Thermal Energy Storage – An Overview

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Abstract

In the contemporary era, where global warming is one of the most pressing environmental issues, there is a critical need to enhance the efficiency of energy utilization, particularly in the domain of energy storage systems. Renewable energy sources, such as solar and wind energy, have gained prominence due to their sustainability and reduced carbon footprints. However, these sources are inherently intermittent, with energy generation fluctuating throughout the day and across different seasons. This challenge necessitates advanced energy storage solutions to bridge the gap between energy supply and demand, particularly in the context of seasonal variations. These seasonal thermal energy storage (TES) systems can significantly contribute to improving overall energy efficiency, reducing reliance on fossil fuels, and minimizing environmental emissions. There are several types of thermal energy storage technologies available, each with unique characteristics and applications. These include sensible heat storage, which relies on the temperature change of a medium to store energy; latent heat storage, which utilizes phase change materials to store and release energy during phase transitions; and thermochemical heat storage, which involves reversible chemical reactions to store energy.

Keywords: thermal energy storage, thermal storage, seasonal heat storage, sensible heat storage, latent heat storage, thermochemical heat storage, energy efficiency, renewable energy, solar energy storage, wind energy storage, global warming.

1. INTRODUCTION

Thermal energy storage can be defined as the temporary storage of thermal energy at high temperature. This concept is not new. It has been used and developed for centuries because it plays an important role in energy saving. Energy is not uniform and its effective use depends on the availability of good and efficient electrical equipment.

This means that solar thermal technology cannot realize its full potential in space heating and domestic hot water use. Energy saving equipment reduces energy consumption and provides low temperature energy recovery while removing energy storage equipment. This is due to the effect of high latitudes, because solar radiation is very different and different heating operations in cold climates determine energy use. The use of summer energy storage can reduce the amount of solar energy that can meet 100% of the building's energy needs.

The aim of such a system is to collect solar energy in the summer and store the heat for use in the winter. This application requires a lot of cheap storage and the best equipment is the use of underground electrical equipment. Although such methods have been developed and proven, it is very difficult to make them cost effective. The music industry could be designed to use annual storage of community hours, which could reduce the cost and increase the reliability of solar heating [15].

Thermal energy storage technology has the ability to increase the efficiency of thermal energy products and is an important factor in compensating for the imbalance between thermal energy supply and demand. A well-designed system can reduce initial and maintenance costs and increase energy efficiency [14].

Energy storage systems can be useful in meeting people's needs for efficient and environmentally friendly use in heating and cooling production, fire electricity and energy consumption. Another important benefit of energy saving is that it can be designed to store solar energy, but it is not limited to this. It can be used to collect excess energy from power plants, especially wastewater, air conditioning waste, industrial process waste, etc. It becomes a kind of energy sink into which we can drain all the energy we don't need at the moment. This type of storage may not be suitable for small homes, but it is useful for central heating [1].

2. CLASSIFICATION OF THERMAL ENERGY STORAGE SOLUTIONS

Thermal energy storage is needed when heat demand does not equal heat production. Thermal energy storage systems are not energy efficient. However, using energy storage for energy saving can indicate better energy efficiency. The energy saving system allows more efficient use of renewable energy and waste heat/cooling returned to the heating and cooling system. Figure 1 shows different thermal energy storage methods according to thermal energy storage temperature, thermal energy storage duration and energy storage status.

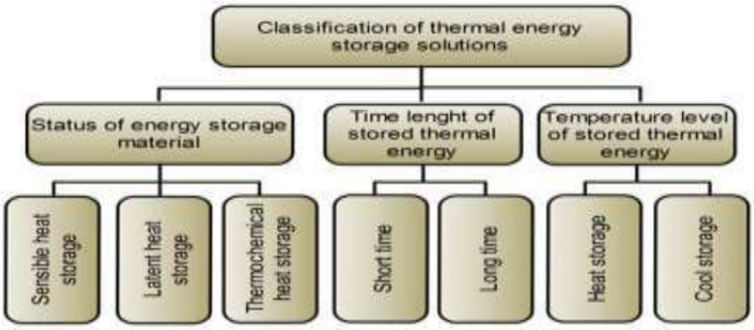

Fig. 1: Classification of thermal energy storage solutions

2.1 Deployment of Thermal Energy Storage Solutions Based On The Use Of Electrical Equipment

According to the thermal energy storage method, thermal energy storage can be divided into:

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

Figure 2 shows the distribution of energy storage technologies according to the energy storage status of the process.

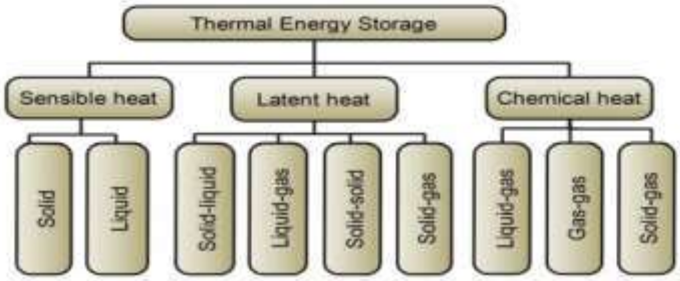

Fig. 2: Classification of thermal energy storage technology based on the criterion of the state of the energy storage material

Sensible Heat Storage

Efficient energy storage devices store or extract energy from heated or cooled air or solids without changing their phase during the process, replacing, for example, water, electricity, oil and some inorganic molten salts, as well as rocks, gravel and refractory materials and other wastes. In solids, the material is always porous and heat is stored or extracted by the flow of gas or liquid through the pores or voids.

Electrical storage materials are used for electrical devices that have the ability to store energy without undergoing a phase change while storing thermal energy. The only process that this material will undergo is a temperature change in one phase. The simplest equation for temperature and pressure is:

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

Of these, T1 is the temperature of the product, T2 is the final temperature of the product, m is the total mass of the product, and cp is the heat capacity of the product.

Since cp is a function of temperature, we can use equation (1) to calculate the total thermal energy stored. However, if the temperature is too low to account for changes in cp, equation (1) can be rewritten as:

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

Where cp.avg is the average temperature potential between temperatures T1 and T2 [11]. According to equations (1) and (2), the specific heat capacity cp can directly affect the

amount of stored thermal energy. Long-term stability ensures that the thermal storage material has low degradation after thousands of thermal cycles.
As can be seen from the above points and equations (1) and (2), it can be said that the ideal heating medium requires the electrical equipment to have four characteristics:

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

Efficient thermal storage devices are easier to manufacture than latent heat or thermochemical storage systems. However, their disadvantages are that they are larger and cannot store or transfer energy at high temperatures. A significant part of the total cost of a storage system is the compatibility with its packaging, which is a requirement for both thermal storage and packaging. The cost of heating solutions depends on the quality of the storage material. It is a method of using very cheap materials such as water, rock, gravel and sand as storage media [18].There are five types of hot water storage: hot water storage, aquifer heat storage, gravel hot water storage, borehole heat storage and cavern heat storage.
The basic principle of latent heat storage is that when heat is applied to a material, the material changes phase from solid to liquid by storing heat as latent heat of fusion, or from liquid to liquid by storing heat as latent heat of vaporization.
In principle, a phase change occurs when a material undergoes a phase change, but the actual phase change process does not actually occur at the temperature. Figures 3 and 4 show the specific heat capacity (cp)-temperature (T) curve and the specific enthalpy (h)-temperature (T) curve of some phase transition materials in general.

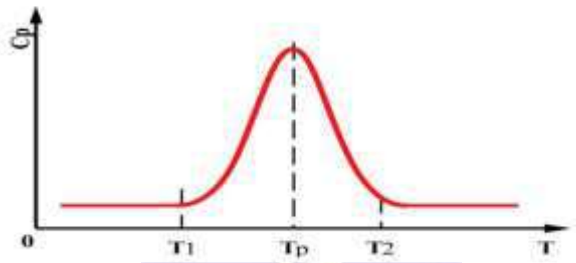

Fig. 3: The specific heat capacity (cp) – temperature (T) curve of certain phase change material

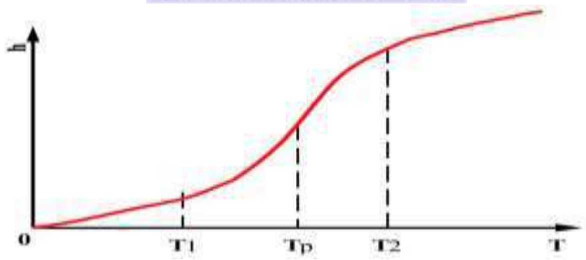

Fig. 4: The specific enthalpy (h) – temperature (T) curve of certain phase change material

We can see that in the temperature range [T1, T2] the cp-T curve meets the maximum time, while the h-T curve shows the closeness of the difference between temperature and cooling, which is due to the work relationship between h-T and cp-T:

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

In practice, the phase transition temperature and enthalpy change during the transformation process of some phase transition materials are measured by an instrument called a differential scanning calorimeter. When tested using a differential scanning calorimeter, net dynamic heat energy is supplied to the tested sample, causing its temperature to increase at a constant rate, and the resulting rate of the differential scanning calorimeter is measured by the curve in the article. In order to obtain the true "net" dynamic heat input to the test sample, reference data must be used. The most commonly used materials in differential scanning calorimeter

experiments are those that have a constant temperature, such as materials that can be heated continuously, such as aluminum oxide and indium metal [7], [19].
Latent thermal energy storage methods suitable for solar heating and cooling have attracted great attention due to the advantage of storing a lot of energy in the form of phase changes of temperature. The latent heat of fusion is the amount of energy that must be absorbed or released when the substance changes from solid to liquid or vice versa [12].
The storage temperature or phase change can be improved by selecting the phase change material in such a way that the thermal gradient of the phase change temperature is optimized with respect to the electrical properties. For example, in the case of paraffins and alkanes, the number of carbon atoms can be varied or different molecular alloys can be formed, allowing the phase transition temperature to vary to a different constant within a certain range [10], [20].
Figure 5 shows the increase in internal energy when energy is added to the object in the form of heat [20]. The well-known effect is temperature (sensible heat) or phase change (latent heat).
Starting from the initial state of O, the addition of heat to the material first causes the good electrical properties of the material (area OA), then the transition of the material to the liquid phase (area AB), the heat of the liquid (area BC), and the liquid to vapor phase transition (area CD) and the sensible heat of the vapor (area D-E).

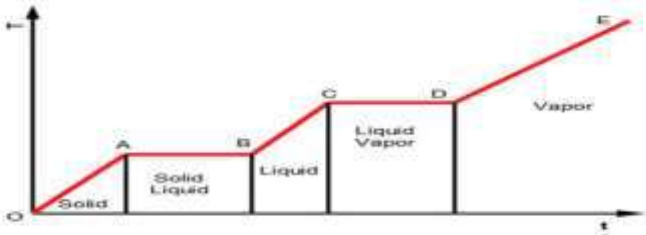

Fig. 5. Temperature (T) - Time (t) diagram for the heating of a substance

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

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

Some of the important elements required for data transfer are:
- A large volume has a high latent heat of fusion, so less material can be used to store energy;
- Special heating elements that provide excellent heat retention while preventing overcooling;
- High thermal conductivity allows a small temperature gradient to be required for charging the storage material;
- High density allows data to fit into a small volume;
- The melting point is within the required operating temperature range;
- Transfer materials must be non-toxic, non-flammable and non-explosive;
- Since there is no chemical decomposition, the life of the latent heat storage system is extended;
- Non-corrosive to household appliances;
- The transfer case should exhibit little or no supercooling during freezing [16].

Transfer materials are packaged in special containers such as tubes, sheets, plastic bags, etc., inside building materials (wall panels, ceilings), or as one would say, encapsulated. Since the drug in some phase change materials separates while in liquid form, there is no need for proper resolidification of phase change materials. They do not solidify at all when the temperature drops, reducing their ability to store latent heat. These problems are being solved

by packaging substitutes in thin containers or by making them perform better than the new generation of low-cost, high-performance, linear crystalline alkyl hydrocarbons [6].
Due to its high cost, latent heat storage is generally used in the following situations:

- People need high-speed power or high-capacity power in residential areas where space is limited or in situations where volume or weight must be kept to a minimum during transportation;
- The load must have power at a constant temperature or a small temperature;
- The storage area is smaller. Small storage facilities have a higher area/volume ratio and therefore higher storage costs. Compactness is important to reduce sealing costs. Similarly, heat loss is more or less proportional to surface area. Compactness is also important in limiting heat in small storage areas [3].

Thermochemical Heat Storage

Heat storage as a chemical reaction can have more heat than the required heat, but it is not yet widely commercialized. Some reverse reactions can be used as a solution for storing thermal energy. The principle of this thermochemical heat storage is as follows:

• Endothermic reaction: $AB + \dot{Q}_1 \rightarrow A + B$	(5)
• Exothermic reaction: $A + B \rightarrow AB + \dot{Q}_2$	(6)

During endothermic reactions, i.e. charging processes, the compound reactant “AB” absorbs a certain amount of thermal energy at high temperature (except for photochemical reactions, compared to reverse exothermic reactions) and decomposes into products "A" and "B". On the other hand, during the exothermic reaction, i.e. during the release process, products “A” and “B” react, producing the compound “AB” and at the same time a certain amount of heat energy. released into the market. In order to avoid simultaneous reverse reactions during payment, it is recommended to write “A” and “B” separately. Therefore, if “A” and “B” are in different states, for example, one in the gas phase and the other in the solid phase, then the reversible reaction will be more favorable for the use of thermal resistance.
Good separation of “A” and “B” products ensures the stability of the reactants, which is a very important product for long-term thermal storage. However, to date, most endothermic reactions can occur at higher temperatures than those normally used in the home or have more specific requirements than those applied in buildings, so thermochemical materials are rarely used in this field [2]. Thermochemical heat storage will be easier to use.
Various reversible chemical processes involving both media have been investigated for their suitability as heat storage. One idea is to use salts such as sodium sulphide and water. For example, solar heat can be used to dry the salt. This stores thermal energy that can be recovered by adding water vapour to the salt. The main problems are corrosion and gas tightness, as the dry salt must be stored in a vacuum. This reaction is combined with the effect of heat. In order to release the stored energy, cryogenic levels of energy must be provided, such as by evaporation of water. During the charging process, energy is withdrawn from the system, for example by condensation. Another reaction is the adsorption of water into zeolite materials. Zeolites are aluminum silicates with high microporosity and an open structure. When dry zeolite material comes into contact with water vapor, the water vapor will enter the glass crystal and cause a chemical reaction that releases heat.
The process is reversed by heating the zeolite material above 1000°C while water is removed (desorbed). The adsorption/desorption process can be repeated almost continuously without any significant effect on the zeolite product [13].
For a thermochemical reaction to be considered for energy storage purposes, the following conditions must be met:

- The reactants should be cheap,
- The reaction should be run near equilibrium, i.e. reversible;
- The energy stored in thermochemical energy must be large enough;

- The reagents must be able to use as much of the solar spectrum in the Earth's atmosphere as possible, with or without the addition of photosensitizers [3].

Storage systems based on chemical reactions have one disadvantage; heat storage effectively dissipates storage heat into the environment and requires insulation.

2.2 Classification of thermal energy storage solutions by using time

The storage capacity of a solar energy system is generally determined by the ratio of monthly maximum solar radiation to minimum solar radiation.

Energy storage is important for interconnected energy sources such as solar heating because the storage demand can continue for a long time. In particular, if the solar heating system is designed to provide, for example, a comparable amount of sunlight, most of the heat provided throughout the year is solar thermal storage, which is important and difficult. Due to the difference between solar radiation and heating, long-term thermal storage in cold and temperate climates is only possible with a thermal capacity of at least three months in existing buildings and about four months in hot solar space. Solar-based thermal storage units with a capacity of 3 to 5 days are installed to meet the hot water demand in the heating area outside the hot season. Summer storage has a longer storage period, generally more than three month.

The combination of solar heating with short-term thermal storage and high insulation standards can meet the heating needs of single or multifamily homes at a reasonable cost. This combination provides a highperformance, costeffective system compared to systems using seasonal products, which are currently unaffordable for a single family [5].

2.3. Thermal energy storage solutions are classified according to the temperature at which the thermal energy is stored.

The most commonly used fuels for heating and cooling are oil, natural gas, coal and electricity. The main advantage of thermal storage is the ability to move heat and cold in space and time, making it possible to use thermal energy that would otherwise be lost if it were available at a certain time and place. false. Energy efficiency can be increased by using new renewable energy sources (solar, geothermal and ambient) and by using waste heat/cooling recovery for space heating and ventilation cooling purposes.

Heat storage

Physically, heat is a type of energy that can be stored in many ways and used for many different purposes. A special property of heat is its temperature: Accordingly, a distinction can be made between low-temperature and high-temperature heat. The first of these is usually used for domestic hot water when used in a single house and is usually stored in small hot water tanks, or in large-scale projects with hundreds or more houses, usually in a container underground. The cost of use and/or value of the container. Long life and high cycle stability are prerequisites for economical use; for example, price competition with existing plants. Heat storage materials have high heat dissipation and respond quickly to temperature changes; for example, they charge and go immediately. High thermal diffusivity allows the stored material to have a wider temperature range. In a dry gravel bed with air flow or through a heat exchanger, for example in a solar domestic hot water storage system, the water-antifreeze mixture flowing from the solar collector must be separated from the hot water before it can be used [8] .

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 reasons for the need for additional cooling include:

- Greater energy efficiency through the use of IT equipment and denser offices;
- The need for indoor air and comfort continues to increase;
- Using large glass on the wall to let in sunlight will make it cooler;
- The open office space has unfortunately abandoned acoustic ceilings and IT floors which prevent heat build-up in the building structure;
- Climate change with heat waves.

Cooling requirements have increased for servers, telecommunications equipment, and four other applications [4].

3. COMPARISON OF SENSIBLE AND LATENT THERMAL ENERGY STORAGE SOLUTIONS

Efficient energy storage systems are simpler to design than latent heat or thermochemical storage systems. However, they have the disadvantages of being larger and not being able to store and transfer energy at high temperatures. Storage at a good temperature reduces energy loss during storage. These losses are a function of storage time, temperature, storage capacity, storage geometry, and the thermal properties of the storage medium. All elements of electronic equipment that can present a significant challenge. When hot or cold enters or leaves the tank, temperature differences occur in different parts of the tank. Therefore, it is very important to keep the data organized, such as the hottest water at the top and the coldest water at the bottom.
The cost of heat treatment depends on the product stored. It is mainly used as a cheap material for liquids such as water, oil and some non-oily molten salts and as a storage material for solids and refractory materials such as rock, sand, gravel. Due to the special structure of hot water and its high charging and discharging capacity, this device seems to be the best device in terms of temperature. The main problem of water storage systems is corrosion caused by long-term operation. Another disadvantage of water storage is that it can be very large in relation to the thermal capacity and can make the whole system very heavy. Stratification problems also occur in large reservoirs and therefore need to be controlled. Corrosion and scaling are not a problem in concrete storage, but as costs increase, the size of the system also increases.
On the other hand, by using time transfer storage, the large capacity that the two types need to do is eliminated. Due to the connection between the electronic equipment and the box, the energy storage loses its energy storage feature after a period of use. Since stone storage machines do not have corrosion and deformation problems, their amortization period is longer, but their initial costs are quite high due to their large size. Transfer materials are packaged in special containers such as tubes, sheets, plastic bags, etc. located inside the building materials (wall panels, ceilings), or encapsulated as the person says. Since the drug in some phase change substances is separated while in liquid form, there is no need for phase change substances to solidify properly.
When the temperature drops, they do not solidify at all, which reduces their ability to store latent heat. Assuming that the box in the transition stage is made of plastic, the product will begin to deform after five years. It has been found that the most common type of work is water storage. On the other hand, the volume of the storage tank is 80 times the replacement period, and the depreciation period is four times the replacement period. The replacement process is the most expensive, but it is also the most compact, and the service life is the shortest due to material deformation and deterioration problems. Because of its compact structure, all costs are low. When the problems related to the transfer process are solved, it will become the best process of the future [3]. Table 1 shows the comparison of different electrical equipment, and Table 2 shows the comparison of the characteristics of heat transfer to the life and life of different types of electrical equipment.

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°C)	Large	Large, depending on the material
Specific heat		
High	Low	Medium
Thermal conductivity properties		
Low, conversion effects improve the heat transfer rate	Low	Very low, insulting
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 different types of thermal stores

Sensible Heat Storage		Latent Heat Thermal Storage Material
Water	Rock	Solid-Liquid
Required Heat Exchanger Geometry		
Simple	Simple	Simple
Temperature Gradients During Charging And Discharging		
Large	Large	Large
Thermal Stratification With Effect		
Existent, Works Positively	Existent, Works Positively	Generally Nonexistent 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	Long

4. CONCLUSION

According to energy storage information, energy solutions can be divided into energy storage, latent energy and thermo chemical energy. As a beneficial solution to the crisis, theoretical research technology and applications in liquid materials and materials have been developed to a mature stage. Thermal storage equipment for indoor and outdoor use is generally used as a separate unit, such as water storage and solar power plant; extend its application to buildings that integrate energy storage as part of the building, such as building envelope. Considering thermochemical energy storage, this device uses a reverse reaction during charging and discharging. The advantage of this process is that if the reaction products can be well separated, the storage medium will be stable and suitable for long-term storage. However, little is known so far about chemical recovery from architectural usage temperature. Solid-liquid phase transitions are frequently used in construction. Their applications can cover all parts of the house, such as walls, floors, ceilings, roofs, windows and shading systems. Both as a thermal buffer to reduce the influence of the external environment and as an automatic space heater to reduce the temperature in the house and increase the comfort of high temperatures.

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