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This study investigates the conventional and alternate energy sources for roadside rest areas. Conservation, solar-thermal, photovoltaics, and natural lighting are described, as are other factors which influence energy usage. The analysis of alternate energy systems using computer codes is also discussed. Recommended solutions to energy needs are presented throughout the report.

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Evaluation of Energy Sources For Roadside Rest Areas

by

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Research Report Number 442-2

Design of Rest Area Comfort Stations

Research Project 3-18-86-442

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

December 1986

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This report is part of Research Study 442, "Design of Rest Area Comfort Stations". The goal of this research project is to develop improved rest area facilities for the State of Texas. A component of this study is to evaluate the energy usage of the rest areas and to recommend measures to reduce the cost of providing services to the public.

This report is a guide to help the designer of future rest areas to reduce the energy costs through conservation and the use of alternate energy. Various design elements and systems are discussed and recommendations for their selection are given. Methods for determining the economic feasibility of a design are discussed.

LIST OF REPORTS

Report 442-1, "Investigation of Requirements for Highway Rest Areas", by T. Straughn, D. Fowler, and K. Perry.

Report 442-2, "Evaluation of Energy Sources for Roadside Rest Areas", by Brian A. Rock and Gary C. Vliet, defines the problems and presents possible solutions for the design of alternate and conventional energy systems for roadside rest areas. December 1986.

ABSTRACT

This study investigates the conventional and alternate energy sources for roadside rest areas. Conservation, solar-thermal, photovoltaics, and natural lighting are described, as are other factors which influence energy usage. The analysis of alternate energy systems using computer codes is also discussed. Recommended solutions to energy needs are presented throughout the report.

KEYWORDS: Rest Areas, Solar, Solar-thermal, Conservation, Daylighting, Photovoltaics, Computer Codes.

SUMMARY

This report describes the investigation of energy usage and potential energy sources for roadside rest areas. The ways in which energy is currently utilized at rest areas were examined and solutions to the energy needs of future rest areas are discussed. The study investigated conventional and alternative energy sources and found that conventional energy is the most economical choice for many applications. Solar-thermal water heating and daylighting were determined to be viable energy sources in most locations in the State, and photovoltaics are feasible in remote locations. Other topics such as cogeneration and wind energy are also discussed.

IMPLEMENTATION STATEMENT

This study provides the basis for the design of energy systems for rest areas. The future designers of comfort stations should investigate:

(1) The conservation of energy to reduce the energy requirements.

(2) For domestic water heating, solar-thermal flat-plate liquid systems as an alternative to conventional water heating methods.

(3) Photovoltaics for remote locations to provide electricity for uses such as low level lighting for security and signs.

(4) Incorporating daylighting into the building design but studying its influence on other energy usage.

(5) Cogeneration of heat and electricity for locations where a fuel source is available and the load is sufficient.

(6) Wind energy if the local wind velocities are relatively constant and sufficiently high.

(7) The retrofit of existing rest area facilities with solar-thermal water heating (See Appendix A).

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CHAPTER 1 - INTRODUCTION

1.1 Background

The Texas State Department of Highways and Public Transportation has recently recognized that its many highway rest areas required renovation or replacement. Since most of the rest areas were built in the 1960's and 1970's, the Department realized that an updated evaluation of the design would be valuable. The Center for Transportation Research at The University of Texas at Austin is performing research which will lead to recommended design criteria. This report is one of three reports which describe the preliminary findings. Topics related to energy conservation, energy use, and alternate energy sources are discussed in this report. A designer or a decision maker should find this report useful in the selection of energy systems for new construction or, to a limited extent, for the renovation of existing rest area buildings.

1.2 Literature Review

This section reviews the more pertinent literature related to the use of alternate energy and conservation measures in highway rest areas.

The Highway Engineer's Guide to Alternate Energy Sources and Applications, U.S. Department of Transportation, Federal Highway Administration, Office of Development, Washington, D.C. 20590, January 1980.

This manual provides a review of many alternate energy technologies, such as photovoltaic, solar-thermal, wind, hydroelectric, biomass,and geothermal. It describes the historical uses of these technologies and reviews the problems associated with each.

Potential highway applications, such as electricity production, space heating, and water heating are reviewed and are given feasibility ratings. The highest ratings are given to cathodic protection, remote electronics, and traffic counting. For rest areas, remote electronics and traffic counters are given a high potential application rating again, while heating, sanitary, and water uses are given a moderate rating. Lighting is given a lower rating due to the high electrical and storage requirements. The manual describes how the various systems will become feasible as the unit costs decrease in relation to the cost of conventional energy sources.

This manual is a good review of solar technologies, design criteria, and applications, but no specific examples involving rest areas are given. The economics and projections have become dated, but the bulk of the material covered is still applicable. An extensive bibliography is included.

<u>North Carolina DOT Looks to the Sun</u>, Public Works, p. 130, September, 1980.

A North Carolina Department of Transportation rest area was designed to reduce conventional energy requirements by using solar-thermal space and water heating, alternate lighting, and extra insulation. The solar-thermal design is similar to that used for residential installations - flat plate collectors with water storage and in-duct heat exchangers. A standard electric water heater is used for backup of the solar water heater. Past installations in that state used incandescent lighting, but more efficient fluorescent lighting was used in this design. Extra wall insulation, double pane glass, and a heat exchanger for ventilation air were incorporated. The simple payback period for the heating system is estimated at eight years, but with funds provided by the Federal Highway Administration the payback period to recover the State's contribution is much shorter.

<u>Solar Energy Augmentation for Hot Water Needs in Connecticut Highway Rest Areas</u>, David R. Jackson, P.E., et al, The University of Connecticut, March 1982.

This report describes the selection, installation, and evaluation of a retrofitted flat plate solar-thermal collector system with silicone oil as the collector circulating fluid and water as the storage medium. The existing hot water heater was retained, but an additional layer of insulation was added to the tank. The system was heavily instrumented and much of the report deals with the collection of data. Comparing their findings to an early version of the F-Chart program, close to a 40 percent under-prediction for one month and 3.2 percent over-prediction for the next month was found. The authors recommend for new installations that the preheat and conventional tanks should be combined, and thus one tank could be eliminated. The payback period for the retrofitted system in that location was expected to be less than 15 years.

<u>Solar Domestic Hot Water System - Harding Township Rest Area Building, I-287</u>, S. R. Sasor and J. Flesch, N.J.D.O.T., February, 1984.

The design, installation, monitoring, and evaluation of a solar-thermal water heating system for a New Jersey rest area are covered in this report. The collectors used an antifreeze fluid and a preheat tank with an in-tank heat exchanger which feeds the existing electrical resistance water heater. Specifications given in the report cover all the materials used in the system.

The flat plate collectors have an over-temperature protection heat exchanger mounted on the top. When a stagnation condition overheats the collector, a valve automatically opens allowing heat to be rejected to the surroundings through a fin-tube heat exchanger. The preheat tank is heavily insulated and an additional layer of fiberglass insulation was added to the existing water heater. As a result of the solar retrofit, five out of six electrical heating elements were disconnected on the old water heater.

The authors concluded that the insulation added to the old water heater was the most cost effective part of the project since it would have a very short payback period. The solar-thermal portion of the project is economical, but the payback period will be longer than the inexpensive insulation. The report indicated that a monitoring project was planned to determine the systems actual performance.

Solar Assisted Heating of a Highway Rest Station, William C. Dries, PhD., ASHRAE Journal, November, 1980.

An air flat plate collector system using pebble-bed storage was chosen for a Wisconsin rest area's space and water heating needs. The air system was selected due to the expected low equipment and maintenance costs. Standardization was an objective of the building design. A 45 degree roof pitch was used to maximize solar energy collection. Standard backup equipment was utilized, as was extra building insulation and an entry airlock. A symmetric floor plan provided an airlock in the center of the building, which helps to reduce infiltration.

The collectors could be mounted on either roof slope, and an analysis showed that a variation of 23 degrees from due south orientation would yield only a 2.5 percent reduction in solar energy collection. This result allows for a wide variation in siting of the standard building. The F-Chart program from The University of Wisconsin was used extensively; it projected that 54.4 percent of the annual heating load would be provided by the solar energy system.

<u>Soil Cover Helps Insulate Rest Area Buildings</u>, Public Works, pp. 110-111, September 1980.

This article reviewed the Minnesota Department of Transportation's Blue Earth rest area on I-90 in southern Minnesota. The rest area uses a combination of earth berms and passive solar heating to reduce the annual conventional energy requirement of the rest area buildings. The buildings are oriented so that the cold winter winds are blocked by the earth berms on the north side, and the winter sun is admitted to the building's interior an the south side. Since the majority of the space conditioning load is heating, insulation was installed between the earth fill and the building walls to reduce the winter conductance of heat out of the building.

<u>Vail Pass Solar Heated Rest Area</u>, David B. Woodham, Colorado Department of Highways and The Federal Highway Administration, March 1986.

This report describes the problems which occurred at a solar-thermally heated rest area building in Colorado. The heating system uses air cooled collectors with rock storage, a domestic hot water preheat piping loop in the rock storage, and an in-duct electrical resistance backup heater. Problems with the control system became apparent soon after the construction was completed in 1980, and it was not until 1983 that some corrections were made. The first rocks used did not provide sufficient free paths for the air to flow through the storage bin. Instead, the solar heated air either went directly to the conditioned spaces or it was lost through leaks in the system.

The redesigned system still performed poorly, providing only an estimated $20 worth of energy monthly. Insufficient insulation in the storage room, night time heat loss through the collectors, and the accumulation of snow on the collectors were cited as major problems that were still unresolved. The authors concluded that the system is now operable, but it is still grossly inefficient. They suggested that further improvements to the storage bin such as incorporating phase change materials may also help improve the system's performance.

<u>Annual Monitored Performance</u>, <u>Solar Domestic Hot Water System</u> - <u>Blanco State Recreation Area</u>, Edwin Mole, Texas Parks & Wildlife Department, September, 1984.

In 1983, a closed-loop, drainback, solar-thermal water heating system was installed at the Blanco State Recreation Area which had 192 square feet of flat plate collectors with 240 gallons of potable water storage. The system can provide 110^{o}F water for a six-shower rest room. An external heat exchanger connects the collector loop to the two 120-gallon preheat tanks, and a conventional electric water heater is used for backup. The daily solar savings fractions are calculated, and the monthly average valves are given; the largest savings fractions occur in the late summer months, and the least savings fractions occur in the late winter.

The author recommends that solar-thermal water heating be incorporated in all future rest room construction, and that retrofitting may be possible on previous construction if electricity would otherwise be used and its cost is over $0.05 per KWH. The author also suggests that the size of future systems be increased to raise the annual solar savings fraction to 0.70 or above.

Experimental System Performance and Comparison with Computer Predictions for Six Domestic Hot Water Systems, A. H. Fanney and S. T. Liu, National Bureau of Standards.

Various system configurations for solar water heating using either water circulation or air circulation through the collectors have been tested and compared to three computer models by the National Bureau of Standards. When the collector areas and the storage volumes were held constant, the single tank and thermosyphon systems using water collector circulation had the best performances (54.4 percent to 57.4 percent), while the double tank water collector circulation systems had 47 percent to 49.2 percent ratings. The performance of the air-based system was 46 percent below those of the double tank systems, and 32 percent below the single tank and thermosyphon systems.

The results from three computer models: F-Chart-3, TRNSYS-9.2, and SOLCOST, were compared to the actual systems performances. For the single tank, double tank, and air based systems all the codes predicted the experimental results to within +/- 8 percentage points. None of the computer codes would model the thermosyphon system. The F-Chart-3 program was the only code which could model all of the other system configurations. Example runs of the F-Chart program are presented in Appendix B.

CHAPTER 2 - ENERGY AND RESOURCE CONSERVATION

2.1 Conservation

Before alternate energy systems are considered for the reduction of conventional energy use, optimum energy conservation measures should be utilized. Studies have shown that conserving energy through the use of increased insulation and other design components is the most cost effective method of reducing conventional energy usage (1). The first and operating costs of conventional as well as alternate energy systems can be reduced when conservation is addressed first, since the equipment size can be reduced.

For roadside rest areas, the continuous use of the facilities limits some areas for potential savings such as night time lighting and space conditioning. Thus, conservation measures should focus on the reduction in energy required to provide the various services such as heating, ventilating, lighting, and hot water. Since service to the public at all hours is the goal of the rest area facilities, any measures taken must be of proven and dependable design, while also having low initial, operating, and maintenance costs.

2.2 Ventilation and Infiltration

With the shift from open air rest rooms to closed, controlled facilities as recommended by the research group (2), conditioning of the interior of buildings will be required. Of primary concern is the control of air quality (odors, etc.) and temperature to provide a comfortable environment for the visitors. Ventilation and air conditioning (heating and cooling) is an area where conservation measures can greatly reduce the energy required for its operation.

Ventilation is achieved by forced and natural ventilation and through infiltration. Forced ventilation yields the best control of air flow and it is recommended for use in rest area facilities that are heated or cooled. Conservation of energy used for ventilation is achieved with the proper sizing of the equipment and with the use of air-to-air (recovery) heat exchangers. To reduce the fan size and its electrical consumption, the ventilation rate should be no more than that which is required by code or ASHRAE Ventilation Standard 62-73 (or its most current revision). Simple exhaust ventilators can be used in facilities where space conditioning will not be provided.

Infiltration is the unintentional flow of air into the building. While infiltration can be of benefit by ventilating the structure, a large amount of energy is lost if the space is designed to be conditioned. Good design and construction practices must be followed to reduce this energy loss. Door and window seals, vapor barriers, and caulking can reduce the openings through which air can travel. Large losses are incurred when the windows and doors are operated. The windows should not be able to open during times of the year when the facility is conditioned, except if an emergency egress is needed. Doors must be well weather stripped and should be of insulated construction, but, due to their constant use, large losses can be expected. The use of revolving doors greatly reduces the infiltration, but their first cost may be prohibitive.

2.3 Heating Requirements

To reduce the rest area's heating requirements for comfort and freeze protection, the net heat loses must be reduced. Interior lighting and solar heat gain through the walls and windows reduce the energy required, but a large amount of heat is lost through the building envelope by conduction and infiltration. To reduce conduction losses, the insulation values of the construction materials must be increased. Walls, roofs, and non-ground-contact floors should be insulated to levels recommended for the region, and in the northern locations windows may require double panes. Full energy analyses will determine the savings and economics of the conservation measures (3).

Recently, conventional forced air combustion heating equipment, such as natural gas furnaces, has become much more efficient. With flue gas heat recovery, efficiencies around 95 percent are common, and pulse-type combustion equipment can produce even higher efficiencies. The cost of these new furnaces can be excessive, so life cycle cost analyses are required to determine if the gain in operating efficiency over that of traditional equipment is worth the additional initial expense.

Another type of forced air heating equipment can double as a cooling unit: an air-to-air electric heat pump. The problem with this type of equipment is that the heat output is inversely related to the outdoor temperature. As it gets colder outside, the coefficient of performance (C.O.P.) falls considerably - sometimes to 1.0 or less. This means that as it gets colder outside, a lower quantity of heat can be provided by the unit. When the building heating load exceeds the heat pump capacity, a electrical resistance heating element is used to make up the difference. During extended periods of cold weather, the cost of operating a heat pump can be excessive. Therefore, a heat pump should be considered for regions where there are not extended periods of cold weather, and a cost analysis over an annual period will determine its viability as compared to other types of equipment.

Forced air general heating can provide a high level of comfort, but if its cost is excessive, radiant heaters should be investigated. Lower first costs and the heating of objects and not air make radiant heating attractive. However, forced ventilation, economizer cycles, and radiant heating can not be combined into one system. Radiant heaters are exposed on the interior of the building, so measures should be taken to reduce vandalism.

2.4 Cooling Requirements

Space cooling requirements can be reduced by using high efficiency equipment, minimizing infiltration (but maintaining air quality), increasing the insulation of the building envelope, reducing the direct solar gain, and utilizing economizer and evaporative cooling equipment. In dry regions, evaporative cooling may be all that is required to provide reasonable comfort levels in the facilities. If cooling is to be provided in more humid areas such as along the Gulf coast, vapor-compression or absorption-cooling equipment must be relied on. Economizer cycles, which circulate outdoor air indoors when conditions are favorable, provide low cost space conditioning and ventilation. To increase the cooling effect, "people cooling" methods can be employed - the motion of air across the skin evaporates moisture, which creates a cooling effect. Ceiling fans or properly located air diffusers which produce substantial air velocities can allow an increase in the sensible temperature of the space. This method of cooling would also be helpful if air cooling is not provided.

Figure 2.1 shows a psychrometric chart with the comfort zone for sedentary individuals (4). The conditions for comfort range from about 71^{O}F to 80^{O}F and the relative humidities from 19 to 72 percent. Energy can be saved by maintaining a heated or cooled environment in the range of comfort. For example, if the humidity is controlled, the temperature need not be above 72^{O}F during the winter or below 78^{O}F in the summer for comfortable conditions to exist for the given parameters. However, since the residence time of the visitors is short in comparison to that used in the determination of the comfort zone, the range of comfort may be larger, thus allowing less conditioning of the building.

2.5 Lighting

Lighting will probably use the most electricity at a rest area. Low level outdoor lighting must be provided for security and safety, and increased lighting

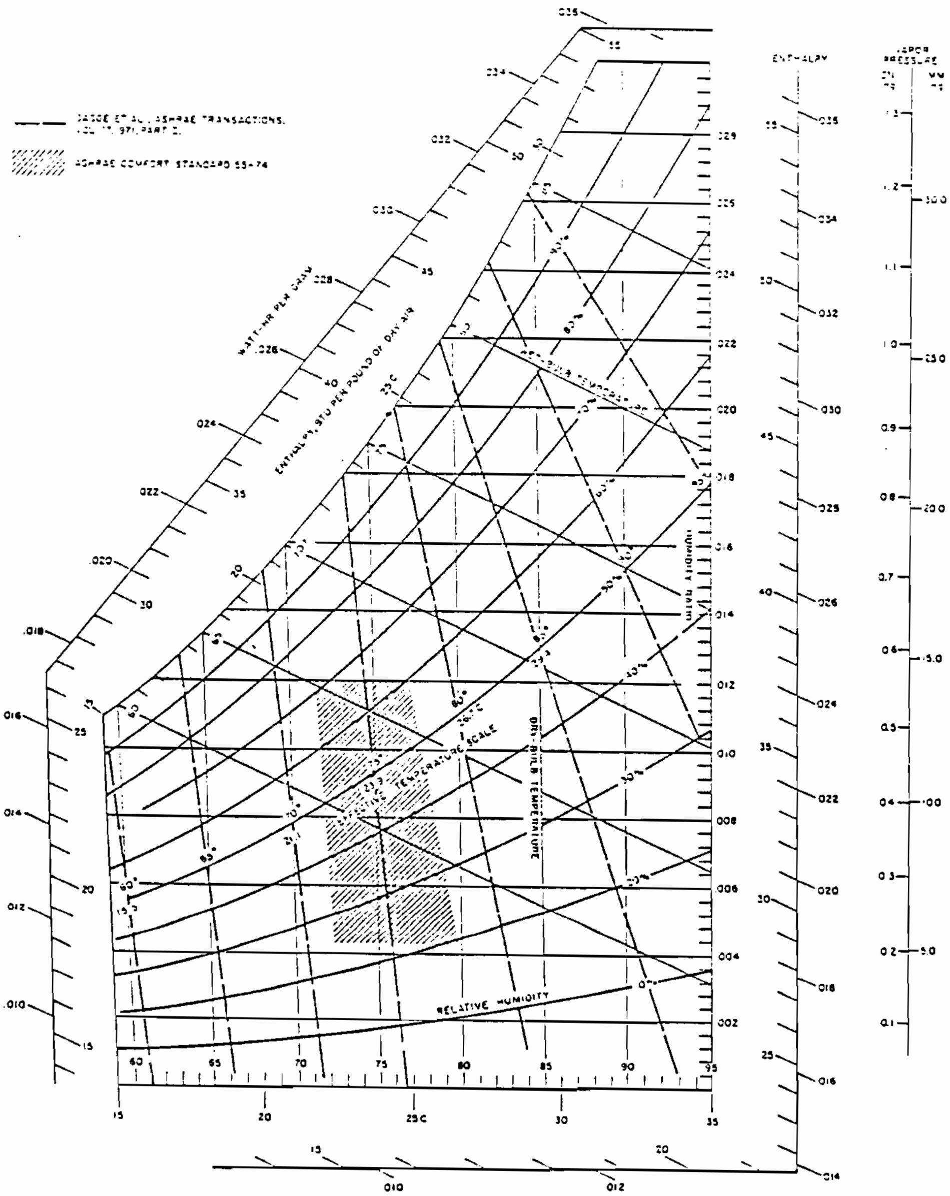


Fig. 2.1 Comfort Zone (4). Applies for lightly clothed, sedentary individuals.

levels are needed in the interior spaces. Energy savings are achieved by using only the level of lighting that is required (not over illuminating), by using daylighting, and by improving the lighting efficiency (3).

2.6 Auxiliary Equipment

Electricity at rest areas may also be used for tasks such as hand drying, sewer treatment, and freeze protection. For hand drying, consider the use of non or low heat units as electrical resistance heating is costly. In the selection of pumps and other motor driven equipment, make sure that the motors are not considerably over-sized and that they operate at or near their peak efficiencies. Lightly loaded or over loaded motors draw considerable power for the unit work accomplished. If only the equipment room is to be heated to prevent freezing, gas heating should be used if available, because its operating cost is lower than that of electrical resistance heating.

2.7 Water Use

Water is a necessary resource at rest areas, and its use should be conserved. Toilets should be selected which use less water per flush, but are also reliable. Flush valve toilets which use water efficiently are recommended. Sink faucets which reduce the flow by metering, spray, or other method can greatly reduce cold and hot water usage.

2.8 Maintenance

The maintenance of the building envelope, equipment, and plumbing is vital to maintaining the reduced energy consumption. Clogged filters, broken windows, and poorly closing doors will quickly increase the energy required to condition the space. Leaks in the faucets, valves, tanks, and piping should be repaired rapidly, since the water is lost to no purpose. The use of quality materials of heavy duty design will reduce the amount of maintenance that is required.

When all the economical paths to energy conservation have been explored, then alternate energy sources, such as solar-thermal and photovoltaics, can be considered for displacing conventional energy use.

CHAPTER 3 - SOLAR-THERMAL WATER HEATING CONSIDERATIONS

3.1 Introduction

The solar-thermal heating of water has been shown to be economically feasible if good design choices are made. The installed systems that are successful have low first costs, long life, and low maintenance requirements and are located at sites where conventional energy sources are relatively expensive. Currently, hot water is not provided at Texas roadside rest areas, while other states routinely include hot water service in the majority of their facilities (1). With the use of solar-thermal energy, the addition of hot water service to new facilities, or retrofitting to existing facilities (Appendix A), could be achieved with low operating and maintenance costs, while also increasing the public's awareness of alternate energy.

3.2 Conventional Versus Solar-thermal

The heating of water is usually accomplished with a gas fired or electrical resistance water heater. These units are mass produced, and as such they are relatively low in first cost as compared to a solar-thermal heater. However, the cumulative fuel cost of these conventional heaters over their lifetime can exceed the cost of a well designed solar collection and storage system. The payback period for a solar water heating system is typically of the order of 5 to 10 years when compared to electric heating. Currently, the cost of electricity per unit of heat is much greater than the cost of natural gas (possibly a factor of two);

thus the payback period would be greater for a solar-thermal system that replaced a gas fired water heater than an electric unit.

3.3 Sizing Considerations

The average daily energy needed for water heating determines the size of the equipment used. Four ways to reduce this energy demand are: 1) lower the quantity of water used, 2) lower the temperature of the hot water being supplied, 3) reduce the loss of heat from the water to the surroundings prior to its use, and 4) raise the temperature of the replacement water coming into the heater. To lower the quantity of water used, various equipment, such as low flow and metering faucets, should be utilized in the facility. The temperature of the water supplied to rest area users does not need to be great, since hand washing is the primary objective. An installation at a New Jersey rest area uses 110 $^{\circ}$F water (2), much less than the 140 $^{\circ}$F usually supplied to residences and far less than the 180 $^{\circ}$F required for sanitizing in commercial applications. Water temperature limiting valves should be used in conjunction with solar water heating systems. They are a safety feature and they also reduce the energy demand.

The loss of heat to the surroundings is easily reduced by increasing the insulation on the various system components. Water heaters are usually supplied with a modest amount of insulation, and adding another layer of fiberglass or other insulation (two or three inches) can easily be accomplished at low cost. These factors for reducing the size of water heating systems become critical in reducing the payback period for alternate energy systems.

The temperature of the feed water is usually that of the water coming from the supply main, but solar energy can be used to greatly reduce or even eliminate the conventional energy normally required to heat the water. Figure 3.1 shows a schematic of a conventional forced circulation solar water heating system.

Solar energy is most efficiently collected when the desired temperatures are low. Many water heating applications are ideal, since the desired temperatures are in the range of 100 to 180°F (typically within 100°F of the ambient conditions), and water demands are often relatively constant throughout the year. Since most of the energy used in water heating is for raising the water to the desired temperature and not for maintaining it at that temperature, solar preheating of the water would displace the majority of the conventional energy normally required. A variety of solar-thermal water heating systems have been developed, and a fundamental difference in the systems is whether conventional energy sources are used in their operation. Passive systems require no conventional energy, while active systems typically use electricity to operate pumps and controls.

3.4 System Configurations

Solar-thermal water heating may be achieved by either active or passive means, as illustrated in Figs. 3.2 and 3.3. Active systems use a pump to circulate the fluid through the collector, since the storage vessel is below the collector. Passive systems either use the

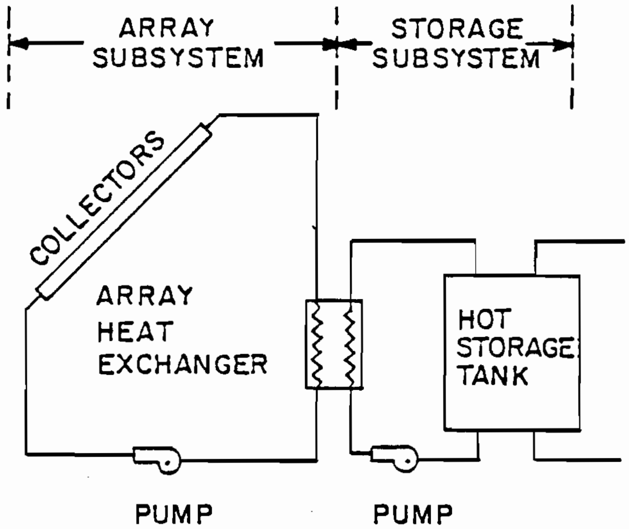


Fig. 3.1 Solar Liquid Heater (3).

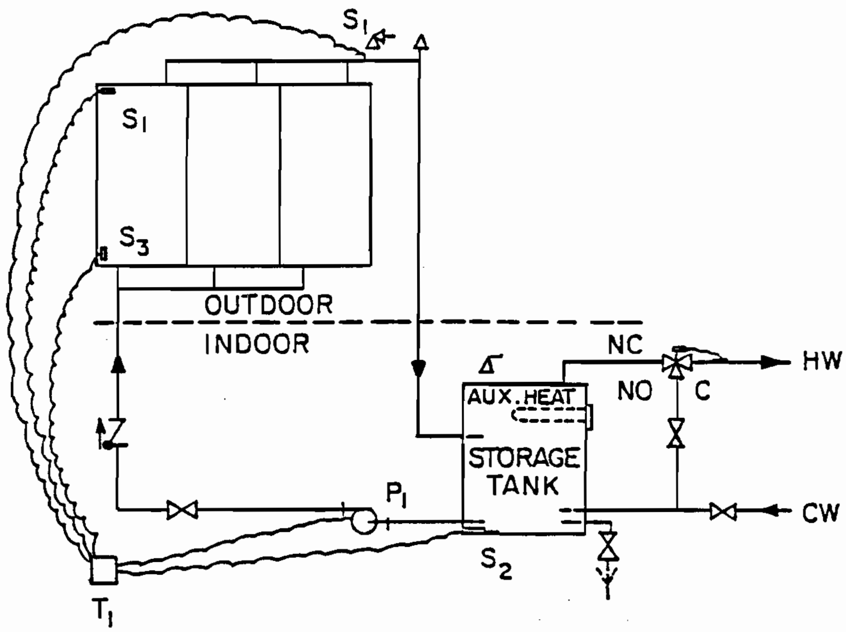


Fig. 3.2 Active Solar-thermal System (4).

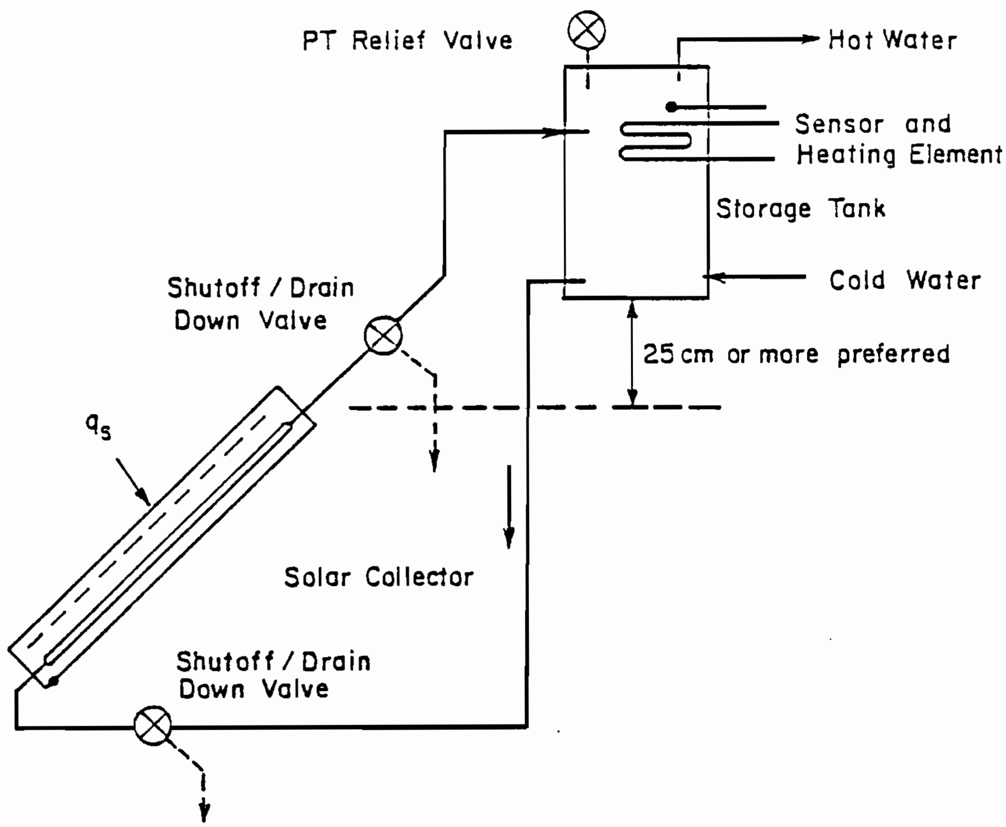


Fig. 3.3 Thermosyphon Solar-thermal System (6).

thermosyphoning effect to circulate water between the collector and a tank above it (Fig. 3.3), or they heat the storage tank directly (not illustrated). The latter has proven to be inefficient due to the small collection area and the substantial loss of the collected heat at night from the poorly insulated glazed vessel. Thermosyphon systems have been used successfully in temperate climates, especially in Florida in the early part of this century, and in other places such as Israel and Hawaii (7). The limitations of this type of system are 1) the thermosyphon effect requires that the storage tank be located a foot or more above the collectors, possibly a difficult architectural feature, and 2) the velocity of the heat transfer fluid may not be great enough to efficiently collect the energy available. Also, the water in the collector may freeze in a cold climate, and thus thermosyphon systems are typically restricted to non-freezing regions.

Active solar energy collection normally uses a pump to circulate the heat transfer fluid. The pump allows the placement of the storage tank below the level of the collector array, and the collection of heat can be controlled by turning the pump on or off. A properly specified pump will provide the necessary flow rate to produce turbulent flow in the collectors and heat exchanger, so as to enhance the heat transfer. Small "can" type pumps are preferable to open pumps since less maintenance is required over the years.

3.5 Subsystem Components

To reduce maintenance requirements, the alternate energy collection system should be of a simple and proven design. The first two components that should be considered are the collection and storage systems. The purpose of the collectors is to gather the incoming solar radiation (insolation) and transfer it to a fluid which will in turn transfer the heat to the storage system. The collectors can either "track" the sun, or remain stationary. Tracking collectors require extensive controls and maintenance to insure correct positioning, while stationary flat plate collectors require much less attention. Flat plate collectors produce the range of temperatures required for domestic water heating, and they are almost exclusively chosen for this application.

Flat plate collectors should be placed in a location where they have an unimpeded view of the sun. Care should be taken not to place them in a location where trees, dust, or snow could reduce the energy collected. However, shading in the early morning and late afternoon is not critical, and, if unshaded during seven or more hours during the middle of the day, the collectors will achieve most of their potential collection.

For the best results, the collectors should face due south, but only a small loss of collection (about 5 percent) occurs if the collectors are within +/- 30 degrees of due south (6). A recommended tilt angle for the collectors is 10 to 15 degrees plus the local latitude (5). For example, Austin is at approximately 30 degrees North latitude, and collectors for water heating should be tilted at 40 to 45 degrees from horizontal. However, this optimum is fairly broad, and if mounted within 15 degrees of this angle the collectors will achieve about 95 percent of their annual potential. Deviation from the optimum angle introduces significant seasonal variations in the solar energy collected. If the hot water demand varies seasonally, the tilt may be altered accordingly. For example, if there is a higher summer demand then the tilt angle should be lower, and if there is a higher winter demand then the tilt angle should be higher. After the preliminary mounting angles and other system components are determined, a manual or computer analysis such as the F-Chart program (8) can predict the performance of the system (see the example problem in Appendix B).

A system which combines space and water heating usually has a main heat storage vessel which includes a heat exchanger for preheating water. The storage medium may be a liquid, a solid such as rock (pebbles), or a phase-change material such as Glauber salt.

The storage medium for a solar-thermal water heating system is usually the domestic water in a storage tank which may be heated directly or indirectly. Some systems circulate the potable water from the storage tank directly through the collector array, but fouling of the collector piping and pumps is inevitable and special design features must be incorporated to prevent freezing. A heat exchanger is used in many systems to separate the collector circulation fluid from the potable storage water. Figure 3.4 shows various configurations of heat exchangers. Where building codes

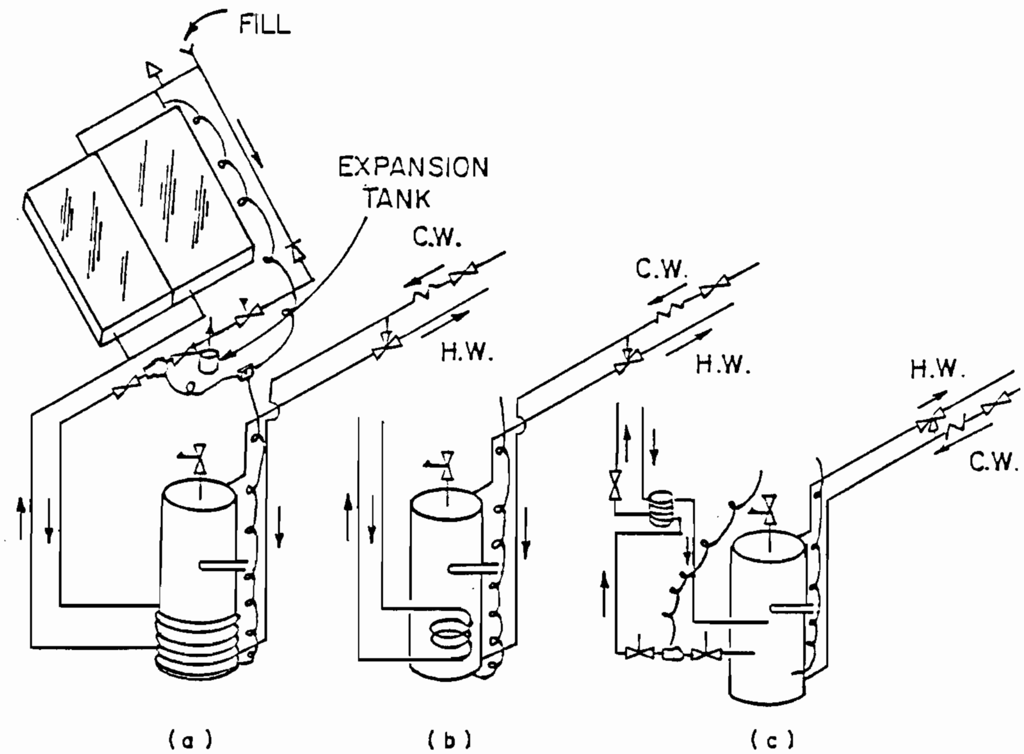


Fig. 3.4 Indirect Solar Water Heating; (a) External Jacket Heat Exchanger; (b) Internal Coil Heat Exchanger; (c) External Shell And Tube Heat Exchanger (9).

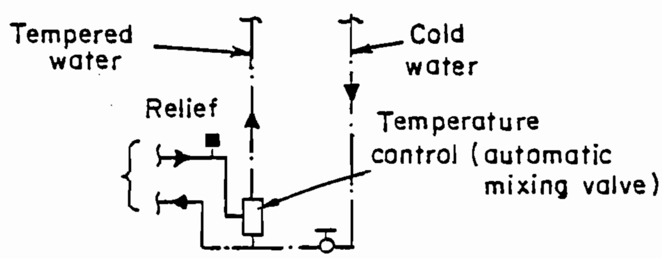


Fig. 3.5 Temperature Moderating Mixing Valve (11).

allow, an in-tank heat exchanger can be used in systems with collector circulating fluids that are liquid, or a heat exchanger external to the tank can be utilized and is required if air is used as the circulating fluid. Since some circulating fluids are toxic, in-tank heat exchangers which are resistant to leakage must be used, or an external heat exchanger which does not have a direct interface between the circulation fluid and the potable water can be employed, but an extra circulation pump is required. Double-wall in-tank heat exchangers add extra protection from the mixing of a possibly toxic circulating fluid with the potable water, but the effectiveness of the heat exchanger is reduced (10). Designers of the alternate energy system must decide which of these heat exchangers best fits their system.

3.6 Suggested Water Heating Systems

The following solar-thermal water heating systems are recommended for roadside rest areas. The loads at these facilities are assumed to be the energy necessary to produce hot water for hand washing and for use in utility sinks. Pressurized hot water spray cleaning and dish washing (for joint-use facilities) require water temperatures of approximately 180^{o}F and are not considered in this assessment.

The temperature of the hot water supplied should be at least 105^{o}F at the faucets (4), and not over 160^{o}F, at which scaling becomes serious. A temperature-moderating mixing valve (Fig. 3.5) should be employed so that the storage tank may exceed 110^{o}F. Since thermal losses will occur in the supply line, a mixing valve with a slightly higher temperature (about 110^{o}F) is recommended. It is essential that the hot water supply line to the faucets be insulated. A circulation system, such as that used in restaurants and hotels, could be installed for the added convenience of having hot water on demand, but additional energy losses are incurred.

In a study for the National Bureau of Standards, various liquid and air based domestic water heating systems were compared for overall system operating performance (12). The liquid-based systems performed similarly, but the performance of the air-based system was well below that of the poorest performing liquid based system. For equal collector and storage size systems, the air system provided about 35 to 45 percent lower energy from solar than did the liquid based systems tested and modelled. For this reason, air based solar-thermal water heating systems are not recommended.

Liquid based systems have used various circulation fluids, such as water, water/antifreeze solutions, and exotic materials, such as silicone oil. Each has desirable and undesirable qualities, and each fluid should be examined for compatibility with a given system configuration. For example, if potable water is circulated through the collectors as in an open loop system, deposits will build in the tubing. Reduced flow and eventually plugged tubing is the result. Closed systems (i.e., with heat exchanger) using water or antifreeze in the collector loop largely avoid this problem. Scaling does take place on the potable side of the heat exchanger, but at a much reduced rate. Due to its reduced maintenance requirements, a closed loop water heating system is recommended and several types are available. The two most proven are drainback and antifreeze systems (Figs. 3.6 and 3.7).

3.7 Drainback System

The drainback system was developed from the open loop draindown concept shown in Fig. 3.8. Drainback systems retain the ability to remove the fluid from the collector during adverse conditions, but they circulate a very small amount of water and not all of the potable water. Drainback systems use a small tank within the conditioned space to hold the collector loop fluid (water), and a heat exchanger between this fluid and the potable water. Various system configurations and components, such as single or two tank, pressurized or atmospheric systems, and internal or external heat exchangers may be used with the drainback design. This type of system provides freezing and overheat protection, and there is at least one experienced manufacturer of this type of system in Texas. With these qualities, drainback systems are a strong candidate for rest area applications.

3.8 Antifreeze System

As with drainback systems, closed-loop antifreeze systems can (and usually) incorporate an internal heat exchanger, which eliminates the need for a second circulating pump. When a proven antifreeze solution such as a mixture of non-toxic propylene glycol and water is used, freeze protection and scaling resistance is achieved. Over-temperature protection is achieved by

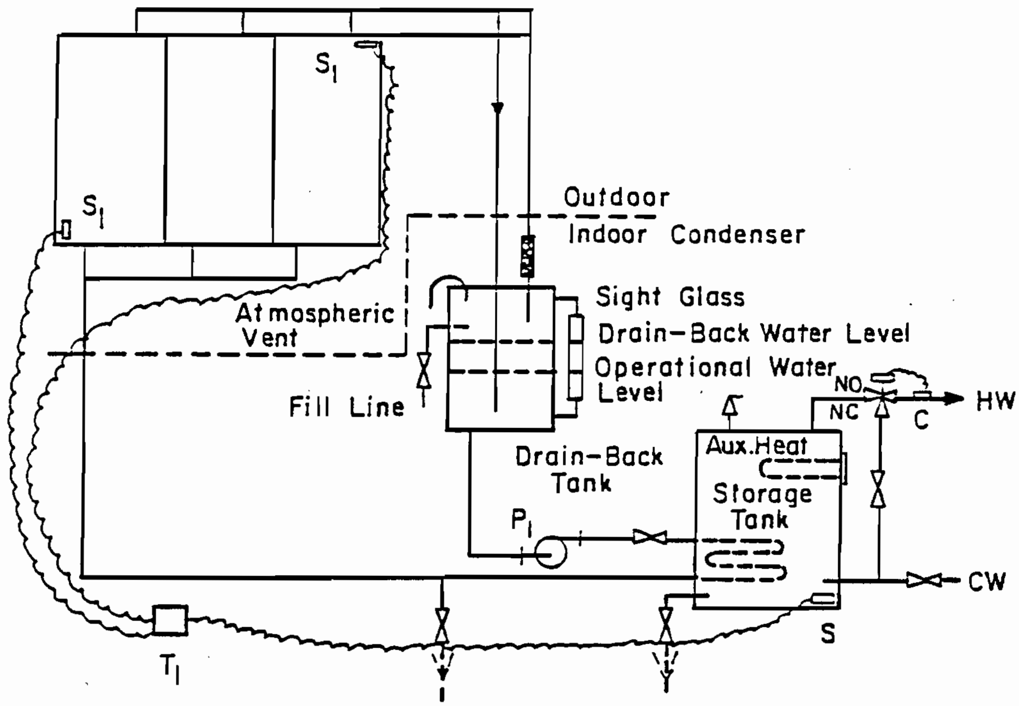


Fig. 3.6 Drainback System (4).

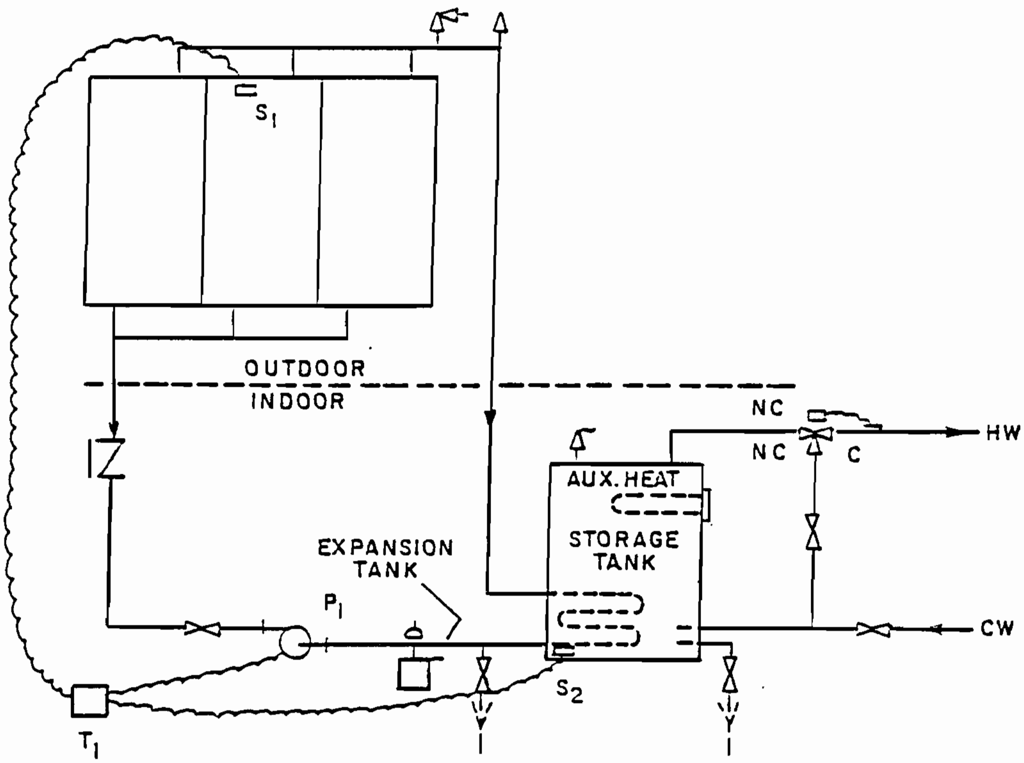


Fig. 3.7 Antifreeze (Indirect) System (4).

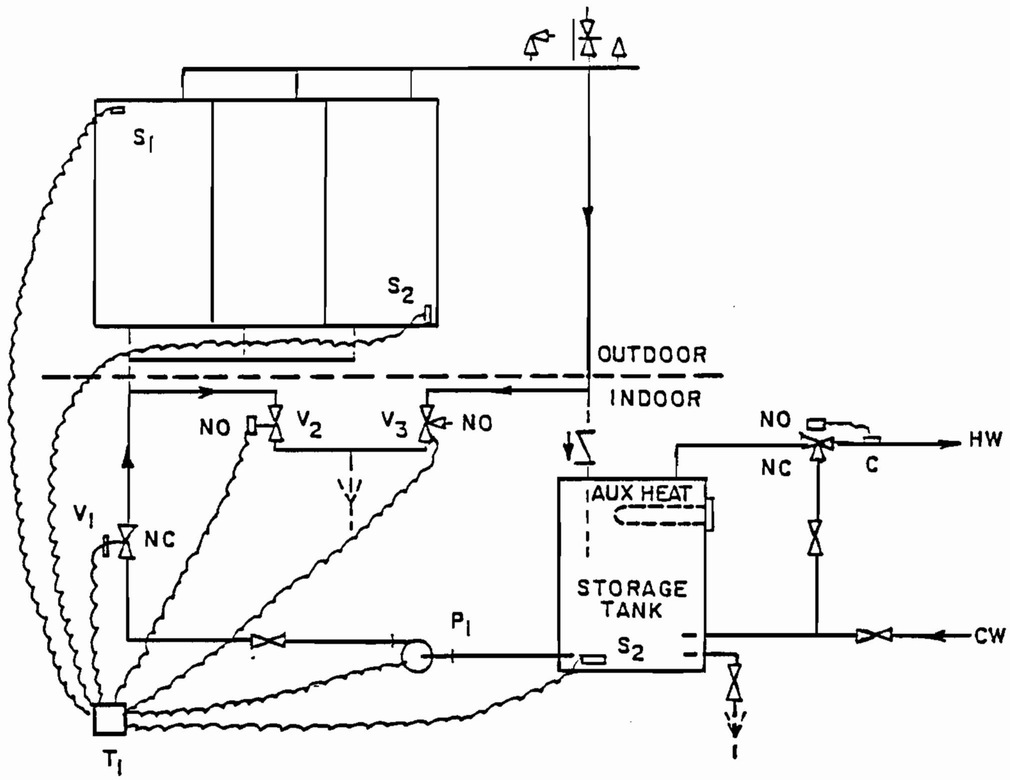


Fig. 3.8 Draindown System (4).

using quality fluids and heat rejection devices. Simple, automatic heat rejection devices that are incorporated with the collectors are preferred. Some devices vent the collector enclosure, while others use a convective heat exchanger to dump the thermal overload to the surroundings. As with the drainback system, closed-loop antifreeze systems offer a proven low maintenance and efficient method for collecting solar energy for water heating.

Solar-thermal energy can deliver the majority of the energy required to provide hot water service to roadside rest areas. When properly designed, installed, and operated, a solar-thermal system will provide years of service and will reduce the conventional energy requirements to provide hot water service. As with any construction, the quality of the finished project depends on the selection of a reputable designer, an experienced installer, and the use of quality materials.

CHAPTER 4 - PHOTOVOLTAICS

4.1 Meeting Electrical Needs

The energy demands for roadside rest areas that may be provided by electricity are: indoor lighting, exterior low level and security lighting, mechanical equipment such as compressors and fans, and electrical resistance heating such as for water or space heating. Electricity may not be the most economical energy source to meet some of these needs. The energy source used to meet the demands of the facility should be guided by (1):

1) Use low-grade heat for low temperature processes, such as using solar-thermal energy for water and possibly space heating;
2) Use high-grade heat for processes requiring high temperatures, such as using natural gas fired steam generators for steam cleaners;
3) Use mechanical or electrical energy to provide torque for mechanical functions, such as using the shaft work from a cogeneration system or electrical power to drive air conditioning compressors; and
4) Use electricity for electronic and pure electrical demands, such as for lighting.

Electrical resistance heating is not recommended for the production of low grade heat. While resistance heating is approximately 100 percent efficient in the terms of useful energy received as compared to energy paid for, the generation and distribution of the electricity from a fossil-fueled central power plant may only be 30 percent efficient. Therefore, only about 30 percent of the recoverable heating value of the fuel is used for heating the water or the building. The use of electrically powered heat pumps is generally preferable to resistance heating for space and water heating. However, a low-grade heat sources such as solar-thermal or geothermal energy should be strong candidates for such low grade heat applications.

For high temperature demands, such as are those which are required for operating steam cleaning equipment, a high grade heat source should be utilized. Electrical resistance heating is inefficient and therefore is expensive, and high temperature solar-thermal systems tend to be uneconomical, therefore for high temperature thermal demands, a source such as natural gas should be utilized.

Mechanical equipment which consumes large quantities of energy, such as pumps and compressors, should be driven directly by a source of shaft work. Typically, shaft work is converted to electricity at a central power plant, and at the point of use the electricity is converted back to shaft work by a motor. Inefficiencies occur at each conversion of the energy, and in its delivery to the site and the rejected heat at the power plant cannot be utilized. If an application exists where there is a need for both shaft work and low grade thermal energy, then cogeneration systems are found to have merit. Such a situation may exist in roadside rest areas, and thus cogeneration systems should be given due consideration.

Electricity should be used for electronic and pure electrical needs. For rest areas, lighting should be the primary electrical load. Efforts to reduce the energy cost of lighting should concentrate on 1) making the lighting system more efficient (discussed in section 5.3), and 2) selecting the most economical source of electricity. The conventional source of electricity is from the utility grid. The cost of this electricity was fairly low until the rise of the cost of fossil fuels in the 1970's. Now, other sources of electricity such as photovoltaics are becoming more competitive with the conventionally produced electricity for remote applications. As the relative cost of photovoltaics drop, a wider range of applications will see their use (2). Photovoltaics should now be considered for remote rest areas, since their long term cost may be less than the cost of extending conventional service to the site. Furthermore, because of its reliability, photovoltaic power should be considered for low level security lighting even at sites which are served by a utility grid.

4.2 Photovoltaics as a Power Source

Photovoltaic (solar) cells produce direct current electricity from sunlight and, in conjunction with batteries and simple control elements, can provide a very reliable, durable, and simple stand-alone source of electricity for a variety of applications. Photovoltaic-produced electricity is expensive and it is not competitive for general purposes; however, for remote installations where conventional electricity is not available and for many applications where a reliable, stand-alone, low power source is needed, photovoltaic cells are seeing wide use. Such applications include highway and railroad traffic signals, remote fire and ranger stations, cathodic protection, emergency lighting of off-shore oil platforms, urban bus-stop lighting, and in limited cases serving as the sole power source for residences that are remote from the power grid. An example is the use of 24 photovoltaic power units for railroad crossing signals between Round Rock and Taylor in central Texas. In these applications, the reliability and not the economics is the paramount factor in the selection of photovoltaics as the power source.

4.3 Cell Characteristics

The voltage-current characteristics of a photovoltaic cell for clear sky conditions ($\sim 1000\ W/m^2$) are illustrated in Figure 4.1 (solid curve A) with the open-circuit voltage and the short-circuit current indicated. Silicon cells produce an open-circuit voltage of about 1/2 volt per cell, independent of the level of solar radiation. The cell power for clear sky conditions (dashed curve) depends on the load impedance and is seen to be a maximum when the impedance line intersects near the "knee" of the voltage-current characteristic, i.e. at a voltage somewhat less than the open circuit value.

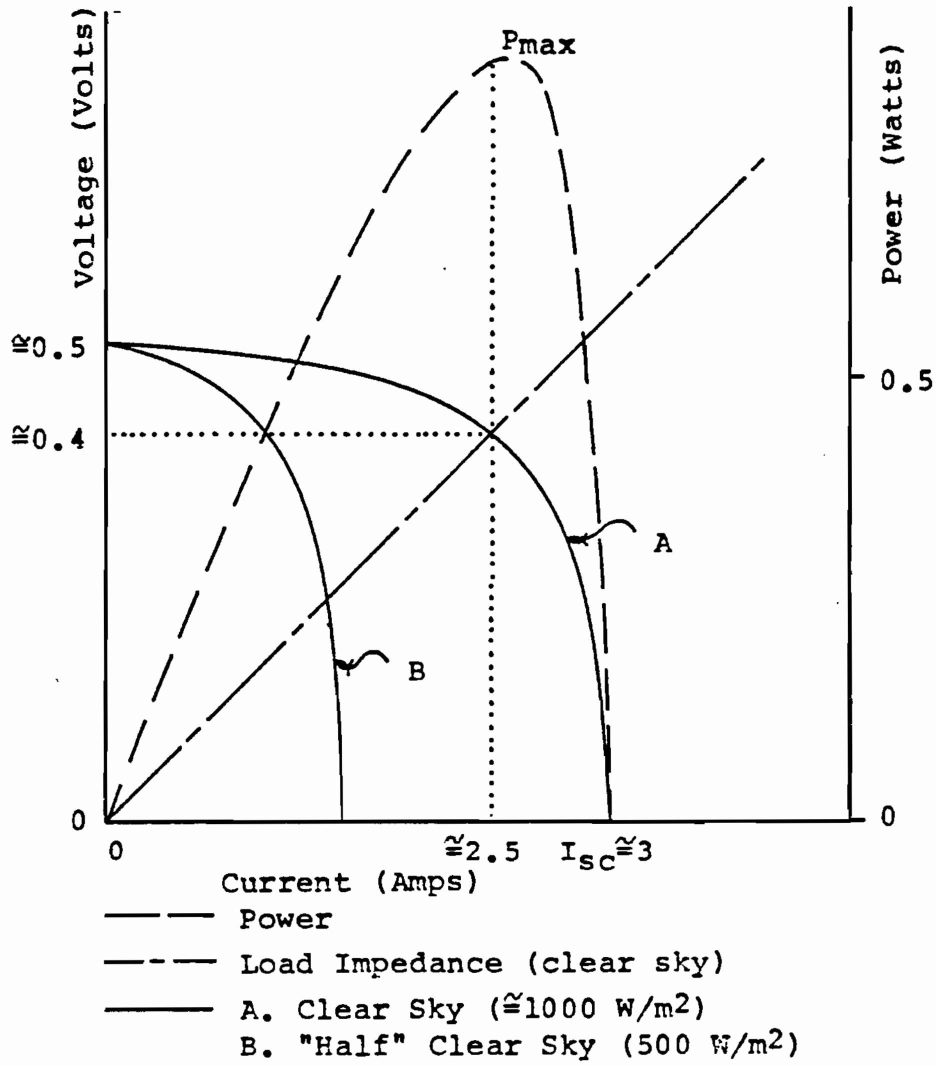


Fig. 4.1 Characteristics of a Typical Individual Silicon Solar Cell.

The cell current varies approximately linearly with the level of solar radiation, and the voltage-current characteristic for the cell exposed to solar radiation equivalent to approximately half that for clear sky (~500 W/m^2) is illustrated by the solid curve B.

The solar array output voltage will depend on the number of individual cells in series and it is common to fabricate solar modules with 30 to 34 cells in series, thus providing approximately 15 to 17 volts open-circuit. However, under nominal load (feeding directly to a load or a battery) the voltage is reduced, but it will still be above 12 volts. If a higher voltage is needed for a particular application, the appropriate number of modules can be arranged in series to achieve that voltage; however, a 12-volt system will generally be of interest. Solar cell modules are added in parallel to achieve the desired current or power.

Figure 4.2 illustrates the voltage-current characteristics for a typical 12-volt system that would produce about 40 watts when integrated with the proper load, that is a load impedance of about 12x12/40 = 3.6 ohms. For a specified solar array (and level of solar radiation) the power output degrades from the maximum if the load impedance deviates from this optimum value.

4.4 Other Required Equipment

For applications such as lighting, where the demand is other than during the daylight hours, storage batteries are needed to store the energy until the time of demand. In addition to the solar array and the batteries, some power conditioning and control elements

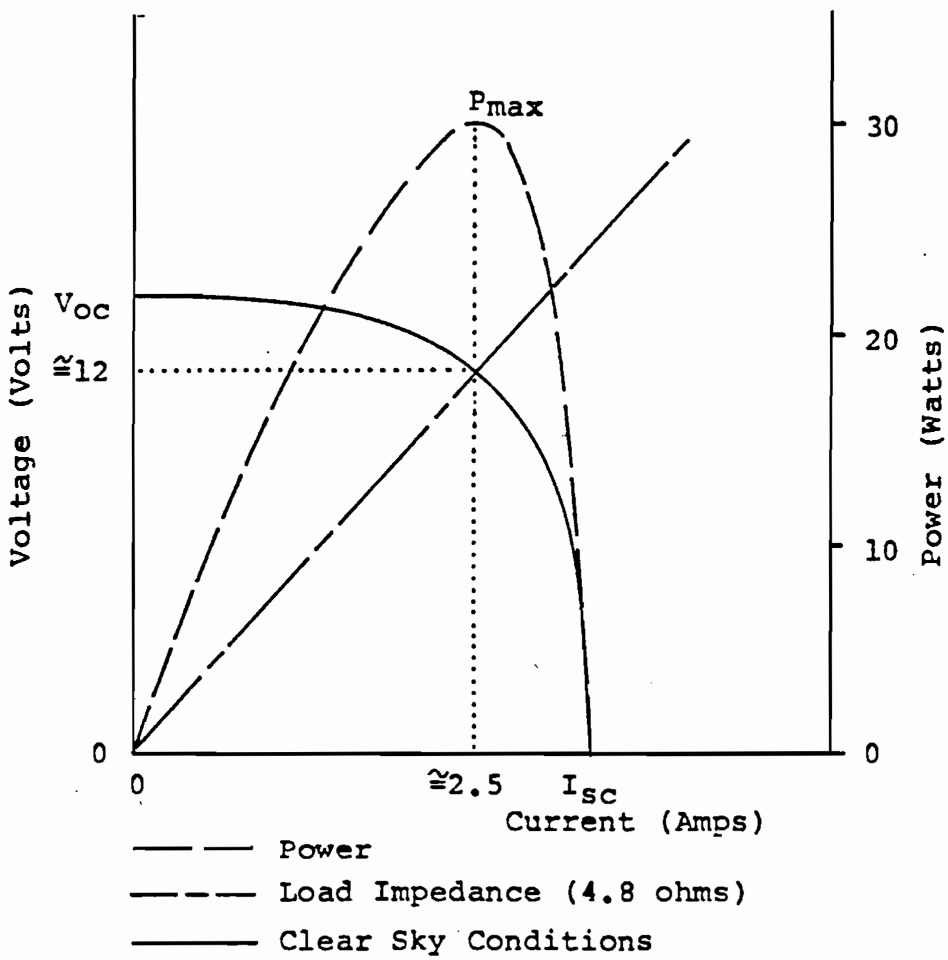


Fig. 4.2 Characteristics of a Typical 12 Volt Photovoltaic System with 30 Watts Peak Output.

are required. One such element is a charge controller between the cells and the batteries, which prevents battery overcharge. For an application such as security lighting, a sensor or timer is needed to regulate the application of power to the load. The sensor would turn the lighting system on when the light level falls below a prescribed level and a timer would turn the lighting system on and off by the clock. A schematic of a security lighting system is shown in Fig. 4.3.

Batteries for photovoltaic applications may be of either the lead-acid type or nickel-cadmium (Nicad). However, lead-acid batteries are the most common, because of availability and cost, but precautions are required for venting and fire protection, and catch-pans are needed for spilled acid.

4.5 Economics

Silicon solar cell arrays are typically about ten percent efficient and thus under clear sky conditions (~1000 W/m^2) will produce about 100 W/m^2 at peak solar conditions. Considering that the fill ratio of modules is typically 70 to 90 percent, the array area requirements are about 0.015 to 0.011 m^2 per peak watt.

The basic cost of silicon solar cells in large volume is about $7 per peak watt (not installed and without batteries or power conditioning/control equipment). However, an installed photovoltaic system with battery storage and of modest power (20 to 100 watt) will typically cost $ 30 to $ 40 per watt.

A schematic of a typical PV lighting system is shown in Figure 4.3. The major components indicated are

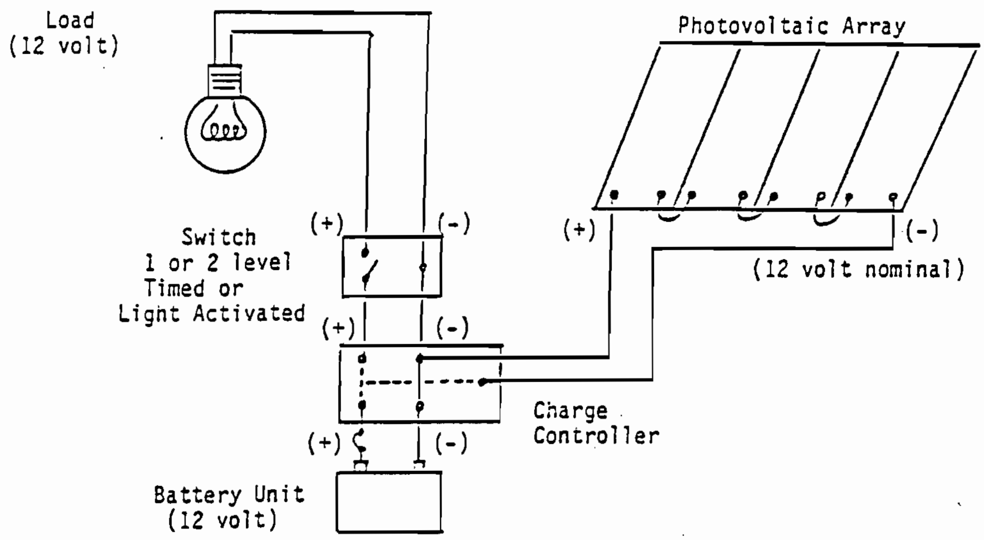


Fig. 4.3 Typical Photovoltaic Lighting Circuitry

the photovoltaic array (panel); the load (lights); a battery storage unit; a charge controller; and a load switch. The system will normally be 12 volt. Photovoltaic modules are usually designed as nominal 12-volt units and are assembled in parallel to obtain the desired power output. The charge controller is used to prevent battery overcharge and also to prevent deep discharge, both of which are necessary to insure long battery life. The switch indicated may be one or more levels (positions) to permit more than one level of lighting; and may be either time or light level actuated. All components shown are commercially available.

The performance and economics of a photovoltaic system can be estimated using the program PV F-Chart. Four example problems using this program are presented in Appendix C. This program is available from F-Chart Software, 4406 Fox Bluff Road, Middleton, Wisconsin 53562.

CHAPTER 5 - INTERIOR LIGHTING AND DAYLIGHTING

5.1 Introduction

The combined use of fluorescent luminaires and daylighting can offset a significant portion of the conventional energy required to light a building normally lit by incandescent light sources. Currently, Texas rest area buildings use open-air structures which provide ventilation as well as daylighting, but closed facilities are recommended for future construction (1). With this new requirement, the type of lighting will impact the energy demand for the facilities.

5.2 Lighting Requirements

Since the rest area facilities are open 24 hours a day, interior lighting must be provided at all times. The selected indoor lighting fixtures (luminaires) need to adequately illuminate the entrance, lobby, and stall areas as well as provide increased lighting levels in the sink/mirror areas. Important considerations in the lighting design should be energy efficient lighting levels and luminaires, glare reduction, vandalism resistance, and the capital, maintenance, and operating costs. Color rendering and noise are of lesser concern since the residence time of the visitors is short.

5.3 Light Sources

Incandescent lighting offers a low first cost option, but the average life of a bulb is approximately 1000 hours, which would necessitate an average of approximately 8 change-outs per year for each luminaire.

Fluorescent tubes have average lives of 7500 hours or more, and as such they would require changing only about once a year on average. Also, fluorescent lighting is approximately four times as efficient in producing light as the incandescent light source. Other light sources, such as quartz-halogen luminaires, can be utilized in the interior of a rest room, but controlling glare becomes a difficult problem. Light sources such as high pressure sodium are extremely energy efficient point light sources, but they are best utilized in large spaces or in outdoor applications such as road lighting.

5.4 Daylighting

Daylighting (natural lighting) can be used to reduce or eliminate the artificial lighting requirements during the day. A problem exists in that the level of daylight available varies with the time of day, the weather, and the glazing and its orientation and shading, as well as other factors, such as dirt accumulation on the glazing. The energy saved by the use of natural lighting should be compared to the additional energy lost or gained through the glazing if the building is to be heated or cooled. South glazing can provide passive solar heating as well as lighting. For east and west glazing, the solar heat gain is excessive in the summer months and little passive solar heat is collected in the winter (actually there is a net loss); therefor such glazing should be limited. When the lighting selections are complete, thermal analyses such as DOE-2, Carrier's E-20-II, and manual techniques can determine the most energy efficient design.

Operable windows may serve dual purposes, admitting light and providing ventilation during mild seasons. If fixed glazing is utilized, an air-to-air heat exchanger is recommended for ventilation during heating or cooling periods. If the building is not to be conditioned, wire screens with adequate free area to provide light and ventilation can take the place of the glazing. When glass is chosen for the glazing material, only tempered glass should be utilized, due to its safety features.

Controls which operate the artificial lighting are required to compensate for periods of varying natural light levels. Figure 5.1 shows that natural lighting is available for a considerable portion of the year in Texas, but artificial light is required for the balance of the year. Manual controls are inexpensive, but users unfamiliar with the building could face dangerous situations and vandalism becomes a problem. Processor (computer) controls can operate the building systems at their maximum possible efficiencies, but first and maintenance costs would be prohibitive for rest area applications. Automatic controls such as photocells with proper delay and override circuits are the best choice for year-round use to balance the natural and artificial lighting requirements (3).

Figure 5.2 shows how the level of light per unit area drops as the distance from the aperture (light) increases. Far from the window, artificial lighting may be required in one part of the building, even though natural lighting is available in another part. Figure 5.3 shows how this effect can be reduced by using

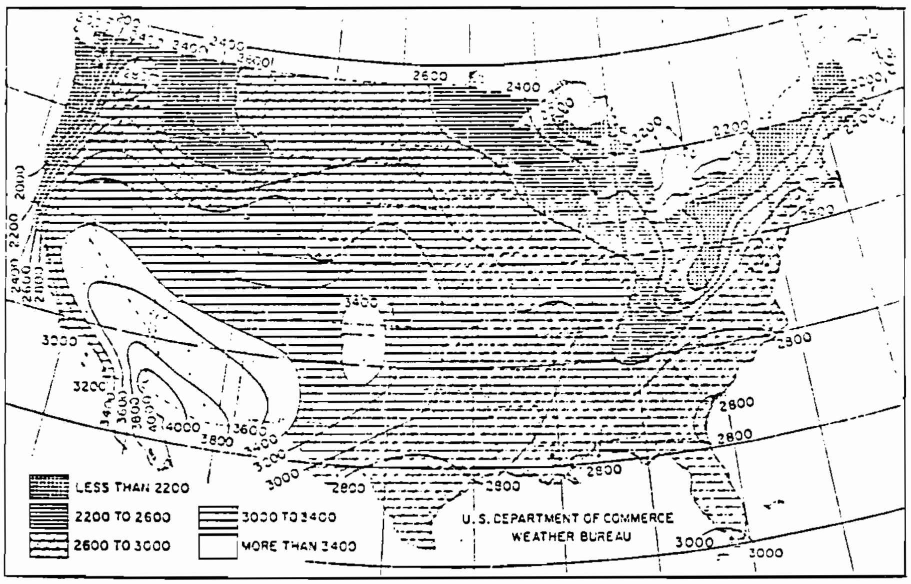
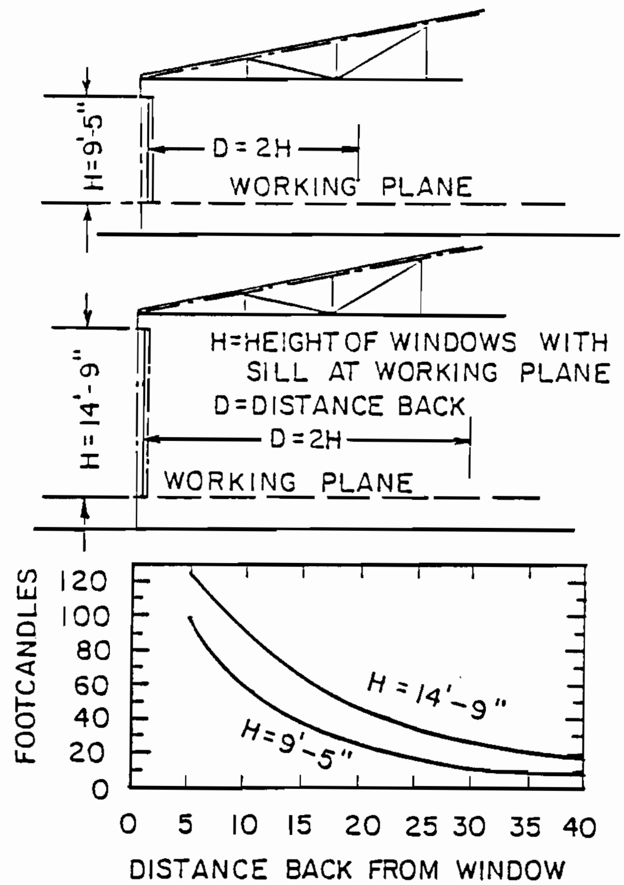
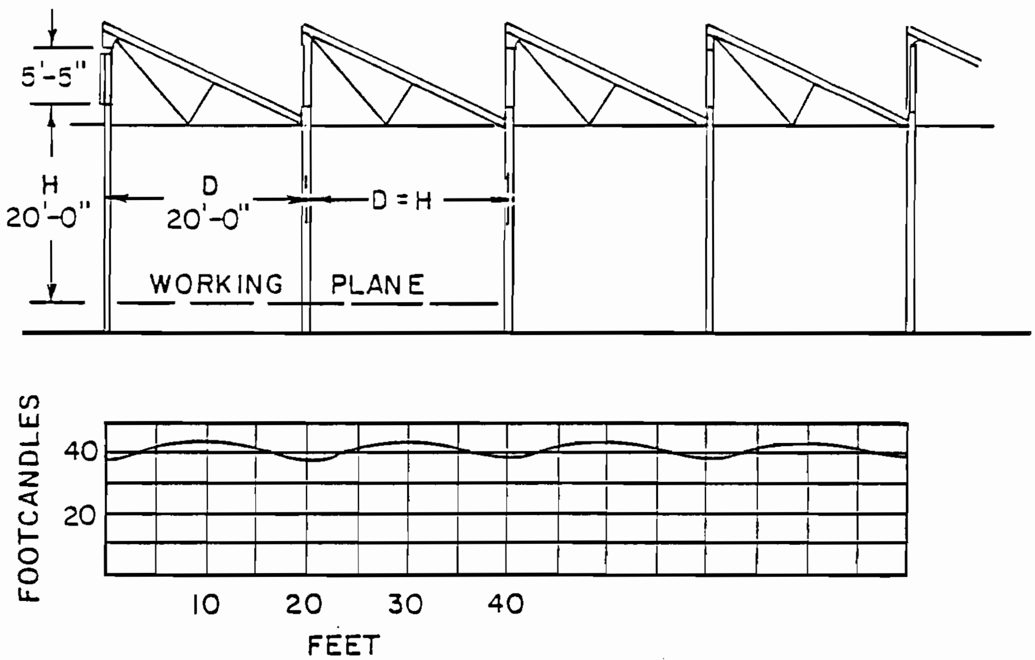


Fig. 5.1 Average Annual Amount of Sunshine in Hours (2).



Illumination distribution from sidewall windows assuming no reflection, clean glass, 1000 footlamberts uniform sky luminance, and window length equal to or greater than 5 times the window height.

Fig. 5.2 Sidewall Window Illumination Distribution (2).



Illumination distribution from sawtooth windows assuming no reflection, clean glass, and 1000 - foot-lamberts uniform sky luminance; equal to mounting height.

Fig. 5.3 Sawtooth Windows Illumination Distribution (2).

multiple clerestory lights (a sawtooth roof line) or skylights, and reflective surfaces (2).

5.5 Glare Control

Since glare is undesirable, any light source should incorporate features to reduce the discomfort. For daylighting, diffusive materials, reflective surfaces, overhangs, louvers, landscaping, and high sidewall or roof installations can reduce the glare from the direct component of daylight. Light from horizontal skylights is difficult to control, and solar heat gain in the summer can be excessive; therefor care should be taken in their design and use. For example, the original design of the Houston Astrodome included clear skylights, but, when the outfielders complained that they could not see fly balls due to the glare, the skylights were painted with a translucent coating.

Daylight can be as bright as 10,000 foot-candles on a very clear day. With proper controls, daylighting can provide most of the lighting requirements for a rest area building during the day, and by doing so it will eliminate the energy needed to operate artificial lighting during that period. With reduced energy consumption as the goal, the use of daylighting is recommended for new rest area buildings as long as consideration is given to the potential problem of glare and the possible increase in heating and cooling requirements.

CHAPTER 6 - OTHER ENERGY SOURCES

6.1 Other than the Sun

Besides solar-thermal, photovoltaics, and daylighting, energy for use at highway rest areas may be obtained through other methods, such as wind, geothermal, and cogeneration technologies. These methods tend to be very site specific and their applications must be designed on an individual basis. The size and time-of-use factors become critical for these energy sources when they are compared to conventional sources for economic viability.

The on-site energy sources need to be evaluated prior to the selection of an energy system. High levels of wind, geothermal potential, and solar access should be checked for, and the conventional energy available, such as electricity, natural gas, and fuel oil, should be determined. The energy requirements of the project must also be estimated for comparison with the energy available. Factors, such as severe weather, site remoteness, and the availability of materials and skilled maintenance personnel, must be considered. When these and other factors are determined, a viable energy supply system can be evaluated for economic viability.

6.2 Wind Energy

Wind energy is usually converted to electrical energy through the use of a wind turbine. Many sizes and configurations are available, such as vertical (eggbeater) and horizontal axis machines. The characteristics of the local wind velocity are a factor in determining the type of wind turbine selected. Low wind velocities with rapidly shifting directions would favor vertical axis turbines since they self-start with lower wind velocities and are omnidirectional, while high wind velocities would be better utilized by horizontal machines. The rotor size is proportional to the desired energy production. The remainder of the electrical system is very similar to that of the photovoltaic system (Fig. 4.3) with the array replaced by the wind generator. The average velocity of the local winds may be sufficiently high in some parts of the Texas Panhandle and the Texas Gulf Coast to consider wind energy, but as of yet most installations have poor economic outlooks. If the cost of conventional fuel sources rises sharply, then wind farms and individual installations may become economical.

6.3 Geothermal

Geothermal energy is a very site specific energy source. Determination of the geothermal energy potential of a site can be quite costly, but for known locations its use should be considered. A rest area in Idaho uses geothermal water circulated directly through fan-coils to meet the space heating requirements (1). Scaling and corrosion with this type of system are problems which the designer needs to address, possibly by separating the geothermal and circulation fluids with a replaceable heat exchanger. Since space heating is not required in some locations in Texas, geothermal energy could be used for water heating. The opportunities for geothermal energy are very minimal in Texas, however.

6.4 Cogeneration

Cogeneration is the combined production of mechanical/electrical and thermal energy from chemical energy. Various system configurations may be used to change the proportions of the types of energy produced. Large power utilities which favor electricity production usually utilize gas turbines which are linked to a heat recovery boiler/steam turbine. But for smaller applications, such as restaurants and hospitals, small packaged positive displacement units with cooling and exhaust heat recovery can provide electricity, space and water heating, and/or absorption or vapor-compression cooling. The Gas Research Institute is actively supporting development of these small systems. Its goal is to reduce the cost of the packaged systems to approximately $700/kW of installed capacity by the 1990's. When this goal is met, small scale cogeneration will be viable in a variety of applications (2).

For small, limited-service rest areas, cogeneration is not likely to become feasible. But, for large, heavily used facilities where air conditioning, space and water heating, and electricity are needed, cogeneration may become feasible. Load size, time-of-use, fuel cost (such as for natural gas or fuel oil), and operating and maintenance costs are factors in the decision process. Cogeneration would be most feasible in locations where electricity is relatively expensive as compared to natural gas or fuel oil. Joint-use facilities, which include a restaurant, can increase the usage of the hot water provided by cogeneration. If a gas station or a convenience store is included in the joint-use facility, the magnitude of the project is increased even more, thus making a cogeneration system more viable.

In the early design stages of a new rest area facility, the energy source should not be immediately assumed to be a conventional utility hookup. Instead, the designers need to identify all energy sources available on the site and then evaluate their economic potential. While designers may be most familiar with conventional energy sources, the optimal system for the facility may be an alternate energy source.

CHAPTER 7

ASSESSING THE ECONOMICS OF ENERGY ALTERNATIVES

7.1 Economics Assessment

In assessing energy options it is imperative that the various alternatives be compared on a life-cycle cost, rate of return, or payback period basis, which includes first, maintenance, replacement, operating, and fuel costs, and that appropriate fuel escalation, interest, and discount rates be used. This is particularly important to alternate energy options, in that they generally are high in first cost but low in fuel cost. With this method, accurate projections of the true costs of the energy alternatives can be made. Two computer codes, F-Chart and PV F-Chart, use this method to perform economic analyses based on the predicted performance of the energy systems.

7.2 F-Chart

For solar-thermal applications, such as water or space heating, the F-Chart method developed at the University of Wisconsin is widely considered to be the best predictor of solar-thermal performance (1). This is a computer version of the original manual F-Chart approach (2). The "F" stands for the fraction of energy provided by solar energy and thus is the fraction of conventional energy saved (displaced by solar energy).

The F-Chart program can be used to evaluate various solar-thermal systems such as pebble bed storage, water storage, and passive storage systems. Also, F-Chart contains a general solar heating category for modeling systems that provide space cooling and process heating. The program is menu driven with various lists of input data being generated for the type of system selected. The program includes default values and information on the climate for many locations. The run time of the program is short, with output appearing on the CRT only, or with the Print On command, output is also directed to a printer. Various forms of output may be printed including graphs, a summary, or tabulated results.

Figures 7.1 and 7.2 show sample required input data for the F-Chart program for the case of a domestic hot water application. This case includes flat plate collectors in an open loop or direct heating design (no heat exchanger). Collector parameters are given in the first section of Fig. 7.1 (FLAT PLATE COLLECTOR), while the city call number, the water demand parameters, backup fuel type, and the collector-storage heat exchanger details are specified in the second part of Fig. 7.1 (WATER STORAGE SYSTEM). Figure 7.2 illustrates the required input pertinent to assessing the economics of the application, including system cost, fuel cost, interests rates, fuel cost escalation rates, as well as other economic parameters. Data on the cost of competing fuels must be gathered, and an estimate of the annual increase of their price must be made. This rate should be determined by examining the past trends and the forecasts of future rates. The cost of the system installation is broken into the cost per unit area of collector (#2) and the area independent cost (#3). The area independent cost includes the storage devices (if

```
01-01-1980
Sample

** FLAT PLATE COLLECTOR **
1  NUMBER OF COLLECTOR PANELS....  26
2  COLLECTOR PANEL AREA..........  1.93          M2
3  FR*UL (TEST SLOPE)............  4.22          W/M2-C
4  FR*TAU*ALPHA (TEST INTERCEPT).  .7
5  COLLECTOR SLOPE...............  45            DEG
6  COLLECTOR AZIMUTH (SOUTH=0)...  0             DEG
7  INCIDENCE ANGLE MOD TYPE(8-10)  8
8    NUMBER OF GLAZINGS..........  2
9    INC ANGLE MODIFIER CONSTANT.  0
10   INC ANGLE MODIFIER VALUE(S).
  1    .999   .998   .995   .981   .953   .882
  .7   .35   0
11 COLLECTOR FLOWRATE/AREA.......  .015          KG/S-M2
12 COLLECTOR FLUID SPECIFIC HEAT.  3.35          KJ/KG-C
13 MODIFY TEST VALUES (1=Y,2=N)..  2
14   TEST COLLECTOR FLOWRATE/AREA  .015          KG/S-M2
15   TEST FLUID SPECIFIC HEAT....  4.19          KJ/KG-C

*** WATER STORAGE SYSTEM ***
1  CITY CALL NUMBER..............  127
2  WATER STORAGE VOLUME..........  3750          LITERS
3  BUILDING UA (0 FOR DHW ONLY)..  275           W/C
4  FUEL (1=EL,2=NG,3=OIL,4=OTHER)  2
5  EFFICIENCY OF FUEL USAGE......  70            %
6  DOMESTIC HOT WATER (1=Y,2=N)..  1
7    DAILY HOT WATER USAGE.......  300           LITERS
8    WATER SET TEMPERATURE.......  60            C
9    ENVIRONMENT TEMPERATURE.....  20            C
10   DHW STORAGE TANK SIZE.......  300           LITERS
11   UA OF AUX STORAGE TANK......  4             W/C
12 PIPE HEAT LOSS (1=Y,2=N)......  2
13   INLET PIPE UA...............  2.5           W/C
14   OUTLET PIPE UA..............  2.5           W/C
15 RELATIVE LOAD HX SIZE.........  1
16 COLLECTOR-STORAGE HX (1=Y,2=N)  2
17   TANK SIDE FLOWRATE/AREA.....  .015          KG/S-M2
18   HEAT EXCHANGER EFFECTIVENESS  .5
```

Fig. 7.1 F-Chart Input

```
*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  1
2  COST PER UNIT AREA............  150          $/M2
3  AREA INDEPENDENT COST.........  500          $
4  PRICE OF ELECTRICITY..........  .04          $/KW-HR
5  ANNUAL % INCREASE IN ELEC.....  10           %
6  PRICE OF NATURAL GAS..........  .18          $/M3
7  ANNUAL % INCREASE IN NAT. GAS.  10           %
8  PRICE OF FUEL OIL.............  .3           $/LITER
9  ANNUAL % INCREASE IN FUEL OIL.  10           %
10 PRICE OF OTHER FUEL...........  5            $/GJ
11 ANNUAL % INCREASE IN OTHER....  10           %
12 PERIOD OF ECONOMIC ANALYSIS...  20           YEARS
13 % DOWN PAYMENT................  100          %
14 ANNUAL MORTGAGE INTEREST RATE.  9            %
15 TERM OF MORTGAGE..............  20           YEARS
16 ANNUAL MARKET DISCOUNT RATE...  8            %
17 % EXTRA INSUR & MAIN IN YEAR 1  0            %
18 ANNUAL % INCREASE IN I & M....  8            %
19 EFF FED+STATE INCOME TAX RATE.  20           %
20 TRUE % PROPERTY TAX RATE......  3            %
21 ANNUAL % INCREASE IN PROP TAX.  8            %
22 % RESALE VALUE................  100          %
23 % CREDIT RATE IN TIER 1.......  56           %
24 MAXIMUM INVESTMENT IN TIER 1..  10000        $
25 % CREDIT RATE IN TIER 2.......  0            %
26 MAXIMUM INVESTMENT IN TIER 2..  10000        $
27 COMMERCIAL SYSTEM? 1=Y,2=N....  2
28 COMM. DEPRECIATION SCHEDULE...               %
  25   38   37   0   0   0   0   0   0   0
```

Fig. 7.2 F-Chart Input (Economics)

any), any equipment such as pumps and piping, and the installation cost for the storage and the equipment.

The most important result of the economic analysis is the life cycle savings. If there are savings over the life of the system, then that system is more economical than a conventional system. If no savings or a loss is predicted, then steps to improve the system's performance and increase the conservation of energy in the building (to reduce the system's size) must be taken.

An example run of F-Chart for a rest area solar hot water installation appears in Appendix B. The system uses an antifreeze (indirect) configuration. Under the FLAT PLATE COLLECTOR category (Fig. B.2), information such as collector size (#2 , 1.56 square meters), mounting angle (#5, 45 degrees), flowrate (#11), and other design parameters are entered. This information is determined from the manufacturer's specifications and from initial hand calculations. Some rules-of-thumb for the rough sizing of various system components are available in Reference 3.

Design data in the WATER STORAGE SYSTEM category describes the type of storage and the load on the system. The load information, such as the daily hot water use (#6), must be determined by comparison to data for a conventional installation, or from an estimate using ASHRAE methods (4).

For the example of an indirect system with an internal heat exchanger, backup electrical heating, and is located in Austin, Texas, 84 percent of the annual energy required to produce hot water is provided by solar energy. A resulting life-cycle savings of $5067 is predicted when this solar water heating system is used as compared to a conventional electric water heater.

7.3 PV F-Chart

For applications involving photovoltaics (direct conversion of sunlight to electricity), an adaptation of the previous method, called PV F-Chart, is available for use on mainframe and personal computers (1). Other systems that can be modeled with PV F-Chart are systems with no utility grid feedback or storage batteries, and systems which feedback to the grid and do not have battery storage. The collector arrays may be of fixed, tracking, and/or of concentrating design. The input required for the PV F-Chart program is considerably less than that for F-Chart. However, the program loading, running, and production of output are completed in the same manner as with the F-Chart program.

Figure 7.3 shows sample input data for the PV F-Chart program for the case of a photovoltaic low level lighting application with battery storage. The first section of Fig. 7.3 (BATTERY STORAGE SYSTEM) specifies the solar input data, such as city call number, the array area, and the storage battery capacity. The collector array area is first estimated by determining the total loads in watts in hour-by-hour, month-by-month increments, and by estimating the power per unit area that can be produced by the chosen collector array. Data from the manufacturer on the array and battery

```
01-01-1980
Trial

** BATTERY STORAGE SYSTEM **
1  CITY CALL NUMBER..............  27
2  OUTPUT 1=SUM 2=DET NEG=GRAPH..  0
3  CELL TEMP AT NOCT CONDITIONS..  100                  F
4  ARRAY REFERENCE EFFICIENCY....  .104
5  ARRAY REFERENCE TEMPERATURE...  95                   F
6  ARRAY TEMP COEFFICIENT * 1000.  2.39                 1/F
7  POWER TRACKING EFFICIENCY.....  .9
8  POWER CONDITIONING EFFICIENCY.  .98
9  % STANDARD DEVIATION OF LOAD..  0                    %
10 EFFECTIVE BATTERY CAPACITY....  1.4                  KW-HR
11 BATTERY EFFICIENCY............  .87
12 ARRAY AREA....................  60                   FT2
13 ARRAY SLOPE...................  50                   DEG
14 ARRAY AZIMUTH (SOUTH=0).......  0                    DEG

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  1
2  COST PER UNIT AREA............  600                  $/FT2
3  AREA INDEPENDENT COST.........  500                  $
4  PERIOD OF ECONOMIC ANALYSIS...  20                   YEARS
5  % DOWN PAYMENT................  10                   %
6  ANNUAL % MORTGAGE INTEREST....  9                    %
7  TERM OF MORTGAGE..............  20                   YEARS
8  ANNUAL % MARKET DISCOUNT RATE.  8                    %
9  % EXTRA INSUR & MAINT IN YR 1.  1                    %
10 ANNUAL % INCREASE IN I & M....  8                    %
11 EFF FED+STATE INCOME TAX RATE.  20                   %
12 TRUE % PROPERTY TAX RATE......  0                    %
13 ANNUAL % INCREASE IN PROP TAX.  8                    %
14 % RESALE VALUE................  100                  %
15 CONSIDER REBATES? 1=Y 2=N.....  1
16   % REBATE IN TIER 1..........  56                   %
17   MAX INVESTMENT IN TIER 1....  10000                $
18   % REBATE IN TIER 2..........  0                    %
19   MAX INVESTMENT IN TIER 2....  10000                $
20 COMMERCIAL SYSTEM? 1=Y 2=N....  1
21   COMM. DEPRECIATION SCHEDULE.                    %
  25   38   37   0   0   0   0   0   0   0
22 COST OF ELECT. (OFF PEAK).....  .2                   $/KW-HR
23 ANNUAL % INCREASE IN ELECT....  10                   %
```

Fig. 7.3 PV F-Chart Input

efficiencies are entered into the program, as are the specifications of the collector area and slope.

The second section (ECONOMICS) includes data required for the economic assessment. For photovoltaics, a cost per unit area of $100 per square foot (#2) includes approximately $70 for the photovoltaic cells and $30 for the enclosure and the installation. The area independent cost (#3) represents the cost of equipment such as storage, switch gear, and controllers. The remainder of the input for the economic analysis is very similar to the F-Chart program, and the additonal information must be obtained in the same manner.

The example problem in Appendix C is a photovoltaic system which utilizes battery storage and a backup feed from the utility. Three high pressure sodium lamps for exterior lighting are powered by batteries which are recharged by photovoltaic cells. Electricity from the utility grid is used for backup, but excess PV power is not sold back to the utility.

In the BATTERY STORAGE SYSTEM category, the city call number (#1) is again for Austin, Texas. There is 600 square feet of collector area (#12), and the collectors are mounted at 60 degrees (#13). The high mounting angle is to maximize the energy collection of the fixed array during the winter months since the lights operate for longer periods. Also in this category, three efficiencies must be entered into the program, but not all three are used with each type of system analyzed. The power tracking efficiency (#7) is the accuracy of the tracking mechanism as compared to the maximum energy that could be collected if the tracking was perfect.

The power conditioning efficiency (#8) is the efficiency of the equipment such as transformers, DC-to-AC converters, and power controllers. The battery efficiency (#11) is the amount of energy that can be retrieved from storage, as compared to the energy that was put into storage. Eighty percent is a typical efficiency for lead-acid batteries.

Appendix C presents several PV F-Chart examples. The first example problem (Figs. C.2 to C.5), which has a 600 square foot array and 42 kW-hr battery capacity, provides 96.7 percent of the annual load from solar energy, with a life cycle savings of $5291. In the second example problem (Figs. C.6 to C.7), the battery storage capacity was halved, while the other factors remained the same. With this system, 94.3 percent of the energy was provided by solar with a savings of $5154. In the third example, the array area was halved but the other factors were kept as they are in the first example. This system provided 70.0 percent of the load, with a life cycle savings of $3869. The last example incorporated half the battery storage and half the collector area of the first example. This system provided 68.5 percent of the load by solar, with a life cycle savings of $3786. From the results of these cases, when the system size is doubled, twice the percent of the load supplied by solar and twice the savings can not be expected.

7.4 Effect of Government Status on Economics

In respect to the economic analysis, a government agency has several advantages over the private sector. If the State self-insures, the cost of extra insurance due to the alternate energy system can be set to zero in the programs. State-owned properties are not taxed, so this cost can be eliminated for the analysis. If a joint-use facility is to be modeled, then property taxation may become a factor, depending on whether the facility is owned by the State or by the private sector.

Usually, funds for new highway construction are appropriated, and 100 percent of the project is paid for without a loan, so no financing costs are incurred. If bonds are sold to obtain the necessary capital, then the cost of the money (interest and bond term) must be included in the economic analysis input. Funds from the Federal Highway Administration (usually 90 percent of the initial cost) can be input into the programs as rebates or as reduced capital cost. The maximum investment allowed is the initial cost of the system, which must be approved by the Federal Highway Administration. Without these funds, it is possible that the alternate energy systems would not be economical from the State's point of view.

7.5 Other Codes

Some other computer codes available for the simulation of solar systems are TRNSYS (the University of Wisconsin), TRACE Solar (the Trane Company), and DOE-2 Solar Simulator (National Technical Information Service). Information on these and other programs may be obtained from Reference 6, but for the analysis of applications, such as those for a rest area, the personal computer based F-Chart program for solar-thermal applications and PV F-Chart for photovoltaic applications are recommended.

CHAPTER 8 - CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

In this report, various methods for meeting the energy needs of roadside rest areas are examined. Many energy sources exist, such as conventional, solar-thermal, photovoltaics, daylighting, wind, geothermal, and cogeneration. Prior to the design of the energy systems, conservation should always be given high priority. With good design decisions, there is a potential for significant savings over the life of the rest area installation.

8.2 Conclusions

Conservation should be the first concern addressed in the design since wasting energy increases the energy system's size and cost of energy. The building environment should be maintained at the minimum comfort level. This means a minimum acceptable temperature and humidity during heating periods, and a maximum acceptable temperature and humidity during cooling periods. Ventilation should be kept to a minimum acceptable level, and infiltration should be reduced. Equipment such as air-to-air heat exchangers should be utilized to reduce the energy loss associated with ventilation. To reduce infiltration, good construction practices should be followed, such as caulking all joints in the building envelope and using vapor barriers.

Lighting equipment should be efficient and require low maintenance. For the interior of the building, fluorescent lighting is recommended over incandescent light sources. Other high efficiency point sources such as high pressure sodium luminaires would be difficult to control in interior applications, but they are recommended for exterior use.

For water and possibly space heating, solar-thermal flat-plate liquid-cooled systems should be considered. For most locations, this type of system will be economical if it is properly designed and installed. Proven system configurations, such as drain-back and antifreeze systems, are recommended. Reducing the first costs is a key to making a solar-thermal system economically feasible. New personal computer based codes such as F-Chart can rapidly evaluate the economics and the performance of a solar-thermal system.

Photovoltaics should be considered for low level and security lighting in isolated locations. For low-energy applications, such as radio transmitters and traffic counters, photovoltaics should always be considered. As the cost of photovoltaic cells drop, PV systems will become economically feasible for a greater variety of applications. The program PV F-Chart is recommended for the economic and performance evaluation of a photovoltaic system.

Since insurance may and taxation can be neglected, and 100 percent down payments with a 90 percent rebate from the Federal Highway Administration are common. Thus, economic analyses tend to be favorable from the State Department of Highways and Public Transportation's point of view. This means that a potential alternate energy system may be more economical for the State than it would be for the private sector.

Natural lighting can be utilized effectively for daytime interior lighting if properly designed architectural features, such as clerestories, are used. However, proper attention must be given to minimizing the heating and cooling loads and controlling glare.

The cogeneration of heat and electricity is currently feasible for locations where a low cost fuel source is available, and this option should be considered. Wind and geothermal energies are very site specific and may find some limited application.

The main conclusion of this portion of the project is that the designer of future roadside rest areas should no longer assume that conventional energy sources are the only alternative. The designer needs to be aware of conservation measures and alternate energy sources and must be able to assess the economics of these options relative to conventional energy. With this "heads up" approach to energy sources, the owner and the users of the rest areas are better served.

8.3 Recommendations

Future research on the renovation of existing rest area buildings would be beneficial. Since the State's current financial position may prohibit the construction of many new facilities, older locations will still need to be relied upon to provide service to the public. Making the buildings more energy efficient and adding new services, such as hot water or security lighting, would extend the useful lifetimes of previously obsolete rest areas.

Joint-use facilities may increase the economic feasibility of a new rest area. Since the energy requirements for this type of construction would be greater, a larger opportunity for savings would exist with the use of alternate energy systems. Technologies, such as the cogeneration of electricity and hot water, steam, and refrigeration, would become more attractive. Research in this area would help to determine the merit of joint-use facilities over conventional rest areas.

APPENDIX A

SOLAR-THERMAL RETROFIT

APPENDIX A - SOLAR-THERMAL RETROFIT

This appendix describes a preliminary project for which the objective was to design a retrofit solar-thermal domestic water heating system for the Williamson County rest area on Interstate 35. In comparison with electricity, which is the only energy source currently used on the site, solar energy is potentially a low cost heat source for water heating. Many rest area buildings in the State of Texas are similar in design to the one in Williamson County, so, if a sample installation was successful, many other systems could be installed with little or no change to the basic system design. Hand calculations show the Williamson County location ($\sim 30.5^{\circ}$ N. latitude) would require a storage volume of 240 gallons and a collector area of 83 square feet.

Using The University of Texas's mainframe computer program SOLSIM, the design would provide approximately 85 to 100 percent of the energy required to provide hot water service of 105°F, and a backup heat source may not have to be provided if the water temperature is allowed to fall during heavy use and poor energy collection periods.

More work is required on this retrofit design. Refinement of the system using the F-Chart program, locating potential suppliers and installers, and developing a plan for cost-cutting are some of the tasks that lay ahead.

APPENDIX B

SOLAR-THERMAL APPLICATION - AN EXAMPLE

APPENDIX B - SOLAR-THERMAL APPLICATION - AN EXAMPLE

A solar-thermal domestic water heater design is evaluated by the F-Chart program in this appendix. A simple antifreeze system with an internal heat exchanger and backup electrical resistance heating is used in the design. Figure B.1 shows the system layout. Five collectors of 1.56 square meters each are mounted at a 45 degree angle and face due south. An insulated storage tank has a double wall, an in-tank copper heat exchanger, and a heating element at the top. Hot water is drawn off the top of the tank, and cold replacement water is introduced at the bottom to promote thermal stratification of the stored water.

Figure B.2 shows the input data for the F-Chart program. Within the FLAT PLATE COLLECTOR section, data on the array are entered. Most of the data is obtainable through the collector manufacturers. Data such as the number of collectors (#1), the flow rate (#11), and the collector slope (#5) are determined by the designer. The collector circulating fluid (#12) used for this example is a 50/50 mixture of propylene glycol and water.

The WATER STORAGE SYSTEM section describes the location (#14 - Austin, Texas), the competing fuel, and the storage characteristics. The fuel (#4) used in this example problem is electricity, which has a 100 percent efficiency of usage (#5). The daily hot water usage (#7) must be determined, as must the water temperature (#8). Data on the storage tank and heat exchanger are then entered into the input file.

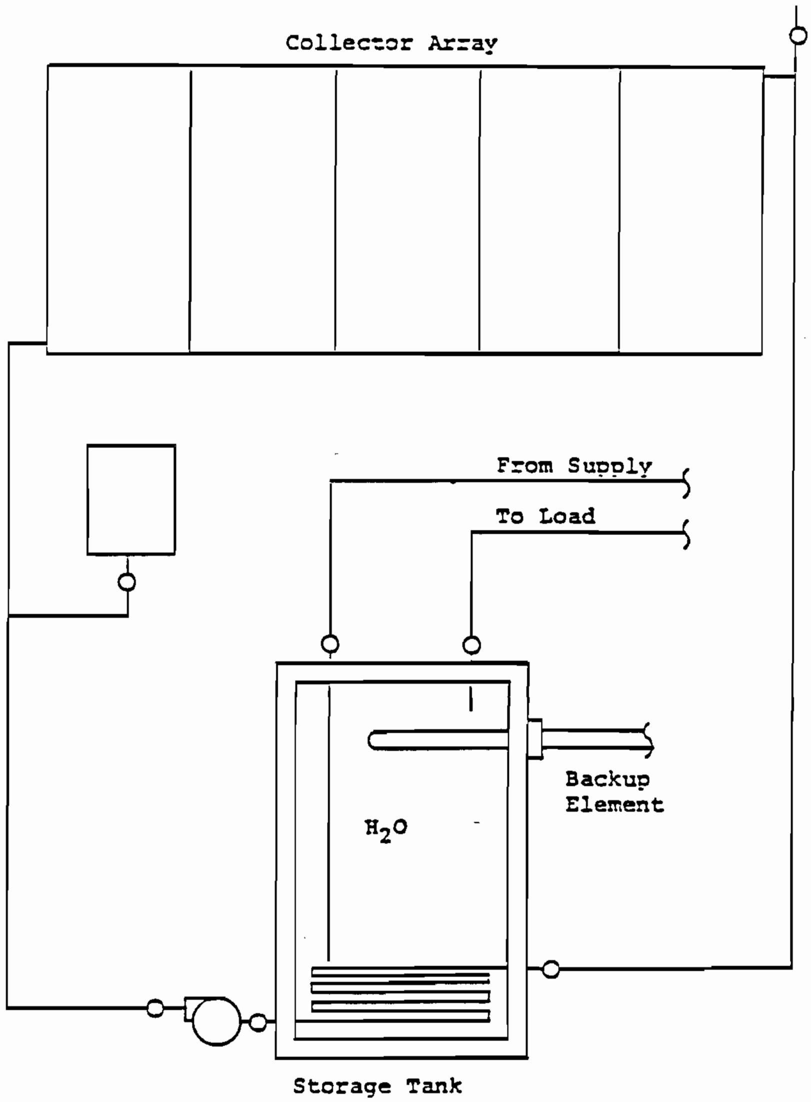


Fig. B.1 Solar-thermal Water Heating Example Layout.

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10-29-1986
APPB

** FLAT PLATE COLLECTOR **
1   NUMBER OF COLLECTOR PANELS....  5
2   COLLECTOR PANEL AREA..........  1.56          M2
3   FR*UL (TEST SLOPE)............  4.22          W/M2-C
4   FR*TAU*ALPHA (TEST INTERCEPT).  .7
5   COLLECTOR SLOPE...............  45            DEG
6   COLLECTOR AZIMUTH (SOUTH=0)...  0             DEG
7   INCIDENCE ANGLE MOD TYPE(8-10)  8
8     NUMBER OF GLAZINGS..........  2
9     INC ANGLE MODIFIER CONSTANT.  0
10    INC ANGLE MODIFIER VALUE(S).
  1   .999   .998   .995   .981   .953   .882
  .7   .35   0
11 COLLECTOR FLOWRATE/AREA.......  .02           KG/S-M2
12 COLLECTOR FLUID SPECIFIC HEAT.  3.56          KJ/KG-C
13 MODIFY TEST VALUES (1=Y,2=N)..  2
14    TEST COLLECTOR FLOWRATE/AREA  .02          KG/S-M2
15    TEST FLUID SPECIFIC HEAT....  3.56         KJ/KG-C

*** WATER STORAGE SYSTEM ***
1  CITY CALL NUMBER..............  14
2  WATER STORAGE VOLUME..........  454.25        LITERS
3  BUILDING UA (0 FOR DHW ONLY)..  0             W/C
4  FUEL (1=EL,2=NG,3=OIL,4=OTHER)  1
5  EFFICIENCY OF FUEL USAGE......  100           %
6  DOMESTIC HOT WATER (1=Y,2=N)..  1
7    DAILY HOT WATER USAGE.......  350           LITERS
8    WATER SET TEMPERATURE.......  43.3          C
9    ENVIRONMENT TEMPERATURE.....  20            C
10   DHW STORAGE TANK SIZE.......  400           LITERS
11   UA OF AUX STORAGE TANK......  6             W/C
12 PIPE HEAT LOSS (1=Y,2=N)......  2
13   INLET PIPE UA...............  2.5           W/C
14   OUTLET PIPE UA..............  2.5           W/C
15 RELATIVE LOAD HX SIZE.........  1
16 COLLECTOR-STORAGE HX (1=Y,2=N)  1
17   TANK SIDE FLOWRATE/AREA.....  .02           KG/S-M2
18   HEAT EXCHANGER EFFECTIVENESS  .6
```

Fig. B.2 Example F-Chart Input for Solar Water Heating.

```
*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  4
2  COST PER UNIT AREA............  150          $/M2
3  AREA INDEPENDENT COST.........  500          $
4  PRICE OF ELECTRICITY..........  .09          $/KW-HR
5  ANNUAL % INCREASE IN ELEC.....  5            %
6  PRICE OF NATURAL GAS..........  .18          $/M3
7  ANNUAL % INCREASE IN NAT. GAS.  5            %
8  PRICE OF FUEL OIL.............  .3           $/LITER
9  ANNUAL % INCREASE IN FUEL OIL.  5            %
10 PRICE OF OTHER FUEL...........  5            $/GJ
11 ANNUAL % INCREASE IN OTHER....  5            %
12 PERIOD OF ECONOMIC ANALYSIS...  20           YEARS
13 % DOWN PAYMENT................  100          %
14 ANNUAL MORTGAGE INTEREST RATE.  11           %
15 TERM OF MORTGAGE..............  20           YEARS
16 ANNUAL MARKET DISCOUNT RATE...  8            %
17 % EXTRA INSUR & MAIN IN YEAR 1  1            %
18 ANNUAL % INCREASE IN I & M....  4            %
19 EFF FED+STATE INCOME TAX RATE.  0            %
20 TRUE % PROPERTY TAX RATE......  0            %
21 ANNUAL % INCREASE IN PROP TAX.  0            %
22 % RESALE VALUE................  100          %
23 % CREDIT RATE IN TIER 1.......  90           %
24 MAXIMUM INVESTMENT IN TIER 1..  10000        $
25 % CREDIT RATE IN TIER 2.......  90           %
26 MAXIMUM INVESTMENT IN TIER 2..  10000        $
27 COMMERCIAL SYSTEM? 1=Y,2=N....  2
28 COMM. DEPRECIATION SCHEDULE...               %
  25   38   37   0   0   0   0   0   0   0
```

Fig. B.2 Continued

The ECONOMICS section describes all factors which will be considered for the economic analysis. The cost per unit area (#2) is dominated by the cost of the collectors. The area independent cost (#3) is primarily the cost of the storage device. Other cost factors, such as competing fuel costs, interest rates, and taxes, are then entered into the program.

The output (Fig. B.3) shows that for this design 84 percent of the annual energy required to heat the water is provided by solar energy. Most of the backup energy is needed during the winter months, when there is a shorter collection period available. Little backup energy is required in the summer months. The output of the economic analysis shows that with an initial investment of $1670 (of which 90 percent is paid for by the Federal Highway Administration), a life cycle savings of $5067 can be expected when solar energy is used to offset electrical energy requirements. The remainder of the output breaks down the costs and the savings and presents a detailed annual cash position statement.

This example shows that the F-Chart program can easily be employed to evaluate the performance of a solar-thermal design. Many other system configurations can be evaluated with the program, such as drainback and direct systems. With one general layout in mind, the designer can easily determine the optimal equipment sizes, such as the collector area and the storage volume, by changing the input variables for the program. With only a brief familiarizing with the F-Chart program, a designer can quickly and accurately evaluate a solar-thermal energy design.

```
*************************************
*              F-CHART              *
*    IBM PC  VERSION 5.6  02/13/86  *
*          COPYRIGHT BY             *
*    S.A. KLEIN & W.A. BECKMAN      *
*          ANALYSIS BY              *
*         Brian A. Rock             *
*    The University of Texas        *
*         Austin, Texas             *
*        (512)  471-5730            *
*************************************
AUSTIN          TX          10-29-1986

APPB
```

*** WATER STORAGE SYSTEM ***
** FLAT PLATE COLLECTOR **

	SOLAR GJ	HEAT GJ	DHW GJ	AUX GJ	F
JAN	3.3	0.0	1.5	0.5	0.65
FEB	3.4	0.0	1.3	0.3	0.76
MAR	4.2	0.0	1.4	0.2	0.83
APR	3.9	0.0	1.4	0.2	0.84
MAY	4.1	0.0	1.4	0.2	0.87
JUN	4.3	0.0	1.4	0.1	0.93
JUL	4.6	0.0	1.4	0.0	0.97
AUG	4.7	0.0	1.4	0.0	0.99
SEP	4.3	0.0	1.4	0.1	0.95
OCT	4.4	0.0	1.4	0.1	0.91
NOV	3.6	0.0	1.4	0.3	0.76
DEC	3.2	0.0	1.5	0.5	0.66
YR	48.0	0.0	16.9	2.7	0.84

FIRST YEAR FUEL COST	$ 67
FIRST YEAR FUEL SAVINGS	$ 355
INITIAL INVESTMENT	$ 1670
DOWN PAYMENT - TAX CREDIT	$ 167
20 YEAR MORTGAGE PAYMENT	$ 0
RESALE VALUE	$ 1670
ANNUALIZED PAYMENT	$ 101
LIFE CYCLE SAVINGS	$ 5067

(continued)

Fig. B.3 Example F-Chart Output for Solar Water Heating.

LIFE CYCLE COSTS

FUEL	$ 958
EQUIPMENT	$ 30
TOTAL	$ 988

BREAKDOWN OF EQUIPMENT COSTS

EXPENSES

DOWN PAYMENT	$ 1670
MORTGAGE	$ 0
MAINT. & INS.	$ 221
PROP. TAX	$ 0

CREDITS

INTEREST	$ 0
DEPRECIATION	$ 0
RESALE	$ 1670
TAX CREDITS	$ 1503

*** ANNUAL CASH POSITION ***

YR	MAINT & INS	PROP TAX	EN- ERGY	TAX SAVE	SAV- INGS	PRES WORTH
0	0	0	0	1503	-167	-167
1	17	0	67	0	338	313
2	17	0	70	0	355	305
3	18	0	74	0	373	296
4	19	0	77	0	392	288
5	20	0	81	0	412	280
6	20	0	85	0	433	273
7	21	0	89	0	455	265
8	22	0	94	0	478	258
9	23	0	99	0	502	251
10	24	0	103	0	527	244
11	25	0	109	0	554	237
12	26	0	114	0	581	231
13	27	0	120	0	611	225
14	28	0	126	0	642	218
15	29	0	132	0	674	212
16	0	0	139	0	708	207
17	31	0	146	0	744	201
18	33	0	153	0	781	195
19	34	0	161	0	820	190
20	35	0	169	0	2532	543
TOT	497	0	2206	1503	12744	5067

Fig. B.3 Continued.

The F-Chart program would be the primary tool for sizing potential solar hot water systems for roadside rest areas in the next phase of this project.

APPENDIX C

PHOTOVOLTAICS APPLICATION - AN EXAMPLE

APPENDIX C - PHOTOVOLTAICS APPLICATION - AN EXAMPLE

In this appendix, a sample problem using photovoltaic generation of electricity for low level lighting is presented and discussed. The design data for the energy collection system and the electrical load are determined, and the PV F-Chart program is used to determine the effectiveness of the system.

Figure C.1 illustrates the system configuration. The photovoltaic array feeds 12-volt direct current power to a charge/load controller which directs the power to the load and/or the battery storage, depending on the relative levels of demand and supply. If the batteries are drained, power as needed is obtained through the backup feed from the utility grid. This design attempts to provide the majority of the energy required to operate the lights, but a backup connection is provided to reduce the array size (a major cost variable) and to provide lighting during a possible system failure. At the same time, the photovoltaic array/battery system may be operable at times when there is a utility outage. A DC-to-AC converter feeds a step-up transformer, which delivers 277 volts to the load. The high pressure sodium lamps each use approximately 250 watts and their ballasts are assumed to consume 25 watts each.

Figure C.2 shows the PV F-Chart input data for the present application. The city call number shown (14) designates solar and weather data for Austin, Texas. The other data in the Battery Storage System category describe the photovoltaic cells and the battery

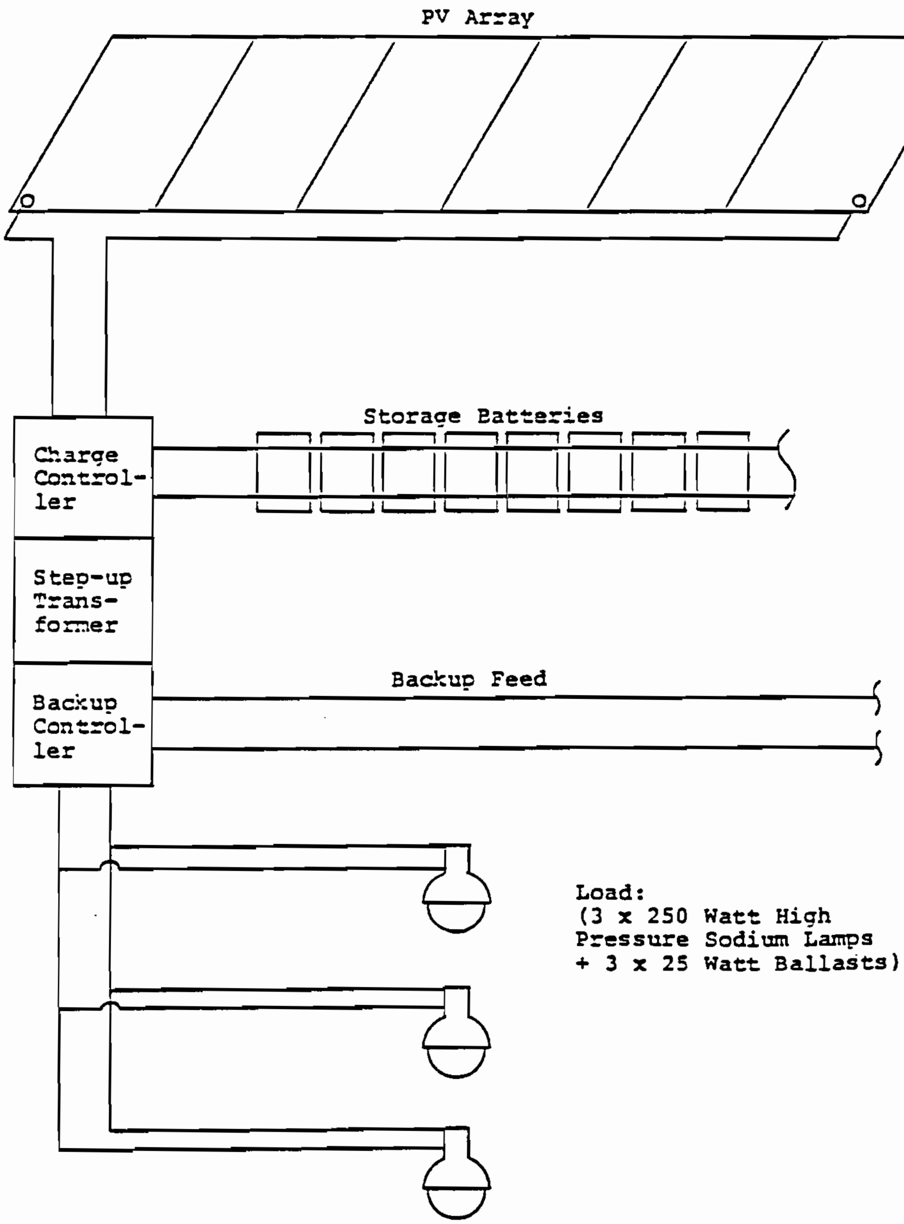

Fig. C.1 Photovoltaic Example Layout for Low Level Lighting.

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10-29-1986
APPC

** BATTERY STORAGE SYSTEM **
1  CITY CALL NUMBER..............  14
2  OUTPUT 1=SUM 2=DET NEG=GRAPH..  2
3  CELL TEMP AT NOCT CONDITIONS..  100           F
4  ARRAY REFERENCE EFFICIENCY....  .11
5  ARRAY REFERENCE TEMPERATURE...  95            F
6  ARRAY TEMP COEFFICIENT * 1000.  2.39          1/F
7  POWER TRACKING EFFICIENCY.....  .9
8  POWER CONDITIONING EFFICIENCY.  .88
9  % STANDARD DEVIATION OF LOAD..  0             %
10 EFFECTIVE BATTERY CAPACITY....  42            KW-HR
11 BATTERY EFFICIENCY............  .8
12 ARRAY AREA....................  600           FT2
13 ARRAY SLOPE...................  60            DEG
14 ARRAY AZIMUTH (SOUTH=0).......  0             DEG

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  4
2  COST PER UNIT AREA............  100           $/FT2
3  AREA INDEPENDENT COST.........  4000          $
4  PERIOD OF ECONOMIC ANALYSIS...  20            YEARS
5  % DOWN PAYMENT................  100           %
6  ANNUAL % MORTGAGE INTEREST....  10            %
7  TERM OF MORTGAGE..............  20            YEARS
8  ANNUAL % MARKET DISCOUNT RATE.  8             %
9  % EXTRA INSUR & MAINT IN YR 1.  1.2           %
10 ANNUAL % INCREASE IN I & M....  5             %
11 EFF FED+STATE INCOME TAX RATE.  0             %
12 TRUE % PROPERTY TAX RATE......  0             %
13 ANNUAL % INCREASE IN PROP TAX.  0             %
14 % RESALE VALUE................  100           %
15 CONSIDER REBATES? 1=Y 2=N.....  1
16   % REBATE IN TIER 1..........  90            %
17   MAX INVESTMENT IN TIER 1....  100000        $
18   % REBATE IN TIER 2..........  90            %
19   MAX INVESTMENT IN TIER 2....  100000        $
20 COMMERCIAL SYSTEM? 1=Y 2=N....  2
21   COMM. DEPRECIATION SCHEDULE.             %
  25   38   37   0   0   0   0   0   0   0
22 COST OF ELECT. (OFF PEAK).....  .1            $/KW-HR
23 ANNUAL % INCREASE IN ELECT....  5             %
```

Fig. C.2 Example PV F-Chart Input for Low Level Lighting.

storage system. For example, the 42 kW-hr battery capacity represents approximately 50 lead-acid 12 volt batteries that would undergo repetitive 15 to 20 percent discharges. The 600 ft^2 collector array has the capability of approximately 5.5 kW output under peak solar conditions.

The Economics category inputs the criteria used in the economic analysis. For example, the \$100 per ft^2 of PV panel represents a cost of about \$11 per peak watt. This value was chosen to include the cost of the collector mounting, electrical gear, and some of the cost of the batteries. Photovoltaic cells by themselves now are approximately \$7 to \$8 per peak watt. Numerous other factors are tabulated in the Economics input table.

Figure C.3 shows the monthly loads that are used for the analysis. Each load is 825 watts, which is equivalent to the total amount of energy required to operate the lamps and their ballasts. The lamps are assumed to operate on whole hour intervals in this example. Timers or other light controllers could phase in lamps, depending on the natural light available. With all of the input data determined, the program can then be run.

Figure C.4 presents the output from the program by month, with an annual summary at the end. The hour by hour entries for SOLAR, LOAD, and XSO represent the sum of the kilowatt-hours for all days in that month for each hour interval. The solar availability for each month is shown at the bottom of the second column, and, when multiplied by the efficiency, it would represent

AVERAGE HOURLY LOADS IN WATTS

TIME	JAN	FEB	MAR	APR	MAY	JUN
0- 1	825.0	825.0	825.0	825.0	825.0	825.0
1- 2	825.0	825.0	825.0	825.0	825.0	825.0
2- 3	825.0	825.0	825.0	825.0	825.0	825.0
3- 4	825.0	825.0	825.0	825.0	825.0	825.0
4- 5	825.0	825.0	825.0	825.0	825.0	825.0
5- 6	825.0	825.0	825.0	825.0	825.0	825.0
6- 7	825.0	825.0	825.0	825.0	0.0	0.0
7- 8	825.0	825.0	825.0	0.0	0.0	0.0
8- 9	0.0	0.0	0.0	0.0	0.0	0.0
9-10	0.0	0.0	0.0	0.0	0.0	0.0
10-11	0.0	0.0	0.0	0.0	0.0	0.0
11-12	0.0	0.0	0.0	0.0	0.0	0.0
12-13	0.0	0.0	0.0	0.0	0.0	0.0
13-14	0.0	0.0	0.0	0.0	0.0	0.0
14-15	0.0	0.0	0.0	0.0	0.0	0.0
15-16	0.0	0.0	0.0	0.0	0.0	0.0
16-17	0.0	0.0	0.0	0.0	0.0	0.0
17-18	825.0	825.0	0.0	0.0	0.0	0.0
18-19	825.0	825.0	825.0	825.0	0.0	0.0
19-20	825.0	825.0	825.0	825.0	825.0	825.0
20-21	825.0	825.0	825.0	825.0	825.0	825.0
21-22	825.0	825.0	825.0	825.0	825.0	825.0
22-23	825.0	825.0	825.0	825.0	825.0	825.0
23-24	825.0	825.0	825.0	825.0	825.0	825.0

TIME	JUL	AUG	SEP	OCT	NOV	DEC
0- 1	825.0	825.0	825.0	825.0	825.0	825.0
1- 2	825.0	825.0	825.0	825.0	825.0	825.0
2- 3	825.0	825.0	825.0	825.0	825.0	825.0
3- 4	825.0	825.0	825.0	825.0	825.0	825.0
4- 5	825.0	825.0	825.0	825.0	825.0	825.0
5- 6	825.0	825.0	825.0	825.0	825.0	825.0
6- 7	0.0	0.0	825.0	825.0	825.0	825.0
7- 8	0.0	0.0	0.0	0.0	825.0	825.0
8- 9	0.0	0.0	0.0	0.0	0.0	0.0
9-10	0.0	0.0	0.0	0.0	0.0	0.0
10-11	0.0	0.0	0.0	0.0	0.0	0.0
11-12	0.0	0.0	0.0	0.0	0.0	0.0
12-13	0.0	0.0	0.0	0.0	0.0	0.0
13-14	0.0	0.0	0.0	0.0	0.0	0.0
14-15	0.0	0.0	0.0	0.0	0.0	0.0
15-16	0.0	0.0	0.0	0.0	0.0	0.0
16-17	0.0	0.0	0.0	0.0	0.0	0.0
17-18	0.0	0.0	0.0	0.0	825.0	825.0
18-19	0.0	825.0	825.0	825.0	825.0	825.0
19-20	825.0	825.0	825.0	825.0	825.0	825.0
20-21	825.0	825.0	825.0	825.0	825.0	825.0
21-22	825.0	825.0	825.0	825.0	825.0	825.0
22-23	825.0	825.0	825.0	825.0	825.0	825.0
23-24	825.0	825.0	825.0	825.0	825.0	825.0

Fig. C.3 Example Loads for Low Level Lighting.

```
*************************************
*        PHOTOVOLTAIC F-CHART       *
*    IBM     VERSION 3.1   02/24/86 *
*            COPYRIGHT BY           *
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*           Brian A. Rock           *
*      The University of Texas      *
*           Austin, Texas           *
*          (512)  471-5730          *
*************************************
AUSTIN            TX          10-29-1986
```

AFPC2

*** BATTERY STORAGE SYSTEM ***

JAN

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
7- 8	227.3	9.8	25.6	50.8	6.5
8- 9	456.4	10.1	0.0	100.0	40.6
9-10	684.4	10.1	0.0	100.0	60.9
10-11	868.2	10.0	0.0	100.0	76.7
11-12	970.8	10.0	0.0	100.0	85.3
12-13	970.8	10.0	0.0	100.0	85.2
13-14	868.2	10.0	0.0	100.0	76.4
14-15	684.4	10.0	0.0	100.0	60.4
15-16	456.4	10.0	0.0	100.0	40.2
16-17	227.3	9.6	0.0	100.0	19.3
MONTH	6414.4	10.0	383.6	3.4	551.6

(continued)

Fig. C.4 Example PV F-Chart Output for Low Level Lighting.

FEB

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
7- 8	249.7	9.4	23.1	62.8	6.0
8- 9	472.0	9.9	0.0	100.0	41.2
9-10	690.4	10.0	0.0	100.0	60.6
10-11	865.2	9.9	0.0	100.0	75.6
11-12	962.4	9.9	0.0	100.0	83.6
12-13	962.4	9.9	0.0	100.0	83.5
13-14	865.2	9.9	0.0	100.0	75.2
14-15	690.4	9.9	0.0	100.0	60.1
15-16	472.0	9.8	0.0	100.0	40.7
16-17	249.7	9.2	0.0	100.0	20.3
MONTH	6479.6	9.8	346.5	4.2	546.8

MAR

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
6- 7	87.7	6.6	25.6	19.8	0.0
7- 8	306.1	8.9	25.6	71.0	5.8
8- 9	554.4	9.6	0.0	100.0	46.7
9-10	794.5	9.7	0.0	100.0	68.1
10-11	985.1	9.7	0.0	100.0	84.4
11-12	1090.5	9.7	0.0	100.0	93.1
12-13	1090.5	9.7	0.0	100.0	92.9
13-14	985.1	9.7	0.0	100.0	83.9
14-15	794.5	9.6	0.0	100.0	67.4
15-16	554.4	9.5	0.0	100.0	46.1
16-17	306.1	8.8	0.0	100.0	23.6
17-18	87.7	6.5	0.0	100.0	5.0
MONTH	7636.6	9.5	358.1	6.5	617.0

(continued)

Fig. C.4 Continued.

APR

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
6- 7	88.6	8.3	24.8	26.3	0.0
7- 8	285.4	8.2	0.0	100.0	20.6
8- 9	503.6	9.1	0.0	100.0	40.2
9-10	711.6	9.4	0.0	100.0	58.8
10-11	875.3	9.4	0.0	100.0	72.8
11-12	965.4	9.4	0.0	100.0	80.3
12-13	965.4	9.4	0.0	100.0	80.1
13-14	875.3	9.4	0.0	100.0	72.4
14-15	711.6	9.3	0.0	100.0	58.2
15-16	503.6	9.0	0.0	100.0	39.7
16-17	285.4	8.1	0.0	100.0	20.3
17-18	88.6	8.2	0.0	100.0	6.4
MONTH	6859.7	9.2	321.8	2.0	549.8

MAY

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
5- 6	23.2	9.5	25.6	7.6	0.0
6- 7	112.1	9.4	0.0	100.0	9.3
7- 8	285.9	7.9	0.0	100.0	19.8
8- 9	501.7	8.6	0.0	100.0	37.9
9-10	704.4	9.0	0.0	100.0	55.9
10-11	862.6	9.2	0.0	100.0	69.5
11-12	949.4	9.2	0.0	100.0	76.9
12-13	949.4	9.2	0.0	100.0	76.7
13-14	862.6	9.1	0.0	100.0	69.1
14-15	704.4	8.9	0.0	100.0	55.4
15-16	501.7	8.5	0.0	100.0	37.5
16-17	285.9	7.8	0.0	100.0	19.5
17-18	112.1	9.3	0.0	100.0	9.2
18-19	23.2	9.4	0.0	100.0	1.9
MONTH	6278.4	8.9	281.3	0.7	538.6

(continued)

Fig. C.4 Continued.

JUN

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
5- 6	37.2	9.4	24.8	12.4	0.0
6- 7	121.8	9.3	0.0	100.0	10.0
7- 8	277.6	7.6	0.0	100.0	18.6
8- 9	498.0	8.1	0.0	100.0	35.5
9-10	704.5	8.7	0.0	100.0	53.8
10-11	864.9	8.9	0.0	100.0	67.8
11-12	952.7	9.0	0.0	100.0	75.2
12-13	952.7	8.9	0.0	100.0	75.0
13-14	864.9	8.9	0.0	100.0	67.4
14-15	704.5	8.6	0.0	100.0	53.2
15-16	498.0	8.0	0.0	100.0	35.0
16-17	277.6	7.5	0.0	100.0	18.3
17-18	121.8	9.2	0.0	100.0	9.8
18-19	37.2	9.2	0.0	100.0	3.0
MONTH	6913.3	8.6	272.3	1.1	522.5

JUL

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
5- 6	31.3	9.3	25.6	10.0	0.0
6- 7	120.2	9.3	0.0	100.0	9.8
7- 8	300.3	7.5	0.0	100.0	19.7
8- 9	540.7	8.2	0.0	100.0	38.8
9-10	766.8	8.7	0.0	100.0	58.7
10-11	942.8	8.9	0.0	100.0	73.8
11-12	1039.3	9.0	0.0	100.0	81.9
12-13	1039.3	8.9	0.0	100.0	81.7
13-14	942.8	8.8	0.0	100.0	73.2
14-15	766.8	8.6	0.0	100.0	58.0
15-16	540.7	8.0	0.0	100.0	38.2
16-17	300.3	7.3	0.0	100.0	19.4
17-18	120.2	9.1	0.0	100.0	9.6
18-19	31.3	9.2	0.0	100.0	2.5
MONTH	7482.7	8.6	281.3	0.9	565.2

(continued)

Fig. C.4 Continued.

AUG

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
5- 6	1.5	9.3	25.6	0.5	0.0
6- 7	94.3	9.3	0.0	100.0	7.7
7- 8	325.7	7.6	0.0	100.0	21.8
8- 9	581.5	8.5	0.0	100.0	43.7
9-10	824.1	8.9	0.0	100.0	64.8
10-11	1014.5	9.0	0.0	100.0	80.8
11-12	1119.2	9.0	0.0	100.0	89.1
12-13	1119.2	9.0	0.0	100.0	88.9
13-14	1014.5	9.0	0.0	100.0	80.2
14-15	824.1	8.8	0.0	100.0	64.1
15-16	581.5	8.4	0.0	100.0	43.0
16-17	325.7	7.5	0.0	100.0	21.4
17-18	94.3	9.1	0.0	100.0	7.6
18-19	1.5	9.2	25.6	0.5	0.0
MONTH	7921.6	8.8	306.9	0.1	612.9

SEP

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
6- 7	93.2	6.5	24.8	21.6	0.0
7- 8	316.5	8.2	0.0	100.0	23.0
8- 9	568.0	9.1	0.0	100.0	45.3
9-10	810.1	9.3	0.0	100.0	66.0
10-11	1001.7	9.3	0.0	100.0	81.7
11-12	1107.6	9.2	0.0	100.0	90.0
12-13	1107.6	9.2	0.0	100.0	89.9
13-14	1001.7	9.2	0.0	100.0	81.2
14-15	810.1	9.2	0.0	100.0	65.3
15-16	568.0	8.9	0.0	100.0	44.7
16-17	316.5	8.1	0.0	100.0	22.6
17-18	93.2	6.4	0.0	100.0	5.3
MONTH	7794.1	9.0	321.8	1.7	615.1

(continued)

Fig. C.4 Continued.

OCT

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
6- 7	87.6	6.0	25.6	18.0	0.0
7- 8	327.4	8.9	0.0	100.0	25.6
8- 9	604.8	9.5	0.0	100.0	50.4
9-10	876.1	9.6	0.0	100.0	73.8
10-11	1092.9	9.5	0.0	100.0	91.6
11-12	1213.3	9.5	0.0	100.0	101.1
12-13	1213.3	9.5	0.0	100.0	100.9
13-14	1092.9	9.5	0.0	100.0	91.0
14-15	876.1	9.5	0.0	100.0	73.0
15-16	604.8	9.3	0.0	100.0	49.7
16-17	327.4	8.7	0.0	100.0	25.2
17-18	87.6	5.9	0.0	100.0	4.6
MONTH	8404.2	9.4	332.5	1.4	687.1

NOV

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
7- 8	256.8	9.4	24.8	57.3	7.2
8- 9	500.3	9.9	0.0	100.0	43.4
9-10	741.6	9.9	0.0	100.0	64.4
10-11	935.8	9.8	0.0	100.0	80.8
11-12	1044.0	9.8	0.0	100.0	89.6
12-13	1044.0	9.7	0.0	100.0	89.5
13-14	935.8	9.8	0.0	100.0	80.4
14-15	741.6	9.8	0.0	100.0	63.9
15-16	500.3	9.8	0.0	100.0	42.9
16-17	256.8	9.3	0.0	100.0	21.1
MONTH	6956.9	9.8	371.3	3.8	583.1

(continued)

Fig. C.4 Continued.

DEC

TIME	SOLAR KW-HR	EFF %	LOAD KW-HR	FO %	XSO KW-HR
7- 8	224.7	9.8	25.6	48.4	6.9
8- 9	457.0	10.1	0.0	100.0	40.5
9-10	689.0	10.1	0.0	100.0	61.0
10-11	876.3	10.0	0.0	100.0	77.1
11-12	980.9	9.9	0.0	100.0	85.8
12-13	980.9	9.9	0.0	100.0	85.6
13-14	876.3	9.9	0.0	100.0	76.7
14-15	689.0	10.0	0.0	100.0	60.5
15-16	457.0	10.0	0.0	100.0	40.1
16-17	224.7	9.7	0.0	100.0	19.1
MONTH	6455.9	10.0	383.6	3.2	553.3

SUMMARY

	SOLAR KW-HR	LOAD KW-HR	F %	BUY KW-HR	XS KW-HR
JAN	6414.4	383.6	91.1	34.0	215.0
FEB	6479.6	346.5	94.9	17.6	232.4
MAR	7636.6	358.1	97.4	9.4	291.6
APR	6259.7	321.8	96.7	10.5	245.1
MAY	6878.4	281.3	98.8	3.3	262.5
JUN	6913.3	272.3	99.9	0.4	253.7
JUL	7482.7	281.3	100.2	-0.5	286.0
AUG	7921.6	306.9	100.0	0.1	306.3
SEP	7794.1	321.8	99.0	3.3	302.0
OCT	8404.2	332.5	99.3	2.2	361.4
NOV	6956.9	371.3	95.2	17.8	243.8
DEC	6455.9	383.6	91.6	32.4	214.4
YR	86197.3	3960.8	96.7	130.3	3214.1

Fig. C.4 Continued.

the D.C. power produced. It is useful to compare the monthly load (LOAD) to the energy stored (XSO). While the latter two quantities cannot be directly related due to the transient collection conditions, the fact that more energy is available for storage (XSO) than is used by the load (LOAD) indicates that the daytime collection may completely offset the nighttime energy usage.

The Summary, shown in Fig. C.4, shows the percent of the energy required which is provided by solar energy (FO). With this design, backup electricity must be purchased in all months but July, but at least 91.1 percent of the monthly energy required is provided by solar energy. The annual fraction of 96.7 percent is probably high and improved economics would result with a lower fraction of the power being supplied by solar energy.

The output of the economic analysis (Fig. C.5) shows that the annual conventional electric cost would be greatly reduced with the use of solar energy, and that there is an overall life cycle savings through the use of solar energy.

The quality of the input data determines the accuracy of the results. When using this design tool (PV F-Chart), each factor should be checked for the products currently available. For example, the price of photovoltaic cells is expected to drop over time and their efficiencies are continuing to slowly increase. It is easy to change the input data to compare how changes, such as array size, battery size, and costs, affect the output, but some judgement is required. If the array area is doubled, the overall efficiency

FIRST YEAR ELECT COST (W/O PV)	$	396
FIRST YEAR ELECT COST (WITH PV)	$	13
INITIAL INVESTMENT	$	64000
DOWN PAYMENT-TAX CREDIT	$	6400
20 YEAR MORTGAGE PAYMENT	$	0
RESALE VALUE	$	64000
ANNUALIZED PAYMENT	$	40
LIFE CYCLE SAVNGS	$	5291

LIFE CYCLE COSTS

ELECTRICITY	$	187
EQUIPMENT	$	209
TOTAL	$	396

BREAKDOWN OF EQUIPMENT COSTS

EXPENSES			CREDITS		
DOWN PAYMENT	$	64000	INTEREST	$	0
MORTGAGE	$	0	DEPRECIATION	$	0
MAINT. & INS.	$	7540	RESALE	$	64000
PROP. TAX	$	0	TAX CREDITS	$	57600

*** ANNUAL CASH POSITION ***

YR	MAINT & INS	PROP TAX	EN- ERGY	TAX SAVE	SAV- INGS	PRES WORTH
0	0	0	0	57600	-6400	-6400
1	768	0	13	0	-385	-356
2	768	0	14	0	-366	-314
3	768	0	14	0	-346	-274
4	768	0	15	0	-325	-239
5	768	0	16	0	-302	-206
6	768	0	17	0	-279	-176
7	768	0	17	0	-255	-149
8	768	0	18	0	-229	-124
9	768	0	19	0	-202	-101
10	768	0	20	0	-174	-80
11	768	0	21	0	-144	-62
12	768	0	22	0	-113	-45
13	768	0	23	0	-80	-29
14	768	0	25	0	-46	-16
15	768	0	26	0	-10	-3
16	768	0	27	0	28	8
17	768	0	28	0	68	18
18	768	0	30	0	110	28
19	768	0	31	0	154	36
20	768	0	33	0	64200	13774
TOT	15360	0	431	57600	54906	5291

Fig. C.5 Example PV F-Chart Economics Output for Low Level Lighting.

probably will not be doubled, and the economic viability of the project will most likely decrease in this case. With some experience using the program, the optimal photovoltaic system can be determined.

To demonstrate the effects of varying the array area and the battery storage capacity, three additional program runs are included in this appendix. Figure C.6 presents the results for half the battery storage size but the same array area as the original run. The overall fraction of the energy supplied by solar drops by only about 2.4 percent over the original case, but Fig. C.7 shows that the overall savings are reduced by $137.

Figure C.8 presents the results for the case with half the collector area but the battery capacity is the same as for the original size. Figure C.9 shows that the percent of the energy supplied by solar energy has dropped by 26.7 percentage points and that the savings are reduced by $1422 over the life of the system.

Figure C.10 presents the results when both the collector area and the battery storage capacity are halved. Figure C.11 shows that the percent of the energy supplied by solar is reduced by 28.5 percentage points over the original case and $1505 less savings can be expected. In these cases, when the size of the system is doubled, twice the savings and twice the solar energy supplied to the load cannot be expected.

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** BATTERY STORAGE SYSTEM **
1  CITY CALL NUMBER..............  14
2  OUTPUT 1=SUM 2=DET NEG=GRAPH..  1
3  CELL TEMP AT NOCT CONDITIONS..  100         F
4  ARRAY REFERENCE EFFICIENCY....  .11
5  ARRAY REFERENCE TEMPERATURE...  95          F
6  ARRAY TEMP COEFFICIENT * 1000.  2.39        1/F
7  POWER TRACKING EFFICIENCY.....  .9
8  POWER CONDITIONING EFFICIENCY.  .88
9  % STANDARD DEVIATION OF LOAD..  0           %
10 EFFECTIVE BATTERY CAPACITY....  21          KW-HR
11 BATTERY EFFICIENCY............  .8
12 ARRAY AREA....................  600         FT2
13 ARRAY SLOPE...................  60          DEG
14 ARRAY AZIMUTH (SOUTH=0).......  0           DEG

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  4
2  COST PER UNIT AREA............  100         $/FT2
3  AREA INDEPENDENT COST.........  4000        $
4  PERIOD OF ECONOMIC ANALYSIS...  20          YEARS
5  % DOWN PAYMENT................  100         %
6  ANNUAL % MORTGAGE INTEREST....  10          %
7  TERM OF MORTGAGE..............  20          YEARS
8  ANNUAL % MARKET DISCOUNT RATE.  8           %
9  % EXTRA INSUR & MAINT IN YR 1.  1.2         %
10 ANNUAL % INCREASE IN I & M....  5           %
11 EFF FED+STATE INCOME TAX RATE.  0           %
12 TRUE % PROPERTY TAX RATE......  0           %
13 ANNUAL % INCREASE IN PROP TAX.  0           %
14 % RESALE VALUE................  100         %
15 CONSIDER REBATES? 1=Y 2=N.....  1
16   % REBATE IN TIER 1..........  90          %
17   MAX INVESTMENT IN TIER 1....  100000      $
18   % REBATE IN TIER 2..........  90          %
19   MAX INVESTMENT IN TIER 2....  100000      $
20 COMMERCIAL SYSTEM? 1=Y 2=N....  2
21   COMM. DEPRECIATION SCHEDULE.            %
 25   38   37   0   0   0   0   0   0   0
22 COST OF ELECT. (OFF PEAK).....  .1          $/KW-HR
23 ANNUAL % INCREASE IN ELECT....  5           %
```

Fig. C.6 Example Input with Half the Battery Storage.

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*** BATTERY STORAGE SYSTEM ***

SUMMARY

	SOLAR KW-HR	LOAD KW-HR	F %	BUY KW-HR	XS KW-HR
JAN	6414.4	383.6	86.5	51.7	232.7
FEB	6479.6	346.5	91.4	29.7	244.5
MAR	7636.6	358.1	94.7	18.9	301.1
APR	6859.7	321.8	93.1	22.1	256.6
MAY	6878.4	281.3	96.3	10.4	269.7
JUN	6913.3	272.3	99.5	1.3	254.6
JUL	7482.7	281.3	100.6	-1.6	284.9
AUG	7921.6	306.9	99.9	0.2	306.5
SEP	7794.1	321.8	97.6	7.8	306.5
OCT	8404.2	332.5	98.4	5.3	364.5
NOV	6956.9	371.3	91.9	30.2	256.2
DEC	6455.9	383.6	87.1	49.6	231.6
YR	86197.3	3960.8	94.3	225.7	3309.4

(continued)

Fig. C.7 Example Output with Half the Battery Storage.

FIRST YEAR ELECT COST (W/O PV)	$	396
FIRST YEAR ELECT COST (WITH PV)	$	23
INITIAL INVESTMENT	$	64000
DOWN PAYMENT-TAX CREDIT	$	6400
20 YEAR MORTGAGE PAYMENT	$	0
RESALE VALUE	$	64000
ANNUALIZED PAYMENT	$	54
LIFE CYCLE SAVNGS	$	5154

LIFE CYCLE COSTS

ELECTRICITY	$	324
EQUIPMENT	$	209
TOTAL	$	533

BREAKDOWN OF EQUIPMENT COSTS

EXPENSES			CREDITS		
DOWN PAYMENT	$	64000	INTEREST	$	0
MORTGAGE	$	0	DEPRECIATION	$	0
MAINT. & INS.	$	7540	RESALE	$	64000
PROP. TAX	$	0	TAX CREDITS	$	57600

*** ANNUAL CASH POSITION ***

YR	MAINT & INS	PROP TAX	EN-ERGY	TAX SAVE	SAV-INGS	PRES WORTH
0	0	0	0	57600	-6400	-6400
1	768	0	23	0	-394	-365
2	768	0	24	0	-376	-322
3	768	0	25	0	-356	-283
4	768	0	26	0	-336	-247
5	768	0	27	0	-314	-214
6	768	0	29	0	-291	-184
7	768	0	30	0	-267	-156
8	768	0	32	0	-242	-131
9	768	0	33	0	-216	-108
10	768	0	35	0	-189	-87
11	768	0	37	0	-160	-68
12	768	0	39	0	-129	-51
13	768	0	41	0	-97	-36
14	768	0	43	0	-64	-22
15	768	0	45	0	-28	-9
16	768	0	47	0	9	2
17	768	0	49	0	47	13
18	768	0	52	0	88	22
19	768	0	54	0	131	30
20	768	0	57	0	64176	13769
TOT	15360	0	746	57600	54591	5154

Fig. C.7 Continued.

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** BATTERY STORAGE SYSTEM **
1  CITY CALL NUMBER..............  14
2  OUTPUT 1=SUM 2=DET NEG=GRAPH..  1
3  CELL TEMP AT NOCT CONDITIONS..  100           F
4  ARRAY REFERENCE EFFICIENCY....  .11
5  ARRAY REFERENCE TEMPERATURE...  95            F
6  ARRAY TEMP COEFFICIENT * 1000.  2.39          1/F
7  POWER TRACKING EFFICIENCY.....  .9
8  POWER CONDITIONING EFFICIENCY.  .98
9  % STANDARD DEVIATION OF LOAD..  0             %
10 EFFECTIVE BATTERY CAPACITY....  42            KW-HR
11 BATTERY EFFICIENCY............  .8
12 ARRAY AREA....................  300           FT2
13 ARRAY SLOPE...................  60            DEG
14 ARRAY AZIMUTH (SOUTH=0).......  0             DEG

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  4
2  COST PER UNIT AREA............  100           $/FT2
3  AREA INDEPENDENT COST.........  4000          $
4  PERIOD OF ECONOMIC ANALYSIS...  20            YEARS
5  % DOWN PAYMENT................  100           %
6  ANNUAL % MORTGAGE INTEREST....  10            %
7  TERM OF MORTGAGE..............  20            YEARS
8  ANNUAL % MARKET DISCOUNT RATE.  8             %
9  % EXTRA INSUR & MAINT IN YR 1.  1.2           %
10 ANNUAL % INCREASE IN I & M....  5             %
11 EFF FED+STATE INCOME TAX RATE.  0             %
12 TRUE % PROPERTY TAX RATE......  0             %
13 ANNUAL % INCREASE IN PROP TAX.  0             %
14 % RESALE VALUE................  100           %
15 CONSIDER REBATES? 1=Y 2=N.....  1
16   % REBATE IN TIER 1..........  90            %
17   MAX INVESTMENT IN TIER 1....  100000        $
18   % REBATE IN TIER 2..........  90            %
19   MAX INVESTMENT IN TIER 2....  100000        $
20 COMMERCIAL SYSTEM? 1=Y 2=N....  2
21   COMM. DEPRECIATION SCHEDULE.              %
  25   38   37   0   0   0   0   0   0   0
22 COST OF ELECT. (OFF PEAK).....  .1            $/KW-HR
23 ANNUAL % INCREASE IN ELECT....  5             %
```

Fig. C.8 Example Input with Half the PV Array Area.

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*** BATTERY STORAGE SYSTEM ***
```

SUMMARY

	SOLAR KW-HR	LOAD KW-HR	F %	BUY KW-HR	XS KW-HR
JAN	3207.2	383.6	57.2	164.4	63.0
FEB	3239.8	346.5	63.2	127.4	61.6
MAR	3818.3	358.1	70.2	106.7	68.8
APR	3429.8	321.8	67.3	105.1	61.6
MAY	3439.2	281.3	75.4	69.2	58.2
JUN	3456.7	272.3	77.2	62.2	52.7
JUL	3741.4	281.3	81.2	52.9	55.5
AUG	3960.8	306.9	79.9	61.7	61.4
SEP	3897.0	321.8	75.9	77.5	66.0
OCT	4202.1	332.5	81.7	60.8	74.1
NOV	3478.4	371.3	63.0	137.4	64.8
DEC	3227.9	383.6	57.4	163.6	62.8
YR	43098.7	3960.8	70.0	1189.1	750.5

(continued)

Fig. C.9 Example Output with Half the PV Array Area.

FIRST YEAR ELECT COST (W/O PV)	$	396
FIRST YEAR ELECT COST (WITH PV)	$	119
INITIAL INVESTMENT	$	34000
DOWN PAYMENT-TAX CREDIT	$	3400
20 YEAR MORTGAGE PAYMENT	$	0
RESALE VALUE	$	34000
ANNUALIZED PAYMENT	$	185
LIFE CYCLE SAVNGS	$	3869

LIFE CYCLE COSTS

ELECTRICITY	$	1707
EQUIPMENT	$	111
TOTAL	$	1818

BREAKDOWN OF EQUIPMENT COSTS

EXPENSES			CREDITS		
DOWN PAYMENT	$	34000	INTEREST	$	0
MORTGAGE	$	0	DEPRECIATION	$	0
MAINT. & INS.	$	4006	RESALE	$	34000
PROP. TAX	$	0	TAX CREDITS	$	30600

*** ANNUAL CASH POSITION ***

YR	MAINT & INS	PROP TAX	EN-ERGY	TAX SAVE	SAV-INGS	PRES WORTH
0	0	0	0	30600	-3400	-3400
1	408	0	119	0	-131	-121
2	408	0	125	0	-117	-100
3	408	0	131	0	-102	-81
4	408	0	138	0	-87	-64
5	408	0	145	0	-71	-48
6	408	0	152	0	-54	-34
7	408	0	159	0	-37	-21
8	408	0	167	0	-18	-10
9	408	0	176	0	2	1
10	408	0	184	0	22	10
11	408	0	194	0	43	19
12	408	0	203	0	66	26
13	408	0	214	0	90	33
14	408	0	224	0	115	39
15	408	0	235	0	141	44
16	408	0	247	0	168	49
17	408	0	260	0	197	53
18	408	0	273	0	227	57
19	408	0	286	0	259	60
20	408	0	300	0	34292	7357
TOT	8160	0	3932	30600	31605	3869

Fig. C.9 Continued.

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** BATTERY STORAGE SYSTEM **
1  CITY CALL NUMBER..............  14
2  OUTPUT 1=SUM 2=DET NEG=GRAPH..  1
3  CELL TEMP AT NOCT CONDITIONS..  100         F
4  ARRAY REFERENCE EFFICIENCY....  .11
5  ARRAY REFERENCE TEMPERATURE...  95          F
6  ARRAY TEMP COEFFICIENT * 1000.  2.39        1/F
7  POWER TRACKING EFFICIENCY.....  .9
8  POWER CONDITIONING EFFICIENCY.  .88
9  % STANDARD DEVIATION OF LOAD..  0           %
10 EFFECTIVE BATTERY CAPACITY....  21          KW-HR
11 BATTERY EFFICIENCY............  .8
12 ARRAY AREA....................  300         FT2
13 ARRAY SLOPE...................  60          DEG
14 ARRAY AZIMUTH (SOUTH=0).......  0           DEG

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  4
2  COST PER UNIT AREA............  100         $/FT2
3  AREA INDEPENDENT COST.........  4000        $
4  PERIOD OF ECONOMIC ANALYSIS...  20          YEARS
5  % DOWN PAYMENT................  100         %
6  ANNUAL % MORTGAGE INTEREST....  10          %
7  TERM OF MORTGAGE..............  20          YEARS
8  ANNUAL % MARKET DISCOUNT RATE.  8           %
9  % EXTRA INSUR & MAINT IN YR 1.  1.2         %
10 ANNUAL % INCREASE IN I & M....  5           %
11 EFF FED+STATE INCOME TAX RATE.  0           %
12 TRUE % PROPERTY TAX RATE......  0           %
13 ANNUAL % INCREASE IN PROP TAX.  0           %
14 % RESALE VALUE................  100         %
15 CONSIDER REBATES? 1=Y 2=N.....  1
16   % REBATE IN TIER 1..........  90          %
17   MAX INVESTMENT IN TIER 1....  100000      $
18   % REBATE IN TIER 2..........  90          %
19   MAX INVESTMENT IN TIER 2....  100000      $
20 COMMERCIAL SYSTEM? 1=Y 2=N....  2
21   COMM. DEPRECIATION SCHEDULE.           %
  25   38   37   0   0   0   0   0   0   0
22 COST OF ELECT. (OFF PEAK).....  .1          $/KW-HR
23 ANNUAL % INCREASE IN ELECT....  5           %
```

Fig. C.10 Example Input with Half the Battery Storage and Half the PV Array Area.

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*** BATTERY STORAGE SYSTEM ***

SUMMARY

	SOLAR KW-HR	LOAD KW-HR	F %	BUY KW-HR	XS KW-HR
JAN	3207.2	383.6	55.4	170.9	69.6
FEB	3239.8	346.5	61.5	133.3	67.5
MAR	3818.3	358.1	68.1	114.1	76.1
APR	3429.8	321.8	65.0	112.6	69.0
MAY	3439.2	281.3	72.5	77.3	66.3
JUN	3456.7	272.3	76.7	63.4	54.0
JUL	3741.4	281.3	82.2	50.2	52.7
AUG	3960.8	306.9	79.8	62.0	61.7
SEP	3897.0	321.8	74.2	82.9	71.4
OCT	4202.1	332.5	79.8	67.0	80.4
NOV	3478.4	371.3	61.4	143.2	70.6
DEC	3227.9	383.6	55.7	169.9	69.1
YR	43098.7	3960.8	68.5	1246.8	808.2

(continued)

Fig. C.11 Example Output with Half the Battery Storage and Half the PV Array Area.

FIRST YEAR ELECT COST (W/O PV)	$	396
FIRST YEAR ELECT COST (WITH PV)	$	125
INITIAL INVESTMENT	$	34000
DOWN PAYMENT-TAX CREDIT	$	3400
20 YEAR MORTGAGE PAYMENT	$	0
RESALE VALUE	$	34000
ANNUALIZED PAYMENT	$	194
LIFE CYCLE SAVNGS	$	3786

LIFE CYCLE COSTS

ELECTRICITY	$	1790
EQUIPMENT	$	111
TOTAL	$	1901

BREAKDOWN OF EQUIPMENT COSTS

EXPENSES			CREDITS		
DOWN PAYMENT	$	34000	INTEREST	$	0
MORTGAGE	$	0	DEPRECIATION	$	0
MAINT. & INS.	$	4006	RESALE	$	34000
PROP. TAX	$	0	TAX CREDITS	$	30600

*** ANNUAL CASH POSITION ***

YR	MAINT & INS	PROP TAX	EN-ERGY	TAX SAVE	SAV-INGS	PRES WORTH
0	0	0	0	30600	-3400	-3400
1	408	0	125	0	-137	-126
2	408	0	131	0	-123	-105
3	408	0	137	0	-109	-86
4	408	0	144	0	-94	-69
5	408	0	152	0	-78	-53
6	408	0	159	0	-62	-39
7	408	0	167	0	-44	-26
8	408	0	175	0	-26	-14
9	408	0	184	0	-7	-4
10	408	0	193	0	13	6
11	408	0	203	0	34	15
12	408	0	213	0	56	22
13	408	0	224	0	79	29
14	408	0	235	0	104	35
15	408	0	247	0	129	41
16	408	0	259	0	156	46
17	408	0	272	0	184	50
18	408	0	286	0	214	54
19	408	0	300	0	245	57
20	408	0	315	0	34278	7354
TOT	8160	0	4123	30600	31414	3786

Fig. C.11 Continued.

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