INTEGRAL PASSIVE SOLAR WATER HEATER PERFORMANCE

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ABSTRACT

Passive solar water heaters can be divided into two classes: systems in which the functions of heat collection and storage are separate (the thermosiphon flat plate systems), and systems with combined collection and storage - the integral passive solar water heater (IPSWH). IPSWH systems are much less widely known despite some inherent advantages, including simplicity, low cost, and resistance to freezing.

The first solar water heaters widely used in the U.S. were IPSWHs. They gradually fell out of favor because of night cooldown and tank corrosion. New materials and designs minimize these problems and promise to bring the IPSWH back into the forefront of solar activity.

This paper describes recent IPSWH experiments evaluating new materials and designs. These are then correlated with work by other investigators to suggest the tremendous potential for IPSWH use around the world.

The characteristics of IPSWHs make traditional solar system test procedures inadequate and a new test procedure for IPSWH systems is proposed.

The low cost of IPSWHs more than offsets their slightly lower performance and will make them the most cost-effective heater for many climates and uses. Renewed commercial activity indicates that these heaters are finally beginning to receive the attention they have deserved all along.

1. INTRODUCTION

Passive solar water heaters can be divided into two major classes: systems in which the functions of heat collection and storage are separate - thermosiphon flat plate systems, and systems with combined collection and storage - the integral passive solar water heater (IPSWH), also known as breadboxes, batchers, etc. IPSWHs are less widely known despite their advantages of low cost, simplicity, reliability, and resistance to freezing.

The first solar heaters patented and widely used in the U.S. were IPSWHs (1). They were successfully used for many years but gradually fell from favor because of tank corrosion and night cooldown. The tank corrosion was caused by high temperature water storage in a galvanized tank. The night cool down resulted from exposure of the storage tank to the cold night sky, with resultant radiant heat loss. The solution that was used to reduce night cooldown was the separation of collection and storage (moved inside). However, separation is not the only way to reduce night heat loss.

IPSWH activity resumed in the late seventies with impetus from Steve Baer and the rediscovery of F. A. Brooks' excellent 1936 paper (2). Many successful installations have been made with traditional IPSWH designs simply by scheduling water use to fit performance. More recent efforts have focused on the use of new materials and designs to reduce night cooldown and provide more freedom in use patterns.

2. NEW MATERIALS

New materials with selective transmissivity and emissivity are particularly well suited for IPSWH use. The selective surface coatings with high absorptivity yet very low emissivity are very effective on tank surfaces and are used by many of the commercial IPSWH builders. The following chart compares IPSWH temperature with and without selective surface coating.

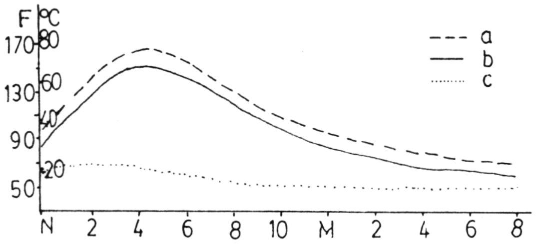

Fig. 1. IPSWH tests. a. single glazed with selective surface. b. single glazed. c. ambient air temperature.

The selective transmission films are also very promising for IPSWH use. These films are transparent to short wave radiation but reflective to long wave radiation. The following chart compares IPSWH temperature with the Southwall Corporation's Heat Mirror^{TM} selective transmission film, single glazing with insulated lid (R-10), and single glazing alone. The Heat Mirror^{TM} transparent insulation worked as well as movable nighttime insulation, and both were much better than single glazing alone.

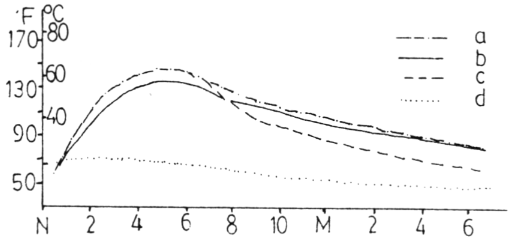

Fig. 2. IPSWH tests. a. single glazed with R-10 night lid. b. double glazed with Heat Mirror^{TM}. c. single glazed. d. ambient air temperature.

The use of phase change materials for IPSWHs is also very attractive for several reasons. A phase change at 43°C to 49°C (110 F to 120 F) would keep radiant losses down and reduce potential for burns or scalding in systems without a tempering valve. It would also extend carryover of high temperatures into the night. Some of the Glauber's salts should be tested in this application.

The other problem that faced early IPSWH builders, tank corrosion, can also be solved with new materials. The most common solution is a glass lined water heater tank, although some manufacturers use stainless steel tanks. Experience has shown that a sacrificial anode should be included with glass lined tanks.

3. NEW DESIGNS

In addition to new materials (unavailable to the IPSWH designer in 1920), several new and promising design solutions have been developed to reduce night heat loss. These include movable insulation (lids, shutters, drapes, etc.), use of an inverted collector with a reflector, and location inside the heated shell.

3.1 Movable Insulation

Steve Baer's "breadbox" water heater with insulated lids for night heat loss reduction considerably improved IPSWH performance. For consistent use and market acceptance, movable insulation must be automated, but for the owner-builder manual operation may be acceptable. A freon transfer or heat motor drive can be used for "passive" operation of movable insulation.

3.2 Inverted Collector

An inverted collector with reflector can also reduce night heat loss by exposing the collector to a warmer radiant environment. This design, first proposed by William Shurcliff in 1973, has been used successfully in Tunisia (3) and more recently evaluated in New Mexico (4). The following chart compares inverted and normal IPSWHs in Santa Fe, New Mexico and Berkeley, California. Both inverted IPSWHs exhibited reduced night cooldown. The Berkeley IPSWH reached lower daytime temperatures due to limitations in the reflector acceptance angles. Designing a reflector with wide acceptance angles will be critical for optimum inverted heater performance.

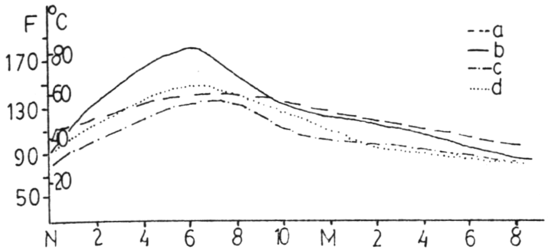

Fig. 3. IPSWH tests. a. inverted Santa Fe, 3/18. b. single glazed with selective surface Berkeley, 6/24. c. inverted Berkeley, 6/24. d. double glazed with selective surface Santa Fe, 3/18.

3.3 Location

Moving the IPSWH into the heated space can also reduce nighttime cooldown. One of the more common solutions is placement of the IPSWH in the upper section of a solar greenhouse (3) or skylight (4). Equally promising results have been achieved by locating the IPSWH in an attic passive collector (5). In higher latitudes with colder climates the IPSWH might simply be placed in a south facing window.

4. OPERATION

The use pattern can increase the performance of these improved IPSWHs, which still exhibit some night cooldown. The first step is careful use of water conserving devices and appliances. This can reduce daily hot water use from 129 liters (34 gallons) per person per day (U.S. average) to half this usage, or 64.5 liters. Careful habits of hot water use, such as running washing machines only with full loads, can further reduce hot water demand to 36 liters (9 gallons) per person per day. And with fanatical attention to use with special fixtures, need can be reduced to as little as 11.4 liters (3 gallons) per person per day.

Careful choice and use of appliances, soaps, and detergents can also reduce the demand temperature from 49°C (120 F) down to 41°C (105 F).

These two steps will increase performance of any solar system, but are particularly helpful for IPSWHs.

And finally, scheduling hot water use for afternoon and early evening when the IPSWH temperatures are highest will both improve IPSWH performance on marginal days in the summer and extend the season for IPSWH use without backup.

In Davis, California (2,814 HDD) these combined steps enabled a basic IPSWH to provide nine months of full service. Improved IPSWH design using selective surface, selective transmission films, and movable insulation can provide similar performance in much colder climates.

5. A TEST FOR IPSWH PERFORMANCE

The very nature of IPSWHs - combined collection and storage - makes traditional performance tests for flat plate systems unworkable. Yet the recent increase in IPSWH activity makes development of a workable performance test methodology important. I would like to propose the following two-part test.

5.1 Stagnant Test

A stagnant test is a fairly useful gauge of IPSWH performance. This test should be run long enough to establish collection efficiency (N = collected energy/insolation), effective insulating value ($R = \Delta T$ x tank area/heat loss, in F - ft^2 - hr/Btu, and the solar performance factor (SPF = N x R) for both summer and winter.

The following table compares the effective R values for IPSWHs tested in California and New Mexico.

Table 1. Effective R Values.

California:	
Double glazed with Heat Mirror™	3.5
Single glazed with lid (R-10)	3.4
Inverted single glazed with selective surface	3.0
Triple glazed (glass and bubble wrap)	2.6
Single glazed with selective surface	2.6
Single glazed	2.1
Exposed jug, painted black	1.3

Table 1 (continued)

New Mexico (4):	
Inverted parabolic	4.3
Breadbox with lid	3.5
Inverted snail	2.5
Skylight with enclosure	2.3
Breadbox without lid	2.1
Skylight heater	1.3

SPF values ranged from 0.2 to 1.3 for a variety of IPSWH systems described by Bristol Stickney. This compares with SPF values of 0.7 to 2.1 for flat plate single tank active systems (4).

5.2 Drawdown Test

A high SPF could be achieved with a system that provided very little hot water and met a very small percentage of demand. Therefore some criteria for use should be included in an IPSWH test. I would suggest the following pattern of drawdown with use given per person. A system must therefore be designated as an x-person system. Typically an IPSWH will have about 114 liters (30 gallons) of storage per person, but improved performance might reduce this figure.

Table 2. Drawdown Schedule.

Time	Drawdown liters	(gallons)
7:00 am	1.5	0.4
8:30 am	2.5	0.7
1:00 pm	2.5	0.7
5:00 pm	19.0	5.0
7:30 pm	38.5	10.2

The IPSWH should be backed up with an electrical heater set to 41°C (105 F) for the duration of this test. Ideally a summer and winter evaluation should be done for various climates. The result would be a performance figure in percent solar hot water per person for different climates.

Until more information of this type is available, it may be useful to develop profiles of IPSWH performance relating water temperature to ambient air temperature. Table 3 is an attempt to do this using performance data from a variety of sources (3). This should prove helpful in designing a system for a specific climate.

6. COST-EFFECTIVENESS

The ultimate determinant of the success of IPSWHs will be their cost-effectiveness. Despite more than five years of remarkably good performance, very little evaluation of IPSWH economics has been done. The potentially low cost ($75 or less with all recycled materials, $500 with all new materials, $1,500 purchased) has been known by IPSWH practitioners to more than offset slightly reduced performance, but no reasonably accurate comparison had been done until recently.

The first side-by-side test of five solar systems confirmed this "common knowledge" even in the 5,900 HDD climate of Pennsylvania (6). The return on investment for their IPSWH was best of all systems and 50 percent better than the more common thermosiphon and draindown systems, and more than twice that of their most expensive active system.

7. ACKNOWLEDGEMENT

Special thanks to John Burton and Peter Zweig for sharing test results, and to Alex Tennant of The Southwall Corporation for permission to test Heat Mirror^{TM}.

8. CONCLUSION

Integral passive solar water heaters are one of the most viable uses of solar energy. With modern materials and new designs, the drawbacks that ended their early widespread use can be overcome. Dramatic increases in commercial IPSWH activity suggest that the advantages of this little known type of system are rapidly achieving recognition (3).

We can expect even more interest in the year ahead as better performance is achieved. A standardized test procedure will help buyers choose the best system for their application.

The cost-effectiveness of these

systems also makes them very desirable for commercial and industrial users, whose main criteria are economics.

The sun is just rising on IPSWH activity.

9. REFERENCES

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Table 3. Increase in IPSWH Temperature Over Ambient Air Temperature, with no Drawdown

Type of IPSWH	Increase at Daytime High	Increase at Nighttime Low	Average Increase
Clear glass bottle or solar pillow	11 to 17°C (20 to 30 F)	0 to 3°C (0 to 5 F)	6 to 8°C (10 to 15 F)
Black collector, insulated box, single glazed	44 to 50°C (80 to 90 F)	11 to 22°C (20 to 40 F)	28 to 33°C (50 to 60 F)
Black collector, insulated box, double glazed or triple glazed	50 to 56°C (90 to 100 F)	17 to 28°C (30 to 50 F)	33 to 39°C (60 to 70 F)

Correction factors: add or subtract from above figures

Transmissive insulation (angel hair): High -3 to -6°C (-5 to -10 F)
Low +3 to +6°C (+5 to +10 F)

Selective surface: High +3 to +6°C (+5 to +10 F)
Low +3 to +6°C (+5 to +10 F)

Insulated lid, closed at night or Heat Mirror^{TM}: High +3 to +6°C (+5 to +10 F)
Low +6 to +17°C (+10 to +30 F)

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