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SOLAR/1051-81/50
(DE81028054)

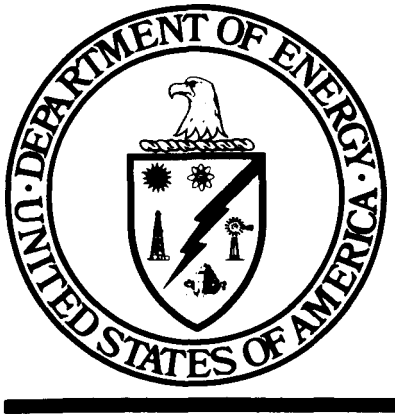
MASTER

Solar Project Description

COLORADO SUNWORKS PARTNERSHIP SINGLE FAMILY RESIDENCE

Longmont, Colorado

August 28, 1981



U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

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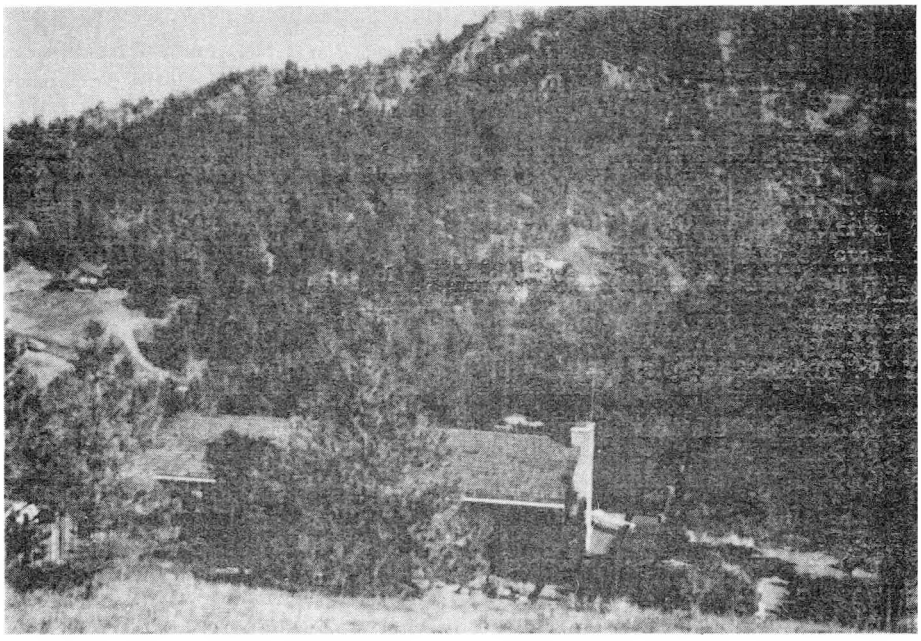
SOLAR/1051-81/50
(DE81028054)
Distribution Category UC-59

SOLAR PROJECT DESCRIPTION
FOR
COLORADO SUNWORKS
SINGLE FAMILY RESIDENCE - LONGMONT, COLORADO



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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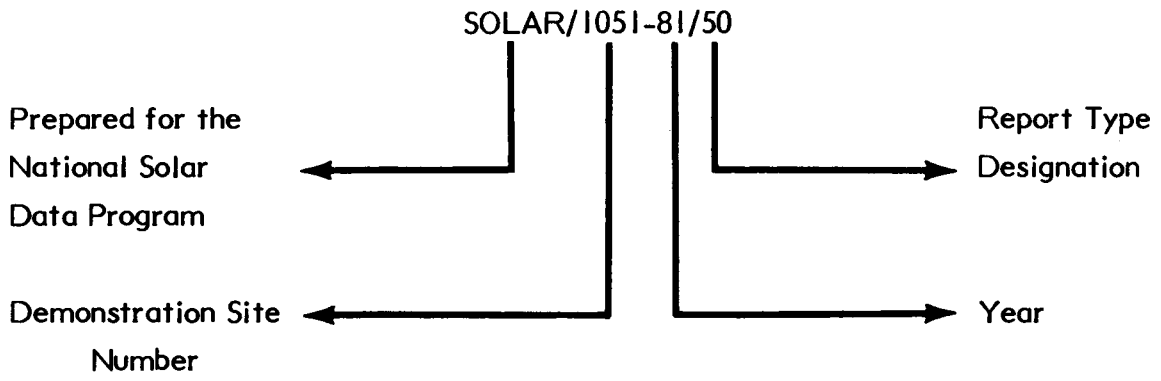
LIST OF FIGURES

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 Colorado Sunworks project site is designated as SOLAR/1051-81/50. 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:

- o Solar Project Description.
- o Operational Experience.
- o System Performance Evaluation.
- o 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 -- Drumwall & direct gain
- o Freeze Protection -- Beadwall movable insulation
- o Application -- Space heat/DHW
- o Storage -- Water drums and concrete walls/slab
- o New or Retrofit -- New
- o Performance Evaluation Instrumentation -- Yes
- o Site-Specific Features -- Contoured earth berms on North, East and West sides of house

II-A SPACE HEATING AND COOLING

The Colorado Sunworks (Grant H-8180) solar energy demonstration project is a passive solar energy system used for both space heating and domestic hot water preheating for a single-family dwelling located in Longmont, Colorado. The building is a three bedroom, single-story house, with approximately 1,800 square feet of living space as illustrated in figure II-A-1.

The passive space heating system, illustrated schematically in figure II-A-2, is a combination drum wall and direct-gain system. Sunlight enters the double glazed windows (approximately 30 square feet) on the south side of the building where the majority of the energy is absorbed by the black painted 55-gallon water-filled drums (54 drums total). The remainder of the energy is either absorbed in the 6-inch-thick concrete slab floor or used to satisfy the daytime space heating demand. The 8-inch-thick exterior insulated reinforced concrete building walls also serve as a secondary solar storage mass.

At night, or during periods of low incident solar energy, heat losses through the glazing are reduced by using movable insulation in the form of a Beadwall. The Beadwall is constructed of two panes of glass spaced 5½ inches apart. Beads of white-colored styrofoam insulation can be blown into the space between the glass or sucked out using electrically driven blowers. When not used for south wall

insulation, the beads of insulation are stored in tanks located in the garage. Operation of the Beadwall is automatically controlled, based on sensors measuring incident solar energy and inside and outside temperature. This automatic operation can be manually overridden.

Distribution of the collected solar energy to the house is by both convection and radiation. A unique feature of this building is the technique used for distribution of collected solar energy from the drums to the north side of the house. The vertically stacked drums near the south wall form a drumwell chimney where heated air rises through ceiling vents above the drums into an open plenum area between the roof and the ceiling of the rooms. Additional vents from this plenum on the north side of the house provide a path for the warm air into the room, thus providing for a thermosiphon flow around the inside of the building.

The building design and construction makes use of a number of energy conservation features. The exterior skin of the building (including the bottom of the slab floor) is well insulated and sealed. Earth berms on the north, east, and west sides of the house provide additional insulation along with a damping of the extremes in temperature variation of the outside skin of the house. The roof is also covered with approximately one foot of earth. Additional energy conserving features include the use of an entry vestibule to serve as an airlock and the placement of the garage to the northwest to serve as a windbreak.

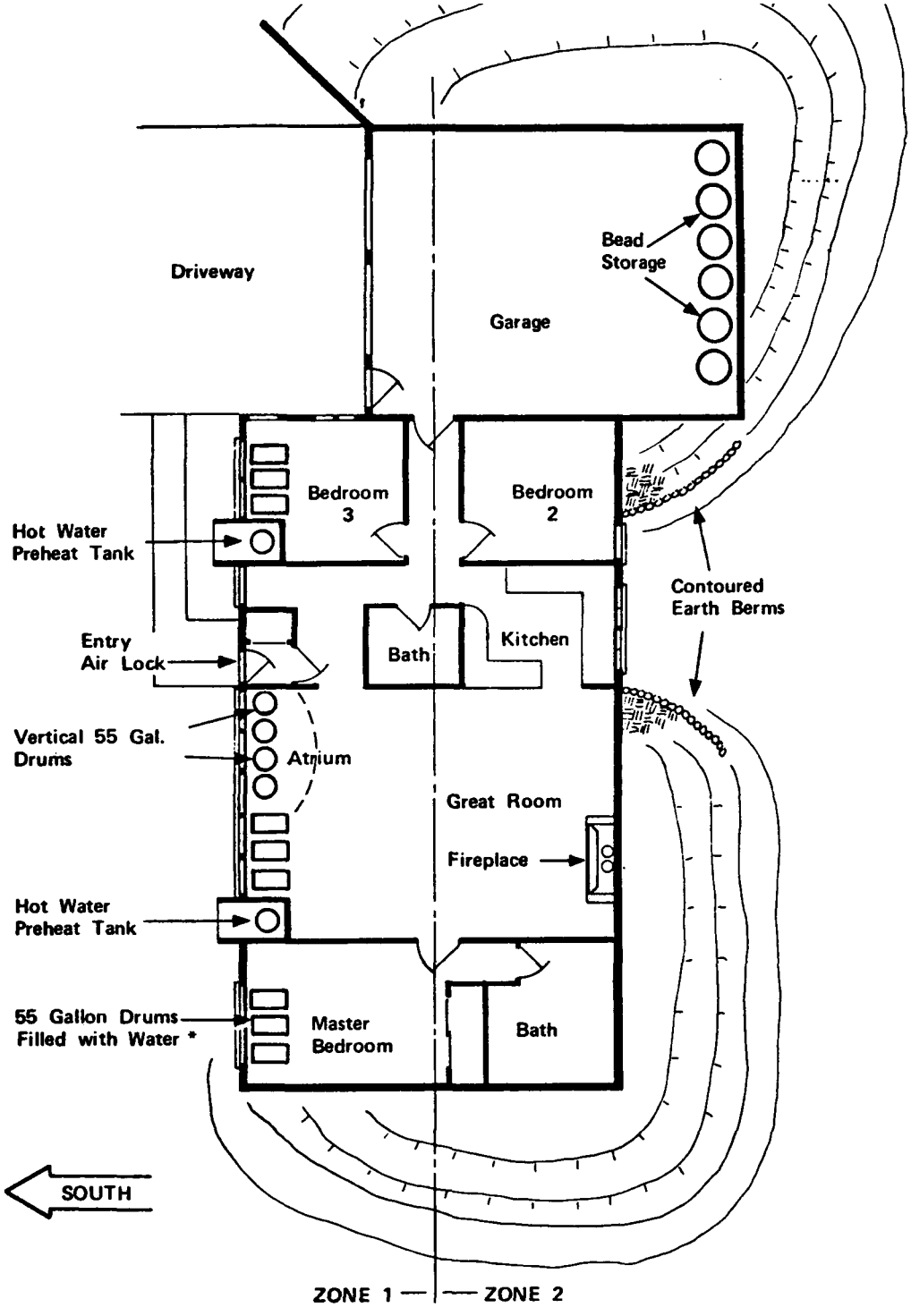
Auxiliary space heating energy is provided by either baseboard radiation or convectors with a gas-fired boiler,or by a wood-burning fireplace. The fireplace has a provision for recirculation of room air while providing outside air for combustion.

Summer overheat protection is provided by several means. A roof overhang over the south wall provides shading from the high summer sun. The Beadwall movable insulation can be closed during the day to prevent solar radiation from entering the building. Cooling of the building is enhanced by the use of nighttime ventilation. Cool outside air can enter the house through open windows, passing over the solar storage masses and removing energy before exiting the building through roof vents located in the plenum area between the ceiling and roof. This natural flow is enhanced by the use of wind turbines above the roof vents as illustrated in figure

II-A-2. When the house is closed during the daytime hours, the cooled solar storage masses absorb energy, thus tempering conditions inside the living space.

II-B. DOMESTIC HOT WATER

The passive solar domestic hot water system (figure II-B-1) consists of two 30-gallon tanks which have been stripped of their insulation, painted black, and positioned next to the south wall (figure II-A-1). Domestic hot water is preheated in these tanks before passing on demand to the natural gas-fired domestic hot water tank where it is raised to operating temperature. The preheat tanks are insulated from the outside conditions at night using the Beadwall movable insulation. Reflective surfaces inside the insulated spaces enhance the absorption of incident solar radiation.



* all drums are stacked horizontally except in the Atrium where a single stack is placed vertically.

Figure II-A-1. Colorado Sunworks Passive Solar Energy System

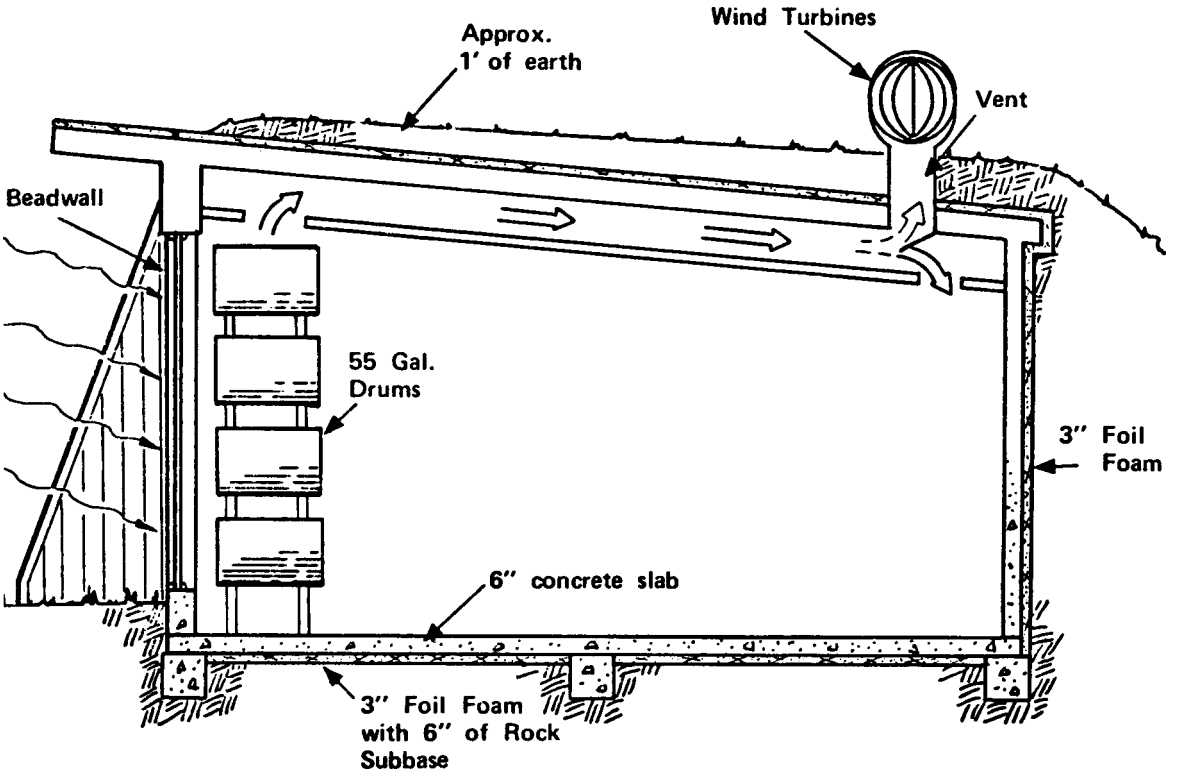


Figure II-A-2. Colorado Sunworks Passive Solar Space Heating System

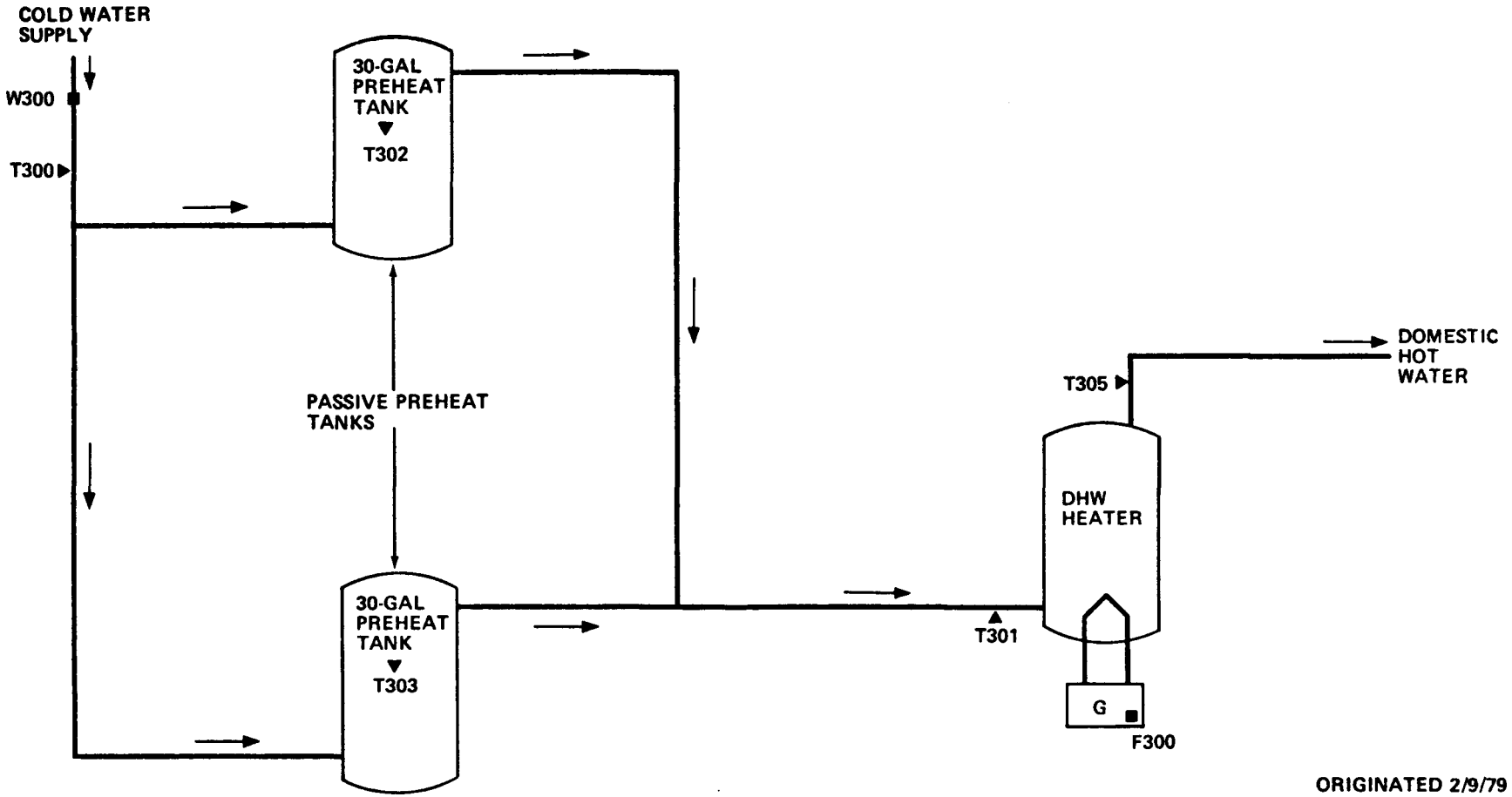


Figure II-B-1. Colorado Sunworks Passive Solar Domestic Hot Water System Schematic

The dwelling has been fully instrumented for performance evaluation since July 1978 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 Colorado Sunworks solar energy system is a passive solar system used for both space heat and DHW in Longmont, Colorado. This document will be broken into two discussions, space heat and DHW.

- Building type - Single family, detached
- Latitude - 40°
- Longitude - 150°
- Altitude - 5,000 ft

HEATING DESIGN TEMPERATURES

- Outdoor - Minus 5° F
- Indoor - 70° F

BUILDING

- Building faces - South
- Average stories above ground - 0
- Average stories below ground - 1
- Height above grade - 0 ft
- Conditioned floor area - 1,800 ft^2
- Roof type - Sloped with 2° pitch

DESIGN HEAT LOSS/LOAD

- Heat Loss - 31,681 Btu/hr
- Heat gain - Variable with user operation of Beadwall
- Shading
  - Heating season - 0%
  - Cooling season - 50% *

    * Cooling value is for overhang; it does not include the bead wall which would increase the value to 100%.

UNAVAILABLE

Figure III-1. Site Plan

- Appliance, lighting and equipment load - 3,333 Btu/hr
- Average horizontal insolation
  - January - 828 Btu/ft^2/day
  - July - 2,400 Btu/ft^2/day
- Annual degree days
  - Heating - 6,360 DD
  - Data location - Denver, Colorado
  - Data reference - Local Climatological Data Annual Summaries, Department of Commerce, National Oceanographic and Atmospheric Administration

MECHANICAL SYSTEM

- Heating
  - Solar - Air passive, thermosiphon
  - Auxiliary - Baseboard radiation or convection with natural gas-fired boiler and a fireplace
  - Distribution - Convection

DOMESTIC HOT WATER

- Daily water demand - 80 gal
- Solar - Passive
- Auxiliary - DWH-1

GENERAL DATA (SPACE HEAT)

- Manufacturer - Colorado Sunworks
- Model name/number - Site built
- Type of system - Air passive/water drumwall

SYSTEM AND COMPONENT SUMMARY

- Collector types - 1
- Circulation loops - 1
- Thermal storage units - 54 each, 55 gallon drums

- Pumps - P-1
- Valves - 2
- Blowers - 1
- Dampers - 1
- Sensors - 2

IV. SOLAR SYSTEM DESCRIPTION (SPACE HEATING AND COOLING)

A. General Overview

This residential solar demonstration project (Colorado Sunworks Grant H-8180) located at Longmont, Colorado is a passive system utilized for space heat. Auxiliary space heating is provided by a gas-fired furnace and a circulating fireplace.

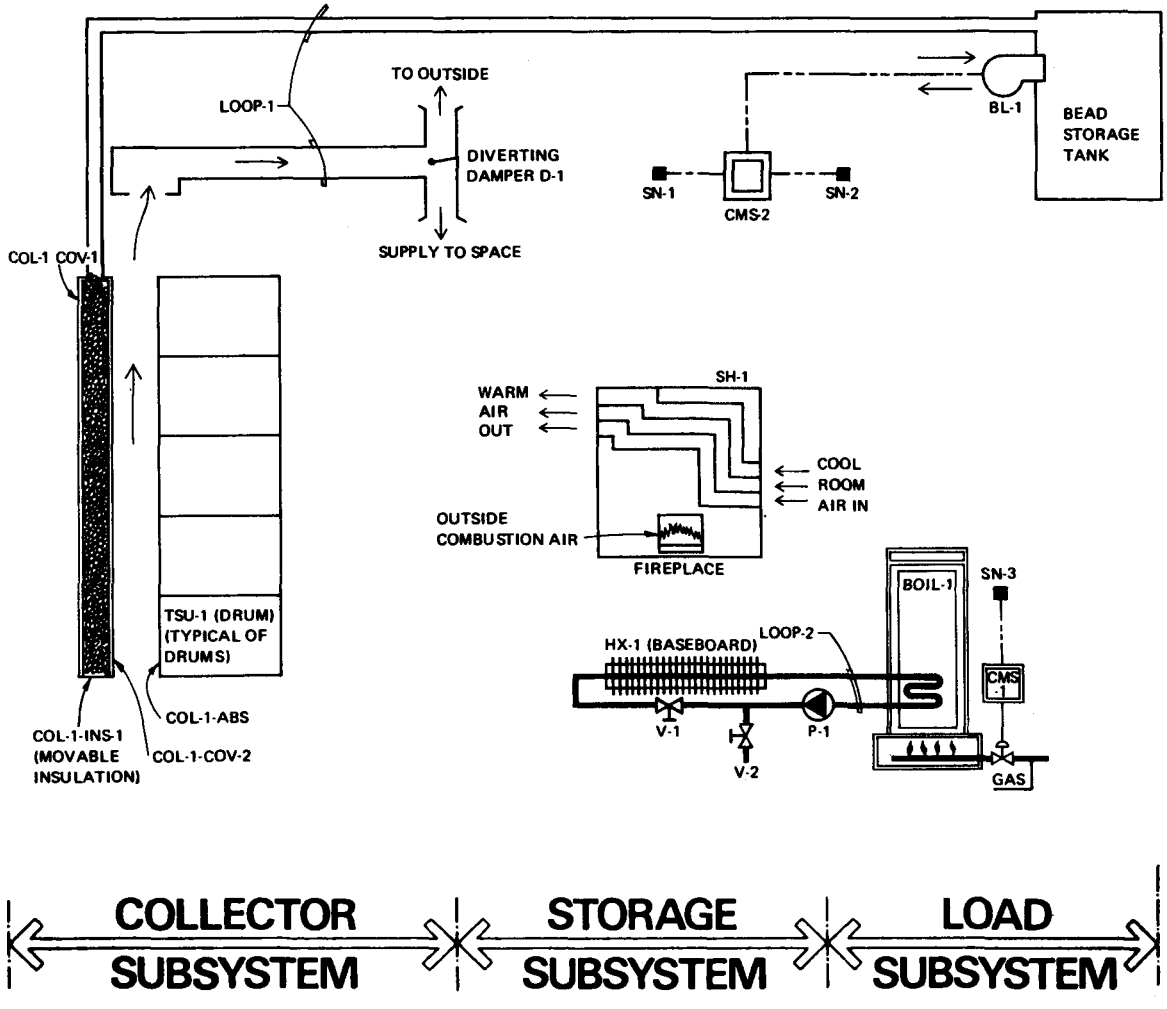


Figure IV-A-1. General Overview

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)

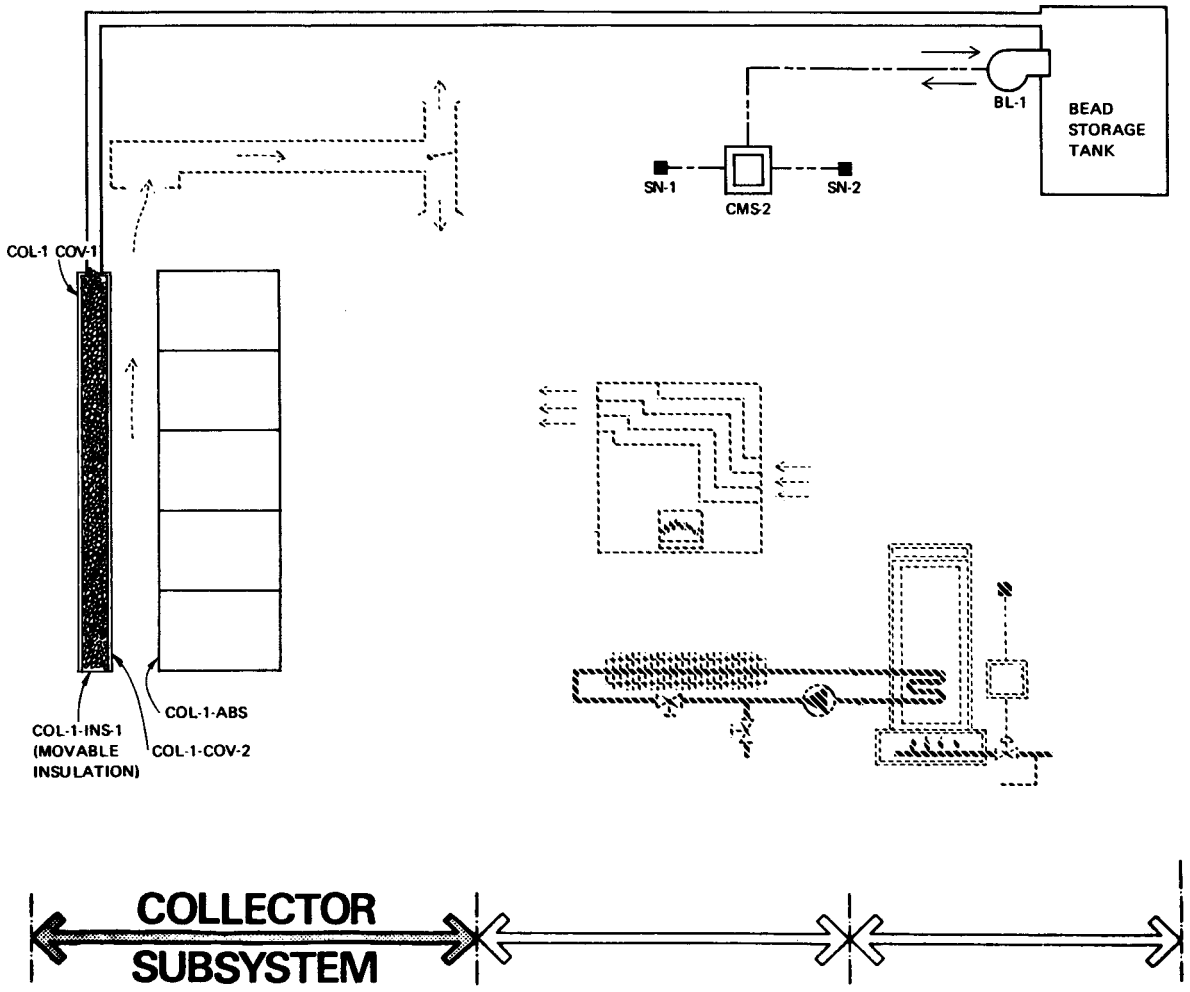


Figure IV-B-1. Collector Subsystem

Collector array system consists of 10 window (gross array of 290 ft^2) collector panels. Freeze protection is provided by movable insulation.

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

- Manufacturer - Colorado Sunworks
- Model name/number - Site built
- Type - Air passive, liquid drumwall
- Location - Wall
- Orientation - Fixed at 0^{o} East of South
- Tilt angle - 90^{o} from horizontal
- Collector characteristics
  - Number of panels - 10 windows
  - Total gross area of array - 290 ft^2
  - Net aperture area - 29 ft^2 per window
  - Net absorber area - 24.8 to 49.6 ft^2 per window
  - Weight per panel, empty - Not applicable
  - Weight per panel, full - Not applicable
  - Weight of filled array and support structure - Unknown
  - Window length - 92 in
  - Window width - 46 in
  - System depth - 55 in
  - Standoff height - 0
- Built-in collector - Forms weatherproof surface of wall
- Collector shading -
  - Area shaded in June - 50%
  - Area shaded in December - 0%
- Cover plates
  - Number of cover plates - Two

SITE BUILT
(ILLUSTRATION UNAVAILABLE)

Figure IV-B-2. Solar Collector

- Cover plate No. 1
  - Location - Outer layer
  - Manufacturer -
  - Product name/number -
  - Material - Glass, Tempered
  - Thickness - 0.187 in
  - Optical properties

	(solar region)	(infrared region)
- Transmittance -	0.85	
- Reflectance -	0.08	
- Emittance -	0.06	

  - Edge or surface treatment, other than coating - None
  - Coating on cover plate material - None
- Cover plate No. 2
  - Material - Glass, Tempered
  - Thickness - 0.187 in
  - Optical properties

	(solar region)	(infrared region)
- Transmittance	0.85	
- Reflectance	0.08	
- Emittance	0.06	

  - Edge treatment - None
  - Coating - None
- Absorber
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Material - Gloss black paint

- Substrate material dimension
  - Thickness - 0.036 in
  - Length - 36.0 in
  - Diameter - 24.0 in
- Number of absorbers per collector - 1

- Coating
  - Coating material - Gloss black paint

	(solar region)	(infrared region)
o Absorptance -	Unknown	
o Reflectance -	Unknown	
o Emittance -	Unknown	

  - Application - Painted

- Insulation
  - Movable insulation provided by a Beadwall system
    - Manufacturer - Zomeworks
    - Product name/number - Beadwall
    - Material - Styrofoam
    - Thermal resistance - R-20

- Frame
  - Manufacturer - Site built
  - Product name/number - Steel clips and 2x4's
  - Material - Steel
  - Protective coating - Steel painted, 2x4's natural
  - Standoffs used - No
  - Number of structure attach points per module to building - Continuous 2x4's
  - Built-in collector - Yes
  - Desiccant - No

- Freeze protection - Movable insulation provided by a Beadwall system
- Overheating protection - Manual switch control of Beadwall
- Passive collector heat transfer control - Beadwall

- Collector performance - Not adaptable to determination by established methods

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

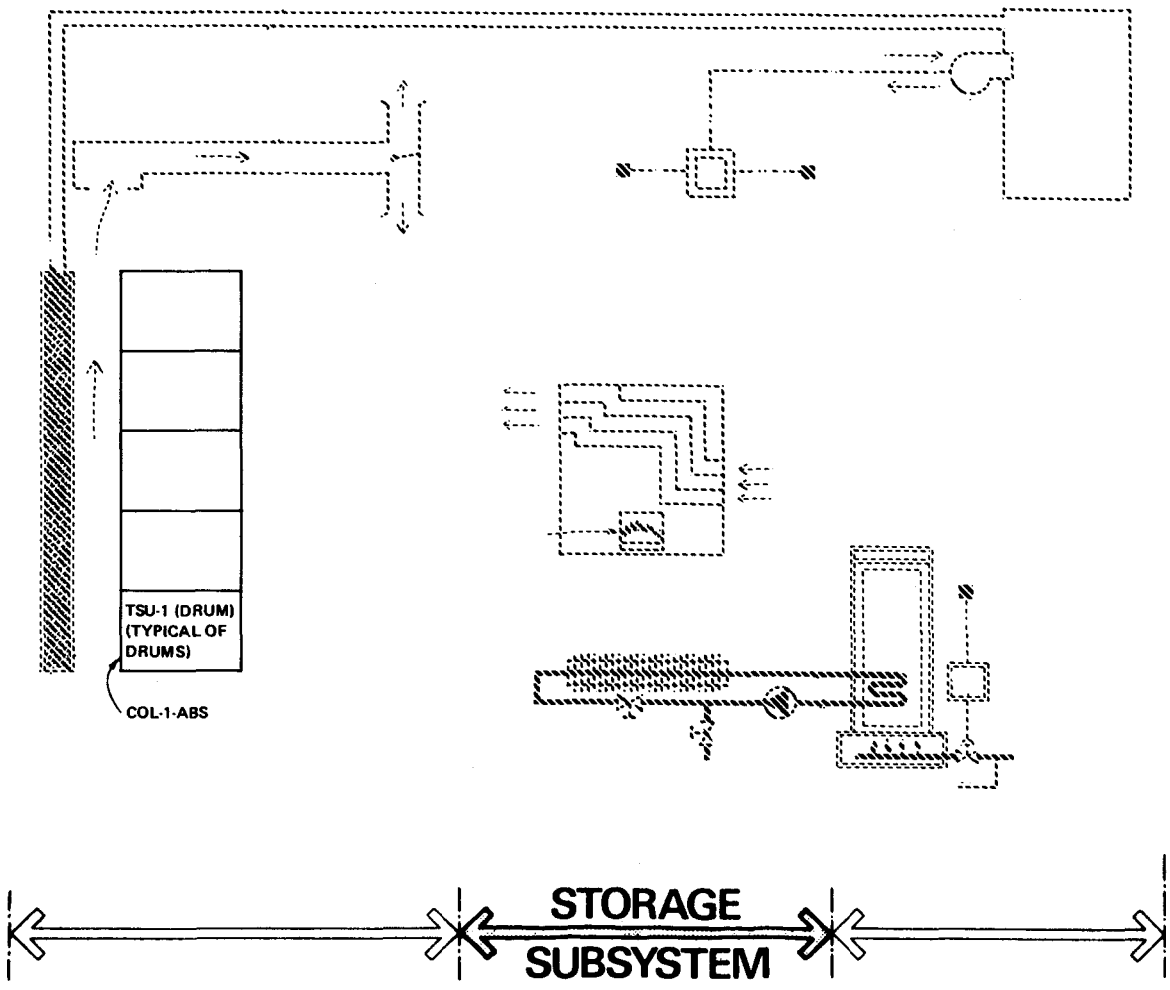


Figure IV-C-1. Storage Subsystem

Solar energy storage is provided by fifty-four, 55-gallon drums. The drums are made of steel with black painted exteriors. Each measures 3 feet in length and 2 feet in diameter.

THERMAL STORAGE UNIT (TSU-1)

- Manufacturer - Unknown
- Model name/number - 55-gal drums (54)
- Total storage container volume - 508 ft^3
- Volume of storage medium - 2970 gal
  - Length - 3 ft
  - Diameter - 2 ft
- Rated operating temperature conditions
  - Maximum - 88° F
  - Minimum - 68° F
- Storage medium
  - Design operating heating temperatures
    - Maximum 88° F
    - Minimum 68° F
  - Design operating cooling temperatures
    - Maximum 75° F
    - Minimum 70° F
  - Medium - Water (99%)
  - 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 - 88° F
  - Minimum - 68° F
- Toxicity - Non-potable

- pH Factor - 7.5
- Inhibitor - Sodium sulfite concentration 1%
- Container construction
  - Type - Steel
  - Interior lining - Baked epoxy
  - Location - In building
  - Auxiliary heaters - No
  - Insulation - No
  - Exterior finish - Paint
  - Filters - No
  - Getters - No

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

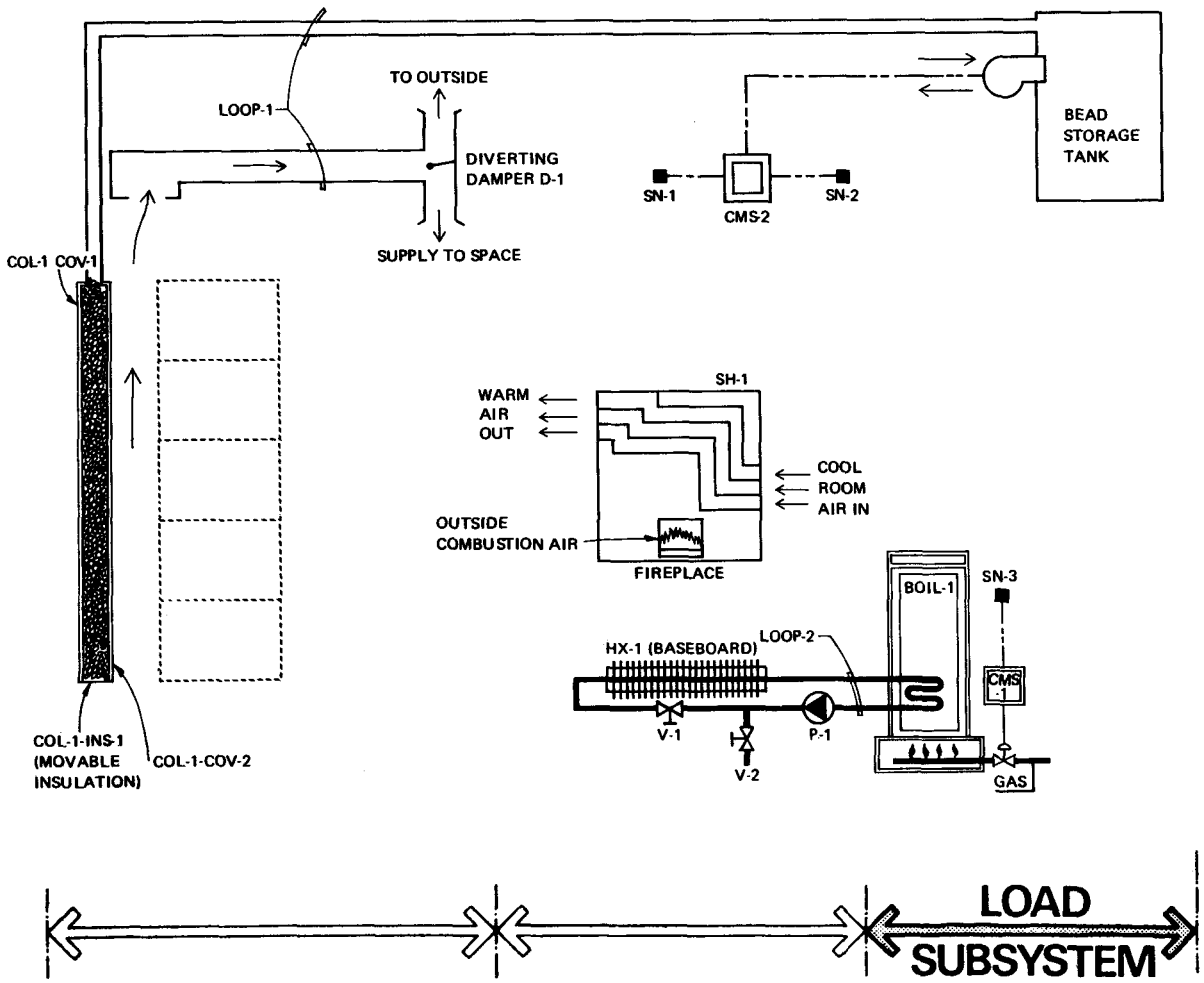


Figure IV-D-1. Energy-to-Load Subsystem.

Solar energy stored in the 55-gallon drums is used to meet the space heating demands. Solar energy is transferred to the building load by radiation and convection. Air distribution to the north side of the building results from a thermosiphon flow around the inside of the building. Auxiliary space heating, supplementing this source, is provided by a gas-fired furnace and circulating fireplace.

Space cooling is provided by nighttime ventilation. Outside air enters the house by use of windows, passing over solar storage masses and removing energy before exiting the building through roof vents in the plenum area between the ceiling and roof. This natural flow is enhanced by use of wind turbines above the roof vents.

AIR CIRCULATION LOOP NO. 1

- Heating
  - Maximum design operating temperature - 88° F
  - Heating design air flow - Not applicable
  - Blower speed - Not applicable
- Components within circulation loop
  - Blower(s) - BL-1 (Beadwall system)
  - Damper(s) - D-1
- Blower (BL-1)
  - Manufacturer - Ametek-Lamb
  - Model name/number - 5750 vacuum motor
  - Motor type - 1.0 HP; 120 V; 1 Phase; 60 Hz
  - Maximum motor speed - 2,800 rpm
  - Drive - Direct
  - Blower speed - Single
  - Design conditions

	Low Static Mode	High Static Mode
- Circulating volume	Unknown	
- Motor operation	1 bhp	

- Damper
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Flow switching
  - Type - Multi-louver
  - Operation - Automatic

- Ducting
  - Type - Aluminum
  - Location - Ceiling plenum
  - Maximum operating temperataure - 100° F
  - Thermal resistance - Unknown
  - Insulation - Unknown
  - Exterior finish - Plastic

CONTROL MODE SELECTOR (CMS-2)

- Manufacturer - Colorado Sunworks
- Model name/number - Beadwall control
- Modes controlled
  - Beads to Beadwall
    - ON - Variable set point
    - OFF - Automatic
  - Beadwall to Bead storage
    - ON - Variable set point
    - OFF - Automatic
- Sensors (SN-1) and (Sn-2)
  - Manufacturer - Colorado Sunworks
  - Type - Temperature, thermister/temperature silicon transistor

LIQUID CIRCULATION LOOP NO. 2 (BASEBOARD FIN TUBE)

- Design maximum operation temperature - 200° F
- Design maximum operation pressure - Unknown
- Heating
  - Design liquid flow - 10 gpm
  - Design pump speed - 1750 rpm
- Heat transfer medium
  - Volume of liquid in loop - Unknown

- Anticipated liquid temperatures
  - Maximum - 160° F
  - Minimum - 68° F
- Provisions for expansion - No, drain valve
- 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 - 160° F
  - Minimum - 68° F
- Toxicity - Potable
- pH factor - 7.0
- Chemical feeder to maintain pH factor - No
- Inhibitor - No

- Components within circulation loop
  - Pump(s) - P-1
  - Boiler(s) - BOIL-1
  - Heat exchanger(s) - HX-1
  - Valve(s) - V-1, V-2
- Piping
  - Rigid - Copper, Type L
  - Insulation - Cellular rubber
  - Location - Above/below grade
  - Filters - No

- Getters - No

- Circulator pump - (P-1)
  - Manufacturer - Bell & Gossett
  - Model name/number - Series 100 18 CU
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure - 3.5 psi
    - Temperature - 250° F
  - Material exposed to heat transfer fluid - Bronze
  - Motor size - 0.125 HP; 115V; 1 Phase; 60 Hz
  - Maximum motor speed - 1750 rpm
  - Drive - Direct
  - Speed - Single
  - Pump speed - 1750 rpm
  - Circulating volume - High head mode - 10 gpm
  - Motor operation - 0.125 bhp
- Distribution Valve (V-1)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Isolation
  - Operation - Manual
  - Type - Gate
- Distribution Valve (V-2)
  - Manufacturer - Unknown
  - Model name/number - Unknown
  - Function - Drain
  - Operation - Manual

- Type - Hose bib
- Materials exposed to heat transfer fluid -

- Heat Exchanger (HX-1) (Liquid to Air)
  - Manufacturer - Sterling Radiator
  - Model name/number - Heatrim Model R American Standard
  - Type of flow - Parallel
  - Heat exchanger design - Fin Tube

	Air Side	Liquid Side
Convection:	Natural	Forced
Part of circulation loop:	2	
Maximum manufacturer's rated:		
- Temperature -		200° F
- Pressure -		190 psi
Heat transfer area		
- Rows	1	
- Fins per inch	4.16	
Material	Copper/Aluminum	Copper
Related pump number		P-1
Liquid temperatures:		
- Entering -	Unknown	160° F
- Leaving -	Uknown	150° F

CONTROL MODE SELECTOR (CMS-1)

- Manufacturer - Honeywell Two Stage Thermostat
- Model name/number - T872F10191-7714
- Modes controlled
  - Boiler to space
    - ON - (SN-3) < 55° F

- Sensor (SN-3)
  - Type - Thermostat

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

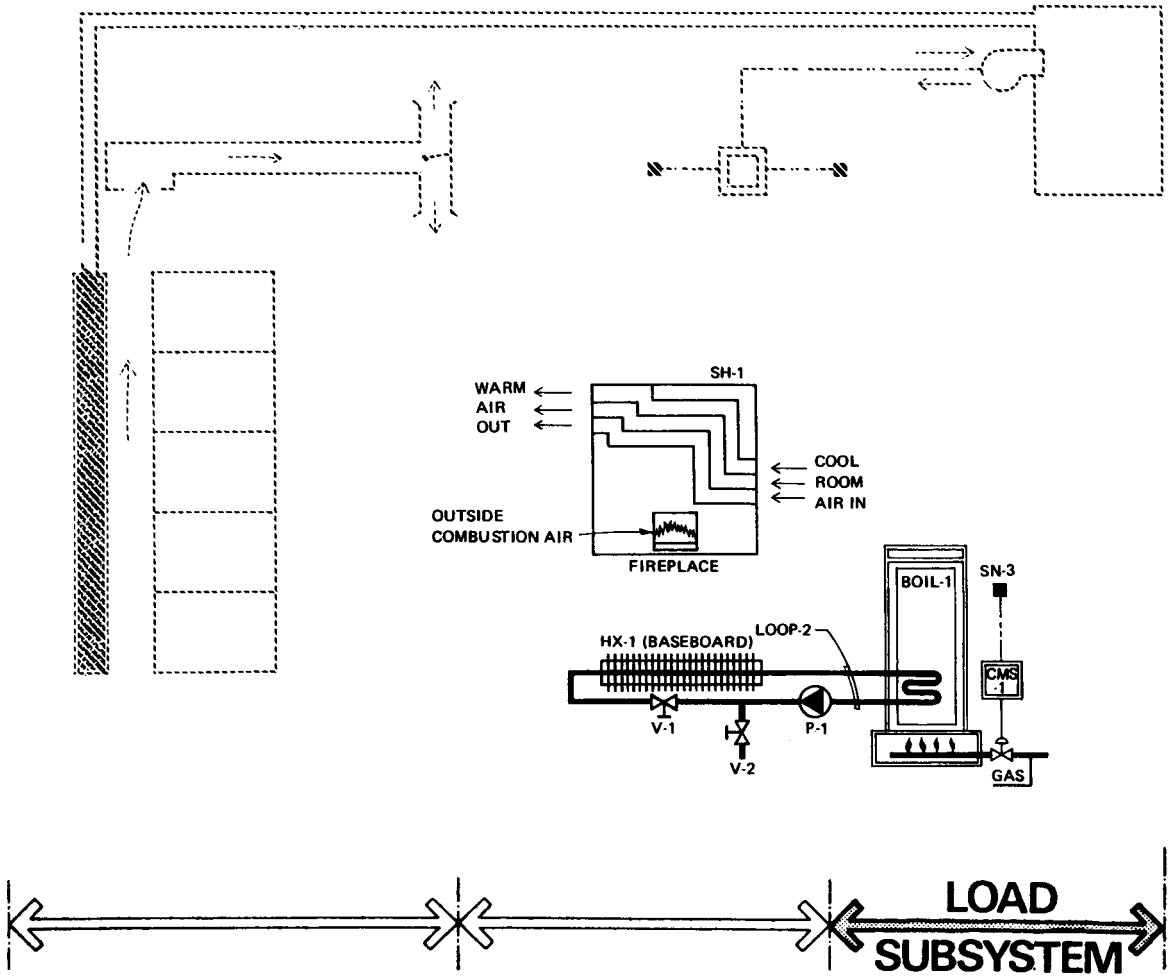


Figure IV-E-1. Auxiliary-to-Load Subsystem

The auxiliary subsystems, BOIL-1 and SH-1 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.

- Boiler (BOIL-1)
  - Manufacturer - Hydrotherm
  - Model name/number - HC-65
  - Energy source - Natural Gas
  - Energy input - 55,000 Btu/hr
  - Energy output - 45,200 Btu/hr
  - Maximum pressure - 250 psi
  - Design operating
    - Pressure - Unknown
    - Temperature - 200° F
  - Heating stages - Single
  - Corrosion protection anodes - No
  - Burner ignition method - Electric
  - Flue vent - Automatic
- Supplemental Heater (SH-1)
  - Manufacturer - Martin
  - Model name/number - Octatherm BWH-36
  - Energy source - Wood
  - Description - Heatilator type fireplace with glass doors and outside combustion air. Hot air vented into room.

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

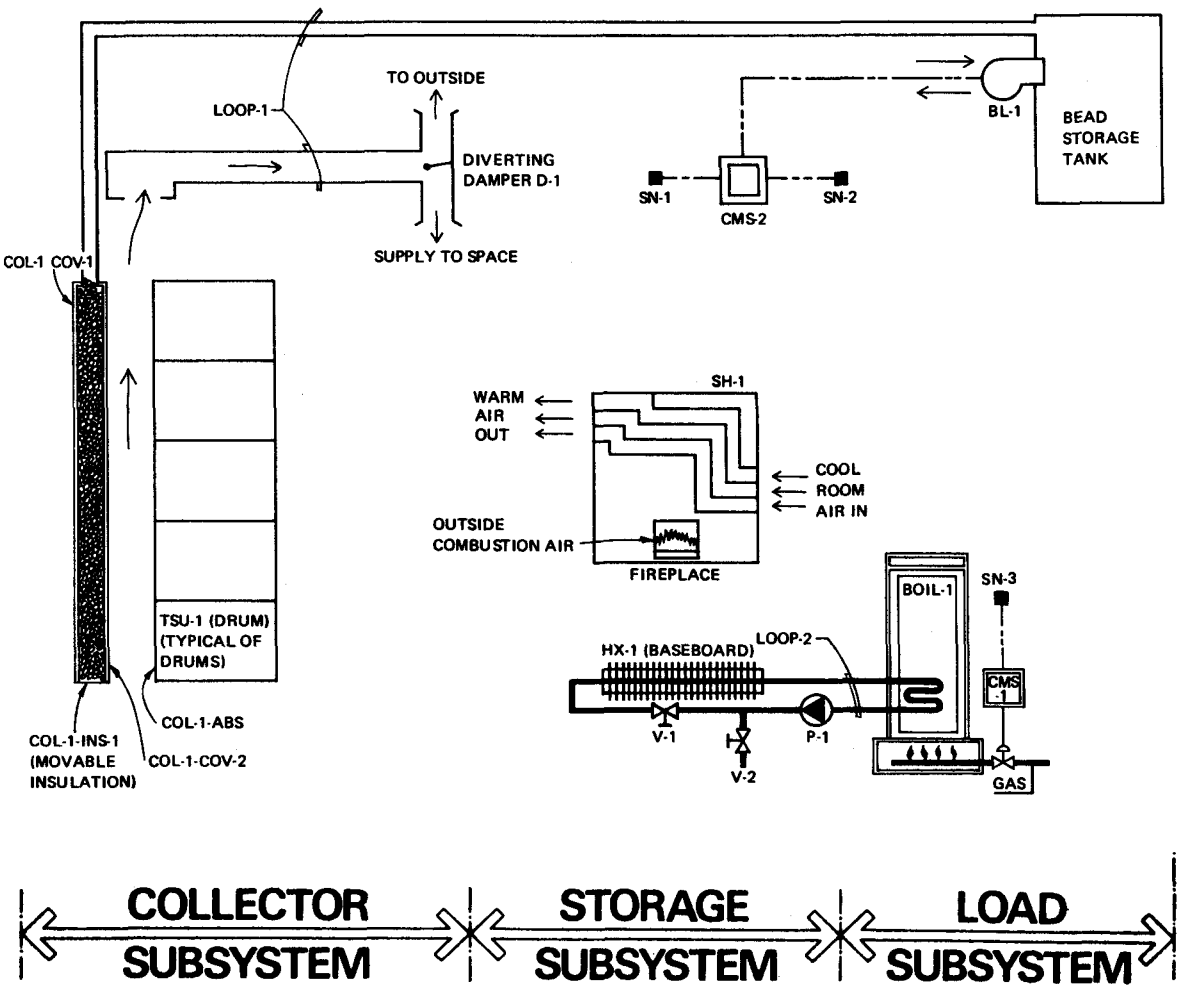


Figure IV-F-1. Controls Diagram

The Sunworks solar system is shown on Figure IV-F-1. The system consists of the following four subsystems: a) collector; b) storage; c) load (space heat); and d) auxiliary load subsystems.

Operation of the solar system and the auxiliary subsystems are not documented in the DIM or monthly reports therefore it is unknown how many modes are involved.

V. SOLAR DESCRIPTION (DHW)

A. General Overview

The passive solar domestic hot water system (figure V-A-1) consists of two 30-gallon tanks which were stripped of their insulation, painted black, and positioned next to the south wall. Domestic hot water is preheated in these tanks before passing on demand to the natural gas-fired DHW-1 where it is raised to operating temperature. The preheat tanks are insulated from the outside conditons at night using the Beadwall movable insulation. Reflective surfaces inside the insulated space enhance the absorption of incident solar radiation.

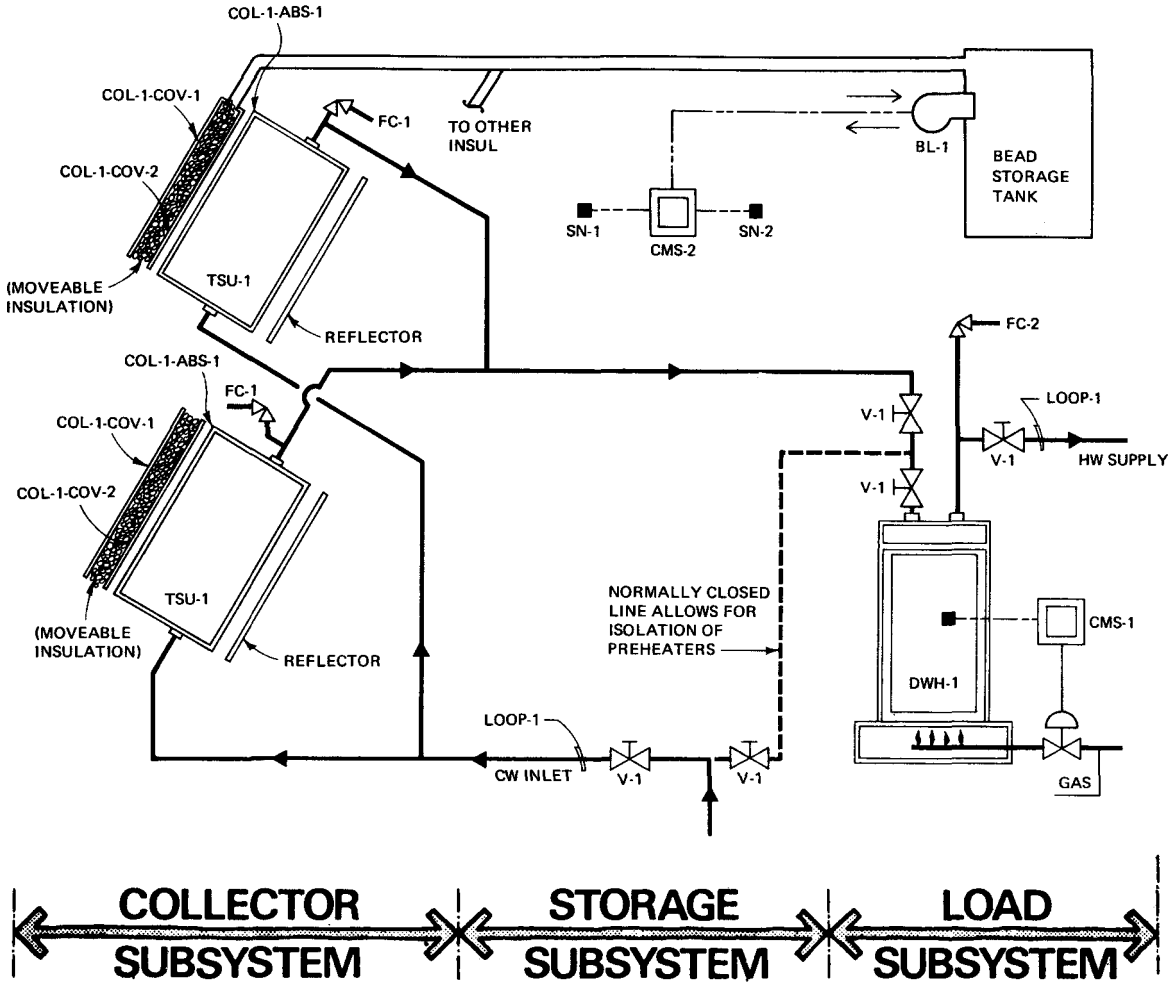


Figure V-A-1. General Overview

DESIGN HEAT LOSS/LOAD

- Heat loss - 1,687 Btu/hr
- Shading
  - Heating season - 0%
  - Cooling season - 50% *
- Domestic hot water daily requirements - 80 gal/day

* Cooling value is for overhang; it does not include the bead wall which would increase the value to 100%.

GENERAL DATA

- Manufacturer - Colorado Sunworks
- Model name/number - Site built
- Type of system - Passive, preheat system

SYSTEM AND COMPONENT SUMMARY

- Collector type - 1
- Number of circulation loop(s) - 1
- Thermal storage unit(s) - TSU-1, TSU-2
- Operational mode(s) - 1
- Valve(s) - 8 total (1 type)
- Blower(s) - 1 type (1 each at bead storage tank)
- Sensor(s) - 2
- Fail safe control(s) - 3

B. COLLECTOR SUBSYSTEM (See figure V-B-1)

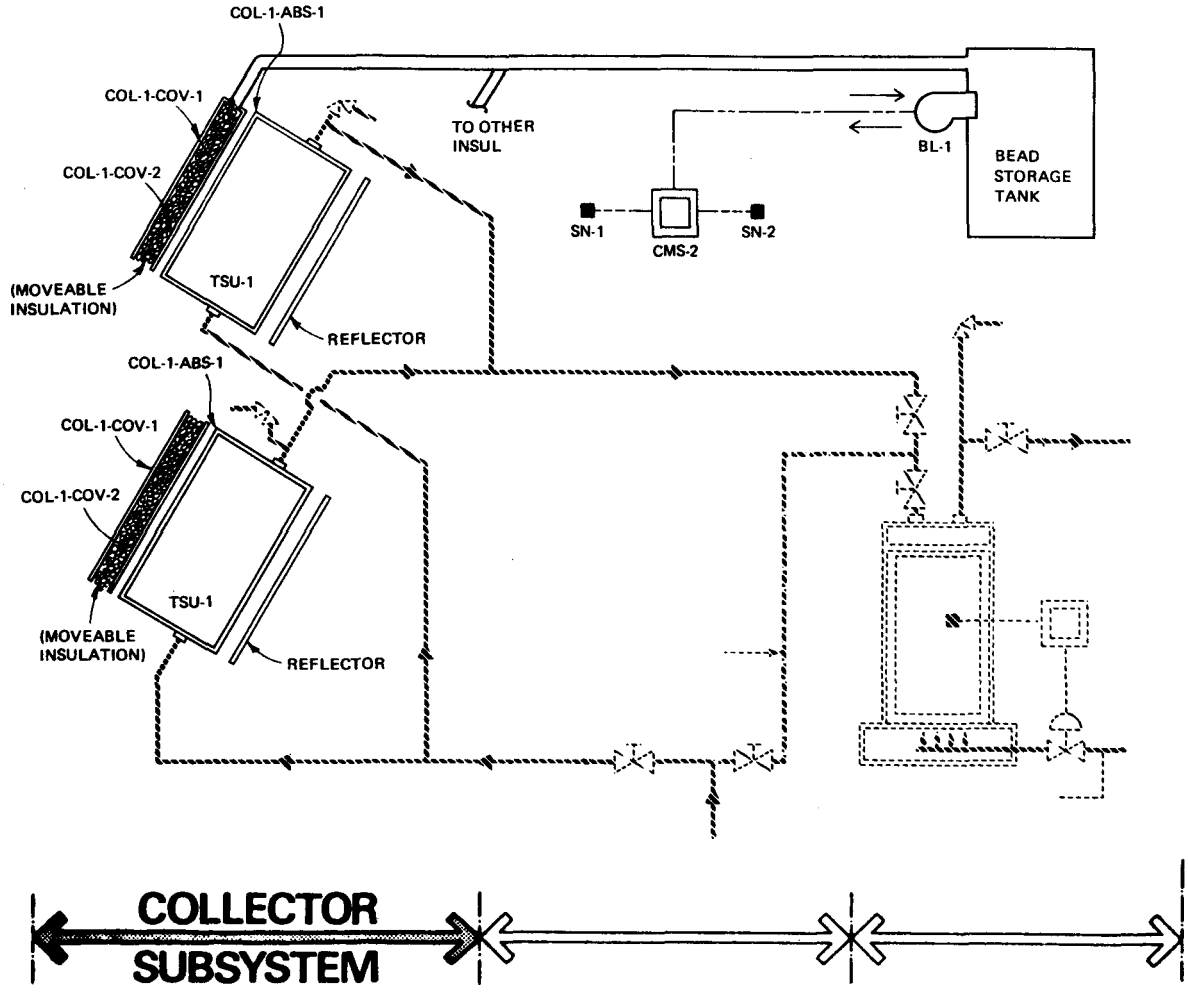


Figure IV-B-1. Collector Subsystem

Collector array system consists of 2 panels (27 ft^2 per array) for DHW. Freeze protection is provided by movable insulation.

COLLECTOR (COL-1)

- Manufacturer - Colorado Sunworks
- Model name/number - Site built
- Type - Liquid concentrating, fixed absorber, fixed trombe meinel cusp with aluminum polished substrate reflector screwed to plywood
- Location - Wall
- Orientation - Fixed at 0^{o} East of South
- Tilt - 90^{o} from horizontal
- Collector characteristics
  - Number of panels - 2
  - Total gross area of array - 29 ft^2 per window
  - Net aperture area - 27 ft^2 per window
  - Net absorber area - 16.75 ft^2 per array
  - Weight per panel
    - Empty - Not applicable
    - Full - Not applicable
  - Window length - 92.0 in
  - Window width - 46.0 in
  - System depth - 5.5 in
  - Standoff height - 0
- Built-in collector - Forms weatherproof surface of wall
- Collector shading
  - Area shaded in June - 50%
  - Area shaded in December - 0%
- Cover plates
  - Number of cover plates - Two
- Cover plate No. 1
  - Location - Outer layer

- Manufacturer - Unknown
- Product name/number - Unknown
- Material - Glass, Tempered
- Thickness - 0.187 in
- Optical properties

	(solar region)	(infrared region)
- Transmittance -	0.85	
- Reflectance -	0.08	
- Emittance -	0.06	

- Edge or surface treatment, other than coating - None
- Coating on cover plate material - None

- Absorber
  - Manufacturer - Colorado Sunworks
  - Model name/number - Unknown
  - Material - Steel
  - Substrate material dimension
    - Thickness - 0.187 in
    - Length - 48 in
    - Diameter - 14 in
  - Number of absorbers per collector - 1

- Coating
  - Coating material - Flat black paint

	(solar region)	(infrared region)
Absorptance -	Unknown	
Reflectance -	Unknown	
Emittance -	Unknown	

  - Application - Painted

- Insulation
  - Layer one - sides
    - Manufacturer - Unknown
    - Product name/number - Unknown
    - Material - Unknown
    - Thermal resistance - Unknown
  - Layer one - back
    - Manufacturer - Zomeworks
    - Product name/number - Beadwall
    - Material - Styrofoam
    - Thermal resistance - R-20
- Frame
  - Manufacturer - Colorado Sunworks
  - Product name/number - Site built
  - Material - Steel/wood
  - Protective coating - Painted
  - Standoffs used - No
  - Number of structure attach points per module to building - 4
  - Built-in collector - Yes
- Reflectors - 2 per collector
- Number of reflectors per collector -
- Substrate material - Aluminum
- Reflective coating - Polished substrate
- Protective coating - None

- Physical dimensions
  - Length - Unknown
  - Thickness - Unl wn
  - Width - Unknown
  - Shape - Locus of points
  - Desiccant - No
  - Freeze protection - Movable insulation provided by a Beadwall system
  - Overheating protection - Manual switch on control Beadwall blower
- Passive collector heat transfer control - Beadwall

C. Storage Subsystem (See figure V-C-1)

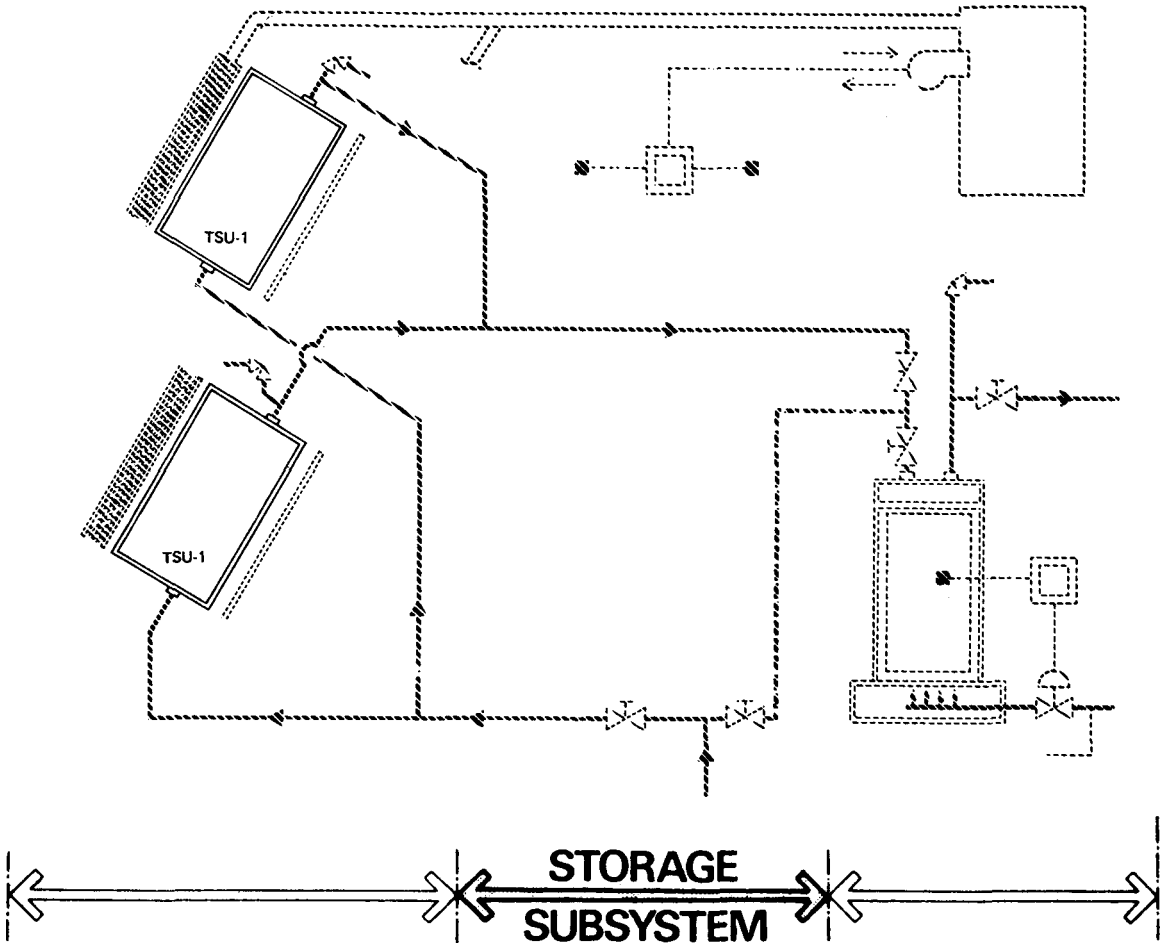


Figure V-C-1. Storage Subsystem

Solar energy storage is provided by two 30-gallon storage tanks. These tanks are made of steel with glass lining. They measure 4.0 feet length by 1.2 feet in diameter and are covered with paint.

THERMAL STORAGE UNIT (TSU-1)

- Manufacturer - Rheem
- Model name/number - Rheemglass 30-gal (2 ea = 60 gal)
- Total storage containers volume - 10.6 ft^3
- Volume of storage medium - 60 gal
  - Length - 4.0 ft
  - Diameter - 1.2 ft
- Maximum rated operating conditions
  - Temperature - 212° F
  - Pressure - 300 psi
- Storage medium
  - Design heating operating temperatures
    - Maximum - 212° F
    - Minimum - 34° 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 recommended use of temperature
  - Maximum - 200° F
  - Minimum - 60° F
- Toxicity - Potable
- pH Factor - 7.0
- Inhibitor - No

- Container construction
  - Type - Steel
  - Interior lining - Glass
  - Location - South wall compartments
  - Auxiliary heaters - No
  - Insulation - No
  - Exterior finish - Painted
  - Filters - No
  - Getters - No

D. Energy To Load Subsystem (See figure V-D-1)

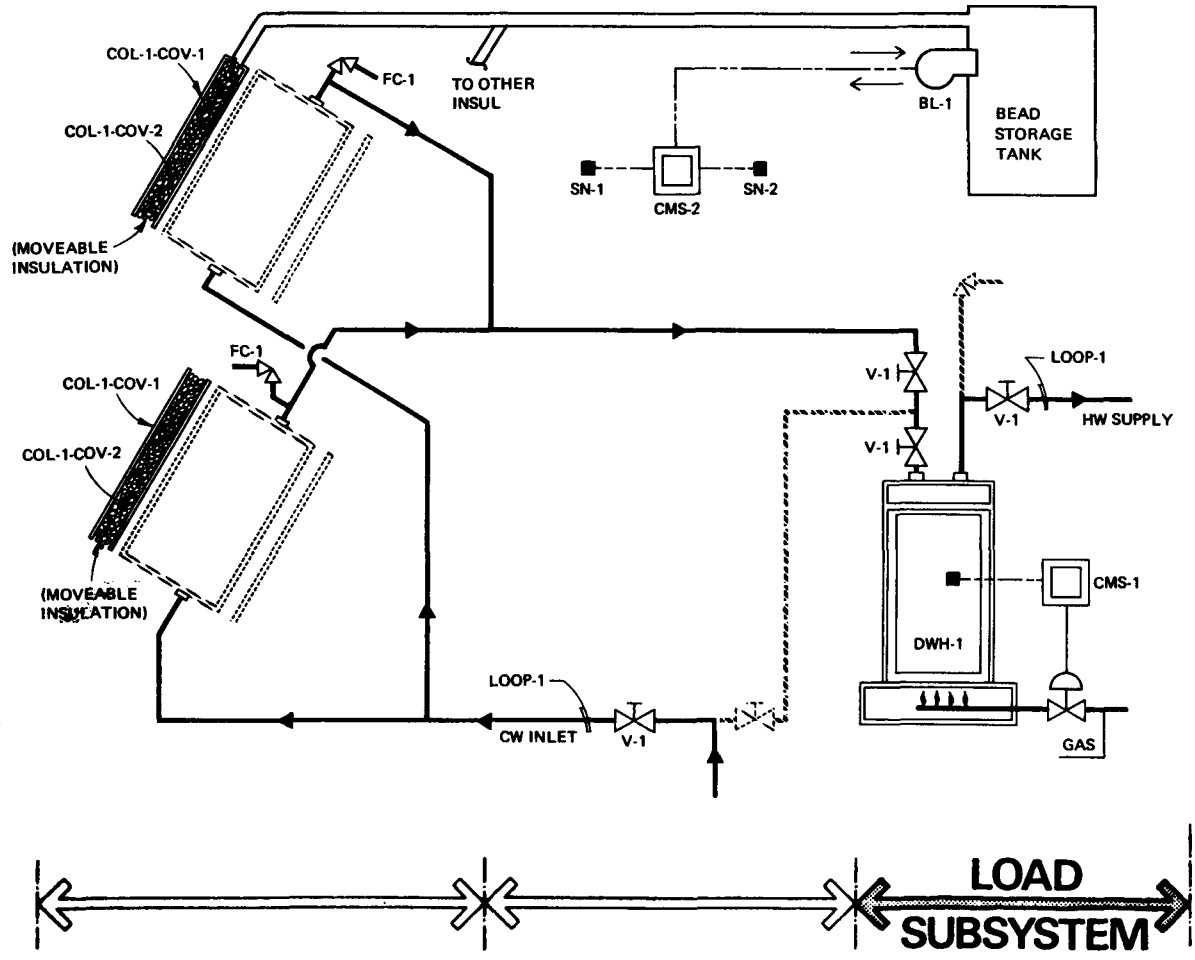


Figure V-D-1. Energy-to-Load Subsystem

Domestic hot water is preheated in the two 30-gallon tanks before passing on demand to DWH-1.

Auxiliary energy is provided by a gas-fired DWH-1 should solar energy be insufficient.

LIQUID CIRCULATION LOOP NO. 1 (HOT WATER DEMAND)

- Maximum design operating temperature - 210° F
- Maximum design operating pressure - 150 psi
- Heat transfer medium
  - Volume of liquid in loop - 60 gal
  - Anticipated liquid temperatures
    - Maximum - 200° F
    - Minimum - 65° F
  - Provisions for expansion - Open system
  - 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
  - Recommended use temperature
    - Maximum - 140° F
    - Minimum - 120° F or as set
  - Toxicity - Potable
  - pH factor - 7.0
  - Chemical feeder to maintain pH factor - No
  - Inhibitor - No
- Components within circulation loop
  - Blower(s) - BL-1
  - Domestic water heater(s) - DWH-1
  - Thermal storage unit(s) - TSU-1 (2)

- Collector(s) - COL-1
- Valve(s) - V-1
- Other(s) - FC-1, FC-2

- Piping
  - Rigid - Copper, Type M
  - Insulation Type - Cellular rubber
  - Location - Above/below grade
  - Filters - No
- Distribution Valve (V-1)
  - Manufacturer - Cash
  - Model name/number - Unknown
  - Function - Isolation
  - Operation - Manual
  - Type - Gate
  - Material exposed to heat transfer fluid -

Control Mode Selector (CMS-1)

- Manufacturer - Unknown
- Model name/number - Unknown
- Modes controlled
  - Gas on for DWH-1
    - ON - Variable set point
    - OFF - Automatic

Control Mode Selector (CMS-2)

- Manufacturer - Colorado Sunworks
- Model name/number - Beadwall control

- Modes controlled
  - Beads to Beadwall
    - ON - Variable Set Point
    - OFF - Automatic
  - Beads to Bead storage
    - ON - Variable Set Point
    - OFF - Automatic
- Sensors (SN-1) and (SN-2)
  - Manufacturer - Colorado Sunworks
  - Type - Temperature, thermister/temperature silicon transistor
- Fail Safe Control (FC-1 & FC-2)
  - Manufacturer - Cash Acme
  - Model name/number - T & P valve
  - Type - Temperature/pressure valve

E. Auxiliary Subsystems (See figure V-E-1)

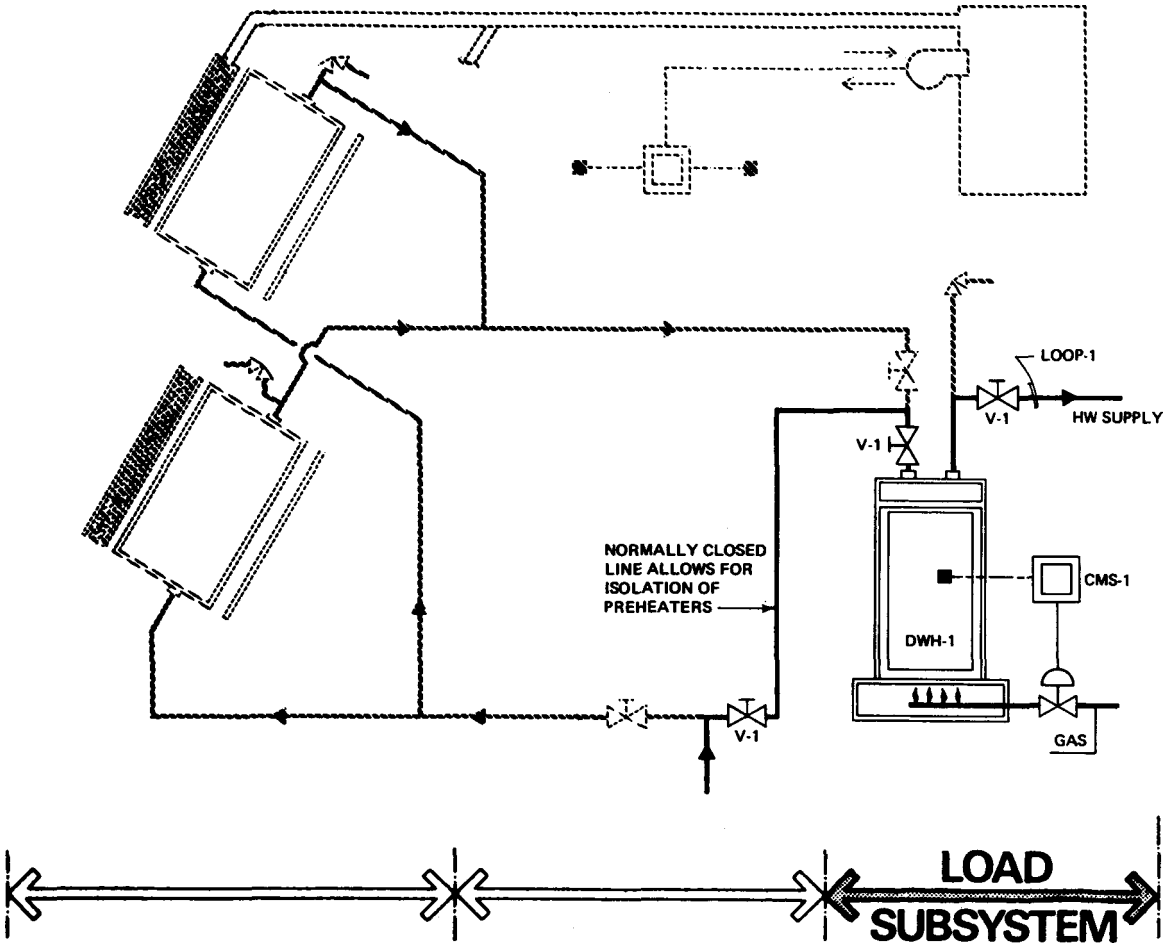


Figure V-E-1. Auxiliary-to-Load Subsystem

The auxiliary subsystem, DWH-1 mentioned in the foregoing Energy-to-Load Subsystem has been grouped in this section for descriptive purposes, the function and purpose has been previously described.

AUXILIARY LOADS

- Domestic Water Heater (DWH-1)
  - Manufacturer - Rheem
  - Model - Rheemglass Fury 22-40-2
  - Energy source - Natural gas
  - Tank size - 40-gal
  - Energy input - 45,000 Btu/hr
  - Energy output - 36,000 Btu/hr
  - Maximum pressure rating - 300 psi
  - Maximum temperature rating - 200° F
  - Design operating pressure - 150 psi
  - Heating stages - Single
  - Maximum recovery rate - 37.8 gal/hr
  - Yearly average inlet temperature - 56° F
  - Design output temperature - 130° F
  - Thermal resistance - Unknown
  - Standby heat loss - Unknown
  - Corrosion protection anodes - No
  - Burner ignition method - Gas pilot
  - Flue vent - Yes

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

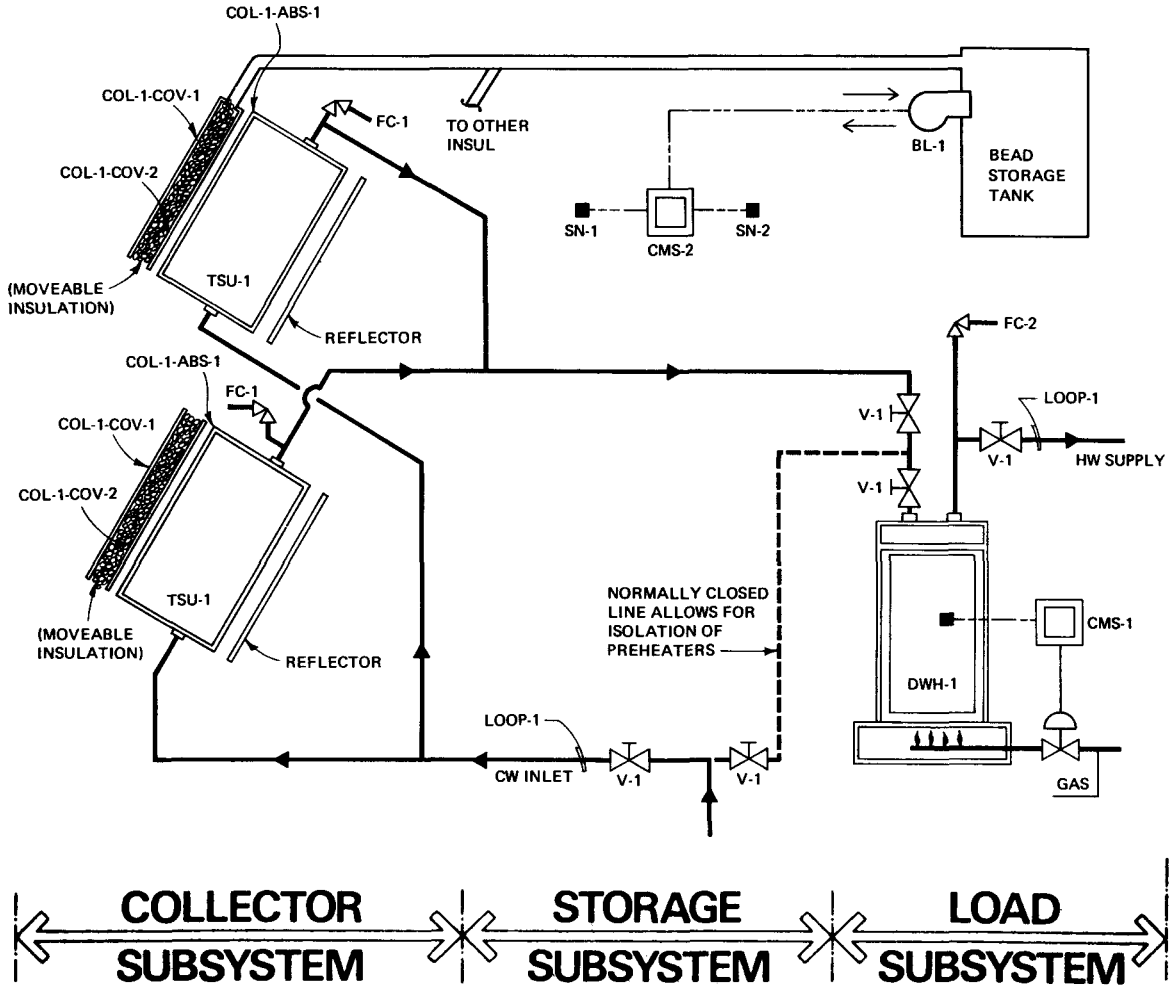


Figure V-F-1. Controls Diagram

The Colorado Sunworks solar system is shown on Figure V-F-1. The system consists of the following four subsystems: a) collector; b) storage; c) load (DHW); and d) auxiliary load subsystems.

Operation of the solar system and the auxiliary subsystems are not documented in the DIM or monthly reports therefore it is unknown how many modes of operations are involved.

VI. 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.

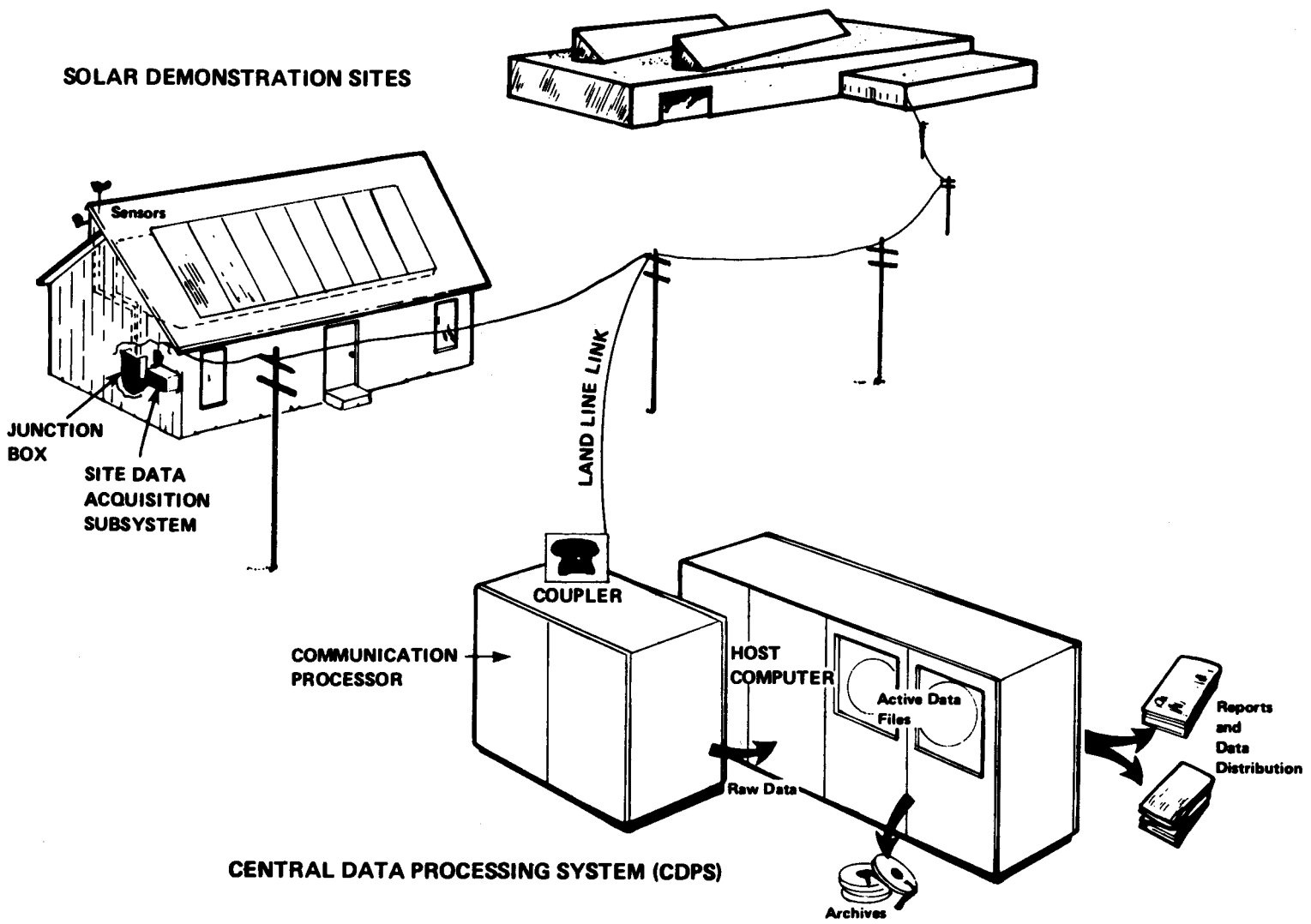


Figure VI-A-1. The National Solar Data Network

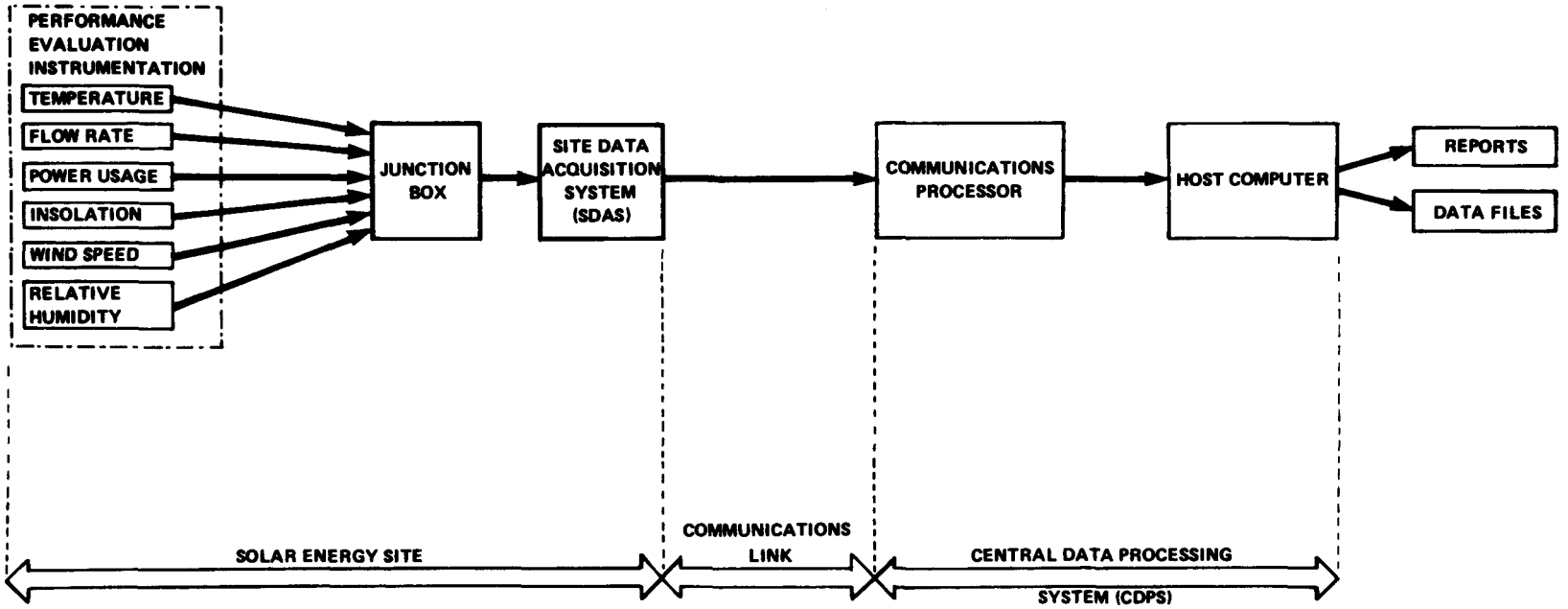


Figure VI-A-2. Data Flow Path for the National Solar Data Network

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 architectual 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 VI-A-1 and VI-A-2). Specific information for temperature, flow, power and miscellaneous sensors are presented in tabular form. Sensor locations are shown in figure VI-B-1.

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
I001	Insolation, on wall of house	Eppley PSP
T001	Temperature, ambient	S53P-60
V001	Wind speed	W-102-P-DC/360
D001	Wind direction	W-102-P-DC/360
S100	Beadwall mode, bedroom 3; open = open	W88ALCPX-12
S101	Beadwall mode, DHW; open = open	W88ALCPX-12
S102	Beadwall mode, atrium, hallway; open = open	W88ALCPX-12
S103	Beadwall mode, atrium, open = open	W88ALCPX-12
S104	Beadwall mode, living room; open = open	W88ALCPX-12
S105	Beadwall mode, master bedroom; open = open	W88ALCPX-12
EP100	Power for beadwall motors	PC5-28
T200	Drum temperature, bedroom #3, inside	S32B
T201	Drum temperature, bedroom #3, outside	S32B
T202	Drum temperature, hallway, inside	S32B
T203	Drum temperature, hallway, outside	S32B
T204	Atrium, top of drum	S32B
T205	Atrium, bottom of drum	S32B
T206	Drum temperature, living room, top, inside	S32B
T207	Drum temperature, living room, next to top, inside	S32B
T208	Drum temperature, living room, next to bottom, inside	S32B
T209	Drum temperature, living room, bottom, inside	S32B
T210	Drum temperature, living room, top, outside	S32B
T211	Drum temperature, living room, next to top, outside	S32B
T212	Drum temperature, living room, next to bottom, outside	S32B
T213	Drum temperature, living room, bottom, outside	S32B
T214	Drum temperature, master bedroom, inside	S32B
T215	Drum temperature, master bedroom, outside	S32B
W300	Flow totalizer	Hersey 430
T300	Temperature, cold water supply to preheat tanks	S53P-60
T301	Temperature, inlet to DHW heater, gas fired	S53P-60
T305	Temperature, outlet of gas DHW heater	S57P-100

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
F300	Gas consumption of DHW heater	ACx-95
T302	Temperature, surface of west preheat tank	S32B
T303	Temperature, surface of east preheat tank	S32B
T304	Temperature, surface of gas DHW heater	S32B
S400	Mode of ceiling vent in bedroom #2	
S402	Mode of ceiling vent in family room west	
S403	Mode of ceiling vent in family room east	
S404	Mode of ceiling vent in master bedroom	
EP400	Power for ceiling duct fans	PC--10F
T400	Temperature of air at base of drumwall bedroom 3	S53P-28
T401	Temperature of air in ceiling duct bedroom 3	S53P-28
T402	Temperature of air at base of drumwall living room	S53P-28
T403	Temperature of air in ceiling duct living room	S53P-28
T404	Temperature of air at base of drumwall master bedroom	S53P-28
T405	Temperature of air in ceiling duct master bedroom	S53P-28
T406	Temperature of return water from perimeter heaters	S53P-60
T407	Temperature of space heat boiler output	S53P-60
W403	Flow rate of water through boiler	MKV 3/4,.7-7
F403	Gas used for conventional heating	AC-95
EP401	Power for circulator pump for conv. space heat	PC5-10
S405	Mode of fireplace	Fenwal 30002
T600	Temperature, surface of concrete dining room	S53P-28
T601	Temperature, concrete - styrofoam interface	S53P-28
T602	Temperature, styrofoam - gravel interface dining room	S53P-28
T603	Temperature, earth, 1 foot below styrofoam, dining room	S53P-28
T604	Temperature, surface of concrete living room	S53P-28

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
T605	Temperature, concrete - styrofoam interface living room	S53P-28
T606	Temperature, styrofoam - gravel interface living room	S53P-28
T607	Temperature, earth, 1 foot below styrofoam, living room	S53P-28
T608	Temperature, surface of concrete floor kitchen	S53P-28
T609	Temperature, inside surface of concrete wall family room	S53P-60
T610	Temperature, concrete-styrofoam interface family room	S53P-28
T611	Temperature, outside surface of styrofoam, family room	S53P-28
T612	Temperature, inside surface of concrete wall bedroom #2	S53P-60
T613	Temperature, concrete-styrofoam interface bedroom #2	S53P-28
T614	Temperature, outside surface of styrofoam, bedroom #2	S53P-28
T615	Temperature, concrete-styrofoam interface roof	S53P-28
T616	Temperatuare, top of styrofoam on roof	S53P-28
T617	Ambient temperature of garage	S53P-28
T618	Ambient temperature of bedroom #3	S53P-28
T619	Ambient temperature of bedroom #2	S53P-28
T620	Ambient temperature of kitchen	S53P-28
T621	Ambient temperature of family room	S53P-28
T622	Ambient temperature of master bedroom	S53P-28
1002	Insolation on an unshaded vertical surface	Eppley PSP
RH001	Relative humidity of outdoor air	HM 14-U
RH600	Relative humidity of indoor air	HM 14-U
T650	Ambient temperature of air-lock entry	S53P-28
T651	Ambient temperature of living room	S53P-28
T652	Ambient temperature of bath #1	S53P-28
T653	Ambient temperature of foyer hall	S53P-28
T654	Ambient temperature of atrium	S53P-28
EP600	Power for home	PC5-70

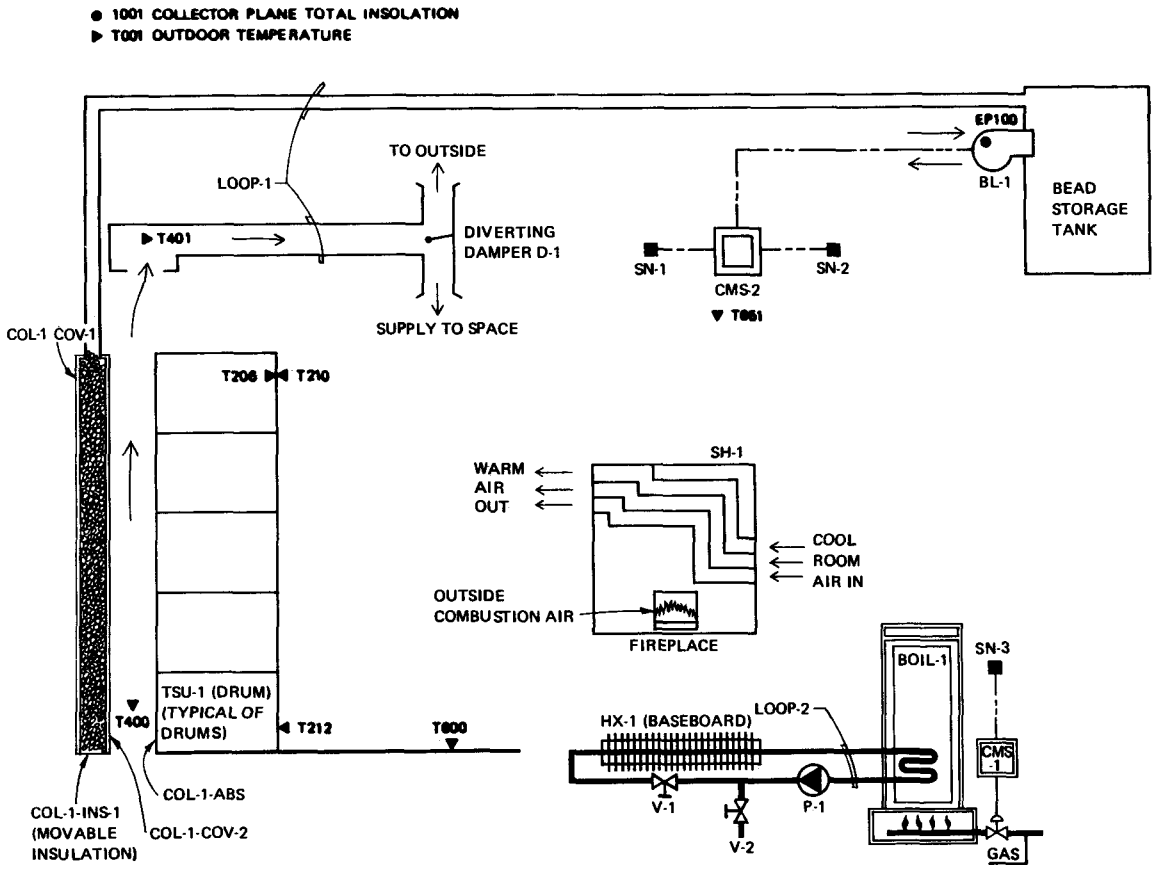


Figure VI-B-1. Space Heat Sensor and Control Diagram

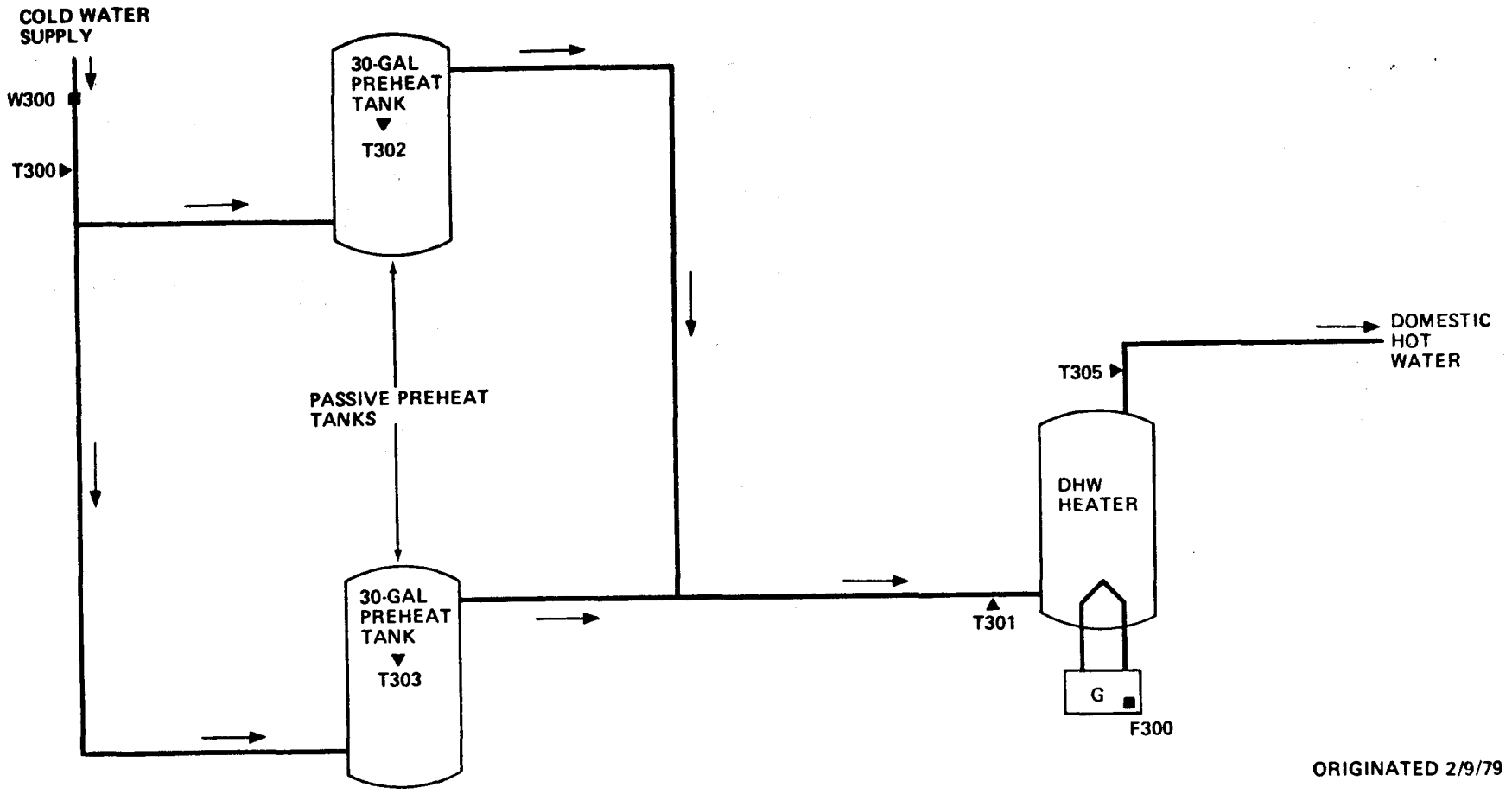


Figure VI-B-2. DHW Sensor and Control Diagram

VII. 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	$	$
Energy Storage		
Distribution and Controls		
Installation		
Other		
Total	$16,633	$10,000

C. Construction Period: December 1977 through July 1978

VIII. 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.

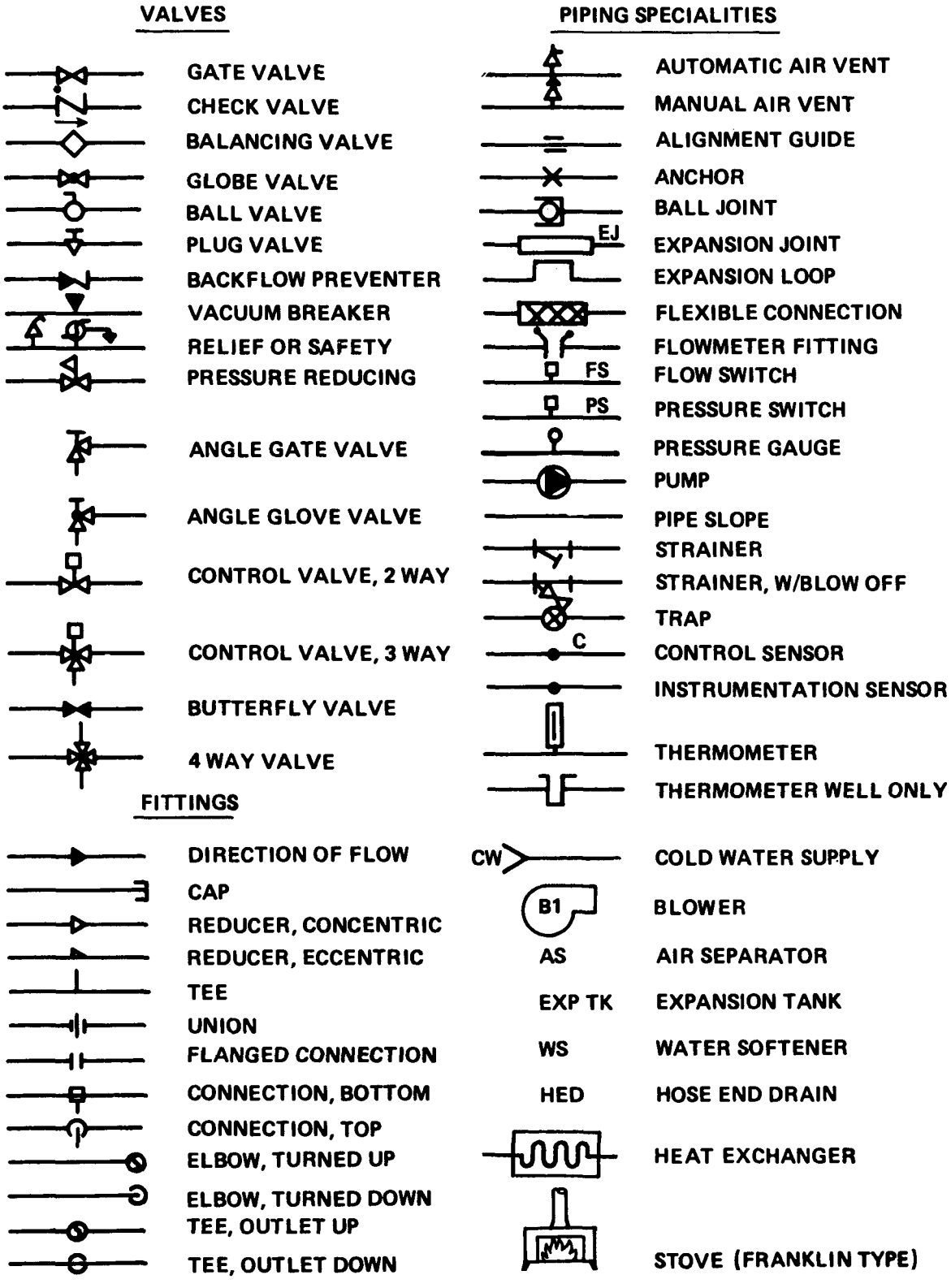
TON OF REFRIGERATION - A unit of refrigeration which is equivalent to 12,000 Btu/hr.

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



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