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Solar thermal energy storage solutions for building application: State of the art

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Abstract

Thermal energy storage plays an important role in fossil fuel preservation. Buildings are a significant contributor to energy consumption. To reduce building energy demand, novel technologies for thermal energy storage are introduced. This paper reviews these technologies with a special focus on renewable energy sources such as solar energy storage systems its benefits. It is found that heat storage is suitable for space heating (low-temperature heat), and has the capacity to reduce building energy demand.

Keywords: Solar energy, Energy storage, Building heating

1. Introduction

Since the beginning of the 21st century, there has been an emphasis on the fight against climate change in the world. It is known that carbon dioxide (CO2), which is the product of total combustion of fossil fuels, is the main cause of global warming or the creation of a greenhouse effect. Carbon dioxide is poorly reactive and difficult to break down, and together with other gases it melts into more parts of the atmosphere and creates a layer that the part of the heat emitted by Earth returns. So, a process like that in a greenhouse occurs, the heat energy that arrives on the Earth by the Sun's radiation is largely retained there.

Increasing the greenhouse effect due to emissions of anthropogenic origin has the effect of increasing the average temperature of the atmosphere, which seriously disturbs the natural balance and thus severely endangeres the climate. Climate change negatively affects the world economy, the flora and fauna and the lack of water. Due to the limitations of fossil fuels and the fact that their combustion pollutants pollute substances, it is necessary to increase the scope of use of renewable energy sources and environmentally acceptable sources of energy.

By using renewable energy sources, it is possible to reduce the consumption of existing resources, but also to preserve the environment and mitigate the effects of global warming. In addition, using renewable energy sources reduces the energy dependence on imports of fossil fuels and avoids turbulence in energy prices. One of the most important renewable sources is solar energy [1].

At the end of 2008, the European Union (EU) adopted The energy - climate package or more laws that should reach 20% lower emissions of greenhouse gases by 2020, 20% of the share of renewable energy in total energy consumption and 20% less energy consumption (compared to that which is expected in the case of non-implementation of special measures by 2020). The popular name of this target is "20 20 20". To achieve this goal, one of the key measures is the use of solar energy, as stated in EU Directive 2009/28 / EC [2].

One of the simplest and most promising measures is the increase in the use of solar energy, which the modern society recognized through the numerous advantages it brings with it. It is necessary to realize the full potential of the technology for storing heat from the sun. With the help of physical and chemical processes, such heat energy can be accumulated.

It is essential that heat storage technologies realize their full potential due to the very nature of solar energy.

Using physical and chemical processes, thermal energy accumulation can be performed. In terms of heat, there is a difference between methods for storing sensitive and latent heat.

1.1. Article goals

With this work, the reader tries to bring the problems of today's society closer in a simpler way. Problems that are due to over-use of non-renewable energy sources and the reasons why it should be transferred to the use of renewable energy sources, in this case solar energy.

The aim of the paper is to briefly explain what actually solar energy is and what is the reason for its storage, and through the mathematical formulas, explain the ways of sweetening the solar thermal energy.

2. Solar energy

First of all, it is worth mentioning that all the energy on the planet comes from:

• Sun energy

• Earth energy

• Gravity energy

The judges, as the nearest star, are almost the source of all available energy on Earth.

The intensity of solar radiation varies, depending on the climate

Climate, but even in the northernmost regions inhabited by people insolation is enough to use this form of energy.

The solar energy itself comes from nuclear reactions at its center where the temperature reaches 15 million ° C [3]. Sun energy is a resource that can be used in certain quantities of any state without import dependency, and it is of great importance that the very fact that environmental energy is purely energy whose energy technology does not pollute the environment in the process of transformation from the original form into a form suitable for use.

In the research literature, it is mentioned that Bosnia and Herzegovina have capacities of solar radiation 1240 $\frac{\text{kWh}}{\text{m}^2}$ from the north of the country to 1650 $\frac{\text{kWh}}{\text{m}^2}$ in the south of the country on an annual basis. Excellent conditions have been established for intensified utilization of such capacities, primarily from heat and power generation. The average for our region is 1300 $\frac{\text{kWh}}{\text{m}^2}$ per year, and the number of sunny days a year is 270 [4].

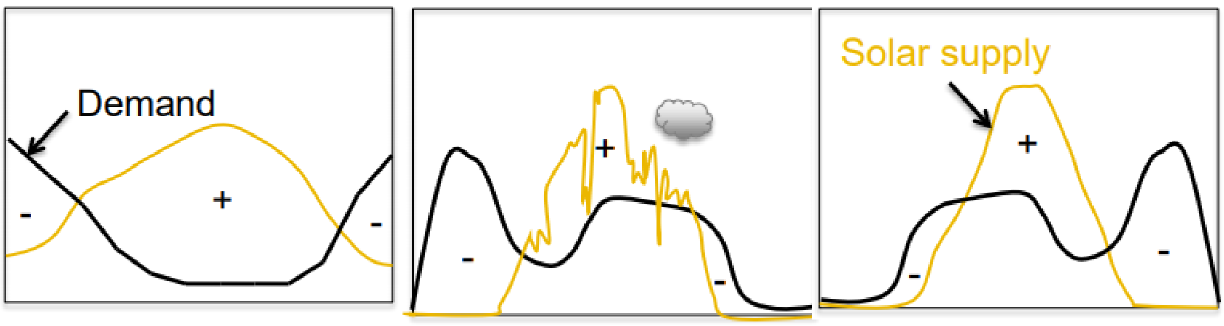
Comparing the solar potential of BiH with other European countries, such as Germany, Poland, Sweden and others, which significantly use solar energy, it can be seen that BiH has significantly higher capacity (10%-30%) annual solar radiation, but underutilized. According to the research, the potentials of solar energy in BiH are 75.5 million Gwh/per year – EVD, 2009.) [4]. “For six hours, the desert gets more energy from the sun than what mankind consumes for a year.” Dr. Gerhard Knies.

3. Energy storage

Since ancient times there was a human need for energy storage to be able to use it for later use. Initially, this need was very simple, and it can be said that was primitive because it has been based most on the history of collecting enough firewood for cooking and heating during cold days. Just in the 18th century the first central warm water preparation appeared in Sweden, and the first heating system appeared in England. With the development of central water preparation, there has been a need for its accumulation so that it is available throughout the day, regardless of consumption. That is the first sensory heat tank of hot water that appeared. Until today, heat storage technology has not changed significantly, but it is improved because better insulating materials are being used, as well as different heat storage materials, while heat storage methods are more developed. Great progress has been made in the use of heat tanks and they are not used today for the accumulation of hot water, but also for the accumulation of ice, storage of waste heat from various industries, and for leveling and prolongation of thermal power plants. As renewable energy sources have become extremely popular, but some of them are very useful because of ease of use and application, heat tanks have been found to be in use with them. Solar energy is used as a renewable source of energy for the direct production of electricity through photovoltaic modules and to produce heat energy that has so far been most used for the needs of hot water and space heating [5]. But solar thermal energy has also begun to be used in the last decades to produce electricity in solar thermal power plants that are built on locations with extremely warm climate, because although such plants are more complex than photovoltaic modules, higher temperatures have a better usability. Namely, the solar thermal power plants respond to hot climate and have no problems as photovoltaic modules where, with the rise in temperature, the usability of the module drops. Solar power plants have the disadvantage of working only with direct sunlight and must be oversized, so they can work with a shorter radiation intensity at least for a few hours a day. Hence, the idea was that this excess heat, which is always generated in solar collectors during the hours of the highest intensity of radiation, is stored in heat storage tanks for later use, thereby extending the plant's operation and becoming more resistant to an unexpected cloud [6][7].

3.1. Solar storage of heat energy

The heat exchanger is a device that serves for (temporary) heat storage on one temperature, or temperature for later use. Stored heat can be deliberately produced by heat, as it was economically produced at some point or saved only as a reservoir. There may be excess heat from the thermal power plant and is stored for prolonging the plant's operation or for faster start-up after the plant's shutdown or it may be the waste heat that the damage is thrown into the environment and stored. This stored energy can later be used for heating water and for heating rooms, or for producing electricity [8].



Daily fluctuations Seasonal Fluctuations Unpredictable fluctuations

Figure 1. Solar energy: fluctuations in different timescales [8]

3.2. Advantages

- Manage mismatch/shift between solar supply and energy demand
- Smooth production and safety issues
- Economic gain (needs to be checked for any storage project)
- Direct heat storage in isolated rigid bodies or fluids is possible even at low temperatures (theoretically T> 00 C), but the stored energy can only be used as heat (eg grited stones or bricks in bakeries burning with cheap electricity overnight)
- High-temperature heat storage can also be used as heat in industrial processes and for heaters (eg Sterling’s engine)

- Heat storage is very suitable for room heating (low temperature heat) but can also be used in conventional TEs and NOs which are the dominant installed capacities in EES

3.3. **Disadvantages**

- Finding a suitable way for fast heat transfer to and from the heat storage unit
- Reduction of heat losses so that the time when the heat is lost is much longer than the time of heat storage
- Heat losses from the central warehouse depend on the surface of the container with the heat storage medium and the total storage capacity depends on the volume of the container
- The surface is proportional to the dimensions of the container and the volume is proportional to the third stage of the container dimensions: large warehouses require relatively fewer insulation than small warehouses (proportional to the size of the warehouse)
- In small warehouses, the heat coefficient of heat is higher, so that relative heat losses are greater in the surrounding area
- The size of the warehouse is also important, so the possibilities of underground storage of heat for community needs over a longer period of time

So far, heat tanks have been most used in households (such as hot water tanks), but their application is growing in many other areas, especially in solar thermal power plants, because it is much cheaper to store heat than electricity with the current technology. Solar radiation is variable throughout the day, and the solar field never gives the constant thermal flow required for stable steam generator operation. For a steam generator to operate normally as long as solar energy is often overlapped, higher volumes of heat accumulate more heat than needed for project steam generating. This excess heat cannot be used in the steam generator so that the amount of heat obtained is regulated by the amount of excess released into the environment or a certain number of collectors removed from the working position. To exploit this excess heat, intuitive installation of a heat tank that intensifies this excess heat returns to the plant when there is no longer sufficient solar flow from the solar field and thus prolongs the drive and significantly increases the plant's profitability [9][10].

A thermodynamic system whose heat capacity is large enough to change heat with other system or environment maintains a constant temperature called heat tank. Its application is in storage of the heat energy that can be then used for hours, days, even months after storage. The capacity of the container depends on its size and the media that is in it, and the use of heat tanks can be suitable for supplying the individual process, more processes, buildings or even cities. Some examples of usage are balancing the energy demand during night and day, storage of heat during summer to use in winter, or storage of cold winter media for the needs of air conditioning in summer. The medium can be used for water, various saline solutions, earth mass, concrete or stone [11][12] .

By choosing the media, the heat tanks are divided into:

- Sensible heat storage
- Latent heat storage
- Sorption or thermochemical heat storage

4. Sensible heat storage

This is by far the most widespread way of accumulating heat. With accumulated growth heat in the medium is growing, as well as the temperature of the medium. The sensitive heat tank uses thermal material capacity during charging and discharging. The amount of accumulated sensitive heat (Q_s) is dependent on mass (m), specific heat capacity of material (C_p), and temperature difference with environment.

$$Qs = C_p \cdot m \cdot \Delta T \ \ (kJ)$$

Figure 1 depicts the dependence of temperature and accumulated heat in the material into which sensitive heat is stored. To be as efficient as possible, the material used for heat accumulation needs to have high thermal capacity, moderate conductivity, moderate density, and a great emissivity. As a material for sensitive heat tanks, most commonly are used solids (stone, brick, concrete) or liquid (water).

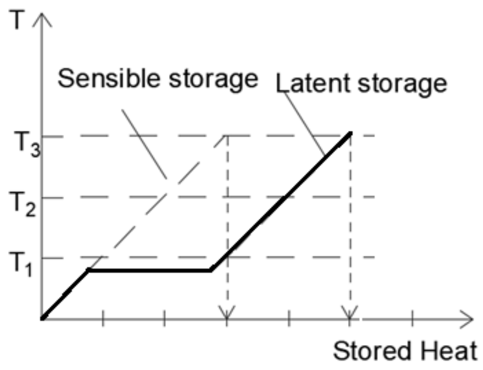


Figure 1 -Heat Accumulation Function in Time for Sensitive and Latent Containers [13]

Among the known materials, wood is not a good material for thermal mass. Furthermore, the heat in the wood cannot be carried in the interior of the material and stored for further needs. Steel, due to its density has good potential for use of accumulation heat but has a couple of shortcomings. First, the poor emissivity of the steel causes the large part of the heat to be reflected by the element rather than accumulated, and second, the good thermal conductivity of the steel is that the accumulated heat is quickly carried out from the core to the surface, where it is released into the room and shortens the charge and discharge cycle. The cycle duration is expressed in minutes, while in order to have the better effect of dampening the daytime oscillation of the temperature it takes to last hours.

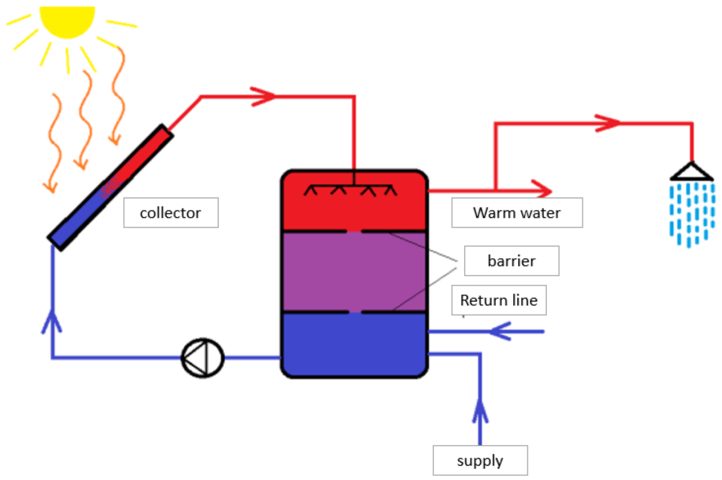


Figure 2. Thermoclective sensor with partitions [6]

It is important that the speeds of entry and discharge of the water are not large so that forcible mixing is as small as possible and thus keeps the warm fluid at the top allowing it to be used even though the whole container is not at the same temperature. Bottles are also installed in the tank, which further slow fluid mixing (Figure 2). Liquids that are used is water due to high thermal capacity, but the temperature is limited by the boiling temperature, so water and ethylene glycol mixtures are used because it is cheaper than using high-pressure tanks. Using oil reduces the cost of high-pressure pipelines required in sensitive water tanks if water is to be used at temperatures above 100 ° C, and the amount of expensive oil required is reduced by placing a cheap solid heat storage medium in the tank. The oil in the tank passes through layers of stone and gravel that serves to fill the holes or through the layers of earthen metals. Work on the same principle as the thermoclinic sensor with one medium only having a solid fluid in the tank.

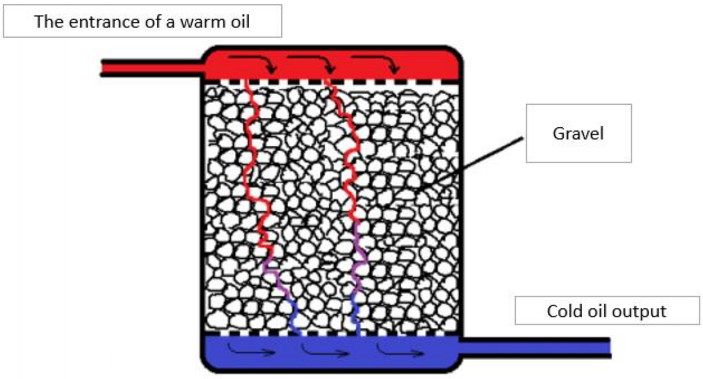


Figure 3. Thermoclac with mixed media [6]

The thermoclinic sensor tank with mixed media can use heat transfer air instead of oil. Solar collectors are not used, but solar cells with air passages [6]. The air passes through the heated solar cell by cooling it and improving its usability, as their usability decreases with rising surface temperatures. The boiled air goes to a tank where it flows through a layer of gravel and sand. Accumulated heat can be used to heat up space or get hot water.

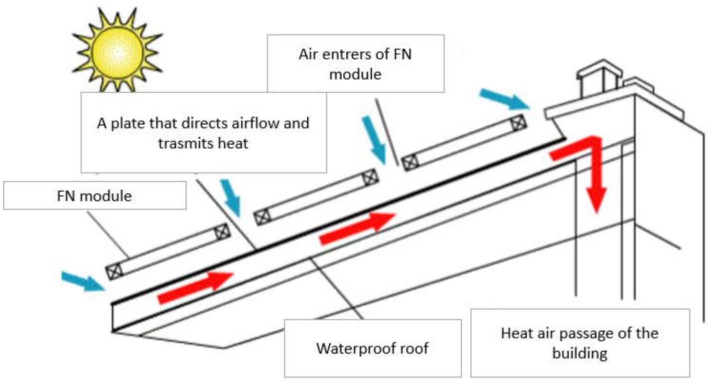


Figure 4. Photovoltaic air-cooled modules [6]

Sensor containers with multiple tanks are connected to the system via a heat exchanger. There are usually two tanks where the first is for the warm fluid and the other for the coolant fluid. When charging the cold fluid through the chiller, it warms up and goes to the other tank, and when it is discharged, it is reversed. For high temperatures, containers with special liquids or with molten solids are used. Residual salts must be kept muddy always because they are at ambient temperature, which is a problem, as they must be equipped with heaters and use energy. Solid temperatures such as silicate and magnesium bricks or molten metals are used for maximum temperatures, but they can only be used in solar towers and solar plates, power plants that concentrate light on a small surface and achieve high temperatures [14].

Materials:

Glass also has a high potential for a thermal tank but is relatively clear for infrared radiation and much of the radiation is just passing through it or reflecting on the surface. By adding pigments, especially blue and green to the glass, the possibility of absorption of radiation increases, which may be a problem during the cooling season. In both cases, for glass and steel, the thickness required for the material to efficiently perform its role of thermal mass is large, the element is difficult and expensive and therefore not a convenient choice for heat accumulation.

Concrete and other massive materials are very good. They have great thermal capacity, moderate thermal conductivity that allows the heat to pass deep into the element and keep it there. High emissivity allows the bulk of the radiation to accumulate in the element and reflect only a small part. It is also possible that concrete or stone can serve in the building and at the same time accumulate and storage heat, while preserving bearing capacity and structure function.

Water also very efficiently accumulates heat and has great potential for storing heat. The water problem, unlike concrete, is that water cannot have any structural function in the building, therefore creates an additional burden on the building. If water is installed in transparent containers, it can provide light and / or look through the thermal mass.

Gases have very little use as sensible heat tanks because they have very low volumetric heat capacity [15].

Sometimes, for the effective behavior of heat tanks and their function in the building, significant thickness of the element is required, and some of the materials, together with the sanitary thermal capacities, are shown in the Table 1 [16][17].

Table 1. Selected material properties

MATERIALS	DENSITY (Kg / m3)	SPECIFIC THERMAL CAPACITY (J / kgK)	VOLUMETRIC THERMAL CAPACITY (106 J / m3K)
Clay	1458	879	1,28
Brick	1800	837	1,51
Sandstone	2200	712	1,57
Wood	700	2390	1,67
Concrete	2500	1000	1,76
Glass	2710	837	2,27
Aluminum	2710	896	896
Iron	7900	452	3,57
Steel	7840	465	3,68
Magnesium	5177	752	3,89
Water	988	4182	4,17

Figure 5. Solar thermal power plant in Grenada, Andosol [18]

Figure 6 shows solar thermal power plants in Spain. In the foreground, there are two-dimensional sensors with indirect storage in which salt is dissolved. One container serves to store a hot salt and the other for cold storage. In the plant description it is stated that the heat tanks are dimensioned for a 7.5-hour drive extension, and this requires 30,000 tons of dissolved salt. Behind them, the collector field is visible from the flow of parabolic collectors[19][20].

5. Latent heat storage

Latent heat storage is based on the accumulation of heat during the melting process, from solid state to liquid or evaporation, from liquid to gaseous and heat release in the reverse case. Accumulated heat (Q_1) in this case is calculated as a specific heat of fusion (q_s) and mass (m).

$$Q_1 = q_s \cdot m \text{ (kJ)}$$

Such containers accumulate a large amount of heat in themselves without major changes to their own temperature. Heat accumulation occurs at the transition from the solid state to the current, from liquid to gaseous and transition from solid to solid state.

For practical reasons we are interested in transition from solid to liquid and from rigid to solid state. Gaseous fluctuations are usually associated with the storage problem, and even with convenient storage in the tank, high pressures are reached so that it goes beyond the limits of practicality. Such containers, though they have great potential, are still used in very small percentage. There is also a problem with storage in large quantities. This arises from the fact that some of the materials are still unexplored. Furthermore, in most cases storage elements do not have any other application in the building, such as a concrete wall that serves as a load-bearing wall and at the same time also has very good thermoaccumulative properties [21].

Materials that migrate from solid to liquid state are usually called latent heat containers, or even phase-change materials. Blending solids is characterized by a volumetric change of less than 10%. The material is embedded in the form with the larger one by volume, usually in liquid state, to eliminate the occurrence of pressure changes conditions. In the melting phase, a certain amount of heat is accumulated and is called enthalpy transition. Despite the accumulated heat, the material temperature remains relatively constant temperature. Then we talk about the latent heat accumulated by the material. Similarly, pry the return from the liquid state to the solid, the accumulated latent heat is released, also at relatively constant temperature.

Figure 1 shows the graph of the function between accumulated heat depending on the temperature of the material.

Some transitions from solid to solid have the same characteristics as transition from solid to liquid, but do not include such a large enthalpy of transition. In such a case, the heat accumulates when the material is transferred from one crystal to the other.

Latent heat tanks are more attractive than sensible heat tanks for less material density and higher thermal capacity with, at the same time, minor in changes temperature. In latent heat accumulation there are some practical problems with poor management heat and variable physical-thermal properties after a certain number of cycles. Also, there is also a problem with the incorporation of phase-changeable materials[22] [16].

Some of the types of materials used in accumulating latent heat exchangers:

• Hydrate inorganic salts

• Alcohols, polyether polyols, fatty acids and fatty acid esters

• Organic PCM - paraffin and alkane blends

• Eutectic mixtures of various materials

6. Thermochemical thermal containers

Heat in such elements accumulates in the form of reversible chemical reactions. The first part of the process is the endothermic reaction of the reactants which takes place due to application of energy desired to be accumulated. The second part is the storage of the product, and the third discharge of the heat in an exothermic reaction. The materials can be organic or inorganic, it is only essential that the chemical reaction is free and saves heat, and the reaction is reversible. In principle, the operation of a chemical tank is not different in the principle of emptying and filling, but only in the heat recovery mode [16][23].

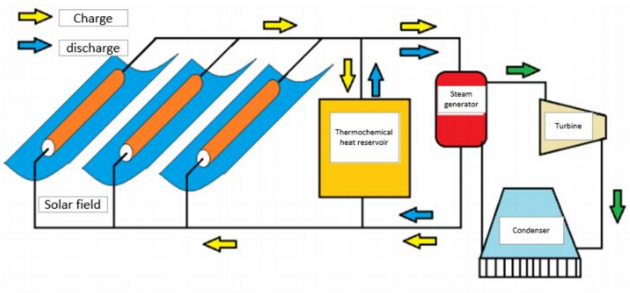


Figure 6. Schematic representation of thermal power plant operation with chemical storage [24]

7. Criteria for design

Which type of tank will be used depends on the available temperature range for storage and use of heat, tank capacity, i.e. size, heat losses from the tank, charging times and use of stored energy and tank price. There are three main criteria for designing solar thermal energy storage that should be considered in design:

- technical properties,
- cost effectiveness and
- environmental impact

Good technical properties are important factors to ensure the technical feasibility of a solar thermal energy system. The technical criteria include a high heat storage capacity and it can be said that it is the most important, then the heat transfer coefficient with the heat transfer fluid (liquid that is heated in the solar collector and transfers the heat to the vapor generator or heat tank) to the material heat storage because it does not have to use the same substance for storing and transferring heat. The technical criterion is often the deciding criterion when constructing or purchasing a tanks tank then comes in another plan [24] [25].

Cost effectiveness determines the payoff period of the investment, and therefore is very important. The cost of a solar thermal energy storage system mainly consists of three parts: storage material, heat exchanger and land cost. Cost effectiveness is usually connected with the technical properties because high thermal storage capacity and excellent heat transfer performance can significantly reduce the system volume.

Behind technical properties and cost effectiveness, there are other criteria that should be considered, such as operation strategy and integration to a specific power plant.

Heat storage material should have good mechanical and chemical stability, should not be aggressive to the material of the heat exchanger or to the heat transfer fluid if they come into contact. The full reversibility is required when filling and emptying the container, ie the material must not degrade in this temperature interval during a certain number of cycles. The container must be well insulated, and the insulation of the material will waste a significant part of the container price. The use of the container must be simple and preferably automated so that it can respond quickly to changes in the thermal flow of the system. When considering economics, it wants to achieve as low price as the whole product. Consequently, the costs of storing heat energy should be as low as possible, thinking of the operating costs and the general investment needed for that additional system. From the materials for making tanks and heat storage materials is expected to have lower prices and availability. It has already been stated that the tank's thermal capacity is one of the determining factors because it depends on the size of the container and what is more it will require less space and the costs associated with land price will be smaller. The impact of the container on the environment must be as small as possible. This is to say about heat storage materials that can be toxic and environmentally-friendly and flammable. If substances are environmentally hazardous, protection systems are required [26][27].

8. Heat exchangers in solar power plants

Solar thermal power plants are now the most widely used, and the most commonly used salt blend is NaNO3 - KNO3 (60%, 40%). These are large containers that can store heat for several hours of power plant operation and are mostly used with two tanks. The solar thermal power plant's developmental flow tends to reduce storage capacity and increase capacity:

- Two containers with direct storage
- Two containers with intermediate storage
- Thermoclin tenk
- Latent tank and chemical, which is only in the experimental phase

The first Solar Power Plant with two direct storage tanks in California's "Solar Energy Generating System I", synthetic oil was also used as a heat transfer fluid and as a heat storage medium. The oil from the hot tank goes to the vapor generator where steam generates and cools down into a cold tank from which it can later return to the system, ie back to the heating collectors. Such a design does not have a heat exchanger, and because of the two tanks, it is eliminated by the lack of sensor tanks to drop tank temperature during discharge, the input temperature of the fuel fluid to the vapor generator causing the steam parameter to decrease. "The Solar Two" is a solar tower that works on the same principle but instead of oil as a fluid for heat transfer, it is a mixture of dissolved salts, allowing higher process temperatures [28].

Two intermediate storage tanks are the most widely used heat exchangers. These are expensive because of the need for a heat exchanger in which the heat transfer fluid supplies heat to the heat storage material [29].

Thermo containers are the cheapest because they use cheap heat storage materials, such as stone and bricks, but have a low density of heat storage and are therefore poorly represented. At present, mostly latent heat tanks are being investigated, especially with more materials of different melting and liquid salts used to transfer and store sensitive heat. In latent containers, solutions are required to increase the thermal conductivity to at least 2 W / mK, and new materials, especially nitrate and nitrite salts and their eutectic mixtures, are tested and the same salts are also tested as heat transfer materials. By perfecting parabolic liquid salt flow collectors due to higher working temperatures put off thermal oil from use, resulting in significant improvements to solar power plants. Liquid salts can be used up to 550 ° C and as they are used for heat transfer and storage, while the heat exchanger between the containers is no longer needed. Due to higher temperatures, less storage materials are needed, and the entire process can be utilized, up to 6% compared to the two-indirect storage tank [30][31]**.** The most widely used salt for heat transfer is $NaNO_3$ - KNO_3 (60%, 40%) because it is most tested and many long - term applications have known properties, life expectancy and stability. The properties of mixtures and eutectic mixtures of the KNO_3, $LiNO_3$, $NaNO_3$, $NaNO_2$, KNO_2 salts are sought, and combinations are sought with the lowest melting temperature to reduce the risk of sealing in the pipes and combinations are obtained with as much as 83 ° C with a melting temperature [32]. These salts also have high latent heat, but due to the low phase conversion temperatures for this observed power plant, they are not suitable because they could only be used as sensory tank.

Passive Solar Architecture refers to the use of sun for heating and cooling of the living space using accumulated heat. Passive systems are simple, have few moving elements, require minimal maintenance and do not require any mechanical sensors. The fundamental principle of passive use of solar energy is that the house opens towards the sun and uses its energy [33].

9. Conclusion

The goal of passive solar systems is to take solar heat into building elements and to release it during periods when there is no sun. At the same time, building elements (or materials) accumulate heat for later use and are available to keep the room comfortable but not overheated. Requirements and approaches for passive solar heating can be listed as follows:

Requirements for passive use of solar energy:

- Glazed facades facing the south.
- Use of heavy materials (thermal mass) for absorbing and distributing heat.
- The length of the building should be placed on the east-west axis.
- The south side of the building should receive solar radiation between 9:00 am and 3:00 pm in progress heating season.
- Frequently used rooms, which require the more light, heating and cooling, need to be placed in the south of the building. Less used rooms in the north.
- The open floor panel optimizes the effect of thermal energy capture.
- Using a shade to reduce the effect in the summer.

Approaches to passive systems:

- Direct intervention
- Indirect operation (Thrombe wall)
- Insulated grip (greenhouse)

Accumulated heat is of great importance for all systems of passive solar energy extraction, as well as in active heating and cooling systems of the building and in some models of passive cooling of the building. It is often used to optimize the effect of energy savings in buildings that primarily rely on mechanical heating and cooling.

References

[1] Schnürer, H., Sasse, C., & Fisch, M. N., " Thermal Energy Storage in Office Buildings Foundations," [Online]. Available: https://intraweb.stockton.edu/eyos/energy_studies/content/docs/FINAL_PAPERS/11A-4.pdf. [Accessed 15 November 2018].

[2] THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, "EUR Lex," 23 April 2009. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN. [Accessed 10 November 2018].

[3] "İzvori energije," unicef, [Online]. Available: http://www.izvorienergije.com/energija_sunca.html. [Accessed 10 November 2018].

[4] Nurdin Čehajić, "Hrčak portal znanstvenih časopisa Republike Hrvatske," 2013. [Online]. [Accessed 10 November 2018].

[5] Jensen, M. V, "Seasonal pit heat storages," *Guidelines,* 2014.

[6] Tian Y., Zhao C.Y., "A review of solar collectors and thermal energy storage," *Applied Energy 104,* pp. 538-553, 2013.

[7] A. S., "Archimede solarenergy," 24 August 2014. [Online]. Available: http://www.archimedesolarenergy.it/molten_salt.htm. [Accessed 14 November 2018].

[8] European Commission, "Hoirzon 2020 Work Programme," *General Annexes . Brussels.,* 2014-2015.

[9] Castell, A., Solé, C., Medrano, M., & Nogués, M., "Comparison of Stratification in a Water Tank," *Journal of Solar Energy Engineering,* p. 131, 2009.

[10] Eames, P., Loveday, D., Haines, V., & Romanos, P, "The Future Role of Thermal Energy Storage," *An assessment of the technical feasibility and factors influencing adoption,* 2014.

[11] Herrmann, "Survey of Thermal Energy Storage," in *Journal of Solar Energy Engineering,* Kearny, D. W., 2002, pp. 124,145-152.

[12] David Dunand Research Group, "Northwestern University," 25 August 2014. [Online]. Available: http://dunand.northwestern.edu/research/index.shtml ,. [Accessed 13 November 2018].

[13] B. Durakovic, PCM-Based Building Envelope Systems: Innovative Energy Solutions for Passive Design, Basel: Springer Nature Switzerland AG, 2020.

[14] " Pyro.co.za.htm," 28 Nisan 2014. [Online]. Available: http://www.pyrometallurgy.co.za/ .

[15] Sibbitt, B., & McClenahan, D., " Seasonal Borehole Thermal Energy Storage-Guidelines for materials & construction," 2015. [Online]. [Accessed 15 November 2018].

[16] Koški, Ž. i Zorić, "Akumulacija sunčeve energije," in *Elektronički časopis građevinskog fakulteta Osijek*, Osijek, 2010, p. 10.13167/2010.1.8.

[17] Kos, Ž, "Fazno promjenljivi materijali," in *Tehnicki glasnik*, Osijek, 2013, pp. 202-205.

[18] "DLR Portal Solar thermal power plants," [Online]. Available: http://www.dlr.de/en/desktopdefault.aspx/tabid-5105/8598_read19485/8598_page-2/gallery-1/gallery_read-Image.1.10817/. [Accessed 13 November 2018].

[19] Solar thermal power plants, "Over 500 experts expected at leading conference Berlin," [Online]. Available: http://www.dlr.de/en/desktopdefault.aspx/tabid-5105/8598_read19485/8598_page-2/gallery-1/gallery_read-Image.1.10817/.

[20] Kuravi S., Trahan J., Yogi Goswami D., Rahman M. M., Stefanakos E. K, "Thermal energy storage technologies and systems for concetrating solar power plants," *Progress in Energy and Combustion Science,* vol. 39, pp. 285-314.

[21] ITW Stuttgart, "Seasonal Thermal Energy Storage," 2008. [Online]. Available: : http://www.itw.unistuttgart.de/dokumente/Publikationen/publikationen_08-08.pdf. [Accessed 14 Novembar 2018].

[22] A-to-Z, "Guide to Thermodynamics, Heat & Mass Transfer," 18 February 2014. [Online]. Available: http://www.thermopedia.com/content/841/ . [Accessed 14 November 2018].

[23] Sibbitt, B., McClenahan, D., Djebbar, R., Thornton, J., Wong, B., Carriere, J., & Kokko, J. , " The Performance of a High Solar Fraction Seasonal Storage District Heating System," *Energy,* vol. 30, p. 856–865.

[24] Gil A, Medrano M, Martorell I, Lázaro A, DoladoP, ZalbaB, Cabeza LF, "concepts, materials and modellization," in *State of the art on high temperature thermal energy storage*, 2010, p. Part 1.

[25] Sunstore , "Project Evaluation Document".

[26] Ullrich, S. , "Versorger Trend: Nahwaermenetze," *Erneuerbare Energien*, pp. 54-57, 2015.

[27] BINE Informationsdienst, "Aquiferspeicher fur das Reichstagsgebäude," [Online]. Available: http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2003/Projekt-Info_13-.

[28] Hendriks, M., Snijders, A., & Boid, N., "Underground Thermal Energy Storage for Efficient Heating and Cooling of Buildings," 2008. [Online]. Available: https://iftech.co.uk/files/Article3_IFTech31March08-ADK91v.pdf. [Accessed 15 November 2018].

[29] Gao, L., Zhao, J., & Tang, Z. , " A Review on Borehole Seasonal Solar Thermal Energy Storage," *Energy Procedia,* vol. 70, pp. 209-218, 2015.

[30] "Archimede Solar Energy," 24 August 2014. [Online]. Available: http://www.archimedesolarenergy.it/molten_salt.htm . [Accessed 13 November 2018].

[31] Longeon M., Soupart A., Formigu J-F., Bruch A., Marty P, "Experimental and numerical study," *Applied Energy,* pp. 175-184, 2013.

[32] [Online]. Available: Pyro.co.za.htm http://www.pyrometallurgy.co.za/ .

[33] Bergan, P. G., & Greiner, C. J., "A New Type of Large Scale Thermal Energy Storage," *Energy Procedia,* vol. 58, p. 152–159, 2014.