Photovoltaic/District-Heated and Desiccant-Cooled Solar Powered Community Using an Insulated Pond

C. Brent Cluff, Associate Hydrologist
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ABSTRACT

In 1987 Arizona's governor announced a goal of constructing a solar powered community that would produce as much energy from the sun as it consumed. As a part of that program the use of a water cooled photovoltaic system evolved.

The thermal energy would be utilized in homes with a district heating and desiccant cooling system. Thermal powered desiccant cooling was selected because it required water with relatively moderate temperatures, 140-160°F, that could be easily transported in insulated low-cost plastic pipe.

Three ASK Corp. desiccant cooling/heating units have been successfully operated in the Phoenix area on a 5000 sq ft solar-powered residence since October, 1985. There also are photovoltaic/ water cooled intermediate concentrators commercially available that have been thoroughly tested through different Department of Energy programs.

This study describes the use of a computer to design a hybrid photovoltaic/thermal system providing heat to a district heating and desiccant cooling system for a 24 home subdivision in the Phoenix area of Arizona. Excess thermal energy is stored in an insulated pond. The gunite coated foam cover of the pond served as a tracking base for the concentrating solar collectors.

1. INTRODUCTION

On January 12, 1987, Governor Mecham of the State of Arizona announced a program for the construction of a solar powered community. A cost-effective way of powering a solar community appears to be the combination of using a hybrid thermal/ photovoltaic collector, with seasonal storage of water in an insulated pond providing thermal energy to the homes in the community. Thermal energy would be distributed using insulation pipes. Desiccant cooling was selected due to the moderate temperatures required and the comfort level provided even on humid days.

In order to demonstrate the cost effectiveness of this system in southern Arizona, a project was designed and a cost was estimated for a 24-home subdivision in the Phoenix area. The 24-home size was selected to compare with the John F. Long Inc. 24-home

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subdivision which obtains electrical power from a fixed photovoltaic array.

2. DESCRIPTION OF SYSTEM

The system selected was an Entech 22x curvilinear fresnel lens collector that would produce both photovoltaic power and hot water at 140-160°F. The system would be mounted on a tracking, and expanded-foam platform floating on a 14 ft deep lined reservoir. The reservoir would be filled with water to store the excess thermal energy to be used when needed.

A district distribution system would deliver thermal energy to heat exchangers to provide domestic hot water and to a desiccant heating and cooling unit on each home. The comfort level of desiccant units, after 6 years of use by George Eddington of Phoenix, is described as being superior to all other types of air conditioning.

The ASK unit either heats or cools outside air depending on the season. A honeycombed aluminum wheel is coated with a desiccant, calcium chloride, which takes the moisture out of the incoming air and moves it into the outgoing air. This transfer is aided by heating the outgoing air with thermal energy from the solar collector. After the incoming air is dried using the desiccant wheel, it is passed through a copper wheel where some of the heat is removed. It then goes through an evaporative cooler. Air temperatures less than 50°F can be obtained even with high humidity and outside temperatures over 100°F. Heating is accomplished with a heat exchange unit. The rotating copper wheel removes heat from air leaving the house and effectively puts the heat into incoming air in the winter time.

3. DESIGN DATA

A computer program (Cluff and others, 1981) was used to size the system for the 24-home prototype using Phoenix "typical meteorological year" (TMY) data for the estimated solar production and average degree days for the heating and cooling estimations.

The heating and cooling loads were based on using a 1800 sq ft home with R-30 in the roof and R-17 in the walls, 15% of the floor area were windows with double paned glass. The assumption was also made that there were no windows on east or west unless totally shaded. It was further assumed that there was shading on south facing windows so there was no direct heat gain during the cooling season. Appliances, lights and people would reduce the heating load but add to the cooling load. With these assumptions, the following formulas were obtained from Haenichen (1987). The formulas give the weekly heating and cooling loads per 1800 square feet house in Btu.

(1) $OH = 6787HDD - 230,947$ (2) $QC = 6787HDD + 1,154,734$

Where:

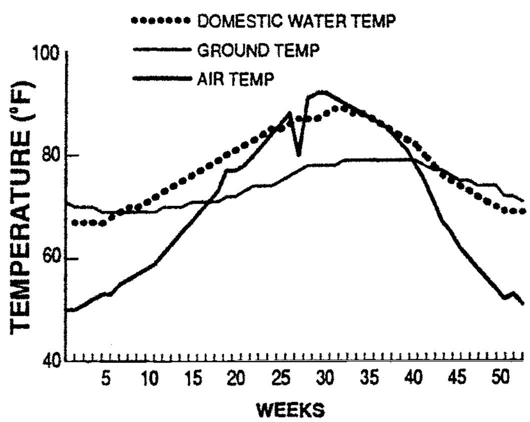
HDD = heating degree days
CDD = cooling degree days

The heating and cooling in Btu/hour is given by:
(3) Heating = 283(68-TMAX)   (4) Cooling = 283(TMAX-78) + 21,000

Where: TMAX = Extreme outside temperature.

The use of these formulas and the average 1941-70 degree day data for Phoenix (Durrenberger, 1978) gave the heating and cooling demands per week in the Phoenix area.

Domestic hot water demand was based on an average use of 80 gpd for a family of four (Anderson, 1981). Domestic water temperature as shown in Figure 1 in the Phoenix area was supplied by Wood (1987). The average air temperature of Phoenix came from Durrenberger (1978), the ground temperature was taken from Cluff (1981). Ground temperatures were used to determine losses from the thermal storage reservoir and from the distribution system.



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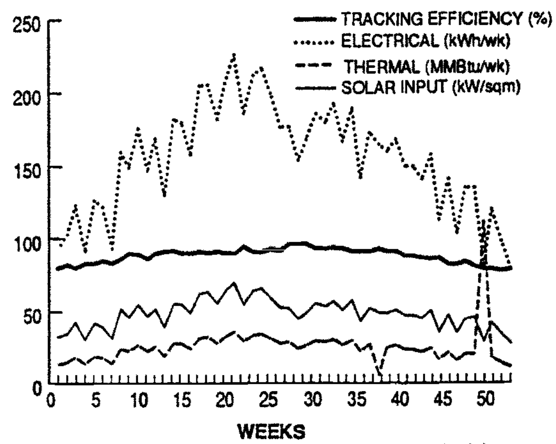

FIGURE 2 100 Entech 22x Modules Dual Track, Phoenix, Arizona

The solar energy input to the system was furnished by Entech Corporation for their 22X linear fresnel lens concentrating modules on a tracking floating platform (See Figure 2). Hourly typical meteorological year (TMY) data for Phoenix was used. This data includes reduction in output due to cloud cover. Entech also reduced tracking efficiency in the wintertime which further reduced output. Shading considerations for all were included in the analysis. The annual thermal efficiency was found to be 52% and the annual electrical efficiency for the 100 22x Entech modules was found to be 12% using Phoenix TMY data. The solar energy input was run at a collector water temperature of 140°F.

The district heating and cooling system was laid out for a 24 home subdivision with 21 homes built around an outer loop and 3 homes plus the central solar collector in an inner area. The lots were approximately 75 ft x 130 ft with a 50 ft roadway.

Each set of lines would serve 12 houses. A 3-inch supply and return line for each of the two systems was adequate. For the last 2 houses, a 2-inch main supply and return lines were used. a 1.5-inch supply and return line was modeled to connect from the main to the middle of each house. Schedule 80 polypropylene pipe was used with 1-inch polyurethane insulation given a heat loss of 83,563 Btu/week/°F. This totals about 10% of the demand if 140°F water was delivered.

The thermal system was designed to feed both a heat exchanger in a solar hot water tank and up to 7 gpm in the desiccant heating/cooling unit at the same time. A thermostat in the house and a thermostat in the domestic hot water tank would activate solenoid valves whenever additional thermal energy was needed. A mixing valve would be installed so the homeowner could control his desired domestic hot water temperature. The thermal energy used by each house would be measured by a commercially available Btu meter.

4. COMPUTER SIZING OF THE PROTOTYPE SYSTEM

The program described in Cluff and others (1981) was used with the data described herein to obtain an optimum sizing. Various computer runs were made before the design in Table 1 was obtained.

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SYSTEM PARAMETERS

Reservoir:

Depth=14 ft, Bottom Dia.=114.3 ft, Top Dia.=123.7 ft.
Surface Area=12,000 sq ft, Bottom Area=10,256 sq ft,
Side Slope=3 vertical:1 horizontal, Volume=155,634 cu ft.

Area of Collector: 5160 sq ft
Number of Houses: 24
System Pipe Loss: 83563 Btu/wk/°F.
Cooling Coefficient: 1
Storage Coefficient: 1
Side Wall U-Factor: 0.00818
Floating Top U-Factor: 0.02655

The selected design includes a reservoir covering size of 12,000 sq ft with a collector size of 5,160 sq ft. The tracking part of the platform would cover only the circular bottom area with a diameter of 115 ft. This will allow the platform to be assembled on the bottom of the pond before water is added.

Figure 3 shows how thermal energy is removed from storage when solar input is less than demand. Figure 3 shows that during the winter, spring and fall there is an excess amount of solar thermal energy that was stored to help meet the cooling load.

There was 11% of the thermal load that was provided by the storage on an annual basis but in week 28 and week 35 as much as 34.5% and 34.3% respectively, of the energy was taken from storage. There was about 13.9% of the total energy input from the sun lost from the storage pond, but 57.4% of the total energy stored in the pond was lost. These losses could be reduced by using a thicker pad of foam on the surface. The platform losses were 72% of the total losses. The losses were 14.9 percent. These losses are not shown in Figure 3 but can be calculated from the ground temperatures given in Figure 1 and system temperatures given in Figure 3 and the constant given in Table 1.

The temperature in the reservoir as shown in Figure 3 goes from 162.3°F to down to 133.6°F. The computer model is based on a thoroughly mixed pond. In actual operation the pond would be allowed to stratify whenever the temperature dropped below 140°F.

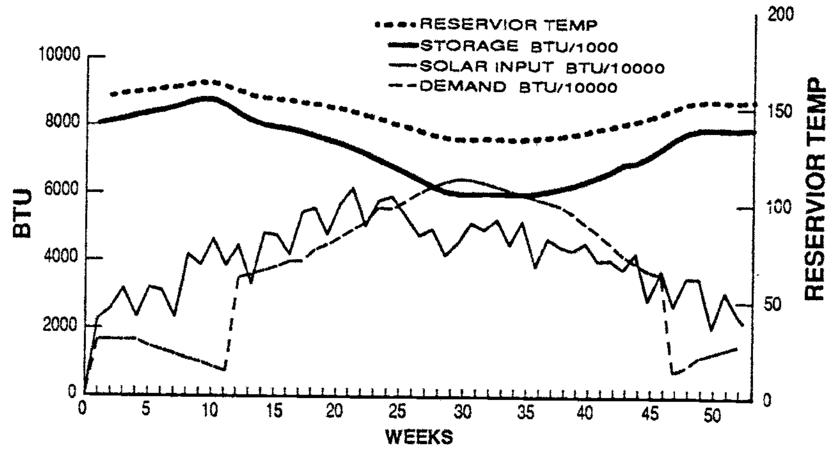

FIGURE 3 Solar Pond Energy Balance

5. SOLAR SYSTEM OPERATION

The production output in usable heat is 2139.1 MBtu or 626,953 kWht and with losses in storage this is reduced to 1949.6 MBtu or 571,393 kWht. As indicated above 14.9% of this energy is lost through the district heating and cooling distribution system, for a net delivered thermal energy of 514253 kWht. Of this amount 121.7 MBtu or 35,669 kWht is used for space heating, 1515.4 MBtu or 444,152 kWht is used for space cooling and the remainder, 312.5 MBtu or 34,432 kWht, is used for domestic hot water.

The space heating and domestic hot water requirements of 70,101 kWht have a direct equivalency with electrical energy used for the same purpose, i.e. making hot water or air. The remaining thermal energy used for cooling has a 1 for 2.6 equivalency with electrical energy, according to Lof (1987), when using a desiccant heating/cooling system from the ASK Corporation. The thermal coefficient of performance in the cooling mode of the desiccant system is 1, whereas for electricity in an air conditioning system it is about 2.6 Thus the electrical equivalent value of the thermal energy used for cooling would be 170,827 kWht. The total electrical equivalency of the thermal system would be 240,928 kWht or 38.4 percent of the total produced or 20% of the total available from the sun.

The direct production of AC electricity from the photovoltaic portion of the 5,160 sq ft (172 modules) system as projected from Figure 2 is 138,578 kWh or 12%. The total electrical production equivalent from the system is 379,506 kWh which is approximately 32 percent of the total available solar energy.

6. ECONOMICS

In 1987 the capital cost of the district heating/cooling system for a 24 home prototype was estimated to be $745,000. This includes $439,500 for the cost of 172 Entech modules, the 4-inch concrete-coated expanded polystyrene floating platform and a 60 KW power conditioning unit. Cost of the desiccant cooling and heating system or the heat-exchanger hot water tanks for each home wasn't included since these costs are similar to the costs of conventional tanks and air conditioning units and would be a part of the construction costs of the subdivision. Thermal storage system including an additional 3-inches of foamed polyethylene and 2-inches of expanded polystyrene insulation under the floating concrete platform cost $87,000 and the thermal delivery system including insulated pipe and 24 Btu meters was $69,000. There was a added 25% of the subtotal for engineering and contingencies. Total savings in an APS service area in 1987 would be $35,737/year. In 1991 the total savings, due to increased rates by APS, would be $40,500/year or about 5.4% of the initial investment. This does not include maintenance and operation costs.

Additional considerations in the determination of economic viability are: 1) as the size of the subdivision goes up the economics definitely improve due to economy of scale, and 2) as APS or other utilities need to construct new electrical generating capacity the unit cost of the electricity from the new plants needs to be compared to the cost of serving the same subdivisions with district heating and desiccant cooling. Before building the 1000 home solar powered community using conventional financing, the smaller system needs to be built to fully demonstrate technical viability.

7. CONCLUSION

The technology for the 24-home prototype is ready to be applied to achieve the goal of a solar powered community that has no associated environmental costs and is competitive in cost with conventional sources of non-renewable energy.

This type of solar energy system has an equivalent electrical efficiency of 32 percent. This means that at a value of 10 cents per kWh this system can produce $150,000 worth of equivalent electricity per acre of collecting area per year. All that is needed is a demonstration to show that the costs of collecting and using this energy is less than its value. Once this is done, unless politics interfere, the commercial market will take over and the construction of solar powered communities will begin.

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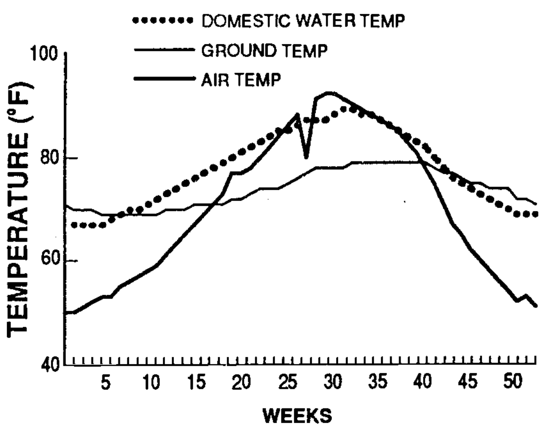

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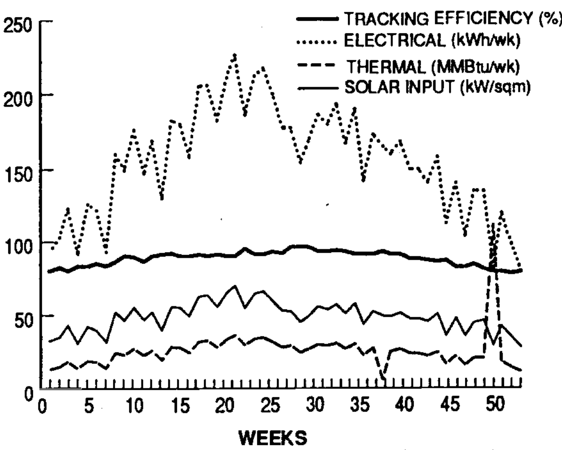

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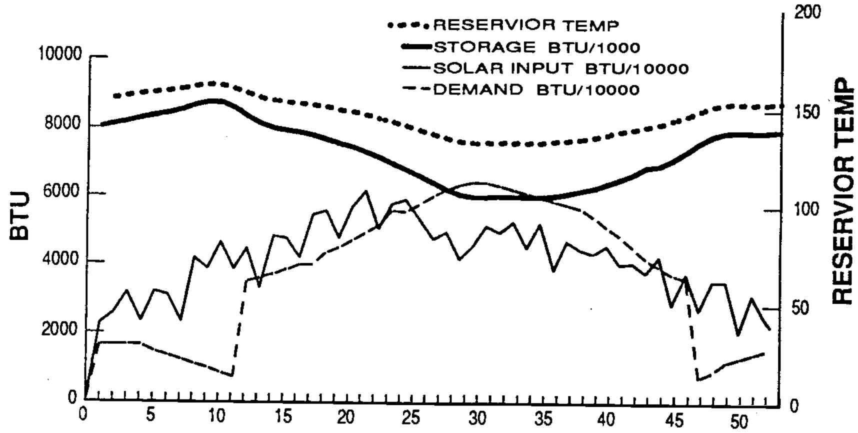

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