Policy reinforcement regarding heat storage technologies
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Heat storage technologies
Markets – Actors - Potentials

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Summary WP4 rewritten report, including market enhancements

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1 Preface

This report is produced as part of the Work Package 4: "Heat storage technologies, markets, actors and potentials" in the PREHEAT project (Policy reinforcement regarding heat storage technologies). The project is funded by the Intelligent Energy Europe program (EIE/05/036/SI2.420010) and carried out in the period 2006 to 2008.

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For information on the PREHEAT project refer to www.PREHEAT.org

Objectives

The objective of the project on policy reinforcement concerning heat storage technologies (PREHEAT) is to provide the industry and decision makers in the EU with a reference framework to maximize the environmental, commercial and economic benefits of the main heat storage technologies for renewables and to increase the attention and funding possibilities for heat storage technologies implementation. On the long term, PREHEAT aims at a coherent European promotion program with a collective approach by the industry, R&D institutions and other market actors. This will lead to a substantially increased utilization of renewable energy, and an increase in rational use of energy.

Scope

The scope of PREHEAT is mainly **heat storage technologies for small-scale renewable energy technologies** in Europe. The main applications considered in PREHEAT are solar thermal systems, biomass stand-alone boilers and biomass driven heating networks.

2 Introduction

Heat storage technologies are supporting technologies which are provided with almost every heating or cooling system available. They are present in renewable energy systems (e.g. solar thermal) and systems rationalizing use of energy (heat pumps, micro cogeneration) as well as in common residential heating systems (boilers).

Because heat storage is part of so many different types of systems, there is no single heat storage market. To discuss the total potential of heat storage, we will have to discuss first the potential of heat storage in its most important applications separately, and then aggregate that on a European level.

This report describes and identifies the present and future national and EU market segments for heat storage technologies, and gives an indication of the most promising heat storage technologies from the market point of view, focusing on small scale RES.

The actual market situation for heat storage systems will be deduced from market data for the residential heating and cooling market. From this, the size of the market for heat storage systems will be derived.

In addition, the existing information on present heat storage technologies and possible future developments is summarized.

3 Sources and Definitions

3.1.1 Sources

The basis for the following chapters on the market situation are company's statements, national and international databases as well as previous market studies for different applications and market segments. Market shares and numbers are from the following sources:

- Eurostat database (PRODCOM) via new XTNET
- Markus company database
- Frost&Sullivan market studies
- Hoppenstedt database
- Companies' statements (e.g. telephone survey, annual reports, annual financial statements, press releases etc.)
- Destatis (German Federal Statistical Office)
- Eco-design Boilers, Task 2 report
- ESTIF market numbers ("Solar Thermal Markets in Europe 2006") and press releases
- ESTTP press releases

Further references are given at the end of the report.

3.1.2 Definitions

As PREHEAT is limited to small-scale RES, this market report is focusing on residential systems. Although the scope of this report is a market analysis, the subdivisons are choosen by technology. The division is in first instance between classical heating systems and renewable energy systems (RES). Each segmentation will be broke down into market situation, actors and market and benefit for heat storage.

As heat storage can also be identified with "cold" storage, there is a division between residential heating and cooling.

This report identifies the possible market for heat storage systems. With regard to the mandatory heating or cooling system - as a heat storage systems is an enabling technology – this report has to look on the market for "thermotechnical products".

The term **thermotechnical products** covers products and systems for space heating and hot water preparation including small scale RES for residential buildings.

4 Heat storage market with regard to classical heating systems

4.1 Market for classical heating and hot water production

4.1.1 Market situation

The market for thermo technical products for heating and hot water production in the private sector, commercial and public buildings, ranging from classical boilers to renewable energy systems including heat pumps is very diverse. For each region, there are almost different condition regarding market structure, end-user characteristics, market competition and regulations.

Therefore, this market features a high number of actors both on the manufacture level as well as on distributor level. In case of the classical domestic heating and hot water segment, there are over 350 brands existing in Europe, which are distributed national or international by over 250 manufacturers. Furthermore there are approximately 130 vendors and brands for renewable energy systems.

The distribution is mainly realised by independent, local acting sanitary companies and wholesale merchants (see **Figure 1**).

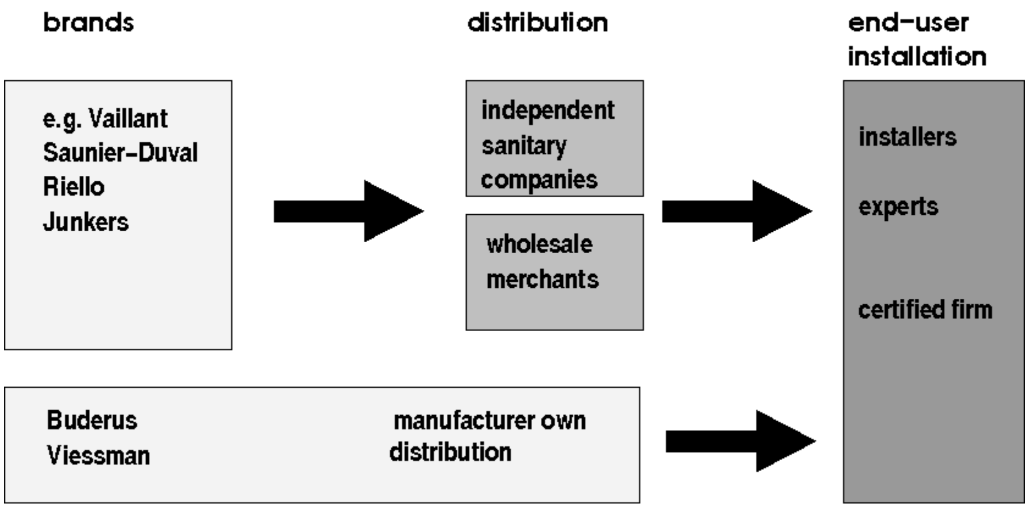

Figure 1 distribution-topology of the thermotechnical market

4.1.2 Actors

The European heating market is one of the most important markets for thermotechnical products in the world. It is still dominated by German companies. Regarding the overall revenue, BBT, Vaillant and Viessmann are the three strongest actors in this market (see **Figure 2**)

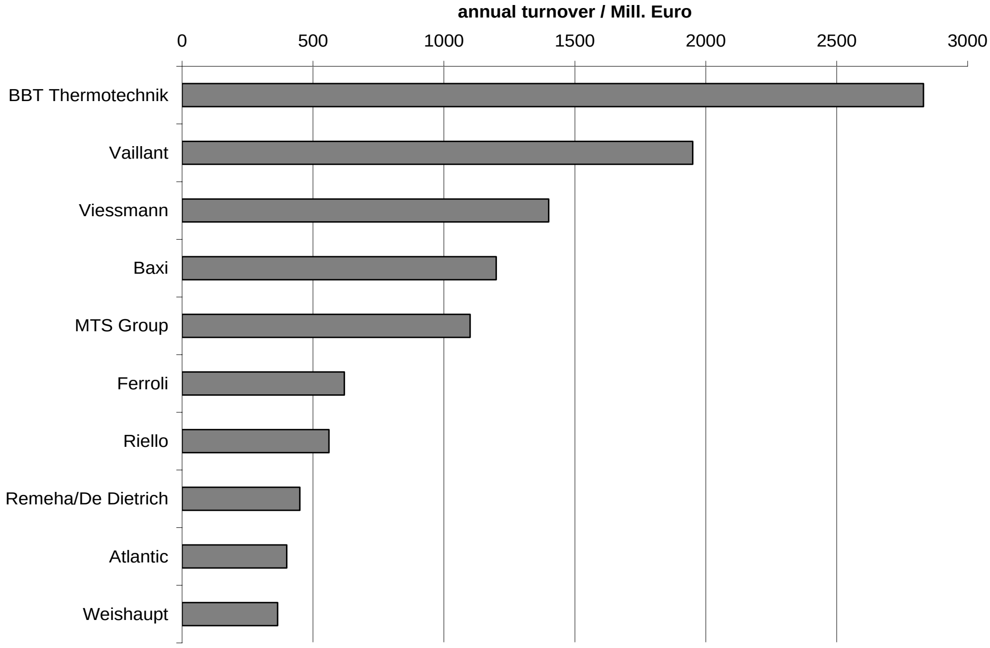

Figure 2 annual turnover in million Euro of the top ten heating market actors

Following are the Baxi Group and the MTS Group on position 4 and 5. Further companies with nameable market shares are Ferroli and Riello from Italy, Remeha/De Dietrich (Netherlands/France), Atlantic (France) and Weishaupt (Germany).

The overall turnover sum of these top ten actors add up to 10.877 billion Euro (see **Table 1**). These actors hold a market share of about 70 percent for gas and oil heating systems in Europe.

Table 1 annual turnover data of the top ten actors

No.	Name	country	business volume / Mio. Euro	year	Source
1	BBT Thermotechnik	GER	2831	2006	Company statement
2	Vaillant	GER	1950	2006	Annual report
3	Viessmann	GER	1400	2006	Annual financial statement
4	Baxi	UK	1200	2006	Baxigroup annual report
5	MTS Group	IT	1100	2006	MTS Group Press Kit
6	Ferroli	IT	620	2006	SHK-Journal
7	Riello	IT	561	2005	Company statement
8	Remeha/De Dietrich	NL/FR	450	2003	Article in "Haustechnikdialog"
9	Atlantic	FR	400	-	Company webpage
10	Weishaupt	GER	365	2004	Wochenblatt Biberach März 2005

A recent market analyse from BBT on the worldwide market for heating systems in 2006, estimates the total market to be worth around € 24.4 billion in manufacturer selling prices. This splits up into three major parts:

The first and largest part is classical heating systems with a share of about 49%. According to BBT, classical heating systems are therefore still dominating the worldwide market with over 11.9 million sold systems. Out of this, classical boilers (non-condensing boilers) apply for the biggest share (21 %) followed by condensing boilers (11%) and hot-air systems (9%), electrical heating (6%) and district heating (2%).

The supply of hot water is the second largest market with a share of 37%. This market consists of two main systems. One the one hand systems with a storage device and on the other hand continuous flow heater systems. Furthermore, these systems can be divided according to the used energy source (Oil, gas …).

Finally, the remaining 14 % are composed of system for the use of renewable energy with solar thermal collectors, electrical heat pumps and solid fuel burners (Source: BBT report).

4.1.3 Market and Benefit of heat storage

For the mentioned system above there is more or less a need for a storage device. Unfortunately, companies like BBT identify storage systems as systems for hot water preparation. In 2006 nearly 40 million hot water storage devices, with a market value of 6 billion Euros worldwide have been sold according to BBT.

This market can roughly be broken down to Europe (38 %), America (35 %), Asia (26 %) and Africa (1 %) (see **Figure 3**). With regard to the absolute number of sold devices, with 10 million devices the American market is the largest individual market.

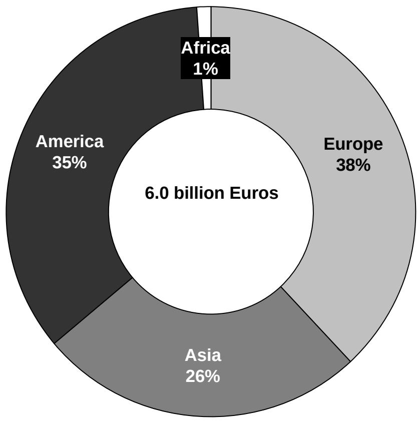

Figure 3 market for hot water storage

With regard to the western European market there has been a significant increased demand on storage devices due to solar thermal systems. Especially in France and Germany this "solar boom" stimulated the market demand on larger storage devices. At the same time France and Germany are the most important European markets with 1.6 million and 1.4 million sold devices followed by Italy (1.3 million), Spain (1.0 million) and UK (0.8 million) . As the overall sum of sold storage devices in Europe in the year 2006 was 10.5 million, this corresponds to market shares of 15 % (FR), 13% (GER), 12 % (IT), 9.5% (Esp) and 7.6% (UK) respectively.

In agreement with market forecasts from different studies, this market will show a growth rate between 2% and 4% per year.

As a first conclusion with regard to heat storage systems we can record, that the classical heating market makes no distinction between the heat sources (renewable or not) and heat storage is almost ever identified with hot water storage.

For the future, it is important to clearly separate heat storages in terms of usage, e.g. heat storage for heating and cooling or heat storage for sanitation (open consumption e.g. shower) in order not to compare two technologies for very different usages.

From a technical point of view, this is can be further motivated by different technical requirements. For example a heating or cooling storage is nearly almost embedded in a closed circuit, whereas heat storages for sanitation are open systems.

This will provide a more transparent and open market for new and advanced storage technologies for both, classical and renewable heating or cooling systems.

5 Heat storage market with regard to small scale renewable energy systems

Although it is mentioned that solar thermal applications are stimulating the hot water storage sells, the market for storage devices is not clearly included or separated from the hot water storage systems in combination with classical boilers. Therefore with regard to renewable energy systems an additional market has to be defined.

Talking about renewables includes in general solar photovoltaics, solar thermal, wind, biomass, hydropower, heat pump and geothermal energy systems. Obviously, there is no demand for heat storage systems for solar photovoltaics, wind power or hydropower systems except the case, where heat is a by-product of electricity storage during charging time and again needed for discharging (e.g. compressed-air store).

For all other systems heat storage devices are needed or can improve the performance in a significant way. In the following sections the market for these systems and the resulting demand for heat storages systems will be identified.

In 2006, worldwide turnovers for renewable energy systems, including solar thermal, biomass and electrical driven heat pumps, increased by 20 percent to 3.4 billion Euros.

The renewable energy market is unlike the classical heating market fragmented. As this market is still new, there are numerous smaller specialized companies, which are in most cases only regional active. Many new companies have joined the market in the last few years and more are expected to follow

On the other hand, this somehow unclear situation tends to result in strong market consolidations. Almost all bigger companies establish an international and renewable oriented structure. For example Vaillant started cooperation with Webasto for fuel cells development, Danfoss absorbed the French heat pump manufacturer Avenir Energie, MTS started a cooperation with Enatec Micro-Cogen (NL) for the development of CHP machines. Baxi also started a cooperation with a CHP manufacturer (Microgen) for development and distribution of CHP machines and Viessmann absorbed Mawera, a company specialized on wood burners.

Taking the market share of the renewable sector into account, the named top ten actors in chapter 4 still hold a market share of about 58 percent.

5.1 Solar heating

5.1.1 Market situation

Since the year 2000, over one million square meters of solar thermal capacity have been installed in Europe every year and the outlook appears promising over the next decade. In agreement to the situation for classical heating systems, Germany, France, Italy and Spain represent the markets where solar thermal installations will be highest in the short to medium terms. The largest market opportunity by far for solar thermal installations is in domestic systems due to subsidies and increasing awareness.

With a spectacular growth of 47%, the European solar thermal market in 2006 exceeded everybody's expectations, reaching 2,1 GWth of newly installed capacity (over 3 million m2 of collector area). The total capacity in operation reached 13,5 GWth, producing clean solar heat and cold. Several factors contributed to this good result like public support in several countries, the dramatic increase of oil and gas prices, the cut-off of the Russian gas supply in January, and the more and more visible signs of climate change (Source: ESTIF).

Unfortunately, after four years of very dynamic growth, the European solar thermal market registered a 10% decrease in sales in 2007. According to a ESTIF press release (21.12.2007), many factors contributed to a 33% decline of Germany's market. Despite good growth rates registered in France, Italy and Spain these developments have been more than outweighed by the dramatic decline of the German solar thermal market, which is still the largest European single market due to an successful 58% growth (1,05 GW_{th} of new capacity) in 2006. This exceptional strong increase was mainly stimulated by a market incentive program ("Marktanreizprogramm"). Regarding a per-capita basis, the German market is exactly half that of Austria, hence there is still a big potential in this market. Therefore, the German renewable heating law is expected to give another boost to the German solar thermal market in 2008/2009.

In consideration of the worldwide development, China is the largest single-market and still becomes more important and determinates the growth in common solar collectors. The newly installed collector area worldwide of 24.3 million square meters in 2006 splits into four major continental markets: Due to the large market in China, the total market in Asia attracts 77% (including Japan), followed by Europe with 16% (including Turkey), India with 2% and America (Latin America, USA, CDN) with 3% respectively.

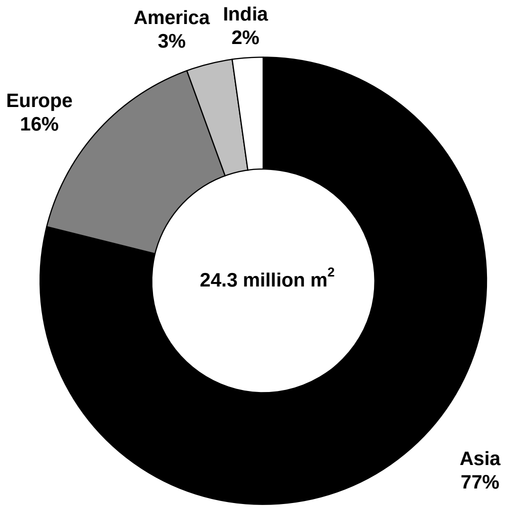

Figure 4 New installed collector area 2006

Assuming a square meter price of 105 € in Asia, India and America (because of a large market in Latin America) and a square meter price of 560 € in Europe (due to technically advanced systems) the market for solar thermal collectors in 2006 increased considerable with a market value of 2.9 billion Euros worldwide (Different calculations are resulting in values between 1.2 and 4.4 billion Euros.

5.1.2 Actors

Many new companies have joined the market in the last few years and more are expected to follow. New-build schemes are increasing and retrofits are also expected to grow significantly. Awareness will increase as net prices fall providing substantial new opportunities for the industry to capitalise upon.

Around 30 significant companies compete in the EU market although thousands operate in the market. There are 203 members in the support group listed at the european solar thermal technology platform (www.esttp.org).

With regard to the market share, the most important are Viessmann (7 %), BBT (6 %), Foco SA (6 %), Wagner Solartechnik (4.5-5 %) and Isofoton (2-3 %).

Viessmann and BBT are, as written above, two leading general heating equipment manufacturers that provide solar thermal products such as solar water heaters and other components apart from selling the complete solar thermal systems for both heating and cold water.

The German company Wagner Solartechnik is one of the key suppliers of complete solar thermal systems. The product line of the company ranges from small and compact collectors for individual homes to large-scale installations on roofs or facades.

Foco SA is one of the largest Greek solar thermal companies. The company produces and distributes complete systems for domestic and large-scale integrated applications apart from supplying different components such as absorbers and collectors. The majority of the sales of the company come from the export markets such as Germany, where its products are distributed under the Ikarus Solar name.

Isofoton is the leading Spanish company in the field of solar PV and solar thermal technologies.The company produces and sells the components (such as thermal collectors and heat exchangers) as well as the complete solar thermal systems for different solar thermal applications such as indoor heating, heating swimming pool water and for sanitary hot water applications.

Other actors without detailed market shares are Consolar GmbH (DE), Arcon Solvarme A/S (DK), Grammer Solar GmbH (DE), KBB Kollektorbau GmBH (DE), Max Weishaupt GmBH (DE), MST Group, Paradigma Energie- und Umwelttechnik GmbH & Co. KG (DE), Schott Rohrglas GmbH (DE), Schüco International KG (DE), Solar Next AG (DE), Siko Solar Ges.m.b.H. (AT), Solution Solartechnik GmbH (AT) SOLVIS GmbH & Co. KG (DE), Sonnen Kraft GmbH (DE), Sonnen-kraft Österreich (AT), Calpak (GR), BP Solar (global), Phönix Sonnenwärme (DE), Zenit Energies (FR), Biasi (IT), ESE SA (BE), SunTechnics (NL), Gorenje (global).

GREENoneTEC holds the market leadership position in the European solar thermal collector market, however it does not make complete solar thermal systems.

In recognition of its potential and new laws for renewable heating (Germany) , more installers are joining the market. There is less competition in this sector compared to the geothermal sector. In recent years, competition at installer level has become more intense as companies have entered the market. Market expansion will continue to attract new entrants at local level for some time until product demand decreases in the long term.

5.1.3 Market and Benefit of heat storage

Market :

Regarding a technical segmentation and the corresponding square meter prices and annual revenue, Europe becomes more important with a world-market share of 49% (Asia 47%). This is due to more technically advanced collector systems (see **Table 2**).

Table 2 solar thermal collector market shares

	sqm /1000 /1000	market value / 1000 €	market share / value	market share / sqm
Asia	13006	1,365,630	46.88%	78.81%
Europe	2594	1,452,640	49.87%	15.72%
America	518	54,390	1.87%	3.14%
India	385	40,425	1.39%	2.33%

Regarding heat storage, an overall market volume can either be deduced from the totally installed and operating collector capacity worldwide, which is about 108 GW_{th}, hereof the total collector capacity in Europe represent about 13.5 GW_{th}.

As almost every solar thermal systems comes with a water storage, the market volume can likewise be deduced from production and sales numbers. Therefore production data for different section were extracted from the Eurostat

PRODCOM database using different PRODCOM categories. The following PRODCOM codes were assessed :

- 28.21.11.20 Iron or steel reservoirs, tanks, vats and similar containers lined or heat-insulated, for liquids, of a capacity > 300 litres (excluding fitted with mechanical or thermal equipment)
- 28.22.12.00 Boilers for central heating other than those of HS 8402
- 29.23.13.75 Absorption heat pumps
- 29.72.14.00 Non-electric instantaneous or storage water heaters

The extracted data is presented in**Table 3**.

Table 3 PRODCOM Eurostat data

		28.21.11.20		28.22.12.00		29.23.13.75		29.72.14.00	
		Jan.-Dez. 2005	Jan.-Dez. 2006	Jan.-Dez. 2005	Jan.-Dez. 2006	Jan.-Dez. 2005	Jan.-Dez. 2006	Jan.-Dez. 2005	Jan.-Dez. 2006
	unit	kg	kg	p/st	p/st	p/st	p/st	p/st	p/st
France	qty	10,600,000	11,000,000	1,011				539,990	457,659
France	€	31,658,000	32,862,550	791,239,000	778,357,000			159,357,000	162,208,000
Netherlands	qty								
Netherlands	€	67,113,000	95,732,000	448,832,000	509,914,000				
Germany	qty	37,931,000	43,881,000	1,046,516	1,249,117			1,043,088	1,462,441
Germany	€	113,273,951	134,536,790	849,498,797	930,273,916			679,890,379	764,787,515
Italy	qty	55,269,000	59,152,000	3,176,680	3,264,087	20,130	30,340	173,316	296,479
Italy	€	156,956,000	170,128,000	1,575,248,000	1,679,533,000	52,211,000	73,774,000	43,247,000	48,805,000
United Kingdom	qty			1,232,989	1,301,994			95,282	
United Kingdom	€	103,600,468	91,521,570	873,217,315	897,940,534			20,817,490	
Denmark	qty			17,115	23,045			83,802	106,327
Denmark	€	21,730,454	18,257,162	43,702,461	67,140,540			32,133,847	38,988,216
Spain	qty	14,476,000	21,639,000	85,590	81,977			939,959	838,457
Spain	€	65,039,190	77,544,537	66,118,479	64,031,753			78,502,849	76,225,605
Austria	qty	15,486,490	20,385,068	51,905	75,337			95,232	263,772
Austria	€	76,680,600	111,648,600	174,647,200	257,951,200			47,321,200	89,319,300
Poland	qty	6,963,000	5,615,000	354,670	438,592			132,298	148,606
Poland	€	22,561,074	20,502,554	149,461,496	205,871,711			14,373,179	18,562,104
EU 25	qty	214,753,059	252,166,201					4,677,720	
EU 25	€	798,209,588	908,722,464	5,344,083,586	5,880,294,007			1,376,899,789	

Some rows are containing blank cells as no data was available. Especially data regarding production of absorption heat pumps is lacking for many countries. For Germany, there is more detailed production information available using the German Destatis database.

The main value of presenting these data here is that they represent the official data currently used by the European community. Beyond, they provide an estimate of the storage market.

In consideration of the numbers in the first row for production of Iron or steel reservoirs, tanks, vats and similar containers lined or heat-insulated, absolute numbers for solar thermal applications are difficult to extract. However, the European numbers can be deduced with respect to the more detailed German data.

For Germany, the value of 134,536,790 € splits into 3 major parts as can be seen in **Table 4**.

Table 4 Detailed data for section 28.21.11.20 Germany

	absolute value / 1000 €	**share / percent**
boilers	52,754	39.21%
tanks for chemicals	20,204	15.02%
other tanks	61,578	45.77%

This means, about 46% of the production is used as heat insulated reservoirs excluding boilers, chemicals, foods etc. Thus this gives an estimate for the market value of the pure (heat) storage tanks. Assuming the same ratio holds in Europe, this amounts to about 418 million Euros in Europe.

In consideration of the numbers in the last row for production of non-electric instantaneous or storage water heaters, this includes solar thermal application as well as instantaneous oil- and gas-burner units. Again, a detailed distinction can be deduced with respect to the more detailed German data.

For Germany, the value of 764,787,515 € splits again into 3 major parts as can be seen in **Table 5**.

Table 5 Detailed data on non-electrical instantaneous or storage water heaters, Germany

	2005		2006	
	absolute value / 1000 €	**share /percent**	**absolute value / 1000 €**	**share /percent**
gas-burners	546,665	80.40%	544,166	71.15%
oil- or solid fuel burner	2,058	0.30%	2,658	0.35%
others e.g. solar collectors	131,168	19.29%	217,963	28.50%

This means, about 28 % of the production in 2006 of non-electrical instantaneous or storage water heaters were solar collectors.

Unfortunately, the overall value for Europe in 2006 was not available through EASY XTNET. In the year 2005, this was about 1.4 billion Euros. Looking on the detailed German data, there was a large increase in 2006.

Summation of the available values in both years (this means all except UK) for the different countries in 2005 yields in an overall value of 1054 million Euros in 2005 versus an overall value of 1198 million Euros in 2006. This accords to an increase of 14 percent and therefore an estimated European total sum in 2006 of 1570 million Euros.

Consequentially this results in an estimate for the European market value of the solar thermal collectors and water storage heaters of about 447.45 million Euros.

Benefits of Thermal Storage to Solar domestic hot water and heating systems

Efficiency Solar thermal systems are systems that are designed to produce hot water for heating and/or sanitation. Systems can be installed to serve a range of buildings from single domestic properties to large-scale district heating. If the system design and control strategy is correctly carried out, the solar heating fraction can be easily increased up to over 50% by using advanced heat storage. The solar fraction for domestic hot water can be increased up to almost 100%.

Economics Through the use of heat storages in combination with solar thermal systems, the consumption of fossil fuels and thus lower operation costs for the end-user can be realised. Furthermore, the use of smaller, cheaper boilers.

Comfort benefits A benefit in this case is a more psychological effect of being more independent of fossil fuel prices.

Environmental impacts As described above, with the use of heat storage a lower fossil fuel comsumption through higher usage of solar thermal systems and thus lower CO_2 emissions can be reached. Beyond, the heat storage contributes to stabilise electricity consumption, less electricity peaks and thus lower CO2 emissions since power plants of lower quality will be used less frequently.

In order to quantify the direct benefit of thermal storage in such systems, we carried out simulations of different storages types in typical DHW solar system. The simulations were performed with the software T-Sol 4.0.

Details on the simulation results are given in Annex B. In summary, the variation of storage tank volume showed that there is an optimum volume for each type of installation. Furthermore the simulation showed, that there is a huge potential for advanced heat storages in order to save as much CO2 emission as possible.

As an impressive simulation result, we received absolute savings of CO_2 emission of 3,7 tons per year per house or about 1 ton per capita.

5.2 Solar cooling

5.2.1 Market situation

As described above, the heat storage market has to be derived from the residential heating **and** cooling market. In this context heat storage can be identified with “cold” storage (e.g. phase change storage like ice-storage). At first glance, cold storage seems somehow completely different with regard to the requirements towards materials and systems. But as described in the technical section, sorption storages or phase change systems can be used for heat storage as well as for cold storage. Looking at the peak loads in the electricity grid on working hours due to electrically driven air conditioning systems, short term cold storage seems economic favorable. The production of cold can be shifted towards nighttime which enables the systems work with higher COP due to lower ambience temperatures and serves as peak shaving due peak hours. In this context, sorption and phase change materials can be used for efficient cold storage. Especially, sorption materials can be used both for storage and cold production within a thermally driven adsorption chiller.

However, the actual residential cooling market is completely dominated by "on-demand" compressor based technology. There are several systems in use, for example split, window, mobile, rooftop, or systems for IT cooling. The market shares of the systems strongly differ in the considered regions. In Europe split units have the main share.

5.2.2 Actors

Looking at the market structure, the air conditioning market is like the solar heating market dominated by a huge number of actors.

Some of the market participants in Europe are the following:

Airwell ACE, Alpha-InnoTec, Axair, Bertuleit & Bökenkröger, Böker, Carrier, Climaveneta, Daikin, DeLonghi, Dimplex, Einhell, Fujitsu General, GK Euro Imex, Johnson Controls Systems, Alfred Kaut, LG Electronics, Midea Europe, Mitsubishi Electric, Mitsubishi Heavy Industries, PA Pichlmüller Apparatebau, Panasonic Marketing Europe, REMKO, Schako KG, Simon & Matzer, Stiebel Eltron, Stulz Klimatechnik, Toshiba Airconditioning, Trane, Vaillant, as well as many Chinese manufacturers.

5.2.3 Market and Benefit of heat storage

The world residential airc conditionier market grew by 10% compared to the year 2005 with 64 million units sold in 2006. This market is continuing to expand steadily, reports e.g. "JARN" magazine. One of the main reasons for this expansion is the rapid growth of the Chinese market and the heat waves in Europe, which doubled the AC demand. The USA and Japanese AC markets have remained stable.

The Chinese market reached over 20 million units in 2006, becoming the world's largest market. Compared to the previous years, the numbers remained on the same level with or drop a little below the 2004 or 2005 level. This is due to confusion caused by the unusually rapid growth, the worsening situation of electric power supply, and the government policy for reinforcing the control of the real estate boom (Source: Refrige.Com Portal).

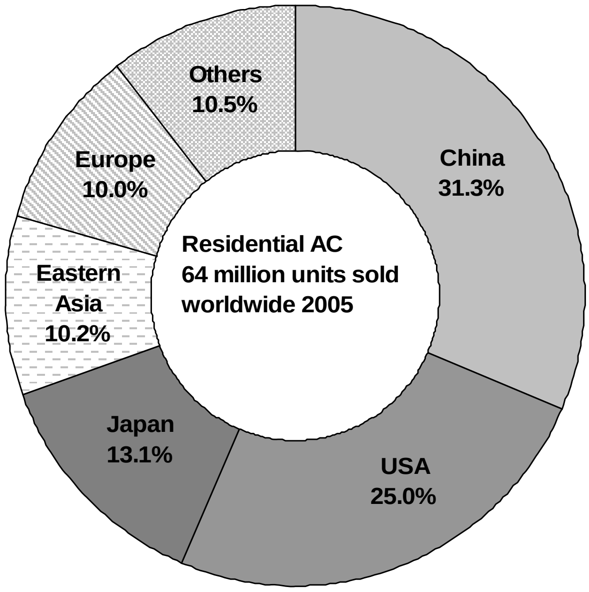

Figure 5 Residential AC units sold in 2005

Until 2000, the US was the world's largest AC market, a position now taken over by China. For the last years,the volume of the US AC market has continued to be larger than 13 million units reflecting the brisk domestic economy, the booming real estate business and intense heat waves in the summer.

The European market compares to 6.4 million sold units or 4.3 billion € turnover respectively. The biggest markets in Europe are Italy and Spain each with more than 1.5 million units.

Table 6: Sold cooling systems in Europe 2005 [8]

	Split	Window	Mobile	Rooftop	For IT
Italy	1,600,000	3,000	130,000	4,000	No data
Spain	1,500,000	6,000	25,000	2,700	3,000
Russia	420,000	140,000	11,000	400	2,700
France	365,000	11,000	66,000	2,200	No data
Greece	330,000	No data	No data	350	2,000

UK	200,000	5,000	106,000	No data	7,000
Germany	90,000	12,000	70,000	No data	6,000

As blackout-hours of the electricity grids will increase as well as prices for electricity, market penetration for advanced cold storage systems will shortly be possible.

With regard to the number of sold systems and the annual turnover there is a big market for cold storage.

Benefits of storage

Efficiency If the system design and control strategy is correctly carried out, the coefficient of performance (COP) of thermal driven chillers and compression chillers can be increased by using heat (cold) storage. The combination of a chiller with a heat storage allows to use night time for production of "cold" with less ambient temperature for recooling and therefore higher COP.

Economics Through the use of heat storages a continious operation of the chiller can be realised and thus lower operation costs for the end-user can be obtained. Furthermore, the use of smaller, cheaper chillers is possible by peak load shaving and a higher reliability of system will make the system economic more attractive. Even with classical compression chillers heat storages can be economic attractive. Especially in Asia, with large difference in electricity tariffs between day and night shifting of production to nighttime will provide economical benefits.

Comfort benefits A basic benefit in this case is an easier control of the room temperature since temperature in the storage tank is more constant than the outlet of the chiller.

Environmental impacts As described above, with the use of heat storage a lower emission through higher COP and thus lower electricity consumption can be reached. Beyond, the heat storage contributes to stabilise electricity consumption, less electricity peaks and thus lower CO2 emissions since power plants of lower quality will be used less frequently.

5.3 Biomass

5.3.1 Market situation

In Europe (EU 25) renewables had a share of 5.7% in the Gross Inland Consumption of energy in 2002 beneath other solid fuels (coal), oil, natural gas and nuclear. 65% of the renewables is captured by biomass.

Most biomass energy facilities in Europe are installed as combined heat and power (CHP) schemes. Chief developers have been Finland, Sweden and Austria where biomass energy already accounts for between 10 and 20+ per cent of respective primary energy supply.

If only renewable heat production is surveyed, biomass has the main share of 96%.

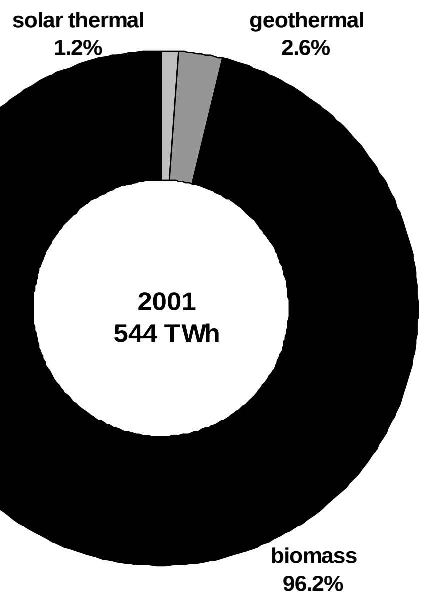

Figure 6 Renewable heat production

The EU White Paper aimes the bioheat to double until 2010 with 872 TWh, related to 1995 and 442 TWh. That accounts for a significant growth in the segment of biomass boilers.

The majority of present biomass power installations relate to operators in pulp and paper, forestry and CHP for district heating schemes. The number of installed stoves and boilers fired by wood pellets has already tripled from 2001 to 2004 with 350 000 units sold in the most important countries Sweden, Austria, Germany, Denmark, Finland, Italy and Poland of the EU. In 2007 17,200 units for solid fuel were sold in Germany, most of them fired with wood. Feedstocks (particularly wood chips, wood residues and pellets) are increasingly being traded internationally. Utility companies and smaller independent power producers are the main end users of large biomass boiler systems. These end-user markets are particularly significant in Scandinavia and Finland and are also growing in the United Kingdom and Germany.

Usually small Domestic systems (less than 1 MW) are not considered in current market studies and reports for output and end-user analysis. The market for medium and large systems generated around 1020 million Euros in 2004 based on installations in the output range above 1MW. The market has been growing in the last few years and the growth is forecast to continue till 2011.

5.3.2 Actors

The main difficulty in extracting market data and shares is due to the quantity of manufacturers in Europe.

The biomass energy market is fragmented and is reflected in the small market shares of the largest active participants. Therefore the biomass boiler market is dominated by a huge number of small actors, for example in Austria there are 37 manufacturers only for pellet heating systems. The main actors in the market of traditional heating and hot water systems are spreading towards the biomass technology at the moment. For example, Viessmann absorbed Mawera in 2006, a manufacturer of wood boilers for heating net applications, and Köb&Schäfer in 2007, manufacturer of biomass boilers from 35 to 1350kW.

5.3.3 Market and Benefit of heat storage

BBT gives the turnover in the EU for solid fuel burners with 500 million € in 2006, the annual market growth is assumed to be 7% . The turnover compares to 577,000 units sold in 2006, the biggest market is Poland with 200,000 units followed by Germany and Czech Republic. The worldwide turnover is given with 800 million € in 2006.

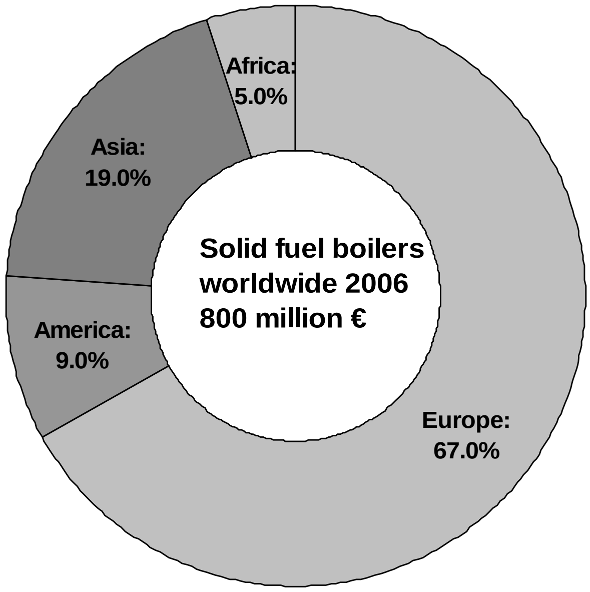

Figure 7 Sold solid fuel boilers in 2006

Table 7: Sold units of solid fuel boilers in Europe 2006

Poland	200,000
Germany	54,000
Czech Republic	49,000
Turkey	30,000
France	27,000
Romania	27,000
Austria	24,000
Baltic states	19,000
Serbia and Montenegro	19,000
Russia	17,000

As every modern central heating coupled biomass boiler and stove is combined with a storage unit, biomass is the most important renewable heat storage market besides solar thermal. The storage helps to reduce the exhaust emissions and improves the comfort for manual loaded systems.

As written above, most biomass energy facilities in Europe are installed as combined heat and power (CHP) systems. Looking on larger systems, some industries produce waste products that can be utilised as fuel and combusted in biomass power plants. For instance, those operating in the pulp and paper industry can negate their waste disposal costs and reduce energy expenses through the introduction of on-site biomass energy schemes.

With the focus on smal scale RES, the market forecats for biomass is quite difficult. There is some uncertainty of supply for end-users, as the increasing use of biomass and the heating related crop production starts to build up social problems. Some participants therefore regard the security of this heating option as risky and an uncertain source.

Benefits of heat storage

The benefits of heat storage for heat-only biomass systems are not as clear as for co-generation systems. However, every intermittent source or every working machine may need a heat storage as buffer.

Efficiency Heat storage can be used as a buffer and therefore increase the efficiency of the system.

Economics Through the use of heat storages a peak load shaving can be realised which results in a reduces boiler capacity and thus lower operation costs for the end-user can be obtained. Depending on the price for wood, pellets etc. the payback of the store purchase can be relatively low.

Comfort benefits A basic benefit in this case is an smoother operation of the system.

Environmental impacts As described above, with the use of heat storage a lower emission of CO2 through increased efficiency of the systems and reduced boiler capacity can be reached.

The utilisation of biomass energy in cogeneration systems amongst all end users has been growing significantly in recent years. Further growth, at the expense of power or heat only plants, is expected by 2011. As a result of this forecast, we give some general comments on CHP in the next section an excursion.

5.3.4 Excursion CHP

CHP in district heating systems are expected to be increasingly installed in Finland and Sweden in particular. The Austrian, German and French markets are also expected to grow.

Heat storage for micro CHP systems is of secondary order, in contrast to thermal solar energy. In other words, even without heat storage a domestic CHP system is in principle capable to replace current gas fired boilers.

However, the efficiency and usability of CHP's is strongly increased with the addition of heat storage. For domestic applications it is very important to separate the heat demand for domestic hot water (DHW) and space heating. In general yields that heat storage will increase the use of the CHP in stead of the auxiliary burner, especially for the production of DHW. Heat storage for micro CHP is mainly focused on DHW production.

At the moment micro CHP is introduced in the EU, leading countries are the Netherlands and the UK. Introduction is at hand in Germany, France and Belgium.

Benefits of an optimized storage in a micro-CHP

The benefits of heat storage are not only for solar installations. Every intermittent source or every working machine may need a heat storage as buffer. Micro-CHP will also benefit from heat storage in several aspects. Besides more operating hours for the CHP there is a higher fraction of load covered by low-carbon. An econonomical aspect is the longer durability of the CHP (less start ups) as well as tariffs shifting and peak load shaving (reduced boiler capacity). Depending on the price obtained for electricity, the payback of the store purchase can be relatively low.

Besides these benefits there are environmental impacts like less emission through less cycling or intermittent behavior, more efficient supplied technology and higher fuel efficiency.

Micro-CHP in combination with compact heat storage (for example thermo-chemical materials) makes it also available for renovated buildings.

The above mentioned benefits of combining heat storage with micro-CHP are also valid for micro-CHP plants for small district heating.

5.4 Heat pumps

5.4.1 Market situation

There is a large variation in the use of heat pumps for space heating within the European countries. However, electrical driven heat pumps show a very dynamic growth in the EU. The country with the highest penetration of the market is Sweden. There the technology had its first appearance in the late 1970s due to the oil-price development. After some problems in early installations heat pumps have reached a high grade of reliability and economy.

In Sweden heat pumps have a share of 90% in domestic heating and hot water, in Switzerland every second new built one- or two family building is provided with heat pump technology. With regard to the German market situation only about 5 % of newly built single family houses are equipped with heat pump systems with an absolute share of 15%. Compared to other countries, e. g. Switzerland, where 50 % of the newly built single family houses are equipped with heat pumps, a very large market potential for heating systems based on heat pumps in Germany can be deduced.

5.4.2 Actors

Looking at the market structure, the heat pump market is like the solar heating market dominated by a huge number of actors.

Some of the market participants in Europe are the following:

Gorenje, Danfoss, Sanyo, Clivet, Carrier, Saunier Duval, Viessmann, Ciat,Airwell, Weider Wärmepumpen GmbH, Heliotherm Heat Pumps GmbH, Shamrock Solar Energies Ltd , Dunstar Ltd , Ecotherm Environmental Solutions Ltd. , Low Energy Solutions , AEG Hausgeräte GmbH, AL-KO Therm GmbH, Blomberg Werke KG, Siemens AG, Stiebel Eltron GmbH & Co. KG, Joh. Vaillant GmbH & Co., Viessmann Werke GmbH & Co. and Waterkotte Wärmepumpen GmbH.

5.4.3 Market and Benefit of heat storage

The actual growth of heat pump market is equally strong due to subsidies from policy and power authorities. They realise the biggest turnover in renewable heat worldwide (1.4 billion € in 2006) and in the EU (812 million €, or 58% respectively). BBT assumes the heat pump market to have an annual growth of 12% in Europe until 2014.

The turnover compares to 242,000 heat pumps sold 2006 in the EU. The biggest market, as mentioned above, is Sweden with 73,000 units sold, followed by Germany with 55,000 and France with 37,000.

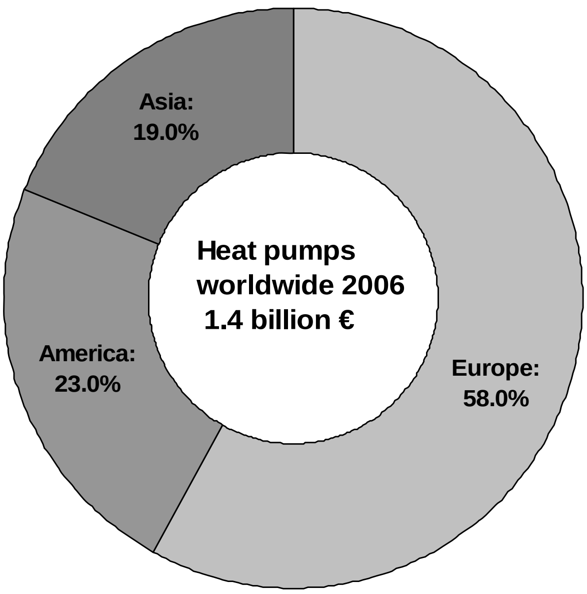

Figure 8 Sold heat pumps in 2006

Table 8: Heat pumps sold in Europe 2006

Sweden	73,000
Germany	55,000
France	37,000
Italy	17,000

Switzerland	13,000
Austria	11,000
Finland	7,000
Netherlands	5,000
Norway	4,000
Czech Republic	3,000

Heat pump systems performance strongly depends on the temperature level, on which the ambient heat is supplied. The higher the level, the better is the COP (Coefficient of Performance, fraction of thermal energy output to electrical energy input).

The impact of advanced storage technologies on heat pump systems depends on the kind of coupling to the ambience. Especially which type of heat source is used for the evaporation of the working fluid (e.g. ground collector, groundwater or ambient air). Since ambient air is subject to a large temperature fluctuation, shifting from times with high ambient temperature to times with high demand by heat storage could result in a higher energy efficiency of the system. These system configurations are task of current research.

To illustrate the benefits of applying heat storage in combination with heat pumps for space heating, energy consumption, costs and number of cycles per day were calculated for one family building equipped with an electrically driven heat pump.

The calculations show several benefits of coupling heat storage with heat pumps. In general, the benefits of heat storage with heat pumps are summarized as follows:

Efficiency If the system design and control strategy is correctly carried out, the coefficient of performance (COP) of the heat pump can be increased by using heat storage. The combination of a heat pump with heat storage allows to use electricity only during the low tariff periods. A larger use of this approach will stabilize the electricity demand and thus minimize peaks for heating and even cooling.

Economics Through the use of heat storages a longer lifetime of the heat pump (less start ups) can be reached. Furthermore tariffs shifting and thus lower operation costs for the end-user can be obtained. Finally, the use of smaller, cheaper heat pumps is possible by peak load shaving and a higher reliability of system will make the system economic more attractive.

Comfort benefits A basic benefit in this case is an easier control of the room temperature since temperature in the storage tank is more constant than the outlet of the heat pump. Furthermore the control of the heat pump is less critical in the case where storage is used (higher inertia of the storage tank compared to the classic system)

Environmental impacts As described above, with the use of heat storage a lower emission through higher COP and thus lower electricity consumption can be reached. Beyond, the heat storage contributes to stabilise electricity consumption, less electricity peaks and thus lower CO2 emissions since power plants of lower quality will be used less frequently.

5.5 Geothermal

5.5.1 Market situation

The market for "geothermal heat storage" is very difficult to address. Roughly speaking, geothermal installations discussed in most studies comprise only of those that produce power. Plants that are designed for the purpose of heat production are usually not included. Similarly, if a plant is installed to produce both heat and power, then it is only the power aspect that is incorporated in most figures.

Even with focus on power production, power supplies from geothermal resources contributes a minor proportion of total renewable energy in the Europe. The market has so far been restricted to a handful of countries. In view of the focus to small scale RES, the European geothermal heat market can be viewed as secondary.

Looking on coupled systems of heat pump and ground source (GSHP Ground Source Heat Pump or Geothermal Heat Pump) the situation is somehow different. As written above, the heat pump market in Germany showed a rather strange development. After a boom in 1980, a strong decrease could be seen with a minimum around 1990.

Among the heat pumps in this first boom around 1980 were only very few GSHP with borehole heat exchanger (BHE). The majority were air-source heat pumps. A reliable statistic distinguishing between heat sources started in 1996. Since then, there is a steady increase in GSHP.

Space and district heating have made great progress in Iceland, where the total capacity of the operating geothermal district heating system had risen to about 1200 MWt by the end of 1999, but they are also widely distributed in the East European countries, as well as in the United States, China, Japan, France, etc.

5.5.2 Actors

In view of domestic heating a distinction between geothermal and heat pumps is crucial, as they are often coupled as written above. Thus actors can be the same as written in the section of heat pumps.

5.5.3 Market and Benefit of heat storage

Geothermal applications can be divided into small scale/depth and big scale or very low / low and medium energy / high temperature applications. The last-mentioned applications are for electrical power production, whereas the waste heat can be used by heating net supply.

As geothermal is intended to cover basic load of electricity, power production is driven continuously. In this context, storing of the remaining waste heat for times with higher demand seems very interesting, if economical competitive storage technologies would be available. The total installed capacity of 842 MW yields in a production of 5.2 TWh of electric energy in EU 2005.

Assuming a conversion efficiency of 30% this leads to a waste heat of at least 10 TWh. As thermal usage of waste heat is not standard in the EU, advanced heat storage technologies can significantly increase the total energy conversion efficiency.

Table 9: Geothermal high temperature for power supply in Europe 2005

	Capacity [MW]	Yield [GWh]
EU	**842.6**	**5,190**
Italy	810.5	5,022
Portugal	16	71
France	14.7	95
Austria	1.2	2
Germany	0.2	0.2

Low and medium energy applications are using geothermal for heating issues. Most of them supply heat to public baths, swimming pools, greenhouses or heating nets.

Table 10: Geothermal low / medium for heating in Europe 2005

	Capacity [MW]	Yield [GWh]
EU	**2,109**	**7,625**
Hungary	715	2,199
Italy	487	1,960
France	292	1,512
Slovakia	186	840

Looking at the small scale / very low energy geothermal applications, these are coupled with heat pumps. Therefore the market for geothermal storage units is almost the same as that for heat pumps in this case.

Table 11: Geothermal very low energy (GSHP) in Europe 2005

	Quantity	Capacity [MW]
EU	**455,435**	**5,378**
Sweden	220,115	2,016
Germany	61,912	805
France	67,820	746
Austria	35,847	716

While applications of low/medium and high energy/temperature realise an annual growth of 2% in installed capacity 2005, the very low energy geothermal coupled with heat pumps (GSHP) rises by 18% in the EU.

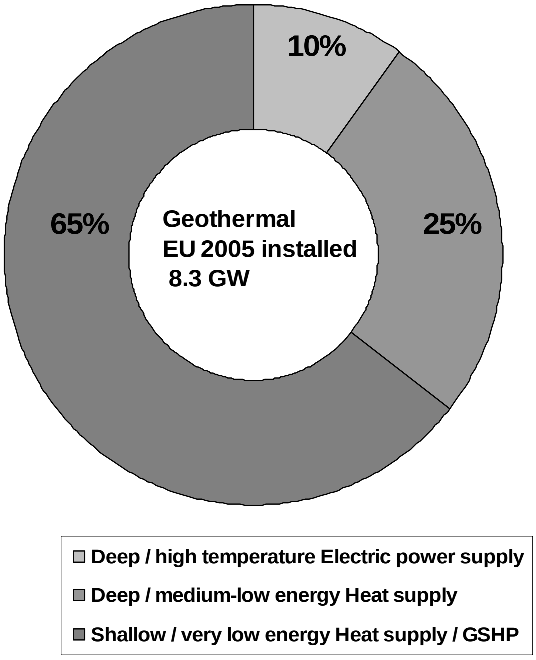

Figure 9 Installed geothermal energy capacity

Benefits of an optimized storage in a geothermal system

Explicit benefits of an advanced heat storage for these systems can not be defined, as usually, with regard to coupled systems (heat pump) the ground source serves as heat storage itself.

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7 Annex A: Heat storage technologies

This annex gives a short overview on existing and possible future heat storage technologies. A detailed review on this topic can be found in the IEA Task 32 handbook on thermal storage [1].

As shown in figure 10, thermal storage options can be split into four physically different technologies:

- Sensible storages, which use the heat capacity of the storage material – mainly water is used for its high specific heat and low cost.
- Latent storages, which make use of the storage material's latent heat during a solid/liquid phase change at a constant temperature.
- Sorption storage, which use the heat of ad- or absorption of a pair of materials such as zeolite-water (adsorption) or water-lithium bromide (absorption).
- Chemical storages, which use the heat stored in a reversible chemical reaction.

Until today, the market is largely ruled by hot water storage vessels due to the qualities, the cost, the simplicity and the versatility of water as a storage medium.

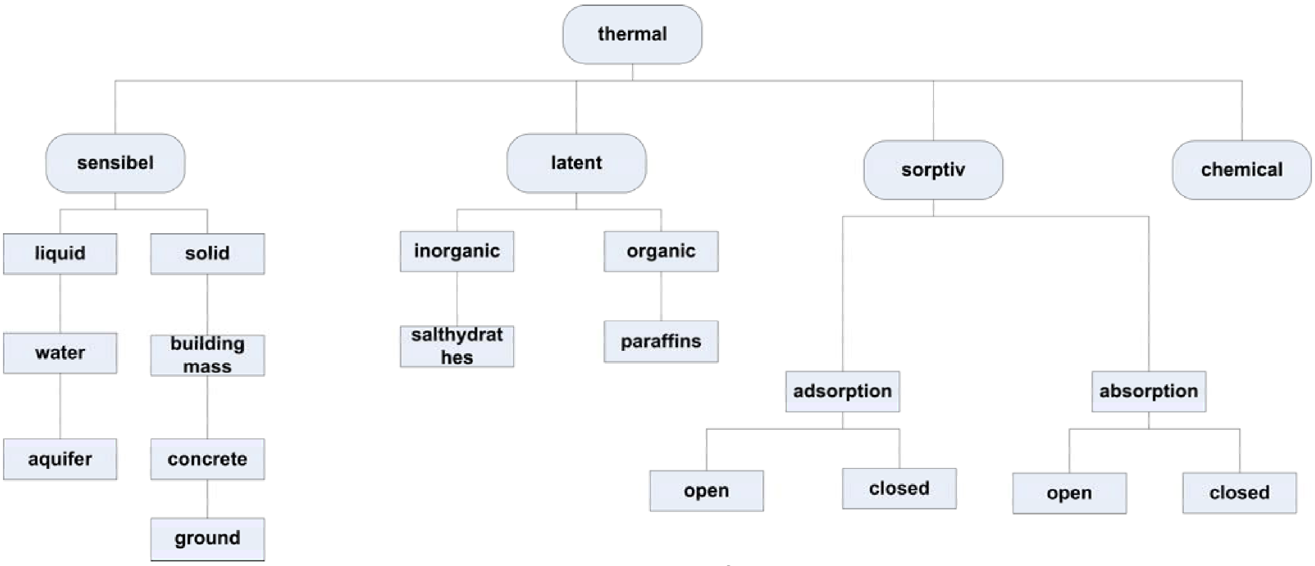

Figure 10 Heat storage classification

7.1 Sensible heat storage

The most cost effective way of storing low (0 - 20°C) to medium (20 - 100°C) temperature heat is water, because it is relatively cheap and convenient material. Furthermore water has, compared to other common storage materials, a very high specific heat capacity (4.19 kJ/kg.K) as well as a very high volumetric heat capacity, which is in particular important for compact storage systems.

Tanks are ideally suited for water storage since they are cheap and easy to produce (for example, 50-1000 L tanks are built by millions each year for the HVAC market). Water can also be stored underground in bore holes (e.g. Duct storage) or by using an underground sand layer (e.g. aquifer). Which storage type is used depends on the application and on the sort of storage: short/mid-term storage or seasonal (long) term storage. In this section we will discuss both types of storage.

7.1.1 Short- and mid-term storage

A solar storage vessel in a domestic water heater system, as shown in Figure 11, is an example of short- and mid-term storage:

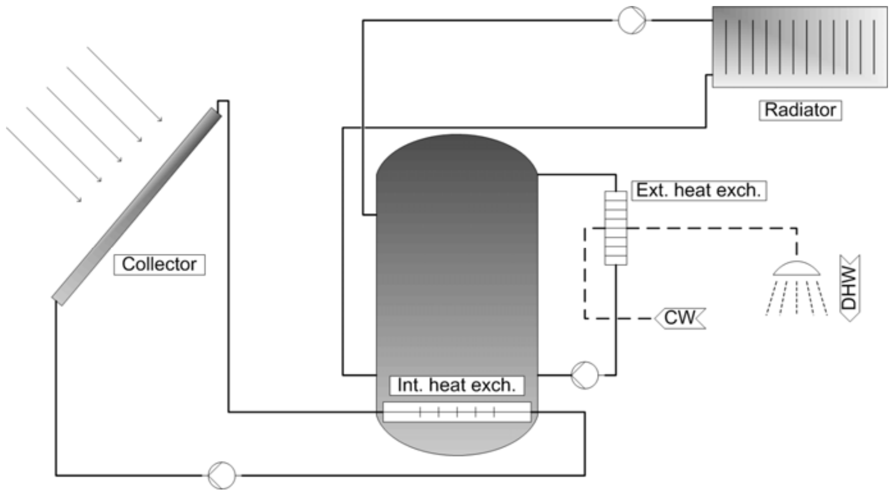

Figure 11 Scheme of a state of the art solar water storage used for heating and domestic hot water

These storage systems mainly use water tanks and since the heat demand is only for a short time period (for example when using the shower), the size of the tanks are small. Of course, the more efficient the solar heat is stored, the smaller the tank. Modern solar storage vessels combine several specific features that improve the overall efficiency of storing solar heat, including:

- Small amount of thermal bridges, in order to reduce the heat losses
- Enhanced insulation for example by using vacuum insulation
- Siphon introductions of pipes to avoid natural convection losses
- Stratification enhancers to increase the exergetic value of the content of the store
- Internal devices to reduce speed of inlet water not to disturb stratification
- Large heat exchangers or mantle heat exchanger.

7.1.2 Seasonal storage

Seasonal storage is often used in combination with office buildings or residential areas. Large water tanks have been built since 1980 with success for solar plants mainly in Sweden, Denmark, Germany and Switzerland.

Very large seasonal storages for district heating benefit from the reduced surface area to volume ratio and therefore lower specific heat losses in comparison with small seasonal storages.

At present there are eight operating central solar heating plants with seasonal storage in Germany. The results (showed in Ref. [3]) from all plants have demonstrated the capability of the system.

Although the specific cost of a large tank have been significantly reduced compared to that of a small storage tank for a one family house, it is still expensive (150 to 250 €/m3 for 10'000 m3 tanks), especially for storage achieving not more than 1 to 3 cycles per year. For comparison: domestic hot water tanks cost 1'000 €/m3 but achieve more than 200 cycles per year!

7.1.2.1 Duct storage

Duct storage uses vertical heat exchangers in the ground to enable heat exchange from and to the ground. This form of storage is cheap and reliable solution for big projects or small projects in combination with a heat pump.

An example of a big and successful project is the Neckarsulm project in Germany. The Neckarsulm storage consists of 528 bore holes each 30 m deep. The present storage volume is 63,200 m3 (see Table 12) and is heated up by 6,337 m2 of collectors. The core of the store reached 62 °C in summer 2003.

Table 12: Neckarsulm design data [4]

	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^2	140,000 m^3

The Neckarsulm project has shown since 1998 that the technology of shallow duct storage is operating as predicted by computer models at a cost lowered by a factor of 4 to 5 compared to a tank storage [4]. Although the store operates with great heat losses during it's warming up time (5 years), it is expected to reach 50% efficiency in 2005.

Duct storage used with a heat pump is common in several countries.

The store operates at low temperatures (0 to 30 °C) without any heat losses. It has been shown that the storage efficiency can reach 90 to 100% when the store is operating around the average natural temperature of the ground.

7.1.2.2 Aquifer

Aquifer storage uses an underground (sand-) layer to store heat or cold and was one of the most promising technologies in the 1980's because of its low cost to access huge volumes of water. Figure 12 shows the operating principle of an aquifer for cold storage:

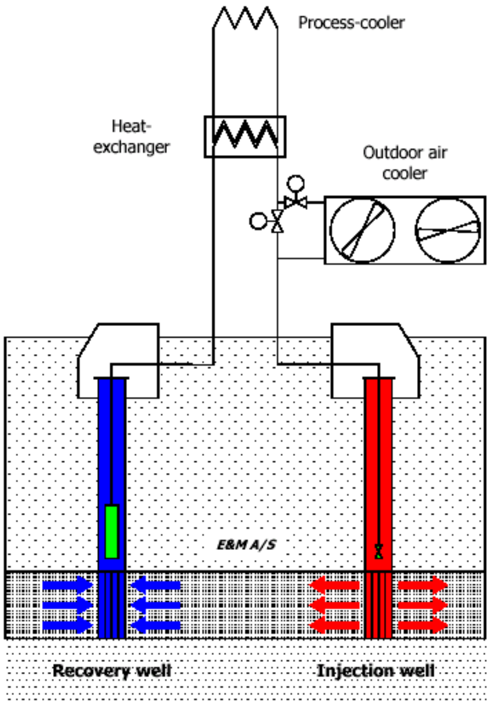

Figure 12 Principle of using an aquifer for a cold storage

An aquifer for cold storage is based on the following principle (see also the above Figure): water from the injection well is cooled in winter, for example with cool outdoor air, and is stored into the recovery well. In the summer, the direction of the water flow is reversed and the water from the recovery well is now used for cooling. An aquifer for heat storage is based on the same principle, but then the charging takes place in summer.

During 1975-1985 pilot plants were built in Denmark, France and Switzerland to test the concept of storing solar heat without a heat pump at 60 to 90°C into an aquifer at a depth of 30 to 200 m. They reach only limited success due to chemical problems (calcite precipitation) or due to buoyancy effects ruining the exergy of the store [6]. 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.

Cold storage in aquifers has become a cost effective technology in some countries (for example in China where there is a long tradition of cold water storage in aquifers). If underground (sand) layers are available for heat storage then competition against electricity costs makes the alternative of free cooling with a coefficient of performance (COP=output heat/supplied work) of more than 20 (!) attractive.

7.2 Latent heat storage

Most latent heat storages are using the solid-liquid phase change of a material to store thermal energy within a small temperature difference. The energy is then stored in the change of the structure of the material instead of rising the temperature. This makes latent heat storages especially useful for applications which operate in a small temperature range. Figure 13 shows a schematic view of the difference between sensible and latent heat storage. Figure 14 shows several classes of phase changing materials at different operating temperature ranges.

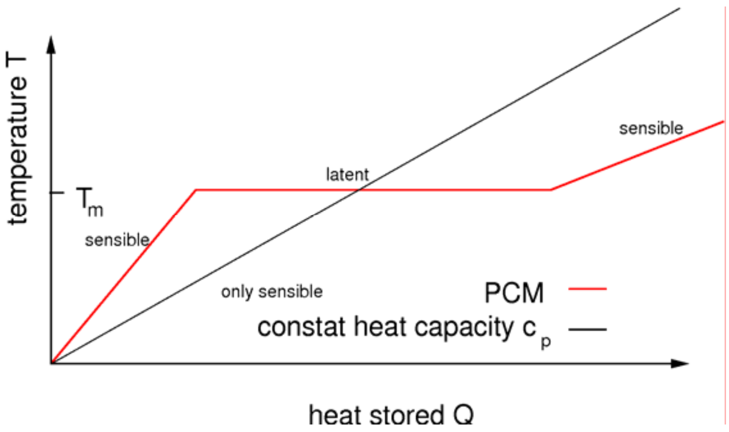

Figure 13 Difference between sensible and latent heat storage

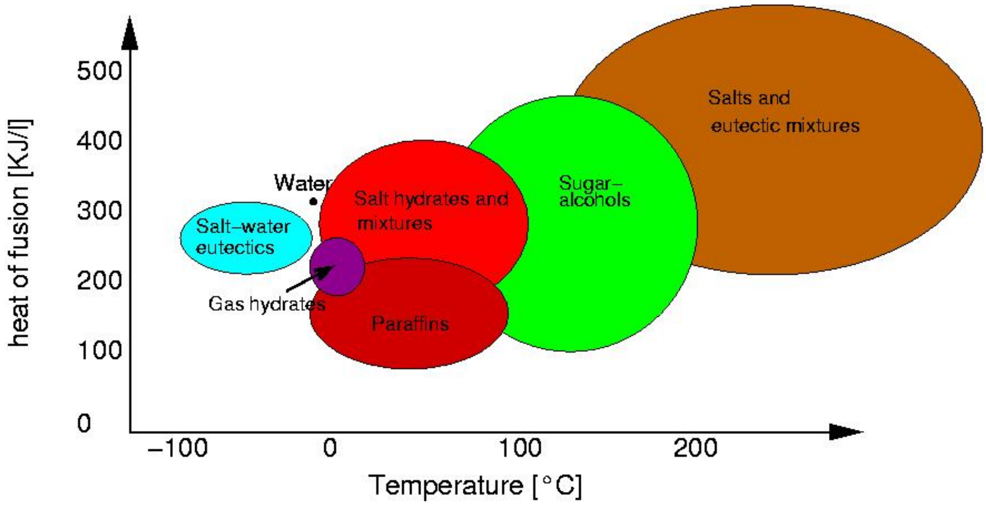

Figure 14 Classes of phase change materials at different temperature ranges

At the moment, mostly two classes of materials are used: organic (mostly paraffin's) and inorganic (mostly salt-hydrates). The advantages and disadvantages of both materials are shown in Table 14.

Table 13 Summary of advantages and disadvantages of salt hydrates and paraffin's for latent heat storage

	Salt hydrates	Paraffin's
Advantages	▪ High storage density ▪ Not inflammable ▪ Different materials at different temperature levels available ▪ Several cheap materials available	▪ accurate choice of melting point ▪ less sub cooling ▪ non toxic ▪ long term stability ▪ micro encapsulation possible
Disadvantages	▪ Mostly corrosive materials ▪ Some materials are toxic ▪ accurate choice of melting point difficult ▪ some show incongruent melting ▪ some are difficult to handle because they are hygroscopic ▪ some show severe sub cooling ▪ till now no micro encapsulation possible	▪ Lower energy density ▪ Flammable material ▪ Might be expensive, depending on the quality

Depending on the application (temperature range, charging/discharging power, volume/weight available) different materials can be chosen.

An ordinary example of a PCM material is ice, where the phase change water-ice occurs. Ice storage can compensate imbalance between heat production and demand.

The advantages of an ice storage system are summarized as follows:

- Reduction of refrigeration machine capacity which results in high efficiency for full operation.
- Redundancy for HVAC system.
- Utilization of night-time discount electricity prices.

Ice is a PCM with a fusion point at 0 °C, but chemicals make it possible to get materials at almost any temperature of fusion, more suited to heating of buildings.

The idea of using PCM in a storage tank in solar systems has been investigated in the 1980s using paraffin. Although it works, solar collectors have improved considerable and are now less dependent on the operating temperatures in the range of 50-80°C. Besides this, paraffin has also a major drawback: it's a highly flammable material.

A few manufacturers provide PCM materials for storing solar heat on the market, which are in the temperature range from 20 to 80°C. Table 1 shows some PCM materials available on the market:

Table 14 Some PCM available on the market for storage of solar heat [1]

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

Even for T=0°C, the company Cristopia [8] manufactures polymer balls that encapsulate water for ice storage. The same idea could be applied to the class 50-60°C PCM materials, which could be encapsulated in a ball shaped storage and become a fluid under the influence of solar heat like a rock bed does with air.

Another possibility is to integrate phase change materials into the building structure to work as peak-shaving heat storage. Since the 1970s, several researchers have tried to use phase-change materials (PCM's) in buildings to enhance the thermal comfort of lightweight constructions, especially to overcome overheating problems in summer.

A new class of latent heat storages under investigation is phase changing fluids. These functional fluids consist of a carrier fluid (e.g. water or water/glycol) and PCM materials which can be microencapsulated paraffin or emulsified paraffin. These phase changing fluids offer an increase heat capacity compared to water for a certain temperature range. This property offers great opportunities for using these phase changing materials as heat storage or heat transfer media for applications operating in a small temperature range.

Depending on the temperature range of the application and the percentage of PCM, an increase of the energy density by the factor of 3-4 seems feasible. First demonstration plants for cold storages are under investigation.

7.3 Thermo-chemical storage

In thermo-chemical storage systems heat is not stored as latent or sensible heat, but by sorption processes or chemical reactions consuming heat during charge mode and releasing heat during discharge mode. Figure 15 shows a schematic overview of this charging, storing and discharging cycle. Under influence of heat a thermo-chemical material dissociates into two components, which are subsequently stored in separate containers. In the discharge mode, the two components are brought together to form the original thermo-chemical material with the release of heat stored during the charge mode.

No reactions occur as long as the two components are stored separately, which means that thermo chemical storage can be used for both short-term (hours/days) and long-term storage (months) with also almost no heat loss and high storage densities.

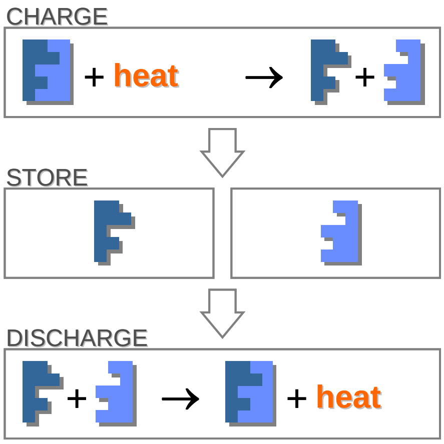

Figure 15 Overview of charging, storing and discharging cycle in thermo-chemical storage systems

Figure 16 shows the classification of thermal-chemical storage systems.

Thermal-chemical storage systems can be divided into heat storage systems using sorption processes and chemical reactions. In sorption processes one species is attached to or incorporated in another species (e.g. water in zeolite) whereas in a chemical reaction species are converted into a new species with new chemical composition (e.g. 2NaOH → Na2O + H2O).

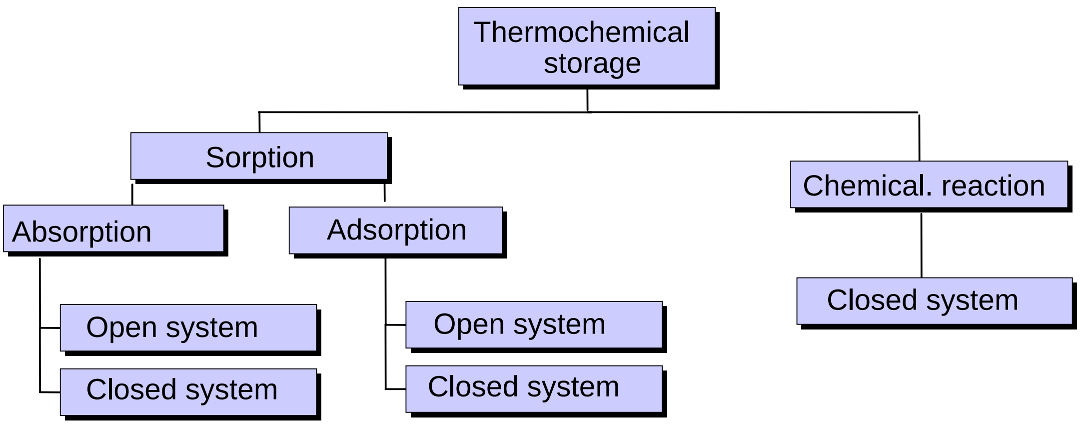

Figure 16 Classification of sorption processes for heat storage application [1]

7.3.1 Sorption processes

The term sorption refers to either adsorption or absorption. Adsorption is accumulation of a fluid (gas/liquid) on the surface of a sorption material, while absorption is a process where the fluid enters the bulk phase without accumulation on the surface.

Sorption processes can be divided into closed and open systems. In open systems the gaseous working fluid is directly released to the environment and thereby the enthalpy is released; for this reason water is often used as working fluid. Examples of open systems are sorption processes for desiccant systems and heat storage systems based on the adsorption process. In closed systems, only enthalpy and not the working fluid itself is released to the environment via a heat exchanger. Closed systems work with a closed working fluid circuit which is isolated from the surroundings.

7.3.1.1 Adsorption (zeolites/silica gel)

The working principle of an adsorption closed heat system where zeolites or silica gel is used as sorption material is shown in Figure 17.

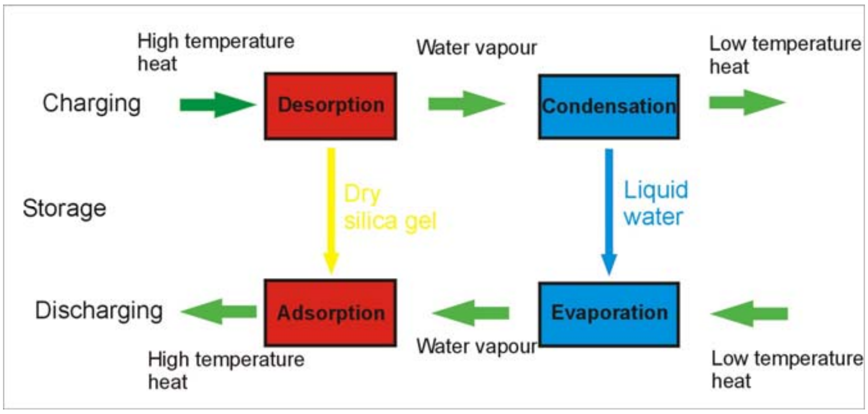

Figure 17 Working principle of an adsorption heat storage in a closed system

In recent years, there has been significant research progress on micro- and mesoporous adsorbent materials suitable for closed and open system solar heat storage applications. Most adsorption heat storages that have been built so far are still based on commercially available adsorbents that have originally been developed for applications like gas separation or catalysis. For the next generation of heat storage systems currently under development, novel adsorbents are being investigated.

For heat storage applications, the choice of adsorbent is determined by the amount of heat that can be extracted from the adsorbent per adsorption cycle. In principle, the heat extracted from the adsorbent is proportional to the amount of vapor adsorbed and therefore the loading spread of the adsorbent over a given cycle is a good figure of merit.

A systematic investigation of adsorbents has been performed at Fraunhofer ISE. Within a new network project, sponsored by the federal ministry of research, optimization strategies and new materials have been developed for the use in heat transformation applications. A selection of some adsorbents and their capacity as well as the integral heat of adsorption are given in Table 15.

Table 15 Selected sorption heat storage materials with capacity and integral heat of adsorption

zeolite type	adsorption capacity [g/g]	integral heat of adsorption [kJ/kg]
Na-A	0.286	1078
Na-Y (2.5)	0.335	1214
Na-Y (5.0)	0.288	940
Na-X	0.388	1289
Na-LSX	0.281	1301

The proof of concept has been given by several demonstration projects. The achievable storage density is 3 to 4 times the storage density of common water tanks.

7.3.1.2 Absorption (salt hydrates)

Absorption heat storage (closed) systems mainly use salt hydrates or salt ammoniates. Two and three phase systems are usual with solid-gas and solid-liquid-gas phase as basic phases. An example of a two phase system is $MgSO_4.7H_2O$:

$$MgSO_4.7H_2O\ (s) + heat \Leftrightarrow MgSO_4\ (s) + H_2O\ (g)$$

This reversible reaction can in theory can store up to 2.8 GJ/m3 of thermal energy at T=122 °C, which is more than 10 times higher compared to the energy density of hot water (0.2 GJ/m3 in the temperature range of 60°C to 100°C). Thus, for the same amount of energy, the storage volume can be significantly reduced!

Within the Dutch WAELS project MgSO4.7H2O is studied at ECN as possible thermo-chemical storage candidate material for seasonal storage in the built environment to overcome the gap between solar energy surplus in summer and heat demand in winter. The high energy density and the fact that no heat losses are associated with thermo-chemical storage makes MgSO4.7H2O an possible ideal candidate for seasonal storage.

An example of a salt-hydrate system that uses 3 phases process (solid, solution and vapor) is the Thermo-Chemical Accumulator (TCA). The process has been developed by the Swedish company ClimateWell AB as a batch process under the name ClimateWell DB220, where LiCl/water pair is used.

During desorption (charging) the solution becomes more and more saturated and when it reaches a saturation point further desorption at the heat exchanger will result in the formation of salt crystals that fall under gravity into the vessel. A sieve prevents the crystals to flowing into the pump, which results in formation of a slurry at the bottom of the vessel.

For discharging, the process is reversed and the saturated solution is pumped over the heat exchanger, where it absorbs the vapor evaporated in the evaporator. The heat of evaporation is provided by either the building (cooling mode) or from the environment (heating mode). As the solution become unsaturated on the heat exchanger, it falls into the vessel and passes through the slurry of crystals to make the solution fully saturated again. Field and lab tests indicate that the technology works and is reliable, but that temperature lift and cost of the salts are limiting factor. The technology is now being commercialized.

7.3.2 Chemical reactions

A chemical storage uses chemical reactions to store or release thermal energy. A chemical reaction is a process that results in the conversion of chemical species.

Many ways exist to convert solar energy (in what form so ever) into thermal energy. Quite obvious is the photo-thermal route as utilized in current solar hot water and space heating systems. Of course the photochemical route (photosynthesis) is the global solar energy conversion mechanism that has provided mankind with vast amounts of energy (stored in fossilized biomass) for heating, lighting and food. Many chemical reactions are not suitable for storage of solar energy in residential areas. In addition to common conditions for a residential thermal energy store like reasonable costs and safe and reliable operation, chemical storages need to satisfy the following criteria:

1. High storage density (> 2 GJ/m3)
2. The chemical reactions need to be:
    a. Controllable and reversible at a rate sufficient to cover domestic hot water (DHW) and space heating and/or cooling loads, direct or indirect via a small intermediate buffer.
    b. Take place at safe (low e.g. < 10 bar) pressures and temperature levels within the range of domestic solar collectors (< 250 °C).
3. In addition, the components involved in the chemical reactions need to be:
    a. Chemically stable.
    b. Safe and easy to handle.
    c. Recyclable and environmentally benign (non toxic).
    d. Inflammable.

Especially the temperature level restriction and the power density (reaction kinetic) conditions pose severe limits to the chemical reactions known. In general, chemical reactions take place at acceptable power levels at elevated temperatures (e.g. >500 °C). There are a few reactions that will be presented that could provide solutions for moderate collector temperatures (< 250 °C).

In an extensive study for medium temperature thermo chemical storage materials (TCM's), ECN and Utrecht University (The Netherlands) identified many candidate materials that were all selected with respect to criteria similar as outlined above and considering both sorption processes and chemical reactions [9]. Table 17 shows the 5 most attractive candidate materials.

Both MgSO4·7H2O and CaSO4·2H2O are hydrates that fall under sorption processes (see also previous section). The iron complexes FeCO3 (carbonate) and Fe(OH)2 (hydroxide) can be viewed upon as attractive chemical storage materials with reasonable storage densities 1.2 - 2.6 GJ/m3 at acceptable temperature levels of 150-180°C.

Table 16 Promising chemical solar storage candidate materials, identified by ECN/UU, The Netherlands [9]

Material name	Dissociation reaction			Energy storage density of C	Turnover Temperature
	C ⇔	B +	A	GJ/m^3	°C
Magnesium sulphate	$MgSO_4.7H_2O$	$MgSO_4$	H_2O	2.8	122
Silicon oxide	SiO_2	Si	O_2	37.9	4065 +HF: 150
Iron carbonate	$FeCO_3$	FeO	CO_2	2.6	180
Iron hydroxide	$Fe(OH)_3$	FeO	H_2O	2.2	150
Calcium sulphate	$CaSO_4.2H_2O$	$CaSO_4$	H_2O	1.4	89

The silicon based system as described by Auner et al., 2003, involves the reaction of silicon with oxygen and/or nitrogen. The exothermic part of the cycle is the "burning" of silicon with oxygen and/or nitrogen which is suitable for application in residential areas. The reverse (endothermic) process is the conversion of the produced silicon nitride and silicon oxide ("sand") back to silicon. This process has to be conducted in an industrial environment because it involves a complex reaction scheme with side reactions including HF and electrolysis of NaF and H2O. For this reason this reaction is not suitable for applications in the built environment. The conclusion of this study is that in principle attractive materials exists, but further research is needed to determine practical aspects like reaction kinetics and mass transfer rates.

A system slightly above the temperature limit of 250 °C is the sodium hydroxide storage suggested by Weber at EMPA Switzerland in 2003.

The reversible reaction

2NaOH ⇔ Na2O + H2O

can store in principle 2.6 GJ/m3 of thermal energy at 300 °C. Quite interestingly, this reaction was used for many years around 1920 in fireless steam locomotives. A research project based on this reaction is underway in Switzerland.

The state of the art of thermo-chemical and photochemical solar energy conversion systems can be characterized according to the next table:

Table 17 Status of two chemical conversion options [1]

	Thermo-chemical	Photo-chemical
Development stage	Demo	Laboratory
Storage density	High	Very high (5-15 GJ/m^3)
Conversion and storage efficiency	High 50-80 %	Low 1 %
Conversion temperature	medium (~200 °C)	Ambient temperature

8 Annex B : Simulations and calculations

8.1 Benefits of Thermal Storage to Solar DHW and Heating systems

It order to globally assess the benefits of thermal storage in systems, simulations with regard to solar domestic hot water (DHW) and heating systems have been performed. These simulations were performed with the software T-Sol 4.0.

The first case study used in the simulations was a one family building. This is due to the fact, that since in 2004 about 84% of the newly built residential buildings in Germany were single family houses.

In the simulation, a natural gas boiler is used with a CO_2 emission of 2,0kg/m³. This corresponds to 0,19 kg/kWh of gas energy unlike this value is higher for the actually used heat due to losses of the boiler and the whole system.

In the case of oil boilers, the CO_2 emissions are 1.4 times higher (0,27kg/kWh). The values for saving natural gas and CO2 emission were re-calculated in MS-Excel.

Within the parameter study, the volume of the storage tank was varied, while the rest of the settings were kept fixed. The parameter used in the simulations are shown in table 18.

Table 18 Parameters used for simulation

Weather	Freiburg, Germany
Hot Water Demand (4 person household)	160 l/d Temp. 50 C Pattern of demand: single family house, morning peak No circulation loop
Backup heating	Gas-upper heating value boiler: max 9kW from T-Sol library Natural Gas H, operating 365 days Efficiency of hot water supply: 70%
Collectors	6 m^2, no shadowing Orientation: south, tilt angle: 30° Pipes 8m inside, 1m outside building, Insulation/diameter: default values
Storage	T-Sol Lib. Hot water storage vessel (w/o stratification) Volume varies (100-2000 liters) Insulation: 100mm No heat exchanger, no heating rod adjustment control with standard values

8.1.1 Results of storage size effect on a 6 & 12 m^2 Solar DHW system

In the following graphs, the result for a 6m² collector field is shown in terms of solar fraction, CO_2 and natural gas savings under the variation of the storage tank volume.

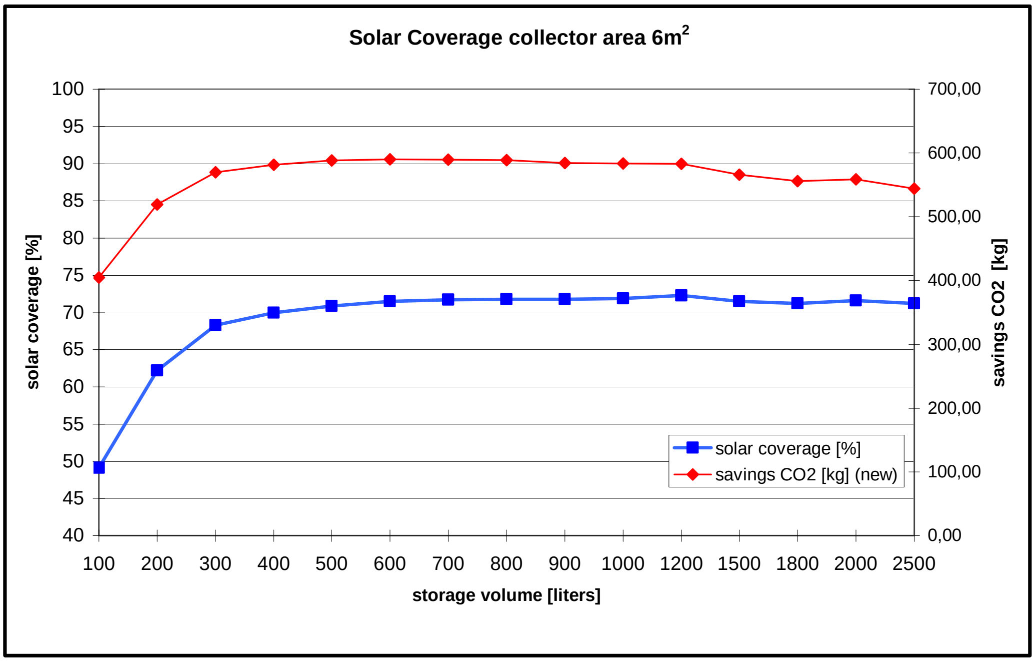

Figure 18 Solar fraction and CO2 emission savings vs. Storage volume for a standard 6 m2 solar DHW system in Freiburg, Germany

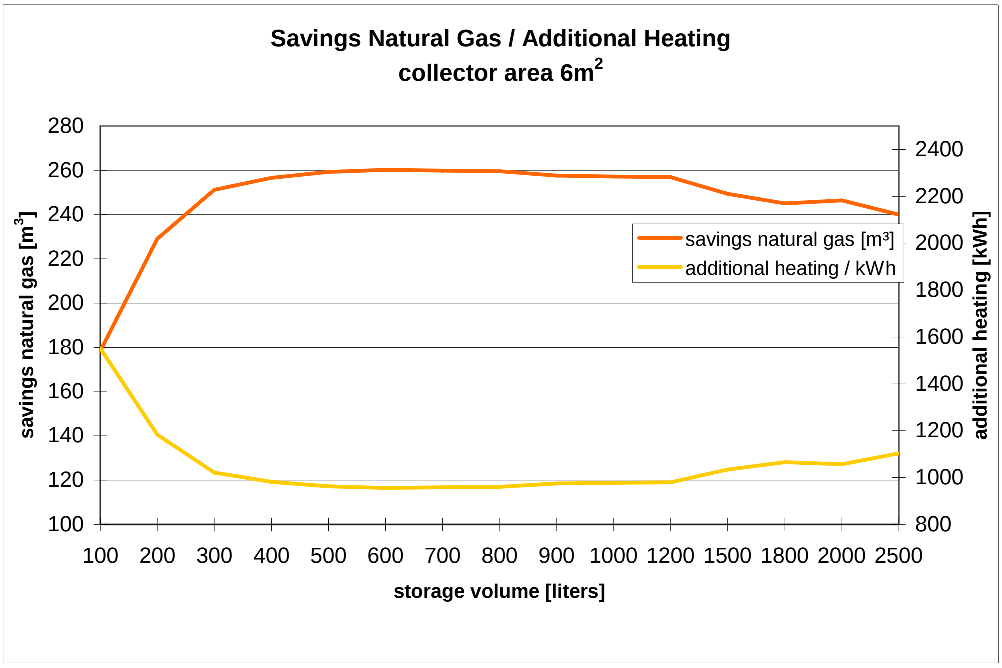

Figure 19 Gas savings and auxiliary heating needed vs. Storage volume for a standard 6 m2 solar DHW system in Freiburg, Germany

As can be seen in the figures above there is an optimum for storage tanks between 500 and 800 liters volume.

Calculations for a fixed collector area of 6m^2 indicate that the solar fraction remains constant for tank volumes larger than 500 liters. However, larger tanks will result in larger heat loss, as the tank insulation thickness was kept constant. This will lead to an increasing heat demand of the backup heating to keep the tank temperature constant. Thus, savings of CO_2 emission are bigger for the tank volumes smaller than ~1000 liters.

In the case of an optimum storage tank volume of 500-800 litres, a solar fraction of 72% as well as 589kg CO_2 reduction per year can be reached respectively.

Calculations performed for a 12 m² Solar DHW system show an optimum storage volume of 800 litres. With this tank volume a solar fraction of 84% and 700kg CO_2 reduction per year can be reached.

8.1.2 Results of storage size effect on a 12 & 20 m² combisystem

Beside DHW systems simulations were performed for two typical combisystems with collector areas of 12 and 20m^2. In contrast to the previous DHW simulation the following heating demand has been taken into account:

Heating:	Low temperature panel heating, in/out: 40°/25°C
Heating area:	120 m^2
Spec. heating demand:	75 W/m^2
Annual heating demand:	115 kWh/m^{2}a

Although the average heating demand in Germany in 2000 was 167 kWh/m^{2}a, a value of 115 kWh/m^{2}a has been chosen for a renovated single family house (Heat Insulation Ordinance 1995 for new buildings, Germany: ~100 kWh/m^{2}a.

The simulation results of the combisystem with a collector area of 12 m² are shown in figure 20 and figure 21.

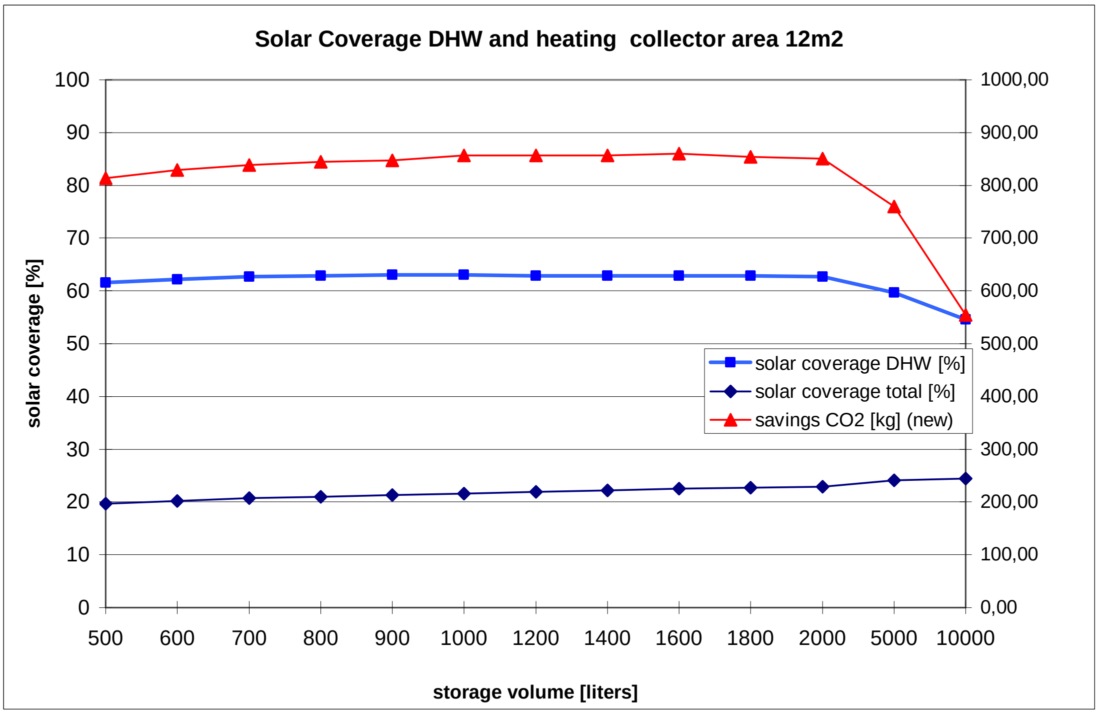

Figure 20 Solar fraction of DHW, both DHW + heating and CO_2 emission savings vs. Storage volume for a standard 12 m² combisystem in Freiburg, Germany

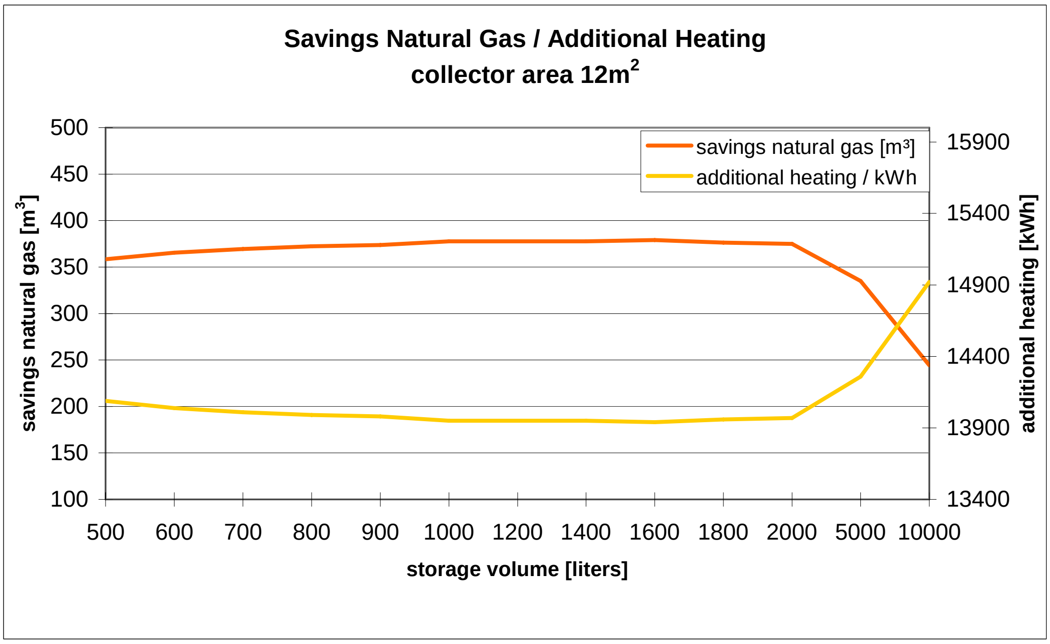

Figure 21 Gas savings and auxiliary heating needed vs. Storage volume for a standard 12 m2 combisystem in Freiburg, Germany

The simulation results show an optimum between 1000 and 1800 liters of storage tank volume. With the defined configuration a total solar fraction of about 22% and 860 kg CO_2 reduction per year can be reached in the optimum case.

The same calculations performed for a 20 m^2 combisystem show an optimum between 1600-2000 liters storage volume. In this case, a total solar fraction of about 29% and 1160kg CO_2 reduction per year can be reached.

With regard to 10.91 million single family houses in Germany this will result in approximately 12.6 million tons if CO_2 reduction per year. This shows the huge potential for CO_2 reduction by using solar thermal equipment.

8.1.3 Effect of the storage insulation thickness

To estimate the effect of the storage insulation thickness, simulations were performed with the same parameters as for heating demand and a 20m^2 combisystem. The storage tank was considered "totally" insulated with 500mm vacuum isolation panel. The optimum volume was 10,000 liters.

The CO_2 savings could be increased by 25% up to 1.470 kg whereas the "maximum" achievable solar fraction is 31%. Therefore a first conclusion regarding the results with a better insulation of a 10 m^3 storage tank is this is not the choice for a advanced storage concept for a higher solar fraction. To reach a higher solar fraction, larger storage volumes will be needed, which is often not possible due to the restricted space in renovated buildings.

8.1.4 Summary of simulation results

Besides the above described systems, simulations were also performed for other situations, where the heating demand of the building is varied and the above simulated installations are placed into several different building standards. The results of these simulations are shown in figure 22.

In this figure the possible savings of a standard 120m² flat are illustrated. The first bar ("Continuance 2000") with a value of 100% corresponds to a CO_2 emission of 5 tons per year. This is a representative value for a standard building in Germany built in 2000.

This standard building is heated by a gas boiler to cover a heating demand of 167 kWh/m^2a (cream color) and DHW backup system (light orange). As mentioned before, the absolute CO_2 emission would be 40% higher! The blue fraction in figure 22 corresponds to the savings due to insulation of the building. Insulating of the standard building already reduces the heating demand to 115kWh/m^2a (second bar).

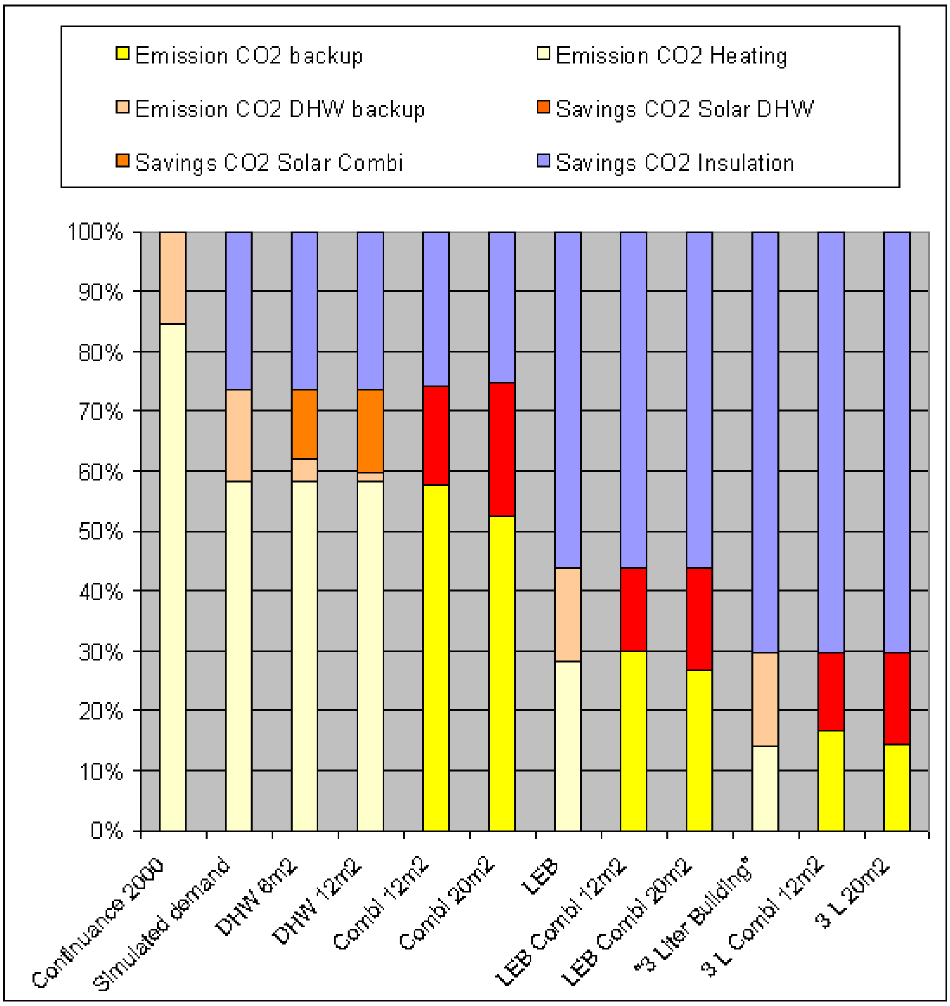

Figure 22 CO_2 emission savings for several systems in Freiburg, Germany

The following bars will include this building standard. The savings of CO_2 by solar fraction of DHW and heating demand are shown as dark orange and red fractions, respectively. The same procedure as discussed above was applied to a Low Energy Building (LEB) with a demand of 56kWh/m^{2}a and a "3 liter Building" with 28 kWh/m^{2}a.

In the last bar of figure 22, it can be seen that the CO_2 emission could be decreased by a dramatical increase of the insulation. Furthermore installing a heat recovery unit on the ventilation air and using a 20 m^2 solar combi system the CO_2 emission could be reduced by more than 85% in comparison to the standard building. This corresponds to an absolute savings of 3.7 tons CO_2 emission per year per house or about 1 ton per capita.

The variation of the storage tank volume showed, that there is an optimum volume for each type of installation in order to save as much CO_2 emission as possible. Also in the case of small DHW solar installations there is a broad region of the curves that is suited (example: for a DHW 6 m^2, the optimal region is 500-800 liters), so complete packages with collectors, boiler and pumping unit can fit several buildings.

8.2 Benefits of using heat storage coupled with a heat pump

To illustrate the benefits of applying heat storage for space heating, energy consumption, costs and number of cycles per day were calculated for one family building equipped with an electrically driven heat pump.

The calculations were performed for a single family building of 100m² equipped with a geothermal heat pump for space heating and domestic hot water supply in a northern French climate.

A conventional hot water tank, heated by the heat pump, is charged during the low tariff period (between 10PM and 6AM) and provides domestic hot water during the day.

A second hot water tank is also charged during the same period by the heat pump and provides the necessary heat for space heating. The size of this heat storage has been defined by simulation to 1250 liters (this size has been determined in order to provide enough heat throughout the day).

In case of a parallel demand, priority is given to the domestic hot water production such that this tank is always charged first in case of the need for domestic hot water in the evening.

This case with double heat storage is compared to two other cases where no additional heat storage is used for space heating. The heat storage for domestic hot water preparation is identical to that in the first case.

This same system layout is simulated for two cases: in a first case a normal subscription of an electricity contract is used (same tariffs all day long) and a second case where tariff shifting is used (in this case the tariff is about 40% lower during 8 hours in the night but the subscription is more expensive).

The following three casestudies were considered:

Case 1:

Heat pump with heat storage for both domestic hot water (DHW) and space heating and operation of the heat pump only during low tariff periods (low tariff contract subscription)

Case 2:

Heat pump with storage for DHW and no heat storage for space heating, operation depending on the load (low tariff subscription)

Case 3:

Heat pump with storage for DHW and no storage for space heating, operation depending on the load (normal tariff subscription)

For the calculations, a constant value for COP of 3.5 has been applied. The results of the calculations are presented in Table 19.

Table 19 Results of calculations for a heat pump in a single family housing (see text for details)

Criteria	Unit	Case 1	Case 2	Case 3
Energy for space heating	kWh	11606	11833	11833
Energy for DHW	kWh	2714	2708	2708
Total thermal energy for building	kWh	14759	14749	14749
Electric energy for heat pump	kWh	4217	4214	4214
Costs for electricity subscription	€	190	190	121
Electricity costs per year	€	275	411	543
Total costs/year	€	465	601	574
Total costs after 15 years	€	6981	9022	8604
Average number of cycles/day	-	2.3	4.4	4.4

The energy consumption for space heating, domestic hot water production and total energy consumption is almost identical in all three cases. The electricity consumption is, due to the constant COP (simplification), also identical.

Table 19 also shows that the electricity costs per year in case of using heat storage for space heating can be reduced to half the cost without heat storage and normal tariff subscription (Case 3). The lifetime of the heat pump is estimated to be 15 years. After this period, installing heat storage for space heating reduces the cost from ~€ 9,000 (Case 2 and 3) to ~€ 7,000 for Case 1 which makes this solution quite interesting. In fact, this difference of € 2,000 is generally higher than the investment cost of additional heat storage (approximately € 1,500). In practice a small heat storage tank is used for comfort issues (stable temperature), resulting in lower supplementary costs. This makes Case 1 economically very interesting.

Besides these economic factors, the number of cycles of the heat pump is halved when heat storage is used. As a result the lifetime of the heat pump will be much higher in comparison to the classic solution without heat storage (Cases 2 and 3).

The calculations show several benefits of coupling heat storage with heat pumps. In general, the benefits of heat storage with heat pumps are summarized as follows:

Efficiency

If the system design and control strategy is correctly carried out, the coefficient of performance (COP) of the heat pump can be increased by using heat storage. The combination of a heat pump with heat storage allows to use electricity only during the low tariff periods. A larger use of this approach will stabilize the electricity demand and thus minimize peaks for heating and even cooling.

Economics

Longer lifetime of the heat pump (less start ups)

Tariffs shifting and thus lower operation costs for the end-user

Use of smaller, cheaper heat pumps is possible by peak load shaving

Higher reliability of system

Comfort benefits

Easier control of the room temperature since temperature in the storage tank is more constant than the outlet of the heat pump.

Control of the heat pump is less critical in the case where storage is used (higher inertia of the storage tank compared to the classic system)

Environmental impacts

Lower emission through higher COP and thus lower electricity consumption.

Contributes to stabilize electricity consumption, less electricity peaks and thus lower CO2 emissions since power plants of lower quality will be used less frequently.

9 References to Annex A and B

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