Storage solutions for solar thermal energy

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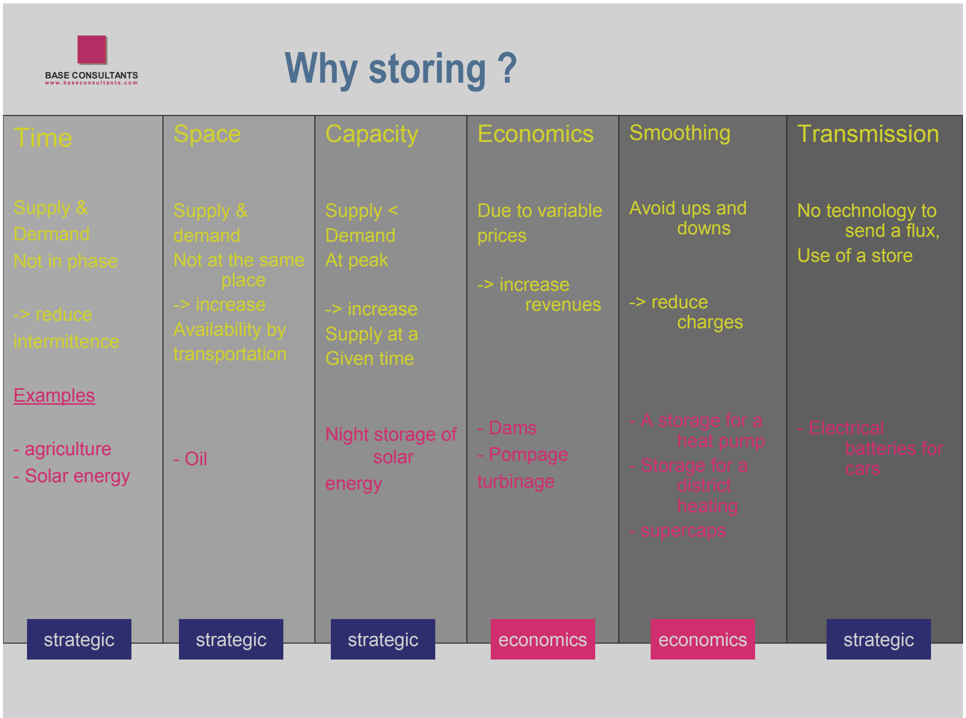
1. Introduction

There are 2 fundamentals objectives why energy needs to be stored:
Economics and strategy!

A store is based on economics when it allows:
- To reduce the financial losses
- To induce new revenues.

A store is decided based on a strategical decision when it allows
- To meet a demand that otherwise would not be met
- To meet a demand at a reduced cost, but this brgins back to an economical reason.

Based on these two principles, there are 6 reasons that would make a storage necessary:



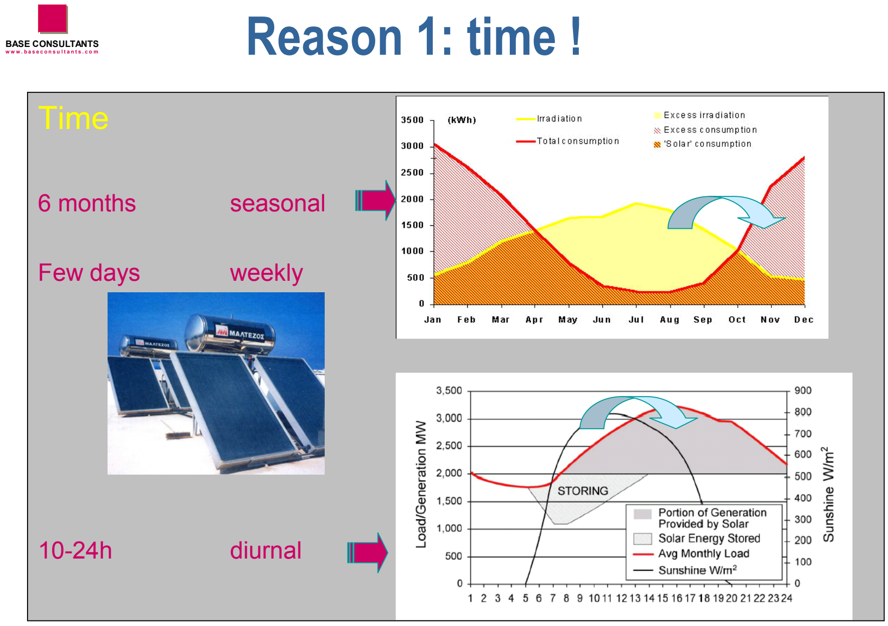
The need for storing energy can be derived from 6 basic reasons (IEA SHC Task 32, Hadorn).

Solar heat storage derives basically from time and space, non-simultaneity of supply and demand.

2. Time and scale

The two main causes for storing heat are:

- Time: diurnal, weekly, seasonal storage. Diurnal storage (1 to 24 hours) is very well studied and developed for solar thermal installations. Weekly storage is seen to be not economical, but some projects make use of a much bigger store than strictly necessary for a 1 or 2 days storage, storing for 2 or 3 weeks to overcome November and sometimes December cold conditions. Seasonal storage has been searched for some 30 years and is one key of the future development of solar energy. We have no generic solution at present, although there are possibilities for large systems to reach 100% solar with a seasonal storage at an acceptable cost. We will see these solutions in a special chapter



- Space: production is not at the location of consumption.
  Example: the solar field in Marstal (Denmark) has more than 9'000 m^2 of collectors. The consumers are located along a 5 km district heating network (diameter 40 cm) that can play partly the role of storing the solar heat. A 2 000 m^3 water store is buffering the solar field production. What is in comparison the storage capacity of the network ? (make adequate assumptions)
  - Suppose the temperature swing can be 30 K i.e. from 60 to 90°C and than in a sunny day the solar power collected is 500 W/m2 on average
  - Storage time of buffer:
    2000 m^3 * 1.163 kWh/m3 K * (90-60) K / (9000 m^2 * 0.5 kW/m^2) = 15 hours
    say one day of solar production !
  - Storage volume of network: 5000 m * 3.14 * 0.4^2/4 = 628 m^3 which would give a 5 hours supplementary buffer

3. Storage of heat: an overview

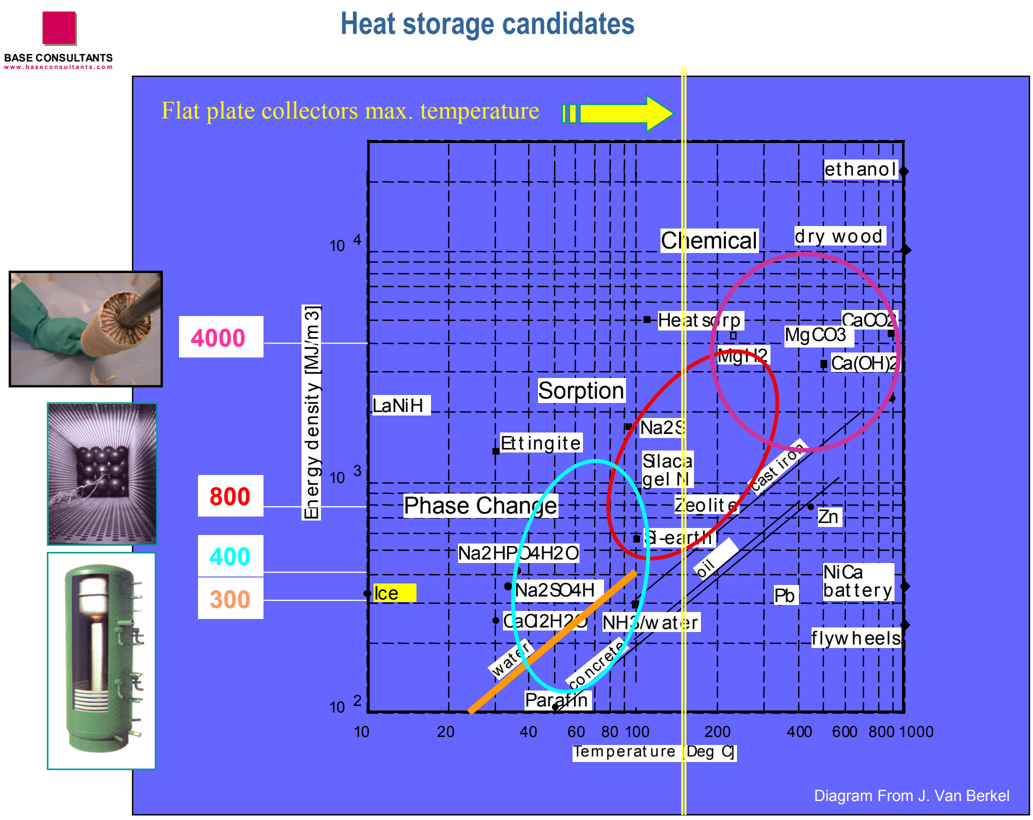
A tent is not known as a comfortable structure in summer. And an igloo is better even in summer. Why ?

	Thermal conductivity @20C	Density @20C	Volumetric heat capacity @20C	Thermal diffusivity @20C
	W/mK	Kg/m3	10+6 J/m3	10-8 m2/s
Air	0.025	1.29	0.001	1938
Water	0.6	1000	4.180	14
Ice	2.1	917	2.017	104
Gasoline	0.15	720	2.100	7
Methanol	0.21	790	2.500	8
Aluminium	237	2700	2.376	9975
Copper	390	8960	3.494	11161
Stainless Steel	16	7900	3.950	405
Concrete	1.28	2200	1.940	66
Marble	3	2700	2.376	126
Glass	0.93	2600	2.184	43
PVC	0.16	1300	1.950	8
PTFE	0.25	2200	2.200	11
Sand (dry)	0.35	1600	1.270	28
Sand (saturated)	2.7	2100	2.640	102
Wood	0.4	780	0.187	214
Cork	0.07	200	0.047	150
Foam glass	0.045	120	0.092	49
Mineral insulation materials	0.04	100	0.090	44
Plastic insulation materials	0.03	50	0.100	30

Thermal properties of some materials for storage by sensible heat

Thermal properties of materials are of major importance as well as the thickness of the material according to Fourier's law.

Water is a good candidate for all kind of heat storage in the range -30 to 200°C. It has been used as such since decades.



Energy density of some storage material: 3 ranges emerge as competitors to water: PCM, Sorption and Chemical storages.

Important criteria for the storage itself in a solar installation are:

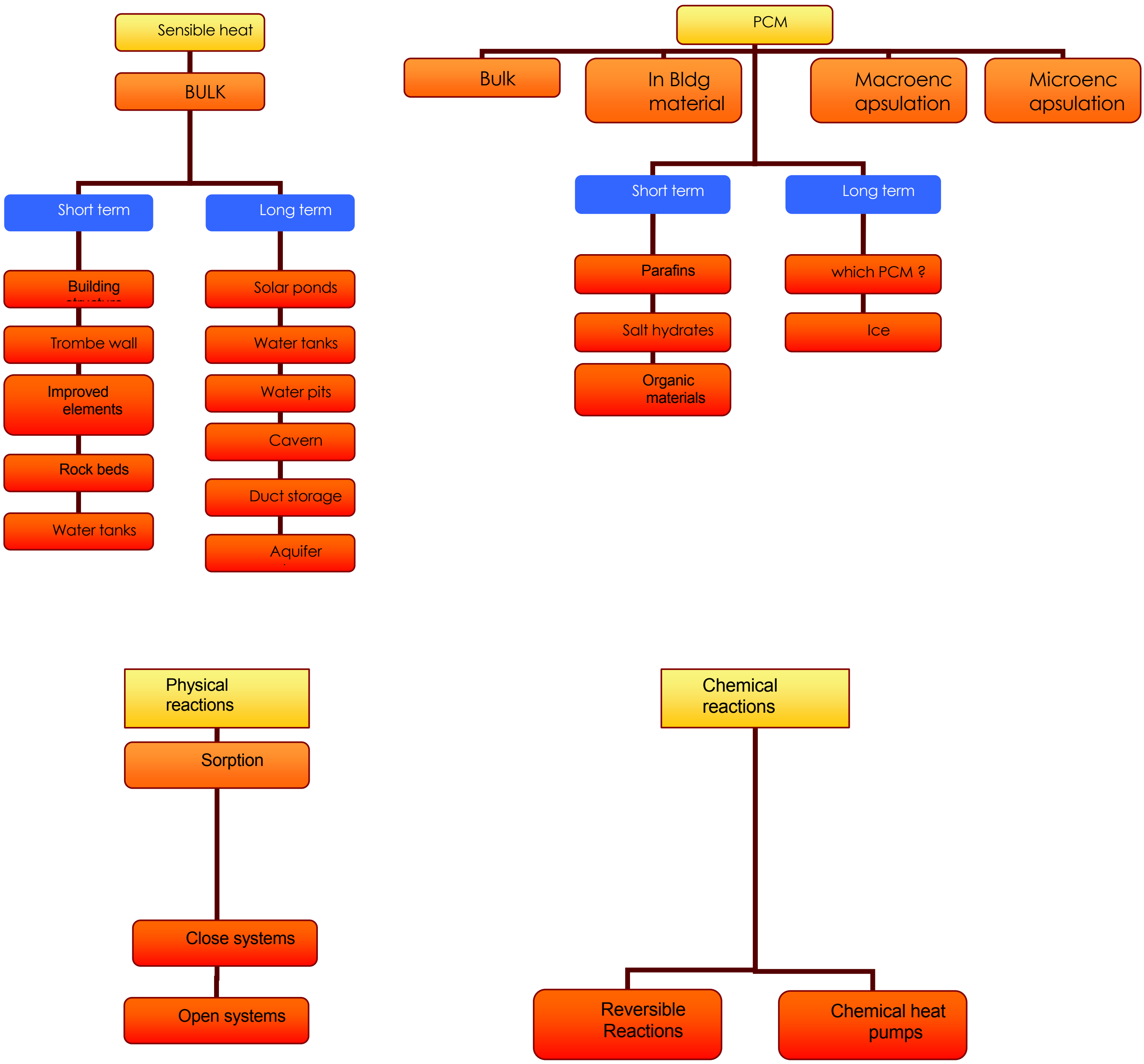
1. Capacity and density (kWh/m3 = kWh/kg * kg/m3)
2. Loading and unloading rate (kW)
3. Efficiency of storage (Eout/Ein, Eout = Ein - Losses)
4. Stability (mechanical, chemical)
5. Chemical compatibility with the container and exchange loop
6. Reversibility during a number of cycles
7. Cost (cts€/kWh): material, container, room needed, access, maintenance, number of cycles achieved
8. Toxicity
9. Recyclability, assessed through a Life Cycle Analysis

The storage material is not the only component of a storage. The heat exchanger plays a crucial role since heat has to be injected into the store when it is available (say noon during a solar day) and withdrawn from the store at peak conditions. The heat exchanger should therefore satisfy three basic criteria:

1. Rating (max power in and out)
2. Hydraulic head losses (should be in accordance with the pump capabilities)
3. Cost (it is always an optimisation parameter).

According to this list of criteria water will be hard to beat for storing low grade solar heat.

A general classification of low temperature storage technologies is shown in the next figure::



4. Storage using the building structure

To collect solar heat, building windows are effective. In order to avoid high temperature swing, thermal mass must however be present inside the protected volume, i.e. inside the insulated envelope. Internal thermal mass can be used from 19 to 24°C, hardly more.

Suppose you have 10 m2 of south facing glass windows. What should be the available volume concrete to absorb 5 hours of sunny radiation without sun protection and with normal transparent double glazing.

V = 10 m^2 * 0.5 kW/m^2 transmitted * 5 hours / ((24-19) * (1.940/4.18 * 1.163 kWh/m^3 K)
V = 25 kWh / 2.7 kWh/m3 = 9.2 m^3

Suppose a 20 cm slab or wall, its surface should be at least : 9.2 / 0.2 = 46 m^2 exposed to the incident solar radiation.

Depth of penetration is however limited and all the thickness of a wall or slab cannot be used during a daily cycle.

For concrete it has been shown that only the first <u>10 to 14 cm can be really used</u> for a diurnal storage.

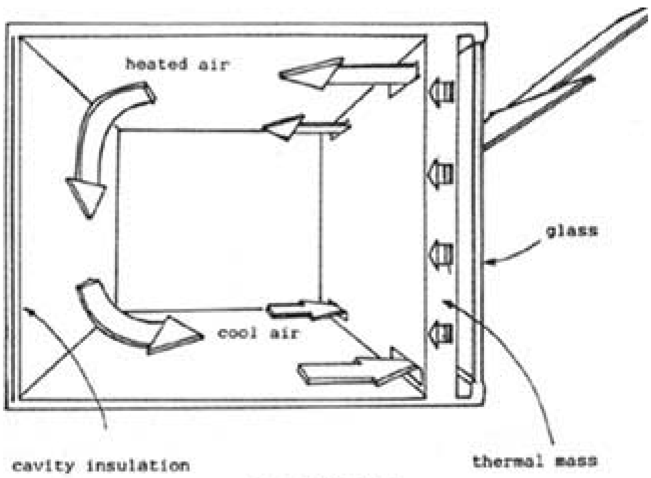
In our example the necessary wall area becomes then <u>70 m^2</u>, free of carpets, paintings, furniture, wood or other thermal and radiation barriers.

Any measure that can improve thermal mass in a building favours the comfort.

<u>Trombe walls</u>

In 1956, Felix Trombe with the architect Jacques Michel invented a wall that could be used for collection and storage. A “Trombe” wall is a south-facing wall built of massive material such as stone, concrete, or adobe which collects heat from the sun to release it gradually into the interior of the building. It is an example of passive solar heating.

A typical Trombe wall consists of an 20 to 30 cm thick masonry wall coated with a dark, heat-absorbing material and faced with a single or double layer of glass. The glass is placed about 1 to 15 cm away from the masonry wall to create a small airspace. Heat from sunlight passing through the glass is absorbed by the dark surface, stored in the wall, and conducted slowly inward through the masonry.



The Trombe Wall

Principles of a Trombe wall can be found at http://www.tew.org/images/trombe.wall.jpeg.

Unfortunately the jewel would have been to collect solar, store it, insulate at night and deliver the stored heat on demand.

The Trombe wall. in its original form and simplicity cannot achieve these four functions. It is best suited in cold and sunny climate (winter in mountains), but in combination with a night insulation.

PCM in walls

To improve storage several solutions of PCM (phase change material), embedded or not, into construction elements have been invented and tested since more than 30 years.

PCM (Chliarolithe in polyethylene containers) in the masonry of concrete blocks have been tested. PCM in tubes in walls or at the ceiling have been also tested. Paraffins in gypsum board have deserved much R&D attention in the 80s but due to their flammability were abandoned.

Today 2 types of PCM solutions for storing into the structure of a building might see a future on the market:

- cool ceilings.
- PCM in microencapsulated balls inside a concrete wall

Climator (www.climator.com) is marketing a so called ”cooldeck” system that keeps the low temperatures in the night and releases the coolness during the day. Its product called ClimSel C24 that changes phase at 24°C. (75°F) This means that air at a temperature of 20°C (68°F) or lower makes the material solid.

At daytime when the temperature goes up, the solid material melts while releasing a lot of coolness. This will cool down the temperature in the office.

Coldeck cassette with ClimSel C 24

The Cooldeck cassette is a holder of the PCM.
The ClimSel CoolDeck Pouches is an aluminium laminate pouch filled with phase change material (PCM)*.
The main ingredients are sodiumsulphate and additives.
Installed in a room or cabinet this is a uinque component for stabilising the temperature at 24° C (75 deg F).

Physical data for the Cooldeck cassette

Length:	2375 mm
Width:	556 mm

Two ClimSel modules is fitting in one cassette.

Physical Data for one module of ClimSel CoolDeck C 24

Phase Change Temperature:	24 C
Maximum temperature:	50 C
Storage capasity 19-29 deg C:	173 Wh
Latent Heat of Fusion:	163 Wh
Specific Heat appr. In PCM :	1 Wh/ C
Specific gravity:	1,45 kg/l
Thermal conductivity:	0,5-0,7 W/m/ C
Wieght:	5,8 kg
Thickness:	15 mm
Lenght:	1090 mm
Width:	490 mm

The advantage of storing into a PCM at 24C is that the PCM stays at the same temperature while absorbing heat when it becomes liquid, and the same remark is true when discharging (solidifying).

PCM in microencapsulated polymers are about to come on the market. They can be added to plaster, gypsum or concrete to enhance the thermal capacity of a room, at a pre-defined temperature (22 or 24C).

Rock beds

Storage of air heated by a solar air system can be achieved in rock beds. The blocks of rock are between 1 to 10 cm diameter. Air is blown through the bed at low speed to heat up the rocks.

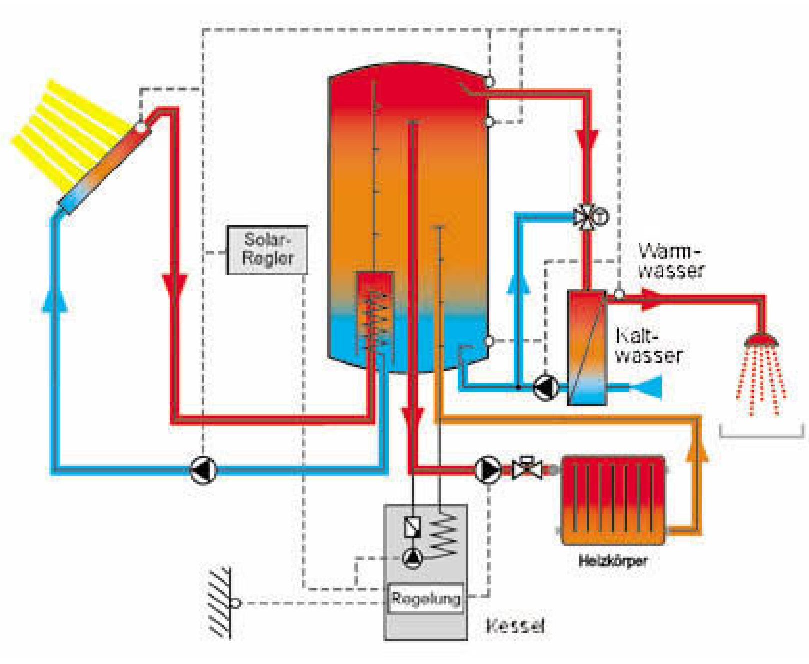
Several solar houses have been built on this principle and works to satisfaction. It is not seasonal storage, and needs a air collecting and distributing system. Water solutions for storage are preferred because water collectors are more efficient than air collectors, and water can transfer much higher power rates than air.

5. Water tanks for diurnal storage

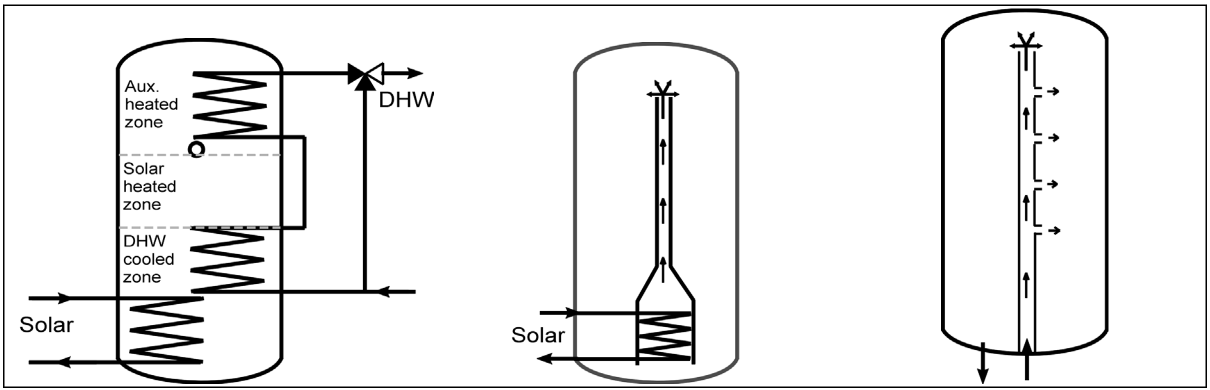
The most cost effective way of storing solar heat is water tanks. Water is a cheap and convenient material and tanks ranging from 50 to 1000 l are built by millions each year for the HVAC market.

A modern solar tank combines several specific features that improve the overall efficiency of storing solar heat:

- Few thermal bridges
- Enhanced insulation, even vacuum insulation in the future
- Improved bottom insulation
- Siphon introductions pipes to avoid natural convection losses
- Reduced number of connections to avoid thermal bridges
- Stratification enhancers
- Internal devices to reduce speed of inlet water not to disturb stratification
- Large heat exchangers or mantle heat exchanger



State of the are solar water storage in 2003, the Solvis tank



Three different methods of causing stratification with internal heat exchangers: several internal heat exchangers (left), stratifying tube with multiple outlets (middle left) and stratifying unit with multiple outlets (right). The stratifying unit can be used with an internal heat exchanger or for other inlets that vary in temperature (IEA SHC 32, W. Streicher, 2004)

6. Storage in PCM

The idea of using PCM in a storage tank has been investigated in the 80s with paraffin. Although it works, the advantage is nowadays not strategic since the solar collector has been much improved and are less dependant on the collecting temperature in the range between 50 to 80C than they were. Parafin has also a major drawback, its flammability.

A few manufacturers propose PCM material for storing solar heat on the market (see table).
From 20 to 80°C, there is some choice.

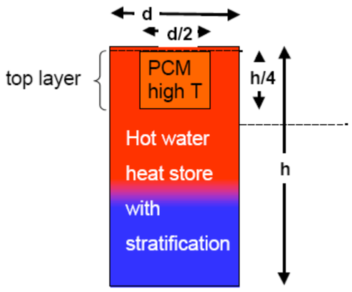
Even from 0°C, the company Cristopia manufacturing polymer balls that encapsulate water for ice storage. The same idea could be applied to a class 50 or 60C material that would end in a ball storage acting with the solar fluid like a rock bed does with air.

PCM name	Type of product	Melting Temp. (C)	Heat of fusion (kJ/kg)	Manufacturer
RT20	Paraffin	22	172	Rubitherm GmbH
ClimSel C 24	n.a.	24	108	Climator
RT26	Paraffin	25	131	Rubitherm GmbH
STL27	Salt hydrate	27	213	Mitsubishi Chemical
AC27	Salt hydrate	27	207	Cristopia
RT27	Paraffin	28	179	Rubitherm GmbH
TH29	Salt hydrate	29	188	TEAP
STL47	Salt hydrate	47	221	Mitsubishi Chemical
ClimSel C 48	n.a.	48	227	Climator
STL52	Salt hydrate	52	201	Mitsubishi Chemical
RT54	Paraffin	55	179	Rubitherm GmbH
STL55	Salt hydrate	55	242	Mitsubishi Chemical
TH58	n.a.	58	226	TEAP
ClimSel C 58	n.a.	58	259	Climator
RT65	Paraffin	64	173	Rubitherm GmbH
ClimSel C 70	n.a.	70	194	Climator

n.a.: not available

Some PCM available on the market for storage of solar heat (from IEA SHC 32, L. Cabeza)

New ideas are to combine PCM material with water in a hybrid storage so that the top part of the storage tank would stay at a maximum of 60C. The optimum position and operating temperature of the PCM is under investigation.



R&D activities tries to enhance the density of storage using a combination of PCM in a water tank or in a two tank system (IEA SHC 32, L. Cabeza).

The cost effectiveness of the solution will still have to be proved.

Exercise: compare an ideal 1 m^3 water tank and an ideal 1 m3 C70 (density 1700 kg/m^3) PCM storage tank in terms of heat capacity over the standard range of a solar combisystem: 20 to 90C

Solution
Water tank capacity : 1 m^3 * 1.163 kWh/m3 K * 70 K = 81 kWh

C70 tank capacity: 1 m^3 * 194 kJ/kg * 1700 kg/m^3 / 3600 kJ/kWh + sensible 1 m^3 * 0.6 kWh/m^3 K * 70K = 91 + 42 kWh = 133 kWh

That is 1,6 times the capacity of the water tank. Will the cost be less than 1,6 times more ?

7. Seasonal storage in large volumes

Seasonal storage is of course possible with sorption and even more with chemical storage. But there is no solution yet.

In the last 30 years seasonal storage has been investigated to reach high solar fractions, up to 100% solar, the final objective.

How big should a tank be to reach 100% solar ?
Many studies have been conducted solve this question. There are a few examples that actually are in operation. In the 80s it was calculated that a seasonal water storage should be as big as half the house, limiting its interest. That was indeed true but what happened is the strong demand reduction for heating a house. Savings of energy prior to investing for a new production device.

For a recent passive house, the volume is much less. With 20 m3 of water it is possible to reach 100% solar in mid-Europe, in average meteorological year. Since climate variations can be as high as 25%, an auxiliary heating system is still recommended. It is interesting to use wood as back up if the user is interested to reach 100% use of renewable energy.

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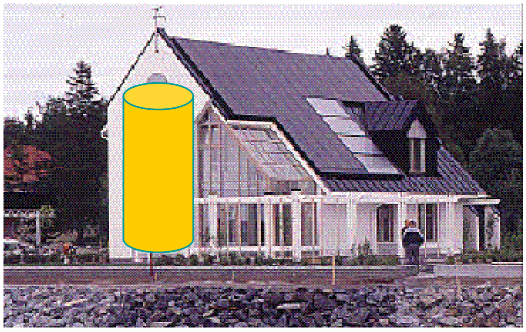
Storage requirement:

compact - efficient - reduced cost

- **Heat demand can be greatly reduced**
  (i.e. factor 4: SH : 80 to 20 kWh/m2)
- **Mid Europe : Heat demand =**
  2'500 kWh/winter + 3'600 kWh/year
- **Heat to store:**
  2'500/2 + 3600/12* 2 months = 1'850 kWh



- **100% solar with water = 20 m³ water at dT=70 K = 1'600 kWh (no loss)**
- **Why not try to reduce this volume ?**
- **Storage solutions for: 90 days storage…or one day ! Because:**
- **If the storage is capital intensive: increase the number of cycles to 365/y**

When trying to deliver as much possible heat from solar to more than one house, say a group of 100 houses, there are several technologies that have been investigated and a few pilot plants built around the world.

They can be ordered in three generic families:

- the water based
- the soil or earth based
- the aquifer based (basically a mixture of water and soil)

We have seen that water is a nice candidate, being cheap even in big quantities.

But why soil?

There are two reasons:

- Accessing huge volume of water requires a tank. The biggest tank we can build is in the order of 20 to 30'000 m^3 at a cost that is above 150 Euro per m^3. Which is not high considering a 1 m3 storage tank for a combi-system can cost 1000 to 2000 Euro. But 30,000 m^3 is not enough in certain cases like a solar district heating system say for 500 dwellings in Denmark or Sweden.
- Soil has adequate thermal properties at a low cost.

We have seen that heat capacity of soil is in the order of 60 to 80% that of water and thermal conductivity is comparable to that of water:

Generic Values for soil W / m K	**0.15 to 4**
Saturated soil	0.6 to 4
Sand perfectly dry	0.15 to 0.25
Sand moist	0.25 to 2
Sand saturated	2 to 4
Clay dry to moist	0.15 to 1.8
Clay saturated	0.6 to 2.5
Soil with organic matter	0.15 to 2
Solid Rocks	2 to 7
Tuff (porous volcanic rock)	0.5 to2.5
Water at 20C	**0.6**
Thermal insulation	**0.04**

Thermal conductivity of soils compared to water and insulation.

Soil can store sensible heat like water but is a bad insulation material !!!!

Conclusions?

An underground storage system must be completely insulated by some insulating material to withstand 6 months of duty or it must be very large.

Minimum volume not to insulate bottom and sides of an underground storage is 20,000 m^3 as an order of magnitude. This means a minimum of 500 dwellings connected to the store.

The true parameter is the time constant of a heat store:

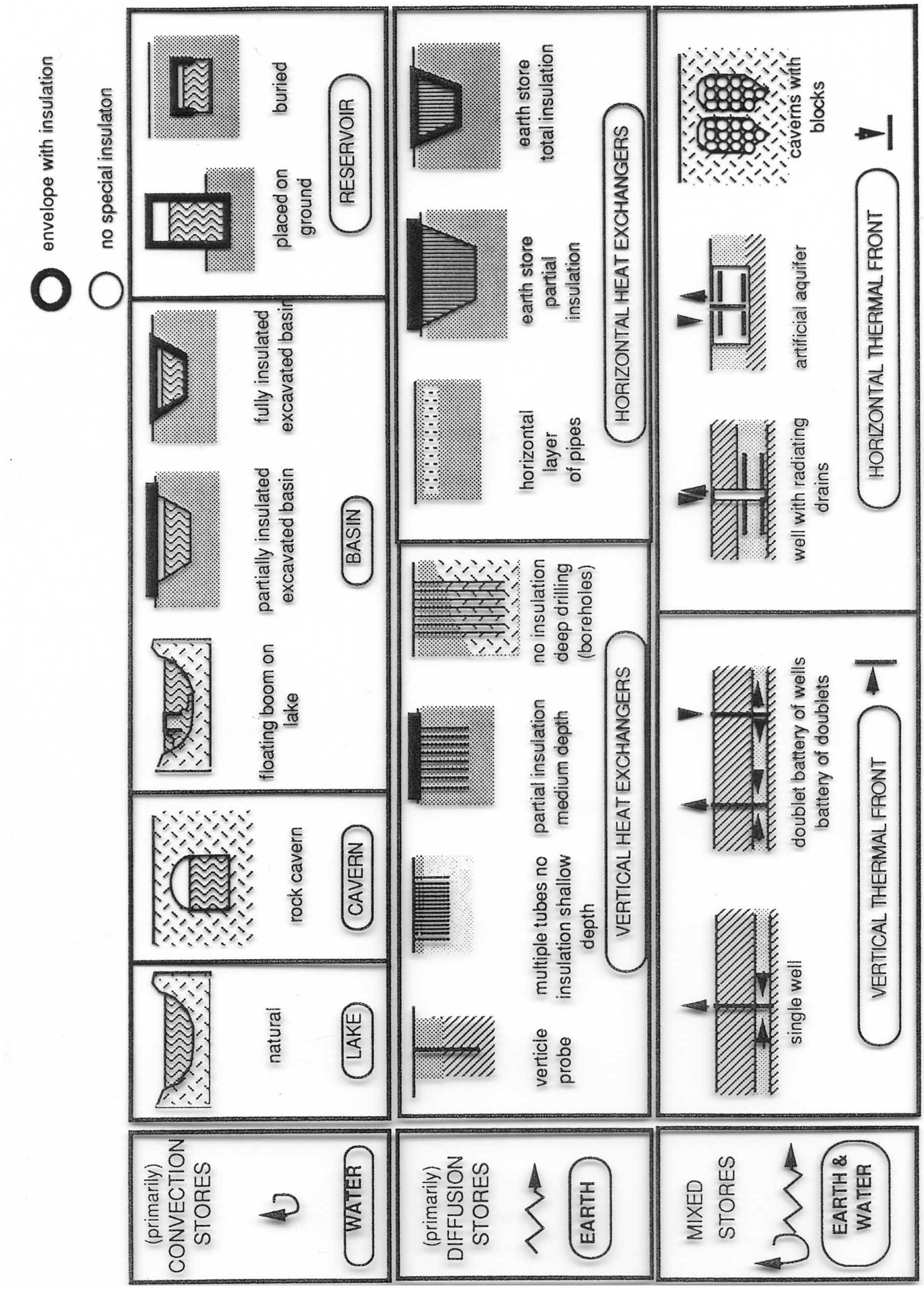
Time constant T = Heat capacity / Rate of heat loss = kWh/K / kW/K

What is the time constant of a 1 m3 cubic diurnal storage tank insulated by 10 cm of mineral wool, assuming thermal bridges double the ideal heat loss rate ?

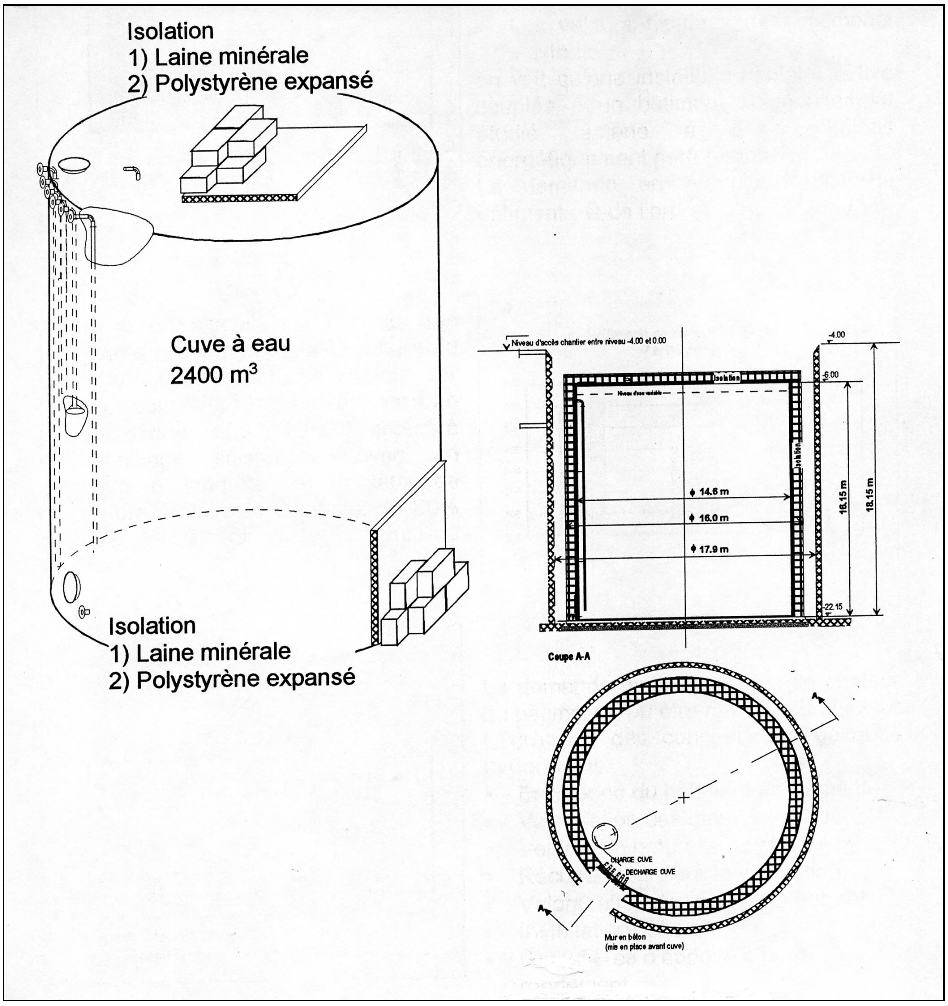
T = 1 m^3 * 1163 Wh/m^3 K / (6 m2 * 0.1 m / 0.04 W/m K) * 2) =
= 1163 / 30 = 39 hours = 1.6 days

<u>For a store to be really seasonal, its time constant should be over 365 days !</u>

The next table shows all seasonal storage technologies that have been worked during the past 30 years.


envelope with insulation
no special insulaton
(primarily) CONVECTION STORES
WATER
natural
LAKE
rock cavern
CAVERN
floating boom on lake
partially insulated excavated basin
fully insulated excavated basin
BASIN
placed on ground
buried
RESERVOIR
(primarily) DIFFUSION STORES
EARTH
verticle probe
multiple tubes no insulation shallow depth
partial insulation medium depth
no insulation deep drilling (boreholes)
VERTICAL HEAT EXCHANGERS
horizontal layer of pipes
earth store partial insulation
earth store total insulation
HORIZONTAL HEAT EXCHANGERS
MIXED STORES
EARTH & WATER
single well
doublet battery of wells battery of doublets
VERTICAL THERMAL FRONT
well with radiating drains
artificial aquifer
caverns with blocks
HORIZONTAL THERMAL FRONT

Large water tanks have been built with success for solar plants in Sweden, Denmark, Germany and Switzerland.



A 2400 m^3 water storage for 1200 m^2 of solar collectors, achieving a 50% solar fraction in a 500 MWh administrative building in Neuchatel, Switzerland (Sorane sa, 1999)

The specific cost of a large tank is much reduced compared to that of a small storage tank for a one family house, but still with 150 to 250 Euros/m3 for 10'000 m3 tanks it is still expensive.

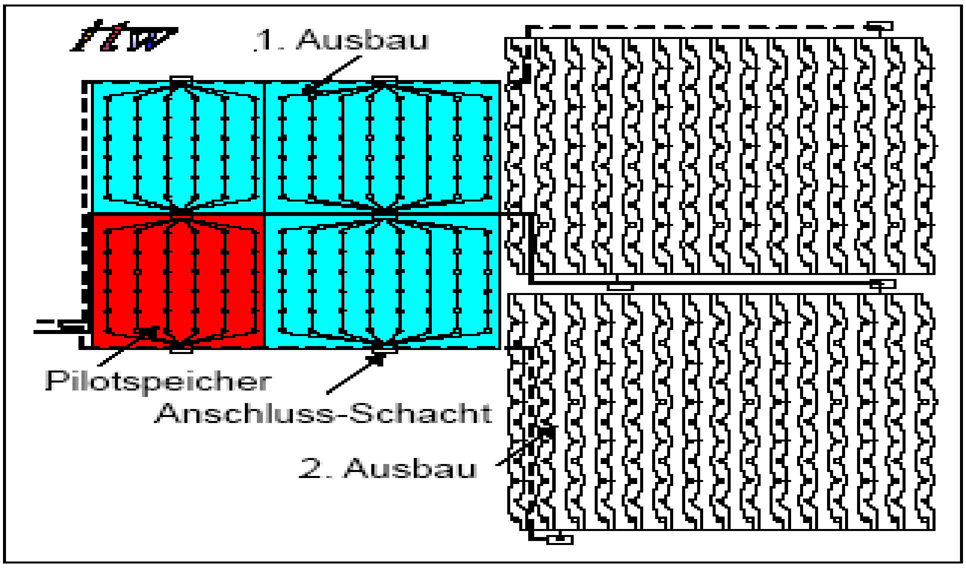
Duct storage are a cheaper and reliable solution. A German project in Neckarsulm is proving well that the technology of a shallow duct storage is operating as predicted by computer models at a cost divided by 4 to 5 compared to a tank storage.

In Neckarsulm storage has 528 boreholes 30 m deep, and a top insulation only thanks to its huge size of 140'000 m^3 in the long run.

The present volume of store is 63'200 m^3 heated up by 6'337 m^2 of collectors. The core of the store reached 62C in summer 2003. The store operates with great heat losses during its warming up time (5 years) but is expected to reach a 50% efficiency in 2005.

	Phase I	Phase II	Final Phase
Schedule	1995-1999	2000-2003	~2010
Housing connected	115 including one school, a shopping centre, and a retirement home	231	739
Power installed	930 kW	1,890 kW	4,830 kW
Heat requirement	977 MWh/a	2,847 MWh/a	8,754 MWh/a
Collector size	2,637 m^2	6,337 m^2	15,000 m^2
Storage volume	20,200 m^3	63,200 m^3	140,000 m^3

Neckarsulm design data (Nussbicker et al., Eurosun 2004).



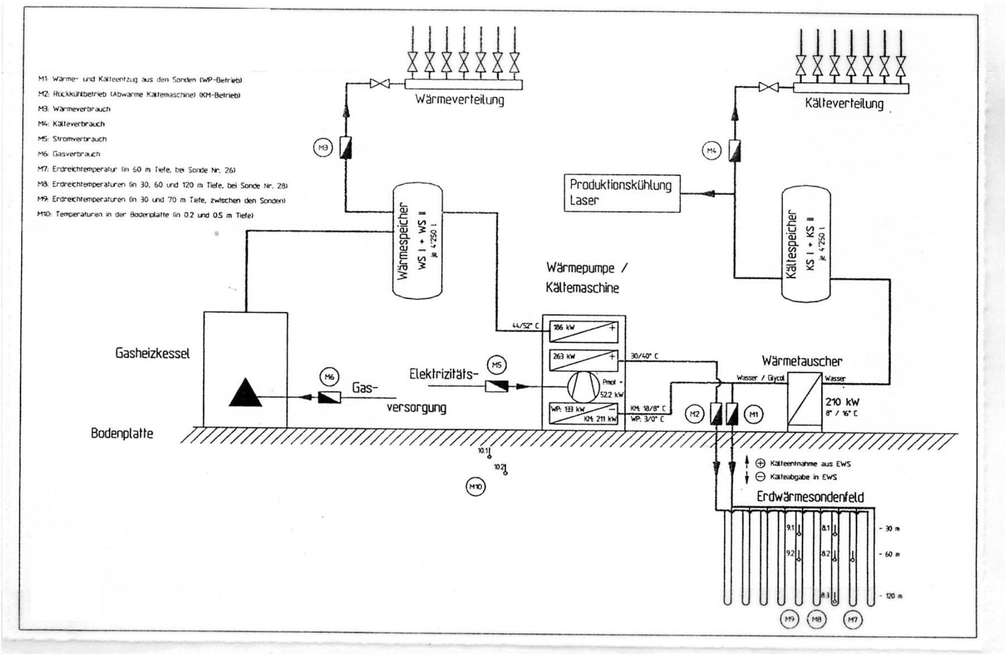
The Neckarsulm storage configuration (Nussbicker et al., Eurosun 2004).

		1999	2000	2002	2003
Collector area (31st Dec.)	m^2	2,636	3,090	5,007	5,007
Heat delivery of solar collectors (secondary side of solar heat exchanger)	MWh/a	802	577	1,696	2,050 +71[1)]
per m^2	kWh/(m^2·a)	304	219[2)]	331[3)]	396[3), 4)]
Solar heat delivery to heat distribution net	MWh/a	224	213	822	629[4)]
per m^2	kWh/(m^2·a)	85	81	164	126[4)]
Total heat demand and heat losses in heat distribution & solar net[5)]	MWh/a	1252	1247	2126	1891
Heat delivery by gas boiler	MWh/a	1,028	1,034	1,303	1,109
Solar fraction (based on total heat demand)	%	18	17	39	39

1) Solar heat gain from adjacent district heating system (Eugen-Bolz-Straße)
2) Jan.-Sep. 2002 2636 m^2; from Sep. 2002 3090 m^2
3) area weighted
4) only Neckarsulm-Amorbach
5) including heat losses, temporary supply of adjacent district heating system (Eugen-Bolz-Straße)

The Neckarsulm measured data (Nussbicker et al., Eurosun 2004).

Duct storage used with a heat pump are common in several countries. The store operates at low temperature (0 to 30°C), thus without any heat losses.



Hydraulic scheme of a typical heat pump on duct storage (36 boreholes, 200m deep, Wollerau, Switzerland)

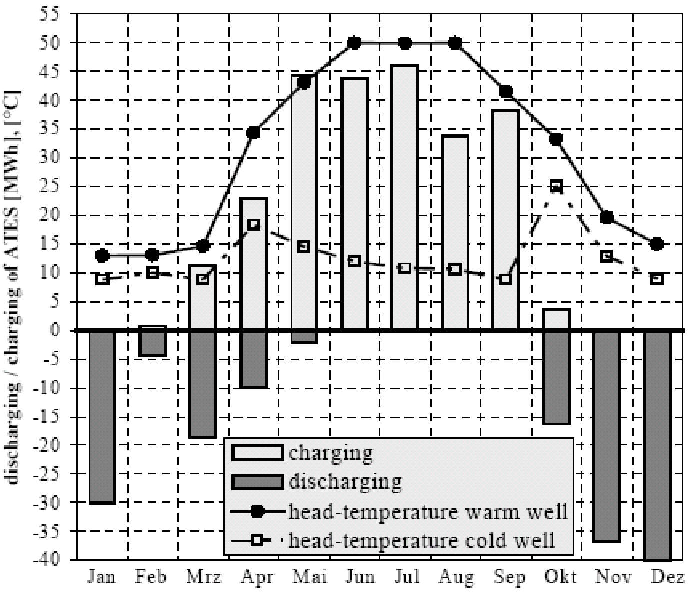
Aquifer storage was the most promising technology in the 80s because of its low cost access to huge volumes of water.

China has a long tradition of cold water storage in aquifers. In Europe and the US, pilots plants to test the concept of storing solar heat without a heat pump at 60 to 90C into an aquifer at 30 to 200 m depth, were built in Denmark, France and Switzerland with limited success due to chemical problems (calcite precipitation) or due to buoyancy effects ruining the energy of the store.

Recent projects in Germany prove to work (almost) well if design is carefully based on the results of the site investigations. But still a strong natural groundwater flow negatively influences the results, and the storage without a heat pump would probably not reach a reasonable efficiency.

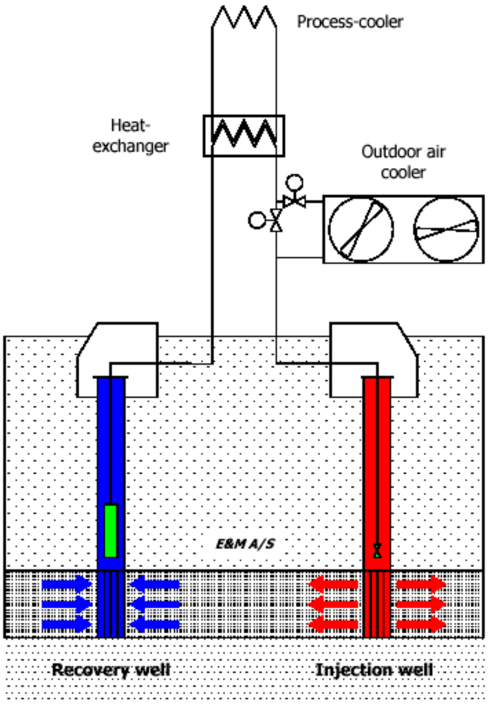
		2001	2002
heat demand:			
space heating	MWh/a	390	366
sanitary hot water preparation	MWh/a	233	231
distribution losses	MWh/a	32	47
total heat demand	MWh/a	655	644
heat production:			
collector heat	MWh/a	348	364
direct use	MWh/a	134	119
ATES charging	MWh/a	214	245
ATES discharging	MWh/a	78	158
heat from gas cond. boiler	MWh/a	420	322
heat from heat pump	MWh/a	100	192
heat pump electricity demand	MWh_{el}/a	24	44
COP heat pump	-	4.1	4.3
solar heat	%	32	43

Heat balance in 2001 and 202 of the Helios complex in Rostock (J. Bartels et al, Futurestock 2003)



Typical loading and unloading pattern of a seasonal storage in aquifer, here the Helios complex in Rostock (J. Bartels et al, Futurestock 2003)

Cold storage in aquifers has become a cost effective technology in some countries. Competition against electricity costs makes the alternative of free cooling with a COP of more than 20 attractive



Rules of thumbs for large seasonal storage are:

Minimum load: 500 MWh recommended

Water storage:
1.5 to 2.5 m2 solar collectors per MWh of load for 40 to 60% of load
1 to 2 m^3 per m^2 of solar collector
Thermal insulation: min. 40 cm at 0.04 W/mK
Solar productivity: 200 to 300 kWh/m^2 in mid Europe climate
Storage cost : 150 to 250 Euros/m^3

Duct storage
1.5 to 3 m^2 solar collectors per MWh of load for 40 to 60% of load
2 to 6 m^3 of storage per m2 of solar collectors
minimum 20,000 m^3 if insulation only on top
15 to 50 W/m of borehole (double U-pipe, quartz bentonite filling)
Storage cost: 30 to 60 Euro/ m of borehole

Aquifer storage
2 to 6 m^3 of water per m2 of collectors
Minimum 50,000 m^3 of storage for a no heat pump system
Minimum depth: 10 to 20 m
Should preferably be used for cold storage
Storage cost: 5 to 20 Euro/ m^3 but very dependant on local conditions
A strong regional groundwater flow (1m/month) can ruin the store

System type	Small solar system for domestic hot water (for comparison)	Central solar heating plant with diurnal storage (CSHPDS)	Central solar heating plant with seasonal storage (CSHPSS)
Minimum system size	–	More than 30 apartments or more than 60 persons	More than 100 apartments
Collector area	1–1.5 m_{FC}^2 per person	0.8–1.2 m_{FC}^2 per person	1.4–2.4 m_{FC}^2 per MWh annual heat demand
Storage volume	50–80 litres/m_{FC}^2	50–100 litres/m_{FC}^2	1.4–2.1 m_W^3/m_{FC}^2
Solar net energy	350–380 kWh/m_{FC}^2 per annum	350–500 kWh/m_{FC}^2 per annum	200–330 kWh/m_{FC}^2 per annum
Solar fraction (new building code)			
Domestic hot water	50 %	50 %	
Total heat demand	15 %	10–20 %	40–60 %
Solar heat cost in Germany	Euro 0.15–0.3/kWh	Euro 0.08–0.15/kWh	Euro 0.16–0.42/kWh

Comparison of design guidelines for solar assisted district heating in mid Europe (Mangold et al. Futurestock 2003)

Regarding large seasonal storage, the present conclusions after many pilot plants are the following:

1. Water technologies are reliable but more expensive. Water tightness is the main problem that can be overcome with stainless steel liners or special very dense concrete

2. Pit storage have some potentials in terms of cost /performance ratio but are difficult to master

3. Duct storage is the most simple . With heat pumps they work fine at low temperature range (0- 30C). The challenge of a no heat pump solar system is proved to be possible in the Neckarsulm project.

4. Aquifer storage is the cheapest technique for huge volumes, when it can be mastered. For cold storage, cost effectiveness is proved (payback time less than 5 to 7 years in Germany, Sweden, Netherlands on more than 200 installations). For warm storage (40 to 90C), the chemical composition of the aquifer and its geometry (natural convection problem) are very determinant and local conditions prevail so that a prognosis is always difficult to make. On site investigations and modelling are required making the process long and somehow costly for a result difficult to assess a priori.

8. Conclusions

Sorption and chemical storage were not treated in this document, as well as solar ponds. There are also other ways to indirectly store solar energy, i.e. using hydrogen as a storage material and a vector of distribution.

High temperature storage was also not discussed. Thermal power plants need some kind of storage at 400 to 500C to overcome clouds or cloudy hours.

Water is still the best storage material for small scale solar installations.

There are ways to improve water tank storage efficiencies but we are reaching limits for diurnal storage. The progress will be more in the overall system and control strategy. The heat exchange also is a research topic.

PCM materials might do a come back in construction elements for cooling and less for heating.

There are some new investigations in sorption materials such as silica gel and zeolites. Chemical stores are also back in the R&D work but to a low level.

For seasonal storage, duct storages have an interesting future with or without heat pumps, and aquifer storage are best suited for cold storage and free summer cooling.

Seasonal storage for one family house is possible through an insulated water tank, but economics show systems with short term storage that can cover up to 50% of the load as more attractive at present.

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