FIELD EVALUATION OF AN UNGLAZED, BUILDING-INTEGRATED, SOLAR DOMESTIC WATER HEATING SYSTEM

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ABSTRACT

Aesthetic appearance has been a persistent roadblock for residential solar energy systems. To address this concern, manufacturers of both solar thermal and electric systems have developed various building integration strategies to incorporate (or at least hide) solar systems within the structure of the building. In late 2005, construction was complete on a home in Litchfield, CT that incorporates roof-integrated, unglazed, solar thermal systems manufactured and installed by Dawn Solar Systems, Inc.

The south-facing roof of the home (shown in Fig. 1) actually consists of three active solar systems. The main southern roof of the home (750 ft^2) incorporates a solar thermal system for space heating. The southern shed dormer (250 ft^2) supports both a thermal system (dedicated for domestic hot water) as well as a roof-integrated PV system using amorphous silicon laminates. Beneath the standing-seam metal roofs, the unglazed thermal collectors consist of cross-linked polyethylene (PEX) piping run in metal heat transfer plates. Propylene glycol solution is circulated through the collectors and through heat exchangers in storage tanks in the basement.

The authors installed instrumentation to monitor performance of the solar systems and currently have 15 months of data. This paper documents the performance of the smaller solar thermal system which provides pre-heating for domestic hot water. During the first 12 months monitored (February 2006 – January 2007), this small system has offset 35% of the domestic hot water load in the home where residents have consumed an average of 47 gallons of hot water per day.

Fig. 1: The south side of the completed home with integrated solar systems.

1. SYSTEM DESCRIPTION

The solar systems in this home are designed to be very well integrated into the home's roof system (Fig. 1). From the outside, there is no visible evidence that solar thermal collectors exist on the south-facing roof, and the solar electric laminates (on the shed dormer) are very low-profile and difficult to detect.

Above the roof deck and beneath the standing-seam metal roof, cross-linked polyethylene (PEX) tubing is plumbed through metal channels designed to hold the tubing in place while facilitating heat transfer (Fig. 2). The collector area for the small system discussed here is the 250-ft^2 area above the shed dormer on the southern roof. The PEX pipes above the roof deck connect to a manifold in the conditioned attic of the home, and larger PEX pipes run from the manifold to a heat exchanger located within a 120-gallon storage tank in the basement. A differential controller senses the temperature beneath the metal roofing as well as in the storage tank; when the roof is substantially warmer, a 50% propylene glycol solution is circulated to transfer energy from the collector to the tank.

On a domestic hot water draw, cold well water flows into the bottom of the solar storage tank. From the top of the tank, preheated water exits and runs to the auxiliary water heating tank; this auxiliary tank is heated indirectly by a condensing, propane-fired boiler.

As discussed above, the larger surface of the southern roof also incorporates solar thermal collection. This collector area is part of a separate system intended for space heating. The shed dormer (shown in Fig. 2 with metal roofing already installed) also includes amorphous silicon PV laminates. Because these two solar systems had not been commissioned when the monitoring began, analysis of their performance is not included in this paper.

2. MONITORING

Performance of the solar thermal system was monitored by measuring several temperatures and fluid flow rates. The authors installed thermistors to measure the following temperatures:

- Outdoor air (in an aspirated radiation shield)
- Four collector temperatures (beneath the roof and above the roof deck where solar collector piping is run)
- Cold water from the well
- Preheated DHW leaving the solar tank (going to auxiliary heater)
- DHW leaving the auxiliary heater (going to DHW loads)
- Solar tank (near the top)
- Glycol solution exiting the tank HX running to the attic manifold
- Glycol solution at the attic manifold running out to the roof collectors
- Heated glycol solution at the attic manifold coming in from the collectors
- Heated glycol solution entering the tank HX coming from collectors

Using turbine meters, two liquid flow rates in this system were measured:

- Domestic hot water
- Glycol solution in the solar collection loop

Fig. 2: The solar thermal collection system installed on main section of southern roof consists of red PEX tubing and metal heat transfer channels. On the shed dormer, the standing-seam metal roof and PV laminates have already been installed over the thermal collection components.

In addition to the temperature and flow sensors, a pyranometer was installed on the roof to measure global horizontal radiation. All sensors were connected to a Campbell Scientific CR10X datalogger, and the datalogger was connected to a modem so data could be collected remotely.

3. RESULTS

3.1 Performance Overview

During the first 12 months monitored (February 2006 – January 2007), the occupants of the home used an average of 47.2 gallons of hot water each day. This resulted in a thermal load of 10.6 MMBtu; the small solar thermal system provided 3.68 MMBtu or 35% of the energy needed to heat this water.

As expected with an unglazed thermal system, performance varied greatly with outdoor temperatures. In January, for example, the system provided only 10% of the water heating load. In July, by contrast, the solar fraction was 60%. The monthly contributions of solar (along with auxiliary energy required) are shown in Fig. 3.

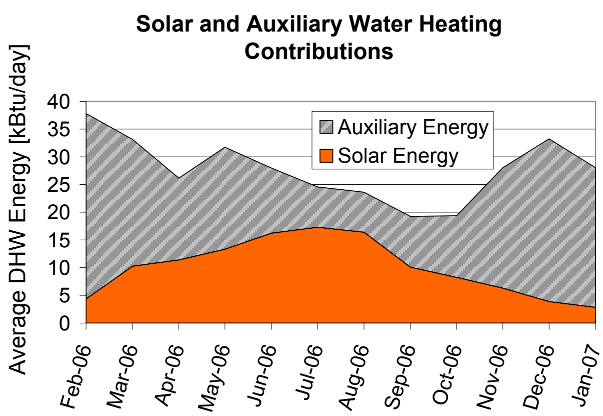

Fig. 3: Average daily energy required to heat hot water during each month monitored. Shaded areas show portions provided by solar and auxiliary propane water heater.

3.2 Temperatures and Available Energy

Because of the low temperatures generated by this unglazed thermal system, it can only provide DHW preheating; i.e. temperatures in the solar tank are rarely sufficient to meet domestic temperature requirements without supplemental heating (DHW is delivered to loads between 120°F and 130°F). During July, the month with the highest solar fraction, the water temperature at the top of the solar storage tank never fell below 75°F and reached a maximum of 121°F. In January, by contrast, tank temperatures ranged from 57°F to a maximum of only 73°F.

These low tank temperatures are a result of the relatively low collector temperatures (i.e., relative to temperatures reached in glazed collectors). For July and January, Table 1 shows conditions during the 15-minute interval when the monthly maximum collector temperatures were achieved. The collector temperature ranges refer to the range in readings from four thermistors installed in the collector area. Note that tank temperatures in the table are the maximum achieved during the entire day (in late afternoon).

TABLE 1: CONDITIONS DURING THE HIGHEST COLLECTOR TEMPERATURES ACHIEVED IN JULY AND JANUARY

Date	July 17	January 07
Time	1:15 PM	2:15 PM
Outdoor Air Temp.	87°F	47°F
Global Horiz. Radiation	760 W/m^2	342 W/m^2
Collector Temp. Range	130°F - 145°F	83°F - 89°F
Max. Tank Temp. (Daily)	121°F	73°F

With water temperature at the top of the solar tank reaching 120°F only once during the year (on July 17), it's clear that this system is suitable for preheating only; it is not a viable stand-alone system. It is also critical that auxiliary water heating in this home is provided by a separate appliance that provides no heat to the solar tank. If, for example, auxiliary heat were provided by a resistive element near the top of the tank, there would be much less opportunity for solar energy collection as the tank would always be warm.

While the low temperatures achieved by this unglazed collector limit the system's performance when compared to conventional glazed collectors, there is a slight silver lining with respect to maintenance and durability. With the maximum antifreeze temperature recorded at 131°F, there is no need for high-temperature protection for this solar system during summer months. In addition, the propylene glycol in this system will probably last longer than glycol in higher temperature systems.

3.3 Pipe Heat Loss

One startling observation made from examining data collected from the system was the large amount of energy lost from pipes running between the solar tank (in the basement) and the collector manifolds (in the attic). The pipe runs are rather long (approximately 50-70 feet each way). The authors were informed by the installers that each PEX pipe was insulated with ½" closed-cell foam. In addition, both pipes were run together in an insulated flexible duct (typically used for forced-air distribution).

Over the 12-month monitoring period, 8.2 MMBtu were collected from the 250-ft^2 collector on the dormer roof (measured using the temperature differentials at the attic manifolds). Only 4.3 MMBtu, or 52%, were transferred to the solar tank heat exchanger. The balance was lost through convection and conduction from fluid in the piping.

When heated glycol reached temperatures of 100°F or more (as measured in the attic manifold), the fluid was between 5°F and 10°F cooler when it reached the solar tank in the basement. In a low-temperature system, this results in a significant overall energy loss.

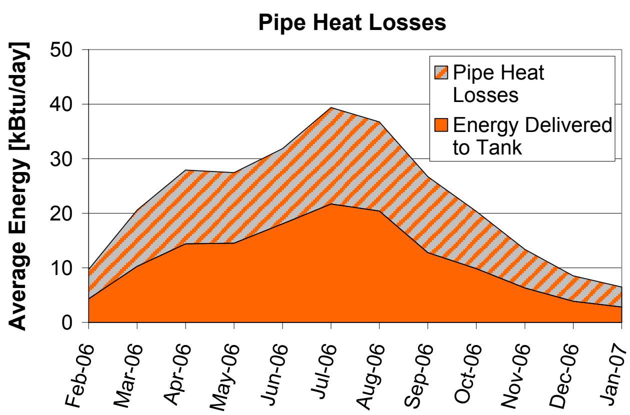

Fig. 4: Average daily heat collected from the roof each month. Areas show both the heat delivered to the storage tank and heat lost from piping.

4. CONCLUSIONS

Because this study was a field evaluation of a single system, it is not appropriate to make general statements about this new technology. From studying this system, however, the major conclusions are:

- This solar thermal system is truly building-integrated; the collectors are not visible from outside the home.
- The 250-ft^2 unglazed collector system provided a significant portion (35%) of the domestic water heating load in a relatively cold Connecticut climate (approximately 6,500 heating degree days).
- Because of the low temperatures achieved by this system, it is only suitable for DHW preheating (i.e. auxiliary water heating is needed throughout the year).
- Because of lower temperatures and light levels, winter performance was much poorer than summer performance.

While the system is not as effective as more conventional systems with glazed collectors, when aesthetics are a dominant concern this roof-integrated, unglazed system is a viable option for providing a portion of domestic water heating loads.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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