Hq. 6160

SOLAR/1029-80/50
DISTRIBUTION CATEGORY UC-59

Solar Project Description

DESIGN CONSTRUCTION ASSOCIATION SINGLE FAMILY DWELLING Big Fork, Montana April 4 , 1980

U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

DISCLAIMER

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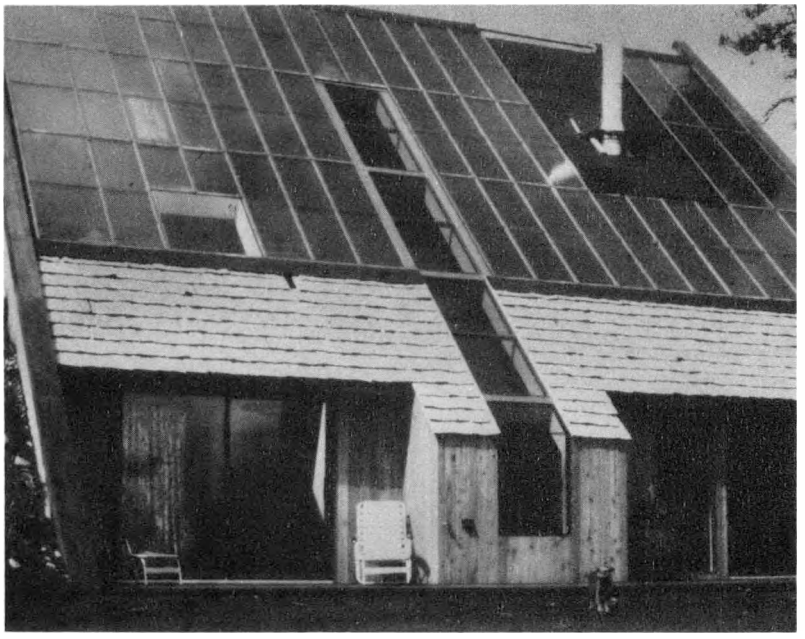
SOLAR PROJECT DESCRIPTION
FOR
DESIGN CONSTRUCTION ASSOCIATION
SINGLE FAMILY DWELLING - BIG FORK, MONTANA



Department of Housing and Urban Development

Under Contract Number

H-2372

David Moore
Solar Heating and Cooling Demonstration Program Manager

By

The Boeing Company
David Beers, Program Manager

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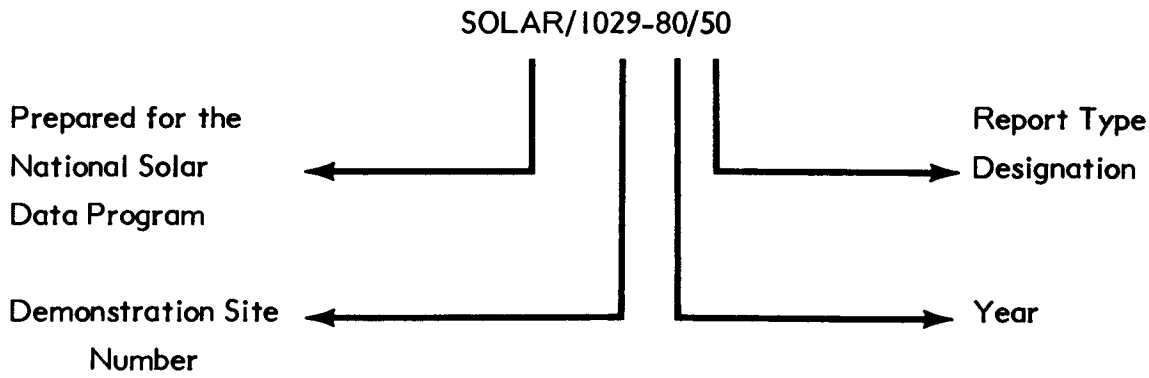
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under a specific format. For example, this report for the Design Construction Association project site is designated as SOLAR/1029-80/50. The elements of this designation are explained in the following illustration:



Demonstration Site Number: Each project has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

Report Type Designation:
This number identifies the type of report, e.g.,

- Monthly Performance Reports -- designated by the numbers 01 (for January) through 12 (for December);
- Solar Energy System Performance Evaluations -- designated by the number 14;
- Solar Project Descriptions -- designated by the number 50;
- Solar Project Cost Reports -- designated by the number 60.

These reports are disseminated through the U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

I. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy (DOE) as mandated by the Solar Heating and Cooling Demonstration Act of 1974. The Department of Housing & Urban Development is responsible to DOE for the Solar Residential Demonstration Program. The overall goal of the Federal Demonstration Program is to assist in the establishment of a viable solar industry and to achieve a substantial reduction in fossil fuel use through widespread use of solar heating and cooling applications. An analysis and synthesis of the information gathered through this program will be disseminated in site-specific reports and summary documents as products of the National Solar Data Program. These reports will cover topics such as:

- Solar Project Description.
- Operational Experience.
- System Performance Evaluation.
- Monthly Performance Reports.

Information contained herein for this Solar Project Description report has been extracted from data collected during site visits and from reference documents such as the project proposal, designer specifications, grantee submittals, manufacturer literature, photographs, specific "as-built" data and other project documentation available. The remaining reports in this series will utilize the Solar Project Description for supporting reference.

II. EXECUTIVE SUMMARY

The following are the major solar energy descriptors:

- o Collector Type -- Liquid flat plate panels
- o Freeze Protection -- Drain down system
- o Application -- Heating and domestic hot water
- o Storage -- 1,500 gallon water tank
- o New or Retrofit -- New
- o Performance Evaluation Instrumentation -- Yes
- o Site-Specific Features -- Fireplace adjacent to storage tank

The Design Construction Association solar energy system (Grant H-2786) is installed in an 2,100 sq ft house located in Big Fork, Montana. The system is designed to provide solar energy for heating and domestic hot water.

Solar energy is collected by flat plate collectors with a gross area of 792 square feet. The collector banks are mounted on the roof of the house and face due south at an angle of 45 degrees to the horizontal optimizing solar energy collection.

Solar energy is transferred from the collector array to a 1,500 gallon storage tank. Water is used as the heat collection, transfer and storage medium. Freeze protection is provided by use of an anti-freeze compound.

Space heating demands are met by circulating hot water from storage through baseboard units in the distribution system of the house. Auxiliary space heating is provided by an electrical heating element in the boiler. Similarly, an electrical heating element in the DHW tank provides energy for water heating.

The dwelling has been fully instrumented for performance evaluation since October 1977 and the data is integrated into the National Solar Data Network.

Original cost estimates for provisioning and installation of the solar system are given in section VI of this report. However, the final solar system cost and the cost of its instrumentation are not included in this report.

III. GENERAL CHARACTERISTICS (See figure III-1. Site Plan)

The following information covers broadly the general characteristics of this system.

- Building type - Single family detached
- Latitude - 48°
- Longitude - 114°
- Altitude - 2,960 ft

HEATING DESIGN TEMPERATURES

- Outdoor - Minus 7° F DB
- Indoor - 63° F DB

BUILDING

- Building faces - South (buried on other three sides)
- Average stories above ground - ½
- Average stories below ground - 1½
- Height above first floor - 29 ft, 8 inches
- Conditioned floor area - 2,100 ft^2
- Roof type - Sloped

DESIGN HEAT LOSS/LOAD

- Heat Loss - 37,468 Btu/hr
- Heat gain -
- Shading
  - Heating season - 0
  - Cooling season - 0

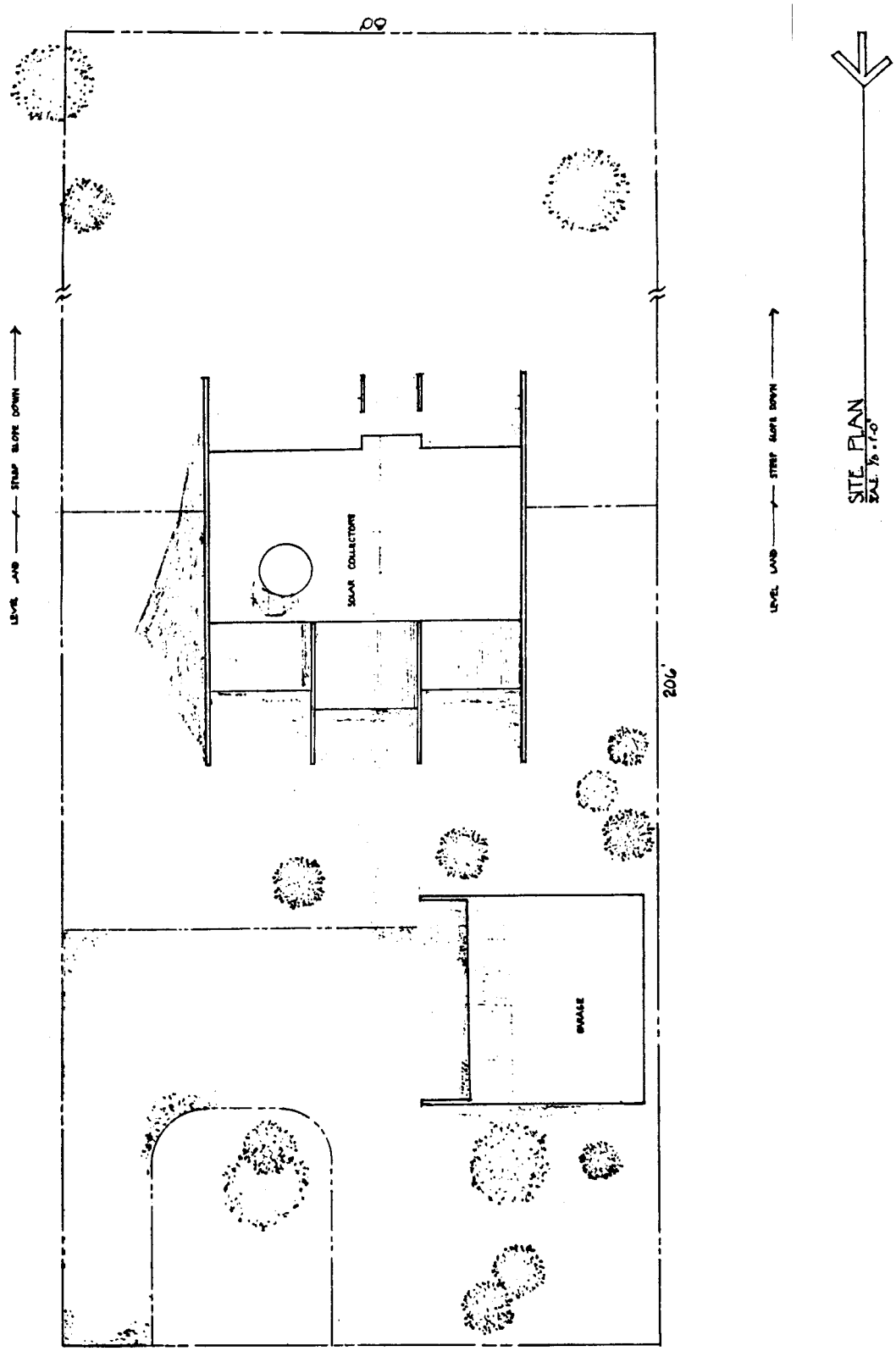


Figure III-1. Site Plan

- Appliance, lighting and equipment load - 1,800 Btu/hr
- Domestic hot water daily requirement - 80 gal/day
- Average horizontal insolation
  - January - 500 Btu/ft^2
  - July - 2,400 Btu/ft^2
- Annual degree days
  - Heating - 8191
  - Data location - Spokane, Wa & Great Falls, Mt
  - Data reference - Local Climatological Data Annual Summaries, Department of Commerce, National Oceanographic and Atmospheric Administration

MECHANICAL SYSTEM

- Heating
  - Solar - Liquid collector, active
  - Auxiliary - Electrical heating element
  - Distribution - Circulation

DOMESTIC HOT WATER

- Daily water demand - 80 gal/day
- Solar - Liquid active collector
- Auxiliary - Electric heating element in DHW

GENERAL DATA

- Manufacturer - Revere Copper and Brass Company
- Model name/number - Unknown
- Type of system - Liquid active

SYSTEM AND COMPONENT SUMMARY

- Collector types - 1
- Circulation loops - 5
- Thermal storage units - 1
- Operational modes - 4
- Pumps - 4
- Valves - 13
- Blowers - 0
- Dampers - 0
- Sensors - 8
- Flow regulators - 0
- Pressure regulators - 0
- Fail safe controls - 5

IV. SOLAR SYSTEM DESCRIPTION

A. General Overview

The Design Construction, site (Grant H-2786) is a single-family residence in Big Fork, Montana. The home is approximately 2,100 square feet of conditioned space. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 792 square feet. The array faces south at an angle of 45 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage and from storage to the space heating and hot water loads. This water is drained from the collector when the collector pump is not operating.

Solar energy is stored in a 1,500 gallon water tank located in the conditioned space. The cylindrical tank has 6 inch concrete walls with 2 inch expanded polyurethane insulation. Preheated city water is stored in a 120 gallon DHW tank.

When solar energy is insufficient to satisfy the space heating load, an electrical heating element in the boiler provides auxiliary energy for space heating. Similarly, an electrical heating element in the DHW tank provides auxiliary energy for water heating. Solar energy in the storage tank is supplemented by auxiliary energy provided by a hydro-heater fireplace which has a heat exchanger water jacket around the chimney. When the fireplace is used, water is circulated from the storage tank through the fireplace and chimney heat exchanger, thereby accumulating additional energy which is returned to the storage tank. Energy from the storage tank is transferred to the DHW tank through an in tank heat exchanger. Hot water used for space heating is passed from storage through the electric boiler and then through a four zone hydronic heating system.

Two fans are installed in the small enclosed chamber above the fireplace in which the fireplace pump (P-4) and the fireplace control sensors are located. These fans are used the cool the chamber ambient and to circulate the warm chamber air into the living space. Both fans operate in parallel with a thermostat in chamber.

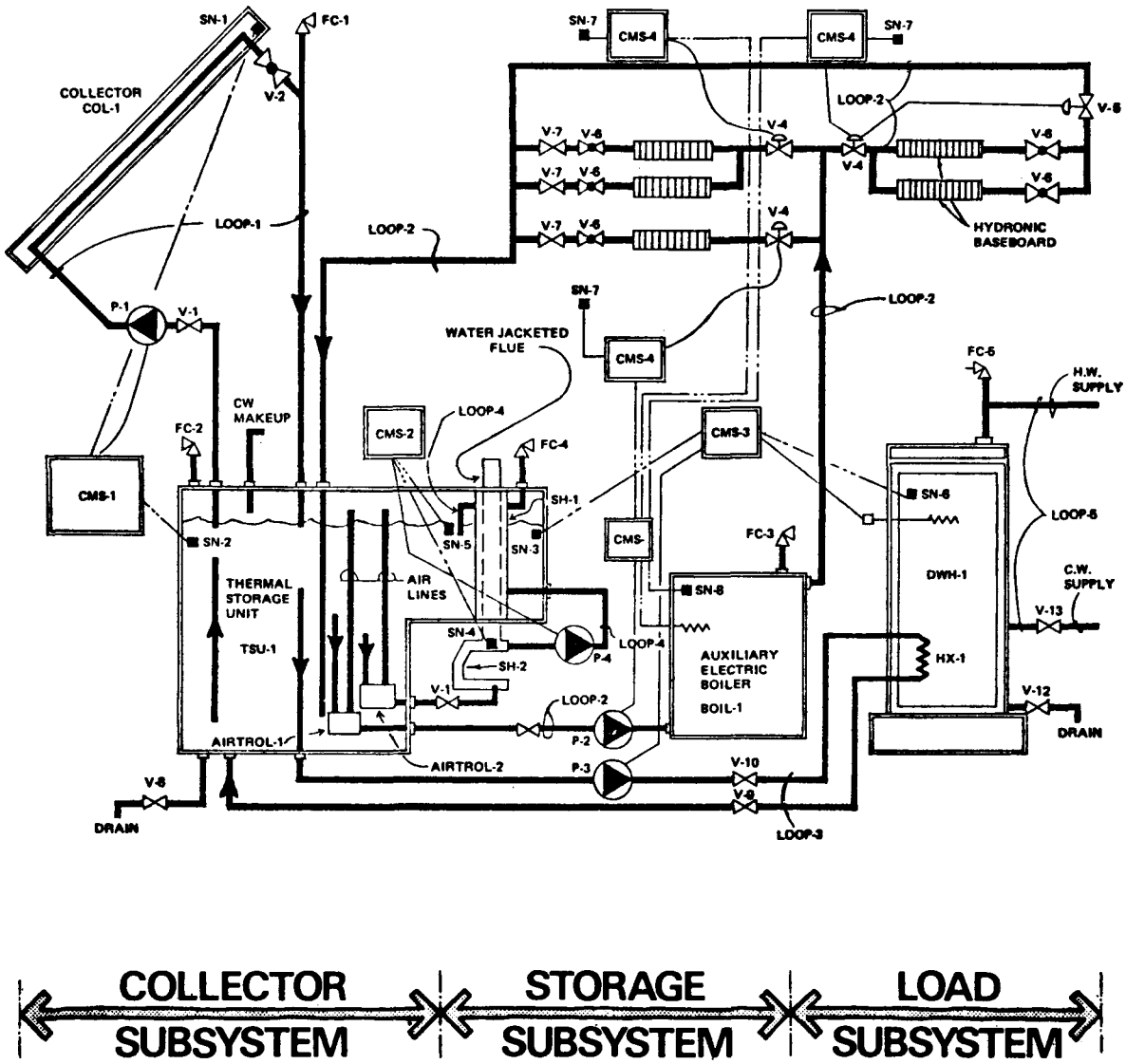


Figure IV-A-1. General Overview

Subsequent sections describe the collector, storage, energy-to-load, and auxiliary subsystem. Specific details of the operating modes and controls are described in the final section. Figure IV-A-1 is a system schematic diagram.

B. Collector Subsystem (See Figure IV-B-1)

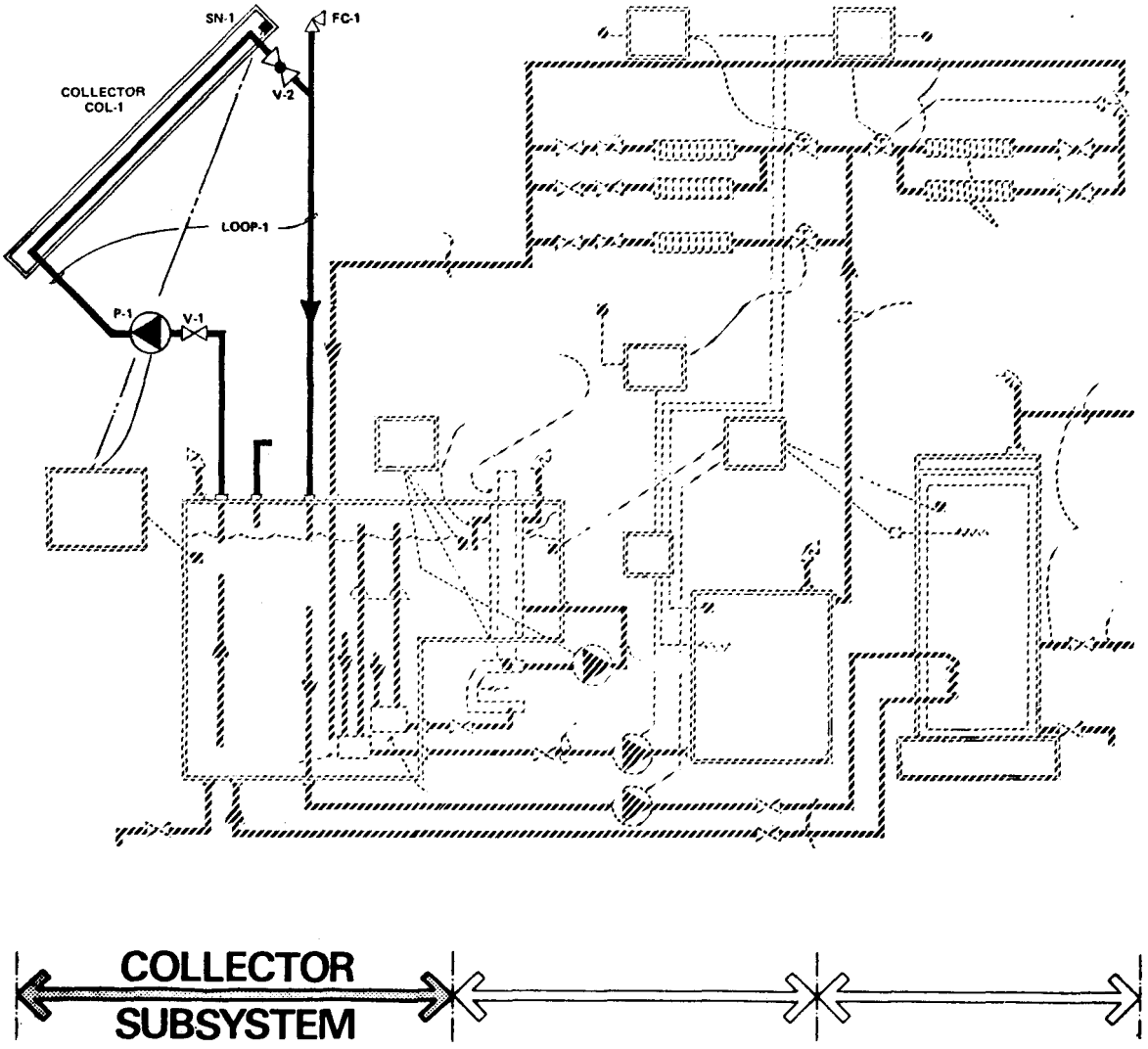


Figure IV-B-1. Collector Subsystem

Collector array system consists of liquid flat place collector panels. Freeze protection is provided by use of a drain down system.

COLLECTOR (COL-1) (See Figure IV-B-2)

- Manufacturer - Revere
- Model name/number - Sun Roof
- Type - Liquid flat plate, tube and plate
- Location - Roof
- Orientation - South
- Tilt angle - 45° from horizontal
- Collector characteristics
  - Number of panels - 51
  - Total gross area of array - 792 ft^2
  - Net aperture area - 792 ft^2
  - Net absorber area - 816 ft^2
  - Weight per panel, empty - 100 lb
  - Weight per panel, full - 103 lb
  - Weight of filled array and support structure - 5,755 lb
  - Panel length - 96.0 inches
  - Panel width - 24.0 inches
  - Frame depth - 1.8 inches
  - Standoff height - 0
- Built-in collector - Yes
- Collector shading -
  - Area shaded in June - 0%
  - Area shaded in December - 0%
  - Maximum shade during functional season - 0% of aperture

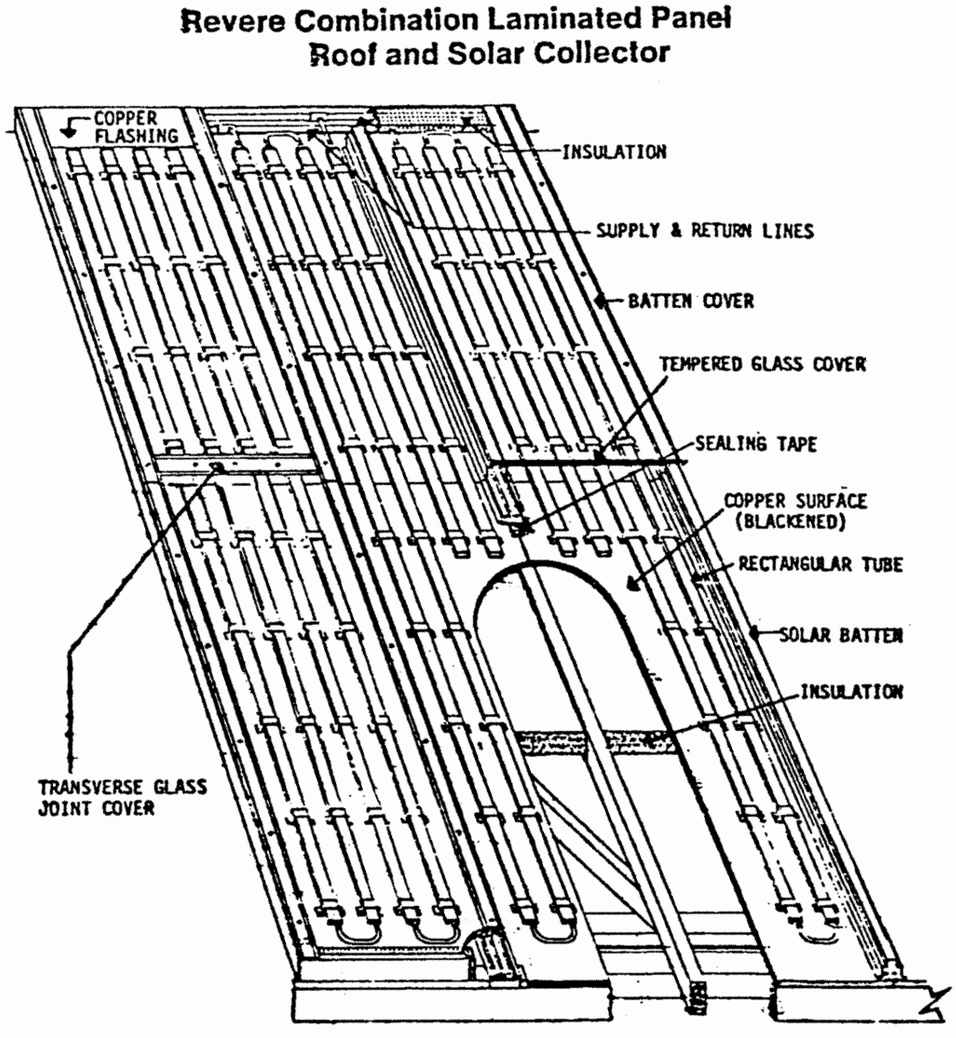


Figure IV-B-2. Solar Collector

- Cover plates
  - Number of cover plates - 2
- Cover plate No. 1
  - Location - Outer layer
  - Manufacturer - Varies
  - Product name/number - Unknown
  - Material - Glass, tempered, low iron
  - Thickness - 0.125 inch
  - Optical properties

	(solar region)	(infrared region)
- Transmittance	91%	91%
- Reflectance	6%	6%
- Emittance	93%	93%

  - Edge or surface treatment, other than coating - Mechanical ground
  - Coating on cover plate material - None
- Cover plate No. 2
  - Location - Inner layer
  - Manufacturer - Varies
  - Product name/number - Unknown
  - Material - Glass tempered, low iron
  - Thickness - 0.125 inch
  - Optical properties

	(solar region)	(infrared region)
- Transmittance	91%	91%
- Reflectance	6%	6%
- Emittance	93%	93%

  - Edge treatment - Mechanical ground
  - Coating - None

- Absorber
  - Manufacturer - Revere
  - Model name/number - Sun Roof
  - Material - Copper
  - Substrate material dimension
    - Thickness - 0.010 inch
    - Length - 96.0 inches
    - Width - 24.0 inches
  - Number of absorbers per collector - 1
- Coating
  - Manufacturer - 3M
  - Model name/number - Nextel Black Velvet
  - Coating material - Flat paint, Black Velvet

	(solar region)	(infrared region)
Absorptance	96%	96%
Reflectance	4%	4%
Emittance	96%	96%

  - Application - Sprayed
- Heat transfer fluid passages
  - Location - Beneath absorber
  - Pattern - Parallel
  - Materials - Copper
  - Wall thickness - 0.032 inch
  - Internal diameter - 0.595 inch
  - Maximum operating conditions
    - Temperature - 296° F
    - Pressure - 65 psi

- Fluid passage bond to substrate - Mechanical connection
- Protective coating inside fluid passage - None

- Insulation
  - Layer one - sides
    - Manufacturer - Varies
    - Product name/number - Fiberglass Batt
    - Material - Rigid urethane
    - Thermal resistance - R-19
  - Layer one - back
    - Manufacturer - Varies
    - Product name/number - Fiberglass Batt
    - Material - Rigid urethane
    - Thermal resistance - R-19
- Gaskets and sealants
  - Inner cover - Various (Dura Ribbon)
  - Outer cover - Various (Dura Ribbon)
  - Backing plate - Various (Dura Ribbon)
  - Penetrations - Various (Dura Ribbon)
- Frame
  - Manufacturer - Revere
  - Product name/number - Sun Roof
  - Material - Wood
  - Protective coating - None
  - Standoffs used - No
  - Number of structure attach points per module to building - Continuous
  - Built-in collector - Yes

- Reflectors - No
  - Desiccant - No
  - Freeze protection - Anti-freeze
  - Overheating protection - None
- Collector performance
  - Method of evaluation - ASHRAE
  - y intercept $F_R(\tau\alpha)_\eta$ - 0.68 $\frac{(^\circ F/hr/ft^2)}{Btu}$
  - Slope - $F_R U_L$ - 1.13

Point Number	1	2	3	4
n = Collector thermal efficiency (η %) -	57.8	46.7	34.6	22.2
t_i or t_f = collector inlet temperature ($^\circ$F) -	110	134	170	200
t_a = ambient air temperature ($^\circ$F) -	77	74	71	65
I_t = insolation intensity Btu/hr ft^2 -	349	318	335	333
ASHRAE $(t_i-t_a)/I_t$ -	0.09	0.19	0.30	0.41

- η = collector thermal efficiency
- U_L = collector heat loss factor
- F_R = collector heat removal factor
- t_a = ambient air temperature, $^\circ$F
- $(\tau\alpha)$ = Transmissivity-absorptivity product at normal incidence
- t_i = collector inlet temperature, $^\circ$F
- t_f = average fluid temperature
- I_t = radiation (insolation) intensity on collector, Btu/hr.ft^2
  - Test flow rate - 60 lb/hr
  - Heat loss coefficient - Unknown
  - Test wind speed - 7 mph

- Test collector area
  - Gross - 16.0 ft^2
  - Net - 14.0 ft^2
- Fluid specific heat - 1.00 Btu/lb/^{o} F
- Test fluid medium - Water

LIQUID CIRCULATION LOOP NO. 1 (COLLECTOR CHARGING STORAGE)

- Maximum design operating temperature - 180^{o} F
- Maximum design operating pressure - 30 psi
- Heating design liquid flow - 30.0 gpm
- Heat transfer medium -
  - Volume of liquid in loop - 1,600 gal
  - Anticipated liquid temperatures - 180^{o} F maximum, 100^{o} F minimum
  - Provisions for expansion - Air cushion in TSU-1
  - Medium - 100% water
  - Specific heat - 1.00 Btu/lb/^{o} F
  - Density - 62.4 lb/ft^3
  - Heat capacity - 62.4 $Btu/ft^3/^{o}$ F
  - Boiling point - 212^{o} F
  - Freezing point - 32^{o} F
  - Maximum recommended use temperature - 200^{o} F
  - Toxicity - Potable
  - pH factor - 7.0
  - Chemical feeder to maintain pH factor - No
  - Inhibitor - No
- Components within circulation loop
  - Pump(s) - P-1
  - Thermal storage unit(s) - TSU-1

- Collector(s) - COL-1
- Valve(s) - V-1, V-2
- Other(s) - Air Trol fitting #1 & baseboard

- Piping
  - Rigid - Copper, type K
  - Piping insulation - None
  - Location - Above grade
  - Filters - None
  - Getters - No
- Circulator pump (P-1)
  - Manufacturer - Bell and Gossett
  - Model name/number - 60 Series
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure - Unknown
    - Temperature - 210° F
  - Material exposed to heat transfer fluid - Plastic (impeller and cast iron body
  - Motor size - 0.50 HP; 230 V; 1 Phase; 60 Hz
  - Maximum motor speed - 1,750 rpm
  - Drive - Direct
  - Speed - Single
  - Pump speed - 1,750 rpm
  - Circulating volume - Low head mode - 30 gpm
  - Operating head (dynamic) - Low head mode - 11.2 psi
  - Motor operation - 0.50 bhp

- Distribution Valve (V-1)
  - Manufacturer - Nibco
  - Model name/number - Unknown
  - Function - ON-OFF
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi
  - Material exposed to heat transfer fluid - Brass
- Distribution Valve (V-2)
  - Manufacturer - Nibco
  - Model name/number - Unknown
  - Function - Flow adjusting
  - Operation - Manual
  - Type - Ball
  - Pressure - 125 psi
  - Materials exposed to heat transfer fluid - Brass

C. Storage Subsystem (See Figure IV-C-1)

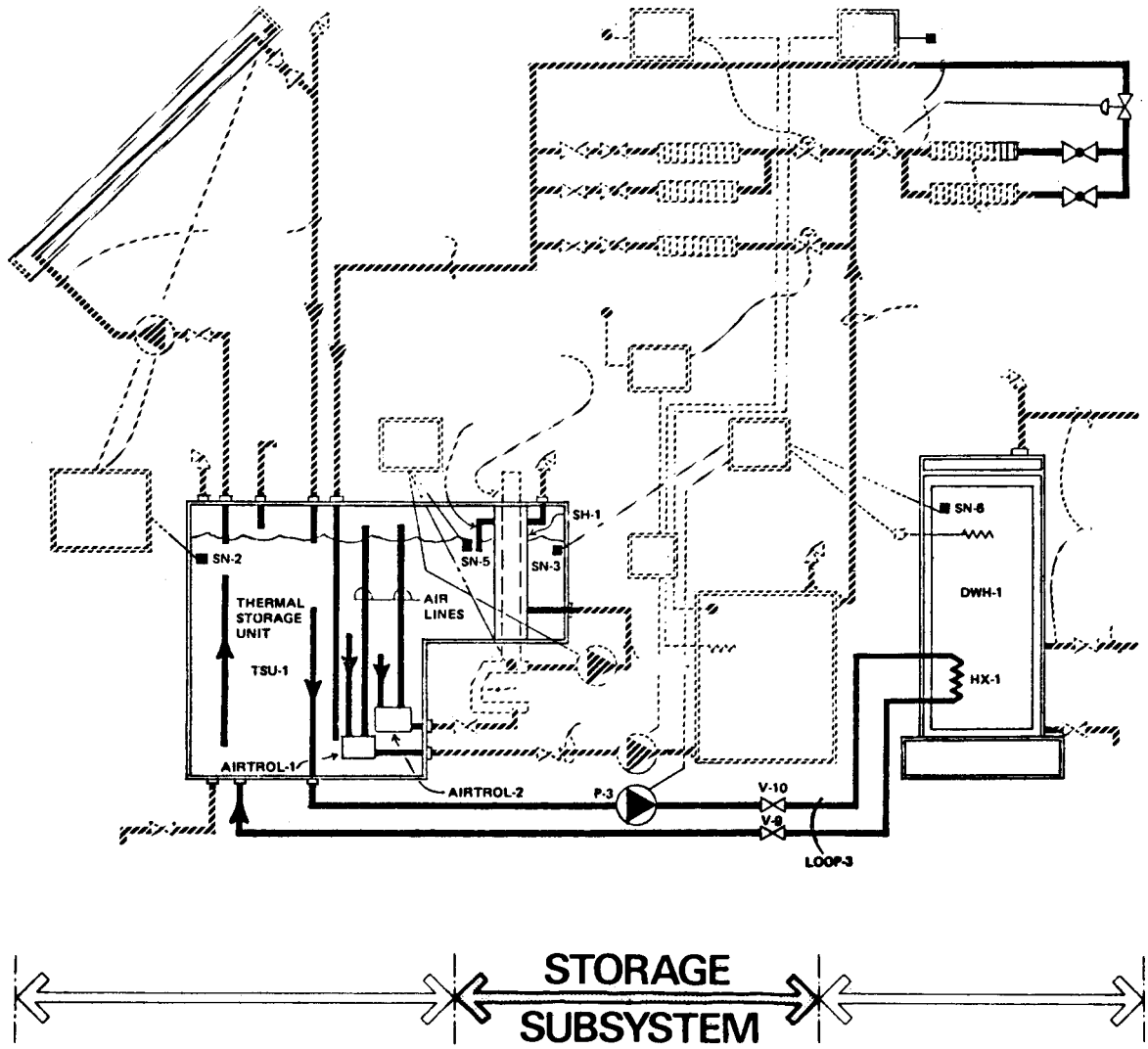


Figure IV-C-1. Storage Subsystem

Solar energy storage is stored in a 1,300 gallon water tank located in the conditioned space. This tank is made of concrete with a 2 inch polyurethane insulation. It measures 10 ft high by 6 ft diameter. Preheated city water is stored in a 120 gallon DWH tank also.

THERMAL STORAGE UNIT (TSU-1)

- Manufacturer - Design Construction
- Model name/number - Field Fabricated
- Total storage container volume - 282 ft^3
- Volume of storage medium - 200 ft^3 (1,300-gal)
  - Height - 10.0 ft
  - Diameter - 6.0 ft
- Maximum rated operating conditions
  - Temperature - 200° F
- Storage medium
  - Design operating temperatures
    - Heating - 180° F Maximum; 100° F Minimum
    - Cooling - N/A
  - Medium - Water (100%)
  - Specific heat - 1.00 Btu/lb/° F
  - Density - 62.4 lb/ft^3
  - Heat capacity - 62.4 Btu/ft^3/° F
  - Boiling point - 212° F
  - Freezing point - 32° F
- Medium manufacturers recommended use of temperature:
  - Maximum - 180° F
- Toxicity - Potable
- pH Factor - 7.0
- Inhibitor - No

- Container
  - Type - Concrete
  - Interior lining - Epoxy
  - Location - Building
  - Auxiliary heaters - No
  - Insulation - Styrofoam
  - Exterior finish - Water resistant paint
  - Filters - No
  - Getters - No

LIQUID CIRCULATION LOOP NO. 2 (SPACE HEATING FROM STORAGE)

- Design operating temperature - 180° F
- Design operating pressure - 30 psi
- Heating
  - Design liquid flow - 10 gpm
  - Design pump speed - 1750 rpm
- Heat transfer medium
  - Volume of liquid in loop - 1,600 gal
  - Anticipated liquid temperature - 180° F Max.; 100° F Min.
  - Provisions for expansion - Air cushion in TSU-1
  - Medium - Water (100%)
  - Specific heat - 1.00 Btu/lb/° F
  - Density - 62.4 lb/ft^3
  - Heat capacity - 62.4 $Btu/ft^3/°$ F
  - Boiling point - 212° F
  - Freezing point - 32° F

- Medium manufacturer's recommended use temperature:
  - Maximum - 180° F
  - Pressure - 11.2 psi
- Toxicity - Potable
- pH factor - 7.0
- Chemical feeder - No
- Inhibitor - No

- Components within circulation loop
  - Pump(s) - P-2
  - Boiler(s) - BOIL-1
  - Thermal storage unit(s) - TSU-1
  - Valve(s) - V-3, V-4, V-5, V-6, V-7
  - Other(s) - None
  - Piping
    - Rigid - Copper
    - Insulation - None
    - Location - Above grade
    - Filters - None
    - Getters - No

- Control Mode Selector (CMS-1)
  - Manufacturer - Heliothrope General
  - Model name/number - DDT-100
  - Modes controlled:
  - Collector to storage
    - ON - (SN-1) > (SN-2) + 9° F
    - OFF - (SN-1) < (SN-2) + 3° F

- Sensors
  - SN-1 - Thermostatic
  - SN-2 - Thermostatic

- Circulator pump (P-2)
  - Manufacturer - Bell and Gossett
  - Model name/number - 100 Series
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure - 3.5 psi
    - Temperature - 210° F
  - Material exposed to heat transfer fluid - Plastic impeller /cast iron body
  - Motor size - 0.08 Hp; 115V; 1 Phase; 60 Hz
  - Maximum motor speed - 1,750 rpm
  - Drive - Direct
  - Speed - Single
  - Pump speed - 1,750 rpm
  - Circulating volume - Low head mode - 10 gpm
  - Operating head (dynamic) - Low head mode -
  - Motor operation - 0.08 bhp

- Distribution Valve (V-3)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - On - Off
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi

- Distribution Valve (V-4)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - On-Off
  - Operation - Automatic, motorized
  - Type - Butterfly
  - Pressure - 125 psi
- Distribution Valve (V-5)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - On-Off
  - Operation - Automatic, motorized
  - Type - Butterfly
  - Pressure - 125 psi
- Distribution Valve (V-6)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Flow adjusting
  - Operation - Manual
  - Type - Butterfly
  - Pressure - 125 psi
- Distribution Valve (V-7)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - On-Off
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi

D. Energy To Load Subsystem (See Figure IV-D-1)

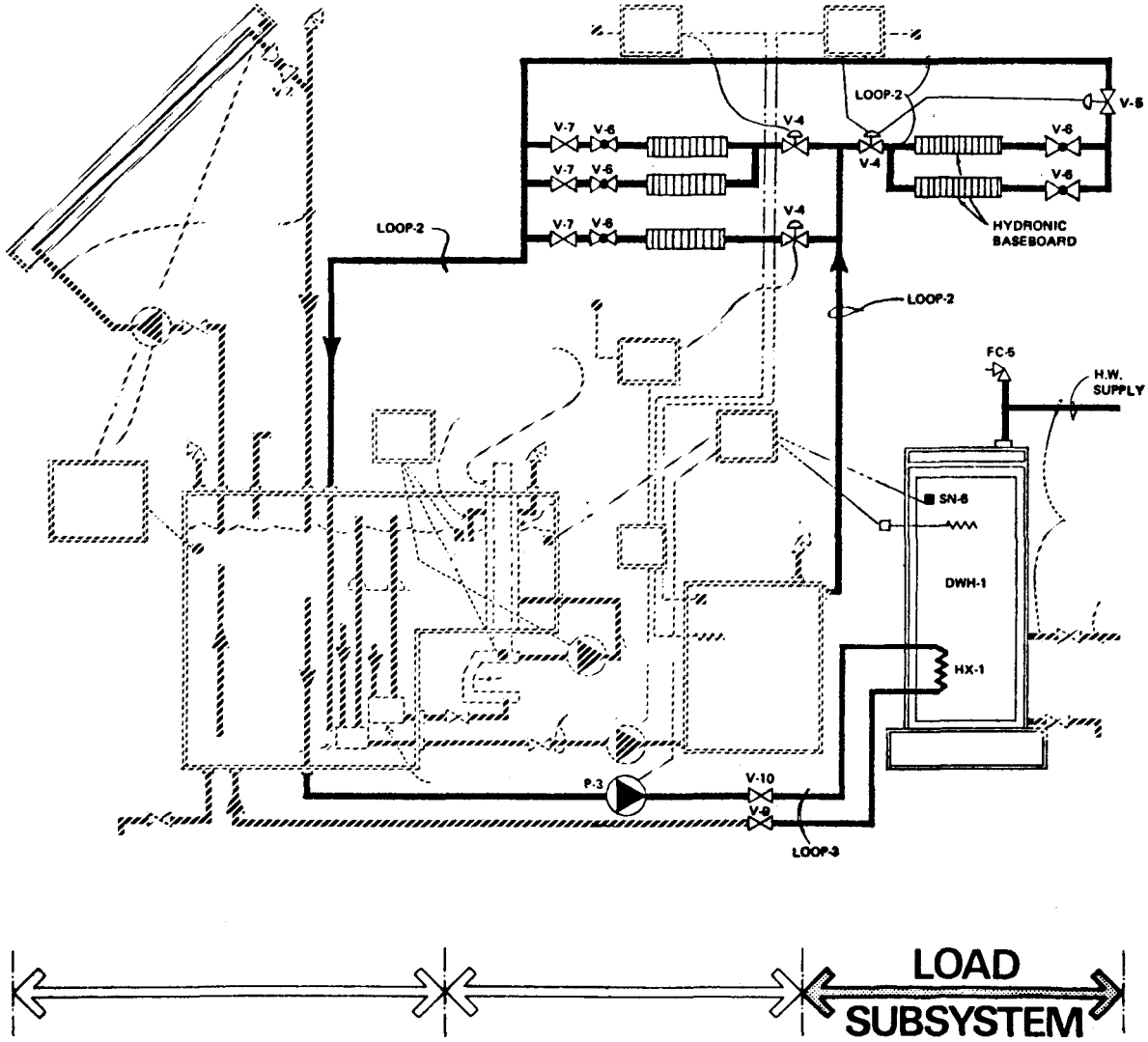


Figure IV-D-1. Energy-to-Load Subsystem

Energy from the storage tank is transferred to the DHW tank through an in-tank exchanger (HX-1). Hot water used for space heating is passed from storage through the electric hot water boiler and then through a four-zone hydronic heating system.

Domestic hot water is supplied by DWH-1 if solar energy is available. When solar energy is insufficient, the heating element will furnish the required amount of hot water.

LIQUID CIRCULATION LOOP NO. 3 (DOMESTIC HOT WATER HEATING FROM STORAGE)

- Maximum design operating temperature - 180° F
- Maximum design operating pressure - 30 psi
- Heating
  - Design liquid flow - 5 gpm
  - Design pump speed -1,750
- Heat transfer medium
  - Volume of liquid in loop - 1,600 gal
  - Anticipated liquid temperature
    - Maximum - 180° F
    - Minimum - 120° F
  - Provision for expansion - Air Cushion TSU-1
  - Medium - Water (100%)
  - Specific heat - 1.00 Btu/lb/° F
  - Density - 62.4 lb/ft^3
  - Heat capacity - 62.4 $Btu/ft^3/°$ F
  - Boiling point - 212° F
  - Freezing point - 32° F
  - Medium manufacturer's recommended use temperature;
    - Maximum - 180° F
    - Minimum - 120° F
  - Toxicity - Potable
  - pH factor - 7.0

- Chemical feeder - No
- Inhibitor - No

- Components within circulation loop
  - Pump(s) - P-2
  - Domestic water heater(s) - DWH-1
  - Heat exchanger(s) - HX-1
  - Valve(s) - V-9, V-10

- Piping
  - Rigid - Copper
  - Interior coating - None
  - Insulation - None
  - Location - Above grade
  - Filters - No
  - Getters - No

- Circulator pump (P-2 and P-4)
  - Manufacturer - Bell and Gossett
  - Model name/number - 100 Series
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure - 3.6 psi
    - Temperature - 210° F
  - Located in loop(s) - 3 and 4
  - Material exposed to heat transfer fluid - Plastic impeller /cast iron body
  - Motor size - 0.08 HP; 115V; 1 Phase; 60 Hz
  - Maximum motor speed - 1,750 rpm
  - Drive - Direct

- Speed - Single
- Pump speed - 1,750 rpm
- Circulating volume - Low head mode - 10 rpm
- Operating head (dynamic) - Low head mode -
- Motor operation - 0.08 bhp

- Heat Exchanger (HX-1)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Type of flow - Parallel
  - Heat exchanger design - Tube inside tank with fins
  - Number of separations - Single
  - External exposed surface - 10 ft^2

	Side One	Side Two
Convection:	Forced	Natural
Part of circulation loop:	3	5
Maximum manufacturer's rated:		
- Temperature -	Unknown	Unknown
- Pressure -	Unknown	Unknown
Heat transfer area	10 ft^2	10 ft^2

	Side One	Side Two
Description		
Length of tubing with fins -	20 ft	20 ft
Diameter of tubing -	Unknown	Unknown

	Side One	Side Two
o Fins		
- Thickness -	Unknown	Unknown
- Length -	Unknown	Unknown
- Diameter -	Unknown	Unknown
o Material	Copper	Aluminum

- o Heating
  - o Design heating capacity - Unknown
  - o Effectiveness - Unknown

	Side One	Side Two
o Design flow rate -	10 gpm	Unknown
o Related pump no. -	P-3	
o Liquid temperatures:		
- Entering -	180° F	45° F
- Leaving -	Unknown	140° F

LIQUID CIRCULATION LOOP NO. 4 (CHARGING STORAGE FROM AUXILIARY FIREPLACE)

- o Design maximum operation temperature - 130° F
- o Design maximum operation pressure - 30 psi
- o Heating
  - o Design liquid flow - 15 gpm
  - o Design pump speed - 1,750 rpm
- o Cooling
  - o Design liquid flow - N/A
  - o Design pump speed - N/A
- o Heat transfer medium
  - o Volume of liquid in loop - 1,600 gal

- Anticipated liquid temperatures;
  - Maximum - 200° F
  - Minimum - 100° F
- Provisions for expansion - Air Cushion in TSU-1
- Medium - Water (100%)
- Specific heat - 1.00 Btu/lb/° F
- Density - 62.4 lb/ft^3
- Heat capacity - 62.4 $Btu/ft^3/°$ F
- Boiling point - 212° F
- Freezing point - 32° F
- Medium manufacturer's recommended use temperature;
  - Maximum - 200° F
  - Minimum - 100° F
- Toxicity - Potable
- pH factor - 7.0
- Chemical feeder to maintain pH factor - No
- Inhibitor - No

- Components within circulation loop:
  - Pump(s) - P-4
  - Thermal storage unit(s) - TSU-1
  - Valve(s) - V-11

- Piping
  - Rigid - Copper
  - Interior coating - None
  - Insulation - None
  - Location - Above grade
  - Filters - No
  - Getters - No

- Distribution Valve(s) - (V-9 and V-10)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - On-Off
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi

LIQUID CIRCULATION LOOP NO. 5

- Heating
  - Maximum design operating temperature - 140° F
  - Pressure - 150 psig
- Heat transfer medium
  - Volume of liquid in loop - Unknown
  - Anticipated liquid temperatures;
    - Maximum - 140° F
    - Minimum - 45° F
  - Medium - Water (100%)
  - Specific heat - 1.00 Btu/lb/° F
  - Density - 62.4 lb/ft^3
  - Heat capacity - 62.4 $Btu/ft^3/°$ F
  - Boiling point - 212° F
  - Freezing point - 32° F
  - Medium manufacturers recommend use temperature;
    - Maximum - 210° F
    - Minimum - 32° F
  - Toxicity - Potable

- Chemical feeder - No
- Inhibitor - No

- Components within circulation loop
  - Domestic hot water heater - DWH-1
  - Heat exchanger(s) - HX-1
  - Valve(s) - V-12, V-13
  - Other(s) - Auxiliary electric heater

- Distribution Valve (V-12)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Drain
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi

- Distribution Valve (V-13)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Isolating
  - Operation - Manual
  - Type - Gate
  - Pressure - 125 psi

- Piping
  - Rigid - Copper
  - Insulation - No
  - Location - Above grade
  - Filters - No
  - Getters - No

CONTROL MODE SELECTOR (CMS-2)

- Manufacturer - Heliothorpe General
- Model name/number - 400
- Modes controlled
  - SH-1 and SH-2 (Fireplace to storage)
    - ON - (SN-4) > (SN-3) + 9° F
    - OFF - (SN-4) ≤ (SN-3) + 3° F
  - Sensors
    - SN-3 - Thermostat
    - SN-4 - Thermostat

CONTROL MODE SELECTOR (CMS-3)

- Manufacturer - Heliothorpe General
- Model name/number - 400
- Modes controlled
  - Storage to hot water
    - ON - (SN-5) > (SN-6) + 9° F
    - OFF - (SN-5) < (SN-6) + 3° F
  - Auxiliary heat to DHW
    - ON - (SN-6) > 120° F
    - OFF - (SN-6) < 160° F
- Sensors (SN-5) and (SN-6)
  - Manufacturer - Heliothorpe General
  - Model name/number - Unknown
  - Type - Thermostatic

- CONTROL MODE SELECTOR (CMS-4)
  - Manufacturer - White

- Model name/number - Unknown
- Modes controlled:
- Storage to space
  - ON - (SN-7) < 68° F
  - OFF - (SN-7) > 70° F
- Sensors
  - SN-7 - Thermostatic
- Auxiliary to space
  - ON - (SN-8) > 100° F
  - OFF - (SN-8) < 100° F
- Sensors
  - SN-8 - Thermostatic

- Fail Safe Control (FC-1 to FC-4)
  - Manufacturer - Watts
  - Product name/number - 174A Model M3
  - Type - Pressure relief valves (set at 30 psi)
- Flow Control (FC-5)
  - Manufacturer - Actronics
  - Model name/number - TP 102-6
  - Type - Pressure relief valve (150 psi)

E. Auxiliary Subsystems (See Figure IV-E-1)

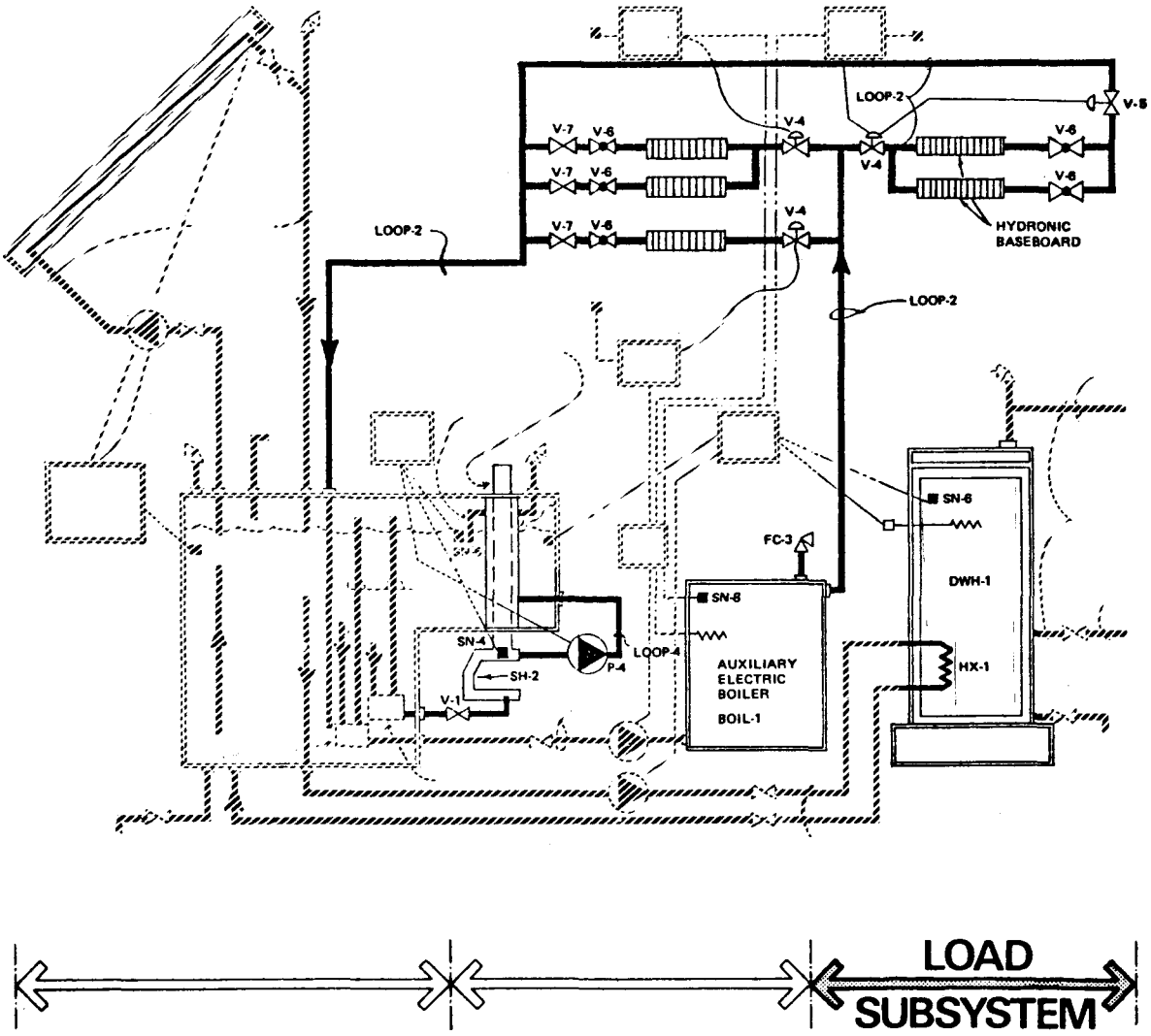


Figure IV-E-1. Auxiliary-to-Load Subsystem

The auxiliary subsystems, BOIL-1, DWH-1 and Fireplace SH-2 mentioned in the foregoing Energy to Load Subsystem have been grouped in this section for descriptive purposes. Their function and purpose have been previously described.

AUXILIARY LOADS

- Domestic Water Heater (DWH-1)
  - Manufacturer - Ford Water Heaters
  - Model - Storex Tank #TC-65-E
  - Energy source - Electric; 230V; 1 Phase; 60 Hz
  - Tank size - 120 gal
  - Energy input - 154,000 Btu/hr
  - Energy output - 154,000 Btu/hr
  - Maximum pressure rating - 150 psi
  - Maximum temperature rating - 180° F
  - Heating stages - Single
  - Maximum recovery rate -18 gal/hr
  - Yearly average inlet temperature - 45° F
  - Design output temperature - 140° F
  - Thermal resistance - Unknown
  - Standby heat loss - Unknown
  - Corrosion protection anodes - Yes, magnesium
  - Burner ignition method - Electric
  - Flue vent - No
- Boiler (BOIL-1)
  - Manufacturer - American Standard
  - Model name/number - EP-34
  - Energy source - Electric; 230V; 1 Phase; 60 Hz
  - Energy input - 34,130 Btu/hr
  - Energy output - 34,130 Btu/hr

- Burner ignition method - Electric
- Flue vent - No

- Supplemental Heater (SH-1)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Energy source - Reclaimed from fireplace flue gases
  - Heater description - Water Jacketed Flue
  - Location - TSU-1

- Supplemental Heater (SH-2)
  - Manufacturer - Unknown
  - Product name/number - Heat recovery fireplace
  - Energy source - Wood
  - Heater description - Water circulated through fireplace to heat TSU-1

F. Modes of Operation (See Figure IV-F-1)

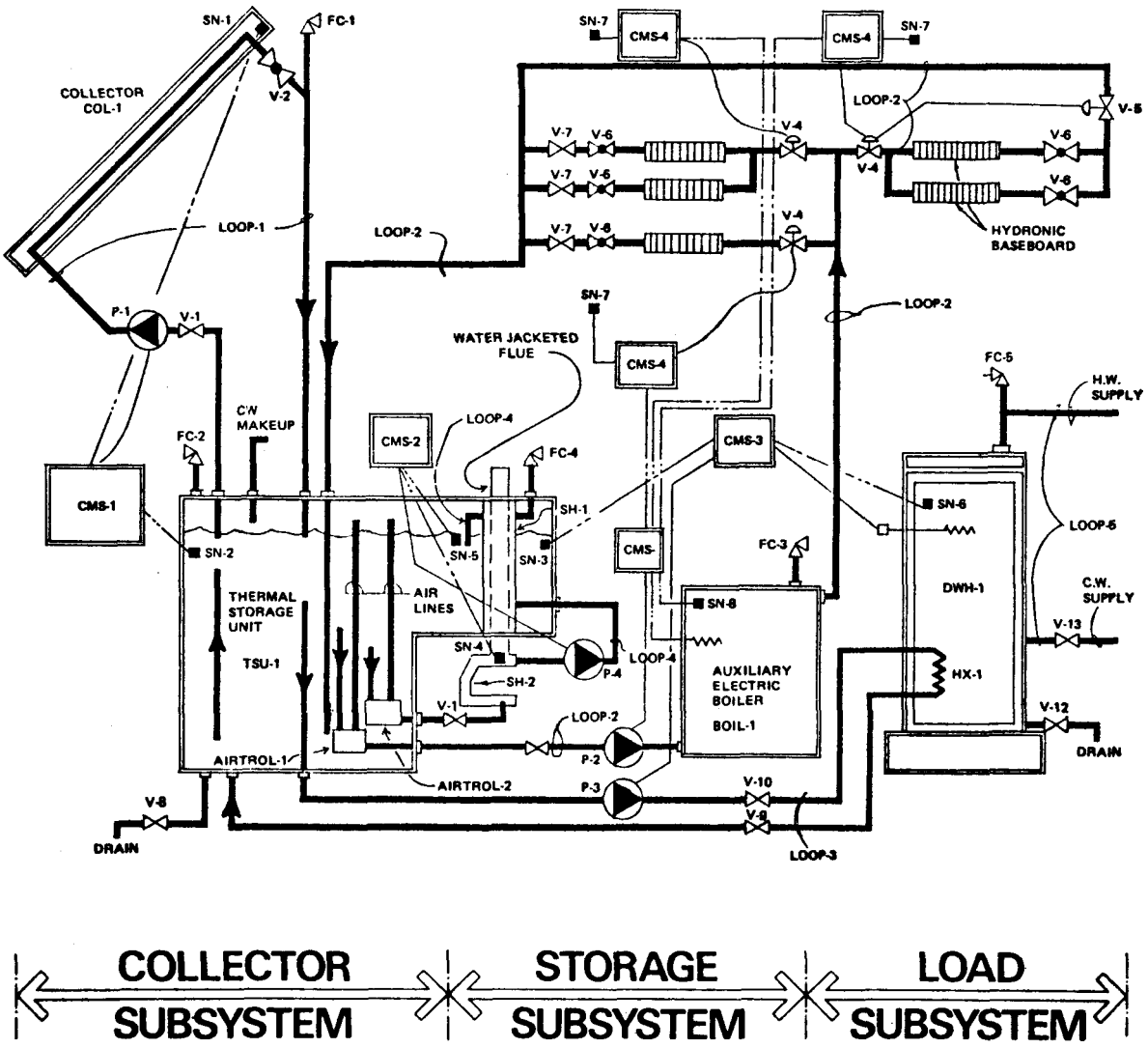


Figure IV-F-1. Controls Diagram

The Design Construction solar system is shown on Figure IV-F-1. The system consists of the following four subsystems: a) Collector, b) storage, c) load (heat and hot water) and d) auxiliary load subsystems.

Operation of the solar system and the auxiliary subsystems may involve one or more of the four modes of operations described below.

Mode 1 - Collector-to-Storage:

This mode activates when the temperature difference between the control sensor located in the collector and the control sensor in the storage tank reaches 9^{o} F. Water is circulated from the storage tank through the collector and back to the tank. This circulation continues until the temperature difference between the two control sensors decreases 3^{o} F, at which point the circulating pump turns off. When the pump stops operating, water is drained from the collector back into the storage tank.

Mode 2 - Storage-to-Space Heating:

This mode activates when any of the four zones demands space heating. The thermostat of the zone demanding heat will activate the solenoid operated control valve for that zone. The thermostat will also activate the circulating pump to allow heater water to circulate from the storage tank, through the boiler, to the appropriate zone (via its control valve) and back to the storage tank. Water continues to circulate as long as any zone demands heat. The electric boiler will provide auxiliary energy if the temperature of the water circulating through the boiler drops below 110^{o} F (set point). When the space heating demand is satisfied, the circulating pump turns off and all open zone control valves close.

Mode 3 - Storage-to-DHW Heat Exchanger:

This mode activates when the temperature difference between a control sensor in the storage tank and a control sensor on the surface of the DHW tank reaches 9^{o} F and terminates when the temperature difference drops to 5^{o} F. If the water temperature in the hot water tank falls below the setting of its thermostat, the electric immersion heater turns on providing auxiliary energy to the water in the hot water tank. This mode also terminates if the temperature in the storage tank, as indicated by another control sensor in the storage tank, falls below 80^{o} F (set point).

Mode 4 - Fireplace-to-Storage:

This mode activates when the temperature difference between a control sensor located in the fireplace and another control sensor in the storage tank reaches 9^{o} F. (This occurs when the fireplace is being used.) The pump turns on to circulate water from the storage tank through the fireplace and chimney heat exchanger, thereby accumulating energy and returning to storage. This mode continues until the temperature difference between the two control sensors drops to 3^{o} F, at which point the pump turns off and the mode terminates. Both fans in the enclosed chamber above the fireplace also operate in parallel with the pump while in ths mode.

V. PERFORMANCE EVALUATION INSTRUMENTATION

A. The National Solar Data Network

The National Solar Data Network (see figure V-A-1) has been developed for the Department of Energy to process data collected from specific residential demonstration sites which were selected for thermal performance evaluation. The data flow in the Network includes monthly and seasonal system performance reports describing the thermal performance of the solar energy system and subsystems.

The performance evaluation instrumentation at each selected demonstration site is part of a comprehensive data collection system that allows for valid analyses of the solar system performance. Collected data are both applicable and practical in calculating thermal performance factors that describe the behavior of the solar system (see NBSIR 76-1137), National Bureau of Standards. Additional instrumentation may also be included as a result of site-specific requirements. Typically, the instrumentation includes sensors that monitor the following:

- Total insolation in the plane of the collector array
- Ambient temperature
- Collector subsystem flow rate and temperatures
- Storage inlet flow rate and temperatures
- Storage outlet flow rate and temperatures
- Storage temperature
- Storage-to-load subsystem flow rate and temperatures
- Auxiliary fuel flow rates

Site data are recorded automatically at prescribed intervals by the Site Data Acquisition System (SDAS). The recorded data are transmitted daily to the Communications Processor in the Central Data Processing System (CDPS). The communications link between every SDAS and the CDPS consists of voice-grade telephone lines and telephone data couplers. A reading is transmitted from the SDAS internal timer with every data sample to ensure that the data are time-tagged correctly.

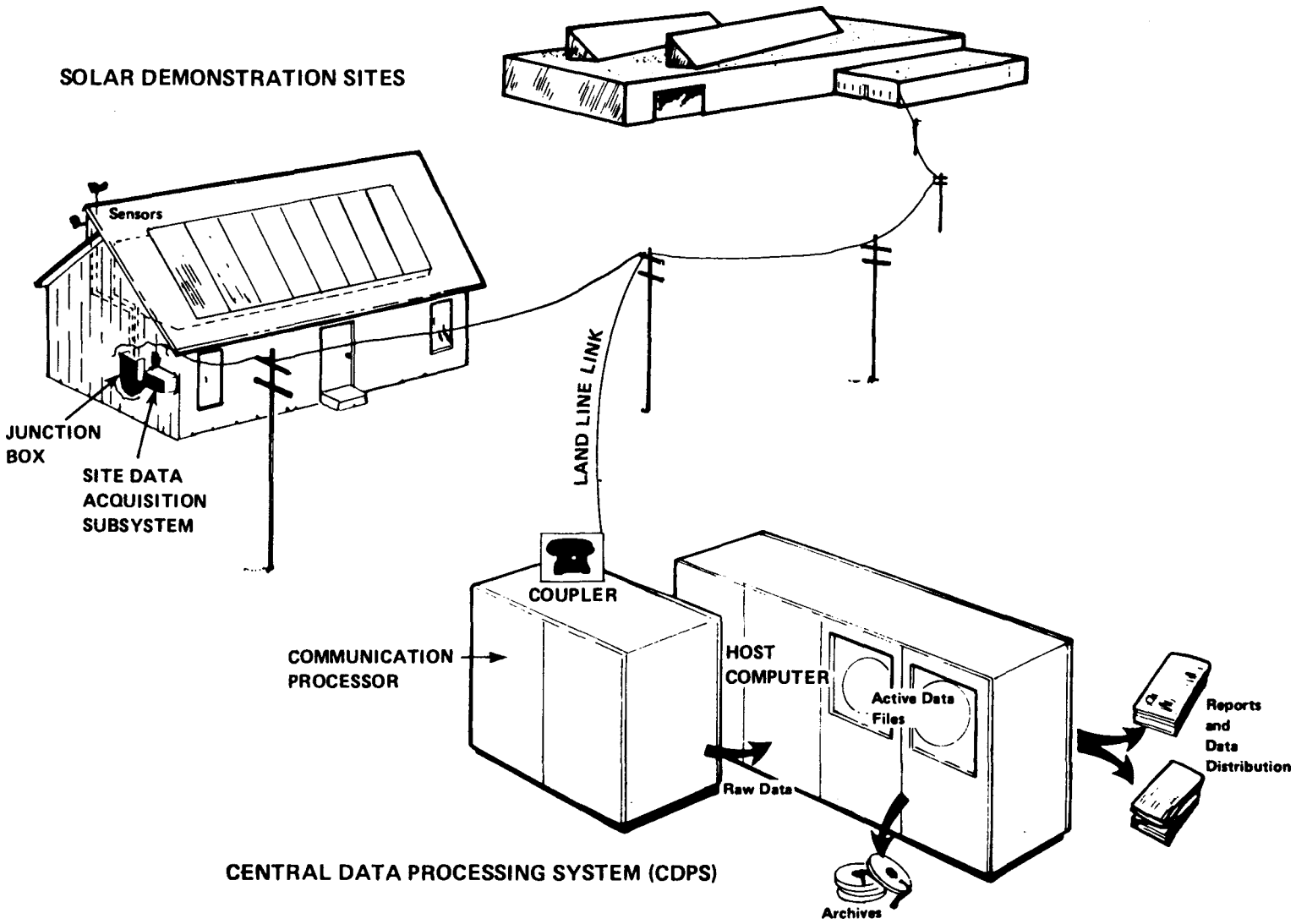


Figure V-A-1. The National Solar Data Network

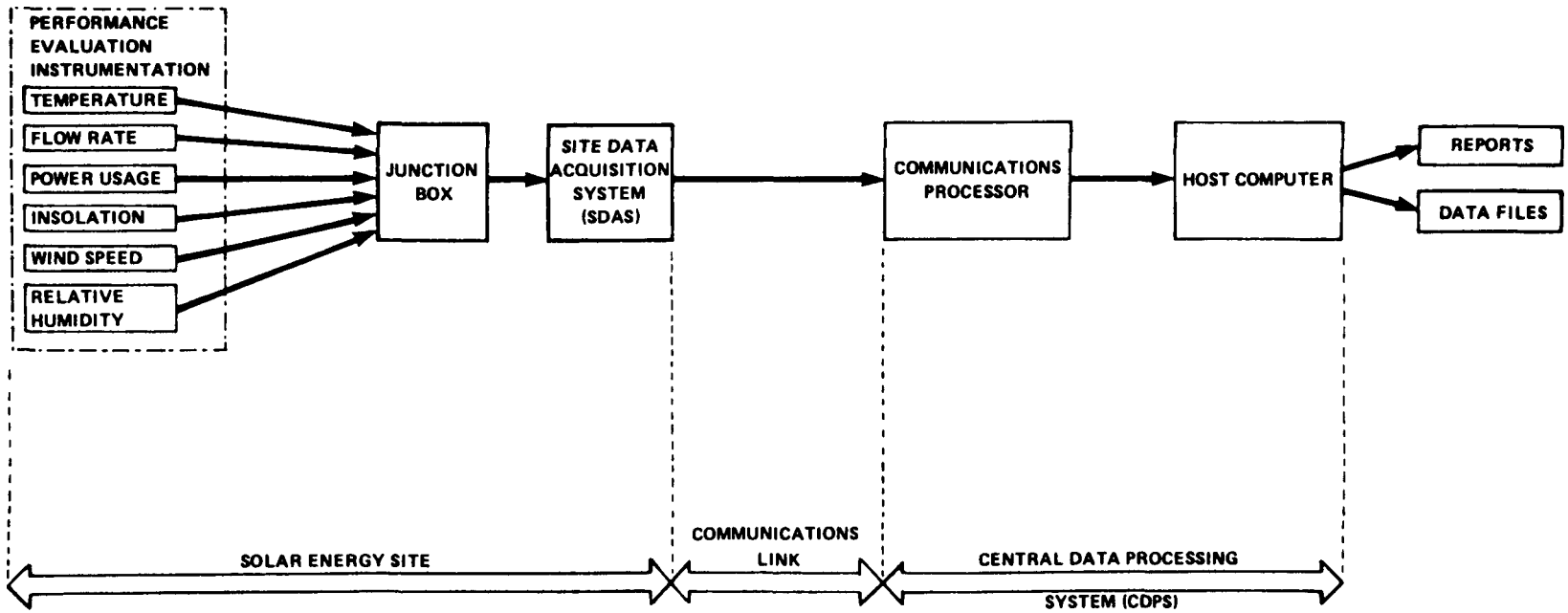


Figure V-A-2. Data Flow Path for the National Solar Data Network

The Communications Processor scans the receiving data to identify any apparent transmission errors and verifies correct site contact by checking the address code transmitted by the SDAS. Data is stored temporarily in the Communications Processor and processed by the Host Computer. The processing includes measurement checking to ensure that the data are reasonable; that is, that they are not beyond the known instrument limits and that they are not erratic. Data which appear questionable are discarded and are not used in the solar system preformance analyses.

Appropriate equations were formulated and programmed to define desired performance factors for the solar energy systems at each selected demonstration site. A performance factor is a number that describes either the efficiency or the quantity of energy lost, gained, or converted by a solar energy system or by a component. All valid data are processed using these performance factor equations to generate hourly performance factors. Hourly performance factors are integrated into daily and monthly performance factors. These hourly, daily, and monthly performance factors are stored in data files in the CDPS. These data files also include measurement data, expressed in engineering units; numerical and textual site identification; and specific site data used in generating the performance factors.

B. On-Site Instrumentation

The on-site instrumentation includes sensors to monitor the various parameters of the solar energy system, a junction box, and a Site Data Acquisition System that stores and transmits data to the Host Computer (see figure V-A-1 and V-A-2). Specific information for temperature, flow, power and miscellaneous sensors are presented in tabular form. Sensor locations are shown in figure V-B-1.

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
I001	Insolation, total	Eppley PSP
T001	Temperature, outside ambient	S53P-60
T100	Temperature, collector inlet (west array)	S57P-60
T150	Temperature, collector outlet (east + west array	S53P-60
T102	Temperature, collector inlet (east array)	S53P-60
T101	Temperature, storage tank outlet, collector loop	S53P-60
T151	Temperature, storage tank inlet, collector loop	S53P-100
W100	Flow, collector loop	MKV-1 1/4-5.0-50.0
EP100	Power, collector loop pump (p-1)	PC5-10
T200	Temperature, storage medium, top of tank	S53P-290
T201	Temperature, storage medium, center of tank	S53P-620
T202	Temperature, storage medium, bottom of tank	S53P-990
T203	Temperature, DHW heat exchanger loop return to storage	S53P-60
T253	Temperature, storage tank output to DHW heat exchanger	S53P-60
T204	Temperature, DHW heat exchanger inlet	S53P-60
T254	Temperature, DHW heat exchanger outlet	S53P-60
W200	Flow, storage tank to DHW heat exchanger loop	MKV-3/4-0.7-7.0
EP200	Power, storage/DHW HX loop pump (P-2)	PC5-1
T300	Temperature, DHW tank cold water supply	S53P-60
T350	Temperature, DHW tank outlet	S53P-60
W300	Flow, (totalizer) DHW	Hersey #430
EP300	Power, DHW tank electric heater	PC5-29 (4 passes)
T400	Temperature, hydronic heater loop return to storage	S53P-60
T450	Temperature, storage output to hydronic heater loop	S53P-60
T401	Temperature, auxiliary heater tank input	S53P-60
T451	Temperature, auxiliary heater tank output	S53P-60
W400	Flow, hydronic heaters	MKV-1 1/4-2.0-20.0
EP400	Power, auxiliary water heater for space heating	PC5-29 (2 passes)
EP401	Power, hydronic heating loop pump (P-3)	PC5-1
T600	Temperature, ambient space heating	S53P-28

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
T205	Power, consumed by fireplace pump (P-4)	PC5-106
T255	Temperature, chimney/fireplace water jacket inlet	S53P-60
T402	Temperature, hydronic heat zone "A" return	S53P-60
T403	Temperature, hydronic heat zone "B" return	S53P-60
T404	Temperature, hydronic heat zone "C" return	S53P-60
T405	Temperature, hydronic heat zone "D" return	S53P-60

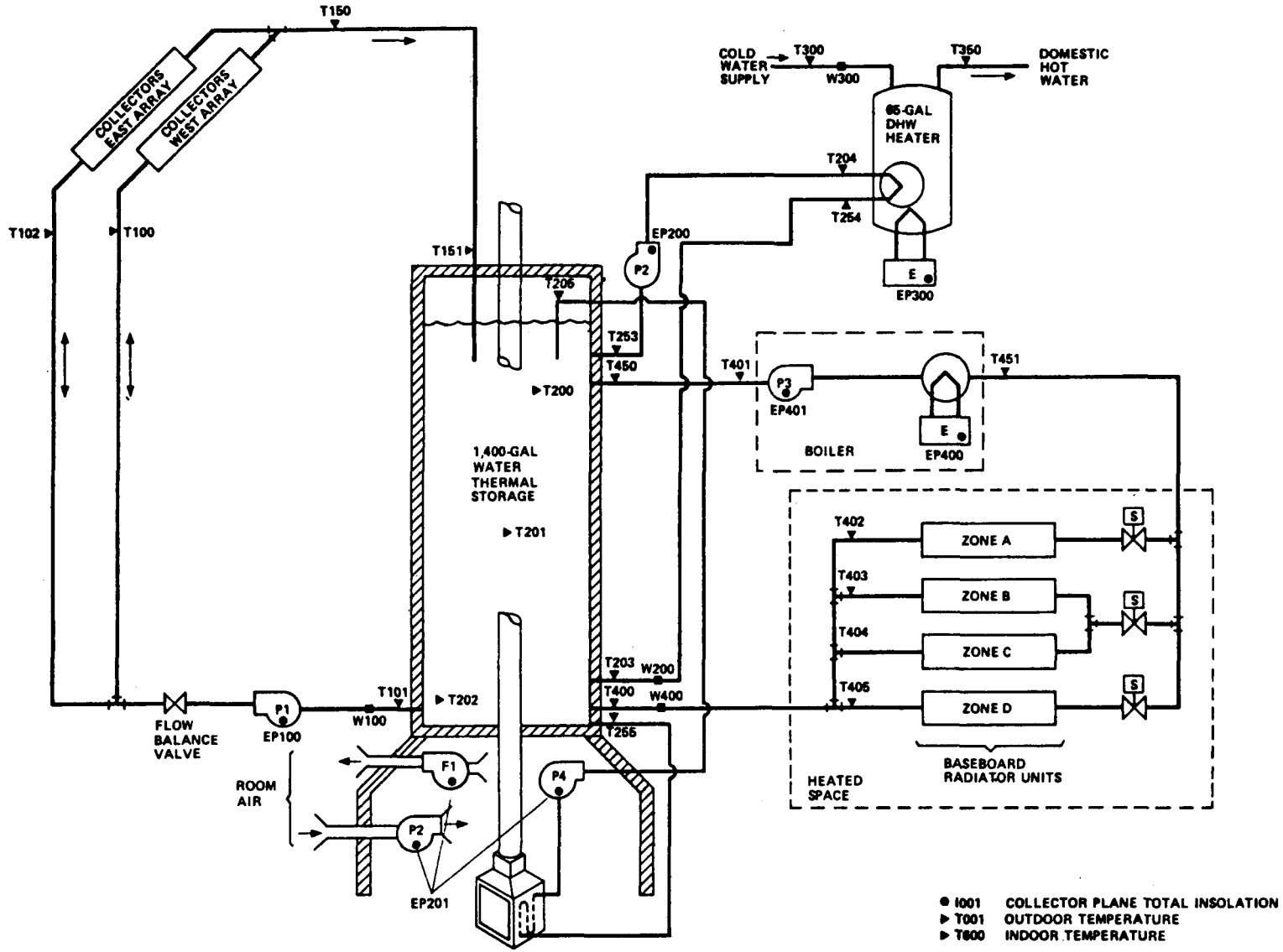


Figure V-B-1. Sensor and Control Diagram

VI. COST DATA

A. General

The following cost data depicts only solar energy portion of the construction costs. Costs of instrumentation is not included since it is not part of the construction effort.

B. Construction Grant Funds

Solar Subsystem	Applicants Request	Construction Grant
Collectors	$ 8,400	$
Energy Storage	1,025	
Distribution and Controls	1,800	
Installation	2,000	
Other	5,470	
Total	$18,965	$13,029

C. Construction Period: June 1977 through June 1978

VII. APPENDIX

A. Glossary

ABSORBER PLATE - The surface in a flat plate collector that absorbs incident solar radiation and transfers the absorbed energy to a heat transfer fluid.
ABSORPTANCE - The ratio of absorbed radiation by a surface to the total incident radiation on that surface.
ABSORPTION SUBSYSTEM - The mechanical equipment that conditions indoor air by an absorption process.
ACTIVE SOLAR SYSTEM - An integrated solar energy system, consisting of collector, storage, solar energy-to-load subsystems, that can condition indoor air or preheat domestic hot water in a controlled manner.
AIR-BASED SOLAR COLLECTOR SYSTEM - A solar energy system in which air is the heat transfer fluid.
AIR CONDITIONING - The process of treating indoor air by controlling the temperature, humidity, and distribution to specified comfort settings as set by the occupants in the conditioned space.
AMBIENT AIR - A term for outdoor air, and may be brought into a building to be conditioned or circulated.
ANTI-FREEZE FREEZE PROTECTION SYSTEM - A freeze protection system that uses additives or solutions to the heat transfer medium, which depresses its freezing point sufficiently to prevent possible water freeze in the solar collectors and the exterior piping.
AUXILIARY ENERGY SUBSYSTEM - The equipment, utilizing conventional energy sources, used to supplement the output provided by a solar energy system and used to provide a full backup system when the solar system is inoperable.
BACKFLOW - The reversal of flow in a distribution system.
BACKFLOW PREVENTOR - A device or means to stop backflow.
BEAM RADIATION - Solar radiation which is not scattered and may be concentrated.
BRITISH THERMAL UNIT (Btu) - A unit of energy that is required to heat one pound of water from 59^{o} F to 60^{o} F.
BUILDING ENVELOPE - The exterior surface of a building that encloses the conditioned space.

CLIMATE - The prevailing or average weather conditions of a specific geographic region as described by temperature and other meteorological data.

COLLECTOR MANIFOLD - The piping that connects the absorber tubes in a collector plate.

COLLECTOR PLATE - A term used for an absorber plate.

COLLECTOR SUBSYSTEM - The assembly that absorbes solar radiation and transfers the absorbed thermal energy to a heat transfer fluid.

COMBINED COLLECTORS - An assembly that both collects solar radiation and stores the thermal energy in the same unit.

CONCENTRATING SOLAR COLLECTOR - A solar collector which focuses beam radiation onto an absorber in order to obtain higher energy fluxes than can normally be achieved by flat plate solar collectors.

CONCENTRATOR - A reflective surface or refracting lens used in directing insolation onto an absorber.

CONDITIONED SPACE - The space in a building where the air is conditioned by heating or cooling.

CONTROL SUBSYSTEM - The assembly of electric, pneumatic, and hydraulic actuated sensing devices used in regulating the solar energy system and the auxiliary energy subsystems.

COOLING TOWER - A heat exchanger that transfers waste heat from an absorption cooling system to ambient air.

DIFFUSE RADIATION - Solar radiation which is scattered by air molecules, dust, or other substances suspended in the air.

DRAIN-DOWN FREEZE PROTECTION SYSTEM - A freeze protection system that prevents potential water freeze-up within the collector and exterior piping by automatically draining and replacing the water with a non-freezing medium such as air, nitrogen, etc.

DUCT HEATING COIL - A liquid-to-air heat exchanger in the duct distribution system used to heat air by passing a hot fluid through a coil in the air system.

EQUIVALENT FULL LOAD COOLING HOURS - The seasonal cooling load for a building described as the total number of hours that the air conditioning system will operate under full load conditions to meet the required cooling load.

EMITTANCE - The ratio of energy radiated by a body to the energy radiated by a black body at the same temperature.

EXPANSION TANK - A tank which will permit water to expand whenever it is heated to prevent excessive pressures on the other system components.

FIXED COLLECTOR - A solar collector that is permanently oriented towards the sun and cannot track the sun nor be adjusted for seasonal variations.

FLAT PLATE COLLECTOR - A basic heat collection device used in solar heating systems, which consists of an absorber plate, with insulated bottom and sides, and covered by one or more transparent covers. There are no concentrators or focusing aids in a flat plate collector.

FOCUSING COLLECTOR - A solar collector using a parabolic mirror, fresnel lens, or other type of focusing device to concentrate solar radiation onto an absorber.

FRESNEL COLLECTOR - A concentrating solar collector which uses a fresnel lens to focus beam radiation onto an absorber.

GLAZING - The transparent cover(s) on a solar collector used to reduce the energy losses from the top of the collector.

HEAT TRANSFER FLUID - The fluid that transfers solar energy from the solar collector to the storage subsystem or to the load.

INCIDENCE ANGLE - The angle in which the insolation strikes a surface and the normal for that surface.

INSOLATION - The total amount of solar radiation on a surface in a given unit of time.

LAMINATED GLASS - A glazing consisting of multiple glass sheets bonded together by intervening layer or layers of plastic.

LANGLEY - The standard unit of insolation defined as 1 langley = 1 cal/cm^2, (1 Langley = 3.69 Btu/ft^2).

LIQUID-BASED SOLAR COLLECTOR SYSTEM - A solar energy system in which either water or an antifreeze solution is the heat transfer fluid.

LOAD - The total space conditioning or domestic water heating requirements that are supplied by both the solar energy system and the auxiliary energy subsystem.

NOCTURNAL RADIATION - The loss of thermal energy by the solar collectors to the sky at night.

NO-FLOW CONDITION - The condition obtained when the heat transfer fluid is not flowing through the collector array due to a shutdown or a malfunction.

OPAQUE - A surface that is not transparent, thus solar radiation is either reflected or absorbed.

OUTGASSING - The emission of gases by materials and components, usually during exposure to elevated temperature, or reduced pressure.

PACKAGE AIR-CONDITIONING UNIT - A factory-made assembly consisting of an indoor coil, a compressor, an outdoor coil, and other components needed for space cooling operations. This unit may also include additional components to heat the condition space.

PARABOLIC FOCUSING COLLECTOR - A concentrating collector which focuses beam radiation by a parabolic reflector.

PASSIVE SOLAR SYSTEM - An integrated solar energy system that can provide for space heating needs without the use of any other energy source other than the sun.

REFLECTANCE - The ratio of radiation reflected by a surface to the total incident radiation on the surface.

REFLECTED RADIATION - Insolation which is reflected from a surface, such as the ground, and is incident on the solar collector.

ROCK BED - A storage tank using uniform-sized rocks to store solar energy in air-based solar collector systems.

SELECTIVE SURFACE - A surface which has a high absorptance for solar radiation and a low emittance for thermal radiation.

SOLAR CONDITIONED SPACE - The area in a building that depends on solar energy to provide for a fraction of the heating and cooling needs.

SOLAR HEATING SYSTEM - An integrated assembly of collector, storage, solar energy-to-load, and control subsystems required to convert solar energy into thermal energy for space heating requirements, as well as the addition of an auxiliary backup system.

SOLAR RETROFIT - The addition of a solar energy system to an existing structure.

STORAGE SUBSYSTEM - The components used to store solar energy so that the stored energy can be used for heating, cooling, or heating water during periods of low insolation.

STRATIFICATION - The horizontal layering in a medium due to temperature differentials, commonly noticed in storage tanks filled with water.

THERMOSTAT - A temperature sensing device which controls the heating and cooling systems for space conditioning or the hot water heater.

TILT ANGLE FROM HORIZONTAL - Angle between the horizontal plane and the plane of collector.

TON OF REFRIGERATION - A unit of refrigeration which is equivalent to 12,000 Btu/hr.

TRACKING COLLECTOR - A set of solar energy tracking collectors that automatically move in order to constantly aim towards the sun.

VAPOR BARRIER - A material which is used to reduce the transmission of water vapor.

ZONE - A portion of a conditioned space which use a common control because of their similar heating and cooling requirements.

B. Legend For Solar System Schematics