BULGARIAN ACADEMY OF SCIENCE
Institute of Information and Communication Technologies
25A Acad. G. Bonchev Street
1113 Sofia, Bulgaria
e-mail: iict@bas.bg

A B S T R A C T

of a

D I S S E R T A T I O N   T H E S I S

For a scientific-educational degree "Doctor"

INTELLIGENT MANAGEMENT OF THERMAL ENERGY SAVING SYSTEMS

Author: Milena Biserova Haralampieva

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Ph.D. Supervisor: Prof. Eng. Dimitar Karastoyanov, Ph.D.

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Chapter I. Energy sources type overview, analysis and systematization.

1.1. Energy storage systems nature and benefits

Energy supply and demand determine the course of global development in every field of human activity. Finding energy sources to meet the growing demand in the world is one of the main challenges of society in the next half century.

The most important directions in the development of methods and tools for energy management are the creation of economical, efficient technologies for energy storage and heat generation, as well as the creation of energy-saving technologies and application of materials and equipment that provide longer service life.

There are a number of methods for energy storage, and their use depends on factors such as purpose, resource, technical capability and more. From an economic point of view and due to the increasing energy efficiency requirements, their demand and research in their improvement are constantly increasing. Their use is extremely suitable for areas where the emphasis is on the production of energy from renewable sources such as sun and wind, as they create an opportunity to optimize production by ensuring a constant supply, despite the periodic source nature.

Intelligent management of energy storage systems leads to increased energy efficiency of both the systems themselves and the fields of integration, which in turn leads to:

- Environmental benefits
- Economic benefits

1.2. Energy

Energy is a scalar physical quantity that describes the ability of a system to change the state of its environment or to perform work. It exists in various forms, such as motion, heat, light, electrical, chemical, nuclear energy and gravitational. Total energy is the sum of all energy forms of the system.

1.3. Energy types

Primary and secondary types of energy are the two main types as shown in Figure1.1. Primary energy is extracted or captured directly from the environment, while the secondary energy is converted from the primary energy in the form of electricity or fuel. Distinguising the primary and secondary energy sources are important in the energy balances to count and record energy supply, transformations, and losses.

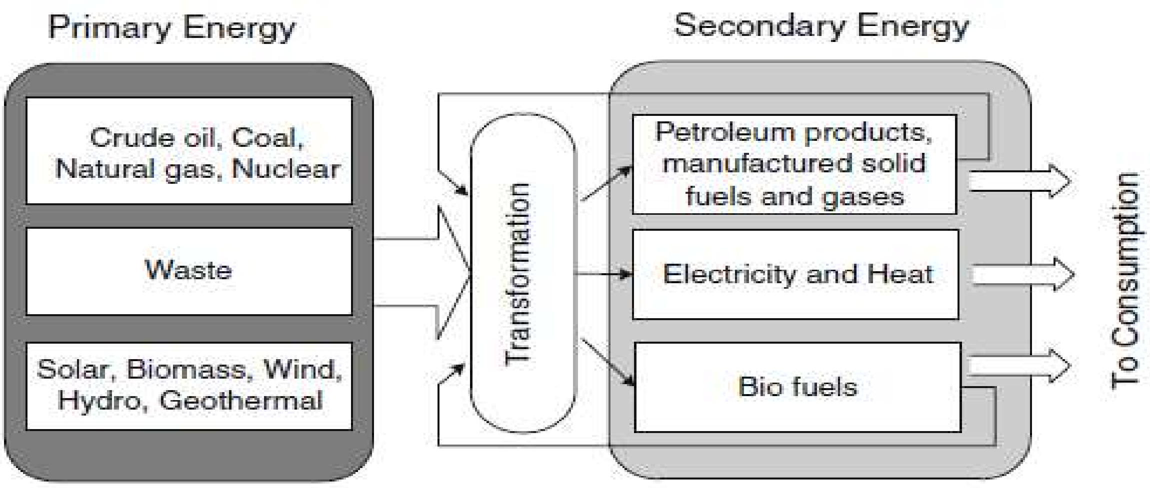


Figure 1.1 Primary and secondary energy types

1.4. Nonrenewable energy sources

It is generally accepted that nonrenewable energy sources or fossil fuels are formed from the remains of dead plants and animals by exposure to heat and pressure in the earth's crust over the millions of years. Major nonrenewable energy sources are:

- Coal
- Petroleum
- Natural gas
- Nuclear

Fossil fuels contain high percentages of carbon and include mainly coal, petroleum, and natural gas. Natural gas, for example, contains only very low boiling point and gaseous components, while gasoline contains much higher boiling point components. The specific mixture of hydrocarbons gives a fuel its characteristic properties, such as boiling point, melting point, density, and viscosity. These types of fuels are known as nonrenewable energy sources.

1.5. Renewable energy sources

Renewable energy comes from natural resources and are naturally replenished. Major renewable energy sources are:

- Hydroelectric
- Solar energy

- Biomass
- Wind
- Geothermal heat
- Ocean

In its various forms, renewable energy comes directly from the sun, or from heat generated deep within the earth. In 2008, about 19% of global final energy consumption came from renewables, with 13% coming from traditional biomass, which is mainly used for heating, and 3.2% from hydroelectricity. Other renewables, such as small hydro, biomass, wind, solar, geothermal, and biofuels contributed around 2.7% and are growing rapidly.

1.6. Hydrogen

Hydrogen is the simplest element. Each atom of hydrogen has only one proton. The sun is basically a giant ball of hydrogen and helium gases. In the sun's core, hydrogen atoms combine to form helium atoms (called fusion process) and gives off radiant energy. This radiant energy sustains life on earth as it drives the photosynthesis in plants and other living systems, and is stored as chemical energy in fossil fuels.

Hydrogen does not exist on earth as a gas and is found only in compound form with other elements, such as water H2O and methane CH4. Hydrogen is produced from other resources including natural gas, coal, biomass, and even water. The two most common production methods are steam reforming and electrolysis in which the water is split into oxygen and hydrogen. Steam reforming is currently the least expensive and most common method of producing hydrogen, while the electrolysis is an expensive process.

1.7. Electric energy

The protons and electrons of an atom carry an electrical charge. Protons have a positive charge (+) and electrons have a negative charge (-). Opposite charges attract each other. The electrons in an atom's outermost shells do not attract strongly to the protons and can move from one atom to another and create electricity. The amount of electricity a power plant generates or a customer uses over a period of time is measured in kilowatt hours (kWh), which is equal to the energy of 1000 watts working for 1 h.

Most of the electricity used in the residential sector is for air conditioning, refrigerators, space and water heating, lighting, and powering appliances and equipment. Electricity is the fastest growing form of end-use energy worldwide and it is the most well-known energy carrier to transfer the energy in coal, natural gas, uranium, wind power, and other energy sources to homes, businesses, and industry. For many energy needs, it is much easier to use electricity than the energy sources themselves.

1.8. Magnetic energy

There is no fundamental difference between magnetic energy and electric energy: the two phenomena are related by Maxwell's equations. The potential energy of a magnet of magnetic moment m in a magnetic field B is defined as the work of magnetic force (magnetic torque).

1.9. Chemical energy

Chemical energy results from the associations of atoms in molecules and various other kinds of aggregates of matter. It may be defined as a work done by electric forces that is electrostatic potential energy of electric charges. If the chemical energy of a system decreases during a chemical reaction, the difference is transferred to the surroundings in the form of heat or light. On the other hand, if the chemical energy of a system increases as a result of a chemical reaction, the difference then is supplied by the surroundings in form of heat or light. Typical values for the change in molar chemical energy during a chemical reaction range from tens to hundreds of kilojoules per mole.

1.10. Energy and global warming

The burning of fossil fuels produces around 21,3 Gigatons of carbon dioxide per year, and natural processes can only absorb about half of that amount, so there is a net increase of 10,65 billion tons of atmospheric carbon dioxide per year.

One tonne of carbon is equivalent to: MW_{CO2} / MW_C = 44/12 = 3,7 tons of carbon dioxide.

1.11. Energy balances

Figure 1.2 shows an open system with mass and energy interactions with its surroundings.

- with no internel source of changing mass and energy;
- with an internal source of changing mass and energy.

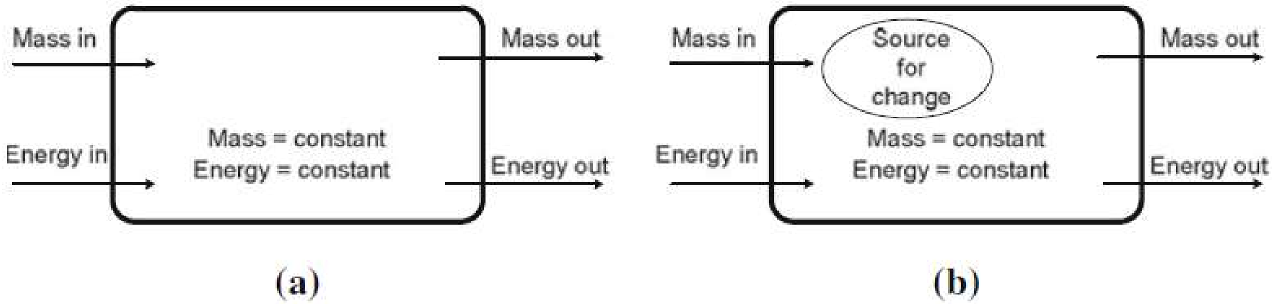


Figure 1.2 (a). An open system with no internal source of changing mass and energy. (b) An open system with internal source of changing mass and energy, entropy and exergy.

Thesis purpose and tasks:

Purpose:

The main thesis purpose is an Innovative approaches development to improve solar heat storage systems.

To achieve this purpose, the following tasks will be solved:

Tasks:

1. A detailed overview, analysis and systematization of the energy sources types will be made
2. An overview of existing methods and tools for research and management of energy storage sources will be made
3. Innovative approaches to thermal energy storage will be explored and an innovative approach based on phase change materials will be proposed.
4. An innovative combined system for heat storage and heat supply in a building will be developed
5. Experiments and simulations will be performed (experimental calculations and technical and economic analysis will be made) with the proposed approaches and the developed systems
6. The results will be tested

Chapter II. Existing methods and tools for energy storage sources research and management

2.1. Energy storage methods

For many energy technologies, storage is a crucial aspect. If we consider the storage of fuels as the storage of the energy embedded in them, then oil is an excellent example. The massive amounts of petroleum stored worldwide are necessary for the reliable, economic availability of gasoline, fuel oil, and petrochemicals.

Compressed air and pumped hydroelectric systems are two of the most widely used methods for long-term storage of electricity.

Thermal energy saving system's energy is accumulated when its production exceeds its consumption, and its access is provided by consumers when necessary. These systems keep energy supply and consumption to be in accordance, to balance the variable nature of renewable energy, to increase overall efficiency, and to reduce carbon dioxide emissions.

An energy storage system is usually characterized by: capacity, power, efficiency, storage period, charging / discharging time and price. Capacity, power and discharge time are interdependent variables. For example, in thermal energy storage systems (TES), high power means increased heat transfer (additional fins of the heat exchanger), which, for a certain volume, reduces the amount of material for active storage and thus reduces the capacity.

Thermal energy can be stored in the form of heat content in a storage medium, latent heat associated with phase changes of materials, or as thermochemical energy associated with chemical reactions occurring at temperatures from - 40 °C to above 400 °C.

Advanced new storage devices are often an integral part of other new technologies and can sometimes become more feasible through storage innovations. Advances in storage are beneficial, especially in wind and solar technologies. Also, new storage technologies can contribute a lot to the development of electric cars.

Energy storage methods can classify into several groups (Figure 2.1).

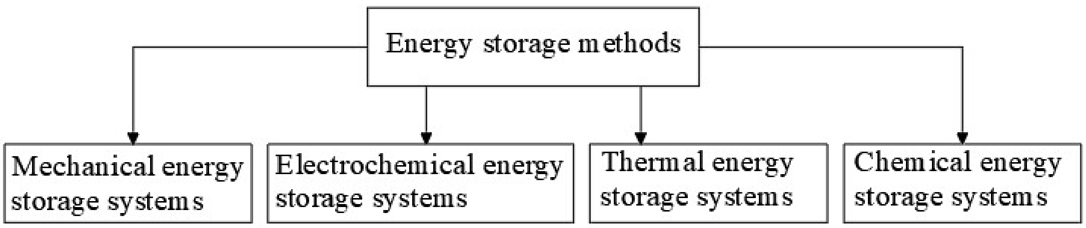


Figure 2.1 A classification of energy storage methods

2.1.1. Mechanical energy storage systems

Mechanical energy may be stored as the kinetic energy of linear or rotational motion, as the potential energy in an elevated object, as the compression or strain energy of an elastic material, or as the compression energy in a gas. It is difficult to store large quantities of energy in linear motion because one would have to chase after the storage medium continually. However, it is quite simple to store rotational kinetic energy. There are three main mechanical storage types: hydrostorage (Figure 2.2), compressed-air storage (Figure 2.3), and flywheels (Figure 2.4).

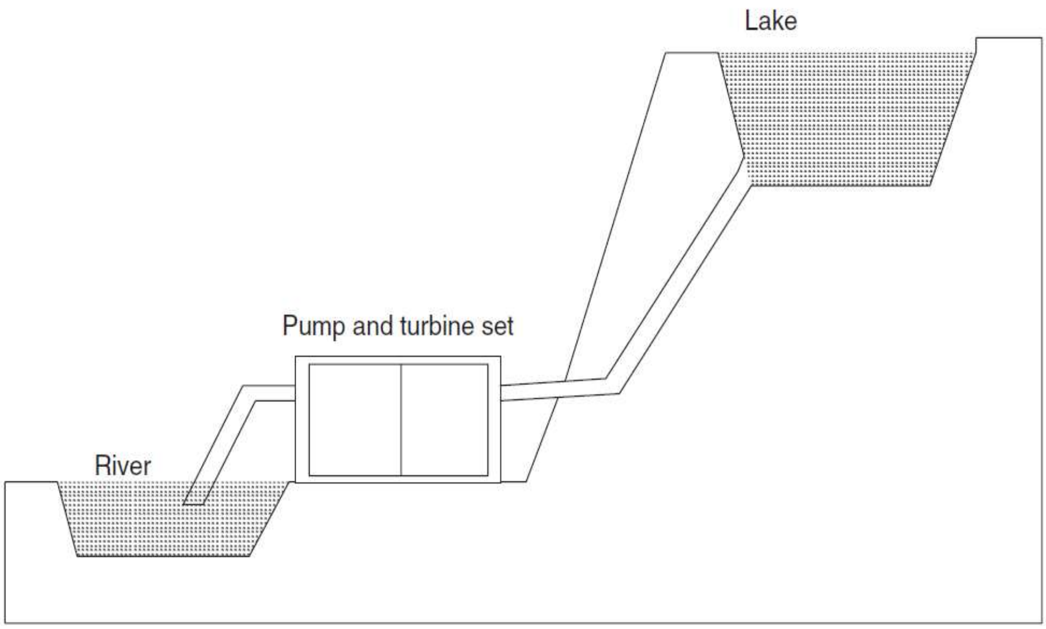


Figure 2.2 A pumped hydfostorage plant

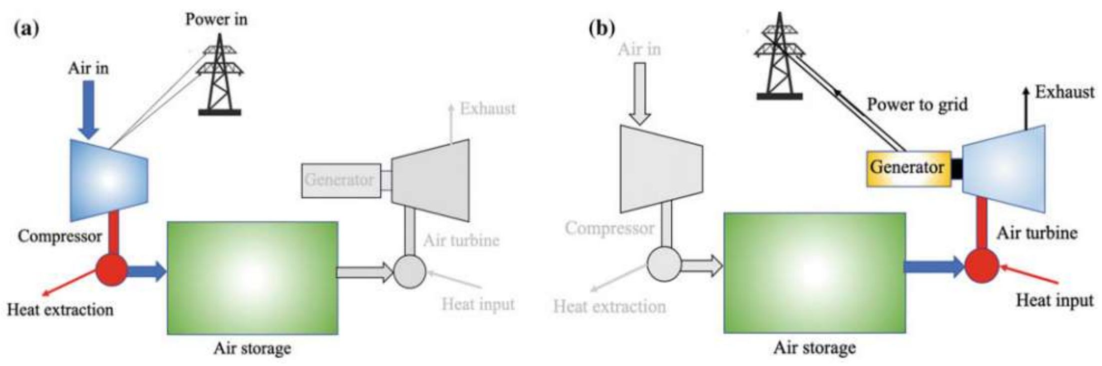


Figure 2.3 (a) Compressed-air system in charging mode; (b) discharging mode

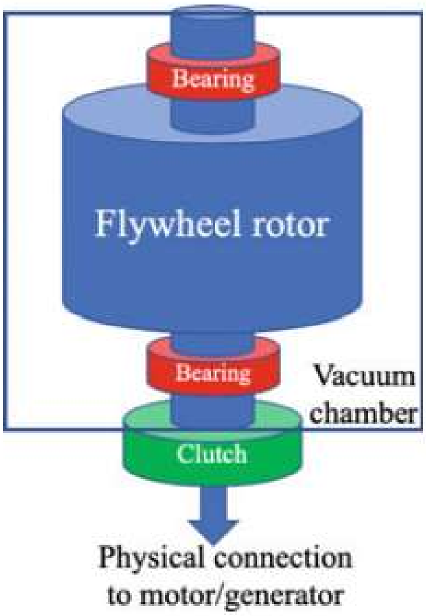


Figure 2.4. Main components of a flywheel energy storage system

2.1.2. Electrochemical energy storage systems

Energy may be stored in systems composed of one or more chemical compounds that release or absorb energy when they react to form other compounds. The most familiar chemical energy saving device is the battery.

The lead–acid battery operates on the principle of the galvanic cell. A single-cell battery consists of two electrodes immersed in an electrolyte (Figure 2.5).

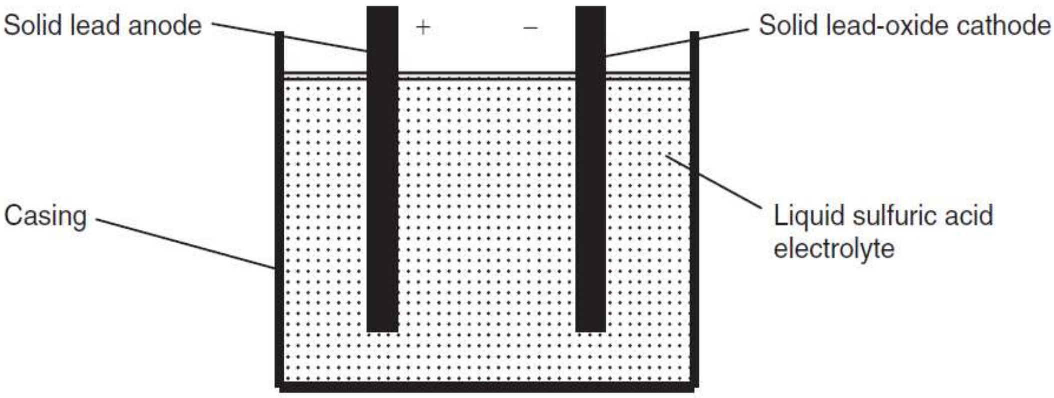
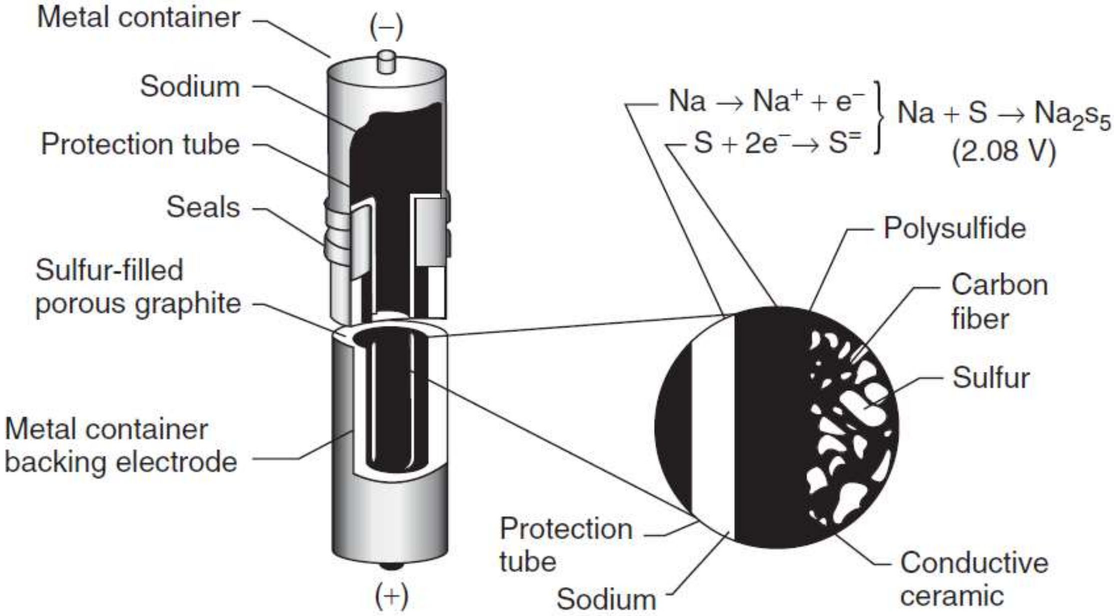


Figure 2.5. Schematic of a liquid-acid battery

The Na–S battery (Figure 2.6) requires high-temperature operation.



Фигура 2.6 High-temperature sodium–sulfur battery

2.1.3. Thermal energy storage systems

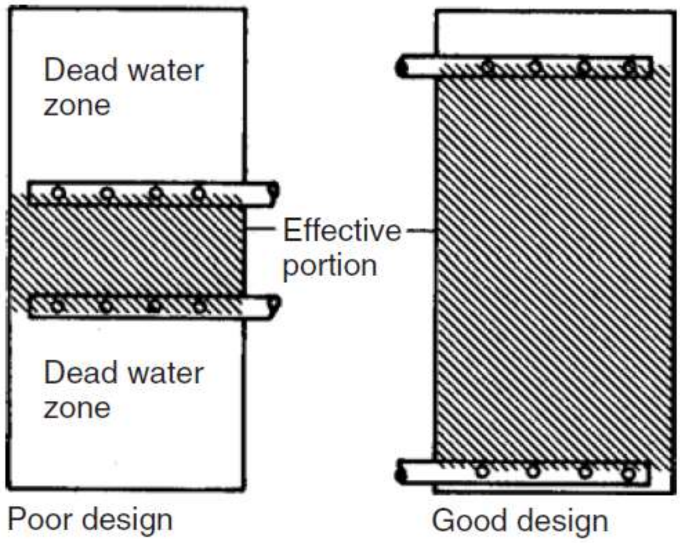
Thermal storage systems can store heat or cold to be used later in various conditions such as temperature, location or power. These systems are divided into three types: Sensible Heat Storage Systems, Latent Heat Storage Systems, and Thermochemical Heat Storage Systems.

Thermal energy saving (TES) tanks for use in heating, air-conditioning, and other applications have, in general, received increasing attention in recent years. Thermally stratified storage tanks have seen more widespread use recently (Figure 2.7).

Other commonly used materials in Sensible Heat Storage Systems are rocks and water. Rock is an inexpensive TES material from the standpoint of cost, but its volumetric thermal capacity is much less than that of water. The advantage of rock over water is that it can easily be used for TES above 100 ◦C. Rock-bed and water storage types can both be utilized in many ways (Figure 2.8).

Figure 2.9 illustrates the operating principle of simple Aquifer Thermal Energy Storage (ATES) systems.

Solar ponds differ in several ways from natural ponds. Solar ponds are filled with clear water to ensure maximum penetration of sunlight. The bottom is darkened to absorb more solar radiation. Salt is added to make the water denser at the bottom and to inhibit natural convection. The cooler water on top acts as insulation and prevents evaporation. Salt water can be heated to high temperatures, even above the boiling point of fresh water (Figure 2.10).



Фигура 2.7 Position of inlet and outlet for a thermally stratified TES tank

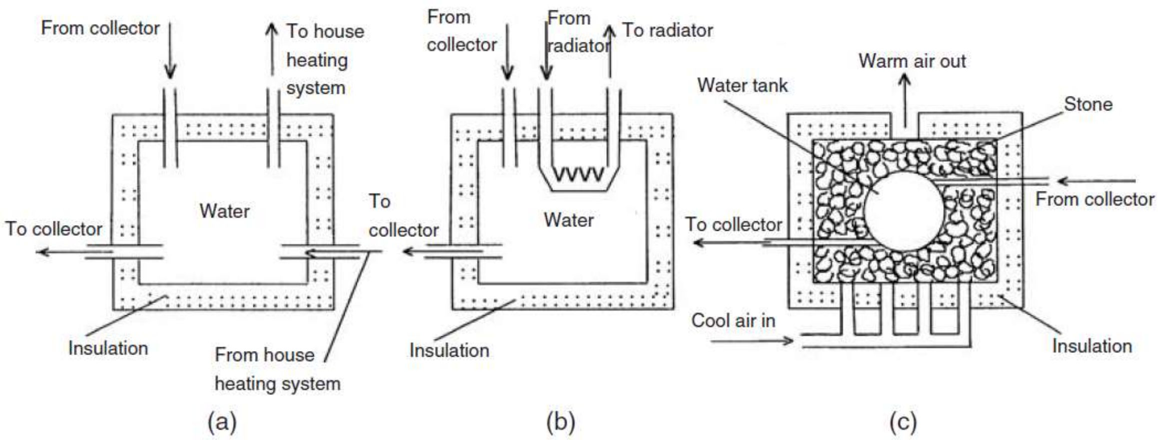


Figure 2.8 Solar storage tanks: (a) heat storage tank directly tied to both the collector and the house heating system, (b) sensible TES system using a heat exchanger to extract solar heat from a storage tank, and (c) using water and stone as storage media

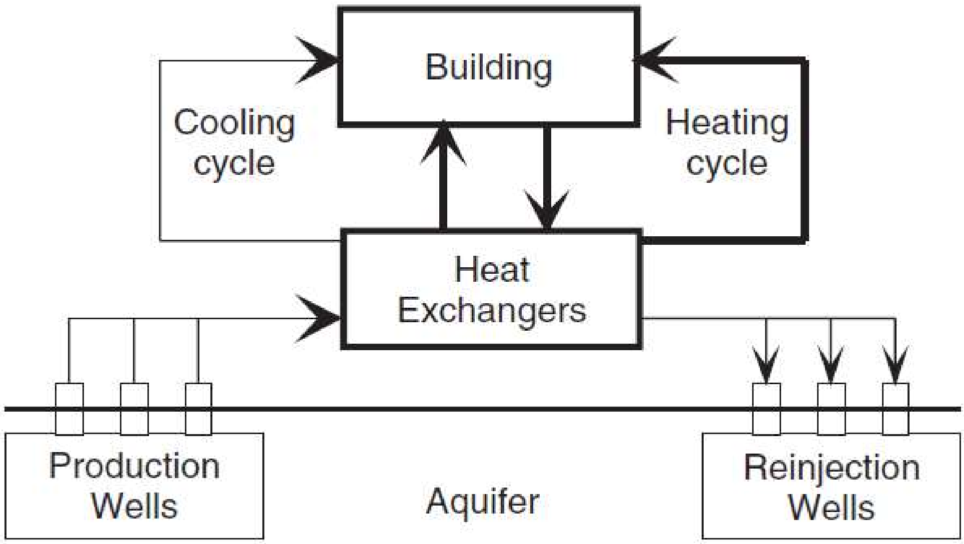


Figure 2.9 Schematic of the operation of an ATES system

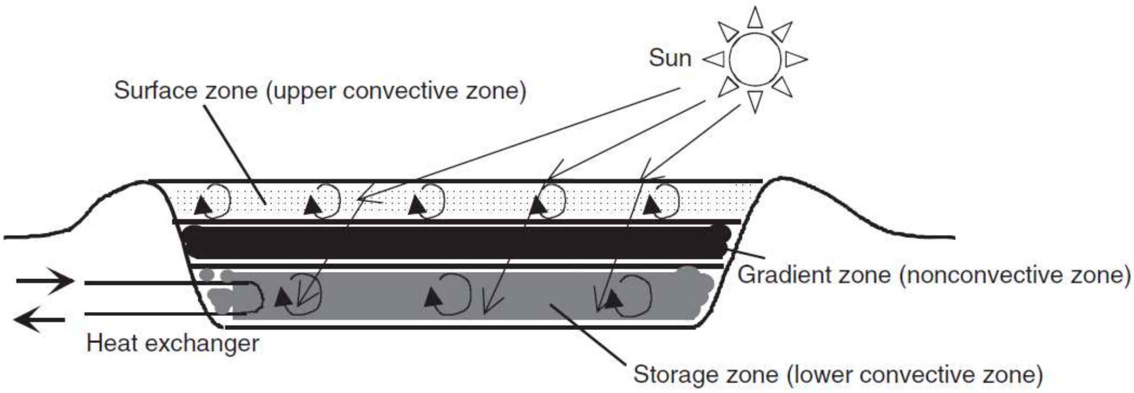


Figure 2.10 A cross-section representation of a typical salinity-gradient solar pond

Another energy storage medium are zeolites. They are naturally occurring minerals with high heat of adsorption and ability to hydrate and dehydrate, while maintaining structural stability (Figure 2.11) .

Knowledge of the melting and freezing characteristics of Phase Change Materials (PCMs), their ability to undergo thermal cycling, and their compatibility with construction materials is essential for assessing the shortand long-term performance of a latent TES.

More than 20,000 compounds and mixtures have been considered as PCMs, including one-component systems, similar mixtures, fusible (eutectic) alloys, and liquids that are in equilibrium with the crystalline phases.

Sokolov and Keizman (1991) developed an attractive PCM application for hot water heating. The system contains a solar pipe consisting of two concentric pipes with the space between them filled with PCM (Figure 2.12).

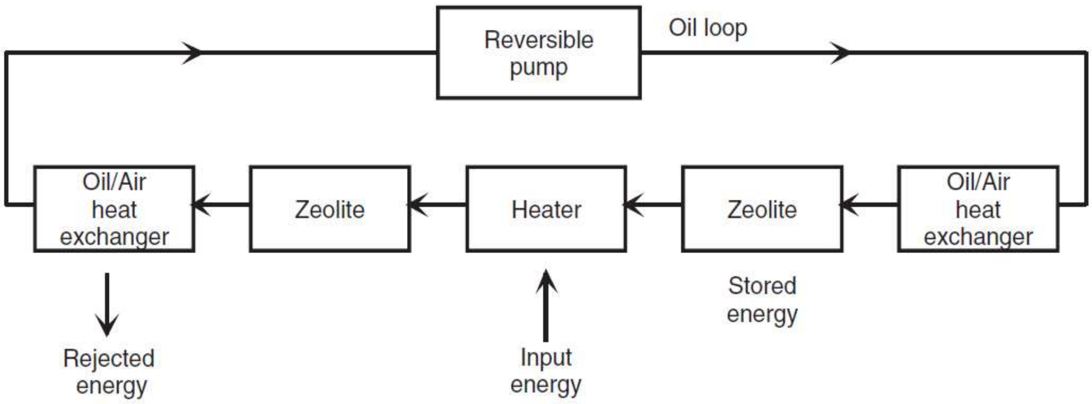


Figure 2.11 A process for using zeolites as a heat storage media

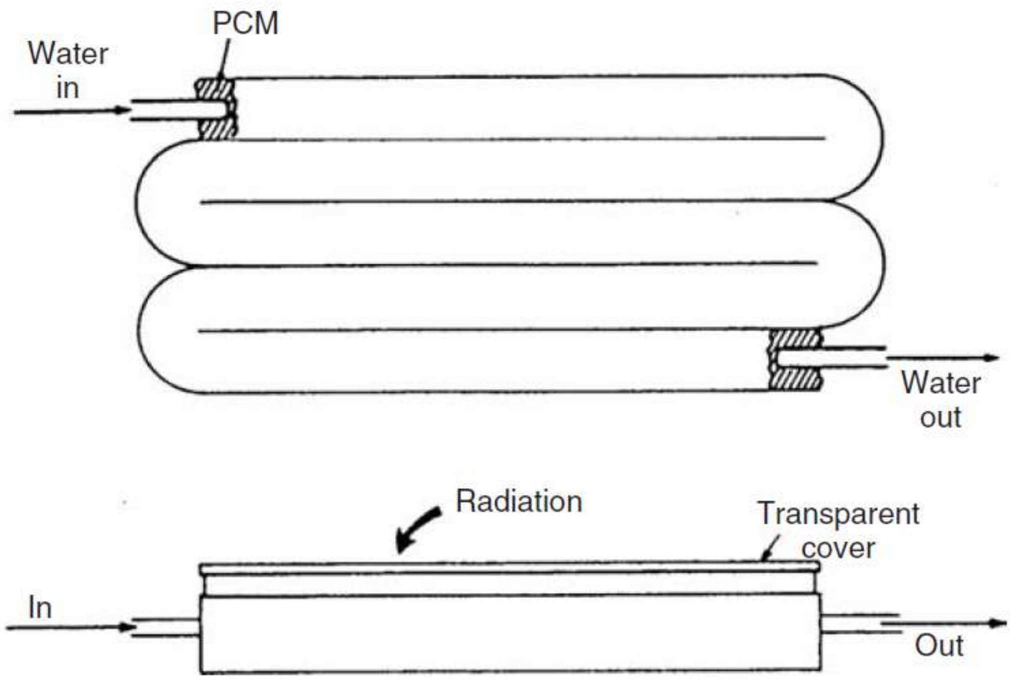


Figure 2.12 A solar TES pipe using a PCM

2.1.4. Chemical energy storage systems

Figure 2.13 shows the relative relationship of energy densities when physical and chemical changes occur.

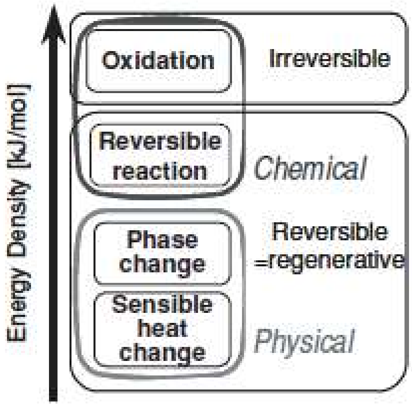


Figure 2.13 Energy density of physical and chemical changes

The reversible chemical reaction can be used for a chemical heat pump. Figure 2.14 shows the types of chemical heat pump.

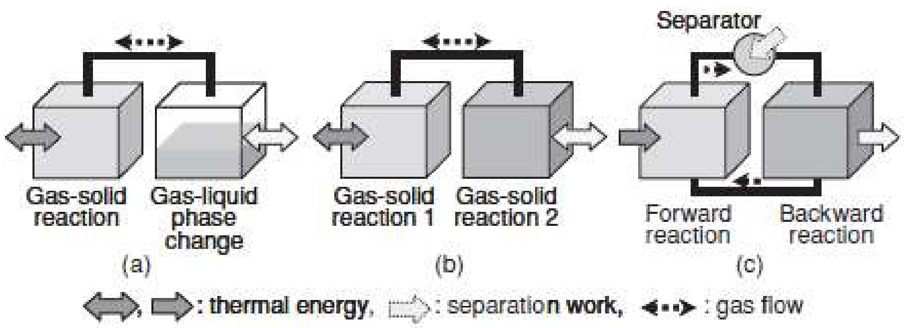


Figure 2.14 Types of chemical heat pumps; (a) reaction-phase change type, (b) reaction-reaction type, (c) reaction - continuous separation work type

Chapter III. Innovative approaches to improve solar heat storage systems.

Solar space heating significantly reduces the use of non-renewable energy sources and alleviates the degree of pollution of the environment and air. To solve the problems of solar instability and insufficient heat storage, an auxiliary heat source is usually added to solar heating systems.

The so-called "combi-system" is a heating system that supplies heat for domestic hot water and space heating in a building, using two energy sources - solar energy and any other auxiliary heat source (Figure.3.1).

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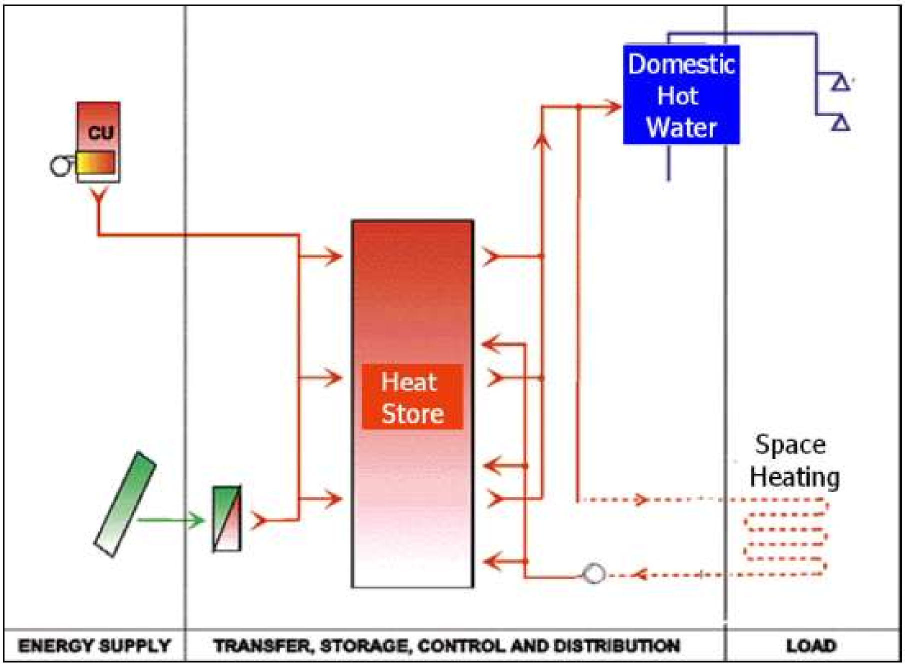

Figure 3.1 Solar system for domestic hot water and heating components

3.1. Solar heat sources (Solar collectors)

A solar collector is the main component of any active solar thermal system. The main task of the solar collector is to collect solar energy, then convert it into the useful heat that is transferred by the working medium (water or antifreeze mixture), or air from collectors to the storage tank.

Main types of solar collectors used in buildings are listed according to their complexity and advancement of technology used:

- Low-temperature unglazed collectors, so-called swimming pool absorbers in the form of black absorbing plastic panels or strips;
- Flat-plate liquid solar thermal collectors;
- Evacuated tube collectors.

The essential element of a flat-plate solar collector is the absorber. The absorber absorbs solar radiation and converts it into heat that is transferred through its surface into liquid or air, which flows under the entire absorber plate or in tubes A cross-section of a sample of flat plate liquid solar collector is shown in Figure 3.2.

Figure 3.2 A cross-section of a flat-plate liquid solar collector

Evacuated collectors are primarily built as tubular collectors. However, flatplate evacuated collectors are also made and they usually are based on very large negative pressure, so-called imperfect vacuum. This type of collector is intended for large sized applications for large roof areas (Figure.3.3).

Figure 3.3 Double glass tube (Dewar tube)

3.2. Heat exchanger

A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids.

The four most common types of heat exchangers, based on the flow path configuration, are illustrated in Figure 3.4.

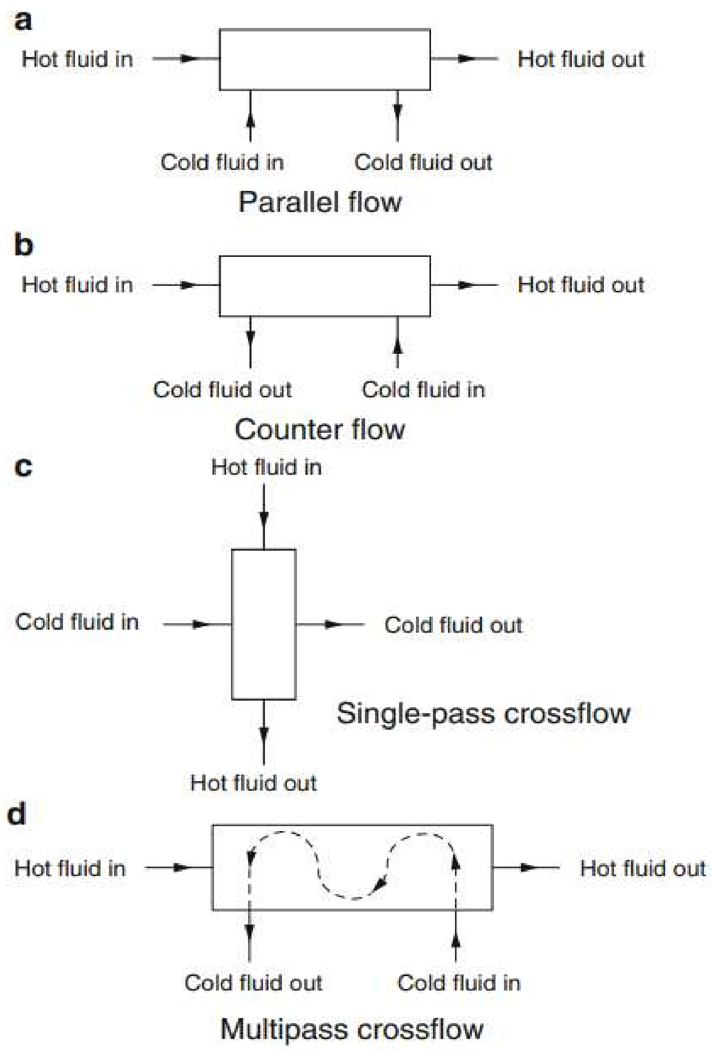

Figure 3.4 Heat exchangers classification according to the flow path configuration

- In simultaneous or parallel streams, where hot and cold liquids connect at the same point, flow in the same direction and exit at the same end.
- In case of countercurrent, hot and cold liquids connect at opposite ends, flow in the opposite direction and exit at opposite ends.
- In single-pass cross-flow heat exchangers, one liquid moves through the heat transfer matrix at right angles to the flow path of the other liquid.

- In multi-pass cross-flow heat exchangers, one fluid flow moves up and down, crossing with the flow path of the other fluid.

According to the transfer processes, heat exchangers are classified as indirect and direct.

According to the design characteristics the heat exchangers can be:

- Shell and tube - Figure 3.5.

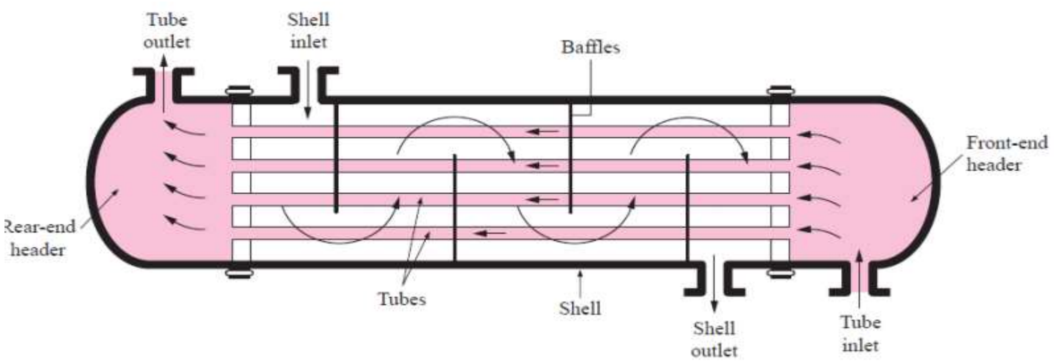

Figure 3.5 Shell and tube heat exchanger

- Plate - Figure 3.6.

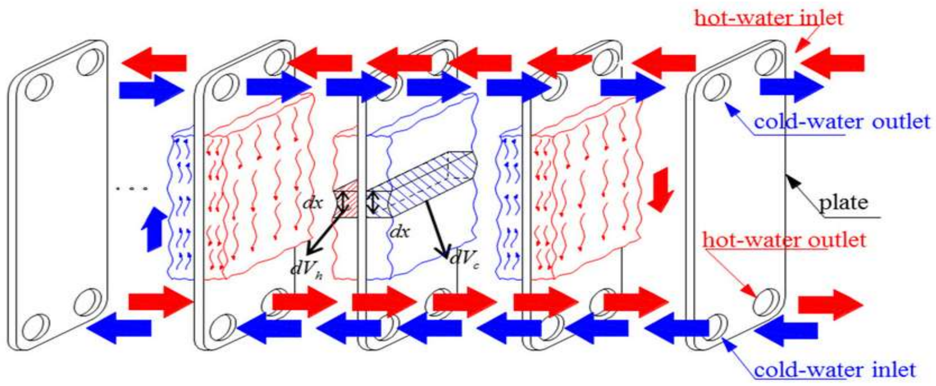

Figure 3.6 Plate heat exchanger

- Plate-fin - Figure 3.7.

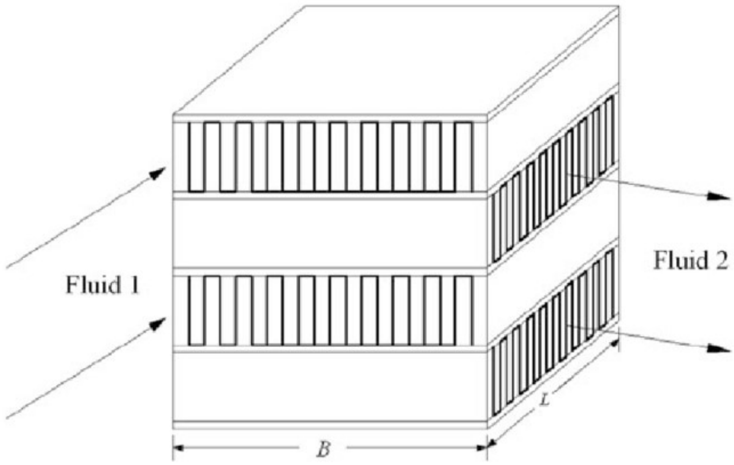

Figure 3.7 Plate-fin heat exchanger

- Flat finned tube - Figure 3.8.

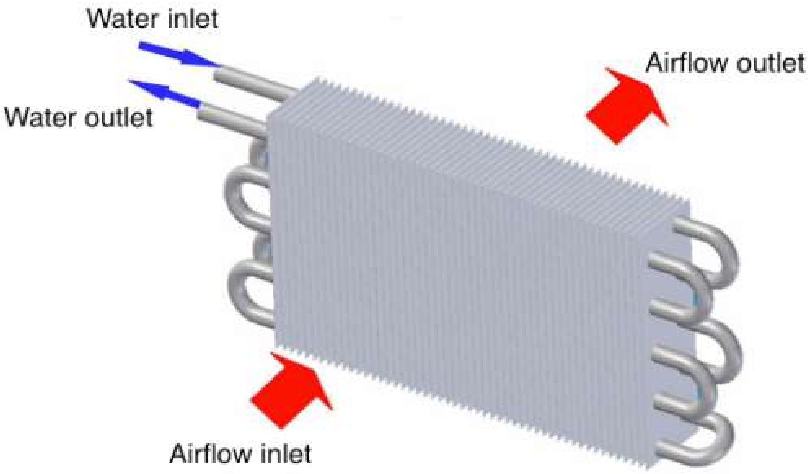

Figure 3.8 Flat finned tube heat exchanger

3.3. Auxiliary heat source

Solar space heating systems are much more complex than systems that provide only domestic hot water. They must be equipped with auxiliary heat sources (Figure 3.9), which can be solid fuel boilers (wood, coal, pellets), liquid, gaseous or electric.

Solar installations are often combined with heat pumps - Figure 3.10.

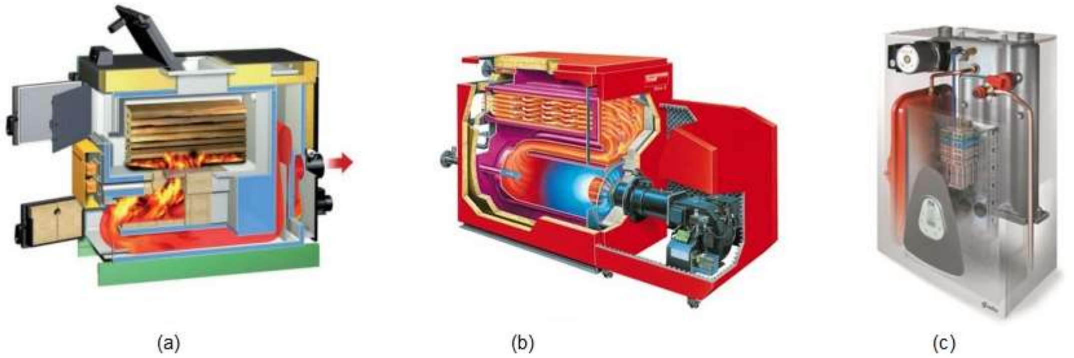

Figure 3.9 (a) solid fuel boiler; (b) liquid / gaseous fuel boiler; (c) electric boiler.

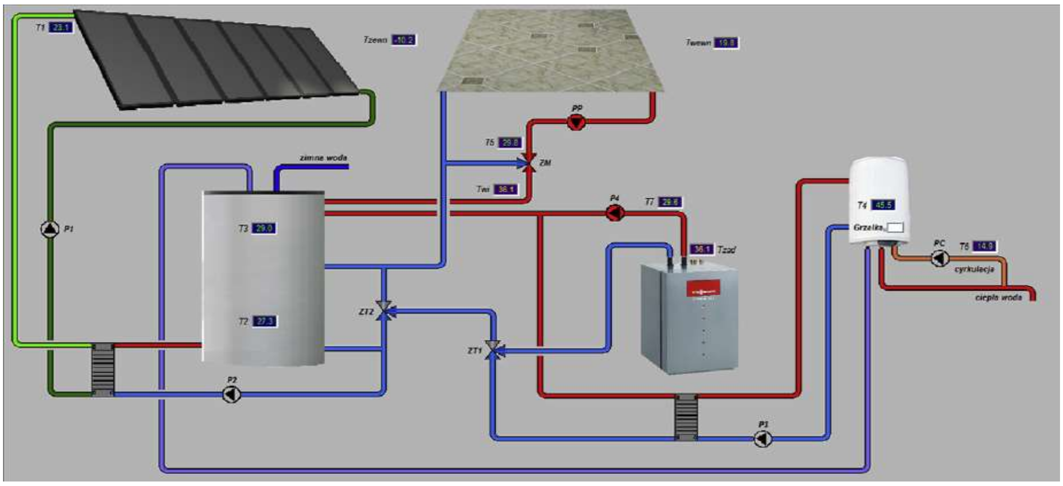

Figure 3.10 Solar heating system with a heat pump.

3.4. Accumulating tang

A typical system using a hot water storage tank is shown in Figure 3.11.

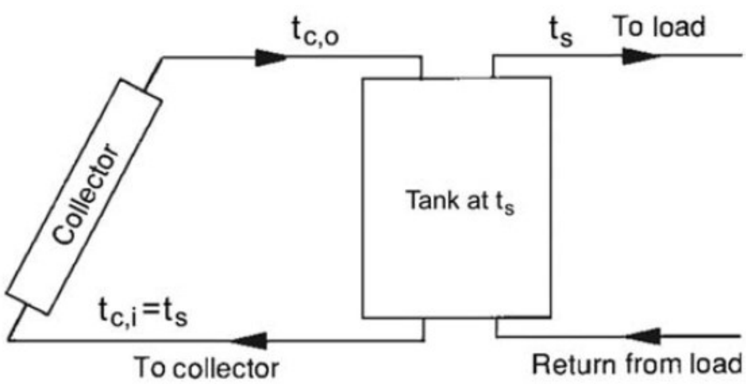

Figure 3.11 Solar system using a hot water storage tank

3.5. Innovative design and selection of storage tank with phase-changing material

Phase-change materials (PCM) used for heat storage are chemicals that go through a transition from solid to liquid at temperatures in the desired range for heating and cooling. During the transition process, the material absorbs energy when it changes from a solid to a liquid state and releases energy as it returns from a liquid to a solid state. The water storage tank is made of steel, and in its total volume there are closed cylindrical tubular containers filled with PCM (paraffin) (Fig. 3.12).

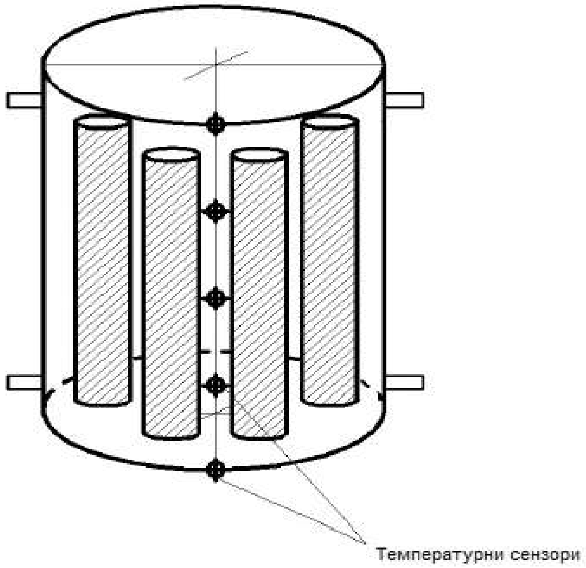

Figure 3.12 Phase-change material storage tank construction

3.6. Building heating system

The first step is usually the choice of heat generator and energy source - solid fuel, gas, oil, electricity; if necessary, both heating and cooling.

There are several options:

- *Boiler heating system*
- *Heat pump system*
- *renewable energy sources usage opportunities*

3.7. Controller

Automated control of building heating systems is implemented centrally, with network platforms or decentralized - through local controllers, thermostats and other modules.

3.8. Innovative heat storage and building heat supply combined system.

The innovative heat storage system, including PCM, is used to store excess energy as latent heat (Figure 3.13).

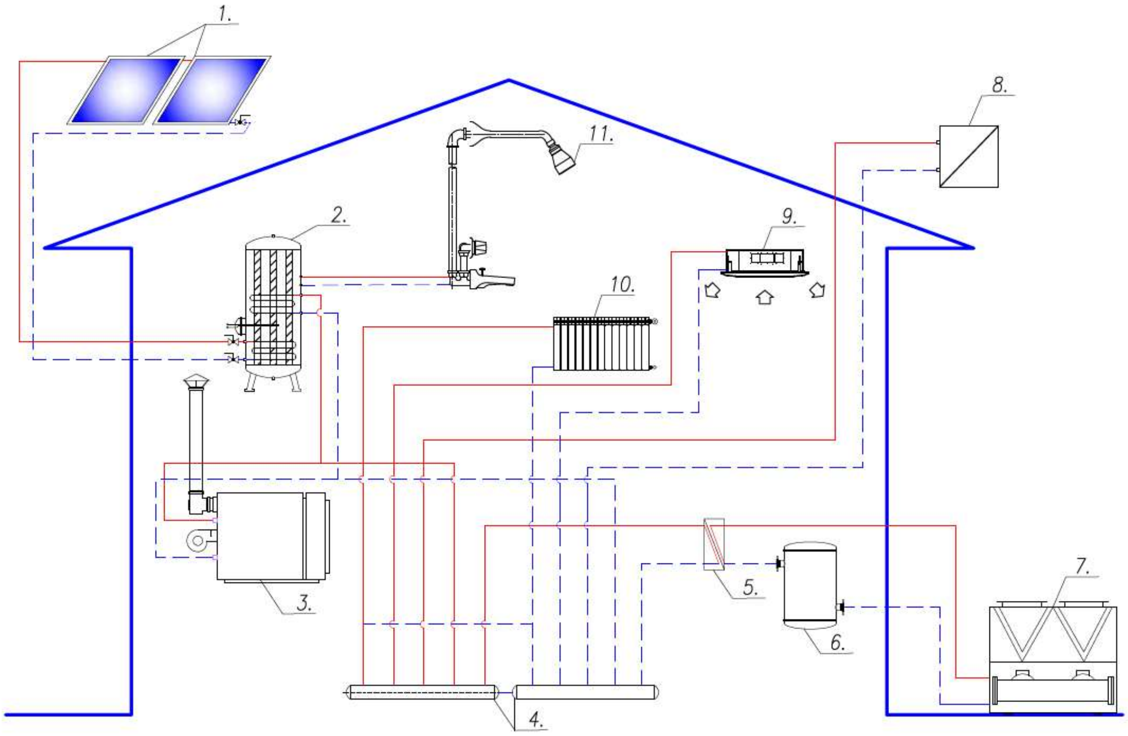

Figure 3.13 Space heating system using PCM storage tank

The system components are:

1. Solar collectors for domestic hot water (DHW);
2. Hot water storage tank with PCM;
3. Pellet boiler;
4. Water distributors;
5. Plate heat exchanger;
6. Buffer storage tank;
7. Air to water heat pump;
8. Heat exchanger (ventilation system);
9. Fan coil unit (cassette type);
10. Aluminium heater;
11. Water supply system.

Chapter IV. Experimental results and simulations.

4.1. Project description and heating system scheme

The considered building is a newly built restaurant, which has the following spaces: a visitors hall, a kitchen with ancillary rooms, an office, warehouses and bathrooms.

A pellet hot water boiler with a fuel hopper and an air-to-water heat pump air conditioning unit is provided for heating. The accumulating tank supply, the heating sections, the air curtain, the floor heating and the other heating units is through separate standpipes, equipped with electronic water supply pumps (Figure 4.1).

To supply the building with hot water, a stainless steel accumulation tank with two coils and a volume of 500 liters is provided. During the heating season the water will be heated by circulation from the boiler, and in the summer it will be heated by means of four flat solar collectors, which will be mounted on the roof at an angle of 45 ° in a southerly direction. The connection between the accumulation tank and the collectors is implemented with insulated copper pipes, and the circulation is realized with a microprocessor controled pump group. A closed expansion vessel is provided to absorb the water expansions in the solar system. The accumulation tank also has an additional electric heater with a capacity of 7.5 kW.

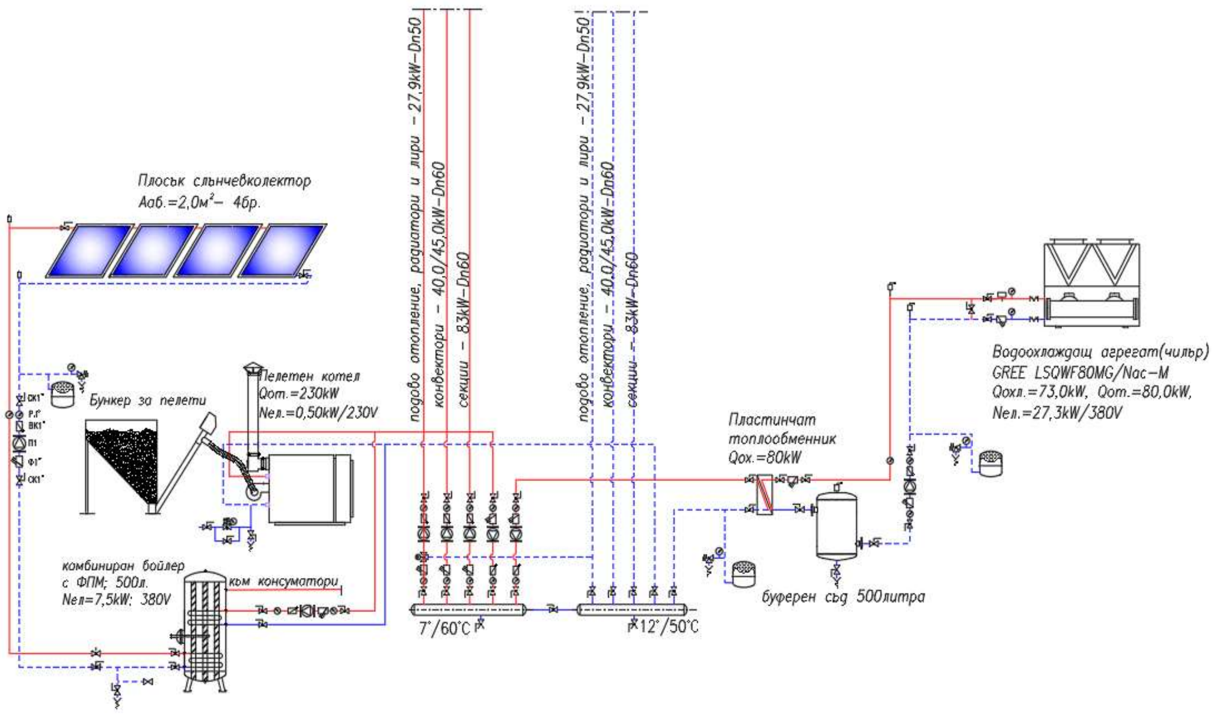

Figure 4.1 Combi-heating system detailed scheme

The solar panels characteristics installed in the system are listed in Table 4.1

Tilt angle	45°
Collector area	4бр. X $2m^2$= 8m2
Overall surface conductance, U_c	8,0 $W/m^2.K$
Heat transfer coefficient inside the tube for water, h_w	1500 W/m.K
Cover transmittance, τ	0,9
Solar absorption of the copper surface,α	0,9
The water inlet temperature, T_{fi}	65°C

Table 4.1 Solar panels characteristics

4.2. Calculating annual hot water energy demand.

The annual energy consumption of domestic hot water (DHW), including heat and circulation losses, can be calculated as follows:

$$Q_{demand}=Q_{DHW} + Q_{losses} ,$$

The energy required to raise the water temperature neglecting any losses is found by:

$$Q_{DHW} = \frac{\mathrm{m}.C_p.\Delta T}{3600}, kWh/day,$$

where:
m (kg) – mass of water to be heated
Cp (kJ/kg.°K) – specific heat capacity of water
ΔT (°K) – required temperature rise
Losses can be calculated taking into account the static losses of the storage tank and the pipeline coefficient of circulation losses:

$$Q_{losses} = Q_{SHL} + Q_{circ} ,$$

where:
QSHL (kWh/day) – standby heat losses
Qcirc (kWh/day) – circulation heat losses
Qcirc = κ. QDHW , κ(%) – assumed loss factor

The annual hot water energy demand can be expressed as follows:

$$Q_{demand} = [(1+k).Q_{DHW} + Q_{SHW}].365, kWh/year$$

Therefore, for the considered storage tank with volume V = 500 l, static losses 2.5 kWh / day (energy efficiency class B) and circulation losses 20%, the required energy for DHW will be:

$$Q_{DHW} = \frac{\mathrm{m}.C_p.\Delta T}{3600} = \frac{500.4{,}18.(60-10)}{3600} = 29{,}02\ kWh/day$$

$$Q_{demand} = [(1+k).Q_{DHW} + Q_{SHW}].365 =$$

$$= [(1+0{,}2).29{,}02 + 2{,}5].365 = 13623\ kWh/year$$

The amount of heat stored in water is expressed by the equation:

$$Q_{H2O} = V.\rho.C_p.\Delta T$$

$$Q_{H2O} = 0{,}5.1000.4{,}18.50 = 104500\ kJ$$

4.3. Calculating solar panels area.

Having calculated the annual energy demand, the collector area should be determined to cover part of the required energy.

On an annual basis, this energy is calculated as follows:

$$Q_{solar} = Q_{demand}.S_{sf},$$

where:

S_{fn} – design solar fraction, typically 30% - 60% (This is an expression of how much of the total energy consumption is supplied by solar thermal).

With a solar fraction of 50%, the following is obtained:

$$Q_{solar} = 13623.60\% = 8174\ \mathrm{kWh}/year$$

The annual solar yield obtained from the solar array is:

$$Q_{solar} = Q'_{solar}.A_{apmin},$$

where:
Q'_{solar} – specific annual solar yield adjusted for location, tilt, orientation and shading (for the Sofia region Q'_{solar} = 1200 W/m^{2}year).
A_{apmin} – minimum aperture area of solar collector array (m^2).

Rearranging the above equation gives the required aperture area to meet the solar contribution of the annual energy demand is:

$$A_{apmin} = \frac{Q_{solar}}{Q'_{solar}} ,$$

For the considered conditions it is obtained:

$$A_{apmin} = \frac{8174}{1200} = 6{,}8\ m^2$$

For the system are provided n = 4 pcs. solar panels with aperture area Aapcoll = 2.0 m^2 each. The total aperture area will be:

$$\mathrm{A}_{ap} = n. A_{apcoll} = 4\ .\ 2 = 8{,}0\ m^2$$

The annual solar yield obtained from the solar array will be:

$$Q_{solar} = Q'_{solar}. A_{ap} = 1200.8 = 9600\ kWh/year$$

4.4. Balancing the array and calculating the system flow rate

The arrangement of the solar panels has a direct impact on the flow rate of the system and therefore on the choice of piping and circulation pump.

In practice we need to keep the array layout simple whilst still minimising the pressure drop across the collector field. We have the added consideration that banking too many collectors together will have an effect on efficiency, particularly on the last few collectors in each series as they start to operate at a hotter temperature and their performance is affected.

To achieve a good hydraulic balance, it must be taken into account that no series of collectors should be larger than 10 m^2. Ideally, the goal is for an even number of collectors and a balanced pipeline. On larger systems the goal is for a total number of collectors that can be divided by 3 or 4 to obtain a suitable array.

When sizing the pipeline, we aming to achieve the following:

- Minimise pressure drop and therefore reduce the pump size and energy consumption
- Maintain pipe velocity between 0.4 – 1.0 m/s
- Ensure that the pipe will fit in the available space
- A choice of pipework and fittings are cost effective both in terms of materials and labour

4.5. Sizing the pcm storage tank volume

Latent heat storage technology reduces temperature fluctuations and offers a higher heat storage capacity per volume/mass. The temperature and the amount of energy stored can be adjusted by selecting a specific phase changing material. Stored heat is transferred by a heat transfer fluid such as water or air in a heat exchanger. When the heat transfer fluid temperature Tf is lower than the melting temperature (Tf<Tm), the phase changing material solidifies and releases its heat of melting to the heat transfer fluid. Respectivly, when the temperature of heat transfer fluid is higher than the melting temperature (Tf>Tm), phase changing material starts melting and stores heat.

The selected phase-change material is paraffin with a mass of 50 kg. The total heat stored by the solid-liquid phase-changing material between the initial and final temperature is determined:

$$Q_{PCM} = m\left[C_{ps}(T_m - T_i) + \Delta H_f + C_{pl}\left(T_f - T_m\right)\right]$$

$$Q_{PCM} = 50[1{,}05.(54 - 46) + 213 + 2{,}384.(68 - 54)] = 12738{,}8\ kJ = 3{,}538\ kWh$$

The water volume that can compensate the total heat stored in the paraffin is calculated according to:

$$V_{H2O(PCM)} = \frac{E}{C_p.\Delta T},$$

where:
$V_{H2O(PCM)}$ – the water volume heated by PCM (l);
C_p = 4184 J/kg.°C – water specific heat capacity;
ΔT - PCM temperature difference (22°C);
E – The energy stored in PCM (J).

Therefore:

$$V_{H2O(PCM)} = \frac{12738800}{4184.22} = 138{,}4\ l = 0{,}138\ m^3$$

The paraffin amount in m^3 will be:

$$V_{PCM} = \frac{\mathrm{m}_{PCM}}{\rho_{PCM}},$$

where:
m_{PCM} – PCM mass (kg);
ρ_{PCM} – PCM dencity (kg/m^3).
In this case it obtains:

$$V_{PCM} = \frac{50}{778} = 0{,}064\ m^3$$

Due to the above, the volume of the storage tank (V1) with PCM will be:

$$V_1 = V - \mathrm{V}_{H2O(PCM)} + V_{PCM} = 0{,}5 - 0{,}138 + 0{,}064 = 0{,}426\ m^3$$

Increasing the mass of paraffin in the storage tank leads to an increase in the energy stored amount (Figure 4.2).

Figure 4.2 Amount of heat stored in paraffin depending on the mass

Conclusion:

Encapsulating phase change materials can maintain the outlet water temperature, especially when the inlet water temperature is reduced at night time. In addition, it is particularly important to insulate the PCM tank well, as insulation increases the productivity of the material. There are also some inconveniences that result from the PCM characteristics. Due to the low thermal conductivity of the material, charging and discharging the tank takes time. The low heat transfer rate between the heat transfer fluid and PCM leads to less efficient thermal systems. Therefore, it is appropriate to use encapsulated FPM to increase the heat transfer area between the material and the heat transfer fluid. Encapsulating the PCM in a sphere shape around the heat exchanger shows cycle stability and better performance for a hot water storage tank.

C O N T R I B U T I O N S:

The thesis contributions are mainly with scientific application and they are as follow:

1. After a detailed review, a critical analysis and systematization of types of energy sources was made.

2. Existing methods of energy storage are discussed in order to choose a method of heat storage.

3. Innovative examples of heat storage are researched and an innovative approach to heat storage based on phase change materials is proposed.

4. An innovative combined heat storage system and heat supply in a building has been developed.

5. Experimental calculations and technical and economic analysis are made with the proposed methods and developed systems.

6. Innovative solutions for energy efficiency and multifunctional intelligent information and communication technologies have been applied in the experimental development.

7. The results were tested in the "MARTMAX" Ltd. company.

Publications in accordance with the thesis topic:

1. **Yosifova V., Haralampieva M..** Проучване и оценка на съществуващи и иновативни технологии за съхранение на енергия. XXVIII Международна научно-техническа конференция – АДП 2019, 2019, ISSN:1310 -3946, 321-326
2. **Haralampieva M..** НАНОТЕХНОЛОГИИ И НАНОМАТЕРИАЛИ ЗА СЪХРАНЕНИЕ НА ТОПЛИННА ЕНЕРГИЯ. ROBOTICS, AUTOMATION AND MECHATRONICS ’ 20, Prof. Marin Drinov Academic Publishing House, 2020, ISSN:1314-4634, 22-26
3. **Yosifova V., Stoimenov N., Haralampieva M..** On-site research with thermal camera on industrial heating. The International Conference on Technics, Technologies and Education ICTTE 2020, 1032, 2021, DOI:10.1088/1757-899X/1031/1/012082, SJR (Scopus):0.2
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ул. проф. Христо Данов №19
1700 София, България
тел.: (+359) 878 252 277
e-mail: office@martmax.bg
www.martmax.bg

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КЛИМАТИЗАЦИЯ И ВЕНТИЛАЦИЯ

ДЕКЛАРАЦИЯ

Фирма "МАРТМАКС" ООД декларира, че разработеният от маг. инж. Милена Бисерова Хараламписва иновативен модел за "Интелигентно управление на източници за съхранение на топлинна енергия" представлява интерес за нашата фирма и ние ще го използваме в нашата практика за проектиране и изпълнение на едно- и многофамилни жилищни сгради.

11.2021г.

Мартин Сариев ....
/управител/