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WINDJAMER^M SOLAR-WATER-HEATING SYSTEM

Final Technical Report

Presented To

Department of Energy

Appropriate Technology Section

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By

James R. Windham, Engineer

April 1982

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Acknowledgments

The author wishes to thank Mr. Rick Dixon and Dr. H. A. Ingley of the University of Florida Mechanical Engineering Department for their dedication and assistance in the execution of this investigation; Mr. and Mrs. Steve Eaton of Sun Energy Connections for their extended efforts in the actual construction of the system; Dr. C. D. Baird of the University of Florida Agricultural Engineering Department for his guidance and support in the project; and his wife, Mary, for her support and assistance throughout the entire project.

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Preface

The perpetration of the investigation of the Windjammer Solar Water Heating System was accomplished in several phases and utilizing some outside agencies to complete the work. Actual construction was done by a professional solar water heating firm on a sub-contract basis.

The testing of the system was contracted to the University of Florida Department of Mechanical Engineering. This was done to take advantage of facilities already established for this purpose, equipment on hand, the expertise of those experienced in solar testing and to gain objectivity in the experiment and analysis.

This report is therefore submitted in two parts. The first part submitted by the author, inventor and manager of the project and the second by the testing agency, via the project manager, presenting the data and technical results.

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Part II

Presented under separate cover

SUMMARY

The results of the Windjammer Solar Water Heating System tests showed that it was not as an efficient system as a comparable conventional system for converting solar energy into heat energy. However, it was determined that the innovative mode used less electric back-up energy for water heating. Reduced fossil fuel energy consumption being the ultimate objective of a solar water heating, the principle employed has been shown to be a workable energy saving concept.

The differential mode of temperature control emerged as the more efficient mode of operation for the innovative system and under comparable conditions is projected to be nearly equivalent to the conventional solar system.

Although the concept has proven workable, the costs feasible, and the potential for considerable improvements exists, additional research and development is needed to advance the design into its most practical application.

INTRODUCTION

The Windjammer Solar Water Heating System is a hybrid system utilizing the principles of most conventional solar water heaters. The innovation of the system is in the water handling mechanism to minimize the use of fossil fuel energies for reserve, make-up and maintenance heat.

The project consisted of the actual construction of a prototype unit so designed to be readily converted to a conventional unit for comparable tests. Tests were conducted in various times of the year for seasonal analysis.

Mechanics, efficiencies and economics were analyzed for practicality and feasibility.

Objectives

The primary objective of the project was to build upon the basic principles of solar water heating in a comparable system which would reduce the amount of additional energies required to provide hot water. Other objectives were to investigate the effects of periods of reduced insolation and the results during periods of low demands.

The costs of the Windjammer System with several options, for comparison with conventional systems, are included in the Appendix.

Freeze protection was included in the system primarily to demonstrate that a viable means of protection is compatible with this system, but not included as a part of the experiment.

Theory of Operation

The theory of the system is to isolate and heat a small quantity of water using solar energy, and when heated, maintain it in a separate vessel to avoid thermal dilution. This was accomplished by having two storage tanks, one

for containing a specified volume of air and water before heating and the second for retaining the heated water until consumption. As water was heated and added to the second tank, the volume of heated water was allowed to fluctuate with supply and demand. Thus the volume of heated water became the independent variable in lieu of the temperature.

Minimal consumption of electrical reserve energy was obtained by the reduction; of the volume of heated water maintained, of maintenance time and of thermal dilution.

The volumetric expansion tank (V.E.T.) was added to the heating circuit only to expand its volume, and prevent excessive cycling of dump mode.

The freeze protection system permitted water in the heating circuit to drain back into the storage tanks and be replaced with air, thereby avoiding static water in the exposed components.

PROCEDURE

The system was constructed and installed by a professional solar water heating contractor. The mechanisms were checked out for proper operation according to design. Components were adjusted to obtain the proper air-water ratios, volumes and pressure upon filling. The various sub-systems were then checked for proper operation. Once all systems were checked out and adjusted to design specifications, the project was then turned over to the Department of Mechanical Engineering, University of Florida for testing and analysis.

CONCLUSIONS AND RECOMMENDATIONS

Test data and results are presented in the "Results and Conclusions" section of Part II as presented in the report by Mechanical Engineering Department.

The cost of a commercial system utilizing the principles of the Wind-jammer System is comparable to a conventional system of the same size. Costs could conceivably be reduced by designing all three control units into a single controller, combining the two storage tanks into a single compartmented tank, by using three-way solenoid valves instead of two-way valves, thus reducing the required number. The experimental system was fabricated utilizing off-the-shelf components to simplify and expedite construction.

The testing procedure included a total dump of all solar heated water at the end of the day--assuming 100 percent usage of heated water by the end of the day. This assumption is not in keeping with the intent of the system design. The capacity of the solar heated water storage tank should include a minimum of the average daily use rate plus the desired reserve capacity, with sufficient collector capacity to heat the total volume. This in theory would then reduce the electrical (reserve) energy input to the thermal maintenance requirements of the reserve capacity of the water. A small amount of over-design in collector capacity, to compensate for this thermal maintenance, would then theoretically reduce the electrical energy requirement to zero.

Freeze protection was achieved by an internal drain down system. This was demonstrated for compatibility and not as part of the experiment. Other means of freeze protection are certainly viable and possibly more economical.

This particular means was chosen as it is applicable to this system whereas it may not be to other systems, and for its simplicity.

Having established a workable system with potential for additional improvement, several recommendations for continued progress have arisen.

The set point of 125°F was chosen to begin tests as this seemed to be a desirable average temperature for water consumption. This temperature was quickly determined to be too low for the particular configuration of components being tested. The result was a very frequent cycling of the heating circuit. The temperature of 150°F was chosen to try to rectify the frequent cycling. This resulted in a feasible cycle period for tank and system size and was used for the remaining tests.

Since the sizing of the volumetric expansion tank (V.E.T.) was arbitrary and frequent cycling of the dump mode was encountered at the 125°F set point, investigation of V.E.T. sizes, system sizes and their ratios, set point temperatures and cycling frequency need more data and analysis.

It is felt that proper relationships of the above parameters would result in an acceptable cycle frequency at lower temperatures increasing the overall efficiency of the total system. This does not present itself as a major nor continuing problem, but a situation in which more data is needed for design input. Also it may be feasible to continuously and simultaneously bleed from and replenish a small amount of water to the heating circuit. This would eliminate the need for the V.E.T. and possibly permit a simpler diversion mechanism.

Conversion efficiency being a little lower than the innovative system, this is an area which further analysis is needed as many of the relative parameters influencing efficiency were the same.

The differential mode of operation having proved a little superior, additional research is needed in the determining of optimum operating set points and temperature differentials.

Secondary recommendations for further investigation include the feasibility of adding a timer to the back-up heating element, and plumbing the system to employ the Goettl circulation principle and/or the means of adding and removing the heated via the top of the V.E.T. The latter two were employed in the prototype inasmuch as they both are theoretically advantageous and inexpensive to include.

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APPENDIX I

SUN ENERGY CONNECTIONS, INC.

Solar Energy Systems • Design • Engineering • Sales • Installation • Service
Residential • Commercial

February 23, 1981

Mr. Jim Windham
6828 S. W. 75th Street
Guinesville, Florida 32601

Dear Jim,

Enclosed please find the pricing breakdown you requested back in December. I am really sorry it is so late in coming, but I have recently gone for my State Plumbing Contractor's License and have put in a few bids on some commercial projects.

If you have any questions regarding prices, components, or figuring, please don't hesitate to call.

Sincerely yours,

SUN ENERGY CONNECTIONS, INC.

Stephen A. Eaton
President

SAE:pe
Enclosures

Material RequiredCost

Rheem 52 Gallon HW Heaters with standard single element (#661-52D)	(2)	\$118.20/ea.
Rheem 6 Gallon HW Heater with standard single element (#64X-6S)		79.20
Watts 3/4" U-5 Pressure Regulating Valve, 25-75 psi range		38.00
Nibco 1/2" Check Valve (Sweat)		10.00
Grundfos Pump Model UPS 20-42 with cord and unions		45.00
Energy Transfer Systems, Inc., Model #3080M (4'x8')		350.00
Mounting Hardware for 4'x8' Collector with roof flashings		22.40
Braukner EA-122 Air Vent Valve		9.09
Honeywell Model #4044B Motorized Valves (Normally Open)	(2)	43.00
Honeywell Model #4044A Motorized Valves (Normally Closed)	(1)	43.00
Intermatic T104-21		23.46
Sensor Wells (to be fabricated) (Estimated)	(2)	10.00
1/2" Gate Valves (Sweat) Nibco	(4)	3.24
1/2" Boiler Drains (Sweat)	(2)	2.11
Clear Silicone Caulking (tube)		4.00
Air Injection Valve		12.25
Temperature Controllers	(3)	53.00
1/2" Type M Soft Copper (25')		.51/ft.
1/2" Rubatex Insulation and ties (25')		.32/ft.
3/4" Type L Hard Copper (8')		.61/ft.
Sensor Wire (30')		.05/ft.
Assorted Copper Fittings/Gas & Solder		25.00

1. Basic Unit Cost as per listed components and required fittings, copper insulation, mounting hardware and miscellaneous:

Materials:	\$ 1,164.00
P & O:	524.00
Labor Allowance:	<u>300.00</u>
System Cost:	<u>\$ 1,988.00</u>

2. Basic Unit with (1) less Timer and (1) less Temperature Controller:

Materials:	\$ 1,088.00
P & O:	490.00
Labor Allowance:	<u>300.00</u>
System Cost:	<u>\$ 1,878.00</u>

3. Basic unit with freeze protection system or original model with (2) Honeywell 4044A (N.C.) and (1) 4044B (N.O.) and (3) Temperature Controllers:

Materials:	\$ 1,207.00
P & O:	543.00
Labor Allowance:	<u>300.00</u>
System Cost:	<u>\$ 2,050.00</u>

SOLAR WATER HEATING WITH A NEW APPROACH

This publication was presented at the "Solar Energy and Conservation Symposium-Workshop", Miami Beach, Florida, December 1978.

It is included in this report to add history and detail to the project.

SOLAR WATER HEATING WITH A NEW APPROACH

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University of Florida
Gainesville, Florida 32611, U.S.A.

ABSTRACT

The success of the conventional solar water heating system cannot be denied, however, it is felt that it can be improved upon. The specific area in which it can be improved is in increased efficiency by the prevention of mixing of cold and hot water--maintaining the solar heated water in a separate tank after heating.

Using this process, water is heated in smaller quantities and is maintained at higher temperatures instead of being mixed with a lower temperature water. Water volume is permitted to fluctuate with supply and demand, reducing the volume of water which must be thermally maintained and minimizing energies required to heat replenish water as consumption occurs. A common link between the tanks maintains line pressure on the entire system and a minimum water volume in the heated water storage tank. It also provides for pre-heating of water if the demand is exceeded by the supply.

The independent variable in this system is the quantity of hot water stored, in lieu of the temperature of the water. Consequently, a more consistent daily water temperature is obtained, advantage is taken of partially cloudy days and it becomes unnecessary to insulate the primary tank.

INTRODUCTION

The recent emphasis on solar energy has generated many designs of collectors and many alternatives in the operation of solar water heaters. With these many variations, the majority of the systems employ the same basic principles--utilizing a flat plate collector, a hot water storage tank and a means to circulate the water through the collector and back to the storage tank. These are connected in series with and prior to a conventional water heater. The water heater is used as a back-up unit and a means of maintaining the desired water temperature.

The success of these principles cannot be denied, however it is felt that they can be improved upon, the particular area of concern being the addition of cold water to previously heated water. Through investigation of operating practices, the theory of separating heated and unheated waters has evolved as a potential means of this improvement. The major deterrent to this theory has been the difficulty of maintaining separation of waters and incoming line pressure simultaneously. Some minor modifications of the conventional solar water heating system design will accomplish these

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and several additional secondary features.

This concept employs three basic components each having several accessory components to aid in the performance of its given function. These consists of a cold (unheated) water storage tank, a water heating circuit and a hot water storage tank and are arranged respectively from the cold water source to the supply outlet. Secondary components include; a check valve to prevent reverse thermo-syphoning when the circulating pump is not actuated, an air valve for achieving the proper pressure-volume ratio, a purge valve and an air-vent valve for air removal and a diversion mechanism for removing the heated water from the heating circuit as necessary. This resultant design is known as the Windjammer Solar Water Heating System.

The cold water storage tank requires no special features and insulation is optional as will be seen. Any properly designed flat plate collector may be used as the primary element in the heating circuit. Additional components are required to complete the circuit and aid in the total performance of its function. The hot water storage tank may be a conventional water heater plumbed for this specific application or any tank designed for hot water storage which is well insulated and to which the necessary components can be installed.

OBJECTIVE

The system has three primary objectives: to eliminate the mixing of heated water with lower temperature water, to minimize thermal maintenance costs and to eliminate unnecessary reheat costs. The first is accomplished by storing heated water in a separate tank and the latter two by allowing the volume of heated water to fluctuate according to supply and demand, thus becoming the system's independent variable in lieu of water temperature. These objectives must be attained at line pressure in order to utilize it to move water into and out of the system and to prevent problems from being generated because of pressure differences within the system.

Secondary objectives which are discussed more fully in various sections of this paper are to; provide for periods of reduced available solar energy, to provide for periods of reduced demands and high insolation, to provide for freeze protection, maintain a reserve of water for use when the design specifications are exceeded, to provide a means of replacing heat lost to the surroundings by conduction, convection or radiation and to provide a secondary means of heating. The latter objective is provided for by the same components that accomplish some of these objectives previously mentioned.

THEORY OF OPERATION

To accomplish these objectives, cold water stored in the primary tank is forced by line pressure into the heating circuit. Within the heating circuit, it is mechanically circulated until it reaches the desired

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temperature and then is diverted into an insulated storage tank until consumption. As this water is diverted it is replaced by water from the primary tank. A common air line between the tanks assures maintenance of line pressure in both.

The secondary objectives of freeze protection, provision for limited insolation and reduced consumption and a reserve supply are all accomplished by an internal transfer of fluid between system components. Secondary heat is provided by a conventional heat source such as an electrical resistance element.

OPERATIONAL PROCEDURE

The operational procedure begins with filling the cold water tank and the heating circuit completely and the hot water tank to its predetermined minimum water level. The air-vent valve will permit the escape of air from the heating circuit and the cold water storage tank allowing them to be filled with water, but causes the filling process to be very slow because of its small opening. Opening an hot water outlet will increase flow rates and reduce fill time. Permitting the cold water tank to overflow into the hot water tank via the common air line, the minimum amount of water for this tank can be obtained. The pressure of the air remaining in this tank must then be increased to the supply pressure without changing the volume of either the air or water within the system. It is now ready for operation.

As insolation begins heating the water in the heating circuit, the primary thermostat (T_1) will actuate the pump and initiate circulation. Circulation continues until the water reaches the desired temperature and is diverted into the hot water storage tank via the diversion mechanism which is controlled by the secondary thermostat (T_2). Various means of diversion are discussed later within this paper. Air being displaced by the incoming solar heated water is transferred via the common air line into the cold water tank replacing water being removed to the heating circuit to replenish the diverted solar heated water. The total volumes of water and air in the system remain the same but is simply transferred among components. A reverse pneumatic action between tanks occurs when hot water is demanded. Water leaving the hot water storage tank for consumption lowers the water level of the hot water tank and the pressure in both tanks, being commonly linked. This lowered pressure then permits the higher pressure of the cold water supply to replenish the depleted volume of water within the system and does so by increasing the volume of water in the cold water storage tank until line pressure and the original volume of water is reached. Again, this process does not change the total volumes of air or water within the system but only replenishes the outgoing water.

FEATURES

The basic theory of operation as outlined above is enhanced by a two-fold feature which requires no additional components or labor if line pressure

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is relatively constant or a pressure regulator preceeds the cold water tank. During periods of good insolation the volume of the hot water stored increases with the volume of cold water decreasing proportionally. The inverse procedure occurs during consumption. When the hot water demand exceeds the supply (during limited insolation, etc.) and the water level is depleted below its minimum desired level, it will be automatically replenished by an overflow from the cold water storage tank via the common air line. A reverse overflow occurs when the supply of hot water exceeds the demand. Once the hot water tank has become filled, water diverted from the heating circuit will cause an overflow from the hot water tank back into the cold water tank, in effect, preheating the water.

ACCESSORIES

Systems in which the pressure fluctuates significantly, as in rural residential supply systems, additional control components are required. These are necessary because of the large change in air volume resulting from the pressure change. The initial operating procedures in filling the system must be carried out at the maximum operating pressure for these systems. This will prevent water from entering the hot water storage tank without being heated, but will not prevent air logging and escape through the hot water outlet. To prevent air escape as a result of logging it may be necessary to transfer water from the cold water tank to the hot water tank. A simple method of transferring water as needed is to actuate both the pump and diverter valve simultaneously. Water is then pumped from the cold water tank, through the heating circuit and into the hot water tank without circulation. To actuate the pump and solenoid valve simultaneously, parallel circuits must be added which would operate independently of the primary controls and would be operated by the same water level sensing device. If the water level sensing device must be installed externally, a plumbing circuit must be added for this. By connecting an auxiliary line from the drain port to the common air line, the water level in this circuit will be the same as in the hot water storage tank. The sensor should be installed in this circuit at the proper height to maintain the desired minimum water level. An example of this is illustrated by the dotted line on Figure 1 which depicts a float switch (F.S.) as the water level sensor.

A more practical way to maintain proper water-to-air volume ratio is to install a pressure regulator in series with the cold water supply prior to the cold water storage tank. This will maintain the proper air to water volume ratio and pressure as described in the Features section.

Freeze protection is achieved by allowing the water in the heating circuit to drain by gravity into the tanks and being replaced by air from the tanks, again a simple transfer of fluids within the system.

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The mechanics of the freeze protection circuitry are dependent upon the particular type of diversion mechanism employed. Electro-mechanical devices such as three-way solenoid valves, zone valves etc. require a secondary circuit by-passing the check valve. This circuit allows water to drain back into the cold water storage tank and must be opened simultaneously with the diverter valve which permits air to move up from the tanks into the collector replacing the water. Totally mechanical diverter devices such as thermally actuated thermostats must be by-passed with a separate circuit for permitting the rise of air into the collector. This circuit must again be energized at the same time as the check-valve by-passing circuit. This method of freeze protection requires an additional solenoid valve installed between the heating circuit and the air vent valve to prevent the loss of all the air from the system when freeze protection is called for. This valve must be normally open and energized simultaneously with the two above mentioned circuits.

CONVENTIONAL SYSTEMS

The advantages of this system are enhanced by a comparison with the present state-of-the art. Conventional solar water heating systems return solar heated water from the collector to the tank from which it came, thereby, mixing it with water of a lower temperature. This effectively results in heating the entire volume of water at once. As hot water is consumed it is replaced with cold water, again mixing cold water with solar heated water and lowering its temperature. This reduction in temperature requires reheating of the water by the back-up heater, utilizing conventional heat sources. This reheated water, if not used immediately, must be thermally maintained, again by conventional heat sources, and during a time when possibly more water could have been heated by solar energy. The reheat and thermal maintenance energies then become wasted energies.

ADVANTAGES

The primary advantage of this system is the maintaining of solar heated water in a separate tank and preventing the mixing of it with lower temperature water. It lends itself to the reduction of volume of stored water, therefore, minimizing energy required for thermal maintenance and reheating. By permitting the volume of hot water to become the independent variable in lieu of temperature, a more consistent daily water temperature is achieved. Separation of tanks allows the cold water tank to be uninsulated.

Internal freeze protection eliminates the need of extra tank liners and/or jackets, heat exchangers, chemicals, heating strips and double walling; is less expensive; does not utilize previously collected energy; nor require conventional heat input.

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This system can be built from standard components and can be utilized for various capacity systems. It can be retro-fitted to existing system and is economically competitive with similar conventional systems. The secondary heating element, serves as a booster, thermally maintains the desired temperature, serves as a back-up heater, retains the quick recovery feature of conventional heaters.

Thermal sensing for control and volume independence become advantageous during limited insolation. Although the limited insolation may not be adequate to meet design specifications (e.g. heating the design volume to the design temperature) the volume of water diverted to the storage tank will be at design temperature. On days of limited consumption this is a very valuable feature.

OPTIONS

In addition to the options previously cited, several others offer flexibility and add advantages which may be attractive to the individual designer. The addition of a small tank in series with the heating circuit will increase its volume and significantly reduce the number of cycles of the diversion mechanism. Several diversion mechanisms are available but vary in costs and operation which determines the design of other components within the system. Thermally actuated valves similar to automobile thermostats are inexpensive, simple and do not require external control but cannot be used in a optional freeze protection circuit without special design or addition of a by-pass circuit. A three-way solenoid valve is the simplest and offers greater system compatibility but is rather expensive and requires external control. A diverter valve actuated by reduced pressure (e.g. kitchen sink hose diverter valves) offers approximately the same characteristics as the three-way solenoid valve but must be used in conjunction with a two-way solenoid valve. A three-way zone valve offers the most practical solution as its characteristics are also similar to the three-way solenoid valve and is not so expensive.

Consideration has been given to stacking of the tanks to conserve floor space, yet the ideal system is to have all components excluding the collector, integrated into a single unit. This may be achieved by insulating the area between the two tank compartments and mounting the pump, valves, etc. on a frame-work atop the unit as is commonly done on conventional units. This would also require internal plumbing. See Figure 3.

It is desirable to have all control logic and circuitry integrated into a common unit. With the current status of control technology, this can be easily achieved economically feasibly and will permit mounting of the control unit onto the tanks with other components if desired.

Figure 1 Schematic Diagram of Solar Water Heating System

T - THERMOSTAT
S.W. - SENSOR WELL
D - DIVERTER VALVE
C - CIRCULATING PUMP
S - SOLENOID VALVE
F.S. - FLOAT SWITCH

Figure 2 Primary Thermostat (T_1) and Secondary Thermostat (T_2)

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Figure 3 Schematic Diagram of Differential Temperature Storage

The Windjammer Solar Water Heating System Installed at the
University of Florida Solar Energy Park

Complete Windjammer System

Water Handling Systems

Solar Collector Rearview

Solar Collector

Cold Water Storage Tank on left

Hot Water Storage Tank on right

Controls and Meters

Hydraulic Controls

Volumetric Expansion Tank

Diversion Mechanism

Temperature Controllers

Windjammer Solar Water Heating System

LEGEND

- Temperature Controller

- Temperature Sensor

- Water meter

- Circulation pump

- Solenoid valve - two way, n.c.

- Solenoid valve - two way, n.o.

- Pressure gauge

- Temperature well

- Air valve

- Union

- Pressure Relief Valve

- Gate valve

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Temperature	Below 35°F	35°-90°F	90°-125°F	Above 125°F
Mode of Operation	Freeze Protection	None	Heating	Purging
Component				
S ₁ - NO ₂	ON	OFF	OFF	OFF
S ₂ - NC ₁	ON	OFF	OFF	OFF
S ₃ - NO ₁	OFF	OFF	OFF	ON
S ₄ - NC ₂	OFF	OFF	OFF	ON
Pump	OFF	OFF	ON	ON
TC-1	OFF	OFF	OFF	ON
TC-2	OFF	OFF	OFF	ON
TC-3	ON	OFF	OFF	OFF

PROJECT: INVESTIGATION OF THE PERFORMANCE
OF THE WINDJAMMER SOLAR SYSTEM

CONDUCTED BY: THE UNIVERSITY OF FLORIDA
SOLAR ENERGY AND ENERGY
CONVERSION LABORATORY (SEECL)

SPONSOR: JAMES WINDHAM AND DOE APPROPRIATE
TECHNOLOGY SECTION

DATE: MARCH, 1982

H.A. Ingley, Ph.D., P.E.
Richard Dixon, P.E.

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Hot Water Availablility Graphs		

Introduction

The University of Florida's Solar Energy Laboratory was contracted to test and evaluate the Windjammer solar water heater system. This system was a forced circulation/batch mode hybrid system.

The approach taken compared the performance of the Windjammer innovative system to the performance of a conventional open loop solar water heating system. The system prototype was constructed such that it could be configured for operation in the innovative or conventional mode. Comparisons of the two operational configurations with systems comprised of identical equipment was therefore possible.

The data presented in this report are for the performance of the innovative and conventional system configurations for winter and late spring/early summer conditions.

System Description

The innovative and conventional systems contained the same basic elements. They were: a 4' x 8' single glazed, black chrome absorber, flat plate solar collector, two 52-gallon hot water heaters, a Grundfos UPS 20-42 pump, and Dekolabs differential controllers. In addition to the common elements listed above, the innovative system utilized a water pressure regulator, several motorized valves and a six gallon insulated water tank.

The principal of operation of the innovative system was to fill one of the two tanks with supply water, thus forcing the air into the second tank through the pressure equilization line. The supply water pressure was reduced at the first tank input to 20 psig resulting in a compressed volume of air in the second tank of 40 to 44 gallons at initial fill. One differential controller sensed the collector temperature and turned on the pump at 90°F thereby circulating water in the collector loop. The water continued circulating through the six gallon tank and collector until another controller sensed that the water in the tank had reached the set point (125°F/150°F). This controller then opened and closed separate controller valves to direct the flow from storage tank #1 into the collector, then into the bottom of the six gallon tank up and out and then into storage tank #2. When the collector loop tank's temperature dropped below the set point, the system once again circulated water through the collector loop. The pump cycle resulted in a net transfer of water from storage tank #1 to storage tank #2. The air displaced from tank #2 passed into tank #1 thus maintaining pressure equilization throughout the system.

The system configured in the conventional solar water heater mode was an open-type system. Parts of the system were isolated by valves and a flow path was generated such that water was drawn from the bottom of storage tank

#1 and returned to the top of that tank. The six gallon collector tank was isolated and storage tank #2 filled with water to force flow through the pressure equilization line back to storage tank #1. The pump controller was modified to sense the differential between the collector temperature and storage tank #1 temperature for differential control.

Instrumentation

The system was instrumented to measure supply water flow into storage tank #1, flow through the collector loop and flow from the six gallon tank into storage tank #2. Badger positive displacement flow meters were utilized for flow measurement. Full tank height sight glasses were installed on storage tanks #1 and #2 and calibrated to provide measurements of water quantities in each.

Temperatures were measured with Type T thermocouples and were charted on a Leeds and Northrup 24 point recorder. Temperature differentials were measured with Type T thermocouple thermopiles and strip charted on a Honeywell 194 two pen recorder. The inlet and outlet temperatures and direct temperature difference were measured for the collector and tanks. For the conventional configuration, the positions were the return inlet to storage tank #1 and outlet from storage tank #1. For the innovative configuration, the positions were the inlet to storage tank #2 and outlet from storage tank #1. Temperature at the bottom, middle and top of each storage tank were also measured.

The solar radiation incident on the solar collector was measured by a Licor LI-200SB pyranometer which was mounted parallel with the collector surface. The pyranometer's output was integrated over the day by a Lintronic Mark V digital volt time integrator.

Procedures

The initial approach to testing was to compare the performance of the test system when configured as a conventional open system with the performance of the batch mode (innovative) system. Testing was conducted in the winter and spring/summer for two weeks in each configuration.

The original set points for the innovative system were 90°F pump turn on and 125°F dump. Freeze protection was effected through manual drain down. The innovative system's pump turn on set point was always maintained at 90°F for all tests, but the dump control was altered in two ways. The first variation was the increase of the dump set point to 150°F. This variation resulted from the observation that on clear days the system heated the entire volume to 125°F initially and began to start cycling before the end of the collection day. The result of this was to artificially limit the total energy collected by the system on a good day. The second variation was to control the dump by sensing the temperature differential between storage tank 1 and the six gallon collector loop tank. This variation resulted from the observation that on cloudy and overcast days, the daily energy collection was little or none. The apparent reason was that the collector could raise the water temperature some but not enough to reach the dump set point.

The dump control differential used was a 30°F difference between storage tank #1 and the six gallon collector loop tank. When storage tank #2 was filled, it would overflow back into tank #1 and effectively start raising both tanks to 30° above the first incremented temperature. The expected effect was that low radiation and temperature days would show increased energy collection and system efficiency.

The conventional configuration for flow used only storage tank #1 to store energy. Therefore, the innovative and conventional storage volumes were approximately equal. As previously stated, the conventional system configuration was an open loop. The pump was controlled by the same pump controller used with the innovative configuration. In all tests it operated in a differential mode with approximate set points of 10°F turn on and 5°F turn off temperature between tank #1 and the collector.

The data were developed and presented in a daylong system efficiency format for comparison of the performances of the innovative and conventional system configurations. The comparisons were made on a seasonal basis. Data were also collected for similar weather conditions on the energy used by the heater elements. For simulated water usage: the usage was simulated by the withdrawal of 50 gallons of hot water at the end of the day. Only the top heater element of storage tank #1 was used for the conventional configuration. The bottom heater element of storage tank #2 was used for the innovative configuration in the fixed temperature controlled dump variation. Energy use data were not collected for the differential temperature controlled dump variation. The heater thermostat set point was 120°F for both the innovative and conventional system configurations.

The daylong system energy collected was determined by measuring the respective temperature differences of the water mass of storage tanks #1 and #2 from start up to shut down. The water temperatures were taken from thermocouples located at the center of one-third sections of each tank. The mass was determined from start up temperatures and the calibrated measurements from the sight glass water levels. The daylong system efficiency was determined from the daylong energy collected and the integrated solar radiation incident on the collector.

Data

The data were presented in several ways in order to provide a variety of usefulness. The presentation of daily system efficiency and power usage comparisons has been mentioned previously. In addition, graphs of the temperature and mass profiles versus time have been provided for comparison of hot water availability.

It has been considered that the availability of hot water to match usage schedules was one of the major benefits of the innovative system's operation. The curves presented are intended to demonstrate the amount of hot water available versus time. The innovative system configuration was operated without the heater element for the test data presented. Therefore the system started with 10 plus gallons of water at cold water supply temperature. The tank water temperature then increased with each dump of the collector loop water. Under normal operating conditions the initial water temperature in storage tank #2 would be near the dumped water temperature. Therefore, the data presented would best be utilized to indicate the mass of water available at different times of the day.

SYSTEM PERFORMANCE DATA
WINDJAMMER SYSTEM-INNOVATIVE CONFIGURATION

System Configuration	Date	Q_{incident} (Btu/day)	$Q_{\text{collected}}$ (Btu/day)	η_{sys} %	$V_{\text{H}_2\text{O}}^1$ (gal)	T_{tank}^1 (°F)	T_{amb}^2 (°F)
Innovative (dump temp-- 125°F)	1/21/81	53,534	19,201	36	30.1	119	73
	1/22/81	49,785	13,680	28	27.8	98	58
	1/23/81	45,633	13,967	31	27.7	97	56
Innovative (dump temp-- 150°F)	2/5/81	65,674	14,598	22	23.0	110	53
	2/9/81	63,178	14,032	22	23.0	112	61
	2/12/81	54,239	16,042	11	11.1	93	43
	2/19/81	53,534	19,201	36	30.1	119	73
	2/20/81	58,841	22,939	39	35.5	122	74
	2/23/81	54,719	14,335	26	23.4	112	63
	2/24/81	80,057	21,830	27	33.2	121	68
	4/23/81	50,059	15,862	32	26.0	125	81
	4/24/81	38,996	10,976	28	15.4	123	81
	4/27/81	32,093	14,809	46	20.9	127	80
	4/28/81	59,507	27,573	46	45.2	133	82
	4/29/81	58,596	17,687	30	32.1	133	83
	5/1/81	54,249	29,894	55	48.8	135	86
	5/3/81	59,722	29,400	49	51.0	144	76
	5/6/81	32,034	8,052	25	10.4	123	
	5/7/81	36,010	11,728	32	15.6	127	
	5/8/81	35,246	8,343	24	10.2	120	
	5/11/81	53,456	24,228	45	44.9	135	
	5/12/81	55,923	21,327	38	38.3	133	
	5/13/81	57,353	29,943	52	51.0	135	
	5/14/81	50,323	22,298	44	36.3	133	

System Performance Data continued

System Configuration	Date	Q_{incident} (Btu/day)	$Q_{\text{collected}}$ (Btu/day)	η_{sys} %	$V_{\text{H}_2\text{O}}^1$ (gal)	T_{tank}^1 (°F)	$\bar{T}_{\text{amb}}^2$ (°F)
Innovative (differential control of dump)	1/26/82	65,420	17,822	27	39.6	121	
	1/27/82	59,595	28,990	49	61.6	120	
	1/28/82	60,662	31,262	52	65.3	121	
	1/29/82	58,283	27,148	46	60.0	116	
	2/2/82	22,205	4,095	18	14.4	97	
	2/4/82	48,081	17,127	36	51.6	105	
	2/5/82	25,093	8,068	32	29.3	98	
	2/9/82	16,154	1,795	11	8.6	87	

¹Volume and temperature of solar-heated water at shut down time

²Average ambient temperature for daylight hours

SYSTEM PERFORMANCE DATA
WINDJAMMER SYSTEM-CONVENTIONAL CONFIGURATION

System Configuration	Date	Q_{incident} (Btu/day)	$Q_{\text{collected}}$ (Btu/day)	η_{sys} %	$V_{\text{H}_2\text{O}}^1$ (gal)	T_{tank}^1 (°F)	$\bar{T}_{\text{amb}}^2$ (°F)
Conventional	3/10/81	72,890	30,212	41	52	140	65
	3/11/81	50,196	22,011	44	52	128	65
	3/12/81	65,273	30,212	46	52	144	67
	3/16/81	64,137	28,054	44	52	139	71
	3/17/81	62,248	30,212	48	52	137	66
	3/18/81	33,033	15,538	47	52	108	70
	3/19/81	39,328	23,738	60	52	125	58
	3/20/81	66,516	25,896	40	52	142	59
	4/14/81	57,725	23,738	41	52		82
	4/15/81	39,837	20,285	51	52		80
Conventional	6/1/81	42,050	10,686	25	52	135	86
	6/3/81	56,481	20,467	36	52	142	87
	6/4/81	54,474	21,345	39	52	144	89
	6/5/81	40,552	16,649	41	52	134	88
	6/7/81	50,117	20,894	42	52	140	91
	6/8/81	34,492	20,461	58	52	137	90
	6/10/81	39,749	20,467	52	52	135	92
	6/12/81	34,551	17,056	49	52	127	83

¹Volume and temperature of solar-heated water by shut down time

²Average ambient temperature for daylight hours

ENERGY USE DATA
WINDJAMMER SOLAR SYSTEM

System Configuration	Date	Q _{heater} (kwh)	Q _{incident} (Btu/day)	T _{amb} (°F)	V _{dumped} (gal)
Innovative 150°F dump	5/7/81	.7	36,009.4		32.5
	5/8/81	2.4	35,245.7		50.0
	5/12/81	1.5	55,923.2		50.0
	5/13/81	1.1	57,352.6		50.0
	5/14/81	2.5	50,323.0		50.0
Conventional	5/20/81	6.3	45,192.8		50.0
	5/21/81	6.5	55,609.9		50.0
	5/22/81	7.2	56,422.5		50.0
	5/26/81	5.1	32,034.4		50.0
	5/30/81	7.5	54,239.2		50.0
	5/31/81	5.9	43,900.5		50.0
	6/1/81	6.5	42,050.1	86.0	50.0
	6/2/81	7.0	52,290.9		50.0
	6/3/81	3.6	56,481.3	87.4	50.0
	6/5/81	2.8	48,854.5	87.6	50.0
	6/6/81	3.0	39,494.8	86.2	50.0
	6/7/81	4.0	59,252.0	90.6	50.0
	6/11/81	4.0	39,336.4		50.0
	6/12/81	4.9	40,288.4	83.2	50.0

Results and Conclusion

The experimental data indicate that the conventional mode of operation for the solar system yielded higher average daylong system efficiency than the innovative modes. The average spring data system efficiency was 46% and the average summer efficiency was 43% for the conventional operation mode.

The innovative operation modes showed lower average system efficiencies and less consistency in the daily efficiencies. The average system efficiency for the 150° dump set point mode was 26% for winter conditions and 39% for spring/summer conditions. The efficiencies varied from 11% to 55% in this mode. The differential controlled dump mode's average daylong efficiency was 34% for winter conditions and varied from 11% to 52%. It should be noted that the data for the differential controlled dump mode included several poor radiation days whereas the winter data for the 150° fixed set point dump mode did not. The differential mode's average system efficiency, 34%, was higher than the corresponding winter average efficiency for the 150° fixed set point, 26%, despite the difference in test days. Extrapolation from this comparison and the trend of higher summer average efficiency for the innovative operation in the 150° fixed set point mode, 26% winter to 39% spring/summer, suggests that the differential set point mode might have average system efficiencies in the mid-40% range for summer conditions. If that did happen, the average performance of the innovative system would be nearly equivalent to the conventional solar system for that season.

The energy consumption data were available only for the 150° dump set point mode of the innovative system. Only limited data was available for comparison with the conventional system energy consumption. The systems were operated by dumping 50 gallons of water from the hot water storage tank at the end of each day.

The data indicate that the innovative system uses less electric backup energy for water heating than the conventional system does. This observation is plausible since the innovative system has less cold water to heat up at the end of the dump. The tank of hot water generated by collection of solar energy during the day was dumped in the evening. The system ended up with storage tank #1 full of cold water and storage tank #2 filled with approximately 10 gallons of cold or diluted tepid water. Only the 10 gallons of water were subject to heating by the heater element. By comparison the conventional system had potentially more cold or tepid water to heat with its top element at the end of the pump because the tank was refilled and both systems collected solar energy before drawing water again.

The test information indicates that the innovative system could have possible benefit where the hot water demand characteristics were such that roughly one storage tank of water was used per day. The advantage comes from having a small volume of water to heat up for stand-by. The advantage is lost if considerably more water is required for daily household demand than was generated by the solar system. Extension of this reasoning would indicate that even though the innovative system efficiency was increased by the differential control mode, the energy use would be greater. The increased energy usage would result from a large volume of water which could potentially need raising from some temperature between supply and thermostat set point temperatures up to the thermostat set point temperature.

In conclusion, it looks like, from the evidence available from the tests conducted and from understanding the physical property characteristics, the innovative system will be less efficient in the collection of solar energy than conventional solar systems. However, the available data suggests that the innovative system could save more electrical energy. It is considered that a further long term investigation of this potential under real use conditions would be warranted.

APPENDIX

DATE: 2/24/81

$I_{\text{DAYLONG}} = 2595.9 \text{ Btu/ft}^2$

Gallons/Cycle = 4.66

$T_{\text{A DAYLIGHT HRS.}} = 68.5^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 150^\circ\text{F}$

Date: 2/23/81

$I_{\text{DAYLONG}}: 1774.3$

Gallons/Cycle: 4.66

$\bar{T}_A \text{ DAYLIGHT HOURS: } 63.2^\circ\text{F}$

$T_{\text{OUMP}} \text{ SET POINT: } 150^\circ$

E.S.T.

Date: 2/20/81

I_{DAYLONG} : 1907.9

Gallons/Cycle: 1.66

$\bar{T}_A$ DAYLIGHT Hrs: 73.1°

T_{DUMP} SET POINT: 150°

DATE: 2/19/81

$I_{\text{DAYLONG}} = 1735.9 \text{ Btu/ft}^2$

GALLONS/CYCLE = 4.66

$T_{\text{A DAYLIGHT HRS}} = 73.4^\circ \text{F}$

$T_{\text{PUMP SET POINT}} = 150^\circ \text{F}$

DATE: 2/12/81

$I_{\text{DAYLONG}} = 1758.7$

Gallons/Cycle = 4.66

$\bar{T}_{\text{A DAYLIGHT HRS.}} = 43.2^{\circ}\text{F}$

$T_{\text{DUMP SET POINT}} = 150^{\circ}\text{F}$

E.S.T.

DATE: 2/10/81

$I_{\text{DAYLONG}} = 1162.5 \text{ Btu/ft}^2$

Gallons/Cycle = 4.66

$\overline{T}_{\text{A DAYLIGHT HRS.}} = 73^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 150^\circ\text{F}$

E.S.T.

DATE: 2/9/81

$I_{\text{DAYLONG}} = 2048.6 \text{ Btu/ft}^2$

Gallons / Cycle = 4.66

$\overline{T}_{\text{DAYLIGHT HRS.}} = 61^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 150^\circ\text{F}$

Cycles

Gallons

0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800

EST

DATE: 2/5/81

$I_{\text{DAYLONG}} = 2129.5 \text{ Btu/ft}^2$

Gallons/Cycle = 4.66

$\overline{T}_{\text{A DAYLIGHT HRS.}} = 53.3^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 150^\circ\text{F}$

DATE: 1/23/81

$I_{\text{DAYLONG}} = 1479.7 \text{ Btu/ft}^2$

Gallons/Cycle = 4.66

$\bar{T}_{\text{A DAYLIGHT HRS.}} = 56.5^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 125^\circ\text{F}$

Cycles

Gallons

E.S.T.

DATE: 1/22/81

$I_{\text{RAYLONG}} = 1614.3 \text{ Btu/ft}^2$

Gallons/Cycle = 4.66

$\overline{T}_{\text{A DAYLIGHT HRS.}} = 58.3^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 125^\circ\text{F}$

E.S.T.

DATE: 1/21/81

$I_{\text{DAYLONG}} = 1916.5 \text{ Btu/ft}^2$

Gallons/cycle = 4.66

$\bar{T}_{\text{A DAYLIGHT HRS.}} = 58.7^\circ\text{F}$

$T_{\text{DUMP SET POINT}} = 125^\circ\text{F}$

Cycles

Gallons

E.S.T.

DATE: 1/19/81

$I_{\text{CAYLONG}} = 1442.2 \text{ Btu./ft}^2$

Gallons/Cycle = 4.66

$T_{\text{A DAYLIGHT HRS.}} = 60.5^\circ\text{F}$

$T_{\text{bump SET POINT}} = 125^\circ\text{F}$

E.S.T.

DATE: 3/9/81

T_{DAYLIGHT} : 68.8 °F

CONVENTIONAL SYSTEM

I_{DAYLOAD} : 2140.6

STORAGE VOLUME: 52 gal.

TANK WATER TEMPERATURE (°F)

150
140
130
120
110
100
90
80
70
60
50

0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900

E.S.T.

DATE: 3/10/81

$\bar{T}_{\text{DAYLIGHT}}$: 65.0 °F

CONVENTIONAL SYSTEM

I_{DAYLIGHT} : 2363.5

STORAGE VOLUME: 52 gal.

DATE: 3/11/81

 $T_{\text{A DAYLIGHT}}$: 64.6°F

CONVENTIONAL SYSTEM

 I_{DAYLONG} : 1627.6

STORAGE VOLUME: 52 gal.

DATE: 3/12/81

T_{DAYLIGHT} : 66.6°F

CONVENTIONAL SYSTEM

I_{DAYLONG} : 2116.5

STORAGE VOLUME: 52 gal.

DATE: 3/13/81

$\overline{T}_{\text{DAYLIGHT}}$: 64.4°F

CONVENTIONAL SYSTEM

I_{DAYLONG} : NOT AVAILABLE

STORAGE VOLUME: 52 gal.

DATE: 3/17/81
I_{DAYLONG}: 2018.4

T_A DAYLIGHT HRS.: 66°F
STORAGE VOLUME: 52 gal.

CONVENTIONAL CONFIGURATION

DATE: 3/18/81
I_{CAYLONG}: 1071.1

$\bar{T}_A$ DAYLIGHT HRS.: 69.6 °F
STORAGE VOLUME: 52 gal.

CONVENTIONAL CONFIGURATION