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# THERMAL ENERGY STORAGE: AN OVERVIEW

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***Abstract:*** *Nowadays, as global warming is becoming one of the most urgent problems in the world, we need to find a better way to utilize energy, especially in the area of energy storage. Currently, most of the renewable energy sources, especially wind energy and solar energy, are timely-based energy sources, whose available energy densities are variable during different days (months). The objectives of such systems are to store solar heat collected in summer for space heating in winter. These systems contribute significantly to improving the energy efficiency and reducing the gas emissions to the atmosphere. Developing efficient and inexpensive energy storage devices is as important as developing new sources of energy.* ***Key words:*** *thermal energy storage, heat storage, storage of thermal energy, seasonal heat storage, sensible heat storage, latent heat storage, thermo chemical heat storage.*

## 1. INTRODUCTION

The thermal energy storage can be defined as the temporary storage of thermal energy at high or low temperatures. This concept is not new; it is been used and developed for centuries because is playing an important role in energy conservation.

The energy source has intermittent nature and its effective utilization is dependent on the availability of efficient and effective energy storage systems. This leads to the fact that the solar thermal technologies will not be able to achieve their full potential for space heating and domestic hot water applications.

During the extraction of the stored thermal energy efficient thermal energy storage systems minimize thermal energy losses and attain high energy recovery with little degradation in temperature. This relates to high latitude locations, mainly because the variations of solar radiation are significant, and in cold climates because the varying space heating loads dominate energy consumption.

The use of seasonal thermal energy storage can substantially reduce the cost of solar energy systems that can supply up to 100% of buildings energy needs. Such systems are designed to collect solar energy during the summer and retain the stored heat for use during the winter. The application requires large inexpensive storage volumes and the most promising technologies were found underground, using ground heat exchangers. Although such systems have been constructed and demonstrated, it is challenging to make them cost effective. Economically justified projects can be designed using annual storage on a community-wide scale, which could reduce cost and improve reliability of solar heating [15].

Thermal energy storage systems have the potential of making the use of thermal equipment more effective, and are important means of offsetting the mismatch between thermal energy availability and demand. Well designed systems can reduce initial and maintenance costs and improve energy efficiency [14].

The energy storage systems can contribute significantly to meeting society`s need for more efficient, environmentally benign use in building heating and cooling, space power, and utility applications. Another significant advantage of efficient energy storage is that, although it may have been designed primarily for the storage of solar energy, it is not restricted to that. It may be used to store surplus energy from the power plants, usually in the form of waste water, waste energy from air conditioners, waste energy from industrial processes, and so on. It becomes a sort of energy sink into which we can throw any form of energy which is not needed for the moment. A common storage like this may not be so applicable for small houses but would be useful for large-scale central heating systems [1].

The technology of energy storage has only recently been developed to a point where it can have a significant impact on modern technology. One main factor that limits its application is that it is a cyclic, time-dependent energy source. That is why energy storage is critically important to the success of any intermittent energy source in meeting demand. This problem is especially severe for solar energy because storage is needed the most when the solar availability, namely in winter.

## 2. CLASSIFICATION OF THERMAL ENERGY STORAGE SOLUTIONS

Thermal energy storage is required when heat demand does not match heat production. Thermal energy storage systems themselves do not save energy. However, energy storage applications for energy conservation enable the introduction of more efficient, integrated energy systems. Thermal energy storage makes it possible to more effectively utilize new renewable energy sources and waste heat/cold recovery for space heating and cooling. In figure 1 is presented different criteria of thermal energy storage technologies, based on temperature level of stored thermal energy point of view, time length of stored thermal energy point of view and status of energy storage material point of view.

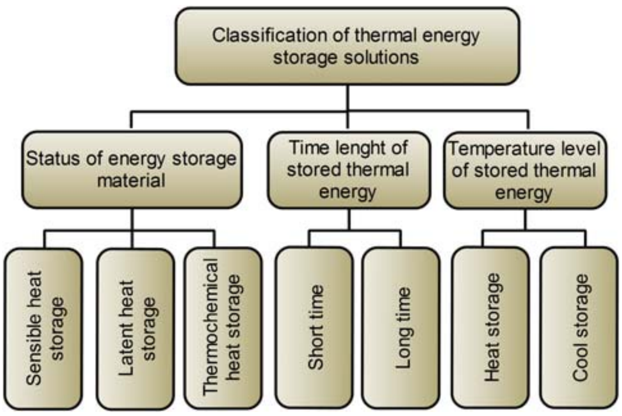


**Fig. 1.** Classification of thermal energy storage solutions

### 2.1. Classification of thermal energy storage solutions by using status of energy storage material

According to the way heat is stored thermal energy storage can be classified in:

- sensible heat: in hot liquids and solids,
- latent heat: in melts and vapor
- chemical heat: in chemical pounds.

In figure 2 is presented the classification of thermal energy storage technology based on the criterion of the state of the energy storage material.

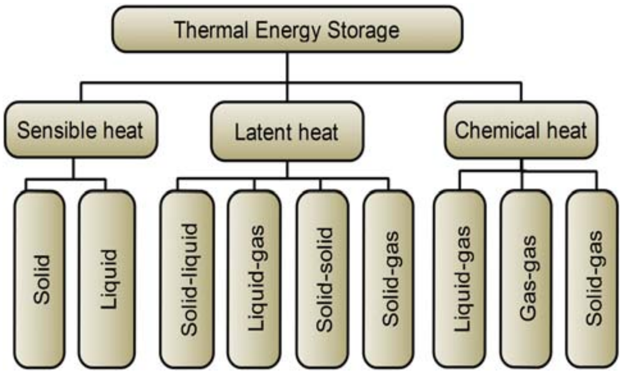


**Fig. 2.** Classification of thermal energy storage technology based on the criterion of the state of the energy storage material

**Sensible heat storage**

Sensible heat storage systems use energy stored or extracted by heating or cooling a liquid or a solid, which does not change its phase during this process, such as water, heat transfer oils and certain inorganic molten salts, and solid like rocks, pebbles and refractory. In the case of solids, the material is invariably in porous form and heat is stored or extracted by the flow of a gas or a liquid through the pores or voids.

Energy storage materials for the sensible heat storage won`t experience phase change process when they store thermal energy. The only process those materials will experience is the change of temperatures within one phase. The basic equation for the sensible heat storage is:

$$Q = \int_{T_1}^{T_2} m \cdot c_p \cdot dT \qquad (1)$$

where $T_1$ is the initial temperature of the storage material, $T_2$ is the final temperature of the material, *m* is the material total mass, and $c_p$ is the specific heat capacity of the material.

As $c_p$ is a function of temperature, we can use equation (1) to calculate the total amount of stored thermal energy. However, if the temperature range is too small to consider the variation of $c_p$, equation (1) can be rewritten as:

$$Q = m \cdot c_{p.avg} \cdot \Delta T = m \cdot c_{p.avg} \cdot (T_2 - T_1) \qquad (2)$$

where $c_{p.avg}$ is the average specific heat capacity between temperature $T_1$ and $T_2$ [11].

The high specific heat capacity $c_p$ can have direct impact on the amount of stored thermal energy based on equation (1) and (2). The long term stability assures the low degradation of the heat storage material after thousands of thermal cycling.

From the foregoing definition as well as equations (1) and (2), we can see that desirable sensible heat storage requires the energy storage material to have four characteristics:

- High specific heat capacity,
- Long term stability under the thermal cycling,
- Good compatibility with its containment,
- Low cost [9].

Sensible heat storage systems are simpler in design than latent heat or thermo chemical storage systems. However they suffer from the disadvantage of being bigger in size and cannot store or deliver energy at a constant temperature. The main factors of the total cost of the storage system depends on compatibility with its containment is requirement for both the heat storage material and the containment. The cost of the sensible heat storage solution mainly depends on the characteristics of the storage material. It is very common to utilize very cheap materials such as water, rocks, pebbles, sands, etc., as the storage medium [18].

There are five types of sensible seasonal thermal storage: hot water thermal energy storage, aquifer thermal energy storage, gravel-water thermal energy storage, borehole thermal energy storage, and cavern thermal energy storage.

### Latent heat storage

The main principle in latent heat storage is that when heat is applied to the material it changes its phase from solid to liquid by storing the heat as latent heat of fusion or from liquid to vapor as latent heat of vaporization.

Theoretically, the phase change material has a phase change point when the phase transition happens, but in practice the phase change process happens in a certain temperature range instead of one exact point. Figure 3 and 4 shows the specific heat capacity ($c_p$) – temperature (T) curve, respectively specific enthalpy (h) – temperature (T) curve of certain phase change material.

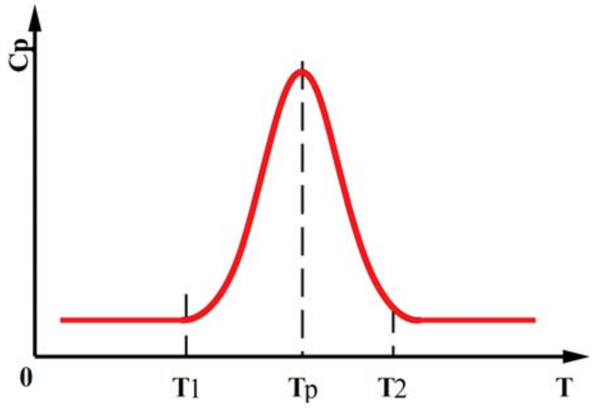


**Fig. 3.** The specific heat capacity ($c_p$) – temperature (T) curve of certain phase change material

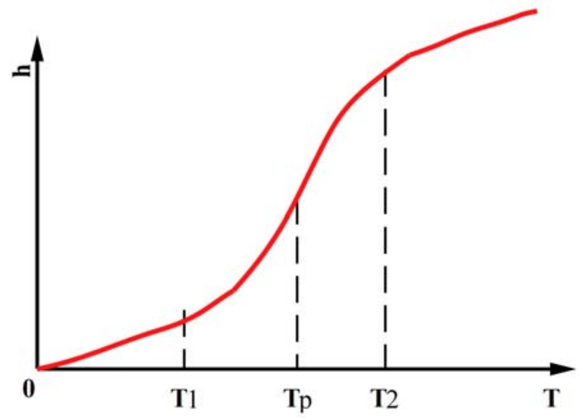


**Fig. 4.** The specific enthalpy (h) – temperature (T) curve of certain phase change material

We can see that on temperature range $[T_1,T_2]$, $c_p$-T curve experiences a peak interval, while the h-T curve presents a corresponding slope change in the same temperature range due to the relations between h-T and $c_p$-T functions:

$$c_p(T) = \frac{dh(T)}{dT} \qquad (3)$$

In practice, the phase change temperatures and enthalpy changes of a certain phase change material during the phase change process are measured by a device called differential scanning calorimeter. When testing with differential scanning calorimeter, a net dynamic heating power will be input to the tested sample to make its temperature increase at a constant rate, and the value of this net dynamic heating power is recorded and finally plotted in the form of differential scanning calorimeter curves. In order to get the correct "net" dynamic heating power input to the tested sample, a reference material should be used. The reference materials normally used during differential scanning calorimeter testing's are those with a constant heating or cooling rate, i.e. with the constant specific heat capacity, such as Alumina and indium metal [7],[19].

The latent heat thermal energy storage method that is suitable for solar heating and air conditioning has received considerable attention due to its advantages of storing a large amount of energy as a phase transition at a constant temperature. The latent heat of melting is the large quantity of energy that needs to be absorbed or released when a material changes phase from a solid state to a liquid state or vice versa [12].

The storage temperature or phase change can be improved by choosing the phase change material in such a way that its phase change temperature optimizes the thermal gradient with respect to the substance with which the heat is being exchanged. For example, with paraffins and alkanes it is possible to vary the number of carbon atoms or form different molecular alloys, which allows a practically continuous variation of the phase change temperature with certain ranges [10],[20].

Figure 5 shows the increase of internal energy when energy in the form of heat when it is added to a substance [20]. The well known consequence is an increase in temperature (sensible heating) or change of phase (latent heating).

Starting with an initial solid state at point O, a heat addition to the substance first causes sensible heating of the solid (region O-A) followed by a solid to liquid phase change (region A-B), a sensible heating of the liquid (region B-C), a liquid to vapor phase change (region C-D), and a sensible heating of the vapor (region D-E).

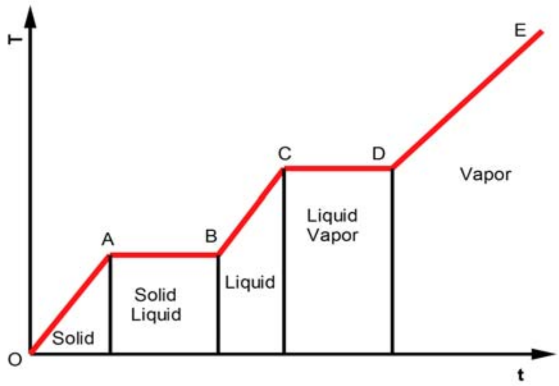


**Fig. 5.** Temperature (T) -time (t) diagram for the heating of a substance

The total amount of heat can be written in the following formula: [6]

$$Q = m \cdot \left[ \int_{TO}^{TA} C_{ps}(T)dT + q_t + \right. \\ \left. + \int_{TB}^{TC} C_{pl}(T)dT + q_i + \int_{TD}^{TE} C_{pv}(T)dT \right] \quad (4)$$

Some of the important properties required for phase change material are:

- High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy;
- High specific heat that provides additional sensible heat storage effect and also avoid sub cooling;
- High thermal conductivity so that the temperature gradient required for charging the storage material is small;
- High density, so that a smaller container volume holds the material;
- A melting point in the desired operating temperature range;
- The phase change material should be non-poisonous, non-flammable and non-explosive;
- No chemical decomposition, so that the latent heat storage system life is assured;
- No corrosiveness to construction material;
- Phase change material should exhibit little or no super cooling during freezing [16].

Phase change materials are either packaged in specialized containers such as tubes, shallow panels, plastic bags, etc., or contained in conventional building elements (wall board, ceiling) or encapsulated as self-contained grains. Because the chemicals in some phase change materials separate and stratify when in their liquid state, phase change materials have not always re-solidified properly. When temperatures dropped, they did not completely solidify, reducing their capacity to store latent heat. These problems have been addressed by packaging phase change materials in thin or shallow containers; compare unfavorably with the newer generation of low-cost, highly efficient, linear crystalline alkyl hydrocarbons [6].

Due to its high cost, latent heat storage is more likely to find application when:

- High energy density or high volumetric energy capacity is desired, e.g., in habitat where space is at a premium, or in transportation where both volume or weight must be kept to a minimum;
- The load is such that energy is required at a constant temperature or within a small range of temperature;
- The storage size is small. Smaller storage has higher surface area to volume ratio and therefore cost of packing is high. Compactness is then very important in order to limit the containment costs. Similarly, heat losses are also more or less proportional to the surface area. Compactness is also an important factor to limit the heat losses in storage of small capacities [3].

### Thermo chemical heat storage

Storage based on chemical reactions has much higher thermal capacity than sensible heat but are not yet widely commercially viable. Some reversible chemical reactions can also be used as one of the solutions to store the thermal energy. The basic principle of this thermo chemical heat storage has been depicted in:

- Endothermic reaction:

$$AB + \dot{Q}_1 \rightarrow A + B \tag{5}$$

- Exothermic reaction:

$$A + B \rightarrow AB + \dot{Q}_2 \tag{6}$$

During the endothermic reaction, i.e. charge process, the compound reactant “AB” absorbs certain amount of thermal energy under relatively higher temperature conditions (compared with reverse exothermic reaction, except for the photochemical reactions), decomposing into the resultants of “A” and “B”. On the other hand, during the exothermic reaction, i.e. discharge process, the resultants of “A” and “B” experiences a combination reaction, forming the compound “AB” while releasing certain amount of thermal energy.

In order to avoid the simultaneous reverse reaction during the charge process, resultants “A” and “B” are advised to be separately collected. Therefore, if “A” and “B” are in different phase form, forms example one is gas and the other one is in solid phase, then the corresponding reversible reaction will be more convenient for the implementation of thermo chemical heat storage. Well separation of resultants “A” and “B” guarantees the stable storage for the reactants, and this feature is very important for the long-term thermal energy storage. However, up till now, most of the endothermic reactions are operated either under a much higher temperature or with more special reaction requirements than the condition for normal building applications, thus the thermo chemical heat storage has been scarcely utilized in this area [2].

Several reversible chemical processes, all of them involving two media, are being investigated for their suitability as a means of thermal storage. One concept is using a salt, such as sodium sulphide and water. The salt can be dried using for instance solar heat. This will accumulate thermal energy, and this energy can be recovered by adding water vapor to the salt. Significant issue is with the corrosion and air tightness since the dry salt must be stored in an evacuated environment. This kind of reactions is combined with a heat pumping effect. Energy at a low temperature level has to be provided in order to discharge the storage, for instance vaporization of water. At the charging process is energy withdrawn from the system for instance by condensing water. Another reaction is adsorption of water in a zeolite material. Zeolites are alumina silicates with high micro-porosity and open structure. When dry zeolite material comes in contact with water vapor, the water vapor will enter the internal crystal lattice and causes a reaction that leads to the release of heat. The process is reversed by heating the zeolite material to more than $100^0C$ when the water is driven off (desorption). The adsorption /desorption processes can be repeated almost indefinitely without any significant deterioration of the zeolite material [13].

For a thermo chemical reaction to be considered for energy storage, the following conditions should be met:

- The reactants should be cheap,
- The reaction should be run near equilibrium, i.e. reversible;
- The energy stored in the thermo chemical energy should be large enough;
- The reactant, with or without addition of a photosensitizer, should be able to use as much of the solar spectrum in the terrestrial atmosphere as possible [3].

The storage systems based on chemical reactions have negligible losses whereas sensible heat storage dissipates the stored heat to the environment and need to be isolated.

### 2.2. Classification of thermal energy storage solutions by using time length of stored thermal energy

The storage need in a solar system is often determined by the ratio of the maximum to minimum monthly solar radiation.

Energy storage for intermittent sources such as solar heating is important as the storage demand may be quite long. Especially, if the solar heating system is intended to provide a high solar fraction, i.e. most of the heat supplied over the whole year is solar heat; thermal storage becomes very important and challenging.

Because of the discrepancy between solar radiation and space heat demand monovalent solar space heating in cold and temperate climates is only possible if a long-term thermal storage with a heat capacity of at least three months in existing housing and of about four month in low-energy housing is provided.

In order to cover the heat demand for hot water in district heating outside the heating season mainly by solar systems a thermal storage with a capacity for 3 to 5 days has be installed. Seasonal thermal storage has longer thermal storage period, generally three or more months.

Combining solar heating systems with short-term heat storage and high standards of thermal insulation allows the heating requirements of a single – or multi- family dwelling to be met at acceptable costs. Compared with systems using seasonal storage (the cost of which are currently not affordable for single-family houses), this combination provides a cost-effective system with high efficiency [5].

### 2.3. Classification of thermal energy storage solutions by temperature level of stored thermal energy

The energy sources, normally, used for heating and cooling are oil, gas, coal and electricity. The principal gain from thermal storage is that the heat and the cold may be moved in space and time to allow utilization of thermal energy that otherwise would be lost because it was available at the wrong place and at the wrong time. Therefore thermal energy storage makes possible the utilization of new renewable energy sources (solar, geothermal, and ambient) and waste heat/cold recovery for space heating and cooling, more effectively.

**Heat storage**

Heat – in the physical sense – is a form of energy and can be stored in a variety of ways and for many different applications. A characteristic property of heat is its temperature: according to this it can be distinguished in low-temperature heat and high-temperature heat. The former is usually applied for domestic hot water supply; it is usually stored in small hot water tanks when used for single family houses, or in large underground containers for large housing projects with hundred and more apartments.

The price of the storage medium and / or the cost of the containment are decisive for the utilization. Long life and a high cycling stability are pre-requisites for an economic application; i.e., at a price competitive with existing facilities. High temperature diffusivity of the heat storage material provides a quick response to temperature differences; i.e., quick charging and discharging. High heat diffusivity yields a high amount of heat being stored.

Heat transfer processes have to be considered: the heat may be either transferred directly to the storage material as, e.g. in a dry pebble bed with air flows or by way of a heat exchanger as in a solar domestic hot water store where the water – antifreeze mixture flowing through a solar collector has to be separated from the hot water for consumption [8].

Heat storage is a crucial issue to match demand for heat with supply of heat, or even with the need to get rid of waste heat. The ground has proven to be an ideal medium for storing heat in larger quantities and over longer time periods, like the yearly seasons. After plants to store summertime solar heat for use in winter heating, storage of waste heat now is emerging. The efficiency of heat storage depends upon the temperature level achieved and upon minimization of thermal losses [17].

**Cool storage**

Currently, the main part of the cooling demand is covered by electricity consuming installations, and about 10% of the global electricity production is used for cooling. When taking into account the growing need for cooling, this situation is precarious as the electricity production of today causes large negative environmental impacts, the cost of electricity results in loss of profit, and systems peaks have turned out to be difficult and sometimes disastrous to handle.

The concept of underground thermal energy storage delivers some of the most promising solution for addressing this challenge –both in economic and environmental terms. Cooling need can be reduced in the demand side, which must have first priority. Secondly, the need for supply of mechanical cooling can be reduced based on utilization of natural sources of energy such as cool night air, underground thermal energy storage using groundwater or geo-exchange systems for thermal energy etc. beginning with the most accessible ones.

The market interest in such systems is rapidly increasing, as the systems have shown to be very profitable and to possess large environmental benefits.

Some of the reasons for the increased cooling demand are:

- Higher internal heat load intensity due to increased use of IT equipment and more closely occupied offices;
- Increasing requirements for internal air quality and comfort;
- Increased use of large glass facades to provide daylight increases cooling load;
- Open office spaces with suspended acoustical ceilings and IT flooring, which unfortunately becomes a barrier for heat accumulation in the building structures;
- Climate change with heat waves.

Increased need for cooling for server and telecommunication equipment as well as four various industrial purposes [4].

## 3. COMPARISON OF SENSIBLE AND LATENT THERMAL ENERGY STORAGE SOLUTIONS

Sensible heat storage systems are simpler in design than latent heat or thermo chemical storage systems. However they suffer from the disadvantage of being bigger in size and cannot store or deliver energy at a constant temperature.

Storage of sensible heat results in energy losses during the storage time. These losses are function of storage time, storage temperature, storage volume, storage geometry, and thermal properties of the storage medium.

All the sensible heat storage concepts have one basic challenge in common. When heat or cold is charged into or discharged from the store, there will be temperature differences in different parts of the storage volume. It is then of the utmost importance that the storage medium can maintain a structured layer, for instance with the warmest water on the top, and the coldest at the bottom.

The cost of the sensible heat storage solution mainly depends on the characteristics of the storage material. It is very common to utilize very cheap materials; for liquid such as water, oils and certain inorganic molten salts and solid like rocks, sands, pebbles and refractory as the storage medium.

Due to high specific heat of water, and the possibility for high capacity rates for charging and discharging, this technology seems to be the most favorable from a thermodynamic point of view.

The main problem with water storage systems is the corrosion for long operation periods. Another disadvantage of water storage systems is that volume of the storage may be very large for large heat capacities and therefore the whole system becomes very heavy. With large storage units, there is also stratification problem and because of this controls are required.

With rock storage there is no corrosion or scale forming problem but volume of the system might increase with an increase in cost. On the other hand by the use of phase change storage systems, large volumes required by the other two types are eliminated. Because of the bond interaction of the storage material and the container, storage material loses its energy storage characteristics after a period of time.

Rock storage systems have larger amortization periods because they have no corrosion and deformation problems, but with their volumes being large, their total initial costs are very high.

Phase change materials are either packaged in specialized containers such as tubes, shallow panels, plastic bags, etc., or contained in conventional building elements (wall board, ceiling) or encapsulated as self-contained grains. Because the chemicals in some phase change materials separate and stratify when in their liquid state, phase change materials have not always re-solidified properly. When temperatures dropped, they did not completely solidify, reducing their capacity to store latent heat.

It was assumed that containers of phase change system are manufactured using plastics and deformation of the material will begin after five years. It was found that the most economical type is the water storage system. On the other hand water storage system occupies a volume 80 times more than the volume occupied by the phase change system and it has an amortization period, which is four times more than the amortization period of phase change systems.

Phase change systems are the most expensive but also the most compact types having least using periods because of the material deformation and degradation problems. Because of their compactness, their total initial costs are small. I the problems associated with phase change systems are solved, in the future they are going to be the most promising one [3].

In table 1 is realized a comparison between different heat storage media and in table 2 is realized a comparison of heat transfer properties and life of different types of thermal storage.

*Table 1*

**Comparison between different heat storage media**

| Sensible heat storage | | Latent heat storage |
|---|---|---|
| Water | Rock | Solid-liquid |
| *Operating temperature range choice* | | |
| Limited (0-100$^0$C) | Large | Large, depending on the material |
| *Specific heat* | | |
| High | Low | Medium |
| *Thermal conductivity properties* | | |
| Low, convection effects improve the heat transfer rate | Low | Very low, insulating |
| *Thermal storage capacity per unit mass and volume for small temperature differences* | | |
| Low | Low | High |
| *Stability to thermal cycling* | | |
| Good | Good | Insufficient data |
| *Availability* | | |
| Overall | Almost overall | Dependent on the choice of material |
| *Cost* | | |
| Inexpensive | Inexpensive | Expensive |

*Table 2*

**Comparison of heat transfer properties and life of different types of thermal stores**

| Sensible heat storage | | Latent heat thermal storage material |
|---|---|---|
| Water | Rock | Solid-liquid |
| *Required heat exchanger geometry* | | |
| Simple | Simple | Complex |
| *Temperature gradients during charging and discharging* | | |
| Large | Large | Small |
| *Thermal stratification with effect* | | |
| Existent, works positively | Existent, works positively | Generally non-existent proper choice of material |
| *Simultaneous charging appropriate discharging* | | |

| | | |
|---|---|---|
| *exchanger* | | |
| Possible | Not possible | Possible with selection of heat |
| *Integration with solar heating / cooling systems* | | |
| Direct integration with water systems | Direct integration with air systems | Indirect integration |
| *Cost of pumps, fans, etc.* | | |
| Low | High | Low |
| *Corrosion with conventional materials of construction* | | |
| Corrosion eliminated through corrosion inhibitors | Non-corrosive | Presently only limited information available |
| *Life* | | |
| Long | Long | Short |

## 4. CONCLUSION

Based on the energy storage material, the energy storage solutions can be classified into the sensible, latent and thermo chemical heat stores.

Considering the sensible thermal storage solutions, the theoretical and technological research and applications for the liquids and solids form have developed to a relatively mature stage. For the residential and buildings applications, the liquids thermal storage are normally utilized as a separate unit, such as water storage and solar pound; while the solids form can not only be implemented as a separate storage unit, such as packed bed storage, but also further extend its applications to be part of building, such as an envelope integrated energy storage.

Considering the thermo chemical energy storage, this technology utilizes the reversible chemical reactions during the charging and discharging periods. The advantages of this technology is that if the resultants of the reaction can be well separated, the storage mediums will be very stable, thus suitable for long term storage. However, up till now, almost no reversible chemical reaction is known to be within the temperature ranges of buildings applications.

Normally solid-liquid phase change materials are utilized for the buildings application. Their application can cover almost every part of the building envelopes, such as wall, floor, ceiling, roof, window and sun shading systems. Then can either be functioned as a thermal buffer to alleviate the exterior environmental influences, or as an “automatic” indoor temperature regulator to attenuate the indoor temperature fluctuations and improve thermal comfort.

## 5. REFERENCES


[1] Dincer, I., *Evaluation and selection of energy storage systems for solar thermal applications*, International Journal of Energy Research, Int. J. Energy Res., 23 1017-1028 (1999)

[2] Duffie, J.A., Beckham, W.A., *Solar engineering of thermal processes*, 3th ed., John Wiley and Sons, 2006

[3] Ercan Ataer, O., *Storage of thermal energy*, in Energy Storage Systems, in Encyclopedia of Life Support Systems (EOLSS), Developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK 2006, http://www.eolss.net

[4] EU Commission SAVE Programe & Nordic Energy Research, Soil Cool /Rekyl project – *Pre-design guide: For ground source cooling systems with thermal energy storage*, Edited by COWI, 2004

[5] Faninger, G., *Thermal Energy Storage*, http://download.nachhaltigwirtschaften.at/pdf/task28_2_6_Thermal_Energy_Storage.pdf

[6] Fatih Demirbas, M., *Thermal energy storage and phase change materials: an overview*, Energy sources, Part B, 1:85-95, 2006

[7] Feldman, D., Banu, D., *DSC analysis for the evaluation of an energy storing wallboard*, Thermochimica Acta, vol 272, pp 243-251, 1996

[8] Hahne, E., *Storage of sensible heat*, in Energy Storage Systems, in Encyclopedia of Life Support Systems (EOLSS), Developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK 2006, http://www.eolss.net

[9] Hasnain, S.M., *Review on sustainable thermal energy storage technologies, part I: Heat storage materials and techniques*,

Energy Conversion and Management, vol 39, pp 1127-1138, 1998
[10] Hassan, E.S.F., *Heat exchanger performance for latent heat thermal energy storage system*, Energy Convers. Mgmt., 31(2):149-155, 1991
[11] Incropera, F.P., Dewit, D.P., *Fundamentals of heat and mass transfer*, 5th ed., John Wiley and Sons, 2002
[12] Khudhair, A.M., Farid, M.M., *A review on energy conservation in building applications with thermal storage by latent heat using phase change material*, Energy Convers. Mgmt., 45(2):263-275, 2004
[13] Nielsen, K., *Thermal energy storage: A state-of-art*, a report within the research program Smart Energy-Efficient Buildings at NTNU and SINTEF 2002-2006, 2003
[14] Pavlov, G.K., Olesen, B.W., *Seasonal ground solar thermal energy storage – review of systems and applications*, Proceedings of ISES Solar World Congress, Kassel (DE), 28.08-02.09.2011
[15] Pavlov, G.K., Olesen, B.W., *Seasonal solar thermal energy storage through ground heat exchangers – review of systems and applications*, Proceedings of 6th Dubrovnik Conference on Sustainable development of Energy, Water and Environmental Systems, Dubrovnik, Croatia, 25-29.09.2011
[16] Ravikumar, M., Srinivasan, DR.PSS., *Phase change material as a thermal energy storage material for cooling of building*, Journal of Theoretical and Applied Information Technology, http://www.jatit.org/volumes/research-papers/Vol4No6/6Vol4No6.pdf
[17] Sanner, B., Knoblich, K., *Advantages and problems of high temperature underground thermal energy storage*, Bulletin d`Hidrogeologie No.17 (1999), Editions Peter Lang
[18] Sunliang, C., *State of the art thermal energy storage solutions for high performance buildings*, Master`s thesis, University of Jyvaskyla, Finland, 2010
[19] Tyagi, V.V., Buddhi, D., *Thermal cycle testing of calcium chloride hexahydrate as a possible PCM for latent heat storage*, Solar Energy Materials & Solar Cells, vol 92, pp 891-899, 2008
[20] Zondag, H.A., Van Essen, V.M., Bleijendaal, L.P.J., Kikkert, B.W.J., Bakker, M., *Application of $MgCl_2 \cdot 6H_2O$ for thermochemical seasonal solar heat storage*, Prezented at the 5th International Renewable Energy Storage Conference IRES 2010, 22-24.11.2010, Berlin, Germany

**Stocarea energiei termice: vedere de ansamblu**

**Abstract:** *Acum, când încălzirea globală a devenit una dintre problemele cele mai urgente din lume, avem nevoie să găsim o modalitate mai bună de utilizare a energiei, mai ales în domeniul stocării energiei. În prezent, cea mai mare parte a energiilor regenerabile, în special energia eoliană şi cea solară sunt surse de energie cu densități variabile în cursul unei zile, a unei luni. Obiectivul principal al acestor sisteme este de a stoca căldura solară colectată (acumulată) în timpul verii şi de a o utiliza apoi la încălzirea spațiilor pe timpul iernii. Aceste sisteme contribuie semnificativ la îmbunătățirea eficienței energetice şi la reducerea emisiilor de gaze în atmosferă. Dezvoltarea unor dispozitive eficiente şi necostisitoare pentru stocarea energiei este la fel de importantă ca şi dezvoltarea de noi surse de energie.*

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