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ABSTRACT

A conceptual breakthrough in solar water heating in the form of a tropical window solar water heater is described. A louvered window that is mass produced and commonly used in Puerto Rico and the Caribbean is employed as a solar collector by replacing louvers with solar radiation absorbing surfaces. The copper thermafin absorbers act as louvers and as solar heat collectors. The window functions as a normal window while operating as a solar collector-water heater. The cost of the tropical window solar collector is in the range of \$75/sq.m. (\$7/sq.ft.) whereas the cost of a flat-plate solar collector is about \$215/sq.m. (\$20/sq.ft.). Because of its technical simplicity and low cost, this novel system has the potential to be manufactured and commercialized in the Caribbean, Latin America, Asia and the Middle East. A detailed description of the system construction and operation is provided and illustrated by photographs and schematics. Various ways in which the tropical window solar water heating system can be incorporated into water heating installations already marketable are mentioned. And, other advantages of the system related to energy conservation and security are briefly discussed. The research installation used to evaluate the thermal performance of the tropical window solar water heater is described and some details about the measuring procedure are given. Finally, the research program being conducted is presented, and the preliminary results of the thermal performance of a single tropical window used as a solar water heater are discussed.

INTRODUCTION

Water heaters are widely used in most countries and when economically acceptable solar water heaters share this market. The use of hot water in large amounts at temperatures between 50° and 100°C (120° and 212°F) for cooking, washing, bleaching, and anodizing represents about 2 percent or 2×10^{17} Joules (0.2×10^{15} Btu) of the total energy use in the continental United States. The preheating of boiler feedwater accounts for an additional 3×10^{18} Joules (3×10^{15} Btu) and some of it can be accomplished by using solar water heaters.

The active type of solar water heaters available on the market usually consists of three major subsystems: 1. Flat-plate or concentrating solar collectors, 2. Hot water storage tank and 3. Control subsystem which includes pumps, valves and temperature sensors. The passive thermosyphon type of solar water heaters is the most popular in Puerto Rico and the Caribbean because water circulates in the system by natural convection and no pump is required. Such a system is shown in Fig. 1 on the roof of a house in Puerto Rico. Also visible are tropical windows commonly used in houses and buildings in the Caribbean region.

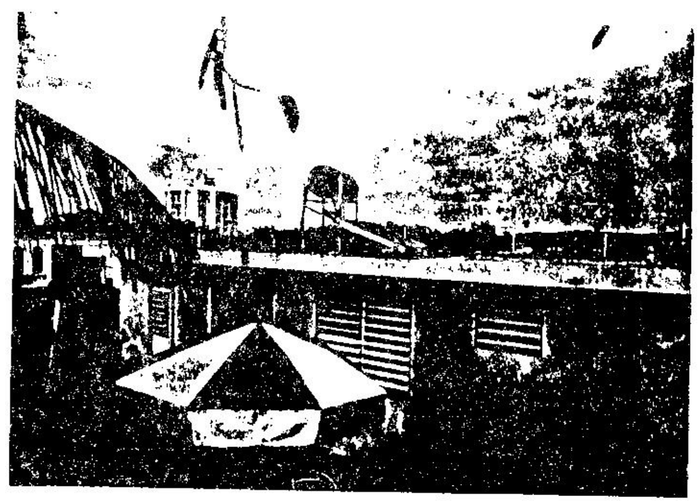

FIGURE 1. TYPICAL SOLAR WATER HEATER USED IN PUERTO RICO.

The novel water heater presented in this paper can be built as an active or passive system. In this system solar absorbers are integrated into a typical window frame; both the absorbers and the window are mass produced and available on the market. The thermafin metal absorbers-louvers collect solar energy that heats water circulating through copper tubing welded to the absorbers. The louvered window into which these absorbers are fitted operates as a normal window in addition to functioning as a solar water heater. Other parts of the system such as pumps, valves and controls are standard plumbing parts also available on the market. Because of its low cost and simple technology this novel solar water heater has the potential for widespread use in Puerto Rico and in other geographical locations with a similar climate.

SYSTEM DESCRIPTION

Some of the louvers in a commercially available tropical window were replaced by copper solar absorbers to collect solar radiation falling on the window. Figure 2 shows a commercial window frame before the installation of the louvers in the foreground, and two tropical windows equipped with solar energy absorbing louvers in the background. The window frame used in the assembled system is 0.91 m. x 1.50 m. (36 in. x 39 1/8 in.); however any commercially available tropical window that allows for movable or immobile louvers can be used to combine the purpose of a window with that of a solar water heater.

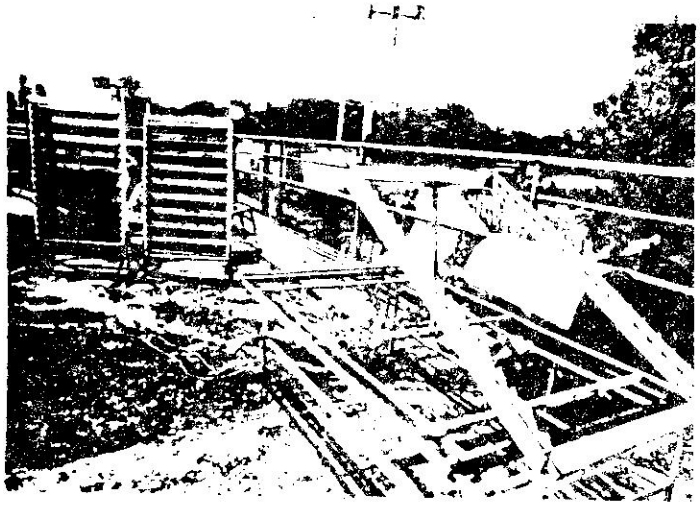

FIGURE 2. GENERAL VIEW OF TWO TROPICAL WINDOW SOLAR WATER HEATERS IN BACKGROUND AND WINDOW FRAME IN FOREGROUND.

This typical frame allowed using nine solar absorbers-louvers and ten transparent glass louvers. The glass louvers were used to avoid shading of the louvers-solar absorbers by each other. Copper thermafin absorbers (corrugated finish) of 0.11 m. x 0.84 m. (4.5 in. x 33 1/4 in.) and of 0.25 mm. (0.01 in.) thickness with welded 1.27 cm. (1/2 in.) outside diameter copper tubing were used. However, various sizes and numbers of louvers-solar absorbers can be used depending on the window frame size and construction. Figures 3 and 4 show close-up views of the front and back of a single window converted into a solar heat collector for heating water.

The solar heat absorbed by the metal louvers is collected by means of a heat transfer fluid that circulates through the copper tubing welded to the back of the louver. This tubing also assures the mechanical rigidity of the louver. Water is used as the heat transfer fluid in the system described here. The copper tubing of the louvers is connected to the headers by means of flexible plastic tubing of 10 cm. (4 in.) length and 1.27 cm. (1/2 in.) outside diameter (see Fig. 5).

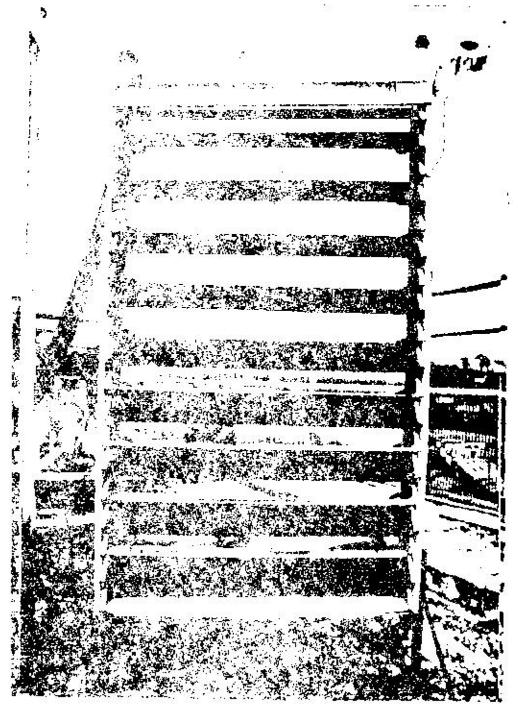

FIGURE 3. FRONT VIEW OF SINGLE WINDOW SOLAR WATER HEATER.

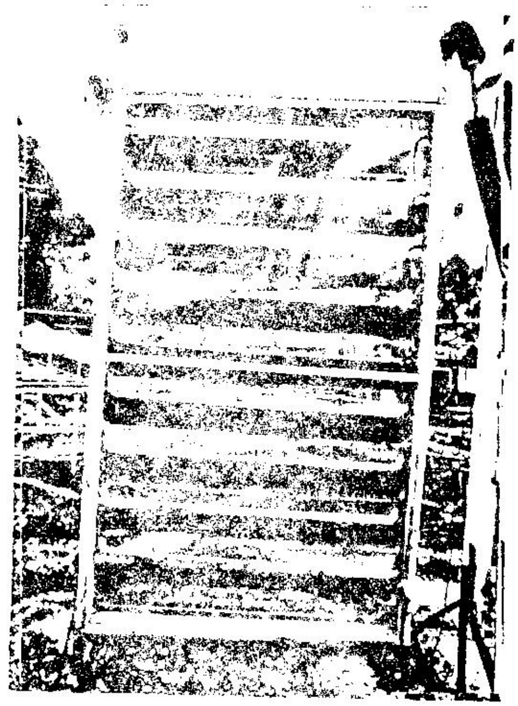

FIGURE 4. BACK VIEW OF SINGLE WINDOW SOLAR WATER HEATER.

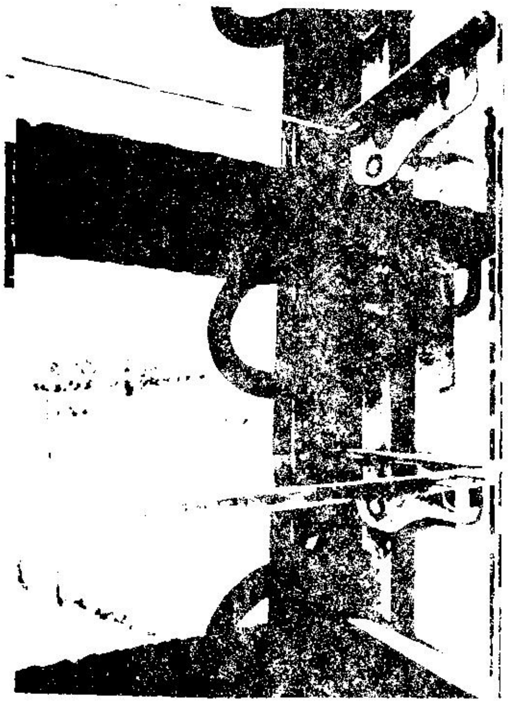

FIGURE 5. CLOSE-UP VIEW OF SOLAR LOUVERS-HEADERS CONNECTION.

To do this, holes were drilled in the copper tubing of the absorbers (one at each end) and short copper tubes of 2 cm. (3/4 in.) length and 0.85 cm. (1/3 in.) outside diameter were soldered to the tubing. The short tubes serve as connectors for the plastic tubing which runs between the headers and the louvers. The length of these connectors and the length of the plastic tubes is such as to assure flexible connections without sharp bendings in the plastic which could impede the water flow and the motion of the louvers.

Headers of 1.52 m. (60 in.) length and 1.58 cm. (5/8 in.) outside diameter were incorporated into each side of the window frame. The two headers move up and down the frame together with the flat rail of the louver opening/closing mechanism to which they are attached by a metal clamp. Although the headers are two copper tubes in our system, PVC tubes can be used as well. Two holes of 2.54 cm (1 in.) diameter each were made both in the upper and the lower part of the frame to allow the unrestricted up and down motion of the headers. Enough space remained between the louver operating mechanism and the frame so that the headers could be thermally insulated with insulating duct tape. The solar louvers used to heat water operate in the window in the same way as standard louvers, thus permitting a complete closing or opening, or any intermittent louver position.

The number of louvers used to collect solar radiation in a window could vary. For optimum operation, however, this number should be such as to use the maximum possible surface for solar radiation collection while avoiding the shadowing of one solar louver-collector by another one. These louvers can be connected, to the headers in a parallel manner as shown in Figure 6; or, they can be connected in series as shown in Figure 7.

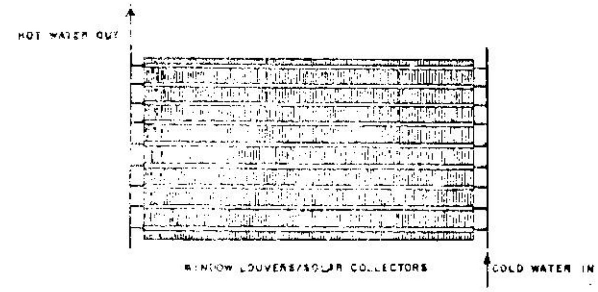

FIGURE 6. PARALLEL CONNECTION BETWEEN LOUVERS AND HEADERS.

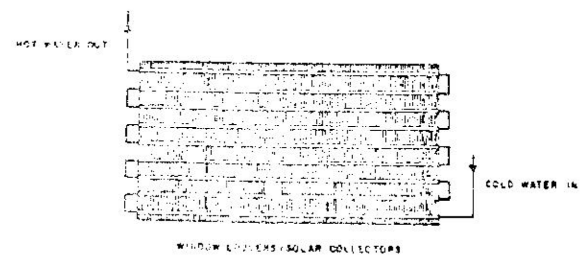

FIGURE 7. LOUVERS CONNECTED IN SERIES.

The in-series connection of louvers does not require headers. This simplifies the system and reduces the cost. The parallel connection of louvers permits water to reach a moderate temperature at different flow rates; the in-series connection permits water to reach a higher temperature at a moderate flow rate. Either a single window can be used in a solar water heating system or several windows connected parallelly or in-series can be used.

A tropical window solar water heating system can operate in an active mode by using a pump to circulate water in the system (see Fig. 8) or in a passive mode as a thermosyphon system by having the hot water circulate in the installation according to thermal convection alone (see Fig. 9).

RESEARCH INSTALLATION AND MEASUREMENTS

Two tropical window solar water heaters were assembled, one with black chrome plated copper louvers and one with stripped copper louvers. They are being experimented with by using the research system shown in Figure 10. The two tropical windows are connected to an installation that is equipped with a heat exchanger for cooling solar heated water, a hot water storage tank, and instrumentation for instantaneous measurement of various thermal parameters such as the heat input, in the

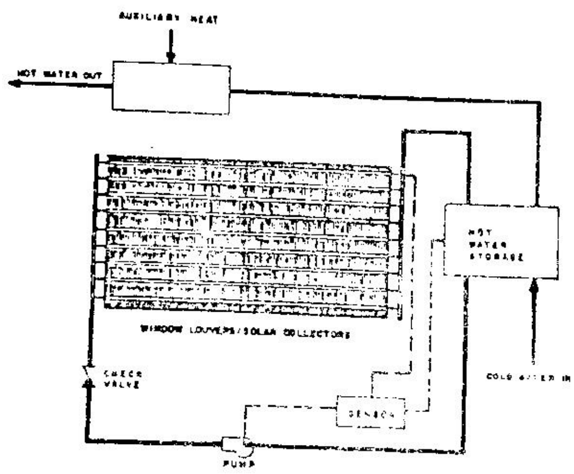

FIGURE 8. SCHEMATIC DIAGRAM OF ACTIVE SYSTEM WITH SINGLE WINDOW SOLAR WATER HEATER.

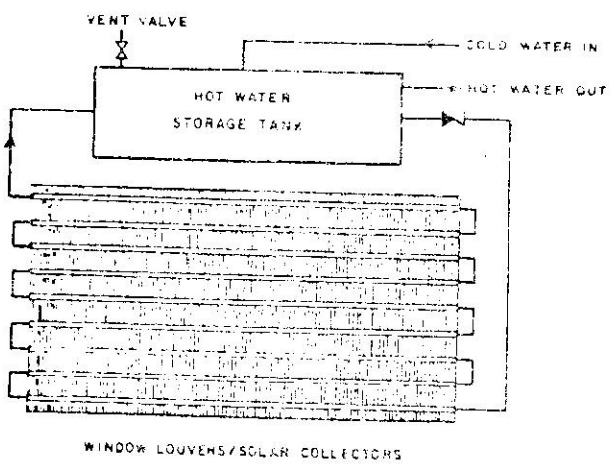

FIGURE 9. SCHEMATIC DIAGRAM OF THERMOSYPHON SYSTEM WITH SINGLE WINDOW SOLAR WATER HEATER.

form of solar radiation, and the heat output, in the form of hot water. A commercially available Btu meter, a photovoltaic pyranometer, a flowmeter and two thermocouples which measure the input and output water temperature are used. The pyranometer installed on the window can be adjusted to follow the orientation of the window and the slope of the louvers. The Btu meter displays the total number of Btu's delivered from the solar system by hot water. The electronic circuit of the meter multiples the flow rate times the input and output water temperature difference times the heat capacity of the water and adds the result over time to calculate the total amount of solar heat collected by the water. The result is displayed on a 6-digit mechanical counter. The pyranometer comes with an integrator which is attached directly to the electronic circuit of the Btu meter. It integrates the pyranometer output to determine the total solar radiation falling on the window. The information from the integrator circuit of the pyranometer is displayed on the separate 6-digit mechanical counter. By dividing the number of Btu's of insolation into the number of Btu's delivered information about the thermal performance of the tropical window solar water heater is obtained. Figure 11 shows details of the thermal performance measurement of a single tropical window solar water heater.

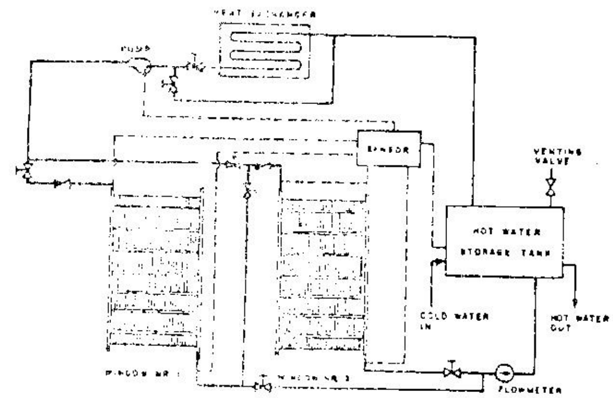

FIGURE 10. SCHEMATIC DIAGRAM OF RESEARCH INSTALLATION.

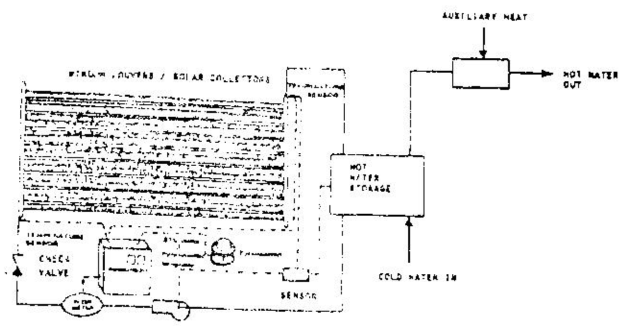

FIGURE 11. SCHEMATIC DIAGRAM OF SYSTEM FOR THERMAL PERFORMANCE MEASUREMENT.

By using the installation described above, the following research is being performed:

1. Active mode of the system operation (the solar water heater contains a pump)
   a) measurements of thermal output from a single window in various azimuthal orientations. These measurements are being performed for louver inclination angles equal to vertical, horizontal and 45°. Louvers connected in series or in parallel are being used.

   b) measurements of thermal output for two windows in various azimuthal orientations connected in series or in parallel. These measurements are being performed for louvers positioned in three selected angles: vertical, horizontal and 45°. Louvers connected in series or in parallel are being used.

2. Passive mode of the system operation (thermosyphon system)
   a) measurements of thermal output for two windows in various azimuthal orientations connected in series or in parallel. These measurements are being performed for louver inclination angles equal to vertical, horizontal and 45°. Louvers connected in series or in parallel are being used.

   b) measurements of thermal output for two windows in various azimuthal orientations connected in series or in parallel. These measurements are being performed for louvers positioned in three selected angles: vertical, horizontal and 45°. Louvers connected in series or in parallel are being used.

The research results will permit the thermal performance of this novel solar water heater to be evaluated in various conditions of operation all year around. The preliminary results show that at noontime the thermal efficiency of a single window solar water heater South oriented can be expected to be in the range of 10 percent. Wind plays a dominant role in decreasing the window performance by increasing convection heat losses.

When determining the solar energy collection area for a window water heater a rule of thumb similar to the one used in the case of standard solar water heaters can be applied. For example, with a 151-189 liter (40-50 gal.) water tank, the area of solar collectors should be about 1.86 sq.m. (20 sq.ft.). In the case of a tropical window solar water heater this will correspond to a total collection area of up to 9.30 sq.m. (100 sq.ft.) depending on the hot water usage. However, the solar energy collection area can be much smaller if only preheating of water is being considered.

In Puerto Rico and the Caribbean tropical windows are used extensively and they sometimes cover whole walls of a house to assure better ventilation. This potentially available large window area for solar water heating could compensate for the relatively low thermal efficiency of a window working as a solar energy collector. And, since windows are used any way, they might as well be used to heat or preheat water by employing solar energy which is abundant in all Caribbean countries.

In a single window solar water heater the water temperature increase may be up to 5.5°C (10°F). This temperature is, however, a function of window size, window orientation, louver heat gain, louver connection type (in series or parallel) and flow rate. Moreover, when several windows are connected together, the type of connection between them plays a major role in the system's operation and performance. All of these parameters are being evaluated at the solar research site of the Center for Energy and Environment Research of the University of Puerto Rico.

CONCLUSIONS

Tropical window frames mass produced in Puerto Rico and solar absorbers mass produced in the continental U.S. were used to convert a louvered window into a novel type solar water heater. Because mass produced subsystems and parts were also used, this tropical window solar water heater is much less costly than other types of solar water heaters sold in geographical locations where tropical windows are one of the elements in house and building construction. For example, the present cost of a window as a solar radiation collector is in the range of $75/sq.m. ($7/sq.ft.)* ($0.81 per linear foot for stripped copper louvers-solar absorbers) while the cost of a typical flat-plate solar collector is about $215/sq.m. ($20/sq.ft.). Another advantage of the described system lies in the cooling effect of the louvers. Since the water takes heat away from the louvers, the ambient ventilating air flowing into the room between the louvers from the outside is not heated by louvers as it is when normal louvered windows are exposed to the sun. Thus energy needed to cool the house interior by using ceiling fans, for example, can be conserved. Also, the plumbing integrated into the tropical window may discourage breaking and entering through it which, therefore, provides a security advantage. In summary, this novel type solar water heater has the potential of being locally manufactured and widely used in the Caribbean, Latin America, and some Asian and Middle Eastern countries because of its simple technology and low cost.

*tropical windows cost about $38/sq.m. ($3.50/sq.ft.) on the retail market in Puerto Rico (1983 prices).