R&D PROGRAMME ON THERMAL ENERGY STORAGE IN GERMANY

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1. INTRODUCTION

In 2005, the 5th Energy Research Programme: “Innovation and New Energy Technologies” was launched by the German Federal Government. Under this programme previous R&D Programmes will be continued with new priorities in the next period. After the first oil crisis in 1974 the main goal of energy policy was to secure energy supply and to become independent from imported oil. The present energy policy of Germany is devoted to sustainable energy supply and climate protection which is the main concern today. Climate change is postulated due to steadily increasing CO$_2$ emissions into the atmosphere by the increased consumption of fossil fuels worldwide. As early as 1990 the Federal Government committed itself to reduce energy related CO$_2$ emissions into the atmosphere by 25% before 2005. This goal has already been partly achieved. In the meantime new long term goals have been set to further reduce the consumption of fossil fuels by 50% until 2050.

As in previous R&D Programmes high priority is given to new renewable energies and energy efficiency technologies. A major subject in this context is R&D on thermal energy storage. Energy storage is a key component in many energy efficient systems. Higher energy efficiency and the deployment of renewable energies offer a great energy saving and substitution potential and pose the challenge to reduce the consumption of fossil fuels by energy conservation and use of renewable energies.

The visions of the German Energy Policy are twofold:

- Increasing energy efficiency: The Federal Government aims to double the energy productivity of the German national economy by 2020 compared to 1990. This means an expected specific primary energy consumption of 4.3 GJ/1000 Euro GDP 1995 (Fig. 1).
- Expanding the use of renewable energies: The Federal Government has set itself the goal of raising the proportion of renewable energies in primary energy consumption to 4.2 % in 2010 and up to 50 % in 2050 (Fig. 2).

Fig.1: Specific Primary Energy Consumption in Germany [source: BMWi]
This paper presents an overview of the scope and topics of R&D on thermal energy storage in the present German R&D Programme. It provides an update of previous reviews presented at recent “Stock” Conferences. The projects in the Energy Research Programme are carried out in close co-operation (joint projects) between research institutes and the industry. Applied R&D projects are generally funded on a 50% cost sharing basis. In 2005, a budget of about 2 million € was spent on 28 R&D projects in the field of thermal energy storage. The total commitments for these projects amounted to about 9 million €. Recently the Federal Government decided to increase the budget for the topics energy efficiency and renewable energies between 2006 and 2009 by more than 25%. The responsibility for the 5th Energy Research Programme [ERP2005] is shared by several Ministries: The Federal Ministry of Economics and Technology (BMWi) is responsible for the topic “efficient energy conversion”, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) for the topic “renewable energies”, The Federal Ministry of Education and Research (BMBF) for institutional funding and the “Networks of Basic Research”. The Programme is managed by Projektträger Jülich PTJ, Forschungszentrum Jülich. The Federal Ministry of Consumer Protection, Food and Agriculture (BMVEL) is responsible in the Programme for bioenergy.

The projects on thermal energy storage are included in the following thematic topics of the Programme:

- “Energy Optimized Buildings”
- “Energy Efficiency in Industry”.
- “Solarthermie2000Plus”.

The Programme focuses on applied research, development and demonstration systems of new innovative technologies. In particular it comprises all promising innovative energy storage technologies. For the implementation and deployment of new concepts and technologies the technical and economic feasibility has been demonstrated in pilot and demonstration plants on a technical scale.

The present overview includes the following main topics:

- Long term thermal energy storage in district heating and cooling systems: development and demonstration of different promising storage concepts: pit, borehole and duct storage, aquifer thermal energy storage (centralized systems),
- Energy optimized buildings: design and monitoring of demonstration buildings and energy systems, general aspects of operation and control of the plants for a minimal energy consumption,
- Phase change materials (PCM): development of micro-and macro-encapsulated materials and components, monitoring of pilot installations and demonstration buildings of PCM based heating and cooling systems,
- Thermo-chemical storage: materials research, development of new applications, monitoring of pilot plants in open and closed sorption systems, transportation of thermal energy.
- Diverse R&D activities: chilled water storage for absorption cooling and small scale advanced solar storage systems for solar assisted heating plants (decentralized system).
2. MAJOR TOPICS OF THE THERMAL ENERGY STORAGE PROGRAMME

2.1 LONG TERM ENERGY STORAGE

The most promising and economic concept of seasonal thermal energy storage for heating and cooling of buildings is underground thermal energy storage (UTES) in pits, aquifer, duct and borehole storage. The application of the most appropriate concept depends on the specific hydro-geological site conditions. For many years various UTES concepts have been investigated and developed with respect to the great energy saving potential in Germany. It is well known that the specific storage costs decrease with increasing plant size. Due to the large size UTES systems fit very well in district heating and cooling systems. In “Solarthermie2000” a minimal plant size is required for the installation of the solar assisted heating plants with seasonal storage (typical plant size: 1,000-5,000 m² solar collectors, 3,000-10,000 m³ pit store). So far eight large-scale seasonal storage plants of different storage type have been constructed, another two new plants (in Munich and Crailsheim) have already been designed and commissioned (Tab. 1). Long term monitoring of the performance is carried out on all plants. All plants with seasonal storage have been designed to cover 50% of the annual heating demand by solar energy.

Results of “Solarthermie2000” (status 2003) have already been published at the 9th International Conference on Thermal Energy Storage 2003 [Mangold2003].

Table 1: Technical design data of central solar heating plants with seasonal storage: Programme Solarthermie2000Plus. (Source: Schmidt, Solites)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Commissioning date</th>
<th>Supply area</th>
<th>Heated living area</th>
<th>Collector area</th>
<th>Storage volume</th>
<th>Total heat demand</th>
<th>Heat delivery* solar system</th>
<th>Solar fraction*</th>
<th>Costs solar system</th>
<th>Solar heat costs*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commis-</td>
<td>m²</td>
<td>m²</td>
<td>m³</td>
<td>MWh/a</td>
<td>MWh/a</td>
<td>%</td>
<td>Mio. €</td>
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<td>Ct./kWh</td>
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<td></td>
<td>sioning date</td>
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<tr>
<td>Hamburg</td>
<td>1996</td>
<td>124 au</td>
<td>14800</td>
<td>3000 flat plate</td>
<td>4500 hot water</td>
<td>1610</td>
<td>789</td>
<td>49</td>
<td>2.2</td>
<td>25.7</td>
</tr>
<tr>
<td>Friedrichshafen</td>
<td>1996</td>
<td>570 au</td>
<td>39500 (390)</td>
<td>5600 flat plate</td>
<td>12000 hot water</td>
<td>4106</td>
<td>1915</td>
<td>47</td>
<td>3.2</td>
<td>15.9</td>
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<tr>
<td>(Planning final</td>
<td>(actual)</td>
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<tr>
<td>Neckarsulm Phase I</td>
<td>1997</td>
<td>6 md,</td>
<td>2700 flat plate</td>
<td>20000 duct</td>
<td>1663</td>
<td>832</td>
<td>50</td>
<td>1.5</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>(Phase II)</td>
<td>(2001)</td>
<td>shopping</td>
<td>(5260)</td>
<td>(63300)</td>
<td>(2200)</td>
<td></td>
<td></td>
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<tr>
<td>Steinfurt</td>
<td>1998</td>
<td>42 au</td>
<td>510 flat plate</td>
<td>1500 gravel/</td>
<td>325</td>
<td>110</td>
<td>34</td>
<td>0.5</td>
<td>42.3</td>
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<td>water</td>
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<td></td>
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<tr>
<td>Chemnitz</td>
<td>2000</td>
<td>Office,</td>
<td>540 vacuum tube</td>
<td>8000 gravel/</td>
<td>573</td>
<td>169</td>
<td>30</td>
<td>1.4</td>
<td>24.0</td>
<td></td>
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<tr>
<td>(Phase I)</td>
<td></td>
<td>hotel,</td>
<td></td>
<td>water</td>
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<tr>
<td>Rostock</td>
<td>2000</td>
<td>108 au</td>
<td>1000 flat plate</td>
<td>20000</td>
<td>497</td>
<td>307</td>
<td>62</td>
<td>0.7</td>
<td>25.5</td>
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</tr>
<tr>
<td>(Phase II)</td>
<td></td>
<td></td>
<td></td>
<td>aquifer</td>
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<tr>
<td>Hannover</td>
<td>2000</td>
<td>106 au</td>
<td>1330 flat plate</td>
<td>2750 hot water</td>
<td>694</td>
<td>269</td>
<td>39</td>
<td>1.2</td>
<td>41.4</td>
<td></td>
</tr>
<tr>
<td>Attenkirchen</td>
<td>2002</td>
<td>30 au</td>
<td>800 flat plate</td>
<td>500 hot water,</td>
<td>487</td>
<td>415</td>
<td>55</td>
<td>0.26</td>
<td>17.0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>9350 duct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>München</td>
<td>2006</td>
<td>300 au</td>
<td>2900 flat plate</td>
<td>5700 hot water</td>
<td>2300</td>
<td></td>
<td>No specif.</td>
<td>47</td>
<td>No specif.</td>
<td>24.0</td>
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<tr>
<td>(in realisation)</td>
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<tr>
<td>Crailsheim</td>
<td>2005</td>
<td>259 au,</td>
<td>7300 flat plate</td>
<td>480 hot water,</td>
<td>4100</td>
<td>2097</td>
<td>50</td>
<td>No specif.</td>
<td>19.0</td>
<td></td>
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<tr>
<td>(Phase I, in</td>
<td></td>
<td>school,</td>
<td></td>
<td>37500 duct</td>
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<tr>
<td>realisation)</td>
<td></td>
<td>shopping</td>
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</tbody>
</table>

Au: accommodation unit, md: multiple dwellings
*: calculated values for long-term operation, #: primary energy savings,
1*: Specifications TU Chemnitz, 2*: specifications GTN, Neubrandenburg, 3*: specifications IGS, Uni Braunschweig, 4*: specifications ZAE Bayern, 5*: specifications ITW Uni Stuttgart
So far the following conclusions can be drawn from the results of long term monitoring:

- The plants have been running well without major technical failures. In some cases conventional components (e.g. heat exchangers, valves, pumps) failed during long term operation. The technical failures could be detected and repaired. In almost all plants the designed solar fraction of 50% was not achieved. This was mainly due to the problem that the return temperatures of the district heating system were remarkably higher and the annual heating demand was smaller than designed. In some cases the housing estate has not developed to the full size as originally planned. The rather high return temperatures in the district heating system reduces the effective useful thermal capacity of the underground store (duct, aquifer, pit) significantly. The new solar plants in Munich and Crailsheim are designed to overcome this inherent problem with an advanced concept by the integration of a gas fired heat pump. With the heat pump low temperature heat from underground storage can also be used when the storage temperature falls under the return temperature of the district heating system. Thus the effective storage capacity is considerably increased.

- Thermal losses of the underground storage systems (pit) in long term operation (over several years) are remarkably higher than calculated. Higher thermal losses are probably due to the increase of moisture in the surrounding soil and/or of thermal insulation of the store.

- Economy: The solar heat was generated with specific costs of about 10-20 EURO Cent/kWh depending on the solar fraction. This means that solar costs are 2-4 times higher than present fossil fuels costs. There is also a great energy saving potential in Germany in industry which can be exploited with seasonal thermal energy storage. Two projects are being carried out to demonstrate the feasibility exemplarily: the energy supply of the Reichstag Building in Berlin and the co-generation (CHP) heat and power plant in Neubrandenburg. Long term monitoring on both plants is fundend to get reliable data of the performance and energy efficiency of the systems. With the constructional and operational costs (economy) the cost effectiveness of the use of waste heat by seasonal storage can be determined. Monitoring data are also used to optimize the control and operation of the plants. From the new 77 MW el (90 MW th) gas fired CHP plant operated by the utility of Neubrandenburg surplus heat in summer is stored in a deep lying aquifer. The heat is used in winter in the low temperature district heating system (return temperature: 30 °C designed) of the neighbourhood. Existing aquifer storage models and simulations tools are validated by experimental data. Particular attention is paid to the water chemistry. First results show that the system operation needs to be optimized. The integration of the aquifer storage requires a better adaptation of the hydraulics of the district heating system.

The most prominent aquifer storage plant in Germany has been erected for the ambitious energy supply of the Reichstag in Berlin. A rather complex energy system has been installed to cover the electricity, the heating and cooling demand of the Reichstag Building and of the adjacent Parliamentary Buildings. The energy scheme was developed to fulfil the commitment of the Parliament to reduce CO2 emissions into the atmosphere by 80% by an innovative energy concept using renewable energies and innovative energy efficient technologies. Electric and thermal energy is generated by several distributed small scale CHP plants which are fuelled with rape-oil. High energy efficiency is obtained by using the waste heat of the CHP plants. The surplus heat which can not be used directly, e.g. for absorption cooling in summer, is stored in the 300 m deep confined aquifer. During the heating period it is to be recovered at temperatures between 70-50 °C for the low temperature heating system. The shallow aquifer (30-60 m deep) assists the cooling of the plenary hall of the Parliament and the offices. Monitoring of groundwater temperatures was required by groundwater authorities to prevent an increase in long term operation. The heat injection in summer is seasonally balanced in winter times partly by heat extraction with heat pumps and partly by free cooling via cooling towers. First data show that the aquifer seasonal storage recovery rate of the heat input is rather high (about 70%).

In recent years another very attractive option has gained increasing attention by designers and architects of commercial buildings: the use of the underground for energy efficient heating and cooling. This option can be used under suitable hydro-geological site conditions. Ground coupled heat pump systems for single and two family residential buildings ("geothermal heat pumps") are commercially deployed today with a rapidly growing market of 20-30% per year. Ground coupled heating and cooling systems of commercial buildings have also become an important concept in the Programme "Energy Optimized Buildings" (ENOBS). This topic has been established to show the technical feasibility and cost effectiveness of various building and air conditioning concepts for low energy commercial buildings. So far 25 demonstration buildings have been constructed. The total specific primary energy consumption of the buildings has to be designed with an upper limit to 100 kWh/m²a, this limit will be reduced to 70 kWh/m²a in the future. One example of the ground coupled demonstration buildings is the Innovation Center Berlin (Fig. 3). For office cooling in summer heat is extracted from the rooms by ducts and pipes in the concrete floor or ceilings and discharged by energy piles in the underground foundation to the adjacent ground (direct cooling without heat pump). In winter the heat is recovered from the ground by heat pumps and delivered to the low temperature floor or ceiling heating in the offices. Since the temperature difference between the underground and the floor heating system is small the COP of the heat pump operation is rather high. The underground serves as a long term store, the concrete floor and
ceilings as short term stores. Long term monitoring confirms a total specific primary energy demand of less than 90 kWh/m²a [Sasse2006].

Several buildings and ground coupled energy systems are monitored to derive guidelines and design tools which can be used for architects and designers for the use of the underground for heating and cooling systems.

2.2 PHASE CHANGE MATERIALS (PCM)

Over the past 10 years, great progress has been achieved in developing PCM by extensive R&D world wide. An increasing number of companies are now looking for business and commercialization of PCM storage technologies, especially for cooling and air-conditioning of buildings. In Germany two ambitious joint projects were carried out dealing with “Innovative PCM storage technologies” (1999-2004) and “Use of PCM in building materials” (1998-2002). The research institutes ZAE-Bayern and ISE-FhG have been engaged with industrial consortia to develop and test new PCM materials and technologies for various applications. Micro-encapsulated PCM (paraffin) was developed which is mixed with plaster or gypsum for light-weight walls. The product developed by BASF is now commercial. With PCM in building components the thermal capacity of light-weight buildings can be substantially increased. The PCM walls reduce large indoor temperature swings by several degrees during a hot summer day. To be effective the PCM has to be discharged thermally on the following nights by cold air ventilation. Through the “passive” PCM cooling element overheating of the office can be avoided or at least be reduced. Thus the electric air-conditioning capacity can be diminished or completely omitted.

Unfortunately the function of “passive” PCM components depends on the weather conditions and cannot substitute completely electric compression chillers. To overcome this problem the concept of an “active” PCM component is investigated and developed by an industrial consortium co-ordinated by ISE-FhG. The active component uses plastic capillary mats which are embedded into the PCM plaster (Fig. 4). Thanks to the capillary mat the heat can be removed in the cooling mode from the wall to an external heat sink (underground, cooling tower). Alternatively the PCM wall can also be used for low temperature heating by a ground source heat pump system.

First results demonstrate the technical feasibility of the “active” system in principle. However, further development and optimization is needed, e. g. to adapt the appropriate phase change temperature of the micro-encapsulated PCM for both the heating and cooling mode. Monitoring of several pilot and demonstration installations need to demonstrate the long term performance in operation in practice. Another new approach is the development of a PCM cool ceiling for air-conditioning of buildings. Suspensions and emulsions of micro-encapsulated paraffin (PCS) can be used as PCM slurries in centralized cooling systems. With the appropriate PCM temperature PCS can replace ice slurries which suffer from the rather low phase change temperature of 0 °C. A joint project of ISE-FhG with the industry was recently initiated to investigate various technical concepts of PCS for air-conditioning. In the first project phase basic R&D deals with the investigation and characterization of PCM materials (suspension and emulsion of micro-encapsulated paraffins). In a following project suitable PCS will be used in pilot and demonstration installations.
The “passive” and “active” PCM systems for the heating and cooling of buildings as well as PCS can be considered as low exergy systems. The R&D activities are combined in the new thematic topic: “LowExergy Systems”. The topic underlines that only low temperature waste heat (e. g. from CHP) or energy from the ambient air or underground is required for the heating and cooling of buildings. Except from the building sector also industrial processes offer a great energy saving potential in Germany. This can be exploited with short term buffer storage systems. So far this has not been possible due to the lack of suitable storage technologies at high temperatures. Storage systems have to exhibit a high thermal power for charging and discharging. A new development of a composite PCM with expanded graphite may overcome the problem of low thermal conductivities of PCM’s. The concept has been successfully developed for low temperature heating and cooling in the project: “Innovative PCM technologies” of ZAE-Bayern with the company SGL. A very high thermal power can be achieved due to the high thermal conductivity of expanded graphite. The concept is now investigated for industrial processes at high temperatures [Buschle2006]. For a pilot case study a PCM store will be developed for the fabrication of porous concrete at 150 °C. Theoretical calculations show that about 40% of the primary energy of the total production process can be saved by heat storage. There are many other industrial processes e. g. in the food industry with an enormous energy saving potential by TES.

2.3 THERMO-CHEMICAL STORAGE

Reversible thermo-chemical reactions (ab- and adsorption processes) in closed and open systems take place with a high reaction enthalpy corresponding to a high specific energy storage density. In fact, thermo-chemical processes generate exergy which can easily be stored without any losses. Therefore thermo-chemical reactions are in principle suitable for long term thermal energy storage. However, regarding the high specific storage costs and the limited annual cycles during lifetime no cost-effective concept could be developed. On the other hand, thermo-chemical reactions can be used more economically for other applications, e. g. air conditioning and de-humidification and cooling. Ongoing R&D in the Programme is focused on the adsorption of water in microporous silicagel and zeolites. It includes the following main topics:

- material development and characterization
- new technologies and concepts (cooling, energy transport)
- demonstration: monitoring of pilot installations

Material development is the basis for possible advances of thermo-chemical storage systems. So far commercial micro-porous materials silica-gel and zeolites are produced for chemical and industrial processes (catalyst, detergents). On the other hand, for energy storage a high specific storage density and long term cycle stability, improved kinetics as well as high thermal performance of devices and reduction of the production costs are essential. By basic material research advanced materials could be developed with tailored properties for the specific storage applications. In addition to materials research, other storage components need to be optimized, e.g. heat exchangers of high thermal power for the use as a chemical adsorption heat pump system and heating device.

Recently a project of the company GRACE [Thamm2005] focused on the development of advanced silica-gel for energy storage. Modified silica-gels were developed which show a 20% higher energy storage density compared to the commercial products. Cycling tests have shown, however that the material deteriorates after 50 to 100 cycles and the specific energy storage density decreases to the original value of about 120 kWh/m³. Another
project deals with basic investigations of micro- and meso-porous zeolites [Jänchen2005]. For many years different material classes of zeolites (recently dealuminated Y zeolites and microporous silicoaluminophosphates) have been investigated. Several research partners co-operate in a network on materials research. Energy storage density increases with de-sorption temperatures to up to 300 kWh/m³ for high desorption temperatures of about 550 K. Partial de-alumination of the ordinary zeolites by a hydrothermal treatment leads to an increasing charging temperature. In the future, these modified zeolites may replace the micro-porous silico-aluminophosphates, closing until now the gap between zeolites and silicagel as far as the charging temperature is concerned. The disadvantage of micro-porous silico-alumino-phosphates is their costly synthesis with an organic template which has to be oxidized (in most cases) to remove it from the porous structure.

Another project deals with the development of an adsorption heat pump of small thermal capacity. Investigations deal with corrosion tests and the development of high thermal capacity heat exchangers. A heating device with zeolite stores has been developed by a company. The heat pump operates with an annual COP~1.3.

Since 1996 a zeolite storage system has been in operation in a school in Munich (Fig. 5). Consisting of 7000 kg zeolite, the storage facility acts as a buffer store between the district heating net and the heat supplying system of the school itself. In low demand periods (weekend, nights), the storage is charged from the district heating net at temperatures of approximately 130 °C. In daytimes, no further energy supply from the net is necessary, the stored energy in the zeolite is sufficient for the demand.

![Fig. 5: Zeolite Storage in a school in Munich.](Source: [BINE])

For climatisation of a jazz club in the neighbourhood, an open sorption system (Lithium-Chloride and water as working fluids) has been installed supplementing the zeolite storage [Hauer2006]. Acting as thermal-driven heat pump, the open sorption system provides the jazz club with cool and dry air. While the zeolite storage nearly fulfils the demand of latent heat (15-17 kW), the open sorption system is expected to provide the sensible heat of about 15 kW.

In 2005, the ZAE Bayern initiated a new industrial project on energy transport by thermal energy storage. In fact, this idea has been investigated in former times, however no feasible concepts could be implemented commercially. By energy transport on trucks or trains waste heat released at remote industrial sites could be used elsewhere, e. g. for the heating and cooling of commercial buildings or for industrial processes. Previous energy transport systems were based on sensible heat stores (hot water, oil) or recently on PCM stores. A cost effective energy transport system requires high energy storage densities and many operating charging/discharging cycles. Preliminary studies carried out by ZAE-Bayern have validated the general feasibility using zeolite as storage material. Within the project a pilot system will be developed and installed at an industrial site to prove the feasibility of the concept in practical operation [Storch2006]. The project is the German contribution to the planned new Annex 18:“Transportation of Thermal Energy by Thermal Energy Storage”.

### 2.4 OTHER STORAGE ACTIVITIES

Thermal stores can be used effectively not only for energy saving, but also for peak levelling of the electricity demand. A common, widespread technology is the use of ice storage facilities for air conditioning of commercial buildings. The ice storage facility is charged during night by electric compression chillers with off peak low tariff electricity. In the second step the ice storage covers the cooling peak demand on the following day. The operation does not save energy, but it does reduce electric peak power. Recently a feasibility study of the utility of Chemnitz has shown an alternative energy saving concept [Urbaneck2006]. Electric chillers can be replaced...
by absorption chillers for peak cooling demand. By absorption chillers a chilled water storage facility is charged
during night to cover the cooling peak demand during the next day. In a pilot project the feasibility of the
concept will be demonstrated in the district cooling system of Chemnitz. There is a great potential also in
industry to replace electricity by waste heat for cooling purposes.
In the Task 32: “Advanced Solar Storage for Solar and Low Energy Buildings” of the IEA Solar Heating and
Cooling Programme advanced solar stores are essential components to increase the solar fraction in solar assisted
heating systems for single or two family houses. Advanced stores are the key component to get high solar
fraction. Different storage concepts (hot water, PCM, thermo-chemical stores) are examined and will be
demonstrated in pilot systems. The German participants, ITW University of Stuttgart and the University of
Kassel examine the best options of advanced water storage systems. Several monitored pilot installations are
planned.

1. SUMMARY AND CONCLUSIONS

The energy policy of the German Federal Government favours the development and deployment of new energy
efficient technologies and the utilization of renewable energies. New advanced storage systems with improved
thermal performance and better cost-effectiveness are key technologies for these systems. Recently the
Government has decided to continuously increase the budget for R&D over the next years. The present status of
R&D on thermal energy storage is an excellent basis for further achievements in future. The efforts may be
focused on material research and the development and demonstration of new storage systems in buildings and
the industrial sector. A main goal is to improve the cost-effectiveness in the various applications.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the co-operation and the valuable contributions of project partners in
particular to use the diagrams in this publication.

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