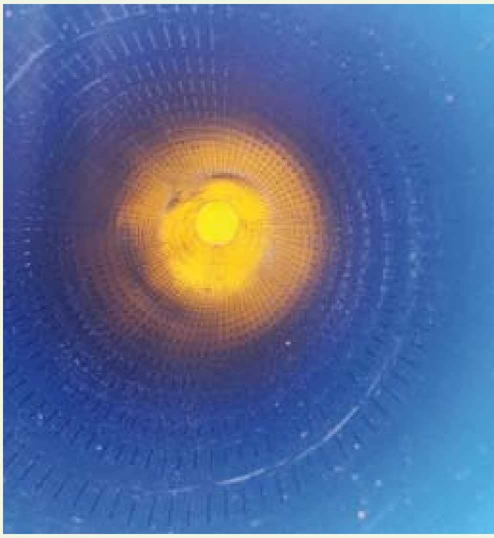
International Energy Agency

Energy Conservation through Energy Storage Programme



Version May 2009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"Energy Storage… another time and place"

We need energy – electrical or thermal – but in most cases not where or when it is available. Enjoying the sound of music while you are jogging, you can not stand beside the socket: electrical energy storages – batteries – make you mobile. The energy you need is stored for a short while and over the distance you like to run. Having a cold beer on a summers evening was possible even before cooling machines were invented. At that time people cut ice from the lakes in winter, transported the ice to the brewery and stored it in deep cellars. The cold was stored from the winter to the summer: An example for long term thermal energy storage and the utilization of renewable energies. In cold climates surplus solar heat from summer can be used in winter for heating of buildings by seasonal storage.


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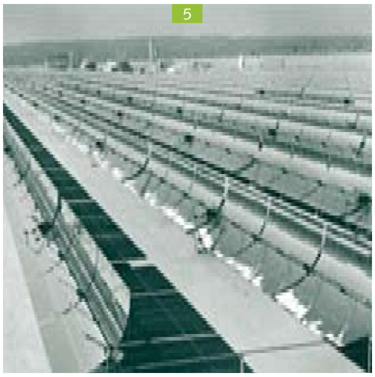
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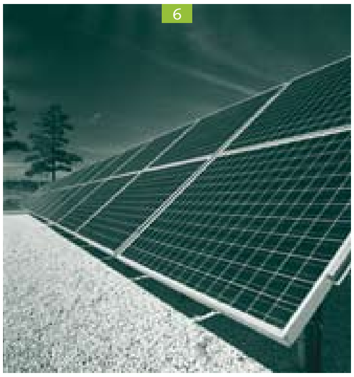
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"Energy conservation… the benefits of energy storage"

Waste heat from industrial processes, steam from solar thermal power plants or electricity from photovoltaic panels are examples for energy sources, which can not be used more extensively without energy storages. A huge potential of energy sources substituting fossil fuels can only be exploited by energy storage systems, utilizing renewables like solar thermal, PV and wind energy. Thermal and electrical energy storage systems enable greater and more efficient use of these fluctuating energy sources by matching the energy supply with the demand. This can finally lead to a substantial energy conservation and reduction of CO_2 emissions.

The growing peak demand of today's energy consumption, essentially caused by electrical air conditioning, leads more often to black-outs all over the world. Such a problem – the shifting of a peak demand for only a few hours or minutes – can be solved by cold storage technologies. In this context energy storages can be the best solution not only from the technical point of view, but also for economical reasons.


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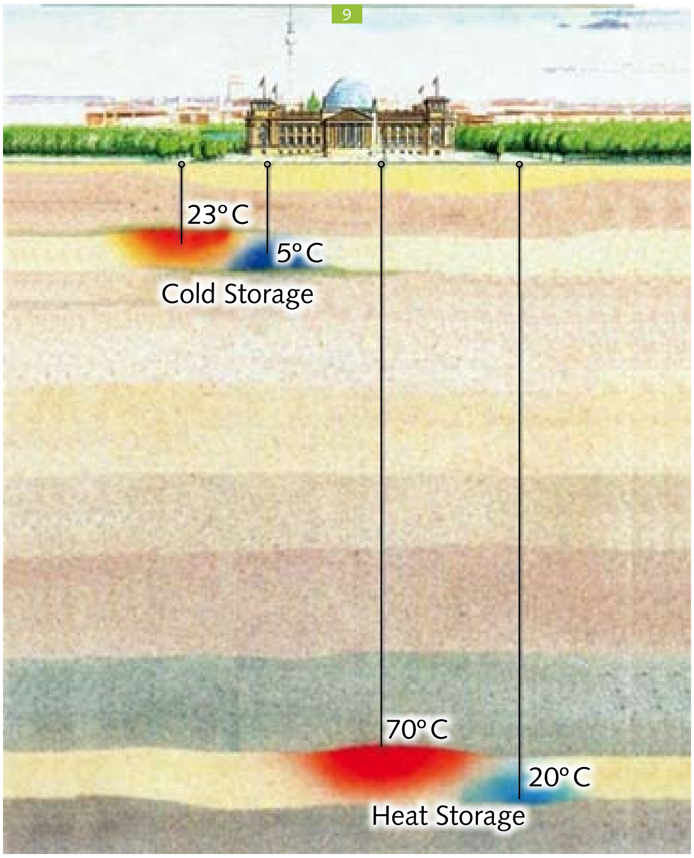
"Energy storage technologies… a big variety"



The energy to be stored can be either electrical or thermal. Both energies require completely different storage technologies. However in the actual application both technologies can meet: The peak demand of electricity for example is in most cases caused by air conditioning, which is a thermal task. The cooling demand can be covered by a cold store (ice or chilled water) which is charged at off peak hours by electric chillers.

Energy storages can be described by their storage capacity (stored energy per mass or volume), power (energy output per time), storage period (how long the energy should be stored) and size. All these parameters can vary over a huge scale: From a latent heat storage to prevent laptops from getting too hot (stored energy in the range of a few Wh) to the heat and cold thermal underground storage system underneath the German Reichstag in Berlin (stored energy in the range of some 2 GWh).

Energy Storage R & D

Many governments have committed to reduce CO_2 emissions into the atmosphere. They have decided to strengthen their national efforts and the international co-operation for research and development (R&D) in the International Energy Agency (IEA) and to increase the deployment of energy conservation technologies and utilization of renewable energy sources. So far in most industrialized countries, renewable energy sources contribute only marginally to satisfy energy demand. Energy storage technologies can help to solve problems caused by the intermittent energy supply of these sources.

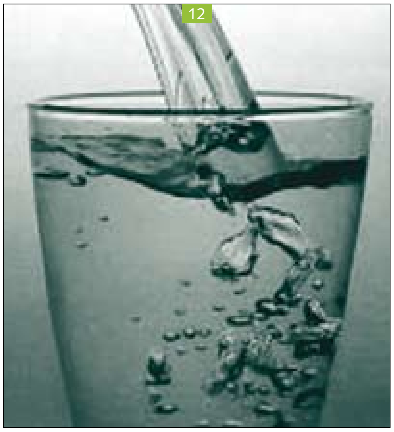
There is a huge potential for the application of energy storage systems. The fact that energy storage systems are not as widely used as they could, is due to several reasons, in particular because most new storage systems are not yet economically competitive with fossil fuels and their long term reliability and performance is not yet proven. There are still some regulatory and market barriers which have to be overcome. Therefore, further attempts are being made to resolve these issues.

The IEA Implementing Agreement on Energy Conservation through Energy Storage (see box below) provides the platform for international co-operation (www.iea.org) in R&D, D. After 2 decades of R&D the emphasis of the co-operative RD&D efforts has shifted towards to implementation and optimal integration of new storage technologies for an efficient use of energy and renewable energy sources. In the future more application oriented topics like thermal energy storage for cooling and industrial processes or mobile thermal storage systems for the utilization of waste heat will be investigated. The issue of implementation and deployment of new energy storage technologies has become a higher priority as the R&D phase is concluding.

Thermal Energy Storage

Thermal energy can be stored in different ways given by the thermodynamics of the storage process. If a storage medium is heated up or cooled down the storage is called sensible. Well known storage technologies are hot or chilled water tanks. The phase change of the medium (e. g. ice-water) requires large amounts of energy without any temperature change, therefore it is called latent heat. These latent thermal storages can provide higher storage capacities compared to sensible heat stores at a constant discharging temperature. One example is ice storage for cooling. Energy can also be stored in reversible chemical reactions. The storage can achieve even higher capacities and is able to deliver thermal energy at different discharging temperatures dependent on the thermo-chemical reaction. An extensively studied reaction for thermal energy storage is the adsorption of water vapour on microporous materials e. g. Zeolites and Silicagel The microporous adsorbens have a huge inner surface and can adsorb large amounts of water.

The Energy Storage Programme is an R&D Agreement established in 1978 between a number of IEA countries with the aim of cooperative research, development, demonstrations and exchanges of information regarding energy conservation through energy storage. The full name reads: "Programme of Research and Development on Energy Conservation through Energy Storage".
The separate activities put into execution within the framework of an Implementing Agreement, are called Tasks or Annexes (more general information is available in the IEA-homepage (www.iea.org)).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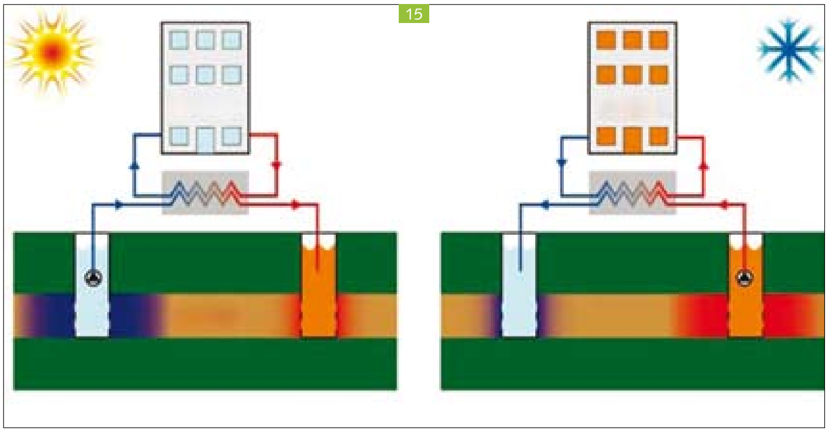
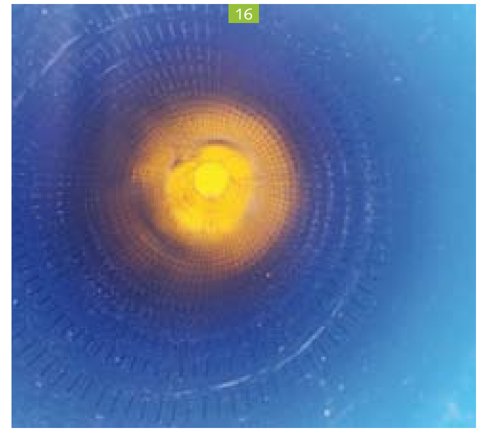
The following organizations and entities have signed the IEA Energy Storage Implementing Agreement:

- Belgium, Ministry of Economical Affairs
- Canada, Public Works and Government Services Canada
- Finland, Technology Development Centre TEKES
- France, Ministère de l'Economie, des Finances et de l'Industrie
- Germany, Forschungszentrum Jülich GmbH
- Japan, Heat Pump & Thermal Storage Technology Center of Japan
- Korea, Ministry of Commerce, Industry and Energy
- Norway, Geological Survey of Norway
- Sweden, Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, FORMAS
- Turkey, Çukurova University, Adana
- United States of America, Department of Energy
- IF Technology (The Netherlands), Sponsor*
- Institute of Heat Engineering (ITC) of the University of Technology Warsaw (Poland), Sponsor*

* Sponsor entity which is not designated by its government (see: www.iea.org)





Sensible Thermal Energy Storage: Water Tanks and Underground TES

The use of hot water tanks is one of the best known thermal energy storage technologies. The hot water tank serves the purpose of energy saving when e.g. applied to a solar tap water system and an energy supply system with cogeneration. One major aim of an electrically heated hot water tank in a tap water system is to shave the peak in electricity demand. A state-of-the-art review as part of the energy storage programme has resulted in the conclusion that stratified water tank storage technology has become mature and reliable. Further R&D efforts are devoted to reduce the specific storage costs which at present are still too high for many applications of energy conservation and utilization of solar energy.

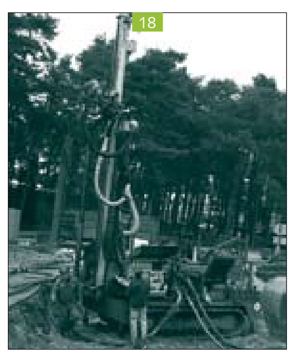
The most frequently used storage technology of heat and cold is underground thermal energy storage (UTES). The aquifer Thermal Energy Storage (ATES) uses natural water saturated and permeable underground layer as a storage medium (see schematic above). The transfer of thermal energy is realized by extracting groundwater from the aquifer and by re-injecting it at the modified temperature level at a separate well nearby. Low temperature heating and high temperature cooling with groundwater fits very well with new concepts of large surface area heating and cooling in walls and at the ceilings (so called low exergy heating and cooling systems, www.lowex.net)

Most applications are about the storage of winter cold to be used for the cooling of large office buildings and industrial processes. It can easily be explained that aquifer cold storage is gaining more and more interest: Savings on electricity bills for chillers are approx. 75 %, and in many cases, the payback time for additional investments is shorter than five years. A major condition for the application of this technology is the availability of a suitable geologic formation. Obviously in the annual average the temperature swing has to be balanced.

Other technologies for underground thermal energy storage are borehole storage, cavern storage and pit storage. Which of these technologies is selected, strongly depends on the local (hydro)-geologic site conditions.

With borehole storage, vertical heat exchangers are inserted into the underground, which ensure the transfer of thermal energy towards and from the ground (clay, sand, rock, etc.). Many projects are about the storage of solar heat in summer for space heating of houses or offices. Ground heat exchangers are also frequently used in combination with heat pumps ("geothermal heat pump"), where the ground heat exchanger extracts low-temperature heat from the soil.

With cavern storage and pit storage, large underground water reservoirs are created in the subsoil to serve as thermal energy storage systems. These storage technologies are technically feasible, but the actual application is still limited because of the high level of investment.

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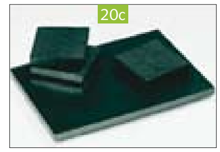
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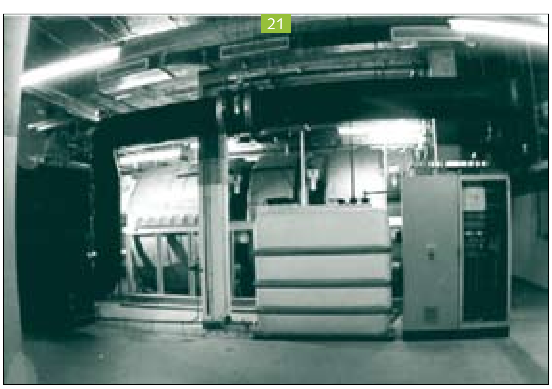
Phase change materials and chemical reactions

Sensible heat energy storage has the advantage of being relatively cheap but the energy density is low and there is a variable discharging temperature. To overcome those disadvantages phase change materials (PCM's) could be used for thermal energy storage. The phase change could be a solid/liquid or a liquid/gas process. Melting processes have energy densities in the order of 100 kWh/m3, e.g. ice, compared to 50 kWh/m3 for sensible heat storage of a temperature change of 50 Kelvin, which is common of hot water stores.

The incorporation of micro-encapsulated PCM materials such as paraffin wax into the gypsum walls or plaster increases considerably the thermal mass and capacity of lightweight buildings. By night the PCM in the microcapsules cools and solidifies. During the day the cool walls, reducing the daily temperature swing by several degrees, and thereby avoiding the need for electric chillers or, at a minimum, reducing the cooling requirements. Another application of active cooling systems is macro-encapsulated salts that melt at an appropriate temperature. The PCM is stored in a building's air vent duct and the cold air is delivered via large-area ceiling and floor a/v systems.

Higher energy densities can be achieved by the utilization of chemical reactions for thermal energy storage. Energy densities in the order of 300 kWh/m3 are possible. Thermochemical reactions like adsorption (the adhesion of a substance to the surface of another solid or liquid) of water vapor to Silicagel or Zeolites (micro-porous crystalline alumo-silicates) can be used to generate heat and cold as well as to regulate humidity. Of special importance in hot, humid climates or confined spaces where humidity levels are high, these open sorption systems use lithium chloride to cool water and Zeolites to absorb ambient humidity.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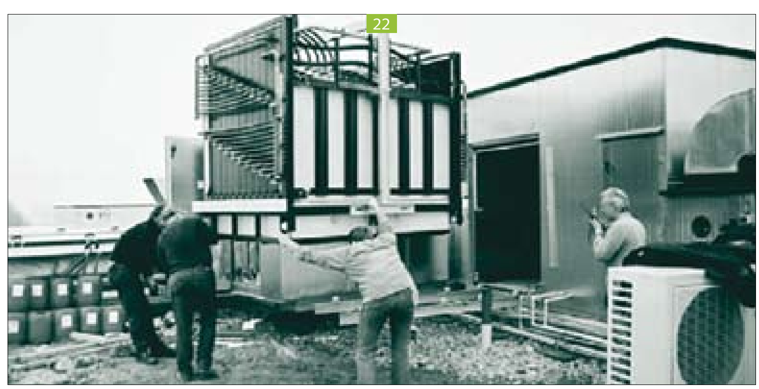
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Applications: Cooling, transportation, industrial processes

The different technologies for thermal energy storage can be used in a huge variety of applications. Domestic hot water, space heating and cooling are probably the most common ones. Most of the sensible thermal energy storage systems are operated for that purpose. Over the last years other applications came up, like cooling, transportation of thermal energy and TES in industrial processes. This development is surely connected to the latest developments in advanced storage technologies like PCMs and chemical reactions. New activities are more application oriented. This includes also combinations of TES technologies for certain applications.

New activities within the ECES are meeting these new challenges. The growing demand for cooling world wide is one of them. TES can provide in this case short term stor-

age for peak shaving as well as long term storage for the introduction of renewable and natural energy resources. The utilization of waste heat e.g. from industrial processes opens a huge potential concerning the reduction of the primary energy demand and CO_2 emissions. For this utilization the transportation of thermal energy in high capacity TES is necessary. For the optimization of industrial processes themselves and a better use of renewable energies for power generation high temperature TES have to be developed. These new fields for thermal energy storage systems will be worked on in the future.

Annexes to the Implementing Agreement (cont. page 10)

A number of Annexes was performed over the last decades. These Annexes have been working on all kinds of energy storage technologies. A complete list can be found on the ECES homepage: http://www.iea-eces.org/annexes/completed-annexes.html. Here are the most recent Annexes:

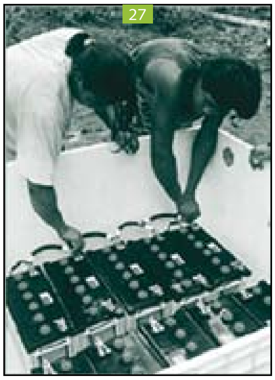
Annex 18 The general objectives of the proposed annex on "Transportation of Energy by Utilization of Thermal Energy Storage Technologies" are to identify state-of-the-art for using different technologies for energy storage and transportation, to broaden and coordinate the knowledge within the field, and to disseminate information. In particular, research on high capacity storage materials and high thermal power charging and discharging technologies that are easy to implement in an energy transport system will be encouraged, along with research on system aspects where heat sources are linked to the customer's need and where these links' impact on system design is assessed. Potential cost-effective applications must be identified (start: June 2006)

Annex 19 The objectives of the Annex "Optimized Industrial Process Heat and Power Generation with Thermal Energy Storage" are to overcome the fragmented research and to achieve synergies from existing and new future high temperature thermal energy storage (HTTES) activities. The objectives of the work to be performed under this Annex are to conduct a general review and assessment study of existing and emerging HTTES technologies, to identify obstacles that need to be overcome to make industrial process heat and power generation with TES more economically and environmentally viable, to identify efficient and economic storage materials, to compare and assess different HTTES concepts and design, to define strategies for efficient storage integration and operation and to support technology transfer (start: December 2006)

Annex 20 This annex is called "Sustainable Cooling with Thermal Energy Storage". Within IEA ECES IA previous Annexes 7, 8, 10, 13 and 14 have looked at various aspects of cooling with TES alternatives. The results of these Annexes have lead to an increase in awareness followed by initiation of TES activities. There is a need for a new annex to provide new combinations of TES for different energy systems in different climates and spread implementation of TES systems (start: January 2006)

Annex 21 Thermal Response Test (TRT) is a measurement method to determine the heat transfer properties of a borehole heat exchanger and its surrounding ground in order to predict the thermal performance of a ground-source energy system. The two most vital parameters are the effective thermal conductivity of the ground and thermal resistance within the borehole. The TRT equipment is usually mounted on a trailer for easy transportation to test sites. This method has been very important in the rapid spreading of BTES systems. It has been a door opener for introducing the technology in "new" countries. The overall objectives of Annex 21 are to compile TRT experiences worldwide in order to identify problems, carry out further development, disseminate gained knowledge, and promote the technology. Based on the overview, a TRT State of the art, new developments and further work are studied.

Annex 22 "Thermal Energy Storage Applications in Closed Greenhouses" – The possibilities of the application of thermal energy storage systems in closed greenhouses should be investigated in this new annex. By controlling temperature and humidity in the greenhouse the production of vegetables and fruits can be optimized. TES might be a key component of such advanced greenhouse concepts.



Electrical energy storage

There is currently considerable interest in electrical energy storage technologies, for a variety of reasons. These include changes in the worldwide utility regulatory environment, an ever increasing reliance on electricity in industry, commerce and the home, the growth of renewable energy sources to meet the growing demand for electricity, and all combined with ever more stringent environmental requirements.

Electrical energy storage enables the decoupling of electricity generation from demand. This is of particular importance to the electricity industry since electricity demand is subject to substantial hourly, daily and seasonal variations. Also, electricity generation, particularly from renewable sources, is also subject to significant variability, both short term (over a few seconds) and longer term (e.g. hourly, daily, and seasonally).

The rapidly accelerating rate of technological development in many of the emerging electrical energy storage systems, together with anticipated unit cost reductions, now makes their practical application look very attractive.

Pictures:

1. Ice cutting for cold storage
2. Mobile electricity storage
3. Ice storage transportation
4. Industrial energy demand
5. Solar thermal power plant
6. Photovoltaic installation
7. Individual air conditioning
8. City black-out. Photo: Flavio Masson
9. Laptop cooler latent heat storage
10. Thermal underground storage system underneath the German Reichstag in Berlin
11. Laboratory set-up for liquid desiccant storage systems
12. Storage medium water
13. Storage medium Parafin
14. Storage medium Zeolite
15. Aquifer thermal energy storage
16. Tube for UTES systems
17. Combined water tank and borehole storage in Attenkirchen/Germany
18. Drilling of a borehole storage system in Belgium
19. Combined heat and power installation at a Canadian government lab
20 a–e. PCM in different containers and structures
21. Adsorption storage system in Munich/Germany
22. Absorption system in Amberg/Germany
23. Compressed air storage
24. Mobile latent heat storage
25. Mobile electrical energy storage system
26. Pumped hydro in Japan
27. Batteries for PV in India

Collaborative Groups, Workshops and Meetings

- Joint Executive Committee Meetings with IEA Implementing Agreement "Energy Conservation in Buildings and Community Systems", "Solar Heating and Cooling", "District Heating and Cooling", and the "Heat Pump Program". A Joint workshop was held together with the District Heating and Cooling IA.
- Participation in the Building Coordination Group (BCG) of Building Related Implementing Agreements (BRIAs), e.g. Future Building Forum: Cooling Buildings in a Warmer Climate.
- Collaboration with the "Experts Group on Science for Energy" (EGSE) of the IEA, participation in their workshops and support by the EGSE for the "Symposium on Material Development for Thermal Energy Storage", June 2008 in Bad Tölz, Germany.
- Participation and engagement of industry through organization of workshops in conjunction with expert's meetings of Annexes.
- Organization of international conferences on thermal ("Stock" conferences) and electrical (EESAT conferences) energy storage applications and technologies.

Planned Annexes to the Implementing Agreement

Annex 23 "Applying Energy Storage in Buildings of the Future" – Sustainable buildings will need to be energy efficient well beyond current levels of energy use. They will need to take advantage of renewable and waste energy to approach ultra-low energy buildings. Such buildings will need to apply thermal and electrical energy storage techniques customized for smaller loads, more distributed electrical sources and community based thermal sources. Lower exergy heating and cooling sources will be more common. This will require that energy storage be intimately integrated into sustainable building design. Many past applications simply responded to conventional heating and cooling loads. Recent results from low energy demonstrations, distributed generation trials and results from other Annexes and IAs such as Annex 37 of the ECBCS IA, Low Exergy Systems for Heating and Cooling need to be evaluated. Although the ECES IA has treated energy storage in the earth, in groundwater, with and without heat pumps and storing waste and naturally occurring energy sources, it is still not clear how these can best be integrated into ultra-low energy buildings capable of being replicated generally in a variety of climates and technical capabilities.

Energy storage has often been applied in standard buildings that happened to be available. The objective was to demonstrate that the energy storage techniques could be successfully applied rather than to optimize the building performance. Indeed the design of the building and the design of the energy storage were often not coordinated and energy storage simply supplied the building demand whatever it might be.

Annex 24 "Material Development for Improved Thermal Energy Storage Systems" - For the performance of thermal energy storage systems their thermal energy and power density are crucial. Both criteria are strongly depending, beside other factors, on the materials used in the systems. This can be the storage medium itself, but also materials responsible for the heat (and mass) transfer or for the insulation of the storage container.

After a number of thermal energy storage technologies have reached the state of prototypes or demonstration systems a further improvement is necessary to bring theses systems into the market. The development of improved materials for TES systems is an appropriate way to achieve this. The material solutions have to be cost effective at the same time. Otherwise the state of the existing technologies can not be brought closer to the market.

The world wide R&D activities on novel materials for TES applications are not sufficiently linked at the moment. A lot of projects are focusing on the material problems related to their special application and not towards a wider approach for TES in general. The proposed Annex should help to bundle the ongoing R&D activities in the different TES technologies.

If you are interested to participate in such an Annex, or if you have related topics, applications, materials or techniques which should be included in the work program of these new Annexes, please contact: hauer@muc.zae-bayern.de.

"Forum on Storage"

In various Implementing Agreements within the IEA framework there is presently some knowledge on storage, and in particular within the Energy Storage IA (ECES) a profound expertise has been brought together over the last 30 years. There is a large potential of synergies that should be used to define possibilities and limits of storage-solutions and to agree on further necessary actions. In joint efforts further RD&D programmes as well as the commercialization of technology can be launched more successfully than in numerous individual actions.

The vision is to establish a platform for exchange and discussion on energy storage, which should be an instrument to better coordinate existing activities, to avoid double work and – as a common effort – to foster new activities.

To start the discussion on this "Forum on Storage" a workshop with all interested Implementing Agreements is planned in September 2009.

Outlook

Both thermal and electrical energy storage are recognized as key technologies for the energy supply of the future. The reasons for this are evident:

- energy storage can contribute to an efficient energy use and related conservation of fossil fuels;
- energy storage enables the use of renewable energy sources;
- energy storage reduces the required power generating capacity through peak (energy) shaving;
- energy storage simplifies the control of energy supply systems;
- energy storage improves the reliability of energy supply systems.

EFFSTOCK 2009

Photo: Norbert Leipold/PIXELIO

Stockholm, 14–17 June 2009

Thermal Energy Storage for Energy Efficiency and Sustainability

The 11th International Conference on Thermal Energy Storage

Edited by Dr. Andreas Hauer
Executive Secretary
IEA Energy Storage Programme

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Is that all you saved from last summer? Energy Storage helps to conserve Energy and to protect the environment!

Further information on the IEA Energy Storage Programme and on energy storage can be found on the following websites:

- http://www.iea.org (general information about IEA)
- http://www.energy-storage.org and http://www.iea-eces.org (general information, tasks and annual reports)
- http://www.fskab.com/annex10/ (Annex 10)
- http://cevre.cu.edu.tr/annex14/ (Annex 14)
- http://www.fskab.com/Annex17/ (Annex 17)
- http://www.webforum.com/annex18/home/index.asp (Annex 18)
- http://www.hptcj.or.jp/annex20/index.html (Annex 20)
- http://www.geo-journal.stockton.edu (electronic journal)
- http://futurestock.itc.pw.edu.pl/ ("Stock" conference 2003)
- www.stockton.edu/ecostock ("Stock" conference 2006)
- http://www.effstock2009.com/ ("Stock" conference 2009)

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