
- Phase change materials

- Thermochemical storage

- Water+sand storage

- Underground storage options

Storage



Source: solartoday.org

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- Stratification
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Storage: water tanks

Characteristics

- **efficient!**

- **cheaper** than electrochemical storage, negligible costs as compared to e.g. batteries (300-3500 USD/kW)

- more **bulky**: less energy density
  → new materials: PCMs,...

- **storage time:** typically several hours to 2-3 days
  But also seasonal storage is possible!!

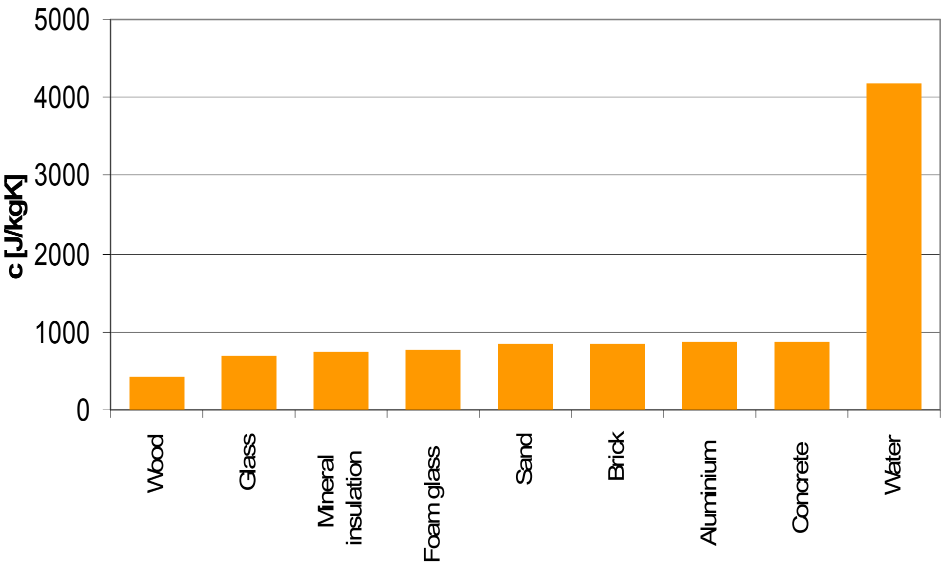
- no waste, no disposal problems!

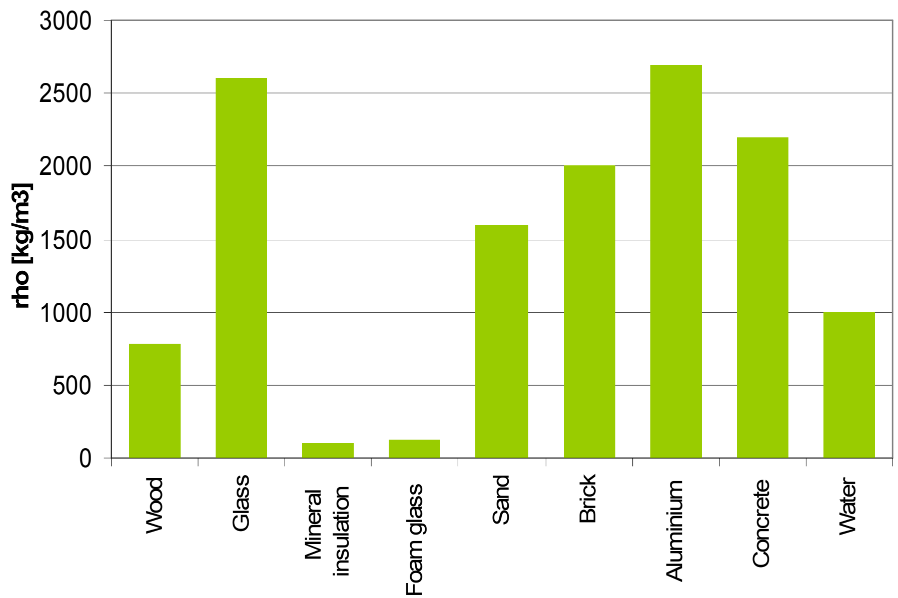
Storage: water tanks

Characteristics

$$\dot{d}\,Q_{sto} = C_{sto} \cdot \left(\frac{dT_{sto}}{dt} \right)$$

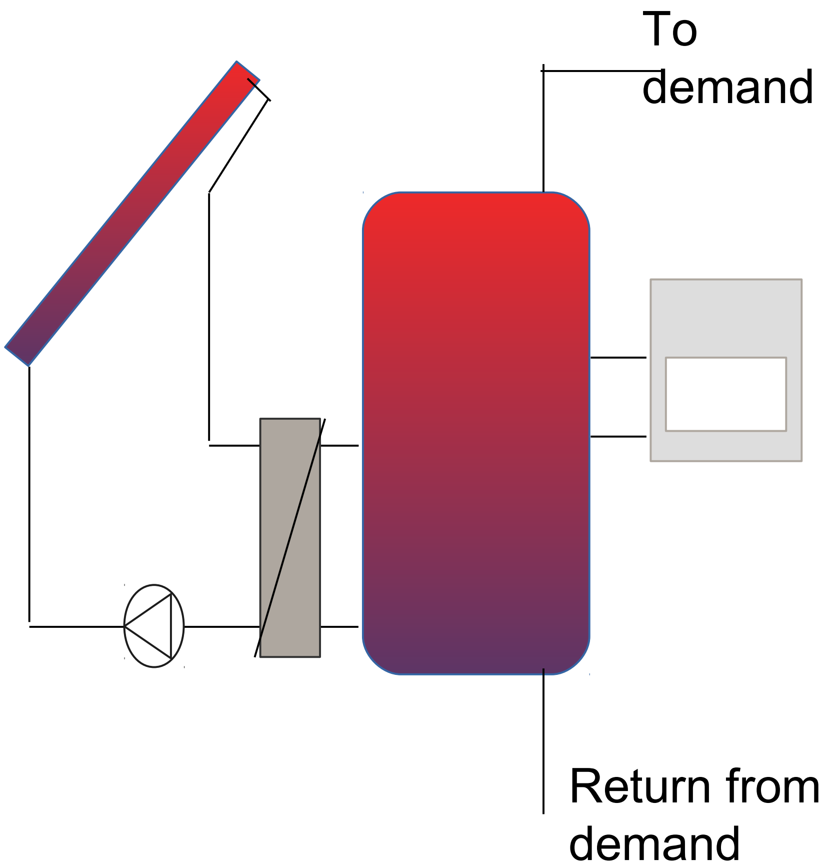
$$C_{sto} = c_i \cdot \rho_i \cdot V_i$$





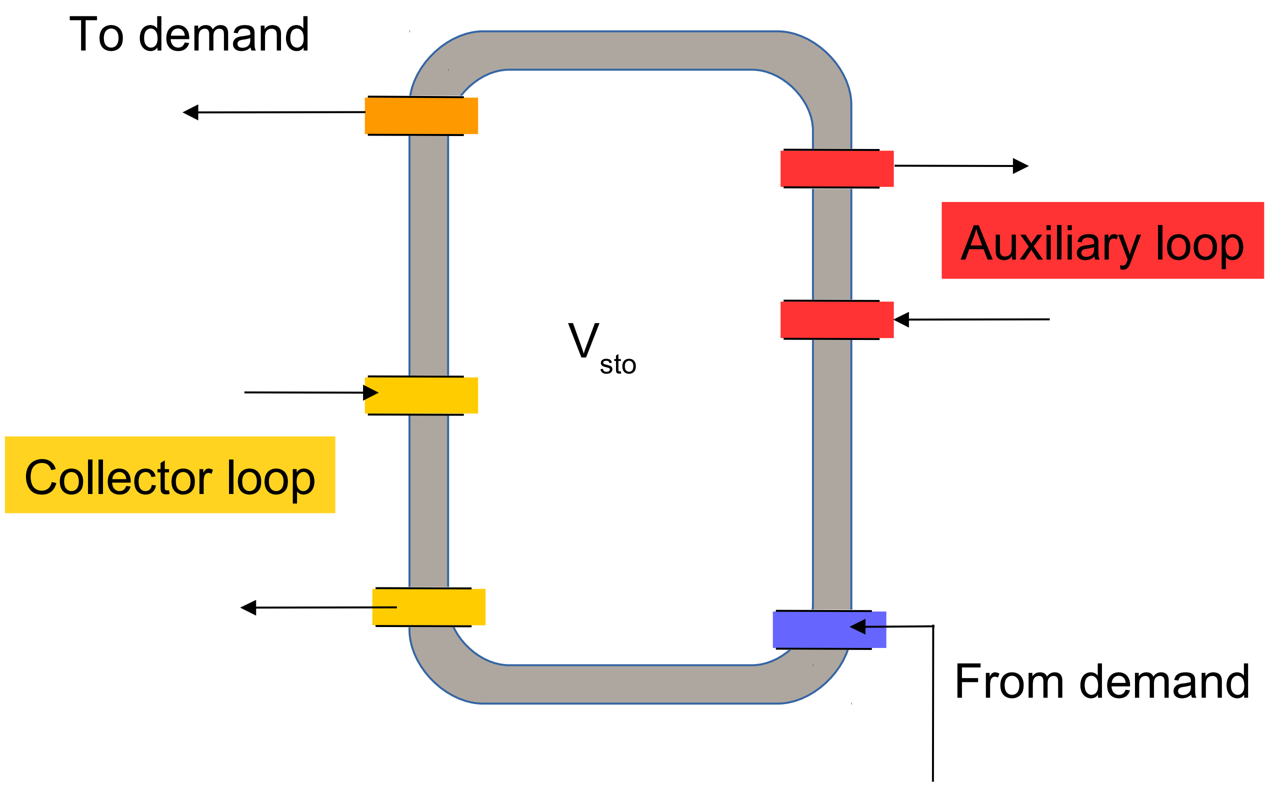
Storage: water tanks

Main heat transfer processes



Storage: water tanks

Main heat transfer processes



Storage: water tanks

Main heat transfer processes

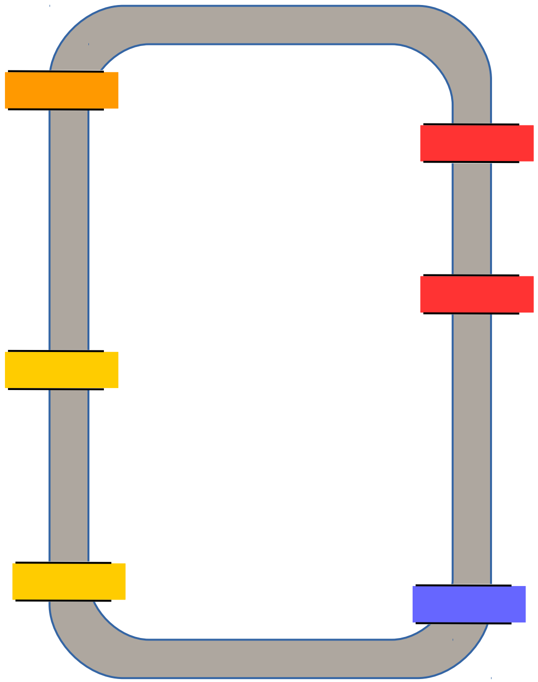
<u>Simplest case: no charging / no discharging</u>

- Heat losses to surrounding: UA_{sto}

- Vertical thermal conductivity walls + fluid

- Convection between fluid layers

- Conduction around inlets/outlets



Storage: water tanks

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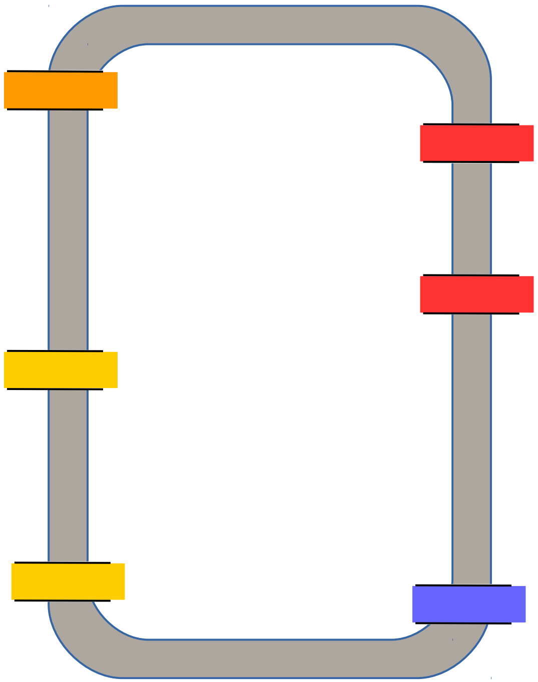


General heat loss equation:

$$U = \frac{1}{\left(\frac{1}{h_i} + \sum \frac{d_i}{\lambda_i} + \frac{1}{h_e}\right)}$$

Storage: water tanks

Main heat transfer processes

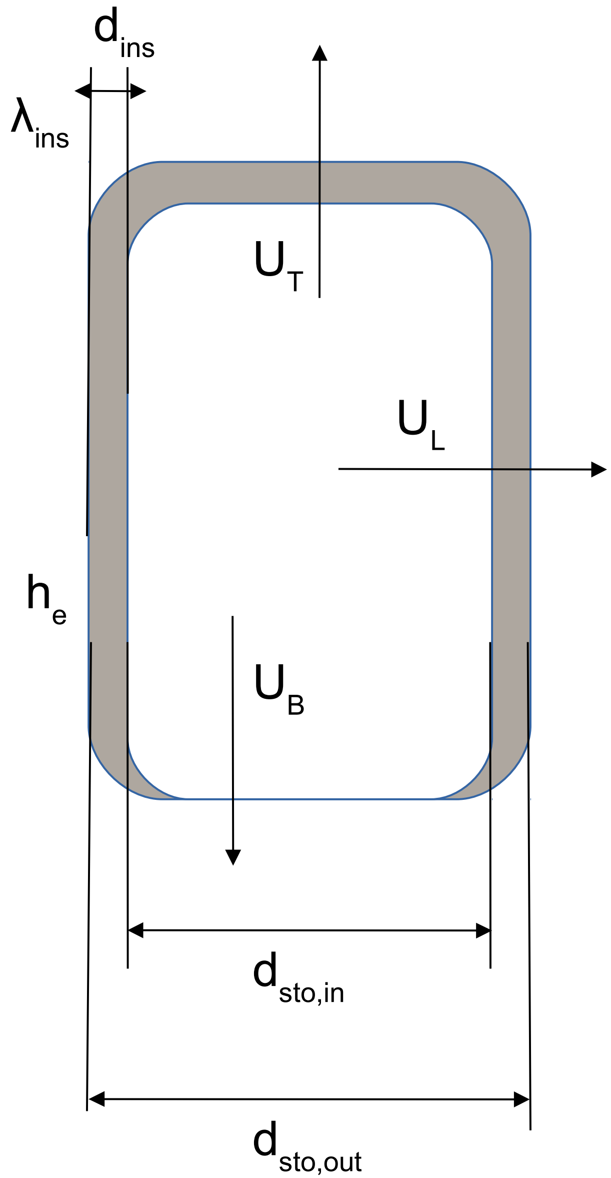
Simplest case: no charging / no discharging
For a cylindrical tank:

$$U_L = \frac{\pi}{\frac{1}{2\lambda_{ins}} \ln \frac{d_{sto,out}}{d_{sto,in}} + \frac{1}{h_e d_{sto,out}}}$$

$$U_T = \left(\frac{d_{ins}}{\lambda_{ins}} + \frac{1}{h_e} \right)^{-1}$$

$$U_B = \left(\frac{1}{h_e} \right)^{-1}$$

$$UA_{sto} = U_L L + U_T A_T + U_B A_B$$



Source: Eicker, 2012

Carl von Ossietzky Universität Oldenburg

Storage: water tanks

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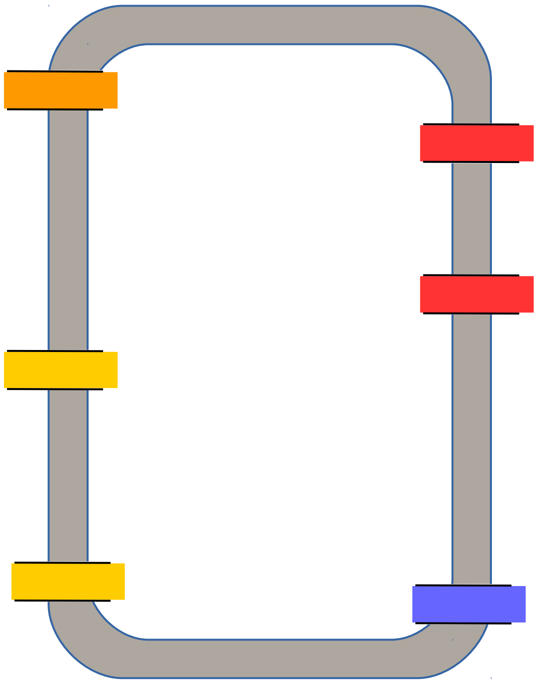

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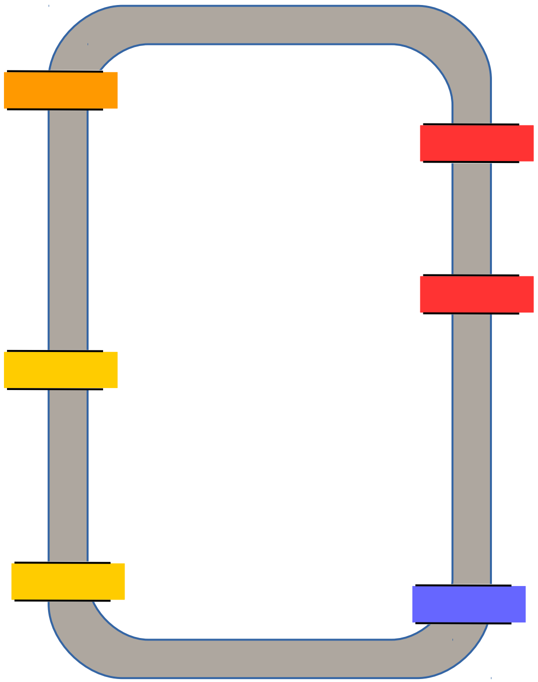
Storage: water tanks

Main heat transfer processes

Simplest case: no charging / no discharging
“Self-discharge” of a storage, with a surrounding temperature T_{surr}:

- Heat losses to surrounding: UA_{sto}
- Vertical thermal conductivity walls + fluid
- Convection between fluid layers
- Conduction around inlets/outlets

$$m \cdot c_{sto} \cdot \left(\frac{dT_{sto}}{dt} \right) = -U_{eff} \cdot A \cdot \left(T_{sto}(t) - T_{surr} \right)$$



Storage: water tanks

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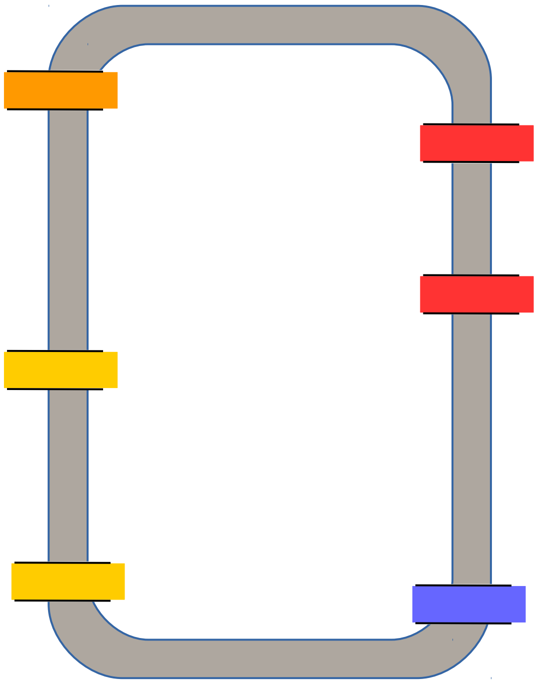
$$T_{sto}(t) = \left(T_{sto,0} - T_0 \right) \cdot e^{\left(\frac{-U_{eff} \cdot A}{m \cdot c_{sto}} \cdot t \right)} + T_{surr}$$



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Storage: water tanks

$$T_{sto}(t)=\left(T_{sto,0}-T_0\right)\cdot e^{\left(\frac{-U_{eff}\cdot A}{m\cdot c_{sto}}\cdot t\right)}+T_{surr}$$

Main heat transfer processes

Simplest case: no charging / no discharging

“Self-discharge” of a storage

Typical values of UA_{eff}

Storage volume [liters]	**Ua_{eff} [W/K]**
400	1.7 – 3.0
1000	3.7 – 5.5

Source: Eicker, 2012

Storage: water tanks

$$T_{sto}(t) = (T_{sto,0} - T_0) \cdot e^{\left(\frac{-U_{eff} \cdot A}{m \cdot c_{sto}} \cdot t\right)} + T_{surr}$$

Main heat transfer processes

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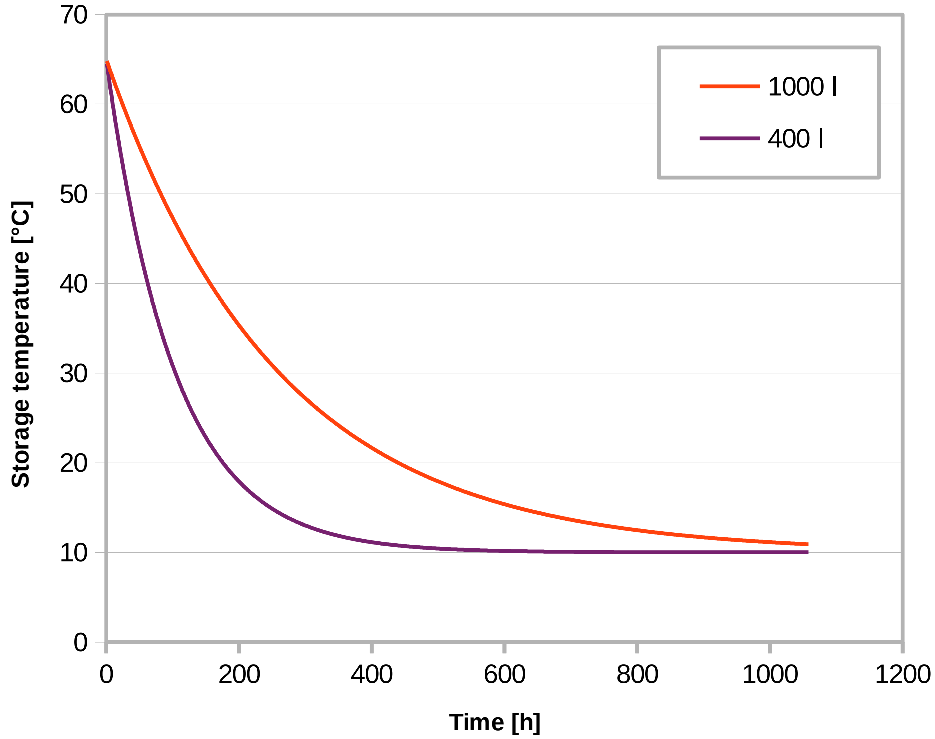
"Self-discharge" of a storage

Example: 1000 - 400 liters, 3.0 W/K, T_{surr} = 10°C, $T_{sto,0}$=65°C



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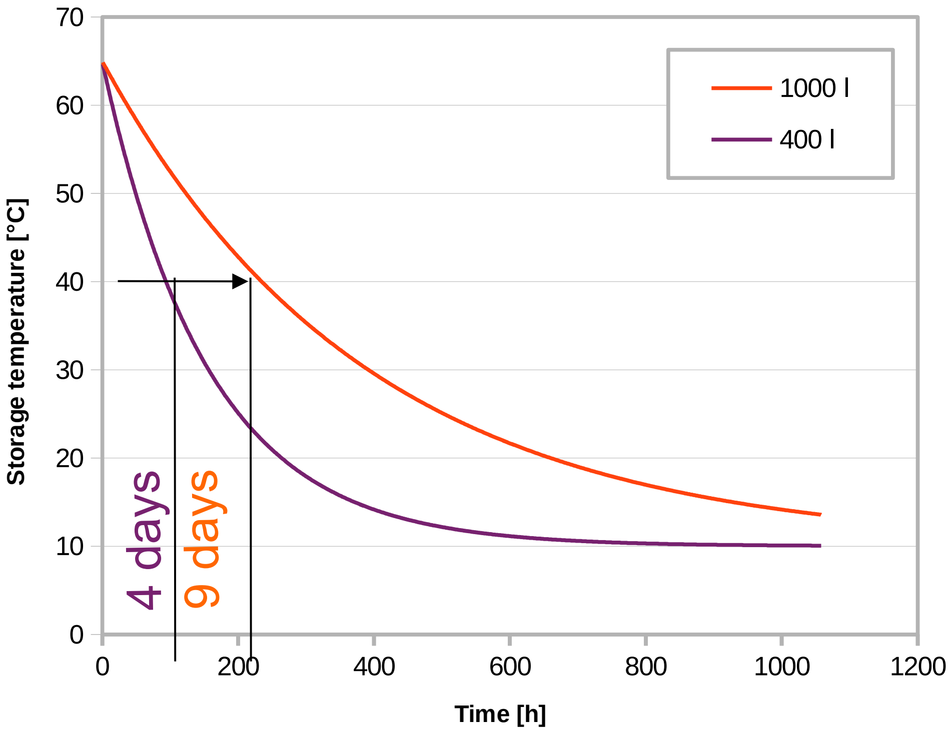
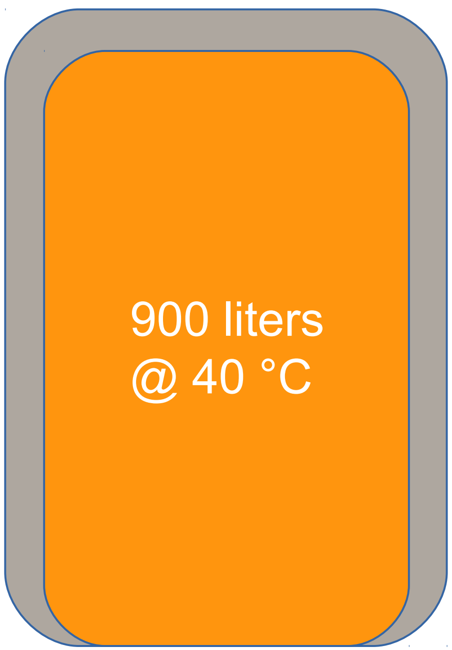


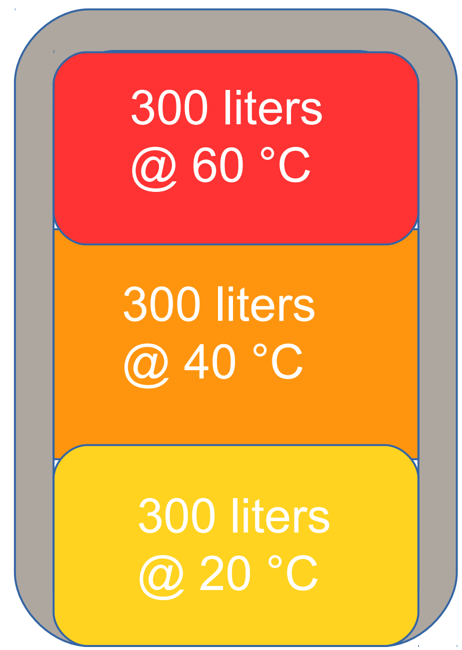
Storage: water tanks

Stratification

Energy content



T_{surr} = 10 [°C]



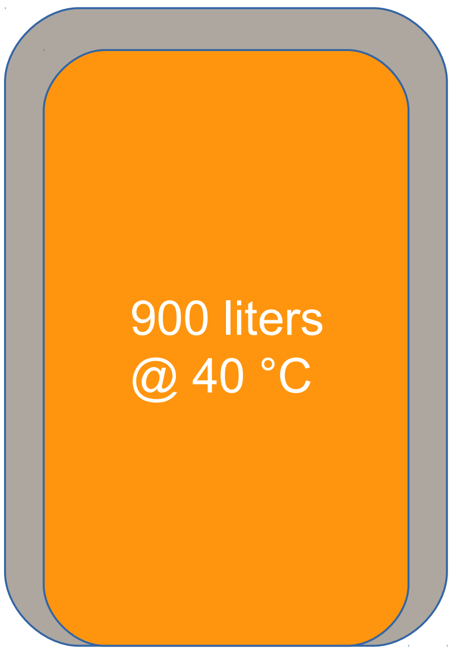
Q_{sto} =112860 [kJ]

Storage: water tanks

Stratification

Energy content:

What is the required auxiliary energy input (from boiler!) needed to supply 450 liters @ 45°C in each case?



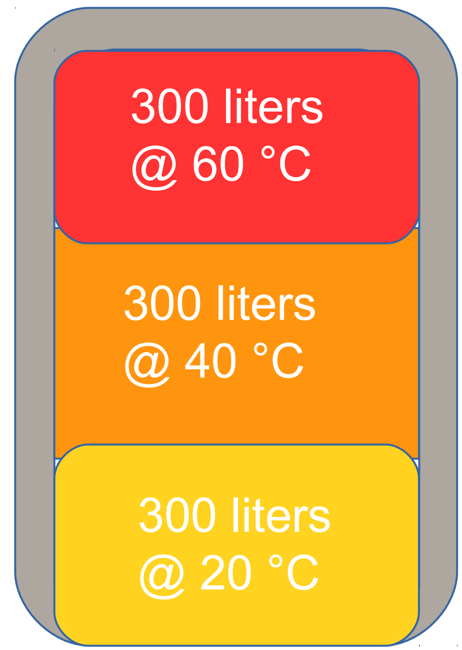
T_{surr} = 10 [°C]

Q_{aux} = 9405 [kJ]

Cold water mixing:
xy liters @ 60°C
& xy liters @ 10°C

Q_{aux} = 0 [kJ]

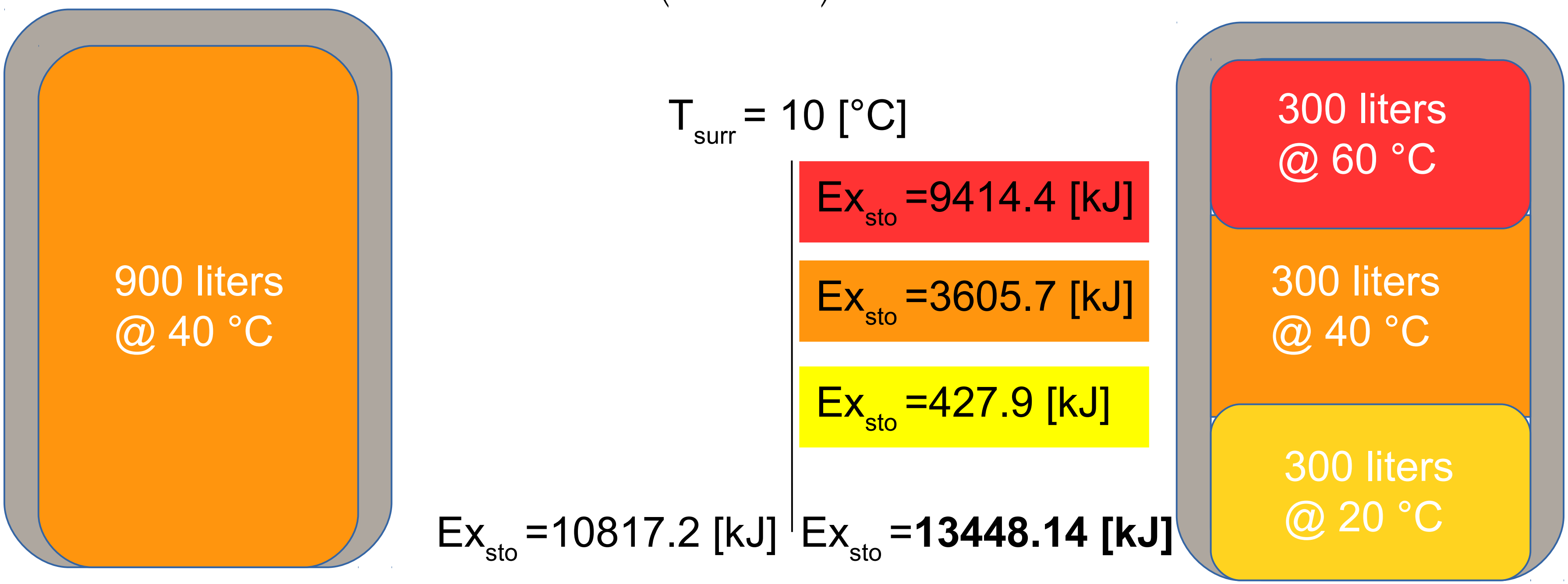
Q_{sto} =112860 [kJ]



Storage: water tanks

Stratification

EXergy content: $$Ex_{sto} = Q_{sto}\left(1 - \frac{T_0}{T_{sto}}\right)$$

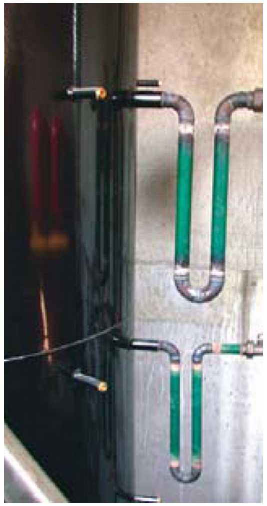


Q_{sto} =112860 [kJ]

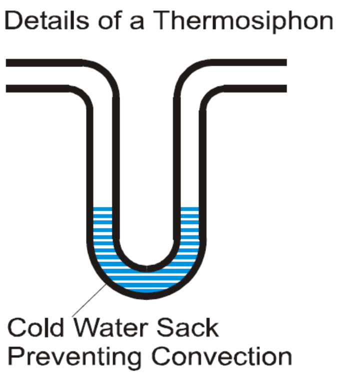
Storage: water tanks

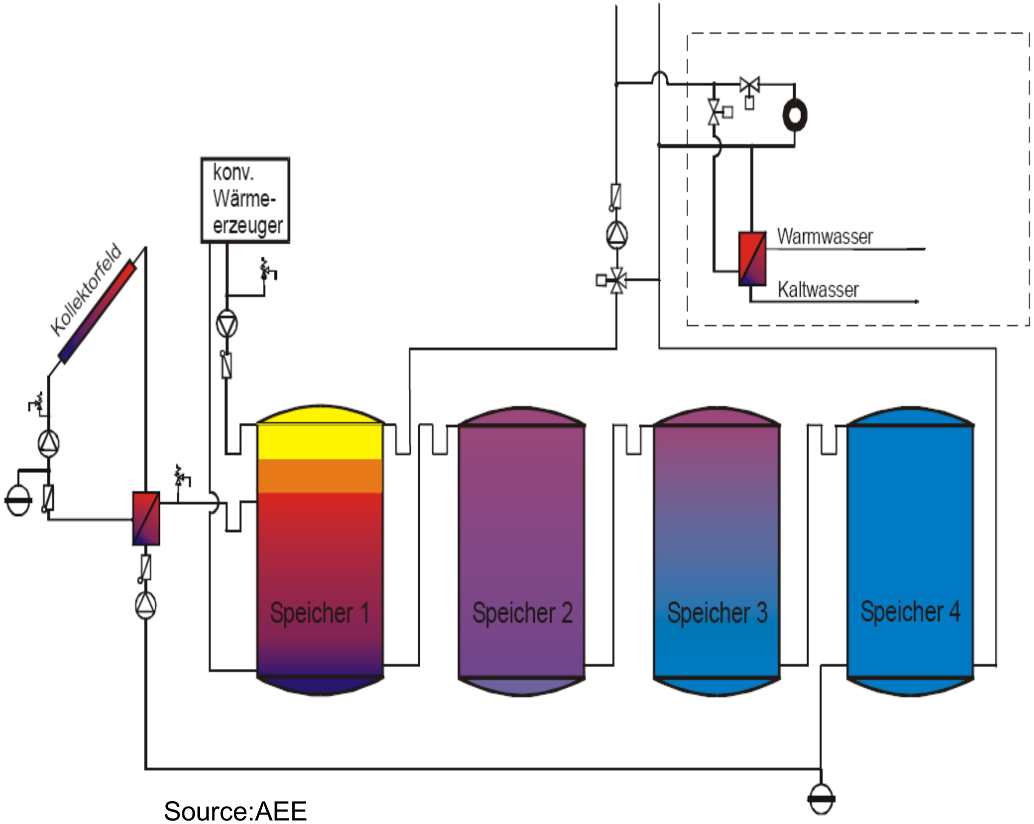
Stratification and losses

- **Single storage tank** is preferrable! – less losses (less insulation problems)
- If not possible: series connection



Source: AEE





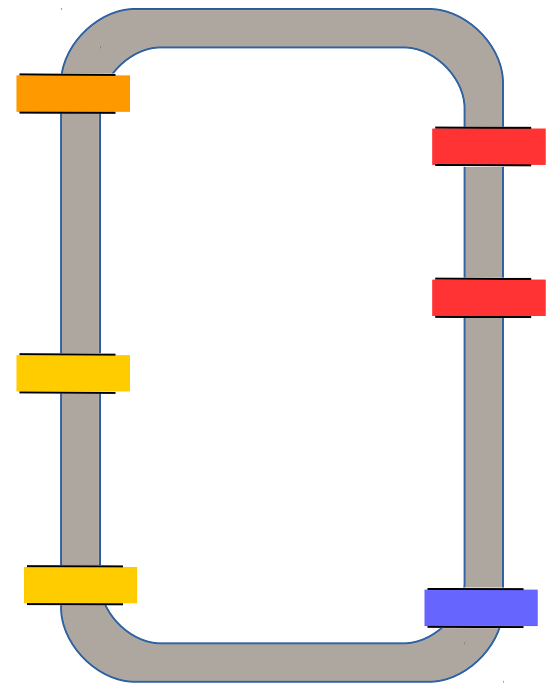
Source:AEE

Storage: water tanks

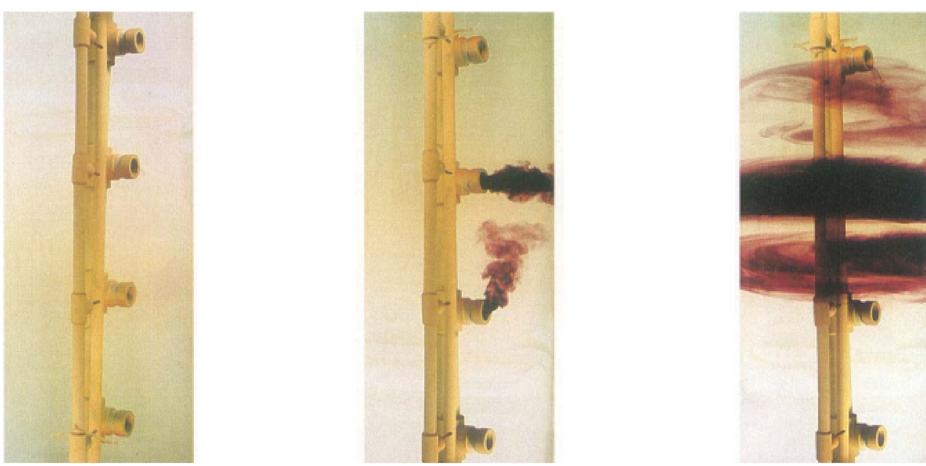
Stratification and losses

Strategies to promote stratification

- external heat exchangers (with stratifiers)
- Appropriate H/D ratio: 2-4
- Draw-offs DHW (@45-60°C): upper part
- Draw-off SH (@30-45°C): middle part



stratification system — solar input — stratified layer



Source: Holtorf, 2014.

Storage: water tanks

Sizing rules of thumb

Water storage tanks:

- **SH+DHW: 50-100 l/m²** (Heimrath)

- **SH+DHW (high solar fraction): 120-150 l/m²** (Remmers)

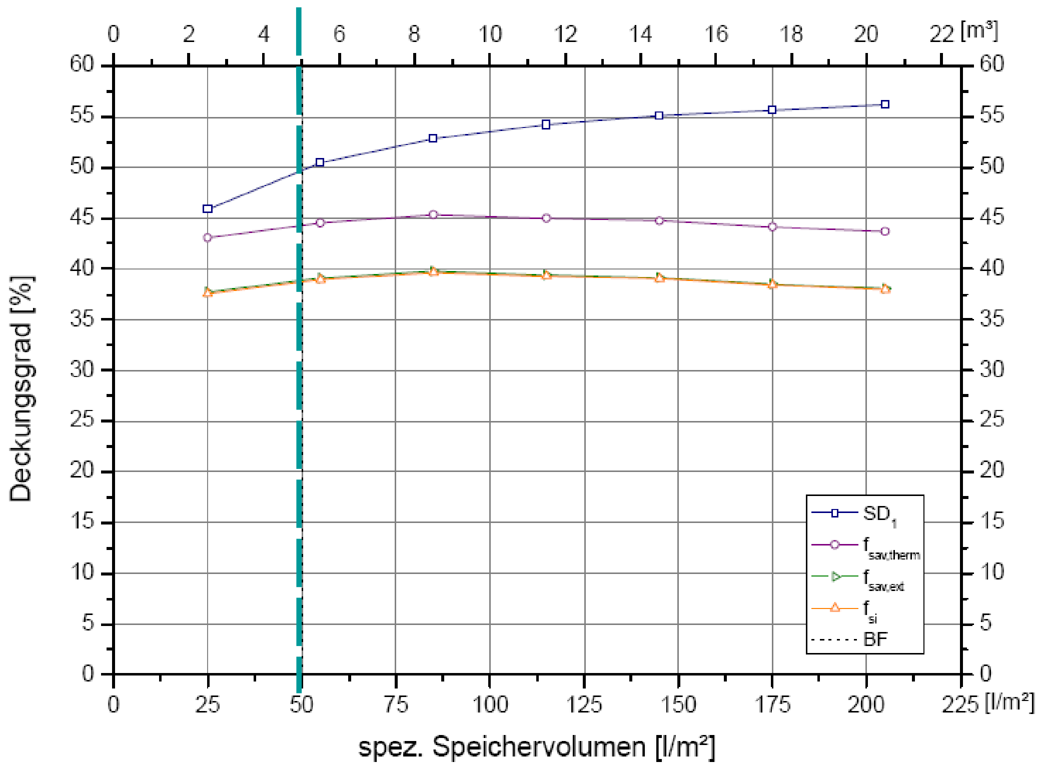
- **SEASONAL STORAGE: 1400-2500 l/m²** (Benner et al.)

H/D ratio: 2-4 to promote natural stratification and reduce losses

Storage: water tanks

Influence on system performance

- Increasing storage size increases solar fraction: more solar energy stored available for demand
- **Threshold:** storage losses and auxiliary pumping energy also increase!!!



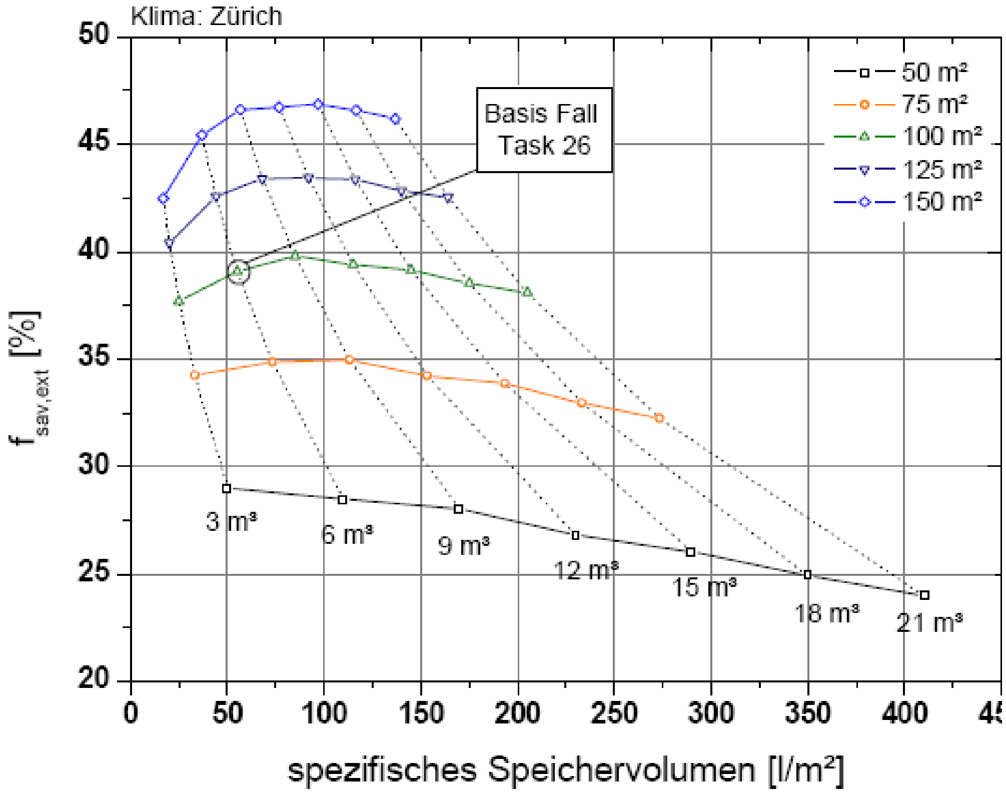
Source: Heimrath, 2004

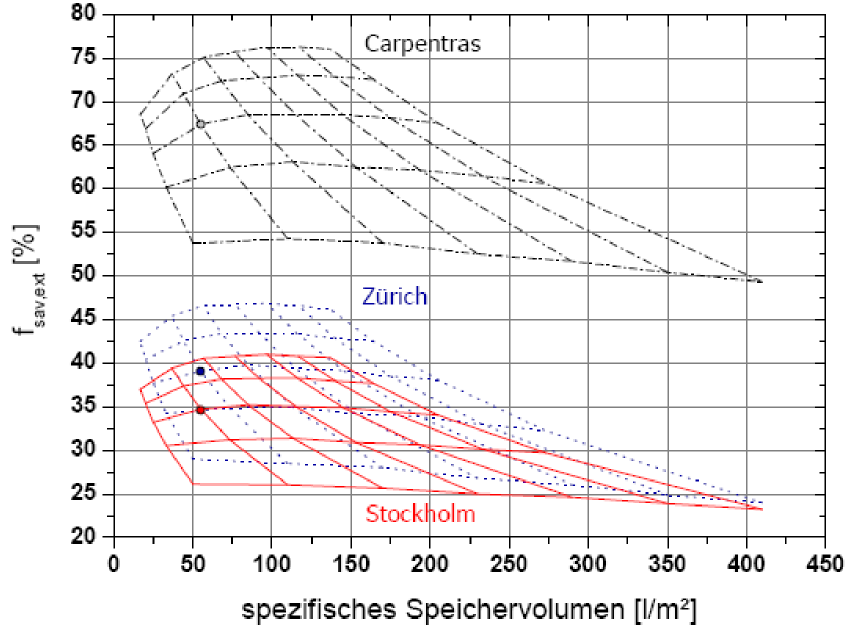
Base case: 100 m2 coll.; 50l/m²

Storage: water tanks

Influence on system performance

Storage size + Collector area (+Climate)





Source: Heimrath, 2004

References

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