Vacuum Super-Insulated Heat Storage for High Solar Fraction

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Objectives

Development of a high efficient sensible heat storage for solar applications:

- Reduction of heat losses
- Increase energy density by increasing the operational temperature range e.g. 40/95 °C to …/130-150 °C
- Improve the performance by stratification

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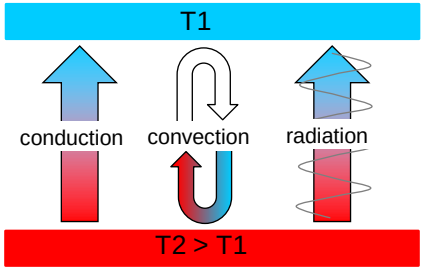
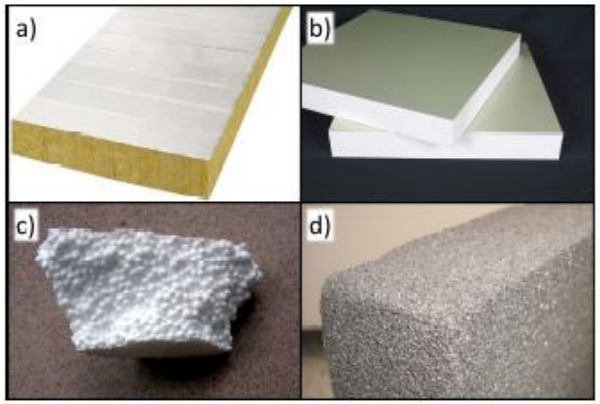
Thermal Insulation

Heat transport mechanisms:

- Conduction
- Convection
- Radiation



Conventional insulation materials reduce this heat transport significantly



material		thermal conductivity (20 °C)
a	rock / glass wool	0.032 … 0.045 W/(m*K)
b	polyurethane	0.024 … 0.035 W/(m*K)
c	polystyrene	0.030 … 0.050 W/(m*K)
d	foam glass	0.040 … 0.050 W/(m*K)

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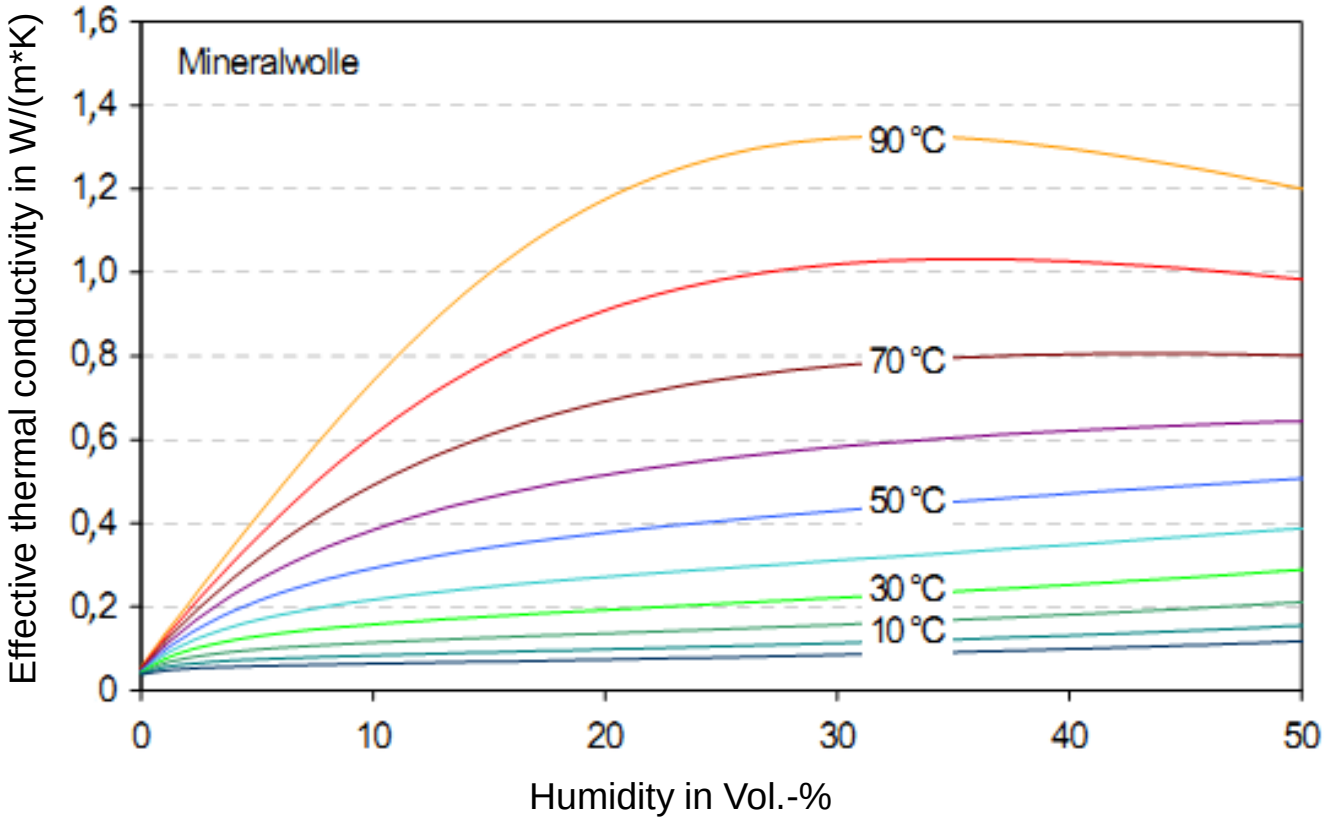
Conventional Insulation and Humidity



- thermal conductivity up to 30 times higher, even above λ_{water}, even for low humidity, extremely critical above 70°C - 90°C
- F. Ochs et al., J. heat mass tr., http://144.206.159.178/ft/490/589701/12094719.pdf

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Vacuum Insulation (VI) („Thermos Flask“)

- double walled container
- evacuation of the annular space below 10^{-3} mbar
- no convection, no gas thermal conductivity

$$\dot{Q} = \frac{A\,\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)}$$

- only heat transport by radiation (dependent on emission ε of the walls and independent of the wall distance d)
- advantage with respect to conventional insulation only for small gaps

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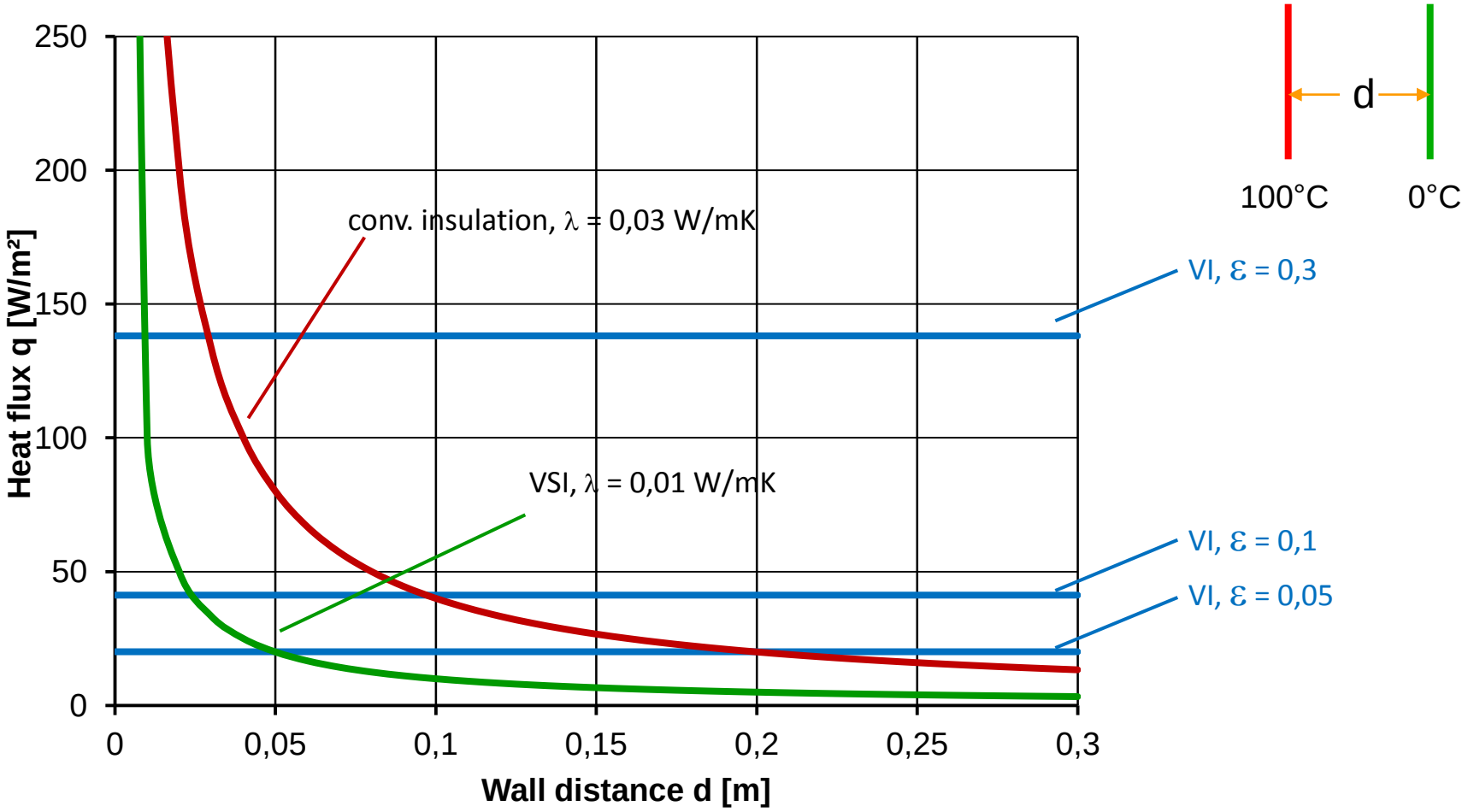
Comparison of Insulation Techniques



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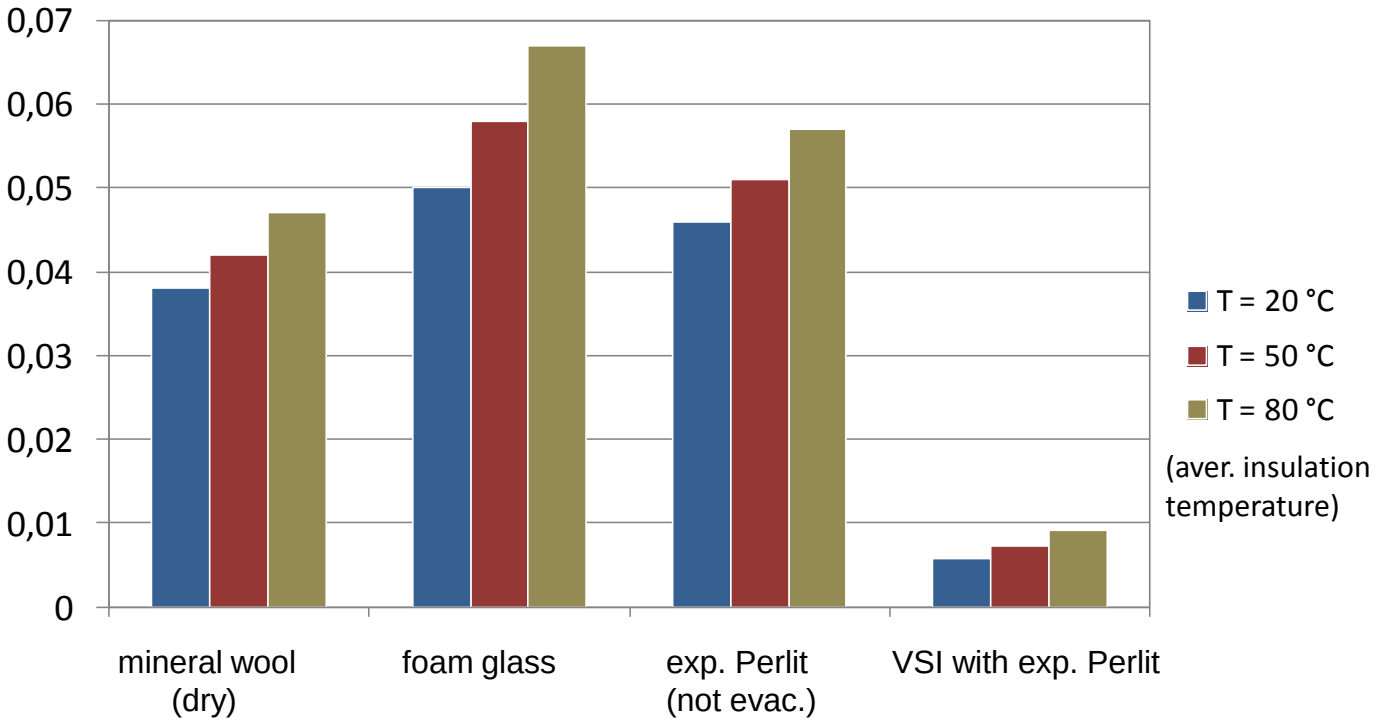
Comparison VSI vs. Conventional Insulation

Source: VDI-Wärmeatlas, own measurements for VSI insulation



⇒ **reduction of thermal conductivity by a factor of 5 - 7**

⇒ **avoid problems with humidity and aging**

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Heat Transport in VSI

convection
gas therm.
conduction

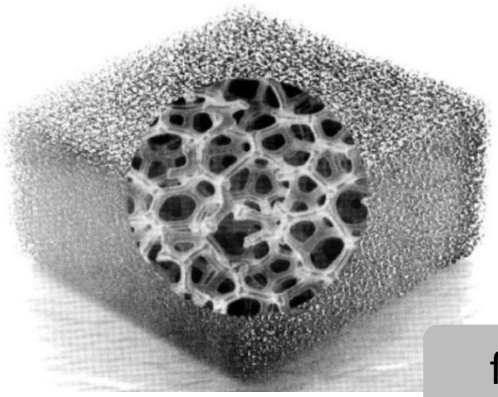
therm.
radiation

solid state
conductivity

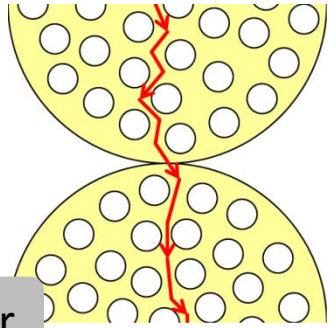
evacuation

absorption +
scattering

smallest
contact area,
“deviation”



vacuum super
insulation



foam | fibers | foils | powder

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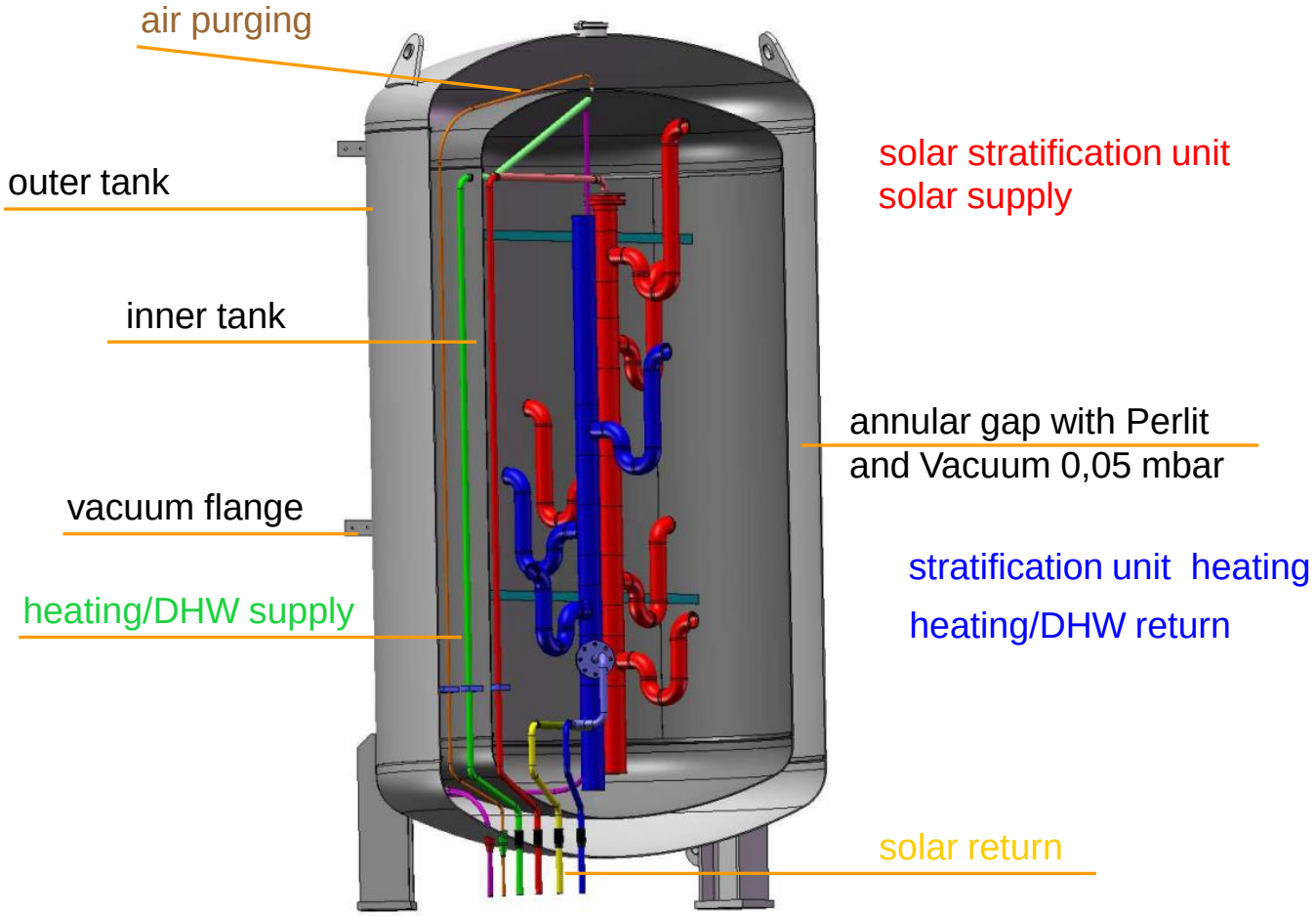
Construction of a VSI Solar Storage



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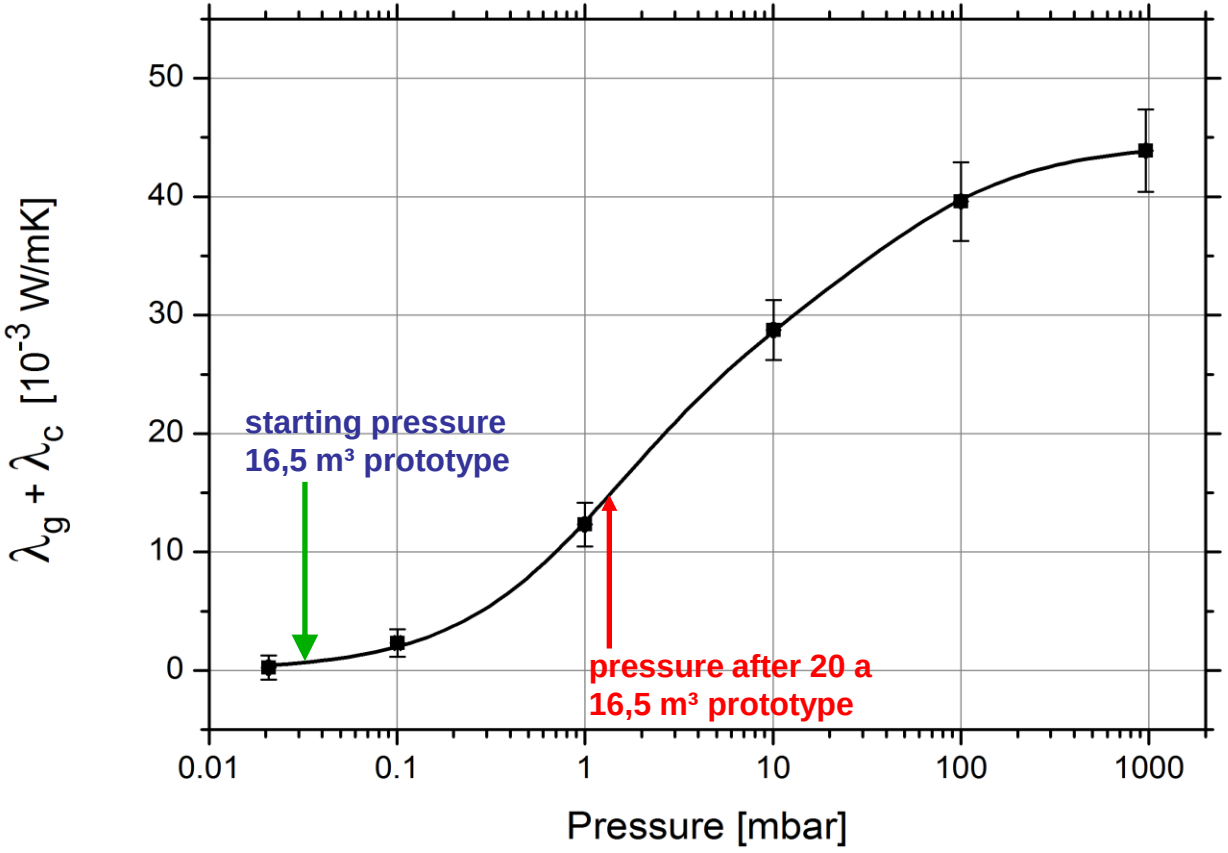
Measurement Result: Thermal Conductivity



After 20 years 1,4 mbar -> Perlit: λ = 0,020 W/mK, pyrogenous silica acid: 0,005 W/mK

3 times better than dry mineral wool, re-evacuation easy possible

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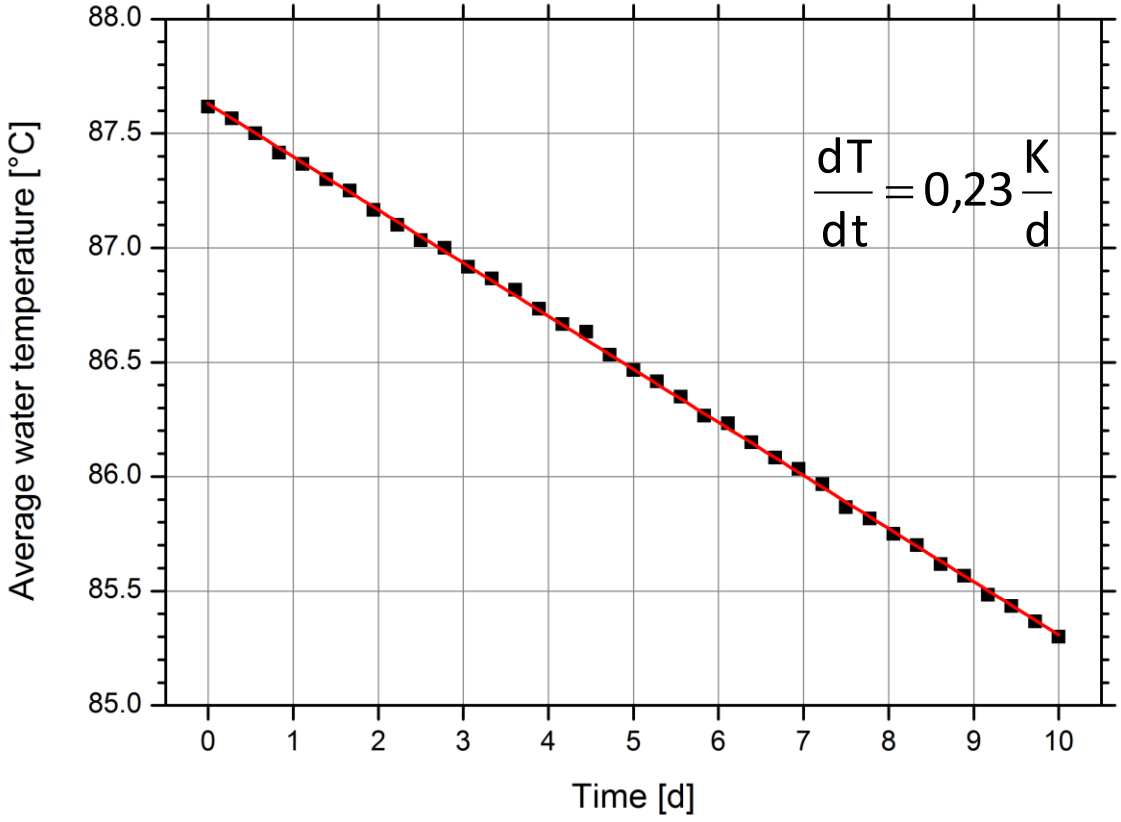
Heat Losses Measurements



UA-value = 1,98 W/K, including pipes, connections and support of the inner tank
λ of the insulation = 0,009 W/mK, potential to 0,007 W/mK

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Temperature Stratification

Two ways of heat supply to the storage:

- Indirect supply via heat exchanger (left)
- Direct heat supply by charging the fluid layer wise (right)

indirect system

direct system

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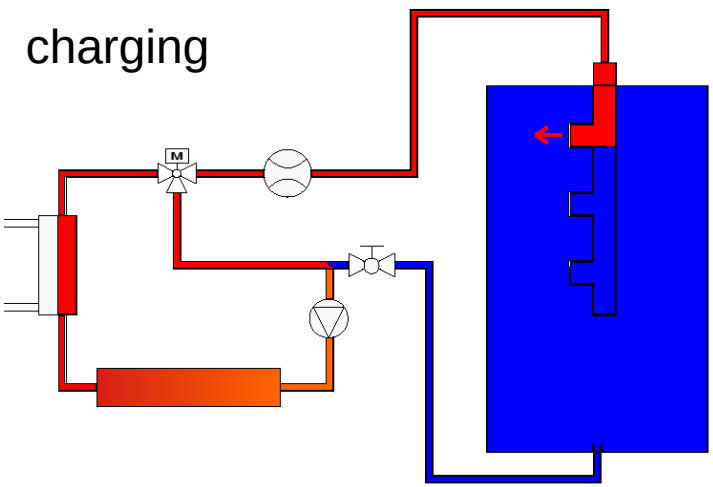
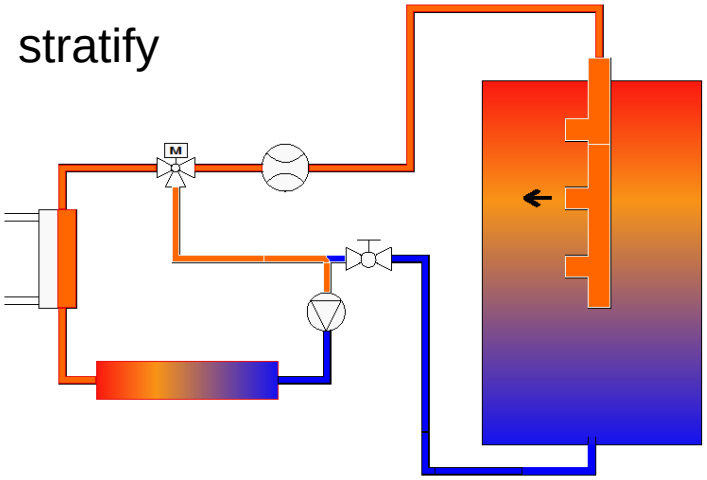
Temperature Stratification

Stratification:

1. Development of a temperature stratification during charging

2. Supply the fluid in a stratified storage to the layer of the same temperature without destroying of the stratification





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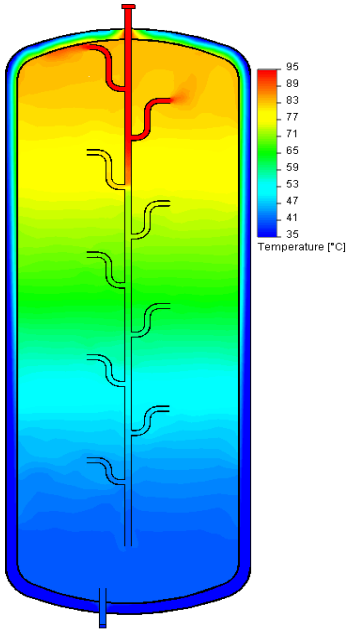
Temperature Stratification

- **Temperature stratification has operational advantages**
  Ideal case: discharge the total heat content at a high temperature level
- **Operational advantages** (higher efficiency) for heat supply by solar collectors, heat pumps or condensing boilers
- Increases the direct use of solar heat
- Important feature for VSI storage because of low losses



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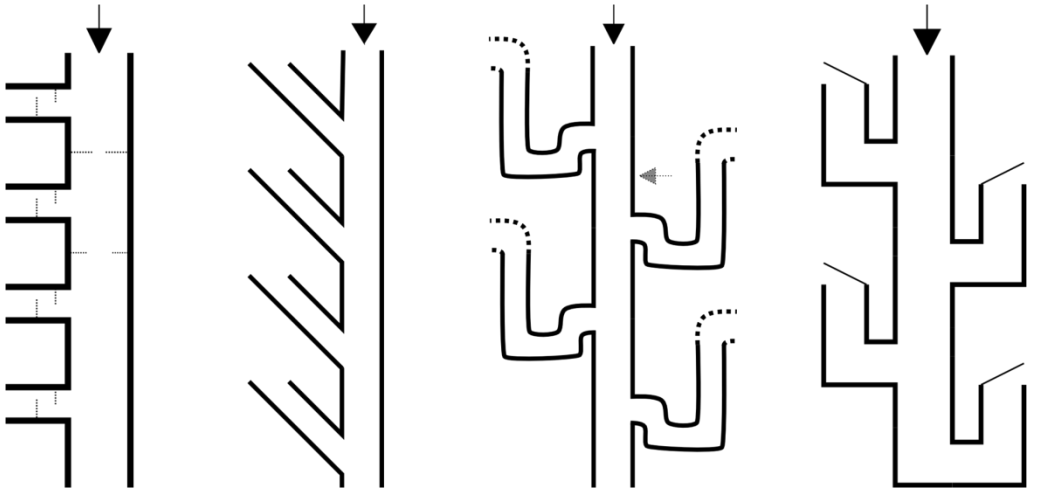
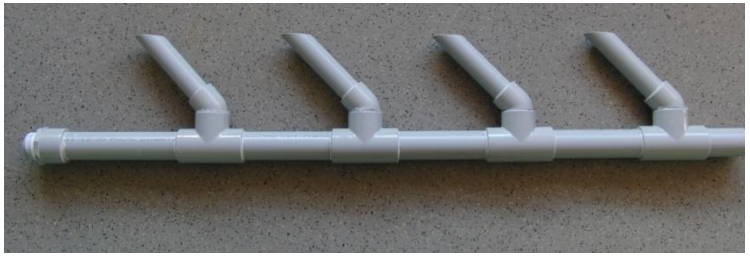
Test of Various Stratification Units



SB 1

SB 4



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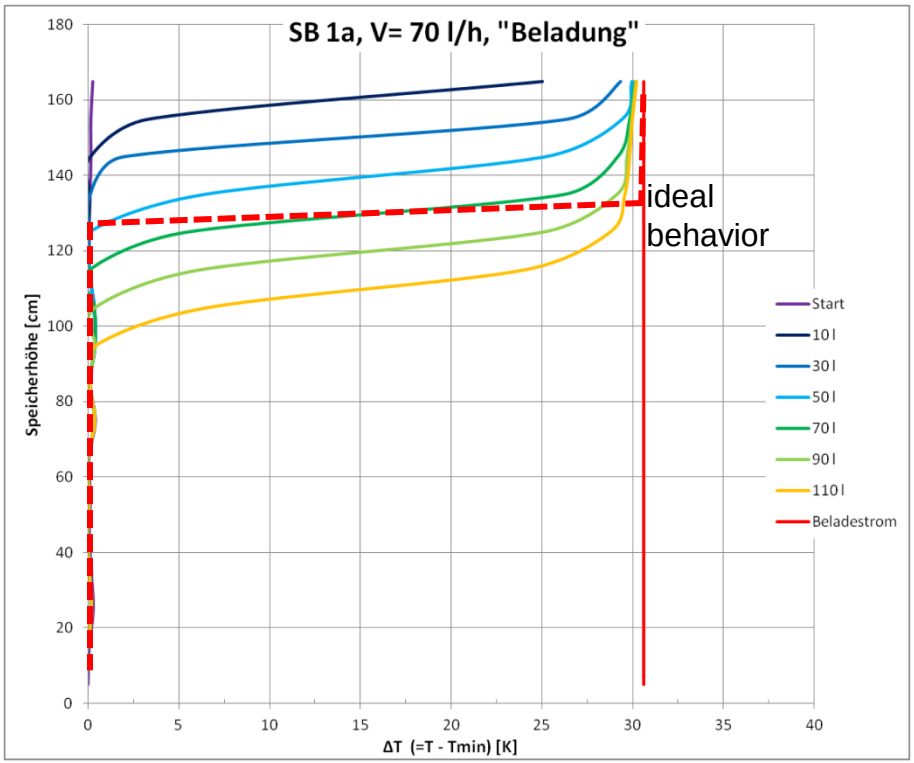
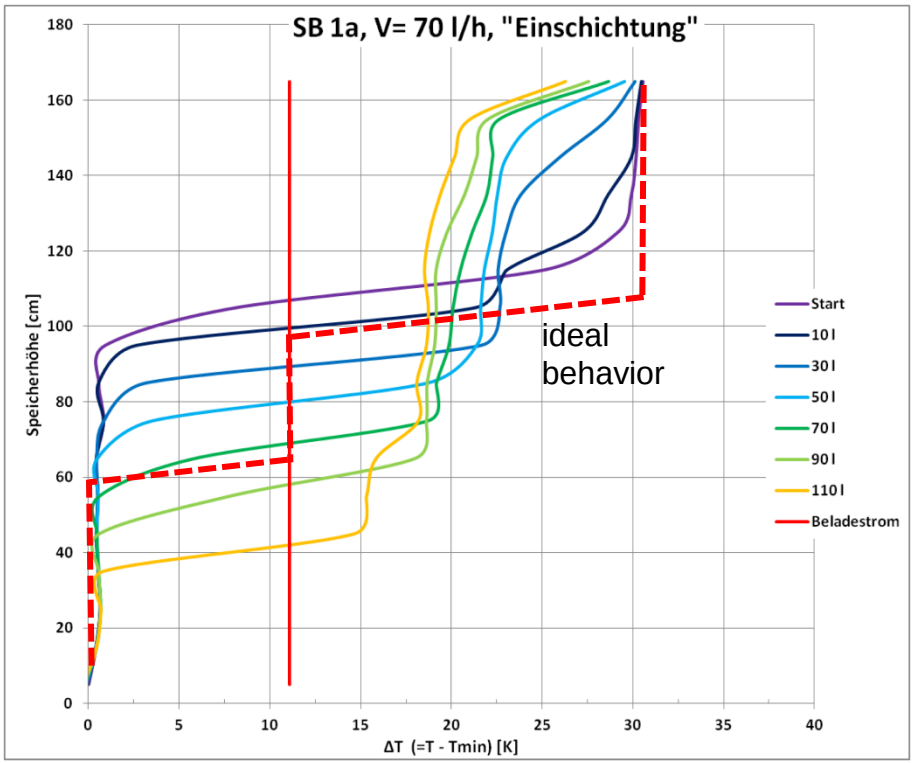
Experimental Results

SB1





OK

poor – mixing of the upper 2/3

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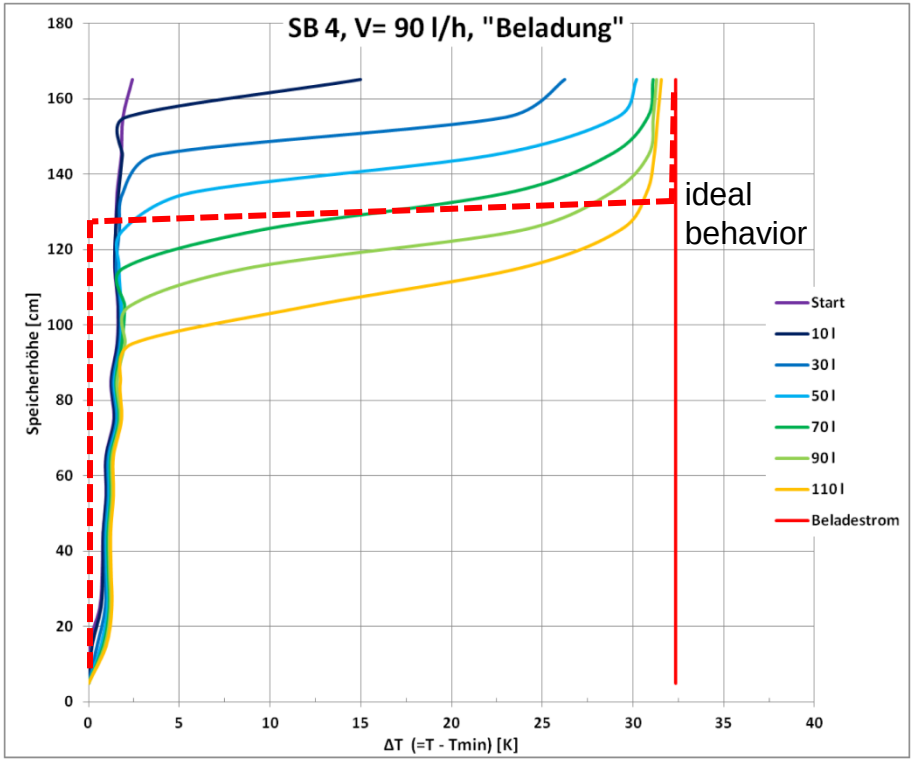
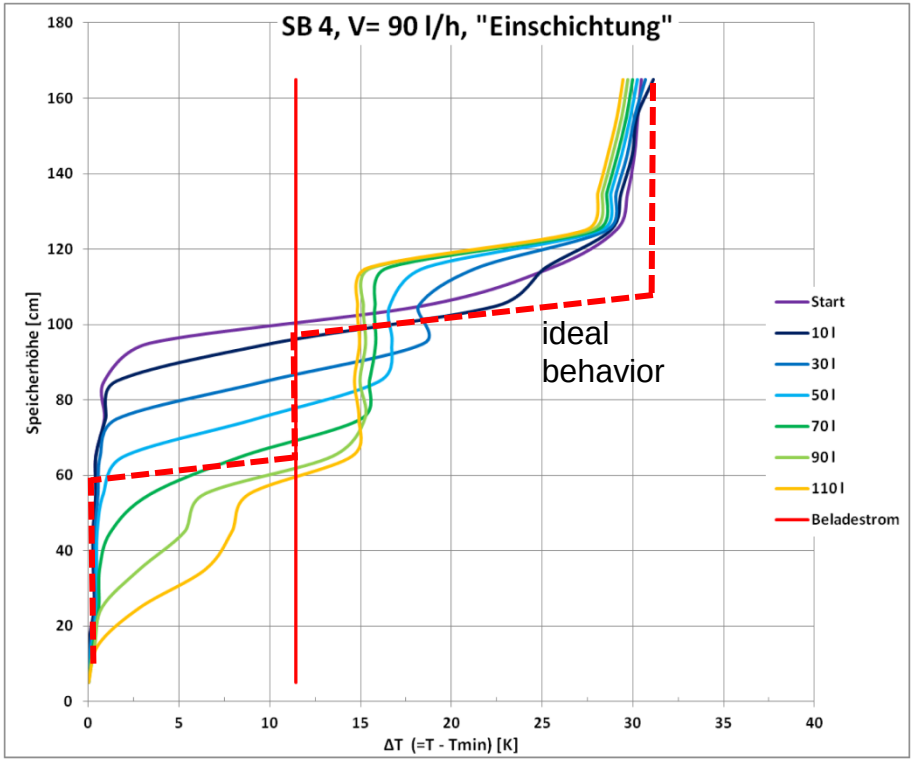
Experimental Results

SB4





OK

almost perfect

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Pilot Storages Produced According to AD2000

Hummelsberger Schlosserei GmbH Am Industriepark 5 84453 Mühldorf am Inn		Hummelsberger STAHL- UND METALLBAU	
Doppelwand Behälter	am 11.06.2012 **0,35 mbar** im Zwischenraum	CE	-1182
Hersteller Nr.	**665**	Vakuum-Pufferspeicher.de **VSI** Vakuum-Super-Isoliert	
Baujahr.	**05-2012**	Inhalt Liter.	ca. **7000**
Projekt Nr.	**110**	Prüfdruck.	**7,0 bar**
Betriebsdruck **max.**	**3,5 bar**	Betriebs. Temp. **min.-.max.**	**5°C - 105°C**
Leergewicht.	**3540 kg**		
Behälter nach EG Richtlinie 97 / 23 EG und AD-2000 Merkblätter			

Bayerischer
Staatspreis

63. Internationale
Handwerksmesse
München 2011

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Solar Space Heating Application

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Solar Space Heating Application

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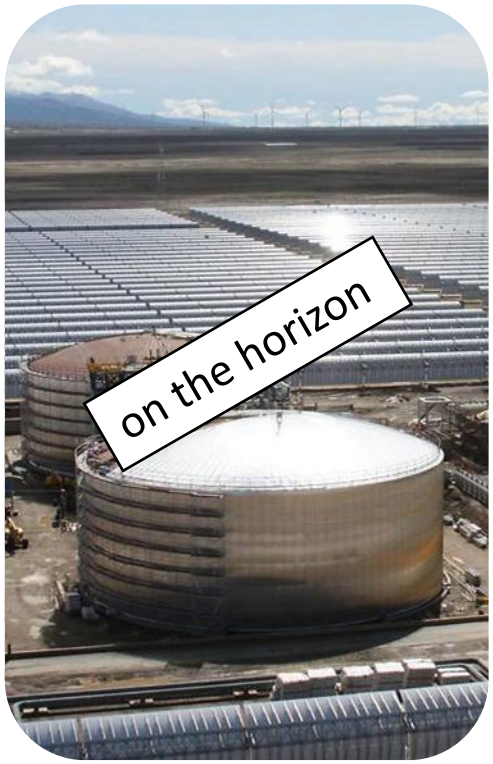
Applications of VSI-Technology

seasonal storage

up to 100 °C

industrial process heat

100 - 300°C



solar power plants

400 - 700°C

Bildquelle: Wikipedia

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Conclusions

VSI storage is applicable for

- sensible
- latent
- thermo-chemical storage

VSI storage allows

- long-term storage with low heat losses
- solar space heating and DHW with high solar fraction

It is especially interesting for higher storage temperatures and interesting for industrial applications

- process heat e.g. food industry
- waste heat and heat recovery
- district heating

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