Exploring Solar Water Heating Systems and Uses at Ft. Stewart, Georgia USA

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This research was performed to explore the different options available for solar water heating. Renewable energy technology has become more popular. As the world looks to reduce energy costs and carbon footprints, this type of technology is being used more frequently. This technology has been around for over 100 years, but developments for this technology have been intermittent due to different obstacles it has faced. It is important to understand how the different systems work and what type of systems are available. This research broke down the basic components that are available for solar water heating in order to get a better understanding of the systems as a whole. Solar waters heaters are capable of providing 40% to 80% of a building's annual water-heating needs (Clyne, 1999). The wide range of savings is not only a result of the different types of systems available, but also because of the different environments that this technology can be used in. The efficiency of these different systems was explored to find the best uses of these different systems in the various environments. A real world problem was discussed and different solutions were given based on the research performed on solar water heating systems.

Key Words: Collectors, Thermosyphon System, Drainback System, Photovoltaic Pump

Introduction

Solar water heating can be used for a wide range of applications. In residential use it can be used to support showers, kitchens, and laundry. Solar water heating can be used for a wide range of commercial and institutional buildings including cafeterias, day care centers, libraries, schools, hospitals, clinics, prisons, office buildings, and gyms. In the United States of America, residential and commercial buildings account for 40% of the total energy consumption of the country (Hudon, Merrigan, Burch, & Maguire, 2012).

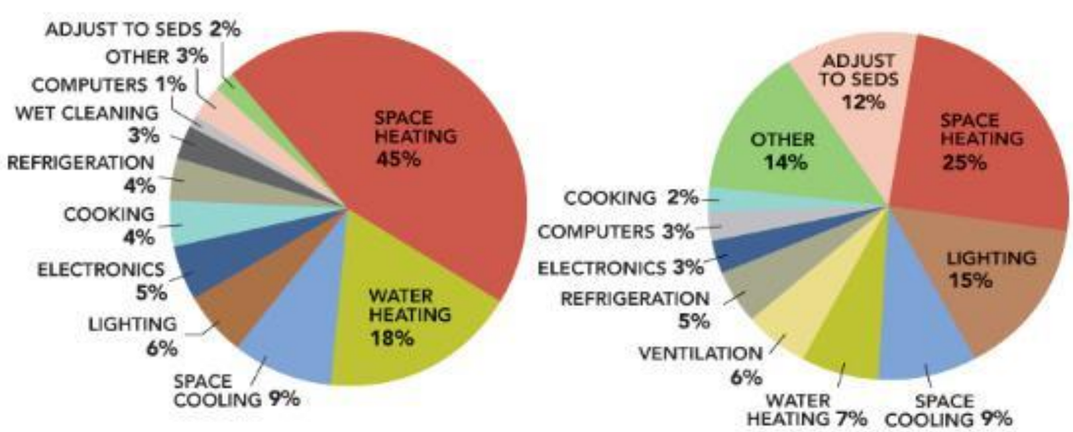

Figure 1: 2008 building energy end-use for residential (left) and commercial (right) (Hudon, et al., 2012)

Water heating accounts for a large percentage of the energy usage in both residential and commercial buildings (see Figure 1). This makes solar water heating an appealing technology for energy savings and reducing carbon footprints of buildings. There are a lot of factors that go into choosing the right type of system. The basic components for a solar water heating system will be broken down in order to gain a better understanding of how these systems operate. Each system primarily uses a different configuration of the components that will be looked at. There are other technologies that can be combined with solar water heating systems to increase the system's efficiencies. A photovoltaic pump is an example of one of these technologies that will be discussed. There are different factors to consider when designing a solar water heating system. A few of these factors are the structure that supports the system, different climates, and hot water load of the facility. These will be looked at to gain a better understanding of the considerations that need to be taken when designing this system. A solar water heating system installed at Ft. Stewart, GA will also be looked at. The current user questions the energy efficiency of the design.

Background

Solar water heating has been around since 1891, when the first solar domestic water heater was patented (Pahl, 2003). The development of this technology since then has been inconsistent. It dropped off during the 1930's due to copper shortages and incentives from electric companies to switch to their hot water heaters. It picked back up during the OPEC oil embargo in the 1980's for a brief period until President Reagan did away with solar incentives (Pahl, 2003). Without the added tax benefit, these systems are hard to economically justify when adding to an existing building (Corporation for Solar Technology and Renewable Resources, 2000). Another reason for the long lapse in the use of this technology is due to the poor designs and installation of the systems installed during the 1970's and 1980's (Corporation for Solar Technology and Renewable Resources, 2000). Presently this technology is being explored again due to the energy efficient and green culture the building industry is heading towards. There have been more than 120,000 solar water heating systems installed between 2007 and 2010 due to a passage of the federal 30% investment tax credit (Hudon, et al., 2012).

Purpose of the Study

Solar water heating is a renewable energy technology. The idea is to use solar energy to create heat for hot domestic water lines. There are many types, configurations, and components of this system available. The purpose of this paper will be to explain how this technology works and explore the different types of systems available to implement this technology. This paper will help readers understand these systems and make an educated decision on which type of system is better for any given situation. There are currently a lot of different sustainable concepts being brought into the construction industry. Solar water heaters are becoming more common on buildings now than in years past. Even though these systems are becoming more common on construction projects, there still seems to be a lack of knowledge on these systems. Talking to the various staff members of prime contractors and mechanical contractors, there is not a good understanding of why different systems were chosen or how different systems will work. This paper breaks down solar water heating to help the reader gain enough knowledge to understand what is being installed and what questions need to be asked about the systems. An issue with a solar water heater that was installed on a project will be shown as an example of how this knowledge is useful.

Components of Solar Water Heating Systems

Different solar water heating systems each contain a different combination of the same basic components. Understanding each of the components and how they support the system is important because it makes it easier to understand how the different systems work when the different combination of components are used. The following list comprises of the main components and functions that each serves.

Solar Collector – collects heat from the sun and transfers it to the system. This is the primary component of the system and includes mounts for support.

Tank - stores the hot water for use when the solar energy available is minimal. Pump – circulates the water or fluid through the system.

Reservoir - stores water that is vacated from the piping system to prevent freezing or overheating.

Heat Transfer System – transfers heat from collectors to end user. This component includes piping, valves, pumps, fans, and heat exchangers.

Controls – manage the flow, collection, and timing of the system.

At a minimum, the tank and solar collector are required for a solar heating water system. The other components are required on an as needed basis depending on the type of system. If properly maintained, the system components of a solar water heater can potentially last greater than 30 years (Mumma, 2011). Along with these components, a solar water heating system is normally installed with an alternative source of hot water. Normally an electric or natural gas system is used for this function.

The solar hot water systems have a high installed cost which limits the amount of systems that are installed. Even though this technology has been proven effective, solar water heaters make up less than 1% of the U.S. water heating market (Hudon, et al., 2012). The solar collectors and mounts make up over half of the total cost of a solar water heating system (Figure 2).

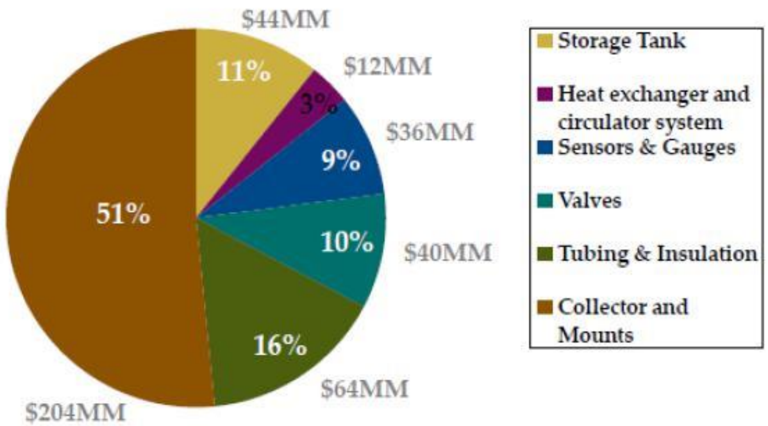

Figure 2: U.S. Solar Water heating Component Market Values in 2009 (Hudon, et al., 2012)

Solar Collectors

There is an assortment of solar collectors available for solar water heating systems. It is important to know the characteristics of each type in order to choose one for a specific application. Collectors are designed as modular units (Society, A.S.E., 2001). This way the size of the building does not necessarily dictate the type of solar collector that is needed. Each collector has distinct characteristics that need to be considered when choosing one for a design. Collectors can be mounted on roofs of building, walls of buildings, and at ground level depending on the type of system that it is installed with and the building that it is supporting. Collectors need to be installed on an incline facing the south and receive the most sunlight during the hours of 0900 - 1500 (Rodgers, McManus & Cooper, 2013). The following is a list of the primarily used solar collectors that will be explored:

- Unglazed Collector
- Flat Plate Collector
- Evacuated Tube Collector
- Parabolic Trough Collector

The unglazed collectors are simple and inexpensive. This collector contains a plastic absorber with extruded flow passages (Clyne, 1999). This collector normally does not contain insulation or an enclosure. Because of the absence of the insulation, this collector needs to be used with a system that requires a low-temperature application where the heat loss to the ambient temperature is negligible. This type of collector is the most used collector in the U.S. because it is the best choice for a pool water heater (Marken, 2012).

The flat plate collector is typically installed on roofs. It is made of a panel shaped box containing fluid-filled tubes mounted on a dark colored absorber. The panel shaped box is a metal enclosure. High temperature insulation and a sheet of low-iron tempered glass are installed on the collector as well (see figure 3). The low-iron tempered glass passes about 7% more light to the absorber than typical window glass. It is also tough enough to withstand most hailstones (Marken, 2012). It is suitable for residential and non-residential uses. It operates well in humid climates where the sunlight is more hazy and diffuse rather than direct (Clyne, 1999). The flat-plate collector has an efficiency range of 40%-50% (Hudon, et al., 2012).

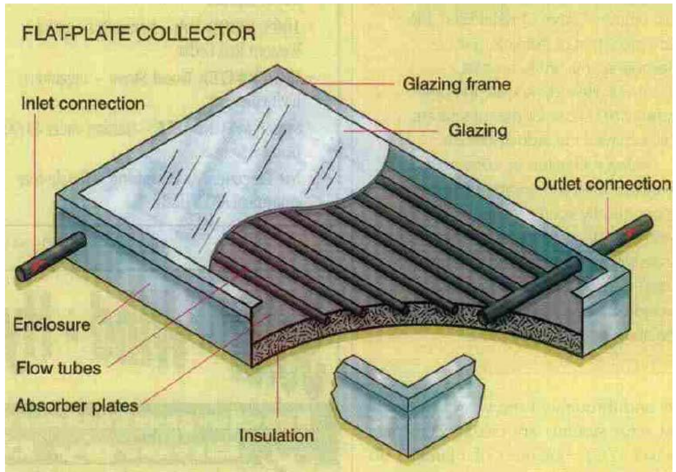

Figure 3: Flat-Plate Collector (Pahl,2003)

The evacuated tube collector has an absorber plate that is surrounded by a glass tube and a vacuum between the plate and tube. The vacuum acts like an excellent insulator that reduces heat loss. This type of collector is often used in colder climates and cloudier regions because of the lower heat loss (Marken, 2012). This collector operates at high temperatures ranging from 170°F - 250°F and has an overall operating efficiency of 30%-45% (Hudon, 2012). It has high efficiency when using both direct and diffuse light (Clyne, 1999). Due to the higher cost of this collector, a study needs to be performed for the area that the system is designed for to see if the payback for this type of collector is worth the additional up-front cost.

The parabolic trough collector consists of a long, U-shaped mirror that focuses the sun onto a fluid filled tube along the center of the trough. This highly efficient collector typically tracks the sun and requires direct, not diffuse, sunlight. This type of collector has a high maintenance cost associated with it because the mirrors need to be constantly cleaned and the high-pressure design of the systems leads to seals needing to be replaced often. It is chiefly used in nonresidential and institutional applications, such as prisons and hospitals (Clyne, 1999). This type of collector is more suitable for facilities that have a higher hot water load. Due to the requirement of direct sunlight, this collector should not be installed in cloudy regions.

Photovoltaic Water Pumps

Some solar water heating systems use pumps to circulate the water or fluid through the system. A pump normally requires traditional fossil fuel based energy. A photovoltaic pump allows the system to operate even more off of solar energy. During the day time peak hours of utility costs, the photovoltaic pumps will run off 100% solar energy. This will reduce utility cost of the facility. There are other benefits to using a photovoltaic pump as well. In a solar water heater, the fluid or water only needs to circulate during times when solar energy is available for use. A photovoltaic pump can act as a fast-response sensor to solar energy and therefore pumping will only occur at the times when the thermal collectors are also receiving radiation (Al-Ibrahim, Klein, Mitchell, Beckman, 1999). There have been test performed that prove the photovoltaic pump solar water heaters outperform the conventional solar water heaters. There is also the added benefit of the pump still working when there is a power loss to the building. The buildings carbon footprint is also reduced using a photovoltaic pump system. This system does have a higher first cost due to the additional collector that is required for the photovoltaic pump.

Solar Water Heating Configurations

There are a few basic configurations that need to be explained to understand how the different solar water heating systems work. The following configurations will be looked at: (1) Active, (2) Passive, (3) Direct, and (4) Indirect. Active solar water heating systems use pumps to circulate the water or fluid through the system (see figure 4). The water is heated at the collector and then pumped to the storage tank. It is stored in the storage tank until it is needed. Active type systems are more expensive than passive systems because they require more components. An active system needs pumps and controls in addition to the solar collector and storage tank. The additional mechanical components also cause this system to have a higher maintenance cost (Clyne, 199). There are multiple benefits that come with this system that need to be considered when weighing the cost. This type of configuration allows a designer flexibility in where the system is installed because the tank does not need to be at a higher elevation than the collector. This also allows for the tank to be placed in a location that reduces heat loss. The user has more control over this system than a passive system because the pump can be either manually controlled or the user can use a control system with a wide range of adjustable parameters.

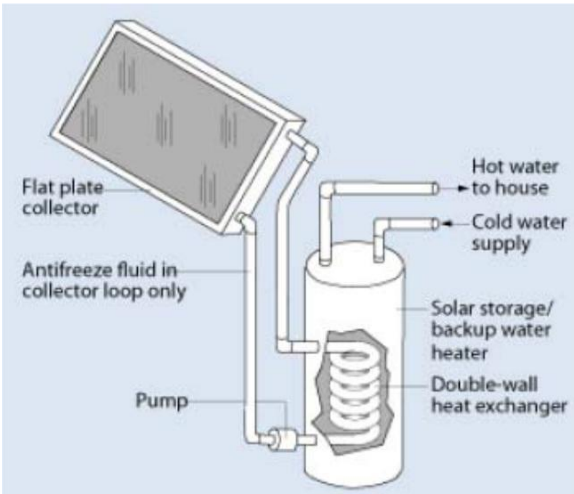

Figure 4: Active & Indirect Solar Water Heating Heating
Configuration (Energy.gov,2012)

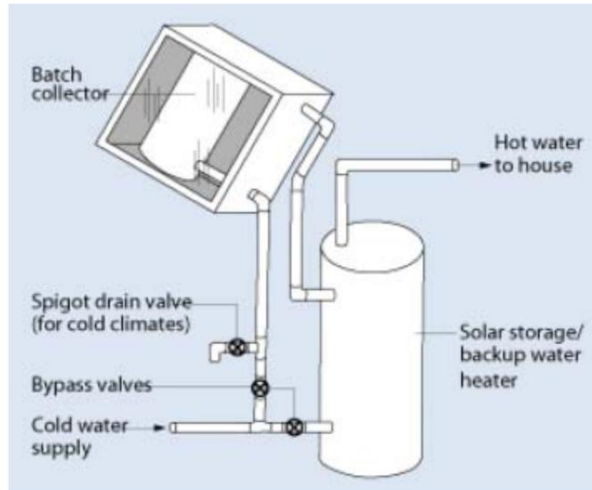

Figure 5: Passive & Direct Solar Water
Configuration (Energy.gov,2012)

Passive solar water heating systems are simple systems that rely on gravity and convection to circulate potable water through the system (see figure 5). This type of configuration is less expensive and requires less maintenance than an active configuration because it requires fewer components to work. The user has less control of this type of system. The additional cost that will need to be considered for this system is extra supports when installed on a roof. This type of system will have water above or inside the collector which will result in a heavier load. Because of the lack of control and design capabilities, this type of system is subject to overheating and freezing. This type of system should only be used in warm, sun-belt climates that do not experience freezing temperatures often (Clyne, 1999). Because this is a simple type of system, if installed in a location described above, it has a longer life expectancy over other types of systems (Energy.gov, 2012)

A direct or open loop system circulates the potable water through the system for heating. This is a simpler system than an indirect loop system because you only have one loop in the system. There are issues that need to be considered when working with a direct system. This type of system is susceptible to freezing because the only loop has potable water and cannot contain antifreeze. There are freeze tolerant collectors that are available for these types of systems. These collectors are built to expand during freezing conditions. Even with these types of collectors available, this type of system is more suited for climates where freezing is uncommon (Energy.gov, 2012). Pumps are optional with direct systems. Using a batch collector will eliminate the need for a pump (see figure 5).These systems are sometimes installed with water softeners to reduce the scale build up that could potentially damage the system. Direct systems are more efficient than indirect systems because there is no heat exchanger, which normally loses heat (Pahl, 2003).

An indirect or closed loop system uses a heat exchanger to transfer the heat from the loop that contains the transfer fluid to the potable water loop. This system has a higher cost associated with it than a direct system. It does offer protection from overheating and freezing due to the chemicals that can be added to the heat transfer fluid (Pahl, 2003). These types of systems have a higher maintenance cost because they contain more components. Indirect systems are better suited for colder climates where sacrificing efficiency and cost are a good trade off for the protection offered during freezing months.

Types of Solar Water Heating Systems

There are multiple systems available for solar water heating using the different components and configurations that have been explored. Each system has benefits and drawbacks that need to be considered when choosing one for a building. The systems that will be looked at are a drainback system, integral collector/storage system, direct circulation system, indirect circulation system, thermosyphon system, and a closed- loop glycol system. A drainback system is an indirect active system that is different than most other system because it includes a reservoir tank. The purpose of the reservoir tank is to allow a safe place for the water or fluid to flow to when the loop is not active. This gives the system freeze and overheating protection. This system also requires controls so the pump can turn on and off at designated temperature limits (Pahl, 2003). This protects the system from freezing because there is no fluid in the system that can freeze when temperatures are too low. This type of system is considered to have the least maintenance of the closed loop systems (Pahl, 2003). There are disadvantages to this type of system. The system requires a bigger pump to be installed than require in other systems because in needs the extra head pressure due to it being an unpressurized system. This results in a higher first cost and operating cost.

An integral collector/storage system is a passive direct system that combines the collector and storage tank into one unit (Clyne, 1999). The collector is insulated on all sides except for the glazed side that collects the solar energy. The insulation and size of these units protect it from freezing (see figure 5). This type of system is easier to maintain and more reliable than other systems because there are not many components required for this system. This system does not require a pump because it uses the building water pressure to circulate water through it (Hudon, et al., 2012). This type of system could result in additional first cost due to the extra structural support needed because of the weight of this system. A direct circulation system pumps water through the system for use. These systems work best were it rarely freezes (Enegy.gov). This system does not require a heat exchanger and falls in the middle of the pricing range for solar water heaters. An indirect circulation system can be used where there are freezing temperatures and cost more than the direct circulation system due to the additional cost of a heat exchanger.

A thermosyphon system is passive system. This system requires a tank to be installed above the collector. Warm, less-dense liquid in the collector rises and remains in the tank above until it is needed. The water will sink back down to the collector as it cools and becomes denser (Clyne, 1999). This type of system has the same structural restrictions as the integral collector system. These systems are reliable but cost more than integral collector systems (Energy.gov, 2012). A closed-loop glycol system is an active indirect system. This system uses a continuous supply of antifreeze to prevent the system from freezing. This system is a good system to combine with a photovoltaic pump to get maximum efficiency from (Pahl, 2003). This system does require some type of protection from overheating due to the potential for the glycol to become acidic at high temperatures. This could result in the degradation of the piping. There is also a higher operation cost with this type of system because the fluid that contains the glycol needs to be change out every few years. A controller should also be installed with this system to prevent the fluid from circulating when there are freezing temperatures as to prevent heat loss from the storage tank.

Considerations for Solar Water Heating Systems

Knowing what components, configurations, and systems are available for solar water heating is important. However, there are other factors that need to be considered when installing one of these systems. The efficiency and functionality of these systems strongly depend on the outdoor temperatures, the temperature in which the water needs to be heated too, and the amount of sunlight that the collector will be exposed too (Clyne, 199). As discussed previously, some systems perform better in the northern climates where it freezes often and some systems perform better in the extremely southern parts of the country where it never freezes but the temperatures are often extremely high. Some collectors perform better in cloudy areas were direct sunlight is not normal like in the northwest areas of the U.S, while others perform better when exposed to frequent and direct sunlight. In cloudy regions, a larger heat storage tank with superior insulation should be considered as well (Rogers, et al., 2012). The efficiency of the collector will increase as the collection tank increases in volume, but the temperature of the usable water will decrease (Comakli, Cakir, Kaya, Bakirci, 2012).

Some other factors to consider when installing these systems are the payback period, cost-effectiveness, and installation area (Clyne, 1999) . The payback period of these systems is shorter for buildings that have a constant hot water load. Buildings that are not used during the weekends or get closed down for extended periods of time, like schools or office buildings have a longer payback period. The local energy cost also needs to be considered. These systems make more sense in areas that have high energy cost. This will also affect the payback period. There needs to be sufficient installation area available for these systems as well. These systems typically require 1 to 1.5 square feet for each gallon of water used per day on average (Clyne, 1999).

Solar Water Heating System at Ft. Stewart, GA

A solar water heating system was installed on a three story administration building at Ft. Stewart, GA approximately a year ago. The system installed is an active direct system that includes evacuated tube collectors, auxiliary boiler, pumps, and controls (see figure 6). The user is questioning the efficiency of the design because this particular system uses a heat dump feature to protect the collectors from overheating. Overheating has been discussed as a potential issue with collectors. The heat dump feature on the current system dumps hot water through a dump valve when the temperature reaches 170°F. When dumping the hot water, another valve opens to let cold domestic water into the system. The dump valve closes when the tank falls below 165°F. The main issue with this feature is that during the summer in southeast Georgia, the outside temperature stays between 90°F-95°F on average. There is also a high level of solar energy available during these times. There is not a large hot water load on this building because it is an administration building that is closed during nights, weekends, and holidays. When the building is in use, the hot water is primarily used in restrooms. During the summer, this system is constantly draining water to keep the solar collectors from overheating. Another way to design a heat dump is to install a long run of copper piping and let hot water flow through it back to the system. The water will radiate a sufficient amount of heat to cool down the system without dumping water. The issue this type of heat dump is that there needs to be sufficient amount of space available to install enough un-insulated pipes to dump the heat required to cool the system. The cost of the copper piping also needs to be taken into consideration, as this will increase the installation cost of this system.

Some of the other viable options that have been discussed previously that would work well under these conditions would be a drainback system or an integral collector/storage system. During the design, these options should have been presented to the user. A discussion of the tradeoffs should have also taken place. A drainback system would eliminate the need to dump water because the collector is protected from the heat by letting the fluid drain to a reservoir when the temperature reaches a certain level. This system will require more energy usage due to the large pump required on a drainback system. The other option that could have been presented to the user would have been an integral collector/storage system. A large volume tank would eliminate the overheating issue as long as the surface that collects the solar energy is limited. With this design it would take longer to raise the temperature of the water in the tank. There would also be additional supports required at the roof to support the additional weight. The designer should have discussed these different types of system with the user to find which would be preferred and to give the user knowledge of how the system that was being installed operates.

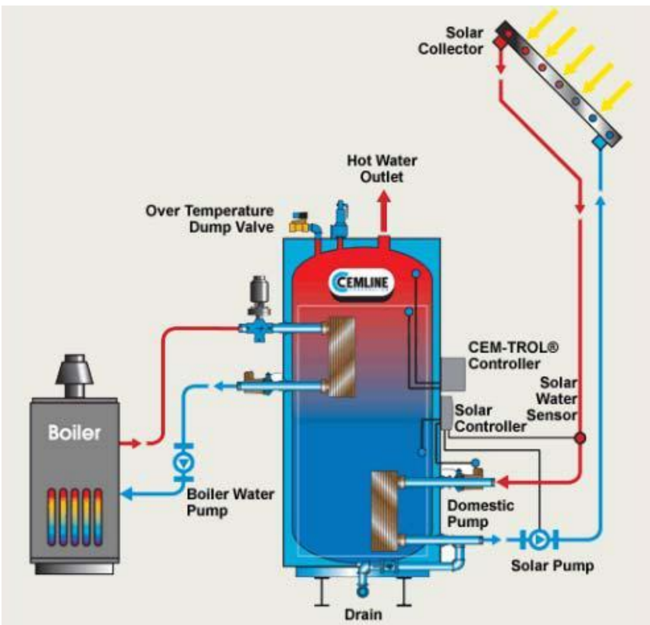

Figure 6: Solar Hot Water System at Ft. Stewart, GA

Conclusion

Domestic hot water systems account for a large part of the total energy usage by buildings. Solar water heating systems is proven technology that will save on energy costs and reduce the carbon footprints of buildings. These systems have been evolving for over hundred years. The development of these systems has stalled at times due to lack of interest and other obstacles. These systems are seen a lot in today's construction world. Different components, collectors, configurations, and systems have been looked at to gain a better understanding of how a solar water heating system operates. Knowing what problems exist such as freezing, scale formation, and overheating, will help tremendously on the design of these installations (Deng, Wang, Zhao, Yao, Wang, 2011). These known issues of solar water heating are constantly being researched to find better ways to implement these systems. Having the basic knowledge of what currently exist for solar water heating will go a long way in designing and choosing these systems. Using the knowledge gained through this paper, solutions for the problem at Ft. Stewart, Georgia were presented.

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