Low-Cost Residential Solar Thermal Systems

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ABSTRACT

To achieve at least 50% reduction in cost of savings for residential solar water heaters (SWHs), polymer materials and manufacturing are being used, which also enable system redesign for parts reduction and easier installation. Two teams are bringing new low-cost systems to the market in FY 2007. Technical support at NREL for modeling and testing provided new models and test procedures for rating innovative integral-collector-storage (ICS) and thermosiphon (TS) systems. The pipe-freeze problem has been satisfactorily solved, enabling cold-climate TS systems. System analyses are under way for multi-function solar systems that affordably supply 100% of water heating, space heating, and space cooling, potentially enabling cost-neutral zero energy homes.

1. Objectives

The low-cost SWH task in the Solar Heating and Lighting Subprogram has the objective to reduce the levelized cost of saved energy (LCOE) from SWH by at least 50%.[1] As in Ref. 1, research started with low-cost passive systems suitable for mild climates in FY 1999, with the focus changing in FY 2007 to cold climate SWH and multi-function systems doing water heating, space heating, and space cooling (consistent with change in FY 2007 program objective to support zero energy homes [ZEH]).

The objectives for NREL support of the low-cost SWH task are to:

- Contract management and technical guidance to industry teams.
- Technical support to industry development teams, including modeling and testing.
- Analyses supporting the FY 2007 shift in program objectives to develop cost-effective thermal technology for ZEH.

2. Technical Approach

The overall technical approach is to: i) use low-cost polymer materials and manufacturing; and ii) simplify design and installation through parts integration and weight reduction, exploiting the formability and light weight of polymers. Since 1999, NREL has been working with two industry teams—Davis Energy Group/SunEarth (DEG/SE) and FAFCO, Inc.—to develop lower-cost SWH systems. After down-selection from five teams in 2001, the two teams were "stage-gated" through prototype development to field trials and manufacturing development in FYs 2005–2006. The industry teams are developing truly innovative systems, which require new models and new procedures for developing the SRCC ratings.

The polymer-based strategy has opened new design opportunities, but also presents new problems. The key problem to be addressed is materials durability under harsh environmental stresses and high temperatures. A minimum lifetime for polymer solar systems is at least 15 years, with 20 desired. These criteria lead to the need for sophisticated and capital-equipment-intensive accelerated testing to identify appropriate materials. Polymer materials testing expertise at NREL and the University of Minnesota has fulfilled that need. NREL concentrated on identifying and testing good candidates for glazings and absorbers; this work is described in the SH&L project description *Durability of Polymeric Materials for Solar Hot Water Collectors.* The University of Minnesota concentrated on heat exchanger design and testing, materials durability for polymer heat exchangers, and scaling in polymer-tube heat exchangers; this work is described in the SH&L project description *Low-Cost Polymer Solar Domestic Water Heating Systems*.

Passive systems (ICS and TS) have a very limited market (mild climates only), as in Fig. 1a. Extending the passive system market northward (as in Fig. 1b) is desirable, as these systems are inherently less costly and more reliable than active systems because they have no pumps, sensors, or controllers. The freeze limitation is due to: i) pipes: the danger of freeze/burst of the pressurized supply/return lines in the home attic; and ii) collectors: the danger of metal tube breakage in the collectors. Collector freeze makes only indirect/glycol TS potentially suitable for cold climates (and only if the pipe freeze issue is satisfactorily resolved).

3. Results and Accomplishments

In FY 2006, *both industry teams submitted their systems for SRCC certification and plan to bring their low-cost SWH designs to market in 2007*. Systems are shown in Fig. 1. The DEG/SE team refined its design and developed detailed marketing and manufacturing approaches. NREL analysis of unglazed SWH systems[2] motivated DEG/SE to develop an unglazed version of its low-cost system. DEG/SE has been developing pilot projects with the Sacramento Utility District, migrant housing authorities in California, and Building America research homes. In FY 2006, FAFCO changed its system type from a glazed, pressurized direct or thermosiphon system to an unpressurized indirect drainback system using an unglazed polymer flat-plate collector. FAFCO developed full-scale prototypes, held successful in-house field trials, and planned to formally introduce the new system in February 2007 at the National Association of Home Builders' (NAHB) International Builders Show. FAFCO is working on a glazed version of the system that will afford higher performance and would be suitable for cold climates.

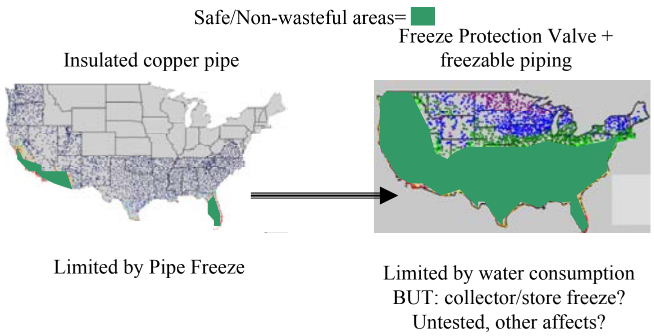

Fig. 1. (a) Geographical limits for passive systems with 3/4" metallic piping and 1" insulation jacket (left side); (b) Market extension with freeze protection valve and freeze-tolerant PEX piping, limited to those areas where water flowing through the freeze valve is less than1000 gal./year.

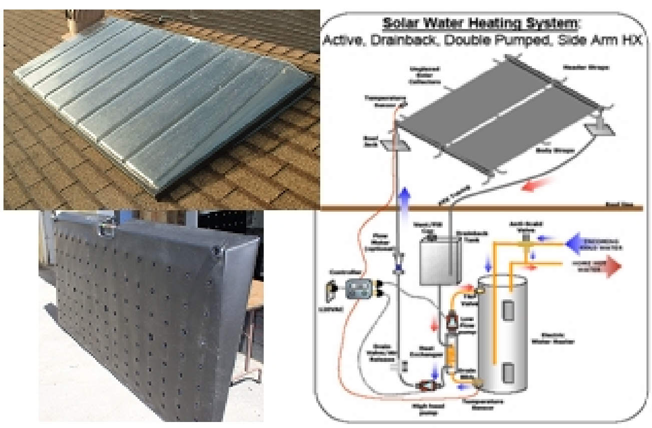

Fig. 2. (a) DEG/SE unpressurized ICS collectors (left); (b) FAFCO unglazed drainback system schematic (the collector, drainback tank, and BOS packaging are all polymer components (right).

New thermal models for glazed and unglazed unpressurized ICS have been developed to predict performance generally, optimize designs, and establish rated performance in SRCC. The collector and heat exchanger sub-models can be calibrated with specific test data, which is a similar process to other test procedures developed at NREL for SRCC use. Staff is working with SRCC to implement the new ICS testing and analysis procedures in the SRCC rating framework. SRCC's specialized software is not standard TRNSYS, and presents numerous problems for types developed under TRNSYS16. Models and test procedures have also been developed for innovative thermosiphon systems that are expected to be part of cold-climate R&D.[3] This work has shown that thermosiphons can be rated by the component-test/system-simulation path (a comparatively quick, inexpensive process compared to system tests), as indicated in Fig. 3.

Eliminating risk of pipe freeze involves: i) a primary freeze protection method (such as a freeze valve letting warm mains water flow through the pipes, or ducting warm room air through a flex tube surrounding the pipes); and ii) a fail-safe backup in the form of freeze-tolerant piping (See Fig. 1b). Papers were published demonstrating that pipe freeze prevention based upon ducting room air works well if the duct diameter exceeds 3"[4]; and that certain PEX piping brands are freeze-tolerant)[5]. Although PEX piping helps solve the freeze problem, it cannot withstand temperatures much above above 100 ºC, so overheat protection is also essential for use of PEX. Boiling of unpressurized storage (with water make-up) is a good form of overheat protection for thermosiphons[3]. Cold-climate thermosiphons based on these principles are now considered possible.

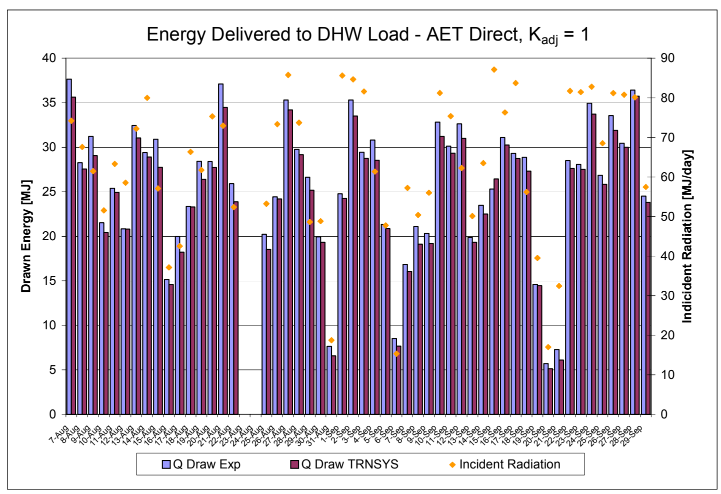

Fig. 3. Day-by-day energy savings for the glazed/direct TS system, measured and modeled, over a 6-week period in summer/fall 2006. The model predicts the savings day-by-day reasonably accurately, with an integrated error of 4%.

Analysis of systems combining the water heating function with space heating and/or space cooling has begun to support the Building America ZEH goal. Simulations were done of "combi-systems" (which combine water heating and space heating, also called "double-play") with sensible storage, as a function of collector and storage size. Systems approaching unity solar fraction demand very large storage volumes, on the order of 3,000–30,000 gallons. Triple-play systems (combi-system + solar-driven cooling) are also being analyzed. Analysis indicates the desiccant technology is more suitable than absorption for cooling, due to higher efficiency at lower temperatures more compatible with solar arrays. Recognizing that desiccants can also be used for thermochemical heat storage (as shown in Fig. 4), a new type of triple-play system based upon desiccant technology is being analyzed that can supply 100% of all three end uses (the "home run" system). A schematic diagram of the system is shown in Fig. 5.

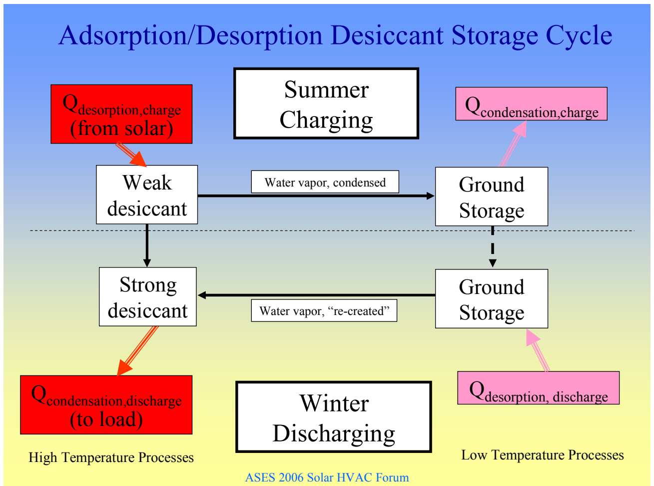

Fig. 4. Desiccant-based heat storage cycle. In the charging part of the cycle, weak desiccant is regenerated in summer. The sensible and latent heat in the scavenging air is transferred via air-to-liquid condensing heat exchanger into a lower-temperature ground storage. The ground-stored heat is used in winter to create water vapor at moderate temperature (e.g., 80º–110ºF), which, when absorbed on the strong desiccant, creates weak desiccant and high temperature heat.

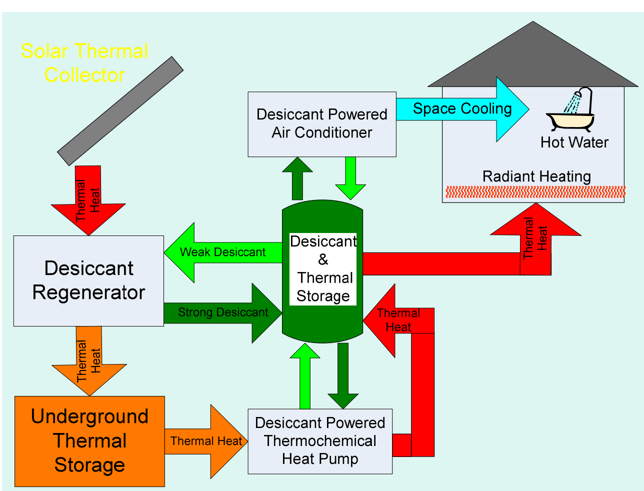

Fig. 5. Schematic diagram of a desiccant-based, triple-play system. The system is 100% solar supply with sufficiently large storage, on the order of 1000 gallons.

4. Conclusions

Use of polymer technology has been successfully applied to reduce the cost of savings by about 50% for mild-climate system types[1]. Two systems that cost less than half of traditional metal/glass systems will be introduced to the market in FY 2007. Models and test procedures for ICS with load-side heat exchanger and for innovative thermosiphons have been developed. The pipe freeze problem has been resolved, enabling cold-climate thermosiphons. Analysis of multi-function solar indicates these systems may be a good option to affordably supply 100% of ZEH thermal needs, including water heating, space heating, and space cooling.

ACKNOWLEDGMENTS

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