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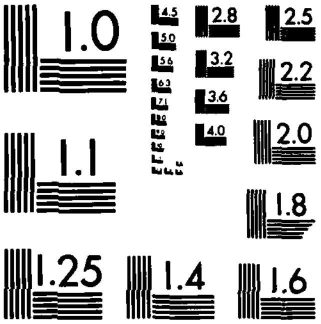

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AUTHOR: L. C. P. Huang, Ph. D., and W. R. Major

DATE: April 1985

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PROGRAM NO: Z0371-01-541A

TECHNICAL NOTE

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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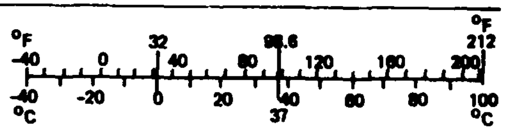
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Many of the Navy and Marine Corps bases have potential for thermal solar pond systems that can cost-effectively displace existing thermal and electrical loads. The salt-gradient solar pond offers a simple method of collecting solar insolation while providing its own storage medium for the energy collected. The economic attractiveness of a solar pond is enhanced by this feature; however, the viability of a given application is dependent on site attributes and requirements. For the salt-gradient solar pond, site specific features such as

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solar radiation, siting area, type of load to be displaced, and availability of salt, clay, and water are important factors affecting the success of each application. An investigation of current salt-gradient solar pond technology was conducted and a preliminary technical and economic analysis was performed for a proposed application at the Marine Corps Logistics Base, Barstow, California.

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Many of the Navy and Marine Corps bases have potential for thermal solar pond systems that can cost-effectively displace existing thermal and electrical loads. The salt-gradient solar pond offers a simple method of collecting solar insolation while providing its own storage medium for the energy collected. The economic attractiveness of a solar pond is enhanced by this feature; however, the viability of a given application is dependent on site attributes and requirements. For the salt-gradient solar pond, site specific features such as solar radiation, siting area, type of load to be displaced, and availability of salt, clay, and water are important factors affecting the success of each application. An investigation of current salt-gradient solar pond technology was conducted and a preliminary technical and economic analysis was performed for a proposed application at the Marine Corps Logistics Base, Barstow, California.

CONTENTS

INTRODUCTION

Although the cost effectiveness is still marginal, solar energy systems have earned a respectable position among the advocates of renewable energy resources. However, both the low temperature solar systems (such as flat plate collectors) and high temperature solar systems (such as parabolic trough and dish) have a common problem: the absence of thermal energy storage, thus limiting solar systems' capabilities and operations. Solar ponds have been proposed as a solution to the storage problem; their very large "thermal mass" is used for both collection and storage of solar energy. The solar energy collected during the daytime could be utilized at night, and the solar energy collected in the summer could be stored for winter usage.

Navy applications that can efficiently utilize the heat output of a solar pond can have favorable life-cycle cost economics because the salt-gradient solar pond offers dual functions of both collecting and storing the solar energy.

Interest was expressed by the Marine Corps Logistics Base (MCLB), Barstow, Calif., in building a solar pond as an alternative energy demonstration. The initial plan was to build an electrical-generating solar pond. However, funding and available technology limited the plan. Since there are no solar ponds installed in the United States that generate electricity at this time, the technology must be considered high risk. Israel claims to have generated electricity from their solar ponds at the Dead Sea, but no performance or cost data have been made available.

To minimize the technical risk, the Naval Civil Engineering Laboratory (NCEL) has recommended that MCLB Barstow demonstrate the solar pond technology by pursuing the available technology for thermal applications, such as space heating, domestic hot water heating, and absorption cooling instead of electricity generation. Two Bachelor Enlisted Quarters (BEQ) buildings have since been selected for experiments on solar pond thermal applications. Details of the study on both the performance and cost effectiveness are presented in this report.

TYPES OF SOLAR PONDS

The three basic types of solar ponds are: (1) the salt-gradient solar pond, (2) the "gel" solar pond, and (3) the shallow water solar pond. Cross sections of the three different types of solar ponds are illustrated in Figure 1 (Ref 1).

Salt-Gradient Solar Pond

A salt-gradient solar pond is a salt-stabilized pond with increasing salt concentration toward the bottom of the pond. The thick and warm concentrated brine in the bottom storage zone is prevented from rising to the top by its higher density. This, in turn, prevents heat transfer (mainly through convection) from the bottom storage zone to the top evaporation zone. The salt-gradient solar pond is relatively inexpensive and easy to construct and operate. Most of the existing solar ponds around the world, such as those at Ohio State University, the Ohio Agriculture Research and Development Center, Argonne National Laboratory, the University of New Mexico, the Dead Sea, Israel, and Alice Springs, Australia (Ref 2) are salt-gradient solar ponds. Their success and continuing operation have clearly demonstrated the validity and practicality of the technology. The construction and maintenance data from these solar ponds provide valuable information in determining whether or not solar ponds can be cost-effective. This Navy evaluation of the solar pond technology planned for MCLB Barstow is on the salt-gradient type of solar pond.

Gel Solar Pond

A gel solar pond is constructed by floating a thick layer of gel on top of the water in the storage pond. The gel should be optically transparent to allow solar radiation to penetrate to the bottom water storage zone. The main purpose of the gel layer is to provide insulation and suppress convection of the bottom hot water layer. Unfortunately, no gel has yet been developed to satisfy all the criteria. A new development, substituting the gel with transparent honeycomb tubes, is currently under investigation by numerous investigators (Ref 3 and 4). The success of these studies might have a great impact on the future of the saltless solar pond.

Shallow Water Solar Pond

A shallow water solar pond is basically a plastic pillow placed on a concrete slab with a glazing cover. The water to be heated is pumped into the pillow during the day to absorb solar radiation, and at night the water is pumped to the load or to storage. This type of solar pond tends to be more expensive than the salt-gradient solar pond.

CHARACTERISTICS OF SALT-GRADIENT SOLAR PONDS

The salt-gradient solar pond is a generic solar system which utilizes water and brine to transmit, absorb, and store solar energy. Salt-gradient layers between the heavy brine at the bottom and the fresh water at the top are designed to suppress the natural convection that would normally occur. The solar-produced heat trapped in the bottom of the pond can be used to provide either thermal energy or electricity.

A typical salt-gradient solar pond is schematically presented in Figure 2 (Ref 5) with profiles of both the salinity and temperature distribution. Normally, a salt-gradient solar pond can be divided into three distinct zones: the surface zone (0.15 to 0.3 meter) with uniform salinity of a few percent (by weight); the salt-gradient zone (1 to 1.5 meters) with varied salt concentration from a few to about 20%; the bottom storage zone (1.5 to 3.5 meters) with uniform salinity over 20%. Both the surface zone and the bottom storage zone are convective zones; however, the salt-gradient zone is a nonconvective zone. This enables the salt-gradient pond to trap solar energy in the bottom storage zone. As the heat builds up, the bottom brine temperature can rise to about 80 to 95°C. This heat must be extracted from the pond and utilized before the bottom storage zone reaches the boiling point because the boiling phenomenon will introduce vertical transport that will completely destroy the salt-gradient pond structure.

Though the objective and output of a salt-gradient solar pond are similar to those of other solar systems, its characteristics differ in many respects from other generic solar systems. These are discussed in the following sections.

Storage

The inherent, built-in storage capability differentiates the salt-gradient solar pond from other solar collectors. Other solar collectors, like the flat plate, Fresnel lens, line-focusing trough, or point-focusing dish, collect solar energy but do not automatically store the energy collected. These systems require an additional storage system, hybrid fuel augmentation, or backup system for continued operation at night and during cloudy periods. The salt-gradient solar pond, on the other hand, not only collects the solar energy but also stores the energy collected in the heavy brine within the bottom region. This unique storage capability enables the solar pond to continuously supply thermal energy all day long, all year around.

Working Fluid Temperature

Because the brine boiling point must not be reached, the temperature of the bottom storage zone will be substantially lower (below 95°C) than the working fluid temperature of most concentrating solar collectors. This low-temperature characteristic prevents solar pond use in major industrial process heat applications because of the need in those cases for steam at or above 150°C.

Efficiency of Power Generation

If electric power generation is the application, the low-temperature characteristic will severely constrain the performance of the power conversion unit. The Carnot cycle efficiency of the solar pond power conversion unit (e.g., an organic Rankine engine) can only reach about 13%, and the overall power plant system efficiency is about 8.5%. The net solar pond power generation efficiency, from solar to electricity, is expected to be between 1 and 2%.

Long Warm-Up Period

The salt-gradient solar pond requires a significantly long period of time (6 months to 1 full year) for warming up before the heat can be extracted from the pond at the desired temperature. Thus, in the planning, designing, and constructing a solar pond, the designers must consider warm-up period if the system is to begin operation at the designated starting date.

Temperature Profile Stability

The temperature stability profile of the solar pond depends on the salt-gradient structure. Without outside disturbance (e.g., wind or mechanical mixing), the only potentially destructive mixing within the solar pond is the boiling transport phenomenon. Therefore, heat must be extracted from the pond before the bottom brine reaches boiling temperature. In addition, either a routine injection of heavy brine into the bottom layer or a flush of fresh water on the top surface layer, or both simultaneously, is required to maintain the salt-gradient structure of the solar pond. Continued measurement and monitoring of the temperature and salt-gradient profiles are necessary for all operating salt-gradient solar ponds.

Seasonal Temperature Variation

A typical seasonal temperature variation of the bottom brine is shown in Figure 3 (Ref 6). It is evident that even with the thermal mass of a quarter-acre solar pond, the usable output temperature of the solar pond varies from a high of 90°C in summer to a low of 30°C in winter. This inherent temperature fluctuation can severely restrict many potential applications of the solar pond, particularly applications without conventional backup systems. A solar pond designed as a standalone system would require careful load profile-matching to guarantee sufficient energy supply throughout the year.

ECONOMIC CONSIDERATIONS

The cost-effectiveness of a salt-gradient solar pond depends on site-specific factors: a well-designed and built salt-gradient solar pond extremely attractive at one location may not be cost-effective at another location. The essential site-specific ingredients that will affect the cost and performance of a salt-gradient solar pond are discussed in the following sections. Also discussed are liner and land costs, which have an important effect on cost-effectiveness, though not considered site-specific factors.

Insolation

Geographic location and weather conditions have a dominant effect on solar radiation: the higher the annual total insolation, the more solar energy will be collected by the solar pond. The insolation is usually measured in kilowatt hour thermal per square meter and has been mapped by many agencies throughout the United States. In general, the insolation level of the South is higher than the North, and the West is higher than the East. The highest insolation obtainable in the United States is about 1,000 W/m^2.

Salt

Although salt is considered an inexpensive commodity, the total salt cost (material plus transportation) can be very high when very large volumes are needed to create a salt-gradient solar pond. In many locations where the solar pond can be built next to a natural salt resource, such as the Salton Sea and Searles Lake in California and the Salt Lake in Utah, the cost of the pond can be greatly reduced because the salt supply is free and available. On the other hand, at some pond locations the price of delivered salt may be $50/ton, and a small 1-acre pond requires approximately 1,500 tons.

Soil Structure

The ideal soil structure for a solar pond has a clay surface layer that allows minimum heavy brine leakage to the surrounding environment and has a well-drained bottom layer to prevent build up of the underground water table, which could increase heat conduction away from the solar pond. The soil structure should also support the shape and weight of the solar pond. A soil boring test is recommended for any designated pond location to determine the feasibility and suitability of the site.

Water Supply

An important ingredient of the solar pond is the water supply. Not only is water required to start the pond, but water is also needed to replace the evaporation and flushing losses. The color, clarity, and pH level of the water are also very important. Clear water on the upper surface of the pond permits maximum insolation penetration to the bottom heat storage zone. Low pH brine (between 4 and 6.5) minimizes electrochemical corrosion. Water supplies of poor quality require specific treatment; this, in turn, increases the cost of the solar pond.

Wind

Wave growth and propagation in the solar pond due to wind can cause excessive mixing in the surface zone and might eventually lead to salt-gradient structure damage. Hence, high wind locations should be avoided in selecting a solar pond site. The longest dimension of a solar pond at any site should be oriented perpendicular to the prevailing wind direction so that waves generated by wind have a limited span to propagate. Wave nets can also be used to suppress the wave propagation but at additional cost to the solar pond. In addition, the chain link fences that used to control access to the solar pond can also be covered up by plastic clothes in the prevailing wind side for wind protection.

Liner

The liner of a solar pond serves two purposes: to retain the hot brine for thermal applications and to prevent salt leakage to the surrounding environment. Because of the high temperature and high salinity brine, only a limited number of plastic liners can satisfy the requirements. The most commonly used liners are made of XR-5 (Shelter Rite registered trademark, polymeric alloy) or Hypalon (DuPont registered trademark, chlorosulfonated polyethylene). Both products have been successfully tested and used in various solar ponds. The installed cost of either liner is about $\$1/\text{ft}^2$. For a 1-acre pond, the liner will cost more than $45,000 - a substantial amount of the construction cost. Further development of materials are expected to continue in order to make the membrane liner both better and cheaper.

Land

For all the diffusive energy collection systems, land costs represent a significant part of the total cost. However, in many Navy/Marine Corps bases, open spaces and buffer zone land can be used for solar pond applications.

POTENTIAL NAVY APPLICATIONS

Although many existing solar ponds have been built for research purposes, the majority were designed to fulfill specific tasks such as generating electricity, heating swimming pools, heating agricultural greenhouses, and supplying domestic hot water and space heating. Potential solar pond applications within the Navy can be categorized into two major areas - electricity generation and thermal utilization. These are discussed below.

Electricity Generation

Utilizing a low-temperature organic Rankine engine to generate electricity from the solar pond is not only attractive but potentially feasible. The potential for continuous power generation without additional storage or conventional backup systems is a major advantage of the solar pond, compared to other solar power generation systems. Unfortunately, because of the necessarily low operating temperature, the organic Rankine engine efficiency, as well as total system efficiency, would be extremely low (approximately 8.5% for the power plant and 1.5% for the overall system). For such a low energy conversion efficiency, hundreds of acres of solar pond area would be needed to make the effort worthwhile. Today, only Israel has generated electricity from solar ponds. These were constructed near the Dead Sea.

Within the United States, no solar ponds generate electricity. The Department of Energy and Southern California Edison's joint project at the Salton Sea has been indefinitely suspended because of financial and political problems. Further research and experiments by the Department of Energy and the technical community are necessary before the Navy can apply solar pond technology to electricity generation.

Thermal Utilization

The low-temperature (below 95°C) thermal energy generated from a solar pond can be readily utilized in Navy residential applications such as space heating, space cooling, and domestic hot water. Space heating and domestic hot water require temperatures between 38 and 45°C, which are well within the operational temperature range of the solar pond. Space cooling, however, requires higher temperatures (in the range of 80 to 95°C) for reasonable performance from the absorption chiller. However, this is close to the temperature at which the boiling phenomenon occurs. Thus, from technical considerations, space heating and domestic hot water applications are much easier to apply than the space cooling application. However, at specific sites, space cooling may be both important and cost-effective because air conditioning units consume expensive electricity and space cooling demands roughly match the solar pond heating cycle.

RESULTS OF PRELIMINARY CONSIDERATIONS

Designing, constructing, and testing of a solar pond system that satisfies space heating, domestic hot water, and space cooling applications simultaneously would be desirable for the Navy to undertake as a project. No solar pond in the United States today has yet accomplished this goal, thus offering a technically interesting and challenging task. Also, the development of the solar pond capabilities on all three application fronts could make the solar pond energy resources not only unique but self-sufficient for many Navy shore residential facilities.

Summary of Preliminary Study

The preceding discussions and evaluations can be summarized as follows:

1. For electricity generation, only very large solar ponds are economically competitive. A 250-acre solar pond (equivalent to 5 MW of energy) is only competitive with a new oil-fired facility. To compete with a coal-fired power plant would require a 26,400-acre solar pond (equivalent to 600 MW of energy). Thus, smaller sized solar ponds are not economically suitable for generating electricity.

2. Construction of very large solar ponds (thousands of acres) in order to generate electricity economically is probably outside the Navy's main objectives and missions. Furthermore, the best sites for large solar pond construction are probably not located on Navy property.

3. Smaller sized solar ponds are only good for thermal applications. Because of the low-temperature limitation (below 95°C), the solar pond thermal application is more suitable for residential, rather than industrial, heat applications.

Table 4. Barstow Solar Pond Life-Cycle Cost Analysis Summary (Analysis 2 of Table 1)

Analysis Item	Discounted Item	Value ($)
Investment		
Construction cost		224,002
Supervision, inspection, and overhead (6%)		13,440
Planning and design cost (6%)		13,440
Energy credit calculation (10% reduction)		225,794
Salvage value of existing equipment		0
Total investment		225,794
Energy savings (+)/cost(-) (determined from Table 5)		604,867
Nonenergy savings (+)/Cost (-)		
Annual recurring (+/-)		-14,435
Discount factor	11.65	
Discounted saving/cost		-168,167
Total net discounted savings		436,700
Discounted SIR	1.93	

Table 5. Analysis Data Annual Savings, Unit Cost and Discounted Savings for Use With Item 2 of Table 4

Fuel	Cost ($/MBtu)	Savings (MBtu/yr)	Annual Savings ($)	Discount Factor	Discounted Savings
Electric	5.95	1,976	11,757	13.4	157,544
Fuel Oil Space Heating	9.87	676	6,672	18.1	120,763
Fuel Oil DWH	9.87	1,828	18,042	18.1	326,560
Total		4,480	36,471		604,867

Table 3. Barstow Solar Pond Cost Breakdown
(Analysis 2 of Table 1)

Investment	Cost ($)
Construction - Total	224,002
Salt	50,484
Liner (installed)	34,114
Pond digging	22,262
Differential cost of:	62,000
Absorption chiller Cooling tower System installation	
Mechanical equipment	26,909
Mechanical equipment installation	14,405
Controls and instrumentation	13,828
Supervision, Inspection, and Overhead (6%)	13,440
Planning and Design (6%)	13,440
Total Cost	250,882

Table 2. Barracks[a] Space Heating and Cooling Loads

Month	Totals (1,000 Btu)	
	Space Heating Load	Space Cooling Load
Jan	90,000	31,104
Feb	96,192	51,840
Mar	60,480	77,760
Apr	18,720	153,792
May	37,440	124,416
Jun	5,760	252,288
Jul	2,592	286,848
Aug	1,440	304,128
Sep	7,200	221,184
Oct	15,840	138,240
Nov	47,520	69,120
Dec	77,760	32,832
Annual Total	460,944	1,743,552

[a] Values listed are for both barracks.

Table 1. Summary of Barstow Life Cycle Cost Analyses

Analysis	Solar Pond Displacement of Barracks Load	Absorption Chiller Maximum Refrigeration Output (tons)	Absorption Chiller Cost Assumption[a]	Pond Size (acre)	Savings Investment Ratio	Payback (yr)
1	100% space heating and DHW 100% space cooling	100	actual	0.88	1.43	17.5
2	100% space heating and DHW 100% space cooling	100	differential	0.88	1.93	12.2
3	100% space heating and DHW 50% summer cooling load 80% remaining annual cooling load	50	actual	0.73	1.53	16.8
4	100% space heating and DHW 50% summer cooling load 80% remaining annual cooling load	50	differential	0.73	2.27	10.6
5	100% space heating and DHW 0% cooling load	N/A	N/A	0.31	2.74	8.7

[a] Actual - Cost of new absorption chiller system.
Differential - Cost of new absorption chiller system minus cost of new reciprocating chiller system.

6. D.D. Weeks et al. "What happens when a solar pond boils?" International Solar Pond Newsletter No. 4. University of Delaware, Newark, Del., Jan 1981.

7. Navy Bureau of Yards and Docks. Mechanical engineering, NAVFAC DM-3. Washington, D.C., Sep 1972, pp 3-1-13 and 3-1-14.

8. E.J. Roschke and Y.C. Wu. Solar pond power plant concepts to the Goldstone Deep Space Communications Complex, Jet Propulsion Laboratory. Pasadena, Calif., Oct 1982.

9. U.S. Congress Military Construction Authorization Act and Appropriation Act: Solar economic analysis criteria, FY82. Washington, D.C.

10. Energy conservation investment program (ECIP) guidance, Manpower Reserve Affairs and Logistics Memorandum. Washington, D.C., 31 Aug 1982.

Now determine the amount of electrical input energy required from an electrical reciprocating chiller (COP = 3) to displace this load. As derived in step 5 of Example Life-Cycle Cost Analysis,

$$\text{Reciprocating chiller electrical input} = (3{,}066 \text{ MBtu/yr}) \cdot (1/3.413 \text{ MWh/MBtu})(1/3) = 299 \text{ MWh/yr} \quad (19)$$

$$\text{Electricity costs at MCLB Barstow} = \$70/\text{MWh} \quad (20)$$

Therefore,

$$\text{Total \$ savings} = (299 \text{ MWh/yr})(\$70/\text{MWh}) = \$20{,}930/\text{yr} \quad (21)$$

For a given solar pond thermal output, this example shows that at MCLB Barstow the dollar value for displacing natural gas used for space heating is over double that of displacing electrical energy used for space cooling. This difference is due primarily to a COP for the absorption chiller of 0.5 versus a COP of 3.0 for the reciprocating chiller. Although electrical energy unit costs in dollars per megawatt-hour are higher than equivalent thermal energy unit costs in dollars per millions of British thermal units, the net result is that solar pond displacement of the space cooling load is less efficient. For the larger solar pond size required for displacing a space cooling load, this inefficiency means an increase in investment costs without producing an equivalent increase in the value of the energy displaced. This results in the lower SIRs in analyses 1 through 4 as compared to analysis 5 of Table 1.

REFERENCES

1. R.P. Fynn and T.H. Short. Solar ponds: A basic manual, OARDC, Ohio State University, Special Circular 106. Columbus, Ohio, Feb 1983.

2. International solar pond letters, Vol 1, No. 3 and 4, by United States Section of the International Solar Energy Society.

3. E. I. Lin. "A saltless solar pond," paper presented at the 1982 Annual American Solar Energy Society Meeting, Houston, Tex., Jun 1982.

4. __________. "Thermal behavior of laboratory model honeycomb covered solar pond," paper presented at ASME Annual Solar Technology Conference, Orlando, Fla., Apr 1983.

5. __________. "A review of the salt-gradient solar pond technology," Jet Propulsion Laboratory, Publication 81-116. Pasadena, Calif., Jan 1982.

Comparison of Space Heating and Space Cooling Load Displacement. The life cycle costs of a solar pond system are primarily dependent on the following:

- Utilization of solar pond thermal energy
- Energy displacement value in dollars of pond thermal energy
- Pond size
- Total capital investment

Utilization and energy displacement value of solar pond thermal energy for space heating and cooling is derived in the following example. This example calculates the dollar value of displacing a space heating load as compared to space cooling for a given solar pond thermal output in millions of British Thermal Units per year per acre.

The following derivations will use the same solar pond thermal output of 6,132 MBtu/yr to compare fuel displacement values for space heating and space cooling applications.

1. Space heating application. Calculate the dollar value of displaced natural gas boiler fuel.

As discussed in step 3, the barracks would utilize approximately 90% of solar pond output. Therefore,

$$\text{Barracks load displaced} = (0.9)(6{,}132\ \text{MBtu/yr})$$

$$= 5{,}519\ \text{MBtu/yr} \qquad (15)$$

Using Equation 8,

$$\text{Annual natural gas displaced} = (5{,}519\ \text{MBtu/yr})/(0.85)(0.8)$$

$$= 8{,}116\ \text{MBtu/yr} \qquad (16)$$

At MCLB Barstow, the natural gas unit cost is $6.20/MBtu, therefore,

$$\text{Total \$ savings} = (8{,}116\ \text{MBtu/yr})(\$6.20/\text{MBtu})$$

$$= \$50{,}320/\text{yr} \qquad (17)$$

2. Space cooling application. Calculate the dollar value of displaced electrical load by using absorption chiller COP = 0.5 (step 3 of Example Life-Cycle Cost Analysis).

$$\text{Delivered cooling to BEQ} = (6{,}132\ \text{MBtu/yr})(0.5)$$

$$= 3{,}066\ \text{MBtu/yr} \qquad (18)$$

A 25-year project life is assumed, and costs are in 1983 dollars. Table 4, along with use of Table 5, gives a summary of this life cycle cost analysis, resulting in an SIR of 1.93. The boiler plant supplying steam to the BEQ buildings is currently converting to natural gas. The SIR would be 1.40 for this example if natural gas was the primary boiler fuel.

Result Comparison and Discussion

As shown in Table 1, the SIRs range from 1.43 to 2.74 depending upon what solar pond configuration, load displacement, and cost assumptions were made. In every analysis, the solar pond supplied 100% of the barracks space heating and domestic hot water load. In analyses 1 through 4 various options for displacing the space cooling load were considered. To isolate the effect each option has on the SIR, space cooling and space heating are discussed separately and then compared in the following sections.

Space Cooling. For space cooling, the solar pond thermal output is used for absorption chilling and displaces a given amount of the existing reciprocating chiller electrical load. The SIR in analyses 1 through 4 (Table 1) varied, depending on two assumptions used in the life-cycle cost analysis: (1) the percentage of electrical load displacement and (2) the cost of the absorption chiller system, either actual or differential cost (see step 1 of Example Life-Cycle Cost Analysis). Comparison of analyses 1 to 2 and 3 to 4 in Table 1 shows that the differences in SIRs are due directly to the absorption chiller cost assumption. For both these comparisons, the life-cycle costs become more favorable when the differential cost of the absorption chiller is used (analyses 2 and 4). Using a differential cost is justified for new construction or when an existing system needs replacement. The useful life of the reciprocating chillers at the Barstow BEQ is being determined.

In analyses 1 and 2 absorption chilling displaces 100% of the space cooling load with an installed capacity of 100 tons of refrigeration. Since the 100-ton chilling capacity is fully utilized during the summer months only, separate analyses (3 and 4) were performed for a 50% absorption chiller capacity, operating in parallel with one of the two existing reciprocating chillers. With an installed capacity of 50 tons of refrigeration, the absorption chiller displaces 50% of the summer (June, July, August) space cooling load but can displace approximately 80% of the remaining annual space cooling load. This allows higher utilization of the absorption chiller and lower installed absorption chiller costs. At the same time it results in higher SIRs as shown in Table 1 (i.e., analysis 3 compared to 1 and analysis 4 compared to 2).

Space Heating and Domestic Hot Water Displacement Only. Solar pond displacement of existing systems for barracks space heating, domestic hot water, and space cooling would reduce fuel consumption at the MCLB Barstow main boiler plant. However, the space heating and DHW applications use the solar pond thermal output more efficiently and, therefore, should be credited with a higher fuel displacement value (see the following section). Efficient use of the pond energy decreases the pond size requirement and lowers investment costs. As shown in analysis 5 of Table 1, this results in a high SIR of 2.74.

(b) To determine electrical displacement, it is assumed electric reciprocating chiller COP = 3.

From analysis step 2,

$$\text{Total space cooling load} = 1{,}744 \text{ MBtu/yr} = 511 \text{ MWh/yr} \qquad (12)$$

It should be noted this load was converted to megawatt-hours per year to determine actual electrical input power using the reciprocating chiller COP. The conversion factor 1 Wh = 3.414 Btu was used since manufacturer COPs are rated using this thermodynamic relation.

With proper units, absorption or reciprocating chiller COPs are calculated as,

$$\text{COP} = \frac{\text{cooling effect}}{\text{electricity input}} \qquad (13)$$

Therefore, from Equation 13, assuming chiller output matches the load,

$$\begin{aligned}\text{Annual electrical savings} &= \text{space cooling load}/\text{COP}_e \\ &= 511/3 \text{ MWh/yr} \\ &= 170 \text{ MWh/yr} \qquad (14) \\ &= 1{,}976 \text{ MBtu/yr}^*\end{aligned}$$

6. The annual O&M cost for the solar pond system was estimated to be 6% of the construction cost (Ref 8). This estimate is based on a fully automated solar pond system utilizing off-the-shelf components; actual O&M costs may be higher due to the "break-in" period associated with new technology.

7. The economic analysis was performed in accordance with the FY82 Military Construction Authorization Act and Appropriation Act (Ref 9) and the Energy Conservation Investment Program (ECIP) (Ref 10). Both have the same analysis criteria, as follows:

- 7% discount rate
- Actual O&M costs
- DOD ECIP energy escalation rates and local energy costs as reported in Department of Energy Information Systems' DEIS II.
- 10% investment cost credit applied to solar system cost

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*Used 11.62 MBtu/MWh conversion specified in Reference 10 for economic analyses.

From the sizing methodology used in Reference 8,

$$\text{Solar pond size} = \frac{\text{annual average thermal demand on solar pond}}{\text{solar pond unit output}}$$

$$= \frac{5{,}380 \text{ MBtu/yr}}{6{,}132 \text{ MBtu/yr/acre}}$$

$$= 0.88 \text{ acre} \qquad (7)$$

4. Table 3 gives a detailed cost breakdown used in determining the total investment for the solar pond system. The investment costs from this table for salt, liner, and digging were acquired from JPL cost estimates (Ref 8). Absorption chiller, reciprocating chiller, and cooling tower cost and performance specifications were supplied by the manufacturers. Mechanical equipment and controls and instrumentation costs were estimated from material and equipment price guides. All installation costs were estimated from manpower requirements. Cost estimates in Table 3 are considered the "most probable"; however, some cost items such as salt can vary considerably, depending upon availability.

5. The total annual fuel oil and electrical energy displaced by the solar pond thermal output is calculated as follows:

(a) To determine fuel oil displacement, the following assumptions are made.

Steam line loss factor, $S_L = 0.85$

Boiler efficiency, $B_e = 0.8$

It should be noted that 15% of the steam is lost in the line from boiler plant to BEQ (approximately 1 mile). For space heating and DHW,

$$\text{Annual fuel oil displaced} = (\text{barracks load})/S_L B_e \qquad (8)$$

Inserting values from analysis step 2:

$$\text{Space heating fuel oil} = 460 \text{ MBtu/yr}/(0.85)(0.8)$$

$$= 676 \text{ MBtu/yr} \qquad (9)$$

$$\text{DHW fuel oil} = 1{,}243 \text{ MBtu/yr}/(0.85)(0.8)$$

$$= 1{,}828 \text{ MBtu/yr} \qquad (10)$$

$$\text{Total fuel oil} = 676 + 1{,}828$$

$$= 2{,}504 \text{ MBtu/yr} \qquad (11)$$

From Table 2:

Total space heating load = 460 MBtu/yr (1)

Total space cooling load = 1,744 MBtu/yr (2)

From Reference 7, assume

DHW consumption = 30 gal/man-day (3)

Therefore,

$$\begin{aligned}\text{Total DHW heatload} &= (\text{total personnel})(\text{daily DHW usage})(365\ \text{days/yr}) \\ &\quad \cdot (\rho)(C_p)(\Delta T) \\ &= (152\ \text{men})(30\ \text{gal/man-day})(365\ \text{days/yr}) \\ &\quad \cdot (8.3\ \text{lb/gal})(1\ \text{Btu/lb°C}) \\ &\quad \cdot (600 - 10°\text{C}) \\ &= 1{,}243\ \text{MBtu/yr} \qquad (4)\end{aligned}$$

Now,

$$\begin{aligned}\text{Total barracks load} &= 460 + 1{,}744 + 1{,}243 \\ &= 3{,}447\ \text{MBtu/yr} \qquad (5)\end{aligned}$$

3. The size of the solar pond can be estimated using the required BEQ annual thermal load derived in step 2 and the unit output of the solar pond. A solar pond facility in the Barstow, Calif., area is estimated to have an average annual energy output of 6,132 MBtu/yr/acre with winter/summer storage zone temperatures ranging from 74 to 90°C (Ref 8). The solar pond size is then calculated as follows:

First, the total annual thermal demand on the solar pond is determined. This differs from the "total barracks load" in that the efficiencies of converting solar pond thermal energy to usable barracks load displacement energy must be considered. A conversion efficiency of 0.9 is used for space heating and DHW and of 0.5 for space cooling, which is based on average absorption chiller efficiencies (COP* = 0.5).

Then, using values determined in step 2,

$$\begin{aligned}\text{Total annual solar pond thermal demand} &= 460/0.9 + 1{,}744/0.5 + 1{,}243/0.9 \\ &= 5{,}380\ \text{MBtu/yr} \qquad (6)\end{aligned}$$

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*Coefficient of Performance.

Economic Analysis

Life-Cycle Cost Analyses Results. Table 1 lists results of the life-cycle cost analyses for a solar pond operating at MCLB Barstow. Five separate analyses representing different solar pond operating configurations, thermal output, and cost assumptions were performed with corresponding pond size, barracks energy displacement, and savings investment ratios (SIR) as shown in Table 1. The following sections provide assumptions and derivations used in the life-cycle cost analyses and discuss reasons for the variance in SIR listed in Table 1.

Life-Cycle Cost Analysis Methodology. Each analysis in Table 1 was performed in the following sequence:

(1) Defined system and desired barracks load displacement

(2) Determined total barracks load

(3) Sized solar pond

(4) Determined capital investment

(5) Determined BEQ annual electrical energy and fuel displaced by the solar pond thermal output

(6) Determined operation and maintenance (O&M) cost

(7) Calculated SIR

The following analysis provides an example of the use of this methodology.

Example Life-Cycle Cost Analysis (Analysis 2, Table 1).

1. The system configuration is defined in this analysis as the solar pond supplying 100% of the barracks space heating, cooling, and domestic hot water load. One hundred tons of refrigeration would be required to meet the maximum cooling load for both barracks. The differential cost of the absorption chiller is assumed for this analysis and is defined as total cost of a new absorption chiller system minus the total cost of a new electric reciprocating chiller system.

2. The thermal energy demand on the solar pond can be derived from an estimated barracks space heating, cooling, and domestic hot water load. Using data collected from a site visit to the BEQ at MCLB Barstow, JPL generated a monthly space heating and cooling load profile from an in-house HVAC computer program. These data are listed in Table 2. The domestic hot water (DHW) load was estimated from the number of men in the barracks (Ref 7). Using these data, the total annual load for both barracks was calculated as follows:

2. Phase 2 is the final design and will provide sufficient design drawings and supplemental data for the contractors to construct the solar pond and maintenance pond, purchase specified hardware, and assemble and install all system components.

This latter phase will also furnish complete operational procedures, maintenance procedures, and scheduling. NCEL can decide on whether to proceed with Phase 2 based on the performance and cost estimate results determined in Phase 1.

The following sections discuss the proposed salt-gradient solar pond at MCLB Barstow and provide results of preliminary life-cycle cost analyses done by NCEL. Table 1 summarizes all analysis results.

Existing BEQ Building and Site Characteristics

Site characteristics such as solar insolation, siting area, type of load to be displaced, and availability of salt, clay, and water, determine the technical viability of a salt-gradient solar pond system for a given application. A preliminary investigation of MCLB Barstow indicated sufficient water availability, high solar insolation, and adequate land for siting a solar pond system adjacent to the barracks.

The barracks considered were two BEQs that require nearly equal amounts of heating and cooling and can be served from a single solar pond. The existing space heating and domestic hot water system for the two BEQ buildings utilize steam from the base central steam boiler plant. Through use of a steam/hot water heat exchanger, hot water is supplied at 85°C to the barracks' fan coil units for space heating. The domestic hot water is heated to 57°C and supplied to three central bathrooms in each of the barracks. For space cooling, an electrical reciprocating chiller and cooling tower system is used. Cold water from the chiller circulates through the fan coil units for space cooling in each room.

The BEQs and site characteristics at MCLB Barstow satisfied the technical requirements for a salt-gradient solar pond and appeared favorable for a cost-effective application.

Proposed Solar Pond System

Figure 4 shows one possible configuration for supplying space heating, cooling, and domestic hot water to both barracks. This configuration corresponds to analyses 1 and 2 of Table 1 where it was assumed the solar pond output displaced 100% of the barracks load. Numerous configuration options exist that affect solar pond size, system cost, and life-cycle cost economics. One configuration option considered (analyses 3 and 4, Table 1) uses the existing electrical reciprocating chiller system in combination with a new absorption chiller system. Another configuration considered (analysis 5, Table 1) uses the solar pond thermal energy for space heating and domestic hot water heating only.

4. The most attractive application of the small solar pond is residential space heating, domestic hot water, and space cooling, for either new housing developments or retrofit of existing facilities.

Further Work To Be Considered

The following recommendations were made as a result of the preliminary studies and the apparent interest in the project by Navy activities.

1. Since solar pond technology is still in the early development stage, the Navy should closely monitor and review new technology in order to utilize any new opportunity for Navy applications.

2. The Navy should continue to investigate solar pond technology in the application of space cooling. Although the technology has a high risk, the payoff could be substantial.

3. The Navy should select and approve one Navy or Marine Corps base for test and evaluation of solar pond technology. MCLB Barstow, through an Engineering Services Request (ESR) to WESTDIV, NAVFAC, has requested a feasibility study of a solar pond application within the base. Subsequently, WESTDIV referred the ESR to NCEL.

Because of its fan-coil heating and cooling system, two BEQ buildings at MCLB Barstow were considered ideal for retrofit for the solar pond residential thermal application. A preliminary feasibility study and economic analysis for that specific application has been conducted in-house, and the results are presented in the CASE STUDY section of this report.

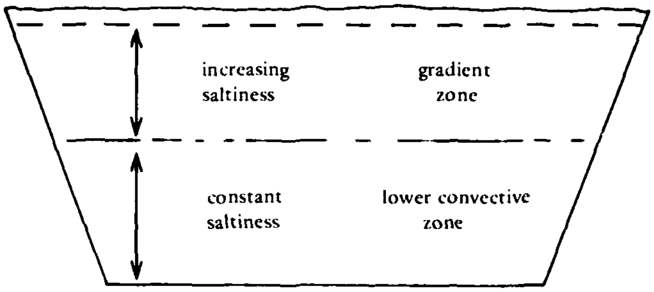
CASE STUDY FOR SOLAR POND AT MCLB BARSTOW

Background

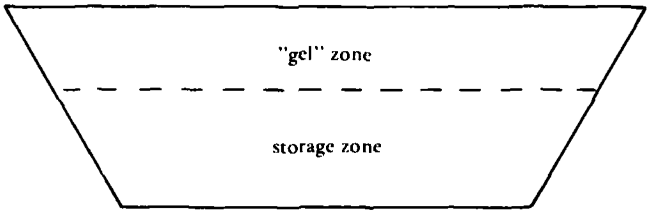
Because of expressed interest by the MCLB Barstow utility division and desirable site characteristics of the Barstow area, a salt-gradient solar pond was considered for the first Navy application of this technology. Constructing, operating, and maintaining a solar pond system at this base would provide the experience and performance documentation required for further implementation of the solar pond technology at other Naval activities.

The Jet Propulsion Laboratory (JPL) is assisting NCEL in designing a salt-gradient solar pond system for MCLB Barstow. The work with JPL is structured in two phases:

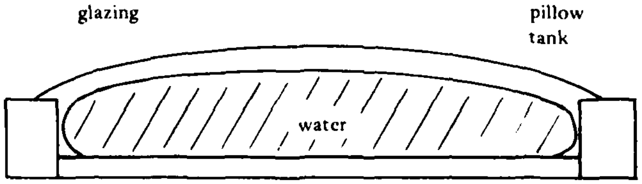
1. Phase 1 is the conceptual design, including determination of all space heating, domestic hot water, and space cooling loads; solar pond size and configuration; mechanical support equipment configuration; and total hardware and installation costs.



Cross section of a salt stabilized solar pond



Cross section of a "gel" pond



Cross section of a shallow solar pond

Figure 1. Three different types of solar pond.

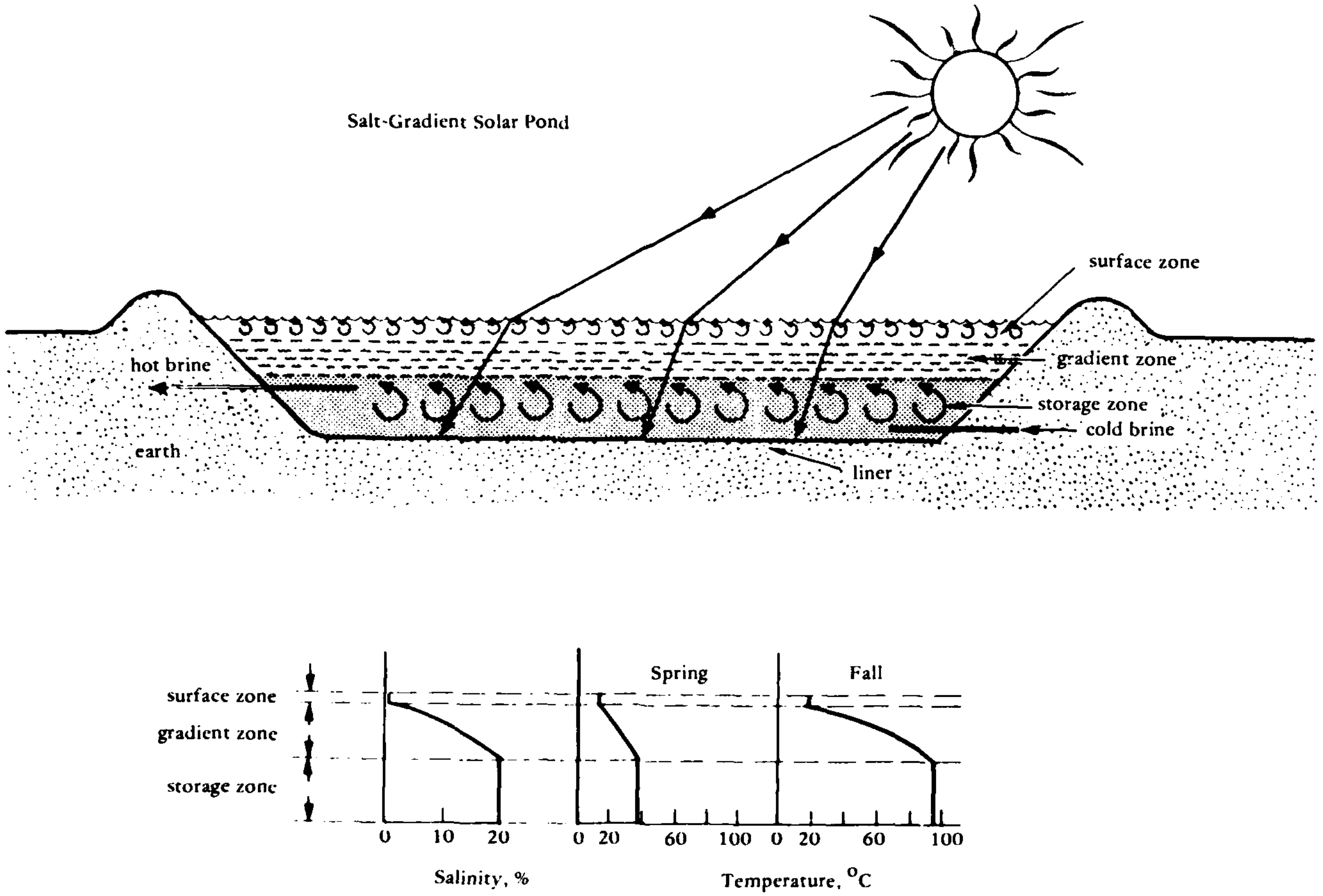


Figure 2. Typical temperature and salinity profile of a salt-gradient solar pond.

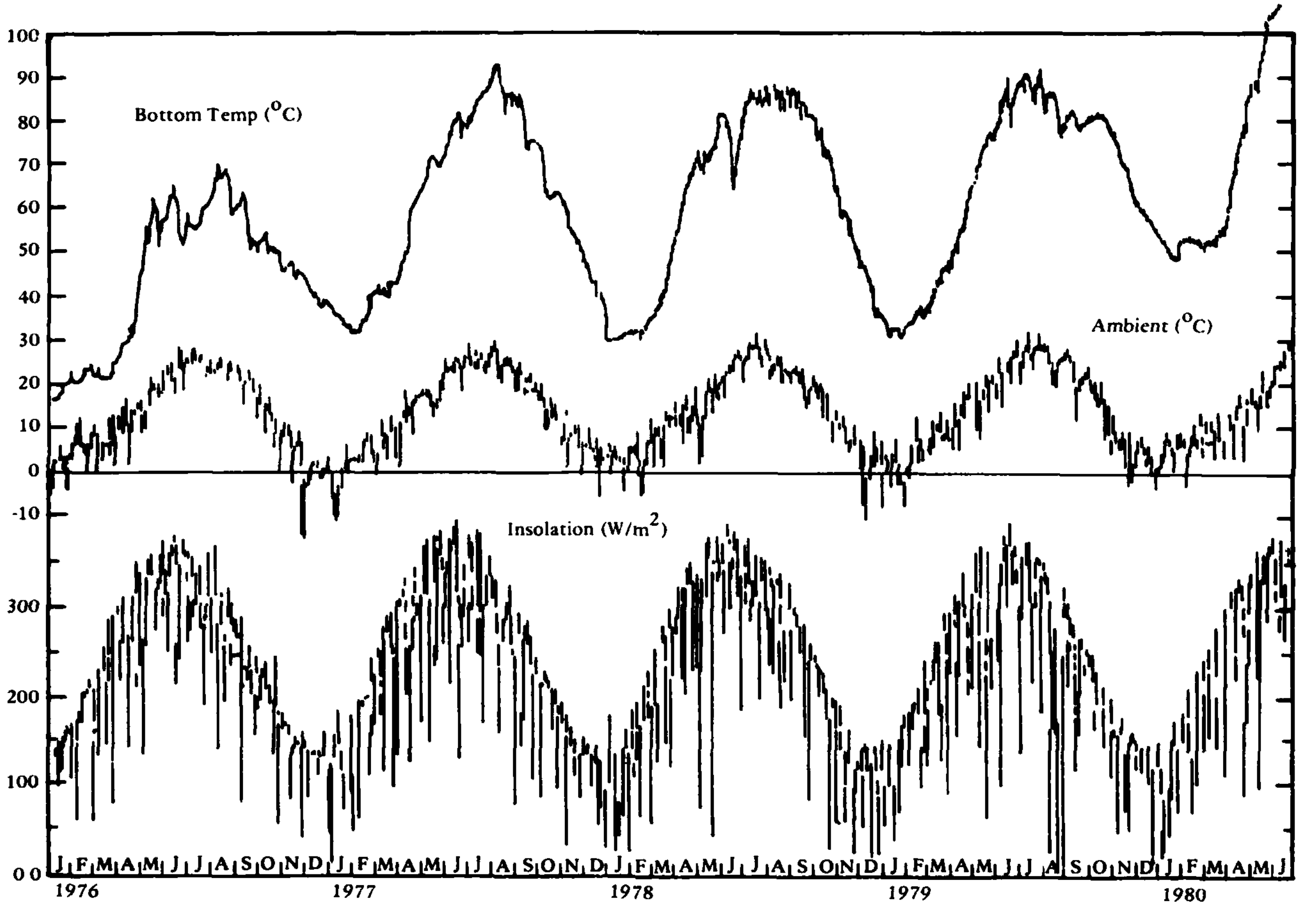
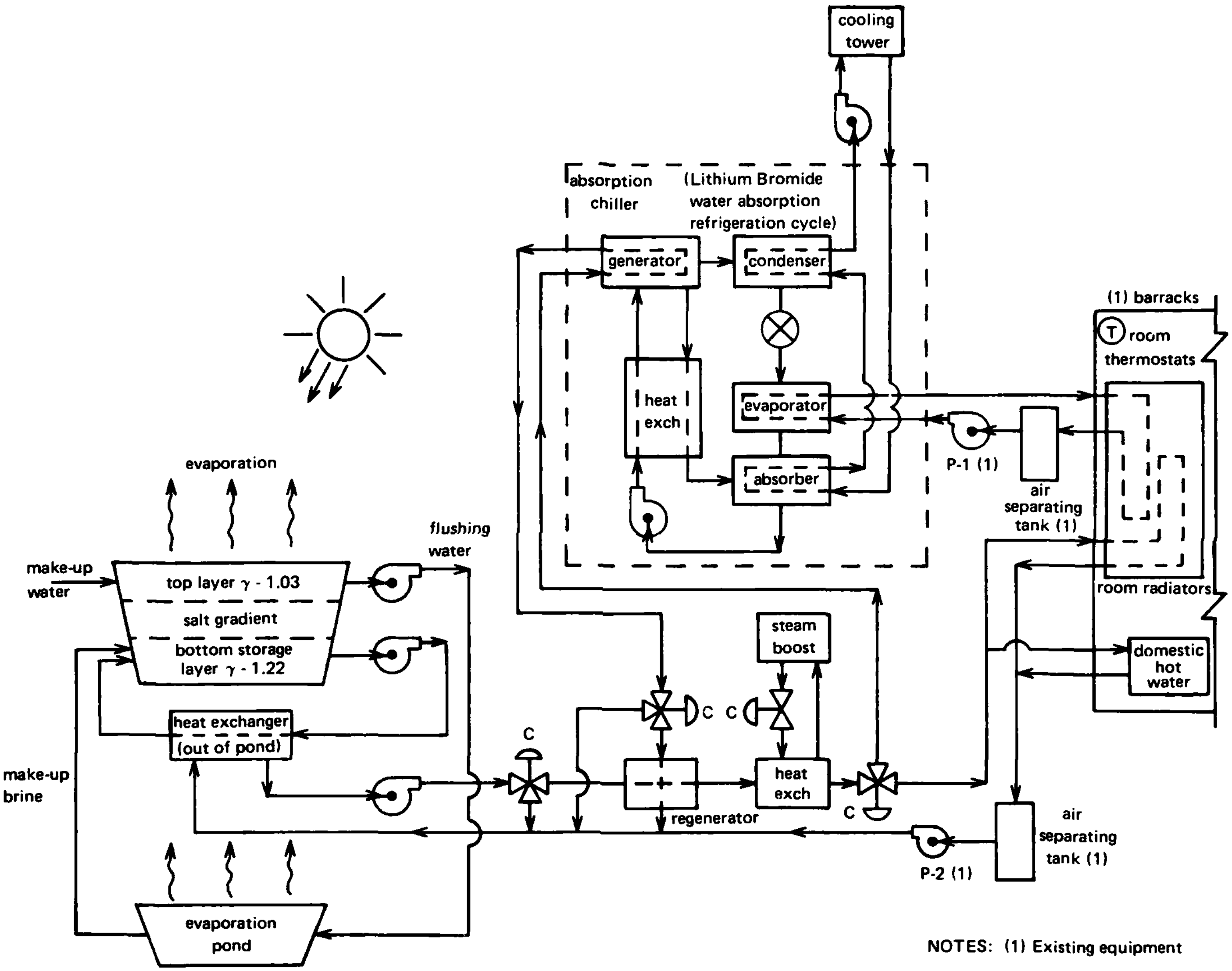


Figure 3. Temperature history of the University of New Mexico solar pond.



NOTES: (1) Existing equipment

Figure 4. Solar pond and BEQ heating and cooling diagram.

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NAVSTA Adak, AK; CO, Brooklyn NY; Code 16P, Keflavik, Iceland; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Dir Mech Engr 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam, Marianas; SCE, Pearl Harbor HI; SCE, San Diego CA; Utilities Engr Off. Rota Spain
NAVSUPPACT CO, Naples, Italy; PWO Naples Italy
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVSUPPO PWO, La Maddalena, Italy; Security Officer, La Maddalena, Sardinia, Italy
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD; Security Offr, Silver Spring MD
NAVTECHTRACEN SCE, Pensacola FL
NAVTELCOMMCOM Code 53, Washington, DC
NAVWARCOL Dir. of Facil., Newport RI
NAVWPNCEN Cmdr, China Lake, CA; Code 2636 China Lake; Code 26605 China Lake CA; Code 623 China Lake CA; PWO (Code 266) China Lake, CA; ROICC (Code 702), China Lake CA
NAVWPNEVALFAC Technical Library, Albuquerque NM
NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092A, Seal Beach, CA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO Colts Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCTC Const Elec School, Code B-1 Port Hueneme, CA
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; Library, Davisville, RI; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS; Technical Library, Gulfport, MS
NCR 20, Code R70
NMCB FIVE, Operations Dept; THREE, Operations Off.
NOAA Library Rockville, MD
NRL Code 5800 Washington, DC
NSC Code 09A Security Offr, Norfolk, VA; Code 54.1 Norfolk, VA; SCE Norfolk, VA; SCE, Charleston, SC
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NUSC DET Code 4111 (R B MacDonald) New London CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Code 221, Arlington VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA
PWC ACE Office Norfolk, VA; CO, (Code 10), Oakland, CA; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 101 (Library), Oakland, CA; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 400, Great Lakes, IL; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 500, Great Lakes, IL; Code 500, Oakland, CA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 590, San Diego, CA; Library, Code 120C, San Diego, CA; Library, Guam, Mariana Islands; Library, Norfolk, VA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Production Officer, Norfolk, VA; Util Dept (R Pascua) Pearl Harbor, HI
SPCC PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA

TENNESSEE VALLEY AUTHORITY Solar Grp (W4-C143), Arch Br, Knoxville, TN
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USCG G-DMT-3/54 (D Scribner) Washington DC; G-MMT-4/82 (J Spencer); Library Hqs Washington, DC
USCG R&D CENTER D. Motherway, Groton CT; Library New London, CT
USDA Forest Service Reg 3 (R. Brown) Albuquerque, NM
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Mech. Engr. Dept. (C. Wu), Annapolis MD
ARIZONA State Energy Programs Off., Phoenix AZ
AUBURN UNIV. Bldg Sci Dept, Lechner, Auburn, AL
BATTELLE PNW Labs (R Barchet) Richland WA
BERKELEY PW Engr Div, Harrison, Berkeley, CA
BONNEVILLE POWER ADMIN Portland OR (Energy Consrv. Off., D. Davey)
CALIFORNIA STATE UNIVERSITY LONG BEACH, CA (CHELAPATI)
CONNECTICUT Office of Policy & Mgt, Energy, Div, Hartford, CT
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
DAMES & MOORE LIBRARY Los Angeles, CA
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA; Col. Arch, Benton, Atlanta, GA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Div Of R&D, Baton Rouge, LA
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MISSOURI ENERGY AGENCY Jefferson City MO
MIT Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.)
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATURAL ENERGY LAB Library, Honolulu, HI
NEW HAMPSHIRE Concord NH (Governor's Council on Energy)
NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
NYS ENERGY OFFICE Library, Albany NY
PENNSYLVANIA STATE UNIVERSITY STATE COLLEGE, PA (SNYDER)
PORT SAN DIEGO Pro Eng for Port Fac, San Diego, CA
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
SOUTHWEST RSCH INST King, San Antonio, TX
UNIVERSITY OF ALASKA Doc Collections Fairbanks, AK
UNIVERSITY OF CALIFORNIA Berkeley CA (Dept of Naval Arch.); Energy Engineer, Davis CA; UCSF, Physical Plant, San Francisco, CA
UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.); Natl Energy Inst (DR Neill) Honolulu HI
UNIVERSITY OF ILLINOIS URBANA, IL (LIBRARY)
UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
ARVID GRANT OLYMPIA, WA
LITHONIA LIGHTING Application eng. Dept. (B. Helton), Conyers, GA 30207
NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
PG&E Library, San Francisco, CA
SANDIA LABORATORIES Albuquerque, NM (Vortman); Library Div., Livermore CA
SEATECH CORP. MIAMI, FL (PERONI)
SHANNON & WILLSON INC. Librarian Seattle, WA
TEXTRON INC BUFFALO, NY (RESEARCH CENTER LIB.)
TRW SYSTEMS REDONDO BEACH, CA (DAI)
UNITED KINGDOM LNO, USA Meradcom, Fort Belvoir, VA
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39 Air pollution
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