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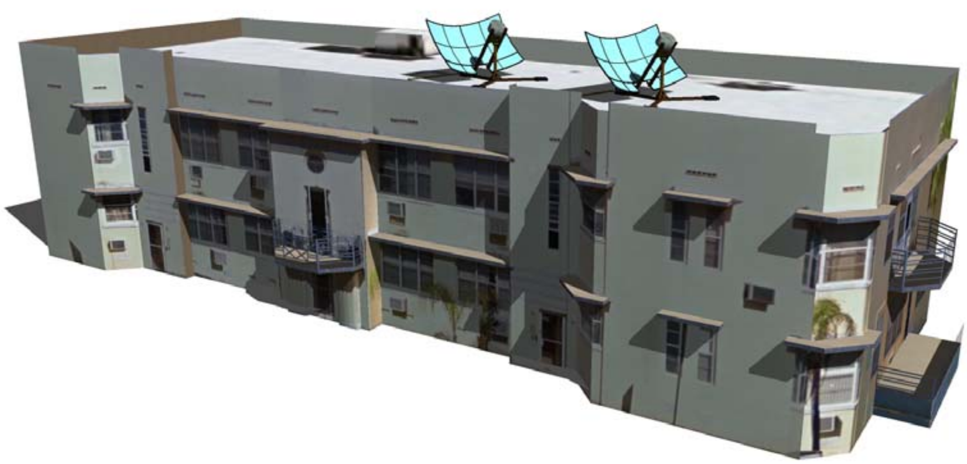
High Efficiency Solar Hot Water System for Multi-Family Residences

With respect to the upcoming workshop: https://www.energy.ca.gov/calendar/index.php?com=detail&eID=3259, Thermal Storage Systems requests consideration of the adaptation of its technology developed under SBIR funding for the US Army consisting of a deployable solar hot water system. This technology is well suited for adaptation to multi-family residences, especially for retrofits, since installation is very simple, eliminating the need for large hot water storage tanks, and most of the plumbing required by flat plate solar systems. Please see attached summary paper.

Additional submitted attachment is included below.

Concept Paper
Commercial-Scale Tankless Solar Hot Water System



Thermal Storage Systems
5646 Valley Oak Dr.
Los Angeles, CA 90068
323.284.0557
info@thermalstoragesystems.com
www.thermalstoragesystems.com

Commercial-Scale Tankless Solar Hot Water System

Thermal Storage Systems' core technology is a proprietary compact high temperature thermal storage system that forms the heart of a deployable tankless solar hot water system currently being developed for use at US Army forward operating bases. A variant of this system, modified for use on mid-sized structures such as apartments, office buildings and hospitals, has the potential to make solar hot water systems considerably more practical and cost effective. Significant savings over the current technology can be achieved through the elimination of hot water storage, heat exchangers and most of the additional plumbing normally associated with these systems. Installation labor typically constitutes about 1/3 of the installed cost of a building solar hot water system, with plumbing materials constituting another significant cost component. With retrofit systems these costs can be an even higher percentage of the total. In addition, the system can eliminate the problem of overheating that limits the capacity of existing systems, while also eliminating the potential for freezing during cold weather.

Background

Solar hot water (SHW) systems have played a key role in the national effort to reduce dependence on energy derived from fossil fuels. To a great extent the success of these systems only has been made possible through subsidies in the form of rebates and tax incentives from federal, state and local governments. Without these incentives the financed cost of SHW systems based on existing technology greatly exceeds the corresponding cost of producing hot water with fossil fuel fired systems. At the present low cost of natural gas in the United States (<$1.00/Therm in some areas) these systems are only marginally attractive even accounting for the available rebates and tax benefits. A new approach that substantially reduces the installed cost of SHW systems would make them more competitive with fossil fuels, increase their prevalence, and decrease the need for taxpayer support.

Current flat plate or evacuated tube SHW systems, while conceptually simple, become complex when the realities of installation are addressed. Integration of flat plate SHW devices into a building's water system can involve extensive (and expensive) plumbing systems and the installation of large hot water storage tanks. The associated costs are a significant consideration in the economics of SHW systems. This is particularly true when considering retrofitting SHW systems into existing buildings[1].

An additional consideration with fixed flat plate or evacuated tube collectors is that they typically cannot be sized to meet all of a building's hot water needs. To prevent system overheating during warm weather, the system's capacity must be restricted to meet hot water demand during the longest days of the year. As a result, it falls short of required production when the days are shorter. For example, a system sized to provide 100% of a building's hot water needs during July may be capable of providing only 20% of the required hot water during January due to the lower insolation in that month.

Thermal Storage Systems (TSS) has a novel approach to providing solar hot water that it believes can address the shortcomings of conventional solar hot water systems and which substantially lowers the cost of system acquisition, installation and operation. TSS is under contract with the US Army to develop a man-portable, self-powered, solar hot water system based on this technology for use at US Army Forward Operating Bases. (Henceforth the deployable solar hot water system, shown in Figure 1, will be referred to as the DSHW). This same

[1] Comments are confined to installations in larger buildings. TSS is specifically excluding SHW systems for single family homes.

technology adapted for use in commercial buildings is projected to have an installed cost of $15-$20 per annual therm for new construction. This is a substantial cost reduction compared to the cost of conventional SHW systems. Even greater savings are possible when retrofitted in existing buildings, for which the retrofit installation of conventional solar hot water systems is problematic.

Deployable System Design

The deployable solar hot water system (Figure 1) uses a two-axis tracking concentrating solar collector mirror that is integrated with a proprietary passive thermal storage device (TSD) located at the focus of the collector[2]. Concentrated sunlight reflected from the mirror is captured and stored directly in the TSD as heat. The TSD retains this thermal energy until there is a demand for hot water, at which time the energy is extracted (in the form of steam) and used to heat water. This approach obviates the need for supplementary hot water storage tanks and their associated cost and complexity. An innovative and unique attribute of the system is its ability to store large amounts of energy in a small volume (0.13 cubic meters).

Figure 1: Deployable 250,000 BTU SHW system. The energy storage device is the grey cylinder located opposite the collector mirror.

Each individual DSHW unit produces a net 250,000 BTU per day for hot water production[3]. This energy is sufficient to raise the temperature of 600 gallons of water by 50 ^{o}F. The solar collector is a rectangular parabolic reflector that is 15 ft wide by 9 ft high and has 133 ft^2 of un-obscured aperture. As the US Army desires that the unit be entirely self-powered, the electrical power required to run the tracker and water pump is produced internally from the stored energy.

The result is a system incorporating a novel and inexpensive passive thermal storage device that has both high power density and high energy density. For comparison, the energy storage density of the TSD is 22,000 BTU/ft^3, whereas the energy that can be stored in a hot water tank operating between 150 ^{o}F and 210 ^{o}F is 3,700 BTU/ft^3. The advantages of high power and energy density manifest themselves in the reduction of system size, insulation requirements, installation complexity, and cost., Unlike conventional solar hot water systems the device delivers full temperature hot water independent of the exhaustion ratio and is relatively insensitive to ambient temperatures.

The overall sizing and many of the features of an individual DSHW were driven by the Army's requirement that multiple units be transportable in 6½ ft long standard shipping containers and by the requirement that it be unpacked and assembled by soldiers without the use of lifting devices.

[2] Patents pending.
[3] This performance assumes that the total solar irradiance is 1 kW/m^2, 80% Direct Normal Insolation, and 10 hours of daylight.

Commercial Systems

TSS intends to adapt the basic technology used in the DSHW system to produce a commercial scale solar hot water system for use in medium-sized industrial, office, and apartment buildings, and other fixed sites. The system will be designed to integrate with standard building water systems and will include a mechanical support system that is appropriate for rooftop mounting. The control system will permit the system to operate seamlessly with an existing building hot water system.

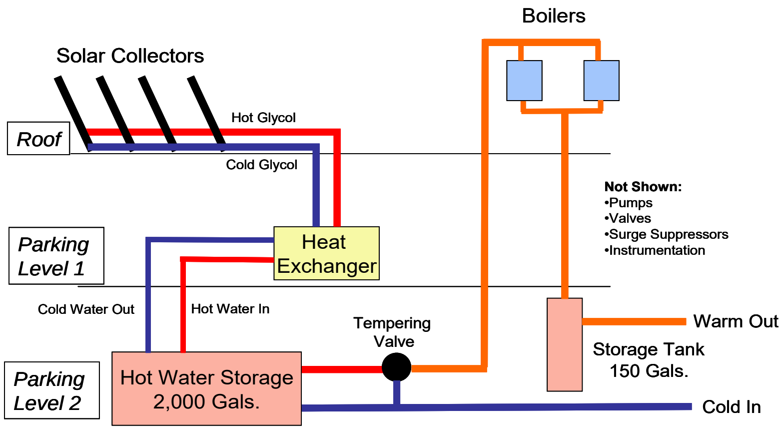
Comparison Example

A new 70-unit apartment building in Southern California (Figure 2) has been equipped with a conventional flat panel-type solar hot water system (the "Comparison System"). A simplified schematic of the Comparison System is presented in Figure 3.

Figure 2: Selected commercial building, installed conventional roof-mounted SHW, and adjunct 2000 gallon hot water storage tank in the building's basement tank (on the right). In the middle photo note the proximity of the natural gas boilers to the solar collector.

The Comparison System is comprised of 1,280 ft^2 of flat plate solar collectors, which are nominally capable of producing 953,000 BTU/day. Water heated by the solar system is stored in a 2,000 gallon basement hot water tank, which serves as a source of pre-heated water to the roof-mounted boilers. Temperatures in the hot water tank range from 60° F at the cold water inlet to a maximum of 210° F at the top of the tank (high temperature limit for the tank). Given this gradient, the tank is capable on average of storing energy equal to 1,250,000 BTU, or slightly more than one day's production by the collectors. This large amount of storage was likely determined based on the usage profile for an apartment building, where demand is likely to be greatest during hours of non-sunlight.

Figure 3: Simplified Schematic of the Comparison System



Hot water usage per unit for a typical apartment averages 76 gallons/day[4]. Assuming a hot water temperature of 140°F which must be heated from 60°F, the total energy required to heat water for a 70 unit building is 3,536,160 BTU/day. This amount of energy amounts to 3.7X the production of the flat plate collectors on the Comparison System. This limitation is likely due to a combination of system high temperature limitations (discussed previously) and economic considerations, given that a simple payback for this system after rebates is around 14 years.

Approach Using TSS Technology

The TSS approach uses roof-mounted collector/TSD assemblies to collect and store solar energy. As with the DSHW, the energy stored in the TSD is used to produce hot water on demand.

As required, a small thermostatically controlled pump circulates water through a heat exchanger in the TSD to produce steam. The steam is then mixed with water at either the inlet or the outlet of the existing roof-mounted boilers using a sparger or eductor inserted into the boilers' 4" water line (Figure 4)[5]. This configuration eliminates the need for any additional plumbing that must penetrate the roof. Also, the heat exchanger and large hot water storage tank employed in the conventional system are eliminated.

To achieve energy collection and storage equivalent to the Comparison System, four DSHW-sized units would be required[6]. The reflector area of each would be the same as for the DSHW. This would provide an aggregate net energy of 1,000,000 BTU/day. Storage capacity of each TSD would be increased from 145,833 BTU to 312,500 BTU

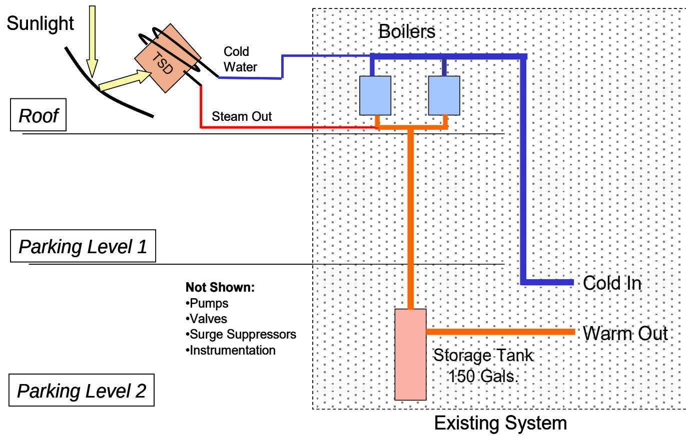
[4] "Domestic Hot Water Consumption in Four Low Income Apartment Buildings" *Energy* Vol 12, No. 6 pages 459-467, 1987

[5] The DSHW design uses a thermostatically controlled mixing valve to combine steam and cold feed water to produce hot water on demand. For building installations with a hot water tank in conjunction with a boiler, this would be an unnecessary expense.

[6] Of course, these would be variants of the DSHW modified to be appropriate for commercial applications

to provide a total of 1,250,000 BTU, equaling the capacity of the Comparison System 2,000 gallon hot water tank.

Figure 4: Notional Schematic of the TSS SHW System



In other installations that do not have roof-mounted boilers, it would be necessary to run a small insulated steam line from the TSS system to the location of the building boiler or existing hot water tank. In any event, the need for a large hot water storage tank, heat exchanger and the substantial amount of associated plumbing would be eliminated. In the case of systems that would be retrofitted into an existing building's hot water system the sparger can be mounted in an available hot water tank port, or at some point external to the tank if a port is unavailable. Again, system plumbing would entail only a single steam line from the DSHW location to that of the building boiler[7].

The TSS approach thus allows a more seamless and less expensive integration of a SHW system into a commercial building. Also, as discussed above, the size of the TSS SHW system is not constrained by the need to prevent overheating on long days, unlike conventional solar hot water systems.

[7] The source of water for the production of steam can be from any outlet that is close to the SHW system (e.g. on the roof) further reducing the plumbing costs.