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# PASSIVE SOLAR WATER HEATING: BREADBOX DESIGN FOR THE FRED YOUNG FARM LABOR CENTER IN INDIO

by
DAVIS ALTERNATIVE TECHNOLOGY ASSOCIATES
BRUCE MELZER BRUCE MAEDA

for
THE SOLAR BUSINESS OFFICE
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EDMUND G. BROWN JR., GOVERNOR

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# NOTICE

THE RESULTS OF THIS REPORT CANNOT BE APPLIED TO BREADBOX INSTALLATIONS FOR SINGLE FAMILY RESIDENCES OR EVEN MOST MULTI-FAMILY INSTALLATIONS.

The analysis and design for this project was conducted for a specific installation with many unique design constraints. The breadbox design had to conform to an extremely high hot water demand with the majority of the water use occurring in the late afternoon. The large water demand meant that the system did not have to store hot water throughout the night. The constraints of the construction budget meant that any system designed for this installation would be severely undersized. The final breadbox design was based heavily on the construction needs of the San Bernardino West Side C.D.C. Overall, this study resulted in a system this is well matched to the design constraints for the project. However, there are large variations between the design requirements of this project and the design requirements for most single family and multi-family installations. Consequently, the analysis and results presented here should not be extrapolated to other breadbox installations. It is important to note that the analytical techniques and the computer model used in this study are applicable to a wide variety of breadbox designs and installations. Additional information on both computer analysis of breadbox performance and system design is available from Davis Alternative Technology Associates.

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Additional copies of this report may be obtained free from:

Solar Business Office
926 J Street  Suite 201
Sacramento, California  95814

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## INTRODUCTION

The goal of this project is to analyze and design an appropriate passive solar preheater (commonly called a bread-box) for multifamily housing units in the Fred Young Farm Labor Center in Indio, California. This system, to be constructed and installed by the San Bernardino West Side Community Development Corporation (CDC), is funded by the Federal Southwest Border Region Commission and administered by the State of California Solar Business Office.

This report is divided into six sections:

Section 1. State-of-the-art Review presents a brief summary of passive preheater systems and the key design features used in current designs.

Section 2. Design Criteria describes the Farm Labor Center, and the design features necessary for producing a system adapted to the requirements of the site, the climate, the users, and the system builders and installers.

Section 3. Prototype Preheater Designs presents the eight preliminary preheater designs reviewed for this project.

Section 4. Performance Evaluations discusses the results of thermal performance simulations for the eight prototype systems.

Section 5. Monitoring Recommendations describes and evaluates alternative monitoring systems for the installation.

Section 6. Final Recommendations presents the consultants' recommendations, working drawings, and performance estimates of the system selected for construction and installation.

SECTION 1. STATE OF THE ART REVIEW

Breadbox water heaters can be defined as solar water heaters with integrated storage and collector functions. Breadboxes generally consist of a water tank, or tanks, placed in an insulated box having a glazed front cover. Several other types of passive water heaters also exist, but these are not covered in this report. These alternative systems include:

1. Suntrays, or shallow ponds with glazed cover.
2. Japanese sun pillows consisting of heavy duty plastic bags filled with water during the day and emptied at night.
3. South African solar heaters consisting of unglazed rectangular tanks.
4. West Indian solar water heaters consisting of a large sun tray with a baffle to allow thermosiphon action to heat the water.

The alternative systems were not considered either because they did not fit the scope of the project or they could not operate under normal water line pressure (30-50 psi).

The term "breadbox" arose in 1973 when Jon Hammond applied the word to one of Steve Baer's early efforts. Since then, most passive water preheaters have been called "breadboxes" for lack of a better name. Breadbox heaters are also called "preheaters," but the term "preheater" is somewhat misleading since many properly sized systems can provide 100% of hot water needs during the summer.

Several key variables exist in current breadbox design. The first variable is horizontal vs. vertical tanks. Systems built in the early 1970's used tanks laid horizontally in the boxes, with their long axis running east-west. To increase stratification in the tank and allow the hottest water to be delivered to the house, tanks in later designs have been stood on end. Many systems use standing tanks tilted back to an optimum collector angle.

The second variable is the use of insulated shutters to improve nighttime performance. One of the most severe problems with breadbox systems is their loss of significant amounts of the heat at night. To reduce these heat losses systems have been constructed with insulated lids that can be closed at night. Often these lids have reflective foil bonded to the insulation to increase solar radiation entering the box during the day when the lids are open.

The main drawback of insulated lids is that they require some manual operation. Automatic freon driven lids have not proved successful, and an inexpensive but durable motorized shutter system has yet to be developed. External lids and shutters are also subject to the sometimes destructive force of the wind and weathering. Work is currently in progress using thermal drapes for insulation inside the box. While this reduces exposure to weather, it does not reduce the need for user operation.

The most recent method of reducing nighttime heat losses is placing the breadbox system within a greenhouse. Insulated breadbox lids are used in some cases, while night insulation for the entire greenhouse is used in others. Even without insulated lids a "breadbox" hot water heater in a greenhouse will have significantly lower heat loss at night.

Plumbing configuration is a third major variable. Some systems have been plumbed in series; others in parallel. Series plumbing reduces mixing between the cold inlet water and the hot breadbox water, with most of the mixing taking place in the first, or first and second tanks. This allows the third or last tank in series to deliver the hottest water to the house.

A parallel plumbing pattern allows the cold inlet water to be evenly distributed among all the tanks. This reduces the effect of the incoming cold water, since each tank experiences only a small temperature drop. There is some indication that series plumbing indeed provides the hottest water to the house, but little quantitative research comparing series and parallel plumbing has been done.

The fourth important variable is the color of the box interior. Breadbox interiors have generally been either painted flat black or lined with reflective materials, although there are designs that use white interiors as well. Black interiors have been used on the assumption that any solar radiation entering the box should be absorbed, and would therefore heat the box interior. The warm air in the box in turn heats the tank. Reflective interiors have also been used in an attempt to get all the solar radiation transmitted through the glazing reflected onto the tank. The effectiveness of reflectorized systems varies with reflector placement within the box. At present there is little research to demonstrate the superiority of either system.

A fifth major variable is tank size and shape. This variable is mainly a function of the available supply and cost of tanks. Optimal tanks are long and narrow because of their larger surface to volume ratio. This, however, may require a larger box and higher costs. The larger the tank surface, the more absorbant area for solar radiation.

The final variable, glazing to mass ratio, has only recently been considered. Although the glass is also a major source of heat loss, adequate glazing area is essential for providing appropriate water temperatures. Without sufficient glazing area, a system simply cannot admit enough heat to raise the water in the tank to the desired temperature.

Current calculations by D.A.T.A. indicate a maximum of 2.25 gallons of water for each square foot of collector glass. For standard domestic hot water applications, this ratio of water to glass will provide 110°F minimum tank temperatures in double glazed boxes in Central Valley climates in summer. A lower ratio of water to glass is necessary for higher temperatures or for increased demand.

Overall, there has been little quantitative research on the performance and design parameters involved in breadbox design. Despite the current popularity of computer modeling of solar heating and cooling systems, very little simulation and modeling of hot water heaters have been done. Nevertheless, a number of breadbox systems of varying design have been built and installed, and the systems are proving to be a low cost source of hot water.

## SECTION 2. DESIGN CRITERIA

The criteria used to develop and evaluate prototype breadbox designs range from the site, the climate, and the load profile to construction considerations such as the lifetime of materials. Although each factor discussed here was considered carefully, the relative weight of each factor varies. Furthermore, several factors conflict and part of the design process involved resolving these conflicts, or at least mitigating their adverse effects on performance.

### The Site

The Fred Young Farm Labor Center in Indio, California contains 253 housing units and houses approximately 1775 people. The residents are farm workers who reside in the center throughout the year. The buildings consist of one story, flat roof linear structures, with 4-6 housing units in each structure. Each 4-6 units is served by one 100 gallon 90,000 BTU water heater. There are a total of 39 water heaters in the center. The project goal is to retrofit breadbox water heaters onto as many water heaters as possible, for the amount of money available.

The City of Indio is located in California's Coachella Valley. The climate is classified as desert, characterized by extremely hot summers, warm winters and low rainfall. Average daytime temperature maximums from June to September are above 100°F, while average minimums from during the same period are above 70°F. December - February maximums average 70°F or higher, while the average minimums range from 38-42°F. The area has abundant solar radiation, with over 740 KBTU/ft$^2$/year incident on a south facing surface tilted 15° from the horizontal.

## The Load Profile

The water consumption patterns of residents is one of the single most important variables in designing and evaluating preheater systems. The load profile consists of two main factors:

1. The total amount of water used during a 24 hour period.
2. The distribution of water use throughout the day.

The load profile and the total amount consumed by residents of the Farm Labor Center vary greatly from the average load for a "typical American family".

A rule of thumb often used for sizing water heaters is that the typical American family consumes approximately 20 gallons of hot water per person each day. A recent study by the Sacramento Municipal Utility District (SMUD), however, indicates an average use of only 12 gallons per person each day. (Home Appliances and Their Energy Use, by Conservation Department, SMUD, July 3, 1978). This water use is normally spread throughout the day, with a substantial portion of the hot water used between 7:00am and 9:00am and the largest percentage of water use occuring in the evening.

In contrast to the "typical American family" Farm Labor Center residents rise early, between 3:00am and 5:00am; in the afternoon, from 2:00pm to 5:00pm, the workers return from the fields and shower. Thus, the greatest demand for hot water occurs in late afternoon. Solar hot water systems are well suited for this load profile, since they provide the hottest water in the late afternoon.

Two contrasting load profiles are shown below. The profile for the "typical family" was taken from Duffie and Beckman, Solar Energy

Thermal Processes. The load profile for the Farm Labor Center was developed by D.A.T.A. staff, in part by using utility bill information provided by the Center.

The second key facet of the load profile is the overall water demand. The total gallon demand per five Center housing units is quite high, over 400 gallons per day. Even though data indicates that the residents probably use less water per capita (10 to 12

**WATER DEMAND LOAD PROFILES**
**Davis Alternative Technology Associates**

Figure 1 Standard Load Profile

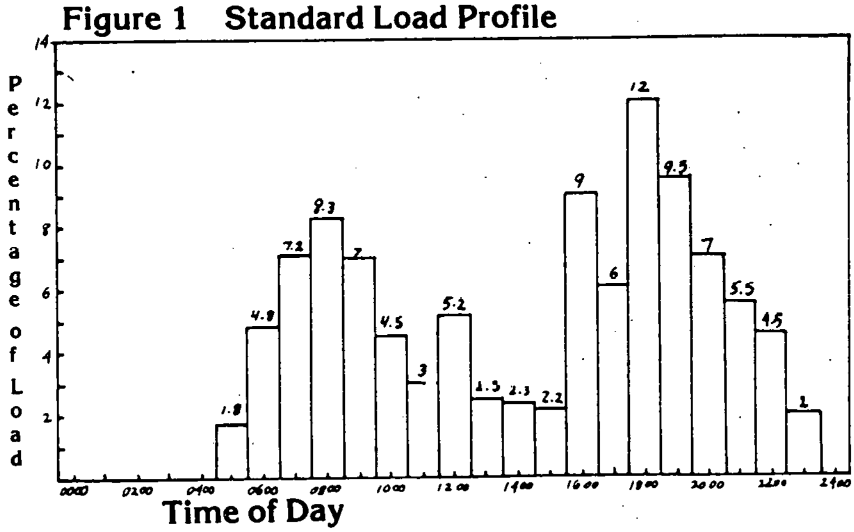
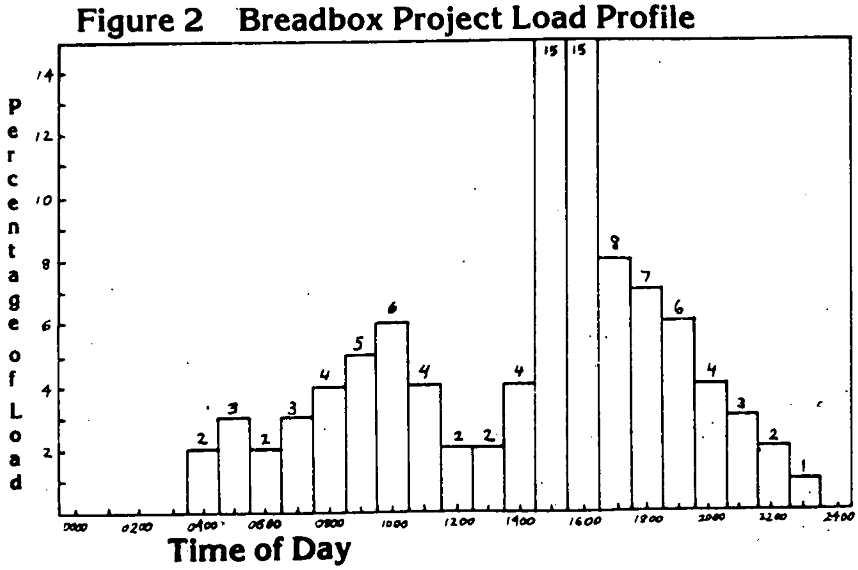



Figure 2 Breadbox Project Load Profile



gallons per person) than a typical American family of four, family size at the center ranges from 5 to 15 persons, with 7 being average.

Cost

The main cost consideration was low initial cost, while still providing a proven and durable system that performs well. All breadbox systems were evaluated on the basis of total material cost, cost/ft$^2$ of collector area, and annual KBTU output/dollar invested. Labor cost was not calculated because CDC will be using trainees whose labor costs will be subsidized by CETA and other assistance programs and grants.

Performance

The performance goal was to provide at least 25% of the annual hot water needs of each building. The performance of each of the prototype breadbox designs was modeled by computer, and each system compared for seasonal and annual BTUs delivered.

Weight

The system had to be light enough not to impose a large load on the roof, less than twenty pounds additional roof load per square foot.

Aesthetics

The system also had to be aesthetically acceptable to housing agency officials and residents. Systems with low profiles presented no aesthetic problems, since they could not be seen from ground level.

Mass Production

Since 28 heaters had to be built at one time, the system selected had to be designed for mass production. This required using standard sized materials with a minimum amount of required cutting. Wood frame construction was preferred because C.D.C.'s shop operations are currently set up to handle wood. However, some sheet metal designs were also considered.

Reproducibility

Since C.D.C. plans to continue building and installing breadboxes after this project ends, the design chosen had to be suitable for single as well as multifamily housing units. There was some conflict between this design consideration and the nature of the load profile. Farm Labor Center installation requires virtually no night storage, since the water use in the afternoon is so high. An optimal system for this project heats up quickly and delivers hot water immediately. A more typical single family installation uses less water, but requires more night heat storage to provide hot water in the morning hours.

Locally Available Materials

The breadboxes should be constructed of locally available materials wherever possible to minimize shipping costs, delivery lead time and the energy consumed in shipping materials.

Lifetime of Materials

The systems had to be constructed of durable materials, and the plumbing design had to minimize corrosion. The lifetime of plywood was assumed to be 20 years; the lifetime of the Kalwall glazing material 10 years.

Shipping

Since the systems will be constructed in San Bernardino and shipped to Indio for installation, they must ship easily and with minimal damage.

Installation Ease

Installation had to be as simple and quick as possible, with the system light enough for a four-person crew to carry. On site fabrication had to be minimized and the plumbing connections also made simple.

Vandalism

Since property in the Farm Labor Center is prone to vandalism, the system's glazing needed to withstand the impact of rocks, bottles, and other projectiles. All prototype systems used Kalwall glazing because of its resilience and resistance to impact. Systems with low profiles not visible from the ground are also less susceptible to vandalism.

Maintenance

Since components and construction are fairly simple, the key maintenance design requirement is the ability to remove the glazing for access to the box interior. Overall, the box and components should require little maintenance.

Risk and Innovation

There is some risk and uncertainty associated with the construction, installation, and operation of any new system; untested material, improper design or faulty construction may result in impaired performance or material failure. Each breadbox design had to be carefully evaluated for such risks. High risk systems were judged incompatible with the project's goal of constructing and installing operating systems, rather than conducting research on breadbox design.

SECTION 3. BREADBOX PROTOTYPES

Based on the state-of-the-art in breadbox design and the design criteria discussed in the previous section, eight prototype breadbox designs were developed. Two important factors were used in developing these prototypes--tank availability and ratio of glazing to the volume of water. The performance of each system was modeled by computer, and each system was evaluated and compared.

One of the central problems facing breadbox designers and builders is the availability and cost of tanks. There is currently one main source of new unjacketed, glass-lined steel tanks in California, American Appliance. Tank prices vary enormously among the various distributors and jobbers who sell these tanks. During the project, 30 gallon tank prices were quoted as ranging from $54.00 (plus shipping) to $122.00 (plus shipping). All of these tanks were manufactured by American Appliance.

Alternatives to American Appliance tanks are available. Stone-lined tanks, for instance, can be shipped from New York, but at substantial shipping cost. Recycled gas and electric water heater tanks are also available in small quantities, but these must be carefully tested since many have leaks. In some areas it is less expensive to buy a new electric water heater and dismantle it, rather than to buy a new unjacketed tank.

Some innovative materials are also available, but there are drawbacks to many of these. Large diameter pipes are available, but most cannot withstand heat and line pressure. Polybutylene has excellent characteristics in withstanding both high temperature and pressure, but unfortunately it is available only in diameters of less than 1 1/2 inches. One manufacturer, SAV, uses galvanized tanks with a device that they claim neutralizes the corrosive properties of water.

A simple low-cost method of coating aluminum irrigation pipe with silicone had been developed before this project by project consultant, Horace McCracken. These coated pipes appear extremely promising, because of the low cost per gallon of tank and the ability of C.D.C. or other small businesses to apply their own coatings. Additional research, development, and testing need to be undertaken, however, before this system can be used.

Copper can be used for tank materials, but at a higher cost than steel. At present there are no commercially manufactured copper tanks available. Large diameter copper pipe is available, but it too is extremely expensive.

The second key design factor used in the breadbox design was the glazing to water mass ratio. Computer studies by D.A.T.A., undertaken before this project, indicate that the glazing to water mass ratio is one of the more important factors in breadbox design. The prototype breadboxes were designed with a maximum of 2.0 gallons per square foot of glazing area.

Computer Analysis

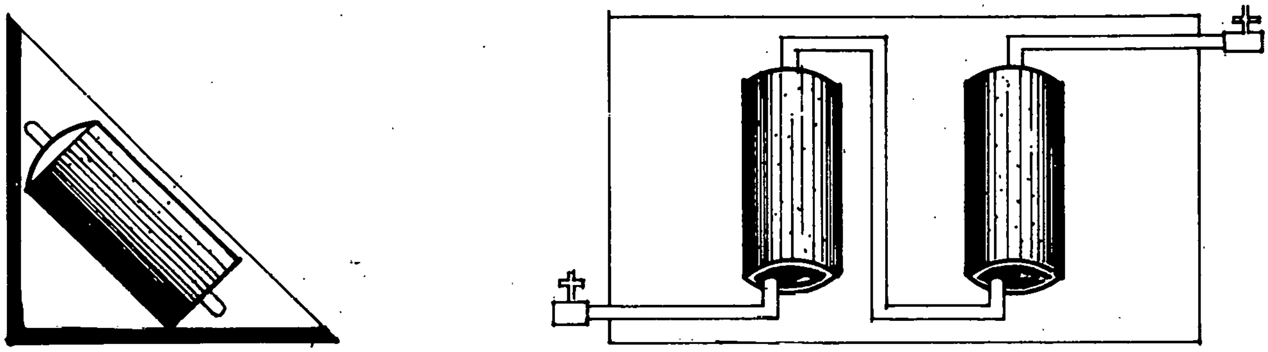
A large number of variables, such as glazing area, tank size, glazing to mass ratio, total storage capacity, and box configuration, affect breadbox design. At least one variable must be held constant when comparing different systems. Initial studies showed that breadbox performance for large load situations is most affected by the total effective glazing area. Thus, the effective glazing area of all systems was held constant at 120 $ft^2$ per installation. In addition, the ratio of mass to glazing area was limited within 1.5-2 gallon per $ft^2$ wherever possible. As stated earlier, this variable is less critical than the total glazing area per system.

Finally, most of the breadboxes using glass-lined steel tanks were designed with 40 gallon tanks measuring 25 by 33 inches. These tanks were considered the most cost effective tanks available when this analysis was being undertaken.

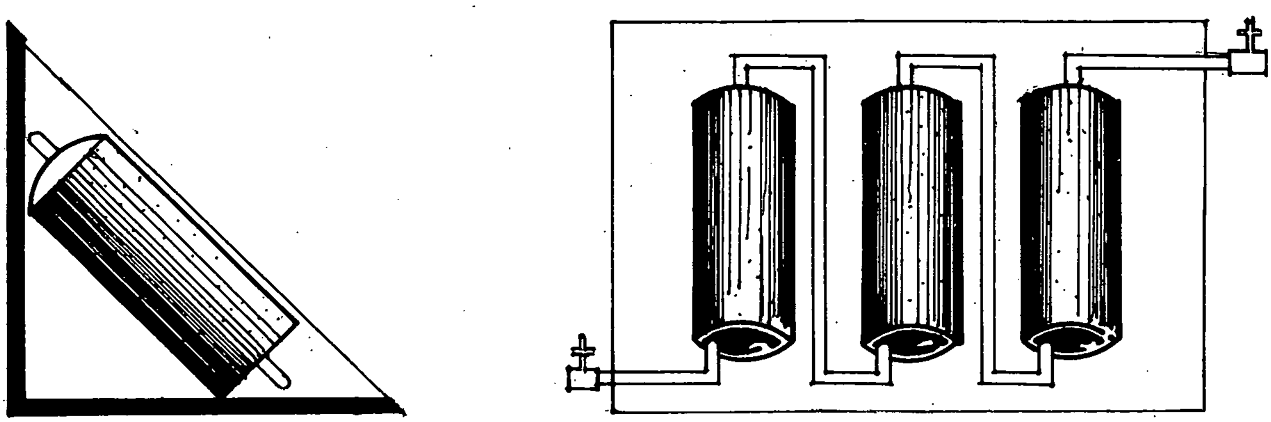
SYSTEM # 1 - TWO TANK VERTICAL BREADBOX

Description: This system uses two 40 gallon tanks set at a 45° tilt. The insulated plywood box has a simple triangular shape. The box is glazed with a single layer of Kalwall also tilted at a 45° angle. The two tanks are plumbed in series.

| | |
|---|---|
| Water Storage: | 80 gallons/unit |
| Glazing Area: | 60 ft.$^2$/unit, 120 ft.$^2$/installation |
| Number of Units: | 2 |
| Estimated Materials Cost: | $320/unit, $640/installation |
| Performance: | 33% Solar, 37.45 KBTU annually/dollar invested |
| Advantages: | Extremely simple box design lends itself to mass production.<br>Low risk, since similar designs have been built throughout California.<br>Simple glazing detail makes maintenance easy. |
| Disadvantages: | Heavy and bulky construction makes installation difficult.<br>High profile makes system susceptible to vandalism. |



System #1 Two Tank Vertical
Figure 3



System #2 Three Tank Vertical
Figure 4

SYSTEM # 2 - THREE TANK BREADBOX

Description: This system uses three 30 gallon tanks tilted at a 45° angle. The triangular box configuration is the same as the one used for system #1. The tanks used are long and narrow (48"x18") and have a greater surface area relative to the amount of water they contain. The tanks are plumbed in series.

| | |
|---|---|
| Water Storage: | 90 gallons/unit |
| Glazing Area: | 60 $ft.^2$/unit, 120 $ft.^2$/installation |
| Number of Units: | 2 |
| Estimated Materials Cost: | $400/unit, $800/installation |
| Performance: | 35% Solar, 31.40 KBTU annually/dollar invested |
| Advantages: | Narrow diameter 30 gallon tanks provide better performance than larger 40 gallon tanks.<br>Simple box design lends itself to mass production.<br>Low risk, since similar designs have been built throughout the West. |
| Disadvantages: | Higher cost since three tanks are used instead of two.<br>Extremely bulky and heavy box makes shipping and installation difficult.<br>Large profile makes glazing susceptible to vandalism.<br>Basic design can be reproduced, but system may be too heavy and large for many residential retrofits. |

SYSTEM # 3 - TWO TANK BREADBOX WITH SUPERHEATERS

Description: This system uses a two tank breadbox system to warm the water, supplemented by a one tank system with a large glazing to water ratio to boost the water up to high temperatures. Both the two tank and the one tank boxes are the same size and shape; both use 40 gallon tanks. All of the tanks are plumbed in series.

| | |
|---|---|
| Water Storage: | 120 gallons |
| Glazing Area: | 120 ft.$^2$/unit, 120 ft.$^2$/installation |
| Number of Units: | 1 |
| Estimated Materials Cost: | $546/unit, $546/installation |
| Performance: | 31% Solar, 41.01 KBTU annually/dollar invested |
| Advantages: | System is well suited for water demand pattern, since it delivers hottest water in the afternoon.<br>The basic box designs are simple and easy to mass produce.<br>Fairly low risk system since box designs have been built before. Although this superheater has never been tested, there are no foreseeable, theoretical or practical considerations that would prevent its use.<br>Easy maintenance due to access to tanks. |

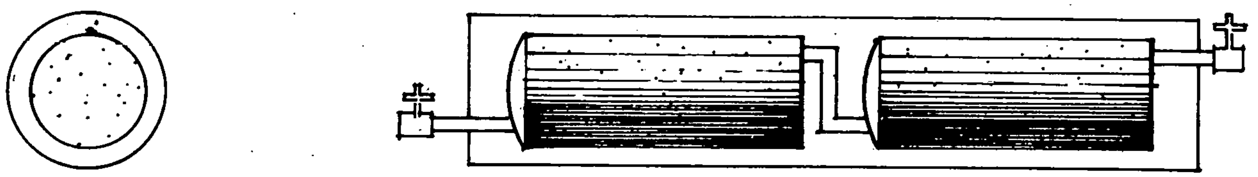
Disadvantages:

System is unsuitable for single family home retrofits since it is designed to handle extremely large, afternoon loads.

Difficult installation since large boxes are difficult to handle.

Plumbing between boxes increases installation cost and labor time slightly.

Large glazing areas and large profile make system susceptible to vandalism.



System #5 Two Tank Bubble System
Figure 7

System #6 Narrow Diameter Bubble System
Figure 8

SYSTEM # 4 - TWO TANK HORIZONTAL SYSTEM

Description: This system is a slightly modified version of the breadbox currently being built by the San Bernardino C.D.C. The system was redesigned to include a larger glazing area using standard glazing sizes. Two horizontal 40 gallon tanks plumbed in series are used.

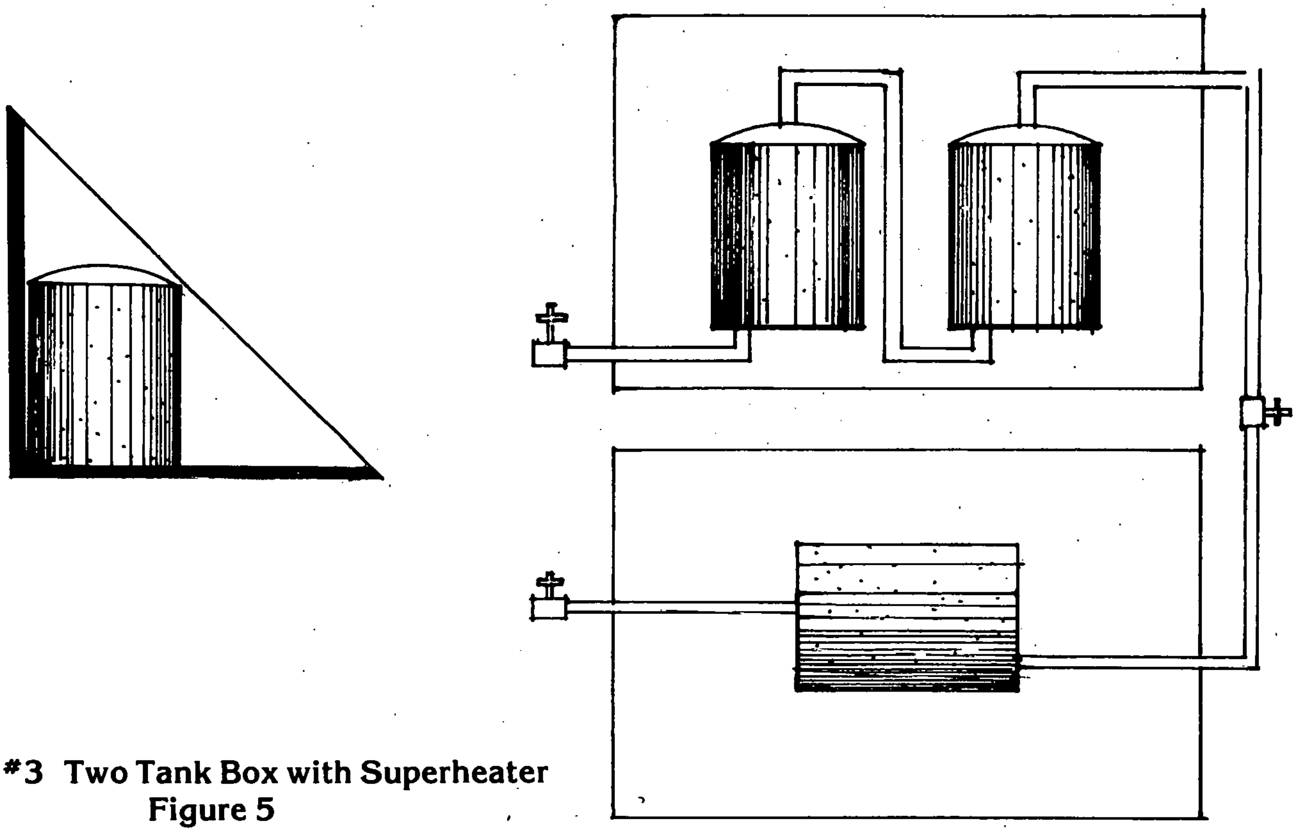
| | |
|---|---|
| Water Storage: | 80 gallons/unit |
| Glazing Area: | 60 ft.$^2$/unit, 120 ft.$^2$/installation |
| Number of Units: | 2 |
| Estimated Materials Cost: | $305/unit, $610/installation |
| Performance: | 34% Solar, 39.66 KBTU annually/dollar invested |
| Advantages: | Easily mass produced since C.D.C. is accustomed to working with this box configuration.<br>Extremely reproducible design, since this low profile system is well suited for residential applications.<br>Low profile also minimizes vandalism potential.<br>Easy installation, since system is relatively compact and easy to handle.<br>Low risk, since C.D.C. has built and installed these boxes before. |
| Disadvantages: | Box shape is not optimal for mass production since a large amount of lumber cutting and glazing flashing is required. |

SYSTEM # 5 - TWO TANK BUBBLE SYSTEM

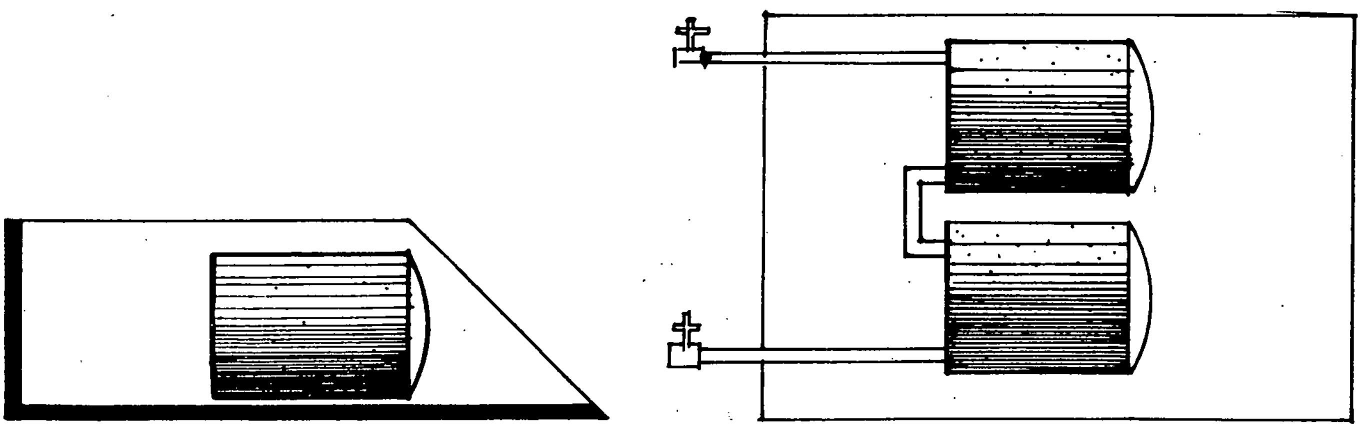
Description: Two 30 gallon tanks, plumbed in series, are mounted in a 24" diameter Kalwall cylinder. This configuration minimizes solid box area required, and is advantageous when glazing costs are less than the lumber costs for the box. There may be problems developing a low cost method of sealing and weather-proofing the bubble ends while also allowing for thermal expansion.

| | |
|---|---|
| Water Storage: | 60 gallons/unit |
| Glazing Area: | 62.8 ft.$^2$/unit, 377 ft.$^2$/installation |
| Number of Units: | 6 |
| Estimated Materials Cost: | \$208/unit, \$1348/installation |
| Performance: | 76% Solar, 46.68 KBTU annually/dollar invested |
| Advantages: | Easily mass produced, since box framing is minimal.<br>Light-weight system imposes small loads on roof and makes shipping and handling easier.<br>Highly reproducible system suitable for residential installation.<br>Low profile minimizes vandalism hazard. |

| | |
|---|---|
| Disadvantages: | Cost per installation is extremely high. |
| | Maintenance is difficult since glazing is not easily removable. |
| | Moderate risk system since weather proofing may be difficult. |
| | Increased installation costs due to large number of plumbing connections required to hook up 6 units. |



System #3 Two Tank Box with Superheater
Figure 5



System #4 Two Tank Horizontal
Figure 6

SYSTEM # 6 - NARROW DIAMETER BUBBLE SYSTEM

Description: This system uses 6" diameter aluminum irrigation pipe placed inside a 30' long, 8" diameter Kalwall cylinder. The aluminum pipe is silicone coated, using the method developed by H. McCracken. The narrow diameter pipe allows fast water heating. The system operates very efficiently, since the demand rate is so high that the water does not stand in the pipes long enough to lose heat. Plumbing connections for the pipe are expensive so longer pipe runs are more cost effective than short ones.

| | |
|---|---|
| Water Storage: | 44 gallons/unit |
| Glazing Area: | 45 ft.$^2$/unit, 270 ft.$^2$/installation |
| Number of Units: | 6 |
| Estimated Materials Cost: | $101/unit, $606/installation |
| Performance: | 41% Solar, 51.15 KBTU annually/dollar invested |
| Advantages: | Extremely easy to mass produce due to simple design and inexpensive, available raw materials.<br>Moderately easy installation. Glazed piping lengths are easy to handle, but connections between pipes must be done on site.<br>Design is well matched to load profile, since it provides quick, efficient water heating. |

| | |
|---|---|
| Disadvantages: | High risk system since aluminum coating method is untested. |
| | Not reproducible for single residential applications, although system is well suited for multi-family or commercial use. |

SYSTEM # 7 - NARROW DIAMETER TRIANGULAR SYSTEM

Description: This system, developed by Horace McCracken, uses 3" diameter silicone coated aluminum irrigation pipe inside a triangular sheet metal box. The system heats up extremely fast due to the narrow tube diameters and operates very efficiently. Since the connections are expensive and the pipes hold a small amount of water, this system would be built in 16 foot lengths. Water storage figures are listed below, but they are relatively meaningless, since water flow through the system is quite fast.

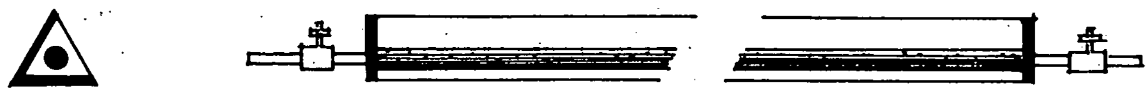
| | |
|---|---|
| Water Storage: | 0.37 gallons/unit |
| Glazing Area: | 12.8 ft.$^2$/unit, 128 ft.$^2$/installation |
| Number of Units: | 10 |
| Estimated Materials Cost: | $29/unit, $290/installation |
| Performance: | 32% Solar, 82.0 KBTU annually/dollar invested |
| Advantages: | Easily mass produced since the system has few components.<br>Suitable for multi-family, commercial and industrial applications.<br>Easy installation since systems are lightweight and easy to handle.<br>Very low profile is not susceptible to vandalism.<br>System matches load profile, since it is a minimal storage, fast heating device. |

Disadvantages:

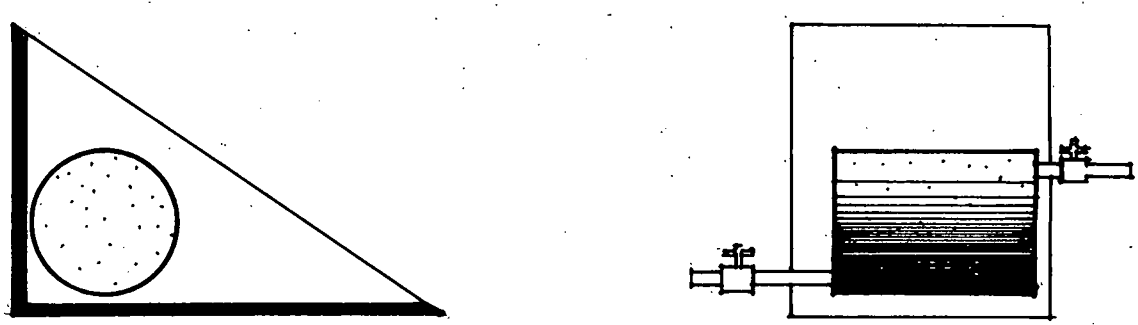
High risk system since silicone coating method is untested. Improperly coated pipe will corrode rapidly.

Potential health hazard, since long term effects of silicone in contact with drinking water supply are unknown.

May be unsuitable for single family units since the system has minimal heat storage.



**System #7 Narrow Diameter Triangular**
**Figure 9**



**System #8 One Tank Triangular**
**Figure 10**

SYSTEM # 8 - ONE TANK TRIANGULAR BREADBOX

Description: This one tank system placed in a triangular box was developed midway through the project to meet the criteria of a small, easy to handle system with a simple box design. In this system, the tank lies with the long axis running east/west, allowing solar radiation to be better distributed across the tank surface in winter. This system is modular; it is easy to add tanks as needed.

| | |
|---|---|
| Water Storage: | 40 gallons/unit |
| Glazing Area: | 28 $ft.^2$/unit, 112 $ft.^2$/installation |
| Number of Units: | 4 |
| Estimated Materials Cost: | $183/unit, $732/installation |
| Performance: | 19% Solar, 18.14 KBTU annually/dollar invested |
| Advantages: | Easily mass produced. This box requires little lumber cutting.<br>Highly reproducible for single family retrofits, since box is fairly compact and the number of boxes can be easily varied to match the hot water load.<br>Easily maintained, since an entire box could be removed and replaced if necessary.<br>Glazing detail allows for quick glazing removal.<br>Low profile minimizes susceptability to vandalism.<br>Glazing set at optimum tilt for location. |

Disadvantages:

System is costlier since separate box is used for each tank.

Plumbing connections between the boxes can be time-consuming and costly for installations of more than two systems.

## SECTION 4. PERFORMANCE EVALUATION

The performance of each breadbox system was analyzed using D.A.T.A.'s computer code BBX, validated against data gathered by D.A.T.A.'s Suncatcher Monitoring Project in the summer of 1979. The program uses hour by hour simulation and yields tank temperatures as well as the total heat delivered by the system. The results of the analysis for each system are presented in the Breadbox Performance Summary Sheet in this section. This section also includes additional analysis of two systems developed during the final stages of the selection process.

### Program Description

The computer code BBX uses hour by hour simulation to model the annual performance of the breadbox systems. Rather than using the very expensive method of modeling the performance for an entire year, breadbox performance is modeled during eight design days, consisting of one typical sunny and one typical cloudy day for each of the four seasons. The program multiplies the clear day performance by the number of clear days in the season, and the number of cloudy days by the cloudy day performance. The number of partly cloudy days are then multiplied by 2/3 of the sunny day performance and 1/3 of the cloudy day performance. Statistical studies of solar radiation indicate that most of the daily radiation on partly cloudy days actually strikes the earth's surface.

The program inputs include the physical and thermal characteristics of the box and tanks, as well as the load profile, climatic and solar radiation data. The box characteristics include the area, orientation and R-value of all walls and glazing surfaces. The input on the tanks includes water capacity in pounds, surface area of the tank, and the surface area exposed to solar radiation. Climatic data includes maximum and minimum daily temperatures, average number of clear, partly cloudy and cloudy days each month, etc.

The program calculations include a heat balance between the key elements of the system, i.e. the outside air temperature, internal temperatures and tank temperature. This heat balance, calculated 100 times per hour, also interfaces with the load profile. The hourly load profile allows heated mass to be drawn from the tanks and cold water to be introduced.

The program outputs include an hourly summary of the maximum and minimum tank temperatures, outside air temperatures, and interior box temperature. It also summarizes net heat exchanges between the various components in this system and the environment. At the end of each day the maximum and minimum temperatures, net BTU output from the system, and a complete summary of the heat balance of each element are printed.

The annualized output includes annual BTU supplied by solar heating, annual BTUs supplied by the back-up heater, total number of gallons used per year, and the percent solar contribution to the total water heating demand. It is important to note that the model simulates the breadbox system when it is actually connected to the back-up system.

Performance Summary

The summary of the performance is presented in the Breadbox Performance Summary Sheet. System #5, the two tank bubble, has the largest percent solar and delivered the largest amount of heat. This is due primarily to the large number of units used. In contrast, the triangular system performed worst by delivering the smallest amount of heat. This appears to be due to the large heat losses through the box walls, since each tank is enclosed in an individual box. With the exception of system #5 and system #8, the systems using more than one 30 or 40 gallon tank performed similarly. This shows that these systems are not particularly sensitive to changes in box configuration.

The performance difference in system #4 using 30 gallon tanks vs. 40 gallon tanks is extremely small. Thus, the system performance for all the tank systems (#1-#5 and #8) would not change greatly if 30 gallon tanks were substituted for 40 gallon tanks. 30 gallon tank systems are a better choice since they lower the cost (30 gallon tanks are less expensive) without significantly lowering system performance for this particular application. In fact, the KBTU/dollar cost differences between the two systems show that 30 gallon tanks are extremely economical--43.97 KBTU/dollar compared to 39.65 KBTU/dollar for the 40 gallon tank system.

# BREADBOX PERFORMANCE SUMMARY SHEET

| System Number | Tanks/Unit | # of Units | Total Capacity | MBTUS Annual Output | % Solar | KBTU/$ |
|---|---|---|---|---|---|---|
| 1. 2 tank vertical | 2 | 2 | 160 gal. | 23.97 | 33 | 37.45 |
| 2. 3 tank vertical | 3 | 2 | 180 gal. | 25.12 | 35 | 31.40 |
| 3. 2 tank plus superheater | 3 | 1 | 120 gal. | 22.39 | 31 | 41.01 |
| 4. 2 tank horizontal | 2<br>2 | 2<br>2 | 120 gal.<br>160 gal. | 24.01<br>24.19 | 33<br>34 | 43.97 (30 gal.)<br>39.66 (40 gal.) |
| 5. 2 tank bubble | 2 | 6 | 360 gal. | 62.93 | 76 | 46.68 |
| 6. Narrow diameter bubble--6" pipe | 30 lin. ft. | 6 | 264 gal. | 31.00 | 31 | 51.15 |
| 7. Narrow diameter triangular (McCracken) | 16 lin. ft. 3" pipe | 10 | 59 gal. | 23.78 | 32 | 82.00 |
| 8. 1 tank triangular | 1 | 4 | 160 gal. | 13.28 | 19 | 18.14 |

## SECTION 5. BREADBOX MONITORING RECOMMENDATIONS

Several levels or options for monitoring are available. The costs and information gathered will generally vary inversely, thus the final decision will be made in conjunction with other project considerations. Several options have been developed so that an intelligent and informed decision which balances project and monitoring goals can be made.

### Basic Output Performance

1. Minimal Requirements

The minimal requirement for monitoring equipment is a single BTU meter for each system to be monitored. This instrument should be placed in a sheltered location between the breadbox outlet and the hot water heater in front of any installed bypass valves. The inlet water temperature also needs to be measured for these units to work; thus, the inlet and outlet plumbing for the breadbox for monitored systems needs to be reasonably close and in a sheltered location. The BTU meter must be installed in a horizontal section of pipe. A 110 volt electrical outlet or circuit nearby is necessary. The Conserdyne BTU meter is recommended due to its reasonable cost and local availability (Glendale, California). There are regrettably few manufacturers producing such instruments for hot water applications.

2. Secondary Considerations

The second step in monitoring should include another BTU meter at the hot water heater outlet. The installation instructions are similar to those above except this installation is for the hot water heater. Both these options require periodic reading of the output of the BTU and gas meters. The more often readings are taken, the better the information, although monthly readings are sufficient. More frequent readings would yield information about the load profile, if done hourly, and the day to day or week to week variation, if done daily or weekly. Hourly readings for 24 full hours one or two days a month would give useful information about both daily load profile and overall performance. This level of monitoring will adequately indicate performance, but will reveal little about the dynamics of the system or how it might be modified to improve performance. The meter readings may need to be compared to solar radiation data although the site has a very high percentage of clear days even in winter. This monitoring could not compare breadboxes to other flat plate collectors or other systems due to the special aspects of the Indio project and site.

Temperature Monitoring

1. Hand Read

In addition to the use of BTU meters discussed in secion 1 above, the inclusion of a multi-channel temperature measuring device would be useful for gathering more information about breadbox performance. Various temperature measuring instruments are sold with active solar system controllers, and there are also instruments available exclusively for measuring temperature. These range in price from $85-$400 and can accomodate anywhere from 3-11 channels. Such temperature measuring devices have to be read periodically depending on the frequency of temperature measurement desired. Generally, the frequency of readings must be greater than four times per day to be useful, with hourly measurements being most typical. Strip chart recording instruments are also available, but the absolute cost and price per channel jumps substantially. For example, a two channel recording system costs $400. This cost must be balanced against the cost of gathering the information by hand and must also consider the total number of temperature measurements per system to be monitored. The instrument recommended for this application is sold by Hawthorne Industries (provided it is readily available), and costs approximately $200 for eight channels and temperature sensors. The following temperatures should be monitored: inlet and outlet temperatures of the system and of each tank within the system; inside breadbox temperatures, and outside temperature. Sensors are available as screw-in fixtures for the tanks and for the inlet and outlet temperatures. Care must be taken to avoid stratification where inlet and outlet temperatures are measured. Ideally, the temperatures should be monitored during 3-4 separate periods of distinctly different weather conditions. This level of monitoring is useful to compare with computer models for validation and for simulation of breadboxes of different designs and applications.

Someone familiar with monitoring of solar systems should install the sensors, although care must be taken to recognize that breadboxes are different from standard flat plate collectors. A schematic diagram of suggested sensor placement appears below:

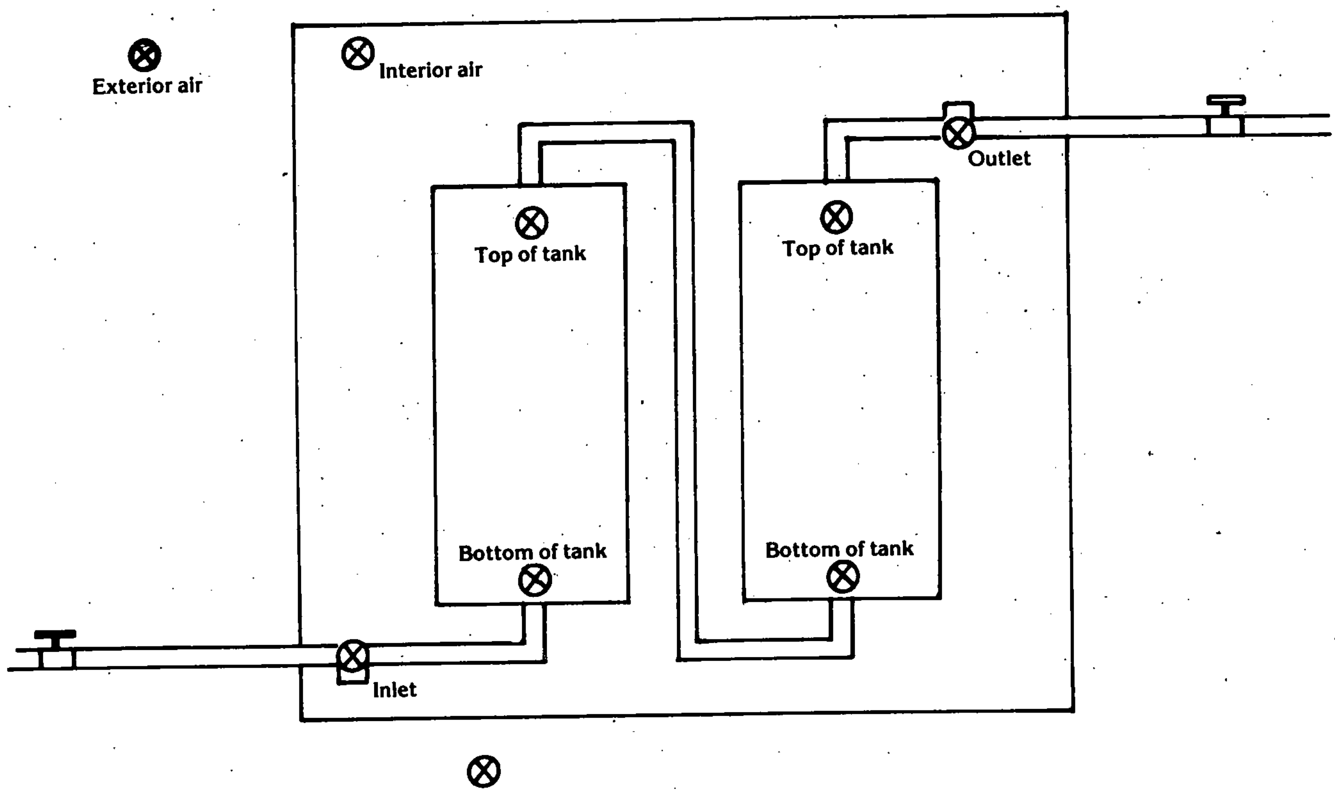



**Figure 11 Sensor Placement Schematic**

2. Automated Recording

It may be possible to attach strip chart recorders to the temperature sensing instruments for the additional cost of renting the strip chart recorder. However, this alternative has not been investigated in detail. If this is done, care must be taken to match the electrical input requirements of the strip chart recorder to the output of the temperature sensing device. Likewise, digital output sensors would probably require a printed output as opposed to strip charts which continuously record temperatures.

In any event, the cost of each monitoring system should not exceed $1,200, since there is a package instrument that will record and print ten channels of temperature information available from DATEL. If the strip charts are used, the time required to reduce data from the strip charts should be considered, and if no recording system is used, for the time required in recording and analyzing any data gathered.

3. Insolation Measurement

A pyranometer may be added to the monitoring system, although the output of a pyranometer is usually different from the output of temperature sensors and the system chosen may not be able to accommodate the pyranometer output. In addition, instantaneous pyranometer output is not very useful, especially if recorded or sensed infrequently. Therefore, integrators are usually used with pyranometers to integrate the total radiative flux. These integrators must either be read daily during the monitoring period or have an output that is compatible with the recording device used. Pyranometers are fairly expensive instruments, with medium quality devices costing $700, although it is possible to purchase an adequate sensor for $100. The integrator raises the price by $400 - $1000.

D.A.T.A. feels that including a pyranometer is not necessary for this project unless comparisons with similarly monitored projects is anticipated, or separate funding is available. Solar data from a nearby solar station will probably be adequate when correlated with local weather data.

4. Fully Automated Data Gathering System

The most extensive monitoring system would still need the minimum specifications given above, but could also use a top quality, rental monitoring system. Sensors for this system could be purchased and installed during the first part of the project. The data acquisition system would allow for a wide range in temperatures and sensors of all types, including pyranometers and pulse counting devices. Therefore, the cost of specific instrumentation for pyranometer sensing could be avoided. Recording and hardcopy of the data could be automatic, avoiding the necessity for human reading of data. A trained technician would be needed, however, to set up the monitoring project and check the instruments regularly during the monitoring period. The instrument rental would be approximately $400 per month, and the technician's services would cost an equal amount or more.

## SECTION 6. RECOMMENDATIONS AND CONCLUSIONS

### Design Matrix

The following system design matrix summarizes how each system relates to the design criteria developed in Section 3. Each system is ranked graphically. A black circle shows that the system relates positively to the design features. The empty circle signifies that it does not conform to the design criteria. A half-filled circle shows that the system has some positive and some negative features.

SYSTEM DESIGN MATRIX

| | 2 Tank Vertical 1 | 3 Tank Vertical 2 | 2 Tank & Superheater 3 | 2 Tank Horizontal 4 | 2 Tank Bubble 5 | Narrow Diameter 6 | Triangular System 7 | One Tank 8 |
|---|---|---|---|---|---|---|---|---|
| COST/ SYSTEM | $640.00 | $800.00 | $546.00 | $546.00 | $1348.00 | $660.00 | $290.00 | $732.00 |
| COST/ft$^2$ GLAZING | 5.33 | 6.66 | 4.55 | 4.55 | 10.04 | 9.25 | 2.41 | 6.10 |
| KBTU/$ | 37.45 | 31.40 | 41.01 | 43.97 | 46.68 | 51.15 | 82.00 | 18.14 |
| % SOLAR | 33 | 35 | 31 | 33 | 76 | 41 | 32 | 19 |
| LOAD PROFILE | ◐ | ○ | ● | ◐ | ● | ● | ● | ○ |
| WEIGHT | ◐ | ○ | ◐ | ◐ | ◐ | ● | ● | ● |
| MASS PRO-DUCTION | ● | ● | ● | ● | ○ | ◐ | ◐ | ● |
| EASE OF RE-PRODUCTION | ● | ◐ | ○ | ● | ◐ | ○ | ○ | ● |
| SHIPPING | ○ | ○ | ○ | ● | ○ | ○ | ◐ | ◐ |
| INSTALLATION EASE | ○ | ○ | ○ | ● | ◐ | ● | ● | ● |
| VANDALISM | ○ | ○ | ○ | ● | ● | ● | ● | ● |
| MAINTENANCE | ● | ● | ● | ● | ◐ | ○ | ◐ | ● |
| RISK | ● | ● | ● | ● | ◐ | ○ | ○ | ● |

● GOOD ◐ AVERAGE ○ POOR

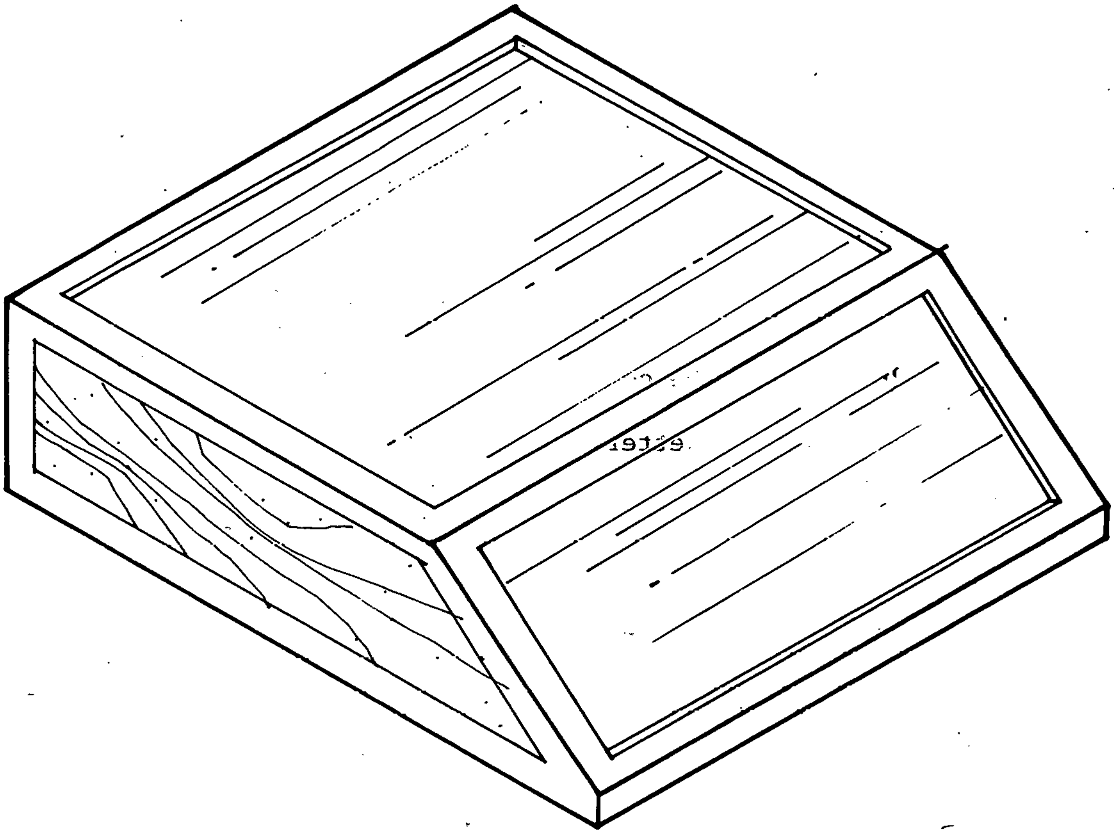
Recommendations

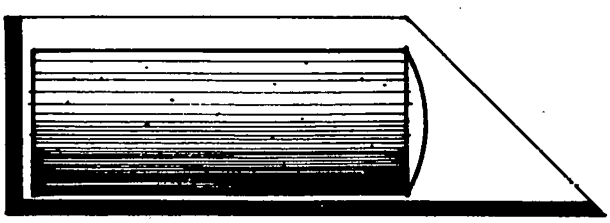
One system was found suitable for use in this project, the two tank horizontal system, #4, similar to the current C.D.C. system. This system has D.A.T.A.'s highest recommendation. The performance of the recommended system falls within the middle range for systems using tanks. The KBTU/dollar is the highest of all the low risk systems. The fact that C.D.C. is familiar with this system and its construction was also a major deciding point. In addition, C.D.C.'s familiarity means shorter lead times before mass production begins. Finally, this system can be replicated for use in other residential applications, so that this project lays the groundwork for C.D.C. to build and install breadboxes as an ongoing business.

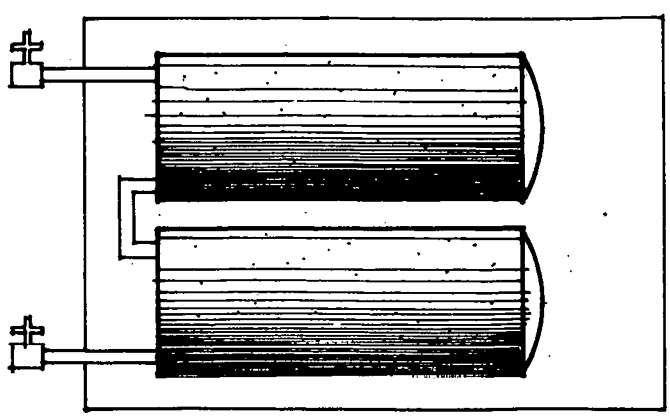
The narrow diameter triangular system developed by Horace McCracken was found to have the highest performance relative to cost, i.e. 82.0 KBTU/dollar. Although the high risk involved with using an untested idea makes the McCracken system unsuitable for this project, it nevertheless deserves further research and support. The system has broad application for high volume, low storage applications such as multi-family housing, commercial and industrial use. The silicone coating technology is extremely simple and offers the potential for C.D.C. and other small businesses to coat their own pipes for system installations. The coating technique could also apply to galvanized tanks and may be a significant breakthrough in solving the problem of tank supply currently facing the breadbox industry. The McCracken system, and the silicone coating technique, deserve serious investigation, and D.A.T.A. recommends that funding be provided for additional research.

# APPENDIX

## BREADBOX SYSTEM SPECIFICATIONS







# SPECIFICATIONS FOR BREADBOX SYSTEM

## FRAMING

The frame shall be constructed of 2x material, construction grade or better. The skin shall be 3/8 B-C Medium Density Overlay (M.D.O.), a long-lasting coated plywood. The 2x frame members shall use a minimum of 2-16d nails. For joints in the sidewalls and back, fasteners applied with a compressed air gun should be used. The skin shall be attached to the frame with 8d nails, or tacks, and mastic. All joints on the exterior of the box shall be taped with flashband (available from Kalwall).

## PAINTING

Although the M.D.O. may be installed without painting, sealing edges and surfaces is recommended. If the box is painted, the Riverside County Housing Authority should be consulted regarding color selection.

Any wood in the box interior that is not covered by insulation shall be painted with aluminum paint. Aluminum paint increases reflection in the box and also prevents the wood from checking and warping due to heat.

BOX INTERIOR

The interior of the box shall be fully insulated with 1 1/4" foil faced rigid insulation. Insulation on the bottom shall be set so that it rests between the 2x4 members, with the top surface of the insulation flush with the top of the 2x4. Insulation on the sides and back is placed directly over the framing. The insulation should be secured with tacks or mastic to insure that it does not get dislodged in shipping.

All joints in the insulation and any edges exposed to sunlight shall be sealed with aluminum foil tape. All holes for plumbing stubs shall be as small as possible and sealed with tape, or foam sealant (Polycell 1 or equivalent) and tape.

PLUMBING

Breadbox tanks shall be American Appliance 18"x48" (30 gallon) glass-lined electric water heater model. The tanks should be placed with their centers 12" in from the outside skin of the box. There should be a minimum of 9" between the top of the tank and the side of the finished box including the insulation. The tanks shall be held down by a minimum of 3 galvanized straps. Screws with large washers should be used to fasten the straps to the 2x4 hold down blocks.

One pressure relief valve shall be located inside the box with a drain pipe that goes to the outside. All other valves shall be located outside the box. If used, the air relief valve which allows air to exit when the tanks are being filled, should have its nipple at the highest point on the tank.

The nipples and plugs may be stainless steel, brass, or galvanized, although to minimize corrosion, stainless steel is recommended. Brass is the next best choice. All other piping shall be copper. Flexible copper connections with dielectric couplings should be used for joining nipples to copper pipe. Brass gate valves shall be used wherever valves are specified. However, the air relief valve may be a simple galvanized assembly, since galvanic corrosion is unimportant in this location. Before glazing installation, each breadbox should be pressure tested with air to the limit specified by local code or 50 psi, whichever is higher.

## GLAZING

The glazing material shall be Kalwall Sunlite premium grade, .040 thickness. Flashing shall be galvanized sheet metal. See plans for exact dimensions of various flashing sizes. Glazing shall be installed with silicone caulk and galvanized flashing, and fastened by neoprene gasket hex head screws (available from GM Industrial).

INSTALLATION

The support structure shall be installed on site, using screws at least 2 1/2" long. Install breadbox plumbing according to plans. All pipes containing hot water must be insulated with Armaflex. The Armaflex should be painted to prevent degradation by sunlight. The backup hot water heater must be insulated with R-6 fiberglass batts. If batts with Kraft paper backing are used, the backing must be removed for fire safety purposes.

# ASSEMBLY AND INSTALLATION GUIDELINES

## INTRODUCTION

The following is a brief set of instructions that spell out the various steps in constructing and installing the system. These instructions are intended as guidelines for laying out and phasing construction of the system. C.D.C. should modify these guidelines wherever necessary.

Since the construction details of this system are different from previous systems, C.D.C. should build one sample box to become familiar with this design. Building a sample box will allow project supervisors to spot potential problems and enable C.D.C. to see what types of templates and other production aids are needed.

## A. FRAMING AND BOX ASSEMBLY

To speed the cutting and assembly of framing members, C.D.C. should consider a coding system for framing members. This code could use colors, or letters and numbers. Coding would allow all the cutting to be done at one time. Each piece could be coded and placed in a bin containing only similar pieces. For example, the code for the box bottom could be red. Each framing member in the bottom would be marked red and would also have a number. All parts that have the same dimensions would have the same number.

Layout and framing could be streamlined by using stencils to mark the layout pattern on the plywood pieces. The stencil would be applied to a full 4'x8' plywood sheet before cutting. The stencil would show the cut lines, as well as the pattern for laying out the 2x4 frame.

Guidelines:

1. Mark and cut 2x4's for back, bottom, sides, glazing support and support structure. Spot check some cuts to insure that the dimensions are correct.

2. Mark and cut plywood for the entire box.

3. Drill holes for plumbing stubs and valves (optional: this step may be performed as Guidelines #7).

4. Paint interior framing members and glazing supports not to be covered with insulation. The recommended color is reflective aluminum.

5. Lay out the 2x4 frames on the appropriate plywood piece, The 2x4 frame members should be flush with the plywood edge except in areas noted on the plans.

6. Assemble each 2x4 frame. Fasten each frame to the appropriate plywood piece with nails, or tacks, and mastic.

7. Drill holes for plumbing (note: this step may be performed as Guideline #3)

8. Assemble the box. Use mastic on all surfaces where plywood meets the 2x4 frame.

9. Install the glazing supports.
10. Ship breadboxes to the site.
11. Place them on roof.
12. Install the support structures.
13. Secure as necessary.

B. PAINTING / STAINING

Staining the box is recommended, even though the M.D.O. is an excellent weather resistant surface. If the box is painted, the flashing may also be painted, but this is optional. C.D.C. should check with the Riverside County Housing Authority regarding painting the flashing and selecting a color.

If C.D.C. decides to paint the flashing, flashing should be precut to the proper length. Repainting the tanks is also optional. While the tanks are painted at the factory, repainting insures their having a good uniform collector surface. Painting also prevents exterior rust that may occur due to occasional condensation on the tanks. The tanks should be cleaned with TSP or the equivalent before repainting. Flat black high temperature barbecue or engine paint should be used.

C. INSULATION AND TANK INSTALLATION

Guidelines:

1. Cut all insulation and mark and cut out holes for plumbing.

2. Install the nipples, elbows, and plugs on tanks. Note: do not install the flex connectors until step 6. This prevents the connectors from getting in the way during the tank installation or from getting damaged or bent.

3. Install insulation in the bottom of the box.

4. Install the tank support blocks.

5. Install and strap down the tanks.

6. Insulate the rest of the box. All insulation should fit snugly in the box. Mastic or tacks may be used to fasten the insulation to prevent its becoming dislodged in shipping and installation. All joints must be taped with aluminum foil tape to reduce infiltration.

7. Insert the inlet and outlet stubs, and the air relief valve through the insulation and into the stub box. Be sure to seal around the openings with tape or foam sealant and tape.

8. Install the pressure relief drain pipe through the insulation and through the box wall. Again, tape or seal around the rough opening.

9. Install the drain valve assembly and seal hole.

10. Install the flex connectors and connect the two tanks. Before the glazing is installed, pressure test the system and all connections to 50 psi, or the pressure specified by the local code, whichever is greater.

## D. GLAZING

Guidelines:

1. Measure and cut glazing material.

2. Place glazing in position and tack it down in two or three places.

3. Position the flashing and then place a silicone caulk bead around the glazing edge. Screw the flashing down part way, until it rests on the silicone but is not tight.

4. Allow the silicone to dry overnight, and then tighten down the screws that hold the flashing.

## E. SHIPPING

Due to the weakness of the glazing and the number of pipes and valves coming out of the box, these systems are fragile. Every effort should be made to avoid damage to the boxes in shipping. A series of shipping blocks has been designed to allow two systems to be stacked together without damaging the glazing. These shipping blocks are fastened by screws (hex head or square drive) or scaffold nails, so they can be easily removed on site. A minimum of three fasteners is required to hold each box onto the shipping block.

F. INSTALLATION

Guidelines:

1. Place system on roof with forklift.

2. Remove shipping blocks, patch holes, and apply touch-up paint to the holes and any other parts damaged in shipping.

3. Install the support blocks.

4. Layout, cut, and partially assemble the plumbing needed to connect the boxes to each other and to the backup system.

5. Pressure test the entire plumbing system and inspect all joints and connections.

6. Insulate all the pipes except for the unions and connectors before the final plumbing connections are made. Be careful not to sweat solder pipes that have been insulated.

7. Apply insulation over joints and unions. It will be necessary to slit the insulation to place it on the joints. The insulation should be tape wrapped to seal the slit(s) with a strong weather resistant tape wrapped around and slightly overlapped for better holding power.

8. Paint the pipe insulation with Armaflex paint to prevent degradation of the insulation.

9. Insulate the backup system.

## SOURCES FOR BREADBOX PLANS

How To Build A Passive System Solar Water Heater, 1976
Horace McCracken
29 West Carlos
Alturas, CA 96101
Cost - $6.00

A horizontal system using duct insulation to reduce night heat loss. Includes performance.

Breadbox Water Heater Plans
Zomeworks
Box 712
Albuquerque, NM

Includes plans for a 2 tank horizontal system with insulated UDI and a 1 tank vertical system with night insulation.

Inexpensive Do-It-Yourself Solar Water Heater Or Pre-Heater
Peter Zweig
Farallones Institute
1520 Coleman Valley Rd.
Occidental, CA 95465
Cost - $1.00

A simple triangular 1 tank system, with a tilted vertical tank.

Vertical-Two Tank-Passive Solar Water Heater (1929)
Horizontal-Two Tank-Passive Solar Water Heater (1979)
John Burton
Integral Design
3825 Sebastapol Rd.
Santa Rosa, CA 95401
Cost - $15.00 for each set of plans

## BREADBOX MANUFACTURERS AND DISTRIBUTORS & INSTALLERS

Integral Designs
3825 Sebastapol Rd.
Santa Rosa, CA 95401
Site built two tank horizontal and vertical system

Solar American Co.
P. O. Box 2088
Newport News, VA 23602
Mass produced single tank horizontal system

Fred Rice Productions
P. O. Box 91277
Los Angeles, CA 90009
Manufacturers and distributors of SAV solar water heaters. Single tank systems, also available parabolic concentrations.

Sun Energy Builders
5838 Robertson Ave.
Carmichael, CA 95608
A mass produced 2 tank system designed to sit flush with the roofline of a house.

Sun Energy International
P. O. Box 6542
Concord, CA 94524
Distributors for a Japanese narrow diameter integral collector storage unit.

Horace McCracken
29 West Carlos
Alturas, CA 96101
A variety of site built, custom designed systems.

American Appliance
P. O. Box 1456
Santa Monica, CA
Manufacturers of glass-lined steel tank. Tank prices vary depending on distributor or jobber, and quantity.

Pelican Associates
2584 Leghorn St.
Mountain View, CA 94043
Distributors for stone-lined steel tanks.

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Solar Energy, July 1974, Vol. 17, pp. 167-172

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American Section of ISES
Newark, Delaware

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"THE THING - A Direct Gain Solar Water Heater For New York City"
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Mid-Atlantic Solar Energy Association, Philadelphia, PA

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"An Invesrted Solar Water Heater for Domestic Hot Water"
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Mid-Atlantic Solar Energy Association, Philadelphia, PA

Diuh Khauh (1978)
"Solar Hot Water - The Easy Way"
Alternative Sources of Energy, No. 32

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Solar Water Heating for the Handyman
Edmund Scientific Co., Barrington, N.J.

Gary Starr and Bruce Melzer (1978)
"An Evaluation of Two Breadboxes"
Proceedings of the 2nd National Passive Solar Conference, Vol. 2
Mid-Atlantic Solar Energy Association, Philadelphia, PA

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