Original Article: Studying the Design of Solar Water Heaters

Milad Karimi

Faculty of Engineering, Department of Mechanical Engineering, Yadegar -e- Imam Khomeini (rah), Shahr-e-Rey Branch, Iran

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ABSTRACT

The amount of solar energy received in Iran is estimated at an average of 18 mega joules per square meter per day or around 10^{16} mega joules per year in the country. This amount of energy is more than 4000 times the total energy consumed in the country. With this amount of received energy and having suitable lands for using the sun and the relatively simple technology of various applications of solar energy, all the energy needs of the country can be provided by using solar energy. Certainly, achieving a high yield requires spending more. Also, in cold regions, reaching a stable system requires the use of various pumps and valves. Therefore, an acceptable system is a system that results in a combination of high conditions, long life, low cost of maintenance and low cost of working conditions. In all existing solar systems, 1 or 2 water storage tanks can be used, provided that an electric element or another heat source is used in one of the tanks to compensate for heat loss resulting from static water. It is obvious that the heat loss caused by one tank is less than the heat loss caused by two storage tanks due to its smaller cross section. In the case of storage tanks, one should pay great attention to their insulation type so that it does not cause heat loss. The use of an auxiliary storage tank or a gas heating system or heating element in times of cloudy conditions will greatly help to compensate for the lack of available heat.

Corresponding Author: Milad Karimi (daktil1367@gmail.com)

Introduction

The uses of solar energy that are used in Iran have been investigated as follows:

A: Devices that use direct sunlight

1- Hot water production;
2- Natural heating of buildings;
3- Unnatural heating of buildings;
4- Cooling of buildings;
5- Cooking food;
6- Drying fruits, vegetables and fish;
7- Desalination of sea water;
8- Production of electrical energy through direct conversion;
9- Production of electrical energy through heat conversion (indirect conversion) [1].

B: Devices that indirectly use solar energy

1- Natural cooling of buildings and winter cold storage;
2- Production of methane gas using animal and agricultural waste;
3- Use of wind energy.

A brief description of the operation of each of the above-mentioned systems and the cost of construction and production and the price of the produced energy of each of them have been determined. A comparison of the price of energy produced in the aforementioned solar energy devices with the price of energy produced through common fossil fuels in the country shows that the use of solar energy is not economical. The main reason for the uneconomical use of solar energy is that oil and electricity are available to consumers almost free of charge in all parts of the country [2].

Reasons for using solar energy in the country

Economical should not be the only reason to use solar energy. It is necessary to pay attention to solar energy for the following reasons and make necessary investments for its wide application:
1- Extravagance in food, natural resources and everything else is prohibited by Islam. Burning oil, this very precious and limited blessing of God for producing hot water for consumption (at a temperature of about 45 degrees Celsius), producing air or hot water for heating buildings (at a temperature of 50 to 90 degrees Celsius) and cooking food (at a temperature of about 100 degrees Celsius) is quite obvious extravagance. Burning fossil fuels for the above-mentioned uses is as wasteful and wasteful (and as a result committing a sin) as burning wheat to meet the same needs. Oil, this God-given blessing, can be used to produce medicine, plastic materials, chemical fertilizers, etc.
2- The use of oil resources in the country has caused air, water and land pollution. The presence of these pollutions, especially the air pollution in big cities like Tehran, has caused many diseases, premature deaths, and a general decrease in the efficiency of people. It is necessary to precisely control and reduce the consumption of these fossil fuels in order to protect people's health. Solar energy is a renewable source of energy that creates the least pollution in the environment [3].
3- The burning of fossil fuels and the creation of carbon dioxide at the global level has caused the temperature of the Earth's atmosphere to rise. The rise in the temperature of the earth's atmosphere and sea water (which is not uniform and is higher in the poles than in the equator) has caused the melting of the polar ice and the rise of the ocean water level, and the continuation of this act is a far more deplorable disaster than all the storms, floods and the earth. It will contain earthquakes. Compared to industrialized countries whose consumption of fossil fuels is very high, Iran does not play a big role in raising carbon dioxide at the global level and warming the earth's atmosphere. But paying attention to this issue (which the industrialized countries of the world have just thought about and are expressing concern about) can create a great image for the Islamic Republic of Iran in the scientific and political circles of the world.
4- The technology of solar energy applications is not so complicated that we need to use foreign experts. In many applications, the necessary technology is already available in the country. In some applications (such as making photocells), the relevant technology can be developed with a little effort.
5- Currently, the Islamic Republic of Iran is the political leader of some third world countries. It is appropriate for this republic to assume the

scientific and technical leadership of these societies. Considering the role that energy plays in the development of countries and the fact that most of the third world countries also have a significant amount of solar energy, the Islamic Republic of Iran can, by investing heavily in the development of solar energy science and technology, become the country that actually exports this technology to the third world and play the role of scientific and technical leadership in the third world.

6- In the past decades, the Iranian government has been importing technology to solve its problems. Almost all the facilities of today's life (such as electricity and all electrical devices, telephones, roads and transportation, cars, computers, etc.) have been obtained by importing technology. With limited oil resources and the end of this very valuable natural resource, we can wait until the industrialized countries solve their energy problems and import the relevant technology as in the past, or take a few years ahead of others and think about the development of the resource. It is solar energy and instead of being an importer, we should be an exporter of solar energy technology [4].

Solar water heater design criteria

The various solar domestic water heating (SDHW) systems are typically divided into two different categories.

1- Direct systems: In this type of system, city water flows directly in the collector.

2- Indirect systems: In these types of systems, hot water is supplied indirectly using a heat exchanger.

In general, no system can always be completely superior to other systems, and each system has its own characteristics, and each does not work perfectly in turn. In order to design a solar water heater that can meet the goals of this project, the following criteria have been proposed.

1- High reliability: Ensuring the perfect functioning of the system in working conditions, which is achieved by removing unnecessary parts and reducing moving parts.

2- Low maintenance and repairs: Which is achieved by using durable parts and heat-carrying fluid that does not need to be replaced in short periods of time.

3- Less energy-consuming parts: Which is achieved by not using automatic valves or pumps with high consumption.

4- Easy installation: Which is usually applicable by presenting the system in the form of a suitable package. Due to the presence of water drain valves to prevent freezing, ventilation during the installation of the water heater, sufficient care must be taken so as not to cause improper operation of the system.

5- Reducing consumer involvement: Which can be achieved by using automatic controllers. Usually, the use of these controllers is welcomed by consumers and has a positive effect on the stability of the system.

6- Low initial costs: Which is achieved by using cheap parts and reducing unnecessary parts and ease of installation.

7- High useful performance of the system: This is possible with good heat transfer from the collector to the hot water storage tank. Obviously, it will not be possible to achieve some of these goals at the same time.

In indirect systems, if the PH of the used fluid is not taken into account, there is a possibility of corrosion in the system. In case of using non-flaky materials in the structure of the collector, the possibility of corrosion and carbonates in the walls of the pipes will be removed, and instead the physical changes caused by high heat and solar radiation will be considered [5].

Recirculation (plus)

The cold water used circulates directly inside the collector by a pump and the only factor that prevents freezing of the circulating fluid is the pump.

Advantages

- Simple without system;
- Good efficiency due to no converter;
- Low costs;
- No need for automatic valves.

Disadvantages

- The limited use of it;
- Absence of an automatic counter system;
- Decay;
- Excessive temperature increase cannot be easily eliminated. The best solution to prevent this is to use automatic valves [6].

Drain out (Drain down)

In this type of system, automatic valves are used to drain the collector and pipes in contact with the environment. So that whenever the cold conditions reach a certain level, these valves automatically drain the water in it. Also, these valves will work when the pump stops working. In the case of automatic valves, it should be noted that the absence of freezing conditions will cause these valves to be idle for long periods of time, which will cause errors in the operation of these systems. As a result, these valves cannot be optimally reliable. Also, in the second case, when the pump is idle for a long time, these valves will function properly, but they will waste a lot of water. In this type of system, if there are waste materials in the water, these materials accumulate in the pump rims and thus cause leakage. In relation to energy consumption, two automatic 15w valves that operate continuously will consume more than a 100w pump.

Advantages

- High efficiency due to the absence of a converter;
- The rise of temperature beyond the permissible limit is controlled by the use of drain valves;
- Low price;
- Special design for draining when the pump stops working.

Disadvantages

- Rotting and corrosion;
- Unreliability of some automatic valves;
- Accurate installation to avoid freezing conditions;
- Water loss.

Drain Back with Air Compressor

In this system an air compressor is used and the construction conditions are similar to drain out, with the difference that the water returns to the tank when the pump is turned off, so that whenever the pump is turned off, the water contents in the collector and pipes flow into the tank and instead of that, air is replaced. When the pump is turned on, the air under pressure returns to the tank. Therefore, in this type of system, the pump has a static limit at the start of work that must be overcome. It should be noted that without the ability to accurately observe the water level in the tank, it is difficult to ensure the proper functioning of the system, and during a power outage, it is not possible to ensure that the system is protected against freezing.

Advantages

- High thermal efficiency due to the absence of an exchanger;
- The possibility of maintaining the system against the temperature rising above the allowed level.

Disadvantages

- Increase in initial costs due to the presence of the compressor;
- Corrosion potential;
- Uncertainty of proper operation during power outage;
- Difficult installation to establish a proper drainage system;
- Presence of static head;
- It is difficult to know the proper functioning of the system;
- Potential to cause caries.

Drain back with liquid level control

Among the direct existing systems, this system has a smaller share in terms of application, but it is generally practical. In this type of system, a level control switch like a water float controls the height of the water level in the tank [7].

Advantages

- High thermal efficiency due to the absence of an exchanger;
- Proper security to prevent freezing;
- Low cost of the storage tank due to not being under pressure;
- Good performance to avoid high temperature;
- Low costs.

Disadvantages

- Use of two pumps;
- Presence of static head;
- Difficult installation to ensure proper system performance;
- Corrosion potential;
- Potential to cause caries.

Themosyphon with electrically protected collector

The most common solar system in the world is this type of system. This system is widely used in Australia, Japan, China, Middle East. It's very simple structure and the absence of control and movable systems have reduced the reasonable price and reliability of this system. Among the direct systems, the thermosiphon system has a lower Nusselt number compared to other systems. (Natural heat transfer in a thermosiphon is less than a system with forced heat transfer by a pump). However, in a thermosyphon system, the total efficiency may be higher than in a system with a pump because in this system there is no energy wasted by the pump, valves and controllers. The most important disadvantage of this system can be considered the weak control of freezing by this system. A solution to prevent this is to use an electrical element for areas where frost rarely occurs [8].

Advantages

- Low initial costs and payment in working conditions;
- High efficiency due to the absence of a converter;
- Absence of automatic valves, pumps and controllers.

Disadvantages

- Restrictions on use;
- Restrictions on storage tank location;
- Corrosion potential;
- Potential to cause caries;
- It is difficult to prevent the temperature from rising above the permissible limit.

Drain out Thermosyphon

The only difference between this type of system and the previous system is the use of automatic valves. This type of system is also not used due to the reasons mentioned for the disadvantages of the thermosyphon system and the lack of proper functioning of the automatic valves during long periods of idleness. Also, the high energy consumption of automatic valves compared to a pump is another disadvantage of this type of system.

Advantages

- High efficiency, due to the absence of a heat exchanger;
- Low initial cost and operating cost due to the absence of pumps and controllers;
- The possibility of evacuation in times of freezing.

Disadvantages

- Using automatic valves, causing pressure drop and high energy consumption;
- Limiting the location of the storage tank;
- The heat loss of the storage tank can be high;
- Difficult installation due to proper operation of automatic valves;
- Corrosion potential;
- Potential to cause caries.

Breadbox (batch)

In the Breadboz system, the storage tank and the collector are combined in a single frame. So that a medium tank or several small tanks are placed in a box-like collector. In this system, the surroundings and the back of the tanks are carefully insulated, and the front of the box is covered with several layers of glass. By using the appropriate cover to prevent this waste, in general, this system with the participation of the user can work properly and be acceptable [9].

Advantages

- Absence of high costs;
- Simplicity of creation by the user;
- Absence of pump controllers and automatic valves.

Disadvantages

- Need for user participation;
- Heat loss from the tank can be high;
- Improper appearance;
- Restricted use only in tropical areas.

Coil in Tank, warp around, Tank in Tank

Indirect systems are usually used with internal converters and the Coil-in-Tank type is considered more than Tank in Tank, Warp Around. In these types of systems, a fluid with antifreeze capability (usually glycol, silicone, or glycerine) is pumped inside the collector and passes through the converter in the tank. Normally, this fluid has the ability to resist freezing. But in conditions of high temperature (93 degrees), there is a possibility of acidification of fluids containing glylol, which will cause corrosion of the collector, in this case, one should be careful in using the fluid. Design standards for residential buildings make it inevitable to use double-wall exchangers for toxic fluids such as propylene glycol to avoid the possibility of water contamination. These heat transfer fluids have lower thermal characteristics and higher viscosity, and we need a pump with more power and higher temperature. Because these fluids have a lower surface tension than water. In some places, it is possible to leak them, so we have to use stronger connections.

Advantages

- Freeze resistance in case of fluid care;
- Use only one pump for fluid circulation;
- Minimization of corrosion if one type of metal is used;
- Absence of decay in the collector cycle.

Disadvantages

- Using a converter with 2 wall layers;
- The need to use an expansion source;
- The impossibility of preventing the temperature from rising too much;
- If there is a leak, there is a possibility of damage to the roof;
- In case of failure of the tank or converter, both must be replaced even if one of them is damaged;
- Natural movement of fluid inside the tank;
- High initial costs, converter, special fluid and other additional components;
- The need to maintain and change the fluid.

External Heat Exchanger

This system is similar to the previous system, with the difference that the location of the converter in this system is different. Usually, two pumps are used in this system to transfer heat from the collector to the water used. Some designers suggest using a pump on the collector side to transfer heat and placing a tank on top of the exchanger for natural heat transfer on the other side. The use of two pumps complicates the control system as well as increases initial costs and operating costs. Normally, the use of the system with the converter outside the tank is used more and provides the possibility of maintenance and repair of the converter.

Advantages

- Prevention against freezing in case of fluid care;
- Easy access to the converter for repair and inspection;
- Good heat transfers from the collector to the storage tank;
- Reducing corrosion to a minimum;
- No decay in the collector cycle.

Disadvantages

- Use of two pumps;
- Increase in initial costs and cost of operation;
- Use a double-wall converter;
- The impossibility of maintaining and replacing the heat transfer fluid;
- The need to use an expansion source;
- The need to use strong connections;
- Leakage causes damage to the roof.

Darin back with load - side heat exchanger

This system is similar to the direct drain back system. with the difference that the current loop on the collector side is generally not under pressure. while the other side (user side) uses a single-wall exchanger to pass the water under pressure and transfer heat. In this system, the converter can be any type of coil or tank in tank that was explained earlier. In this type of system, a simple storage tank is used, in the upper part of which a limited space is allocated for air storage, and like other drain back systems, when the existing water pump is turned off, it returns to the tank. In some cases, the use of a double wall exchanger will be unavoidable.

Advantages

- Using converters with a single wall;
- Ensuring frost resistance;
- Collector operation conditions at low pressure;
- No need to use automatic valves;
- Preventing corrosion in the collector ring;
- No need to use pressure tanks, thus reducing costs.

Disadvantages

- The installation conditions are difficult due to the special conditions of draining water from the collector;
- Presence of static head;
- Potential to increase performance costs.

Drain back with Collector - Side Heat Exchanger

This type of system is similar to the indirect drain back load side heat exchanger system, with the difference that in the collector ring, the fluid passes through the exchanger. In this type of system, other converter designs such as warp around or tank in tank can also be used.

Advantages

- Using a converter with a single wall;
- Good performance against freezing;
- Good performance in conditions where the temperature rises too high;
- The working condition of the collector is at low pressure;
- No need for automatic valves;
- No decay in the collector;
- Minimum time to compensate for lost heat.

Disadvantages

- Difficult and precise installation for proper draining of fluid from the collector;
- Having a static head for the pump;
- The need for an additional tank for drain back;
- Susceptibility to increasing operating costs.

Two-phase – Thermosyphon

In this system, the liquid refrigerant reaches the boiling point in the collector and steam is formed. This vapor moves to the storage tank where it is compressed and returns to the collector as a liquid. In terms of performance, this system is similar to the direct thermosiphon system, with the difference that this system is resistant to thermal freezing. The efficiency of this system will not be significant compared to drain back systems, but this system can be compared with pumped systems. The noteworthy point in the installation of these systems is that it requires sufficient skill in the field of refrigerants [10].

Advantages

- Propensity for high productivity;
- No need for pumps, controllers and automatic valves;
- Frost resistance;
- No decay in the collector ring.

Disadvantages

- The difficulty of installation and the need for sufficient skill;
- The efficiency is not high enough;
- The possibility of heat loss in the tank is high;
- Resistance to high temperatures is simply not possible.

One Phase Thermosyphon

In this type of system, a fluid such as glycol is used. Although this system is not widely used compared to other systems, tests have shown that its efficiency can be assumed to be equivalent to 90% of a direct telephone system.

Advantages

- No need for automatic valves, pumps, controllers;
- Frost resistance;
- No decay in the collector;
- Minimal corrosion.

Disadvantages

- Low efficiency;
- Heat loss from the vine cannot be high;
- Resistance to high temperatures is simply not possible;
- Need an expansion source.

Inexpensive systems

Among the systems introduced in Iran for tropical regions, the Breadbox system is preferable to the drain back system. Also, ICS system can be used in these areas with good efficiency.

- In general, according to the costs paid, the potential for reducing the price, high efficiency, stability and simple installation, a drain back system is introduced as the best choice for home solar water heaters.
- According to the choices available in the drain back system, the use of a siphon and proper drainage will be useful in increasing the efficiency of the system.
- In the drain back system, one of the defects is the presence of static head, so in this pump system, in addition to the static resistance of the pipes, it must also overcome the static head caused by the fluid column. On the other hand, if there is a siphon flow, a controller is needed to adjust the pump to work in different periods. Despite these measures, due to the low efficiency of existing pumps, the wasted energy of the system is higher than other existing systems.
- Both load-side and collector-side converters can be used in drain back systems. With the explanation that in the second choice, it is possible to use cheaper tanks, although it requires sufficient care in the design so that its useful performance is high.

- Plumbing is considered as one of the main parts of the cost. To reduce costs, CPVC and PB pipes can be used as an alternative to copper pipes. However, comparing the two pipes, the second one (pb) is cheaper and more acceptable in plumbing.
- Depending on the type of system, wood, plastic and thin metal sheets can be used for storage tanks.
- The use of cheap collectors, plastic pipes and cheap storage tanks can greatly reduce the payment costs.

Cheap collectors

- Among the collectors used in solar water heaters, polypropylene fiberglass collectors with black fluid are used more than others.
- Collectors made of thin layers of Teflon are known to be effective and the only problem is their price.
- Depending on the type of design, different materials are used for different parts. For the collector, if the temperature of the collector is high, thin polymer layers such as Teflon and Tefels can be used. Also, both aluminum and steel metals are suitable substitutes for copper in the production of absorbent plates [11].
- Among the materials investigated for use in transparent coating, several polymers were identified, among which polymer fluorocarbons such as Teflon, Tefels and Kynar have better properties than acrylic polymers. Also, glass, as a suitable cover, is always the most consumed material that can be used in the transparent cover structure [11].

Conclusion

After examining different solar water heaters and understanding the capabilities of each of these systems to meet the design criteria in this project, we narrow down the scope of design and examine systems that suit the country's climatic, economic and cultural conditions. In this regard, considering the diversity of Iran's climate, we will compare 4 solar systems selected from among the introduced systems under the same conditions and in most cases we will introduce a suitable system proposal. It should be noted that according to the perspective of this project, high efficiency and reasonable economic price are considered two main factors and to a large extent, they affect other design criteria. Therefore, in introducing the optimal system, you should pay attention to this point. Among the 13 introduced systems, 4 drain back, ICS, drain out and Breadbox systems are close to the design criteria proposed in this project. In a general view, the very simple structure of the breadbox system is clear, so that the payment costs of this system are lower compared to other water heaters. Another example is the ICS system, which can save a large part of the costs by presenting this system in the form of a package. Not needing a pump as one of the expensive parts and other things has made this system chosen in tropical regions. The other two examples that we have learned more about their function and structure in the past seasons have a relatively higher price. It should be noted that in this table, these 4 systems have been compared with each other in terms of structural materials, and many selection criteria or factors affecting the selection criteria for choosing the right system have not been mentioned. For example, resistance to freezing is one of the important factors that affect the useful life of the system, while this problem does not exist in drain back systems. ICS system is very vulnerable to it.

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