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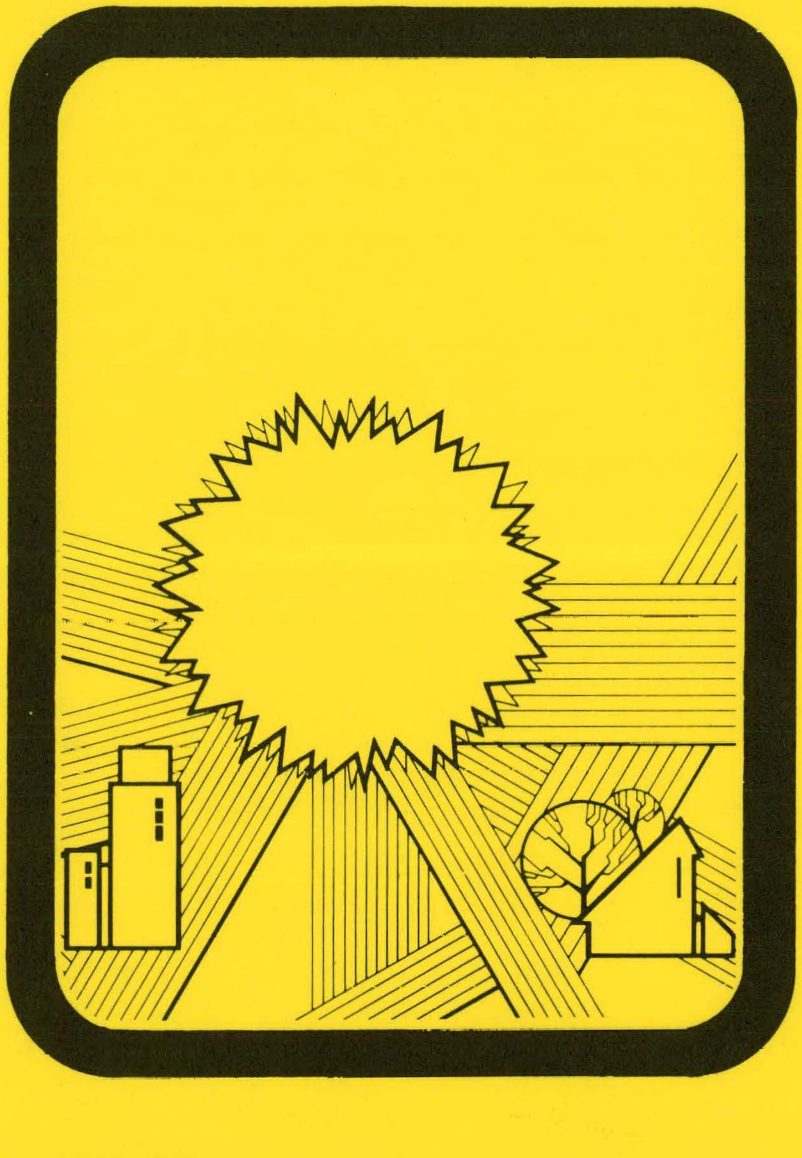
(DE82013260)

COMPARATIVE REPORT: PERFORMANCE OF ACTIVE SOLAR SPACE HEATING SYSTEMS

MASTER

1980-1981 HEATING SEASON



U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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COMPARATIVE REPORT

PERFORMANCE OF ACTIVE SOLAR SPACE HEATING SYSTEMS

1980-1981 HEATING SEASON

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EXECUTIVE SUMMARY

This report provides data and information on 32 solar heating sites in the National Solar Data Network (NSDN). Of these, comprehensive data is included for 14 sites which cover a range of system types and solar applications. A brief description of the remaining sites is included along with system problems experienced which prevented comprehensive seasonal analyses.

Several general statements may be made concerning the seasonal performance of these sites with respect to each other based on data and observations from the heating season:

- Building energy consumption should be reduced through conservation measures prior to the consideration of a solar heating system. Such measures as the addition of insulation, weather stripping, storm windows, and set-back thermostats, among others, will minimize the energy required to heat the building. This results in a reduction of auxiliary energy use, with consequent energy savings, and increases the solar fraction of the load.

- Liquid systems achieved higher collection and heating subsystem coefficients of performance than air subsystems due to the higher efficiency of liquid pumps and the greater heat capacity of liquids.

- Air systems were comparable to the best liquid systems in the percent of incident and collected solar energy delivered to the loads. This good performance is due to thermal losses to the building, lack of collector and storage to load heat exchangers, and the option of delivering solar energy directly from the collectors to the loads.

- Solar-assisted heat pump systems utilized high percentages of incident solar energy. The use of low temperature solar energy from storage increased collection efficiency, reduced thermal losses, and increased solar utilization.

- Low-cost, low-temperature solar collectors perform efficiently when coupled with a solar-assisted heat pump. The use of this combination could lower solar system cost.

- Solar heat exchangers and terminal heating equipment should be sized to use low temperatures to maximize solar utilization.

- Solar heating systems which also provide cooling through absorption chillers exhibited high thermal energy losses. Increased pipe and storage insulation should be considered due to the high operating temperatures required.

- Consideration should be given to a summer/winter operating mode change in absorption cooling systems to allow collectors to operate at lower temperatures for heating. The operation of absorption cooling equipment requires high temperatures which are not necessary for heating. Some cooling systems employ a collector control strategy which varies the flow rate to maintain a high collector outlet temperature. A

control strategy change, in consideration of the lower temperature requirements of heating systems, would permit the collectors to operate more efficiently, and increase solar energy utilization.

- Recirculation of storage water for collector freeze protection in cold environments increases operating energy costs and wastes collected energy.

- Solar systems which use electricity as the auxiliary energy source provided dollar savings that are almost three times greater than sites with a natural gas auxiliary.

- Misadjustment of the collector set point controls caused the rejection of stored energy in many sites.

- Control system failures caused pumps to operate continuously and resulted in manual operation at some sites.

- Complex system designs using three-way valves, mixing valves, bypasses, and multiple operational modes, along with poor conceptualization of control sequences, led to poor performance or system failure.

- System designs which allow auxiliary energy to be delivered to storage reduce solar energy utilization and collection.

The NSDN is a primary vehicle for the Federal Government to track the performance of the many representative space heating systems selected for demonstration and research purposes. The purpose of this report is to present the most recent composite performance results for selected active solar space heating sites in the Network. The results presented have been developed on the basis of analysis of instrumented sites monitored through the 1980-1981 heating season. The sites analyzed include a cross section of major types of active solar heating systems distributed on a regional basis throughout the United States.

Millions of individual measurements from these sites provide a large reservoir of data for operational and comparative analysis. The detailed measurement data for these systems has been analyzed and is presented on the basis of monthly and seasonal performance factors. The data points recorded by on-site instruments were accumulated, reduced, and analyzed in accordance with a hierarchical structure which leads to an understanding of overall system performance. For the NSDN, this hierarchy consists of the following:

Scan Level [five (5) minute interval on-site]

Conversion to Engineering Units

Hourly Averages and Sums

Daily Averages and Sums

Monthly Averages and Sums

Seasonal Averages and Sums

In addition to this hierarchy which addresses single-site data, analyses are conducted which combine the performance results of multiple sites and allow comparative analyses to be accomplished.

Parameters and performance indices presented include overall system delivered loads, solar energy delivered to the loads, solar fraction of the load, coefficients of performance, energy collected, solar energy losses, and various subsystem efficiencies. The comparison of these factors has allowed evaluation of the relative performances of various systems. A matrix of performance indices has been constructed to facilitate comparison of the representative solar heating installations.

Analyses for which comparative data is provided include:

- Collector efficiency, total and operational
- Solar collected per square foot per day
- Ratio of collector area to storage heat capacity
- Ratio of collector area to floor area
- Solar collection coefficient of performance
- Percent of incident and collected solar energy to loads
- Ratio of measured to long-term insolation
- Heating load per square foot of floor area per day
- Solar heating fraction, measured and design
- Percent of heating load from solar losses
- Solar used for heating per square foot of collector per day
- Overall solar system coefficient of performance
- Overall solar heating coefficient of performance
- Percent of collected energy lost
- Heating energy savings per square foot of collector
- Heating dollars saved per square foot of collector
- System energy savings per square foot of collector
- System dollar savings per square foot of collector

The NSDN was established by authorization and appropriations of the U.S. Congress and is administered through the Department of Energy by the Argonne National Laboratory. The availability of these results of the NSDN are in large part due to the continuing support of these and other organizations including the National Bureau of Standards, National Aeronautics and Space Administration, several professional societies, grantees and owners of buildings who have participated, as well as the many analysts, engineers, and field people of Vitro Laboratories and other staff.

Information related to manufacturers and system designers has been included in the site descriptions for reference purposes. Inclusion of this information and analysis data pertaining to any specific design or product in no way represents an endorsement of that design or product by either the Federal Government or Vitro Laboratories.

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Section I

INTRODUCTION

The purpose of this document is to present the most recent composite results of analysis of solar space heating data. This was performed by Vitro Laboratories for selected active sites in the National Solar Data Network (NSDN). Results presented have been developed on the basis of analysis of instrumented sites monitored through the 1980-1981 heating season.

NATIONAL SOLAR DATA NETWORK (NSDN)

One of the principal objectives of the National Solar Heating and Cooling Demonstration Program established by the National Solar Heating and Cooling Demonstration Act of 1974 is the collection and evaluation of solar information, and its dissemination to all potential users. In order to achieve this objective and to ensure that all related activites are conducted uniformly, the National Solar Data Program, including the National Solar Data Network, was established.

Approximately 5,000 residential and commercial solar demonstration sites have been established since the inception of the National Solar Heating and Cooling Demonstration Program. As of the end of March 1981, ninety-four of these sites were instrumented and included in the National Solar Data Network. Additional sites will be selected by DOE for instrumentation for research purposes.

The Department of Energy (DOE) has responsibility for the solar energy program; however, other government agencies are significantly involved. Those agencies include the Department of Housing and Urban Development, the National Aeronautics and Space Administration, the Department of Defense, the National Bureau of Standards, Argonne National Laboratory, and the Department of Health, Education and Welfare. State and local governments, portions of the private sector, and other groups within DOE are also active participants.

The original purpose of the National Solar Heating and Cooling Demonstration Program, which includes the NSDN program, was to promote early commercialization of solar systems. The emphasis under the Reagan administration has shifted to research and development. The NSDN sites selected by DOE include a broad range of solar system types and geographical locations within the United States. These sites are equipped with a Site Data Acquisition Subsystem (SDAS). Sensors are sampled automatically, and the data are stored at each site for one or more days (Figure 1). Since December 1979, the data have been transmitted over telephone lines to a central computer at Vitro Laboratories in Silver Spring, Maryland, where data reduction and analysis take place. Thermal performance of each site is analyzed and the results are reported in site-specific Monthly Performance Reports. Performance over longer time periods is presented in Solar Energy System Performance Evaluation Reports.

OBJECTIVES OF THE COMPARATIVE REPORT

The NSDN is a primary vehicle for the Federal Government to track the performance of the many representative heating systems selected for demonstration purposes. The different types of heating systems have been included in the NSDN because a history of performance is needed to act as a basis for recommendations concerning various options available and further research needs.

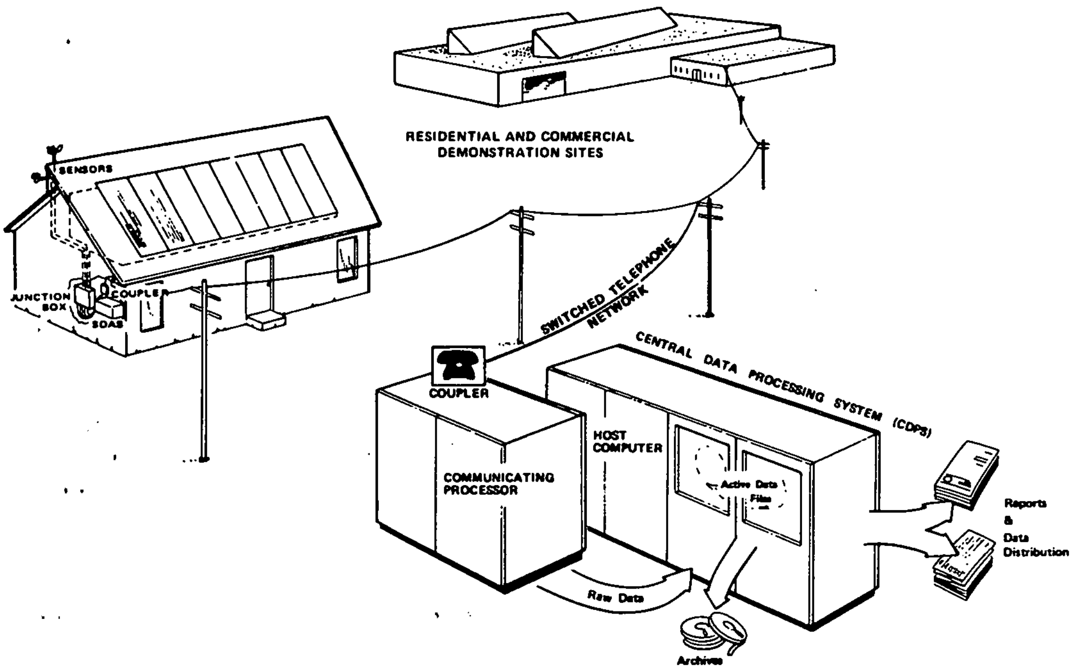

Figure 1. The National Solar Data Network

The NSDN detailed measurement data for these systems were analyzed in accordance with standarized procedures and are presented on the basis of hourly, daily, monthly, and seasonal performance factors. Millions of individual measurements were collected and reduced, providing a large reservoir of data for operational and comparative analysis.

Parameters and performance indices presented include overall system delivered loads, solar energy delivered to the loads, solar fraction, various coefficients of performance, energy collected, solar energy losses in the system, various subsystem efficiencies, and savings relationships. The comparison of these factors has allowed evaluation of the relative performance of various systems. A matrix of performance indices has been constructed to facilitate comparison of the representative solar heating installations.

OVERVIEW OF SPACE HEATING ANALYSIS CONCEPTS

Analysis of space heating requires a general philosophy which can be applied to all systems to assure commonality and comparability of results. Within the NSDN, such a philosophy with attendant methodology has been developed consistent with National Bureau of Standards documentation, NBSIR 76-1137 (Reference 1), and the results presented reflect that philosophy.

Initial NSDN analysis concentrated on analysis of energy gains and losses associated with individual equipment and subsystems. This technique has been fully extended over the past year to analysis of the interfaces between subsystems to permit better understanding of overall system operation, energy flow, and energy losses.

Embodied in the NSDN methodology employed during the 1980-1981 heating season are the concepts of both equipment load (energy gains) and thermal energy flow analysis.

EQUIPMENT LOAD (ENERGY GAINS). The equipment load or energy gains method is characterized by the measurement of gains from the space heating and cooling equipment. These gains are a function of the building heating and cooling demands not satisfied by other sources. These other sources could be passive solar energy gains, passive cooling, and other internal energy gains such as lights, cooking, wood burning, domestic hot water system losses, people's body heat, etc. Figure 2 diagrams the major energy flows for a typical space heating system.

ENERGY FLOW. Thermal energy flow analysis requires definition of the boundary surrounding the physical structure of the system to be analyzed and the major components within that boundary. Energy flows across the boundary and between components are measured and analyzed. Performance factors are constructed from the energy flows to assess the solar system's thermal effectiveness. This type of analysis depends upon an understanding of solar radiation, flows between subsystems, auxiliary and operating energies, load requirements and losses as shown in the hypothetical flow diagram, Figure 2. Appendix C contains actual flow diagrams for the heating season for selected sites.

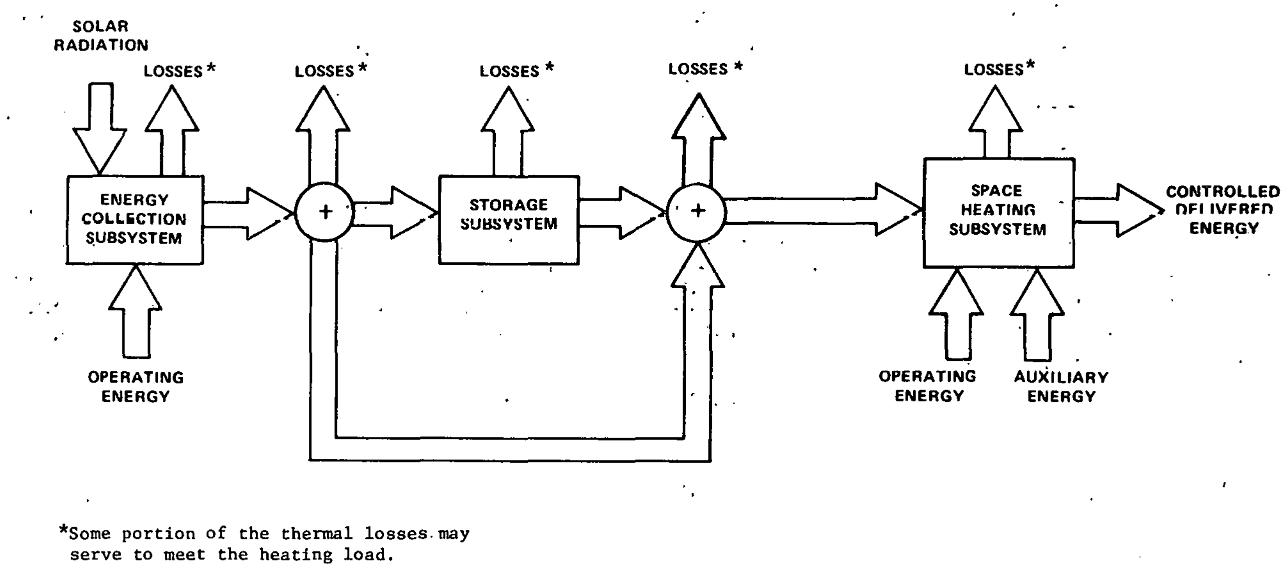

Figure 2. Typical Space Heating Flow Diagram

Monthly performance factors calculated for NSDN sites include:

- System level performance:
  - Thermal performance of the system
  - Solar fraction
  - Total energy consumed
  - Total energy saved
  - Comparison savings (passive systems only)
- Subsystem level performance:
  - Thermal performance of each subsystem
  - ECSS solar conversion efficiency
  - Solar fractions
  - Energy consumed, energy saved

These calculations are made on the basis of the availability of sensor data from each site.

Two major types of data are collected: 1) data from solar system sensors for thermal performance assessments, and 2) weather data. Data collection emphasizes measurements that are intended to lead to performance assessments at the system and subsystem levels rather than at the component level.

Solar system sensor data consists of:

- Temperature sensors in each subsystem
- Flow meters in each subsystem
- Auxiliary power used via wattmeters, flow meters
- Mode sensors (i.e., on/off, etc.)

Weather data consists of:

- Insolation, in the plane of collector (all sites)
- Ambient temperature (outdoor, all sites)
- Wind speed and direction (some sites)
- Relative humidity (some sites)

A more detailed discussion of space heating analysis methodology is contained in Appendix D and in the Solar Energy Analysis Guide (Reference 2).

IDEALIZED SOLAR SPACE HEATING SYSTEM CONCEPTS

This report provides information on solar heating sites of the NSDN. Many different types of systems were selected for NSDN instrumentation from among those in the overall demonstration program. A typical solar space heating system (Figure 3) would normally include a collector array with pump or fan to circulate the liquid or air collection fluid to storage or, in some system designs, directly to the heated space. Heat exchangers are used when subsystem isolation is required or when energy conversion from one medium to another (liquid-to-air, etc.) is used.

Variations in design of storage type, auxiliary energy source, other loads (domestic hot water, cooling), valving, piping, and system controls may be expected to affect subsystem and overall performance.

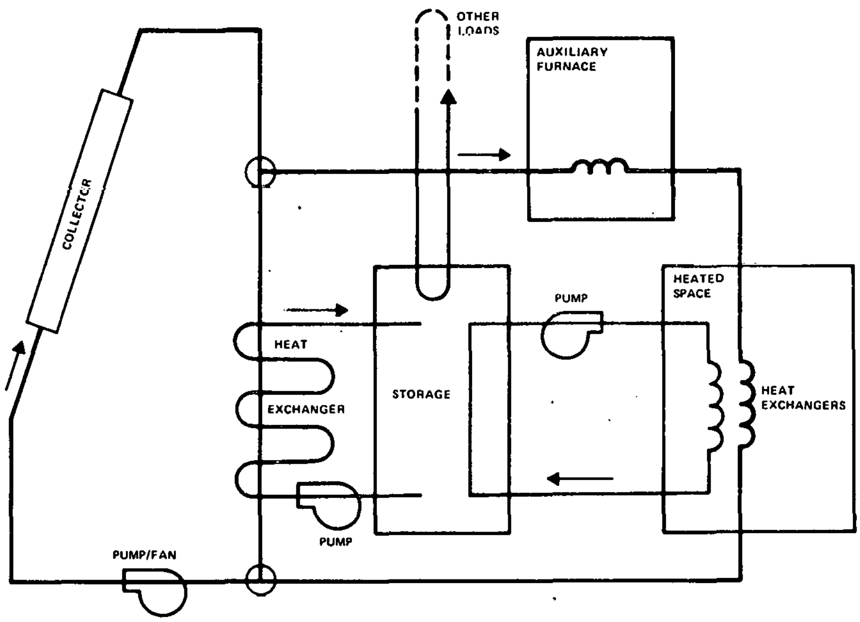

Figure 3. Typical Solar Space Heating System

Schematics, which identify the systems components and interconnections, are included in Appendix B.

REPORT ORGANIZATION

Sections of this report have been organized to permit the reader to examine areas of special interest as well as to highlight general results. Section II contains tables and discussions of individual site parameters such as collector areas, storage tank sizes, manufacturers, building dimensions, etc. Also included in Section II are summary descriptions of sites which had system problems which prevented their inclusion in the comparative analysis.

Section III contains tables and summaries of 1980-1981 heating season data. In addition, analysis results are presented in graphic form to highlight key summary information. The performance indices in this report are presented in graphs which separate the systems into two major groups by collector type: liquid and air.

Section IV provides a summary of comparative results of multiple NSDN systems' operation for the 1980-1981 heating season with discussions of specific cases and conclusions which may be drawn from the data.

Section V provides a list of references used.

Specific detailed data and information necessary to support the development of results presented are contained in Table 3 and the appendices to this document.

Section II

OVERVIEW OF SITES

A prerequisite to understanding the comparative results of the solar heating systems discussed in this report is knowledge of the solar systems themselves. This section presents a brief discussion of the sites which are included in the comparative analysis. More comprehensive site descriptions are provided in Appendix A.

Table 1 provides a listing of the sites including site number and identifies them by system type and application. Table 2 gives the site location, major solar and auxiliary systems, and building characteristics.

Table 1. SYSTEM TYPES AND APPLICATIONS

		SYSTEM TYPE		APPLICATION			
SITE NO.	SITE NAME	AIR	LIQUID	SH	SH,DHW	SH,SC	SH,SC,DHW
006	Olympic Associates		X				X
014	Terrell E. Moseley		X		X		
032	Troy-Miami Library		X	X			
047	GSA		X				X
083	Saddle Hill Trust Lot 36		X		X		
139	Summerwood M		X		X		
145	San Anselmo School		X			X	
163	Matt Cannon		X		X		
164	Montecito Pines		X		X		
194	Spearfish High School	X			X		
195	Billings Shipping		X	X			
216	RHRU Clemson	X			X		
236	First Manufactured Homes Lot 10	X			X		
253	Helio Thermics 8	X			X		
	TOTALS	4	10	2	9	1	2

DHW = Domestic Hot Water
SC = Space Cooling
SH = Space Heating

Other space heating solar systems are in the NSDN. However, for various reasons, the data were insufficient for a seasonal analysis. Summary descriptions for those sites which prevented the preparation of a seasonal report are presented later in this section.

COMPARATIVE ANALYSIS SITES

Olympic Associates, Site Number 006. Olympic Associates is an office building located in Richland, Washington. The solar system uses flat-plate collectors through which ethylene glycol is circulated. Solar energy is stored in a 9,000-gallon water tank and is used for space heating, cooling, and domestic hot water.

Table 2. SITE CHARACTERISTICS

Site Number Site Name Location	Collector Type, Area Collector Fluid, Freeze Prot. Storage Type, Capacity	Building Type Heated Floor Area Storage Location	Auxiliary 1 Auxiliary 2 Solar Delivery	Comments
006 Olympic Associates Richland, WA	Flat-plate, 6,000 ft^2 Ethylene Glycol (35%) Water, 9,000 gal.	Commercial, office 14,000 ft^2 Underground	8 air-to-air heat pumps Electric strip heater 8 water-to-air duct coils	Direct collector-to-load option, solar space cooling, DHW preheat
014 Terrell E. Moseley Lynchburg, VA	Flat-plate, 400 ft^2 Water, draindown Water, 2,000 gal.	Commercial, office 1,780 ft^2 Unheated attached building	Solar-assisted heat pump Natural-gas boiler Water-to-air duct coil, > 85°F, Solar-assisted heat pump, < 85°F	Site-built collectors, DHW preheat, low DHW load
032 Troy Miami Library Troy, OH	Evacuated tube, 3,264 ft^2 Water, recirculation Water, 5,000 gal.	Commercial, library 23,000 ft^2 Underground	Electric strips in ducts Electric baseboard Water-to-air duct coils	Direct collector-to-load option
047 GSA, Federal Youth Center Bastrop, TX	Flat-plate, 21,760 ft^2 Water, draindown Water, 15,000 gal.	Commercial, institution 149,671 ft^2 Outside (two tanks)	Natural-gas boilers Water-to-air heat exchanger	Several individual buildings Solar space cooling and DHW
083 Saddle Hill Trust Lot 36 Medway, MA	Flat-plate, 315 ft^2 Glycerol (60%) Water, 750 gal.	Residence, single 1,916 ft^2 Basement	Oil furnace Wood stove Water-to-air duct coil	DHW preheat
139 Summerwood M Old Saybrook, CT	Flat-plate, 340 ft^2 Water, draindown Water, 600 gal.	Residence, rowhouse 1,375 ft^2 Crawl space	Heat pump - solar and conventional Electric strip heater Water-to-air duct coil	Poured-concrete, insulated storage tank. Solar DHW. Heat pump uses solar at > 40°F. Air-to-air mode < 40°F.
145 San Anselmo School San Jose, CA	Evacuated tube, 3,740 ft^2 Water, recirculation Water, 2,175 gal.	Commercial, school 34,000 ft^2 Outside	Chiller/heaters (2) Natural-gas-fired Water-to-air heat exchanger	Solar space cooling
163 Matt Cannon Gainesville, FL	Flat-plate, 597 ft^2 Water, none Water, 1,000 gal.	Residence, apartments (4) 2,420 ft^2 (total) Outside	Electric strip heater Water-to-air duct coil	DHW preheat
164 Montecito Pines Santa Rosa, CA	Flat-plate, 950 ft^2 Water, draindown Water, 2,000 gal.	Residence, apartments (8) 6,912 ft^2 (total) Underground	Natural-gas boiler Water-to-air duct coil	DHW preheat
194 Spearfish High School Spearfish, SD	Flat-plate, 8,034 ft^2 Air Rock, 4,150 ft^2	Commercial, school 43,000 ft^2 Basement mechanical room	Natural-gas boilers to water-to-air coils Forced air from storage or collectors.	DHW preheat coil in collector duct. Direct collector-to-load option.
195 Billings Shipping Billings, MT	Flat-plate, 2,147 ft^2 Propylene glycol (50%) Water, 2,500 gal.	Commercial, office/warehouse 4,900 ft^2 Underground	Natural-gas boiler to water-to-air coils Water-to-air coils	Direct collector-to-load option
216 RHRU Clemson Clemson, SC	Flat-plate, 388 ft^2 Air Rock, 1,161 ft^2	Residence, single 1,484 ft^2 Basement	Electric strip heater Forced air from collectors or storage	Air entering collector may be preheated in greenhouse. DHW preheat. Direct collector-to-load option.
236 First Manufactured Homes Lot 10 Lubbock, TX	Flat-plate, 288 ft^2 Air Rock, 216 ft^2	Residence, single 1,280 ft^2 Within building	Electric strip heater Forced air from collectors or storage	DHW preheat. Direct collector-to-load option.
253 Heliothermics 8 Greenville, SC	Flat-plate, 416 ft^2 Air Rock, 870 ft^2.	Residence, single 1,086 ft^2 Under house	Electric strip heater Forced air from collectors or storage	Glazed roof and attic space serves as collectors. Direct collector-to-load option. DHW preheat.

Heat exchangers located in the air ducts provide solar space heating. A 25-ton absorption chiller uses solar energy to provide cooling. A heat exchanger located in a preheat tank heats domestic hot water. Auxiliary space heating energy is supplied by electric heat pumps.

Terrell E. Moseley, Site Number 014. Terrell E. Moseley, located in Lynchburg, Virginia, uses site-built flat-plate collectors to provide space heating and DHW. The drainback array utilizes water as the collection medium. Solar energy is stored in a 2,000-gallon water tank. Solar energy can be used directly in a duct heating coil or as an assist to the water-to-air heat pump. Before delivery to the DHW heater, domestic hot water is preheated in a heat exchanger located in the storage tank. A natural gas boiler supplies energy to storage when stored solar energy is low.

Troy-Miami Library, Site Number 032. The Troy-Miami Library is located in Troy, Ohio. The solar system utilizes evacuated-tube collectors to provide space heating only. Water is the collection medium and the recirculation of storage water provides freeze protection. Solar energy is delivered through the duct heat exchangers and auxiliary energy is supplied by duct-mounted electric heating coils. Storage is provided by a 5,000-gallon buried water tank.

GSA, Site Number 047. GSA is a prison facility in Bastrop, Texas. Solar energy is used for space heating, domestic hot water, and cooling. The large, flat-plate collector array uses water as the collection medium and a draindown strategy for freeze protection. Solar energy is stored in a 15,000-gallon water tank and a 25,000-gallon water tank.

Saddle Hill Trust Lot 36, Site Number 083. Saddle Hill Trust Lot 36, a single family residence in Medway, Massachusetts, uses solar energy for space heating and preheating domestic hot water. A glycerol solution is the collection fluid which is circulated to a flat-plate collector array. Solar energy is stored in a 750-gallon water tank located in the basement. A duct-mounted heating coil delivers solar energy for space heating. Solar energy is supplied to a heat exchanger located in the DHW tank for hot water heating. Auxiliary space heating is provided by an oil furnace.

Summerwood M, Site Number 139. Summerwood M, a condominium in Old Saybrook, Connecticut, uses solar energy for space heating and domestic hot water. A flat-plate collector array, which uses water as the collection medium, delivers energy to a 600-gallon storage tank. The draindown method is used for freeze protection. For space heating, solar energy can be used directly in a duct heating coil or as an assist to a heat pump. The heat pump can operate in the solar-assisted water-to-air mode or in an air-to-air mode. Solar energy is supplied to domestic hot water through a heat exchanger located in the domestic hot water tank.

San Anselmo School, Site Number 145. The San Anselmo School is located in San Jose, California. The solar system is used for space heating and cooling. An evacuated-tube collector array uses city water as the collection medium and recirculation for freeze protection. Collected solar energy is stored in a 2,175-gallon water tank. Solar space heating is provided through the heat exchangers in the air handlers. The absorption chillers use solar energy for cooling. Auxiliary energy for heating and cooling is provided by gas-fired absorption chiller/heaters.

Matt Cannon, Site Number 163. Matt Cannon, an apartment building in Gainesville, Florida, has a flat-plate collector array which uses water as the collection medium. Storage consists of a 1,000-gallon, aboveground water tank. Space heating is provided through a heat exchanger located in the return air duct. Auxiliary energy is supplied by electric strip heaters. Solar heated water is circulated through a heat exchanger jacket around a preheat tank for domestic hot water.

Montecito Pines, Site Number 164. Montecito Pines is an apartment complex in Santa Rosa, California. One eight-apartment unit is instrumented. Solar energy is used for space heating and preheating domestic hot water. Flat-plate collectors are used, water is the collection medium, and a draindown strategy is employed for freeze protection. Solar energy is transferred to the space heating system from a storage heat exchanger to air duct heating coils. A storage heat exchanger is used to preheat city water on demand.

Spearfish High School, Site Number 194. Spearfish High School, located in Spearfish, South Dakota, utilizes flat-plate air collectors and a rock storage bin. Solar heated air is delivered to the building through a duct system either directly from the collectors or from storage. An air-to-water heat exchanger, located in the collector return duct, heats water which is stored in a preheat tank.

Billings Shipping, Site Number 195. Billings Shipping is a freight distribution facility and office area in Billings, Montana. The solar system is utilized for space heating only. The flat-plate collectors use a propylene glycol solution as the collector fluid. Solar energy is stored in a 2,500-gallon, buried water tank. Solar heated water is transferred to an air handler heating coil either directly from the collection loop heat exchanger or from storage. A gas-fired boiler provides auxiliary energy.

RHRU Clemson, Site Number 216. The Rural Housing Research Unit (RHRU) is a single family residence on the property of Clemson University in Clemson, South Carolina. The solar system employs flat-plate air collectors and a greenhouse to collect solar energy which is stored in a rock storage bin. Solar energy is delivered to the building by circulating air to the collectors or storage. Auxiliary energy is provided by electric strip heaters. An air-to-water heat exchanger is located in the collector return duct to preheat cold water for the domestic hot water system.

First Manufactured Homes Lot 10, Site Number 236. First Manufactured Homes Lot 10 is a single family residence in Lubbock, Texas. The flat-plate collector array uses air as the collection medium. Solar energy is stored in a rock storage bin. Solar heated air is delivered to the building either directly from the collectors or from storage. An air-to-water heat exchanger, located in the collector return duct, heats water to be stored in a preheat tank. An electric strip heater is used as the auxiliary energy source for space heating.

Helio Thermics 8, Site Number 253. The Helio Thermics 8 solar site is a single family residence in Greenville, South Carolina. Solar energy is used for space heating and preheating domestic hot water. Solar energy is stored in a gravel bed under the house. The system employs a glazed roof and attic space as the collectors. Solar heated air in the attic is delivered either directly to the building or to storage. Cold water thermosiphons through black sheet-metal plates in the attic to preheat domestic hot water. An electric heating strip located in the air supply duct supplies auxiliary energy.

PROBLEM SITES

The following sites did not perform adequately during the heating season due to system problems. System problems are defined as problems arising from system failure, misadjustment, mismatching, or other deficiencies relating to the operation of any of the solar energy system components or subsystems, including the solar collector array, pumps, controls, the heating equipment, storage tank, and related devices. The following section includes short descriptions of the solar systems and a few sentences describing the types of problems which prevented normal system operation during the heating season.

<u>Albuquerque Western II</u>. Albuquerque Western II is a four-story, 101-unit apartment building in Albuquerque, New Mexico. The solar energy system consists of two independently-controlled systems: one system serves domestic hot water (DHW) preheating needs; the other serves to preheat hot water used in space heating. Only the space heating system is described in this report.

The solar energy system has an array of concentrating and tracking SOLCAN collectors with a gross area of 5,733 square feet. The array faces south at an angle of 35 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage. Solar energy is stored underground in a 57,000-gallon concrete storage tank. During the space heating season, the heated water from storage is continuously circulated throughout the building in order to satisfy the space heating needs for each apartment. When solar energy is insufficient to satisfy the space heating load, auxiliary heating is provided by three in-line gas-fired Raypack 945T hot water boilers.

The solar energy system did not perform well last season due to a burned-out collector pump which prevented collection until the end of the heating season.

There is an inherent problem at this site which results in a less efficient use of the collected solar energy than would be expected. This problem is caused by the auxiliary energy subsystem, which is contributing heat to the storage tank instead of removing stored energy. When there is a space heating demand, heated water leaves the storage tank and enters the boiler, where it is heated 2°F to 5°F. The water cycles through the heat exchangers and returns to the storage tank at about the same temperature that it left the storage tank, maintaining a storage tank temperature of 125°F. In this mode of operation, the storage tank serves more as a reservoir for the auxiliary subsystem than as storage for the solar energy subsystem.

This is a surprisingly common problem which should be addressed in all designs.

<u>Animal Control Center</u>. The Animal Control Center site is an animal shelter located in Albuquerque, New Mexico. A combination of active and passive solar energy systems are used to provide space heating for the 4,500 square feet of conditioned space.

The active system has 728 square feet of Albuquerque Western Solar Industries, Inc., Model SOLCAN concentrating tracking collectors. The collectors heat water which is delivered to the conventional hydronic heating system either directly, via a heat exchanger, or from a 1,500-gallon storage tank. Hot water from the conventional hydronic heating system provides radiant floor heat to the kennels and supports forced air heating to the kennels and office space. A conventional gas-fired boiler provides supplemental heat to the water.

The passive solar system consists of clerestory windows with an opening area of 425 square feet (approximately 30% of the floor area of the kennels). A hinged combination reflector and night insulation panel, controlled by a standard Wadsworth ventilation sash controller, is used to direct the solar energy onto the floor of the kennels.

The major problems at the Animal Control Center include overheating of the passive kennel area, and leakage of collector fluid from a series of air purge valves located on the piping of the rooftop collector array. The tracking-type solar collectors were also not focused properly with respect to the path of the sun, causing poor collector performance as well as rejection of stored solar energy.

The passive aperture control system appeared to be too simplistic in concept (i.e., the aperture control was based on insolation only) and allowed solar energy to enter the kennel area even when the temperatures were already sufficient for the animals.

Bond Construction. The Bond Construction site is a single family residence in Gladstone, Missouri. The home has approximately 1,400 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 American Heliothermal Microm II flat-plate collectors with a gross area of 465 square feet. The array faces south at an angle of 37 degrees to the horizontal. An ethylene glycol solution is the transfer medium that delivers solar energy from the collector array to a Young Radiator external heat exchanger. Water is the transfer medium that delivers solar energy to the space heating load. Solar energy is stored in the basement in an 800-gallon steel Ionic Solar custom-built storage tank with walls approximately one-fourth-inch thick. The storage tank has four-inch polyurethane insulation on the bottom, and eight-inch fiberglass insulation on the top and sides. Preheated city water is stored in an 82-gallon American Appliance domestic hot water (DHW) tank. When solar energy is insufficient to satisfy the space heating load, the gas furnace provides auxiliary energy for space heating. Similarly, an electrical immersion heater in the DHW tank provides auxiliary energy for heating the supply water. Solar energy is transferred from the storage tank to the hot-air heating system by a liquid-to-air heat exchanger. This is contained in the furnace duct work. Solar energy is transferred from the storage tank to the DHW tank by an annular heat exchanger jacket around the hot water tank. The house also contains a fireplace with an integral fan. The fireplace is instrumented for monitoring fan power consumption.

The solar energy system at Bond Construction experienced severe failure resulting from an electrical storm on December 7, 1980. Auxiliary energy supplied space heating during the downtime. The lightning apparently caused the control circuit to fail. The site was repaired late in January 1981. Solar systems subject to severe electrical storms should be carefully grounded to prevent failure during lightning strikes.

In the past, Bond Construction has also had severe corrosion problems. In May 1981, the following repairs were made:

1. Storage tank interior coated
2. Iron pipe switched to copper throughout the system
3. All fittings cleaned and replaced if needed; noncopper fittings changed to copper

Brookhaven National Laboratory. The solar system at the Brookhaven National Laboratory's Animal Quarantine Center in Upton, New York consists of flat-plat collectors by Raypack, a 5,300-gallon storage, a domestic hot water preheat, and a space heating subsystem. Backup heating is by electric resistance heaters. Propane gas is the auxiliary backup for the domestic hot water system. The solar system is designed to provide 20% of the annual space heating load and 100% of the annual hot water heating load. There is a separate heat transfer loop for the collectors and storage tank. Nutec, an ethylene glycol antifreeze, is used in the collector and heating subsystems to prevent freezing.

During the heating season, the Brookhaven National Laboratory's system provided three percent of the total system load. The solar system experienced numerous mechanical and control problems, including poorly-timed operation of at least five pumps for collection, storage, and space heating flows. The pumps ran continuously at times, and failed to operate at other times. Typically, a pump such as the storage distribution pump would operate continuously for periods from several days to over three months. This pump operation had severely limiting effects on system performance.

Chicago Navy Pier. The Chicago Navy Pier site is a building complex located in Chicago, Illinois on a man-made peninsula extending over three-fifths of a mile into Lake Michigan. The Navy Pier's East End complex is used as a year-round recreational and cultural facility. The solar energy system is designed to supply 33% of the space heating requirements for the Terminal Building, a 36,000-square-foot, three-story masonry structure serving as the gateway to the East End complex, which also utilizes solar energy for space heating.

The Terminal Building is served by a split system; perimeter areas heated by fan coil units using room air exclusively, and circulating hot water at a maximum 160°F; and interior zones heated by ducted forced warm air. Auxiliary energy is provided by two 85-hp gas-fired boilers.

The 300 collectors are Chamberlain Model 711301 flat-plate type with a black chrome selective surface. The collectors face due south and are tilted 52 degrees from the horizontal. The gross collector area is 9,217 square feet. The collector fluid medium is a 50% ethylene glycol/50% water mixture with anticorrosion additives. Water is used as the energy storage medium and heat transfer medium in the storage and space heating loop. The collector pumping system is controlled by the absorber plate temperature set point method. Overheat protection is provided by a heat exchanger which utilizes a closed circuit of lake water for cooling.

Storage consists of two 7,500-gallon, aboveground storage tanks located in a nearby building. The tanks are insulated by three inches of fiberglass insulation.

The system controls have not been working properly for over a year. The site operators have to manually switch to solar heating mode because the automatic transfer control does not work.

Problems with storage utilization make the collectors operate at high temperatures, for which they were not designed. As a result, there is a low collector efficiency of approximately 10%. Due to baffles in the storage tank, there is little energy being transferred from the collector loop to storage. These baffles reduce mixing of water in the storage tank and appear to cause the same slug of water to recirculate in the collector and load loops. As a result, the heating solar fraction was seven percent last season.

Columbia Gas. The Columbia Gas site is a three-story, 25,000-square-foot office building in Columbus, Ohio. The solar energy system, which was added to the existing building, is designed to provide 30% of the building's total annual thermal energy requirements. The expected annual solar contributions for the three subsystems are 32% for space heating, 23% for space cooling, and 70% for hot water. The collector subsystem is comprised of 44 Honeywell, Inc. north/south tracking, concentrating collectors, facing five degrees east of south. The collectors rotate about an approximate east/west axis to track the daily variation in the sun's elevation angle, and direct the solar radiation toward the absorber tube mounted above the reflectors. The collector array is arranged in 11 rows with a total gross area of 2,978 square feet.

The collector loop heat transfer fluid is a 47% solution of Dowtherm SR1. The collected solar energy is transferred to the loads, or to a 5,000-gallon water thermal storage tank via a liquid-to-liquid heat exchanger. Incoming city water is heated for use as domestic hot water on demand, by passing it through another heat exchanger located within the water thermal storage tank. A conventional 50-gallon gas-fired hot water heater augments this solar hot water energy from the tank heat exchanger. Solar-heated water is also used for space heating and cooling. This thermal energy is supplied either to fin tube heating coils for space heating, or to an absorption chiller for space cooling. When solar energy is insufficient to satisfy heating or cooling demands, thermal energy is provided by an auxiliary gas-fired boiler.

The site has been operational since 1978. The solar fraction for the site has been averaging one to two percent for the heating/cooling/domestic hot water subsystems. The solar system performance is poor due to inherent design problems and operational requirements. The collector trackers failed to accurately focus solar insolation on the absorber tubes, resulting in poor performance. Also, there is a high diffuse component of solar insolation in this region of the country which cannot be utilized by concentrating collectors. The heating system requires water temperatures of 160°F which reduces solar utilization.

Dallas Recreation Center. This solar energy system is installed in the North Hampton Park Recreation and Health Center in Dallas, Texas. The building contains an area of 16,000 square feet, which provides room for an 8,000-square foot gymnasium, a locker room, and a health care clinic. The solar energy system is designed to provide 30% of the annual space heating, 48% of the annual space cooling, and 90% of domestic hot water requirements.

The solar energy system contains 238 single-glazed, flat-plate collectors, manufactured by Lennox Industries, Inc., providing a gross area of 4,258 square feet. The collectors are mounted in 16 rows on the roof of the building and face south. The collectors are tilted at an angle of 25 degrees from the horizontal. The heat transfer medium is an aqueous solution of 34% ethylene glycol. The capacity of the collector loop is 475 gallons.

Space heating is accomplished by the transfer of thermal energy, using heat exchangers, to the air handling system. Space heating is supplemented by a gas-fired boiler. The thermal energy is stored in a 6,000-gallon hot water storage tank, which is located above ground in the mechanical room and is insulated with four inches of urethane.

Space cooling is supplied by using solar energy to operate an ARKLA absorption chiller. Chilled water is stored in a 2,000-gallon tank located above ground in the mechanical room and insulated with four inches of urethane. Auxiliary space cooling is provided by two vapor compression units.

Supply water is preheated by a heat exchanger on the hot side of the absorption chiller condenser loop. Preheated water is further heated by a heat exchanger between the hot water storage and the domestic hot water heater. A conventional 100-gallon natural-gas water heater provides additional thermal energy to satisfy the load requirement.

The solar energy system at Dallas Recreation Center is primarily a space cooling system, with heating actually a smaller portion of the yearly load. While the site exhibited a fairly high heating solar fraction, the net yearly energy savings were actually negative. Several control problems prevented full use of solar-chilled water from the solar cooling system. The net savings were also reduced by the high operating energy requirement for the cooling towers.

Design Construction. The Design Construction site is a single family residence in Bigfork, Montana. The home has approximately 1,800 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 1,400-gallon water tank located in the conditioned space. The cylindrical tank has six-inch concrete walls with two-inch expanded polyurethane insulation. Preheated city water is stored in a 65-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.

The solar collectors at Design Construction are disintegrating and are to be replaced. High stagnation temperatures led to a failure of the "Revere Sunroof" collectors. In a nearly similarly constructed site, the wooden collector supports actually ignited and caused a small fire.

First Baptist Church. The Solaron solar collector array at the First Baptist Church in Aberdeen, South Dakota, has a total area of 1,253 square feet. It uses air for the heat transfer fluid and has a rock storage of 700 cubic feet. The collector is south-facing at a 30-degree tilt angle, which conforms with the existing roof pitch. Aberdeen is at 44 degrees north latitude. The church was designed to be energy efficient with well insulated walls, few doors and windows, and an earth berm on the north wall.

The solar collection and storage system is designed to provide 30% of the heating load and 52% of the hot water. Solar heating of the church is confined to the large sanctuary and an adjacent meeting room. An electric auxiliary boiler provides backup heat to the sanctuary and the adjacent meeting room, and also heats a series of offices on the south side of the sanctuary.

Domestic hot water is heated by a heat exchanger located in the hot air duct from the collector. Hot water is stored in a 100-gallon storage tank adjacent to the auxiliary electric water heater. Solar preheated hot water is available to the auxiliary tank on demand.

The most significant drawback to performance of this air site is the excessive leakage rate from the solar collectors and manifolds, causing severe drops in stored energy. Also, several of the air system components have been subject to jamming (such as motorized dampers), indicating some air components need careful selection.

Fort Polk Exchange. The Fort Polk Exchange site is a post exchange shopping center located approximately 130 miles northwest of Baton Rouge, Louisiana. The center has 70,000 square feet of floor space and is divided into four heating and cooling zones with independently-controlled air-handling units. The site is equipped with a solar energy system designed to supply 87% of the space heating and domestic hot water loads and 59% of the space cooling load.

The collector subsystem is composed of two arrays, totaling 11,728 square feet (gross area) of evacuated-tube collectors. The energy transport fluids in the collector arrays are 38% and 39% ethylene glycol/water solutions. Collected energy is transferred, via heat exchangers, to a water transport medium for load support and storage. A 100,000-gallon tank is used for storage of solar heated water during the heating season and for cold water storage during the cooling season.

Solar domestic hot water heating is provided by circulating solar heated water through a heat exchanger located in the domestic hot water boiler circulation loop. Auxiliary heating is provided by a gas-fired boiler.

Solar space heating is provided by circulating water either directly from the storage-collector loop to the air handling units or by using the solar storage as a heat source for two reciprocating heat pumps. Auxiliary heating is provided by the domestic hot water boiler which is used to heat the storage tank so that it can be used as a heat source for the heat pumps.

Solar space cooling is provided by a 228-ton absorption chiller. Solar heated water is supplied to the chiller generator directly from the collector heat exchanger. Auxiliary cooling is provided by the two reciprocating heat pump chillers. Heat of rejection from both the absorption and reciprocating chillers is rejected to a cooling tower. Chilled water is stored in the 100,000-gallon tank during off-peak hours to help meet the peak hour demand.

Design and control problems characterize the excessive complexity of this solar system. The site operates in undefined modes (i.e., the proliferation of valves, pipes, and cross connections allows nondesigned flows to occur), degrading performance.

Irvine School. The El Camino Real Elementary School, referred to hereafter as Irvine School, is located in central Orange County, California. The school is approximately ten miles from the Pacific Ocean, and was built in 1971. The building contains 41,109 square feet of floor area and is normally occupied five days a week by 850 children and 60 adults. Building occupancy is uniform throughout the year since the school operates on a trimester plan. The solar energy system was added to the existing building and was designed to supply 50% of the annual building heating and cooling demand.

The solar energy installation includes 4,950 square feet of evacuated tubular glass collectors, a heat rejector, and a heat exchanger from the collector loop to the load loop. The collector array faces south at an angle of 25 degrees to the horizontal. Water is used as the medium for delivering solar energy from the collector array to the heat exchanger for transfer to the load subsystems. Existing load loop components were unaltered except for controls. These load loop components include a four million BTU per hour boiler, two 100-ton absorption chillers, 41 heating coils, and seven air-handlers. Since heating demands are low due to the moderate climate and most of the load demand occurs during the day, no solar energy storage is provided. The collected solar energy is transferred directly from the collector loop to the load loop via the heat exchanger. If collected energy exceeds the load loop demand, excess energy is rejected via the heat rejector.

The site did not measure up to the intended design performance levels. Among the most serious problems are collection system control misadjustments which prevent the full utilization of solar energy when available. Also, auxiliary energy from the boiler system can enter the solar collector subsystem, thus causing heat rejection and reducing collection efficiency.

Kansas City Fire Station. A solar energy system is installed at Kansas City Fire Station No. 24 in Kansas City, Missouri. The system is designed to supply approximately 50% of the annual space heating requirements for the Fire Station. The Fire Station consists of three apparatus bays and a personnel area with a total floor area of 8,800 square feet. The site has an array of 144 flat-plate collectors, manufactured by Solaron, with a gross area of 2,808 square feet. The collector subsystem consists of three arrays of collectors at two different tilt angles. The largest array consists of 1,872 square feet of collectors on the south-facing wall of the Fire Station at a tilt of 53 degrees to the horizontal. The remaining collectors consist of 936 square feet on the roof of the station facing south at a tilt of 45 degrees to the horizontal. Solar energy storage is provided for space heating by a pebble bed containing 71.5 tons of stones. A 120 gallon preheat tank stores solar energy for domestic hot water. Air is the medium used for transferring energy from the collector array to the pebble bed or directly to the personnel or apparatus bay areas. An air-to-water heat exchanger located in the collector-to-rock bed ductwork transfers solar energy to the domestic hot water preheat tank. When solar energy is insufficient for space heating, three heat pumps furnish auxiliary energy to the personnel area. Four electric unit space heaters furnish auxiliary energy to the apparatus bays. Auxiliary heating for hot water is provided by two 120-gallon domestic hot water heaters containing standard electric resistance heater elements. The solar energy system is manually converted to summer mode operation by opening a slide gate damper which isolates the storage from the solar energy system.

The thermostatic controls which run the solar system are located in the main garage area, accessible to the station personnel. The building occupants created a system problem by constantly adjusting thermostats and inhibiting system performance. Public areas are not the ideal place for adjustable thermostats. Also, the heat pumps' control system was not operating properly.

Lake Valley Fire House. The Lake Valley Fire House Number 2, located at South Lake Tahoe, California, is a small fire station using solar energy to preheat domestic hot water and provide space heating and snow melting. The solar energy system is designed to supply approximately 50% of the space heating and domestic hot water energy requirements for the building. The upstairs dayroom and kitchen are heated by baseboard radiators while the downstairs sleeping quarters and engine room are heated by a radiant slab. Auxiliary energy is provided by a 325,000-BTU propane-gas-fired boiler, a 65-gallon propane-gas-fired hot water heater, and an upstairs wood stove. In addition, a unique snow melting capability is provided to the front engine ramp by circulating solar heated water through coils in a specially designed asphalt ramp. Since the snow-melt ramp can use solar energy at much lower temperatures than is practical for space heating, it is expected to increase the total solar energy usable by the system.

The solar energy system has an array of 16 flat-plate collectors manufactured by Western Energy, Inc. The array has a gross area of 352 square feet. The collector array, mounted on an A-frame structure in the backyard, faces south at an angle of 55 degrees from the horizontal. Water is used as the medium for delivering solar energy from the collector array to the 1,200-gallon energy storage tank. Freeze protection is provided to the collectors by draindown of water and is provided to the snow-melt ramp by the use of a 50% solution of ethylene-glycol. The domestic hot water subsystem relies on the supply water for flow through a heat exchanger in the solar storage tank and the auxiliary domestic hot water heater. The heating loads to the building zones and to the snow-melt ramp are supplied from either the solar storage tank or from the auxiliary boiler but not from both simultaneously. While the loads are in the auxiliary heating configuration, solar energy can be concurrently used to charge storage and heat domestic hot water. If the snow-melt ramp is operated while space heating is in use, both loads must receive energy from the same source. Space heating cannot be performed with auxiliary energy while using solar energy to melt snow.

Late in 1978, the collector array draindown control system failed, resulting in subsequent freezing damage to the collector array. The replacement solar collector field was completed in December 1980. The collector control system was operated manually. The performance during 1981 was documented from February to June, and resulted in a 49% solar fraction for that period.

Lawrence Berkeley Laboratory. The solar system at Lawrence Berkeley Laboratory utilizes flat-plate collectors by Sunworks. The system is designed to provide 32% of building heat and domestic hot water. There is a 2,000-gallon hot water storage tank. Water is used as the heat transfer fluid and there is a heat exchanger between storage and the loads. Gas-fired boilers are the auxiliary backup. A key factor in retrofitting this building with solar energy is the design change from 100% outside air to an air recirculation loop with 10% outside air. The air recirculation loop will reduce heating loads substantially and allow water of a lower temperature to be circulated in the building heating coils.

The addition of a new recirculation system had not been completed in time for the 1980-1981 heating season. The flow-through type of system simply creates too great a load for the solar design. The measured solar fraction was four percent of the 2,286 million BTU system load.

Oakmead Industries. The Renault and Handley Building, referred to as Oakmead Industries, is one of two nearly identical solar heated buildings located at the Oakmead Industrial Park, in Santa Clara, California. This commercial building contains approximately 60,000 square feet of floor area and is normally occupied six days a week, not including Sunday. The solar energy system installation is a retrofit and was designed to provide 85% of the annual heating requirements and 90% of the annual hot water demand.

The building has two central heating zones, one for the north zone of the building and the other for the south zone. The north zone heating system provides space heating for the central electronics area and for several offices. The north zone is heated by a combination of solar energy from a liquid-based flat-plate collector array and an auxiliary gas-fired furnace. The south zone heating system provides space heating for the warehouse area. The south zone is heated by a hybrid passive/active solar energy system installed on the south wall, solar energy from the liquid flat-plate collectors, and by an auxiliary gas-fired furnace.

Both the liquid and air solar collection systems were subject to control problems which prevented full collection of solar energy and resulted in the rejection of stored solar energy. The air collectors were activating during evening hours, rejecting energy. The liquid collector pump ran continuously for at least two months. Control adjustments were made; however, the problem was finally repaired in June 1981, after five months of operating continuously. Other system problems included failure in the north zone heat distribution system to operate as designed, resulting in poor heating distribution in the building.

Padonia School. The Padonia School site is a one-story 45,000-square-foot elementary school in Cockeysville, Maryland. Its retrofit solar energy system is designed to provide 75% of the space heating and cooling required for the cafetorium, library, and administrative suite, a total area of 10,000 square feet. The energy collection subsystem consists of three liquid-filled, movable collectors (gross area: 349 square feet; net area: 270 square feet), and three stationary trough reflectors (gross area: 3,398 square feet; net area: 3,185 square feet) mounted on the roof facing south. The movable collectors intercept reflected insolation by moving in an arc in the north/south plane. Collected energy is stored in a 9,300-gallon hot water storage tank. The system interconnects with the existing air handler unit water-to-air heat exchanger coils. Auxiliary space heating and cooling are supplied by the school's existing heating, cooling, and ventilating equipment.

The solar system was down for repairs during the heating season. The absorber tubes have frozen and sprung leaks.

The site has AAI tracking, concentrating collectors, which are no longer being marketed. The site is one of a kind and expensive. The roof trusses are hand-built and curved to accommodate the collectors.

The seasonal performance has been marginal.

Washington Natural Gas. The Washington Natural Gas Company site is a single family residence in Kirkland, Washington. The home has approximately 2,607 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 591 square feet. The array faces south at an angle of 57 degrees to the horizontal. Air is used as the medium for delivering solar energy from the Solaron collector array to storage and to the space heating and hot water loads. Solar energy is stored underground in a 273-cubic-foot bin containing 27,300 pounds of smooth stones. The bin has two inches of styrofoam insulation. Preheated city water is stored in an 80-gallon preheat storage tank and supplied, on demand, to a conventional 50-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, a gas furnace provides auxiliary energy for space heating. Similarly, a gas-fired unit in the DHW tank provides auxiliary energy for water heating.

System problems in 1980-1981 prevented the full utilization of solar energy for space heating. The primary problem, which continued for several months, was that air flow was shunted through the collectors when it should have gone through the storage bin. This incorrect circulation prevented any use of energy from storage. This circulation also caused auxiliary energy loss through the collectors at night. The collector-to-storage mode, however, operated properly, so that solar hot water heating was accomplished.

Again, control problems appeared to be the primary reason for this site's poor seasonal performance.

Wyoming Rural Electric. Wyoming Rural Electric is a two-story office building located in Casper, Wyoming. Solar energy is used to heat ten offices with a total floor space of 9,030 square feet.

The collector subsystem is composed of 58 three-by-five-foot flat-plate collectors manufactured by Solargenics, Inc. of Chatworth, California. The 870 square feet of collectors are mounted on a south-facing wall that is tilted at 62 degrees to the horizontal.

Solar energy is stored in a 1,500-gallon tank, also manufactured by Solargenics, filled with water. The tank is located outside and to the east of the building. Auxiliary heating is provided by a 60-kw electric duct heater located in a combined heating and cooling unit mounted on the roof of the building. The heater activates in eight successive stages.

Several problems prevented this solar system from operating effectively. The solar collection system is freeze-protected by a solution of antifreeze and water with a nominal freezing point of -30°F. The secondary freeze protection system activates the solar collection pump to circulate the collector solution when ambient temperatures fall below this level. During the heating season, the actual set point was 30°F, which is at least 60°F too high. The cold climate in Wyoming caused this auxiliary freeze protection system to operate excessively during the heating season, causing rejection of stored energy.

Additionally, a circulation pump which routes heated water to the heating coils in the building was manually set to operate continuously through the entire heating season. This operation had several effects, including low storage temperatures, increased operating energy (reducing savings), and excessive use of auxiliary fuel.

The solar collector array also had mechanical problems. Several collector panel supports failed and an upper row of solar collectors slid down the mounting frame and impacted a lower row, creating minor leakage. This problem was subsequently repaired.

SUMMARY

In summary, the single most common system problem with the aforementioned sites was control system deficiencies. These can be divided into several categories, including:

- Misadjustment of thermostat/differential control temperature settings - this was the most common (and also the simplest to rectify) adjustment problem.
- Improper collection system startup/shutdown - this situation results in rejection of stored energy to the environment. The degree of performance degradation is related to the degree of mismatching of the collector pump operation to available solar radiation.
- Pumps operating continuously - several of the sites had pumps which operated for periods measured in months, either due to neglect, ignorance, or an emergency situation at the site.
- Failure of the control system component resulting in either manual system operation or excessive auxiliary use when solar energy could have been utilized.
- Poor conceptualization and design of control and mode logic including excessive complexity of design - this problem occurred at many large commercial projects.
- Freeze protection strategy - can either result in damage if the system fails to prevent freezing, or can result in excessive energy rejection if, for example, a circulating system operates for great lengths of time.

Mechanical and structural problems also caused poor performance at the previously-mentioned sites. Such problems at these sites included:

- Pump, fan, or damper failure - resulting in inhibiting of collection, distribution, or storage of solar energy.

- Structural failures - causing leaks, etc.
- Lightning discharge - caused failure at one site.
- High temperature failures - leading to collector system degradation.
- Freezing failure.

Design problems can also lead to poor performance. Examples of these design problems include:

- Overcomplexity - results from a proliferation of unnecessary tempering valves, three-way valves, pumps, bypasses, modes of operation, and selection of operating strategies not compatible with the irregular supply of solar energy.
- Auxiliary energy entering storage - a common problem. The addition of auxiliary thermal energy to storage will reduce solar energy use. Storage tanks must be isolated from auxiliary sources to optimize solar collection.

Section III

SEASONAL COMPARATIVE DATA

In this section, the various seasonal performance parameters are presented in a bar chart format along with a discussion of the results. The charts and accompanying discussion are presented in three subsections, each dealing with a general area of solar system operation and performance. Collection and storage subsystem factors are presented first. Next, are the load or heating system factors. Parameters which illustrate savings relationships are presented last. Even though these parameters are divided into distinct subsections, a discussion of one parameter may require the use of another parameter in a different subsection for illustration purposes. A thorough familiarization with the available charts and data is suggested prior to beginning the discussion. Table 3 lists the values used to generate the charts and discussion.

A. COLLECTOR AND STORAGE SUBSYSTEM FACTORS

1. Collector Array Efficiency, Total and Operational. The total and operational collector array efficiencies are presented in Figures 4 and 5. The average seasonal storage temperatures for each site are also given on these figures. Heating subsystem performance is indirectly related to the efficiency of the collectors. Solar energy is provided to the heating system components either directly from the collectors or indirectly through storage. The temperature requirements of the heating subsystem will dictate the temperature at which the collector/storage system operates. In general, a heating system which can utilize low-temperature solar energy will help improve collection efficiencies by lowering the operating point temperature.

Total efficiency is the ratio of solar energy collected to the total available insolation. Factors affecting total efficiency include control system strategy, collector type, collector heat loss coefficient, collector and storage operating temperatures, weather conditions, and system application.

Operational efficiency is calculated as the ratio of solar energy collected to the solar insolation available while the collector is operating. Operational efficiency exceeds total efficiency due to the elimination of control system effects and weather factors.

The Summerwood M (Site Number 139) solar site achieved the highest total efficiency and second highest operational efficiency. During the heating season, the storage temperature was maintained at an average of 103°F. This site utilizes solar energy from storage either directly in a duct coil if the temperature is greater than 85°F, or through a solar-assisted, water-to-air heat pump if the temperature is between 40°F and 85°F. The use of a heat pump allows the utilization of stored solar energy well below the temperature level at which it can be used directly. This condition occurred during November, December, January, and February, the coldest part of the heating season.

Another solar-assisted heat pump system, Terrell E. Moseley (Site Number 014), had good total and operational collector efficiencies of 28% and 32% respectively. The average storage temperature was 100°F. The Terrell E.

Table 3. PERFORMANCE FACTOR VALUES

	Site Numbers													
Collector Subsystem	006	014	032	047	083	139	145	163	164	194	195	216	236	253
Total Solar Incident (million BTU)	884.69	114.58	701.69	6721.22	95.15	107.49	681.64	99.36	388.97	2959.82	559.35	205.00	76.54	88.37
Operational Solar Incident (million BTU)	469.38	101.23	590.87	4458.37	70.82	78.27	639.49	45.28	337.67	2732.73	352.58	148.67	69.38	66.16
Solar Energy Collected (million BTU)	104.41	32.25	155.45	1413.62	31.35	37.42	112.74	25.36	109.81	727.29	111.53	44.73	20.70	15.89
Collector Operating Energy (million BTU)	4.79	2.47	16.21	68.37	0.71	2.09	6.15	0.59	8.06	58.75	4.37	2.83	1.04	1.20
Total Collector Efficiency (%)	11.80	28.15	22.15	21.03	32.95	34.81	16.54	25.52	28.23	24.57	19.94	21.82	27.04	17.98
Operational Collector Efficiency (%)	22.24	31.86	26.31	31.71	44.27	47.81	17.63	56.01	32.52	26.61	21.63	30.09	29.84	24.02
Collector COP (BTU/BTU)	21.80	13.06	9.59	20.68	44.15	17.90	18.33	42.98	13.62	12.38	25.52	15.81	19.90	13.24
Daily Average Solar Incident (BTU/ft^2)	807	1351	1012	1270	1237	1184	1211	1374	1347	1350	1193	1567	1471	1426
Long-term Daily Average Solar Incident (BTU/ft^2)	1021	1284	982	1282	1061	1163	1372	1498	1521	1459	1347	1309	1884	1308
Ratio of Measured and Long-Term Insolation (BTU/BTU)	0.79	1.05	1.03	0.99	1.17	1.02	0.88	0.92	0.89	0.93	0.89	1.20	0.78	1.09
Collector Array Area (ft^2)	6000	400	3800	21760	315	373	3740	597	950	8034	2146	721	288	416
Solar Collected per Ft^2 per Day (BTU/ft^2·day)	95.61	380.31	192.96	267.34	409.56	412.85	199.63	351.07	380.23	331.60	245.15	342.76	397.10	252.96
Percent Incident to Loads (%)	8.74	24.43	12.16	6.85	31.16	21.97	2.46	10.77	20.97	16.93	8.48	13.90	17.02	15.20
Percent Collected to Load (%)	74.02	86.79	54.91	32.55	94.58	63.12	14.90	42.19	74.28	68.89	42.54	63.72	62.95	84.52
Average Ambient Temperature (°F)	43.7	44.9	39.7	59.9	39.5	41.0	54.2	54.5	54.2	43.9	41.4	48.5	48.0	45.4
Storage Subsystem														
Storage Heat Capacity (BTU/°F)	75015	16670	41675	125025	6251	5001	18129	8335	16337	76323	20838	22059	4104	14600
Average Storage Temperature (°F)	96	100	104	135	139	103	137	115	114	90	121	89	108	72
Change in Stored Energy (million BTU)	-0.22	0.04	-4.36	19.94	-0.01	0.53	0.19	0.04	0.79	20.50	-1.03	0.60	0.01	0.14
Storage Capacity Liquid (gallons)	9000	2000	5000	15000	750	600	2175	1000	1960	-	2500	-	-	-
Storage Capacity Rock (ft^3)	-	-	-	-	-	-	-	-	-	4017	-	1161	216	768
Ratio Collector Area to Storage Heat Capacity (ft^2/(BTU/°F))	0.080	0.024	0.091	0.174	0.050	0.075	0.206	0.072	0.058	0.105	0.103	0.033	0.070	0.028
Space Heating Subsystem														
Space Heating Load (million BTU)	668.38	35.08	279.81	5807.54	71.59	38.41	93.31	18.70	204.46	924.22	245.58	34.33	11.42	24.94
Controlled Delivered Energy (million BTU)	596.82	29.34	279.76	5344.22	13.50	35.36	93.31	18.13	204.46	550.75	245.58	24.58	4.90	8.73
Total Solar Energy Used (million BTU)	57.99	27.99	85.95	460.15	18.06	21.65	12.15	7.72	58.16	483.24	47.44	26.31	9.29	12.91
Measured Solar Energy Used (million BTU)	57.99	27.99	85.95	460.15	5.75	20.83	12.15	7.72	58.22	175.63	47.44	16.63	2.66	1.63
Solar Losses Contributing to Load (million BTU)	0.00	0.00	0.00	0.00	12.30	0.81	0.00	0.00	0.00	307.84	0.00	9.74	6.62	11.25
Total Heating Operating Energy (million BTU)	5.58	9.02	69.87	661.89	0.91	3.70	71.63	3.52	15.41	230.94	23.36	0.89	0.82	2.98
Heating Solar Specific Operating Energy (million BTU)	5.58	2.17	11.53	11.77	0.16	0.59	0.23	0.61	5.02	55.55	0.50	0.89	0.66	0.99
Overall Solar Heating COP (BTU/BTU)	6.32	6.03	3.09	5.74	14.89	8.56	2.60	7.45	5.40	2.31	9.74	6.54	3.05	1.44
Heating Fossil Savings (million BTU)	0.00	46.59	0.00	766.91	30.10	0.00	20.25	0.00	96.93	680.61	79.08	0.00	0.00	0.00

Table 3. PERFORMANCE FACTOR VALUES

Space Heating Subsystem (continued)	Site Numbers 006	014	032	047	083	139	145	163	164	194	195	216	236	253
Heating Electrical Savings (million BTU)	38.59	-5.29	74.41	-11.77	-0.17	11.80	-0 23	6.77	-5.02	-55.55	0.00	26.31	8.63	12.91
Solar Fraction Heating (%)	8.68	79.79	30.72	7.92	25.23	56.37	13 02	41.28	28.45	52.29	19.32	76.64	81.35	51.76
Design Solar Fraction Heating (%)	71	65	67	46	43	57	70	78	46	57	54	77	69	75
Heating Degree-Days (°F·day)	3666	4359	5237	1772	5896	5722	1647	1086	3063	5806	4751	2800	3121	2926
Long-term Heating Degree-Days (°F·day)	5007	4168	5392	3087	5510	5395	1815	1014	2830	7160	6164	2980	3346	2981
Conditioned Space (ft^2)	14,000	1670	23,000	149,671	1916	1375	34000	2420	6912	43000	4900	1484	1280	1086
Ratio Collector to Floor Area (ft^2/ft^2)	0.429	0.240	0.165	0.145	0.164	0.271	0.110	0.247	0.137	0.187	0.438	0.487	0.225	0.383
Heating Load per Ft^2 Floor Area per Degree-Day ($BTU/ft^2 \cdot {}^oF \cdot day$)	13.02	4.82	2.32	21.90	6.34	4.88	1.47	7.12	9.66	3.70	10.55	8.26	2.86	7.85
Heating Solar Used per Ft^2 Floor Area per Degree-Day ($BTU/ft^2 \, {}^oF \cdot day$)	1.13	3.85	0.71	1.73	1.60	2.75	0.12	2.94	2.75	1.94	2.04	6.33	2.33	4.06
Heating Solar Used per Ft^2 Collector per Day ($BTU/ft^2 \cdot day$)	53.10	330.07	106.69	87.02	235.94	238.86	21.51	106.87	201.39	220.33	104.28	201.61	178.22	205.52
Percent of Heating Load Met by Solar Losses (%)	0.00	0.00	0.00	0.00	17.18	2.11	0.00	0.00	0.00	33.31	0.00	28.37	57.97	45.11
Net Heating Savings (million BTU)	38.59	41.30	74.41	755.14	29.93	11.80	20.02	6.77	91.91	625.06	79.08	26.31	8.63	12.91
Net Heating Savings per Ft^2 Collector per Day ($BTU/ft^2 \cdot day$)	35.34	487.03	92.37	142.81	391.01	130.19	35.45	93.72	318.25	284.99	173.82	201.61	165.55	205.52
Net Dollars Saved Heating ($)	684.73	98.70	1320.31	2960.87	266.10	209.38	79.61	120.12	311.55	1827.37	326.85	466.84	153.13	229.07
Net Dollars Saved per Ft^2 Collector per 1000 Degree-Days ($\$/ft^2({}^oF \cdot day/1000)$)	0.031	0.057	0.066	0.077	0.143	0.098	0.013	0.185	0.107	0.039	0.032	0.231	0.170	0.188
Heating Days	182	212	212	243	243	243	151	121	304	273	212	181	181	151
Average Building Temperature (°F)	73.0	67.0	73.7	-	68.8	65.1	69.4	66.3	71.6	73.7	68.3	75.5	71.3	70.8
System														
Total System Load (million BTU)	540.62	35.08	279.81	5807.54	92.59	41.70	129.60	28.25	269.85	924.22	245.58	40.65	19.60	32.42
Total Solar Energy Used (million BTU)	77.28	27.99	85.35	460.15	29.65	23.62	16.80	10.70	81.57	501.02	47.44	28.50	13.03	13.43
Total Solar-Specific Operating Energy (million BTU)	10.89	5.00	27.74	80.14	1.81	2.93	6.77	1.36	13.08	115.91	4.87	3.91	1.81	2.19
Overall Solar System COP (BTU/BTU)	7.10	5.60	3.08	5.74	16.38	8.06	2.43	7.87	6.24	4.32	9.74	7.29	7.20	6.13
Solar Losses as Percent of Collected Energy (%)	26.19	13.09	47.90	66.04	42.42	35.46	84.93	57.65	25.00	28.29	58.39	34.94	37.00	14.60
Total Net System Savings (million BTU)	35.08	38.52	58.21	686.77	39.87	11.48	21.23	8.74	122.87	612.47	74.20	25.51	10.03	12.23
Total Net System Savings per Ft^2 Collector per Day ($BTU/ft^2 \cdot day$)	32.13	454.25	72.26	129.88	520.87	126.66	37.59	120.99	425.45	279.25	163.09	195.48	192.41	194.70
Total Net Dollar Savings ($)	522.45	48.69	1032.86	1747.47	442.47	203.70	-4.40	155.08	329.81	944.27	240.26	452.64	177.97	217.01
Total Net Dollar Savings per Ft^2 Collector per 1000 Degree-Days ($\$/ft^2({}^oF \cdot day/1000)$)	0.028	0.028	0.051	0.045	0.238	0.095	-0.00	0.239	0.113	0.020	0.024	0.224	0.198	0.178

SITE NAMES

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032	TROY-MIAMI LIBRARY	194	SPEARFISH HIGH SCHOOL
047	GSA, FEDERAL YOUTH CENTER	195	BILLINGS SHIPPING
083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
139	SUMMERWOOD M	236	FIRST MANUFACTURED HOMES LOT 10
145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

SYSTEM TYPE KEY

NUMBER	TYPE
1	LIQUID SYSTEMS
2	AIR SYSTEMS

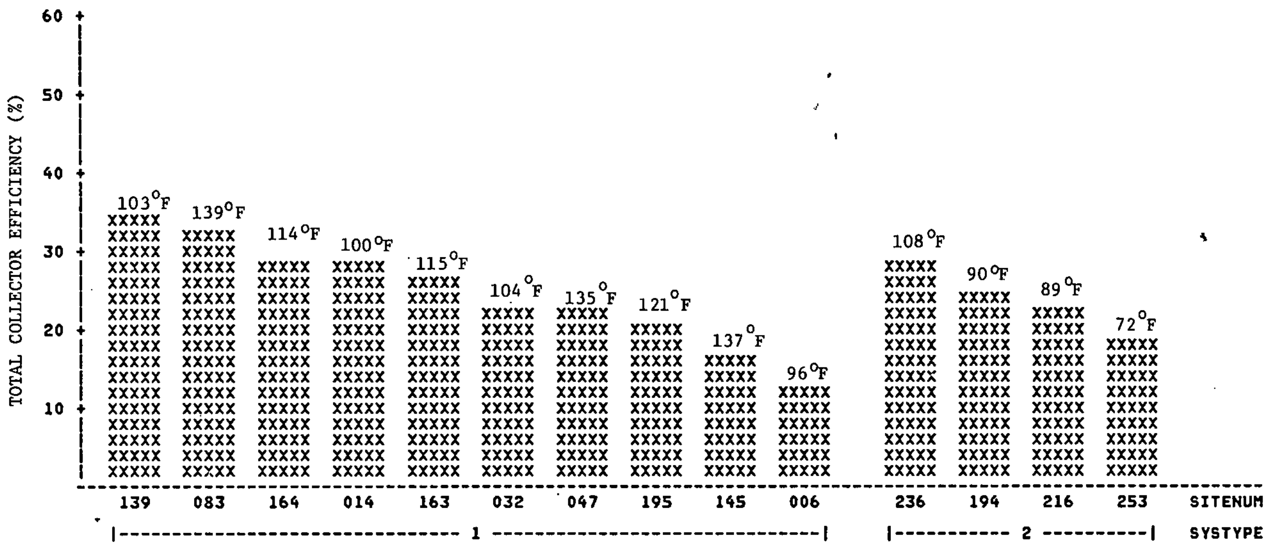

Figure 4. Bar Chart of Total Collector Efficiency with Average Storage Temperature

SITE NAMES

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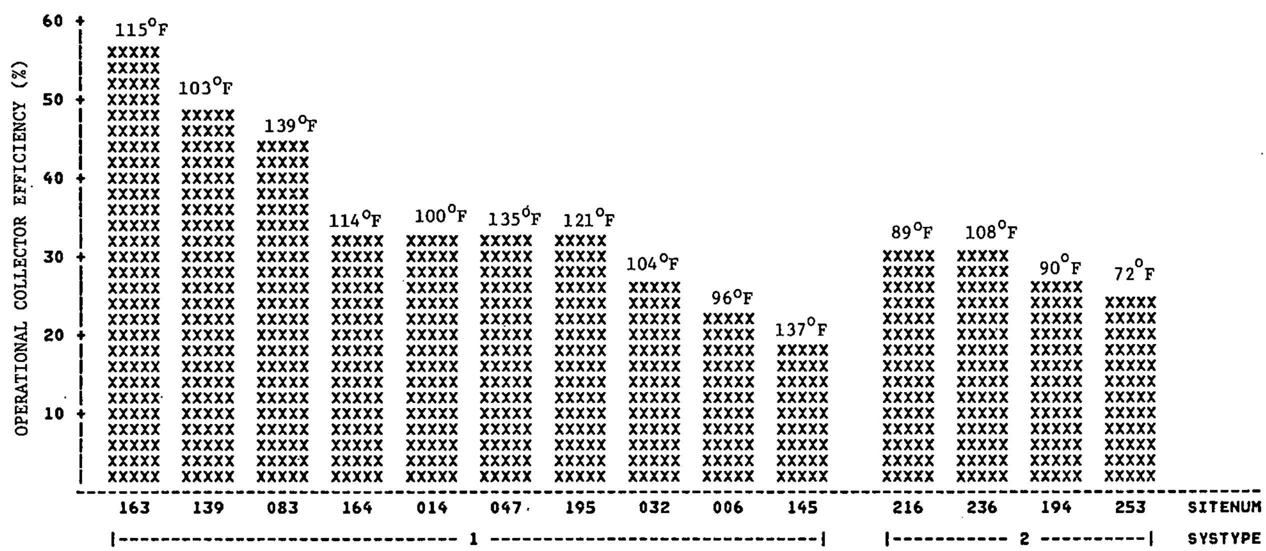

Figure 5. Bar Chart of Operational Collector Efficiency with Average Storage Temperature

Moseley site utilizes site-built, flat-plate, liquid collectors which further illustrates the effect of low storage temperatures on collector efficiency.

The Matt Cannon (Site Number 163) solar site achieved the best operational efficiency of 56% while maintaining storage at an average temperature of 115°F.

The Olympic Associates (Site Number 006) solar site exhibited the lowest total efficiency and the second lowest operational efficiency even though storage averaged 96°F. Low collector efficiency at this site may be due to weather patterns prevalent in the Pacific Northwest region. Winter cloud cover is common as is localized fog due to the Snake and Columbia Rivers. When solar insolation is available, partly cloudy conditions often prevail causing intermittent collection. These unfavorable conditions may be amplified by the fact that the collectors are double-glazed and the measured insolation was only 79% of the long-term average.

San Anselmo School (Site Number 145) also exhibited low total and operational efficiencies. During the heating season, storage was maintained at an average of 137°F. This site utilizes solar energy for both space heating and space cooling. To obtain sufficiently high temperatures to operate the absorption chillers, the control system bypasses storage to allow the collector fluid to reach 175°F. At this temperature, a valve diverts the collector fluid to storage. A misplaced control sensor for this valve often prevents flow to storage. Low collector efficiency is due to the high operating temperature dictated by the system application.

The total efficiency of liquid sites and air sites is roughly comparable; however, liquid sites show an advantage in operational efficiency. This can be due to the low heat capacity of air which forces the collector plate to operate at higher temperatures. Liquid collectors, with a larger wetted area and greater fluid heat capacity, permit a more rapid removal of energy from the collector thus allowing lower operating temperature.

Although air systems collect approximately the same percentage of total available insolation as liquid systems, they operate for longer periods of time to achieve this performance. Thus, operating energy requirements of air systems are significantly greater than liquid systems. Figure 9 on Page 30 is a graph of the collection coefficient of performance (COP) for liquid and air systems. This COP is a ratio of solar energy collected divided by the operating energy. The graph shows that liquid systems generally provide more solar energy collected per unit of operating energy.

2. Solar Energy Collected Per Square Foot Per Day. The solar energy collected per square foot of collector area per day is presented in Figure 6. This parameter is a measure of the daily average performance of one square foot of collector over a particular site's heating season. The length of the heating season varies between sites; therefore, the heirarchical order of performance will not necessarily be the same as indicated in the total collector efficiency chart (Figures 4 and 5).

This performance factor is a function of the same variables which affect total and operational collector efficiency. The values presented here, although site specific, are a good indication of what can be reasonably expected to be collected by similar sites in the same geographical region.

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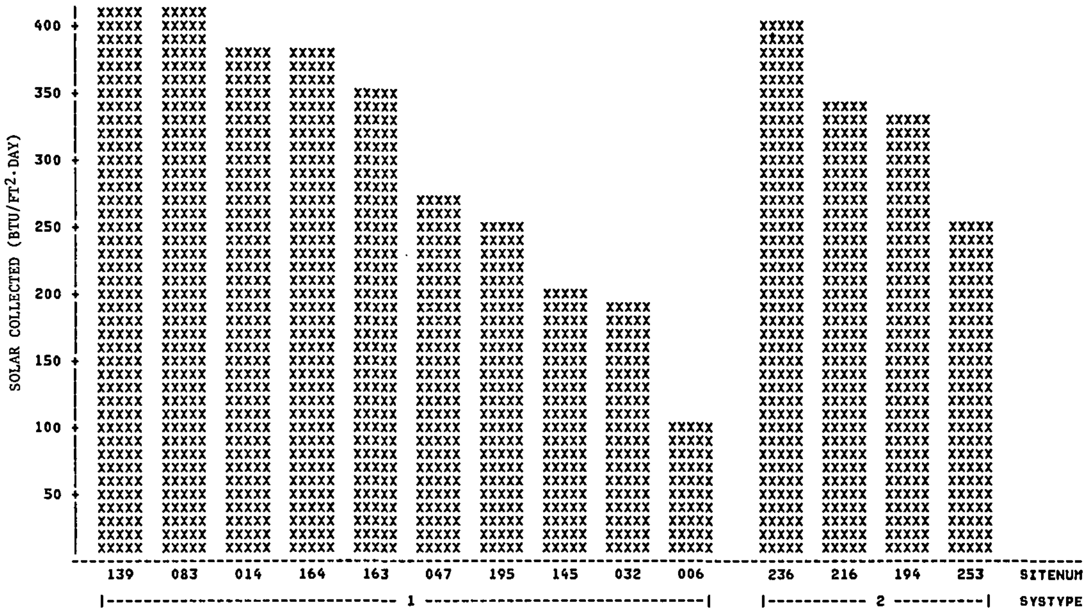

Figure 6. Bar Chart of Solar Collected
Per Square Foot Per Day

3. Ratio of Collector Area to Storage Heat Capacity. Storage volumes for liquid systems are often expressed in gallons and for air systems in pounds or cubic feet. In order to more reasonably compare the relationship between the collectors and storage in both system types, storage heat capacity is used. The ratio of collector area to storage heat capacity is presented in Figure 7.

Storage heat capacity is defined as the product of the storage medium's mass weight and specific heat. The heat capacity then is the number of BTU required to raise storage 1°F. The subject ratio is given in units of $(ft^2/(BTU/°F))$. Each solar site has its own unique ratio of collector area to storage heat capacity. In general, as this ratio increases, storage will increase in temperature more quickly for a given collector output. As storage increases in temperature, collection efficiency is reduced. The temperature requirements of the space heating distribution system should be considered when the collectors and storage unit are sized. The collector area to storage heat capacity ratio should be such that storage is maintained in a temperature range that can be utilized by the terminal heating equipment while at the same time being low enough to allow efficient collector operation.

The two solar sites with the highest collector to storage heat capacity ratio, San Anselmo School (Site Number 145) and GSA (Site Number 047), maintained average storage temperatures of 137°F and 135°F, respectively. These two sites also had among the lowest total and operational collector efficiencies.

The Terrell E. Moseley (Site Number 014) site had the lowest collector to storage heat capacity ratio and achieved one of the best collector efficiencies.

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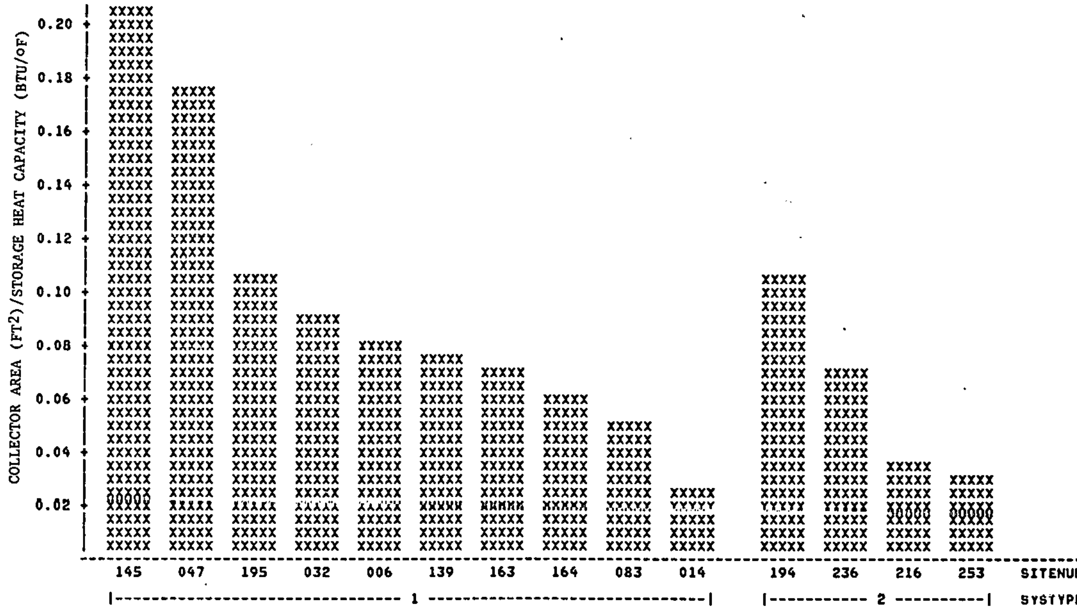

Figure 7. Bar Chart of Ratio of Collector Area to Storage Heat Capacity

Although Helio Thermics 8 (Site Number 253) had a low ratio along with a low storage temperature of 72°F, collector efficiency was also low. This was due to the glazed roof and attic space collector system employed at the site. Air leakage and the large area for conductive heat loss prevented efficient operation of the collector subsystem.

4. Ratio of Collector Area to Floor Area. The ratio of collector area to floor area is presented in Figure 8. The measured heating solar fraction for each site is also given at the top of the bar which represents the site.

5. Solar Collector COP. Solar collector coefficient of performance (COP) is a ratio of the solar energy collected to the energy required by collector blowers or pumps. COP is a measure of the efficiency of the collector subsystem.

A bar chart of solar collector COP is presented in Figure 9. Liquid systems with an average COP of 23 performed better than air systems which averaged 15. This higher COP is due to the fact that fans and blowers are less efficient than liquid pumps and air has less heat capacity than liquids.

6. Percent of Incident and Collected Solar Energy Delivered to the Total Load. The percent of incident solar energy delivered to the total load, identified in Figure 10, is a measure of the overall solar system efficiency. Energy losses from the collectors, transport, and storage subsystems, and distribution equipment is included in this overall efficiency. The percent of collected solar energy delivered to the total load is presented in Figure 11. This parameter excludes collector inefficiency and provides a measure of the mechanical system efficiency in the delivery and storage of collected energy.

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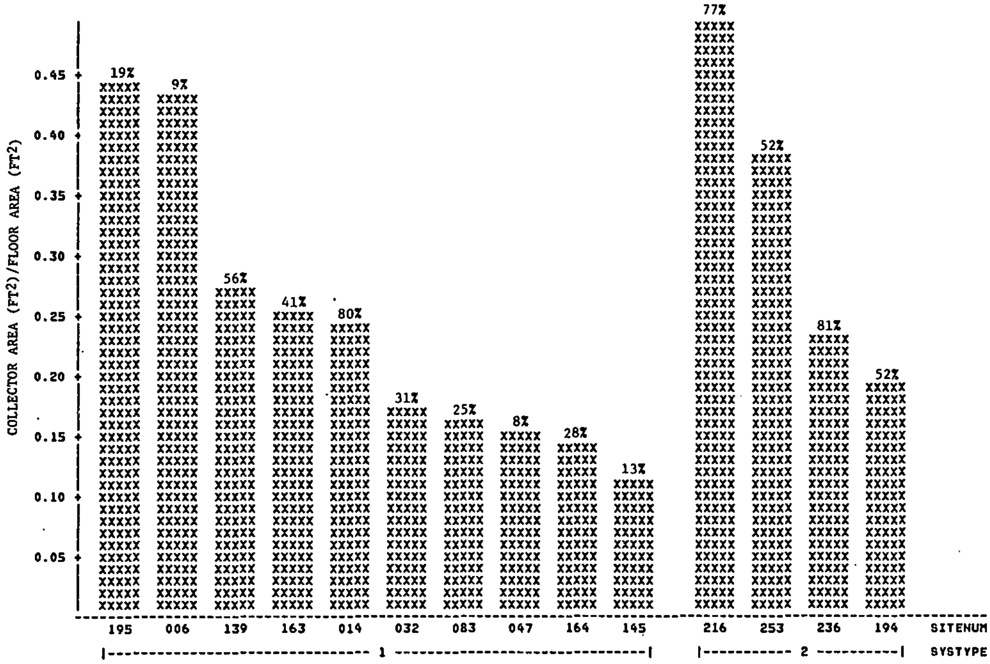

Figure 8. Bar Chart of Ratio of Collector Area to Floor Area with Measured Solar Fraction

SITE NAMES

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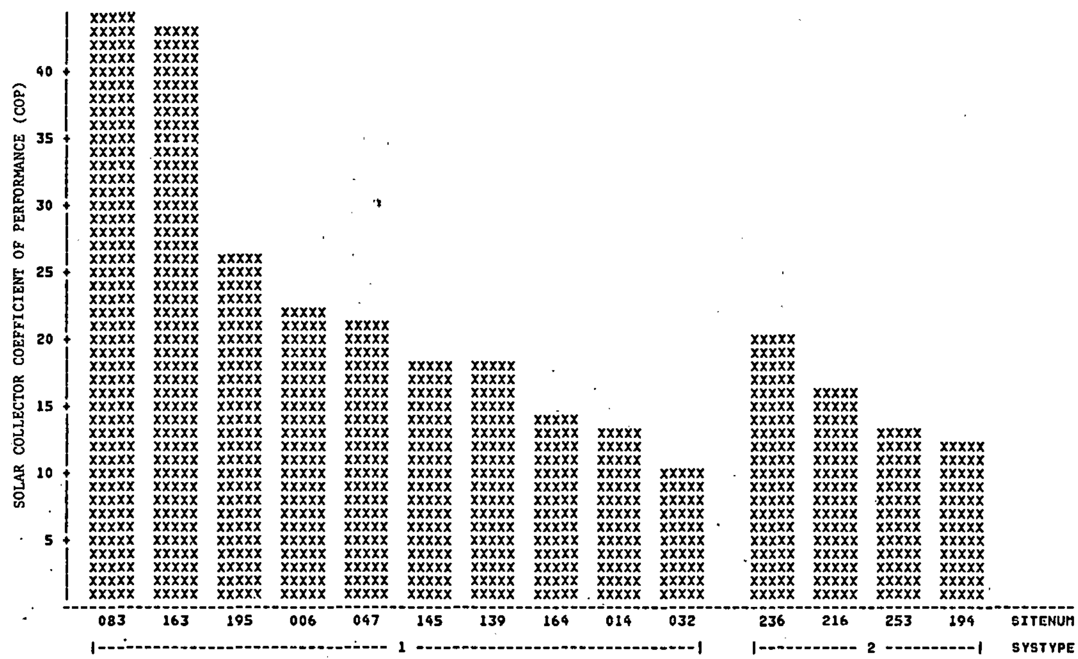

Figure 9. Bar Chart of Solar Collector COP

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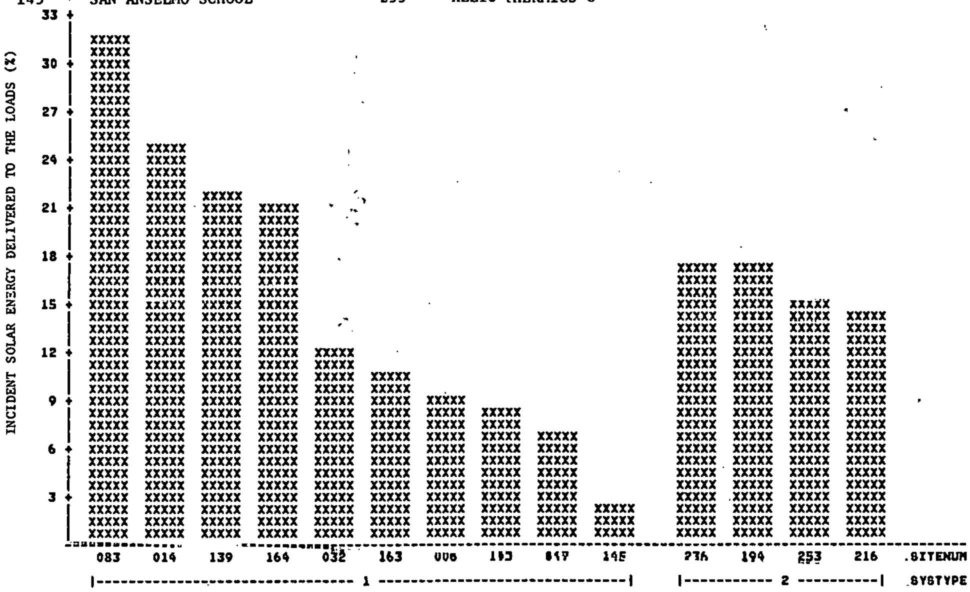

Figure 10. Bar Chart of Percent of Incident Solar Energy Delivered to the Load

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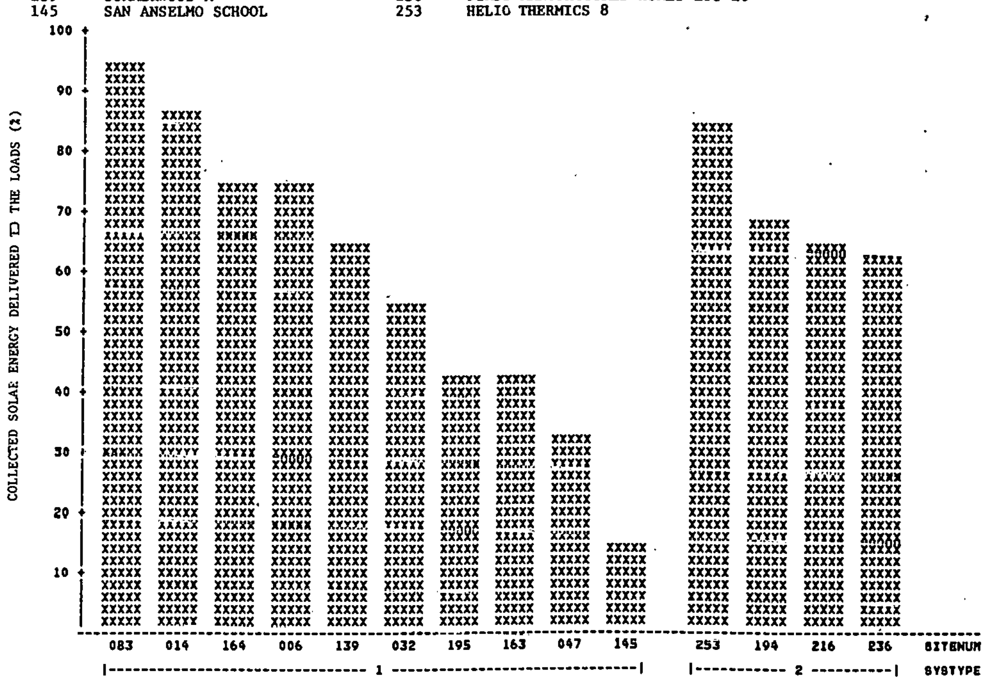

Figure 11. Bar Chart of Percent of Collected Solar Energy Delivered to the Load

Saddle Hill Trust Lot 36 (Site Number 083) exhibited the best efficiency for both the percent incident and collected solar energy delivered to the load. This site achieved this good performance due to large solar thermal losses which contributed to the heating load. The system equipment delivered 5.75 million BTU to the space heating load, while losses from the thermal storage tank contributed 12.30 million BTU. Terrell E. Moseley (Site Number 014) achieved the second best performance in both categories. This site, however, delivered all solar energy used through the mechanical equipment rather than through uncontrolled losses to the load. This shows that solar-assisted heat pumps deliver a high percentage of incident and collected solar energy to the loads because they can utilize low-temperature solar energy. Collection efficiency is also improved. Another heat pump site, Summerwood M (Site Number 139), also performed quite well in delivering incident solar energy to the load. However, large solar losses which did not contribute to the load reduced this site's relative ranking in the percent of collected energy delivered to the load.

Both Terrell E. Moseley (Site Number 014) and Summerwood M (Site Number 139) have the option of delivering solar energy directly to the load through duct heat exchangers when storage temperatures are high enough to allow efficient operation. When storage temperature drop below the minimum temperature that can be efficiently utilized with these heat exchangers, solar energy is diverted through the solar-assisted heat pump. This allows the system to further utilize solar energy below the minimum temperature at which it can be used directly. Saddle Hill Trust Lot 36 (Site Number 083) can only use solar energy for heating in the duct heat exchanger which requires relatively high temperatures. The high temperature requirement at this site limited the direct use of solar energy.

San Anselmo School (Site Number 145) was the worst performer in both categories. This is due to the method of collector control which inhibits collector startup or varies the flow rate to allow the outlet temperature to reach a high temperature. The control strategy prevents the collection of incident energy by shortening the operational period and by increasing the operating point temperature, which reduces collection efficiency. Additionally, since solar energy is collected at a high temperature, thermal losses from storage tank and piping are increased, thus reducing the percent of collected energy delivered to the load.

7. Ratio of Measured to Long-Term Insolation. Solar insolation is an intermittent and variable source of energy. Solar systems are sized to meet desired portions of energy loads based on long-term, measured insolation. Since this energy source is variable, the measured insolation in any given time period will differ from the expected long-term average. Consequently, the performance of a solar system is affected by the amount of insolation incident on the collector array. Figure 12 identifies the ratio of measured to long-term insolation at each site during the heating season.

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
014	TERRELL E. MOSELEY	164	MONTECITO PINES
032	TROY-MIAMI LIBRARY	194	SPEARFISH HIGH SCHOOL
047	GSA, FEDERAL YOUTH CENTER	195	BILLINGS SHIPPING
083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
139	SUMMERWOOD M	236	FIRST MANUFACTURED HOMES LOT 10
145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

SYSTEM TYPE KEY

NUMBER	TYPE
1	LIQUID SYSTEMS
2	AIR SYSTEMS

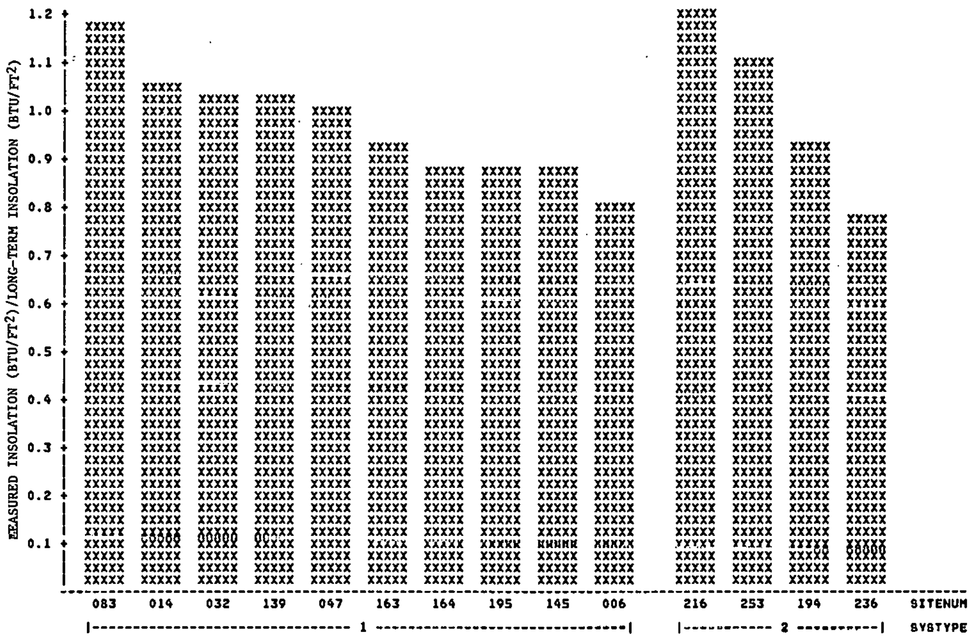

Figure 12. Bar Chart of Ratio of Measured Insolation to Long-Term Insolation

B. LOAD SUBSYSTEM PERFORMANCE FACTORS

1. Heating Load Per Square Foot Floor Area Per Heating Degree-Day. The heating loads of various buildings are a function of building design, construction materials, use patterns, and weather conditions. An important element to consider in the application of solar energy to space heating is to minimize the heating load. Solar heating equipment is relatively expensive compared to auxiliary heating equipment. To maximize the use and benefits of high-cost solar heating systems, primary attention should be given to reducing the required heating load through conservation measures in the design and construction phase of new buildings as well as retrofit conservation measures in existing buildings.

Figure 13 illustrates the heating loads per square foot of floor area per heating degree-day. There is a wide variance in these results. The commercial sites ranged from a high of nearly 22 BTU/ft^2·°F·Day to less than two BTU/ft^2·°F·Day. The two sites with the highest unit heating loads, GSA (Site Number 047) and Olympic Associates (Site Number 006), and the two with the lowest, San Anselmo (Site Number 145) and Troy-Miami Library (Site Number 032), are commercial type buildings. The residential sites ranged from a high of about 10 BTU/ft^2·°F·Day for Montecito Pines (Site Number 164) to less than three BTU/ft^2·°F·Day for First Manufactured Homes Lot 10 (Site Number 236). From the bar chart of heating solar fraction, Figure 14, the general pattern develops that those sites with the lowest heating load per square foot of floor area per heating degree-day have the highest solar fractions.

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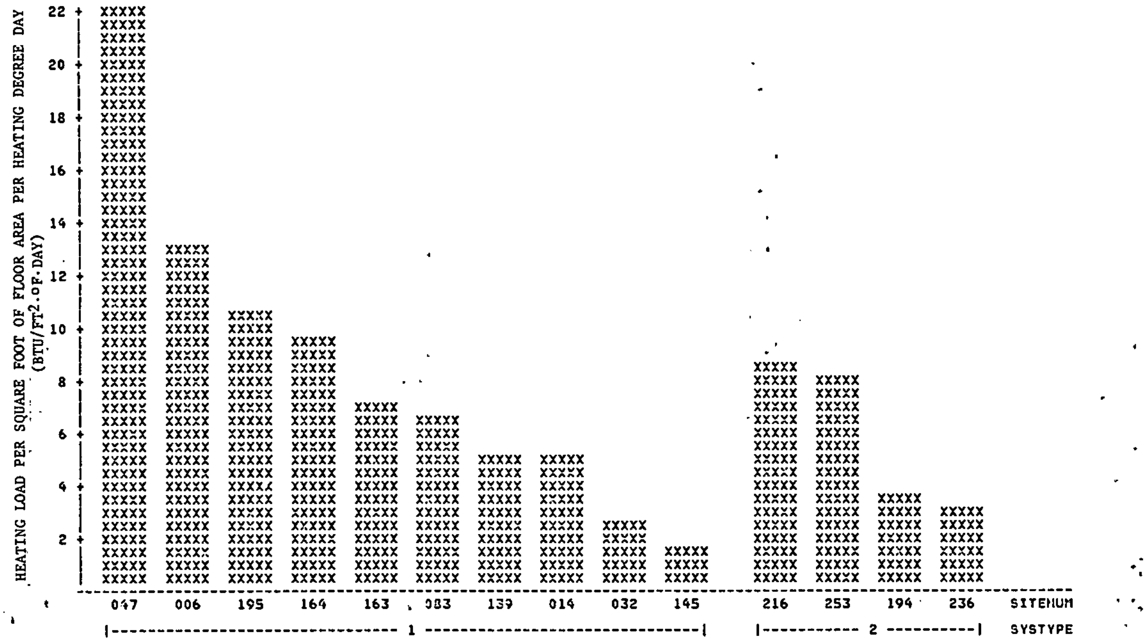

Figure 13. Bar Chart of Heating Load Per Square Foot of Floor Area Per Heating Degree-Day

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
014	TERRELL E. MOSELEY	164	MONTECITO PINES
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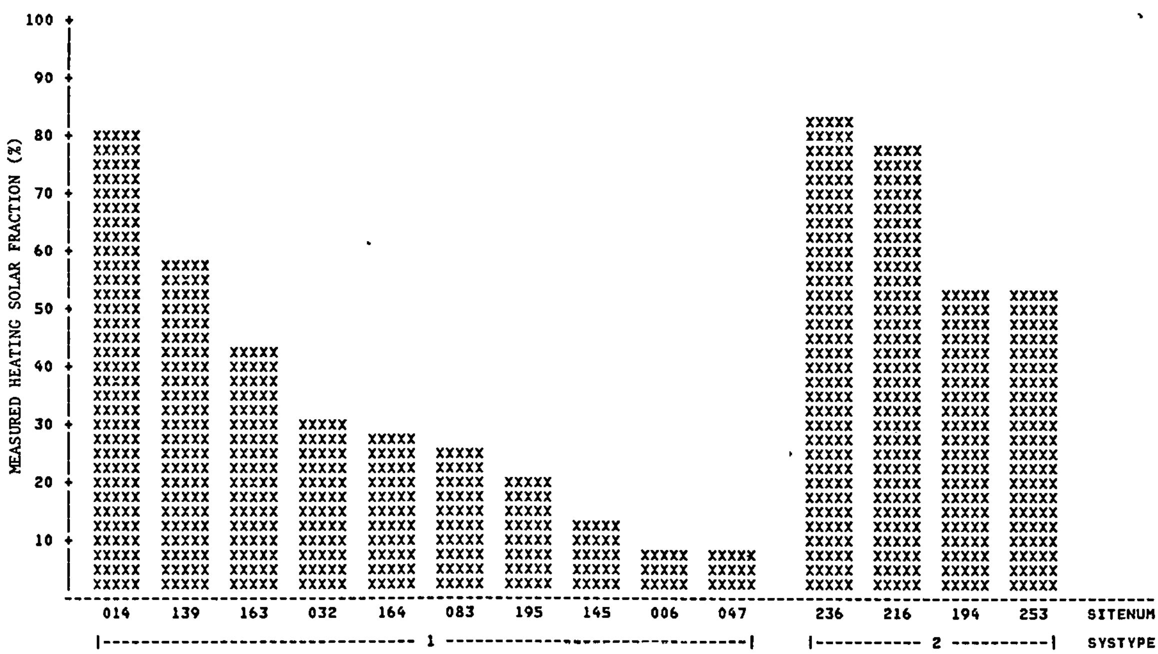

Figure 14. Bar Chart of Measured Heating Solar Fraction

A heating degree-day is a value which provides a measure of temperature difference and time. Its calculation assumes that a building will require heating at 65°F outside ambient temperature. Heating degree-days are calculated daily by subtracting the average of the high and low temperatures from 65°F, when the average is less than this base temperature. Dividing a building's heating load by the heating degree-days and floor area will give a normalized value of its energy requirement for heating.

2. Heating Solar Fraction, Measured and Design. The measured heating solar fraction is presented in Figure 14 and the design heating solar fraction is given in Figure 15. This factor represents the fraction of the equipment heating load met by solar energy, including solar thermal losses. In general, solar heating systems are designed to meet a particular fraction of the load which has been determined to be the most cost-effective use of the solar heating equipment. Attempting to increase the solar fraction beyond this point, with an increase in solar system size, will result in small performance gains for relatively large increases in equipment cost. The design solar fraction is based on several factors such as long-term insolation and temperatures, expected system operational performance, financing and equipment costs, and auxiliary fuel rates. Regardless of how the design fraction was determined, many assumptions about environmental conditions and operational performance have to be made. The variability of environmental factors, load projections, and system dependability and operation between what is expected and what actually occurs should be kept in mind when comparing design and measured solar fractions.

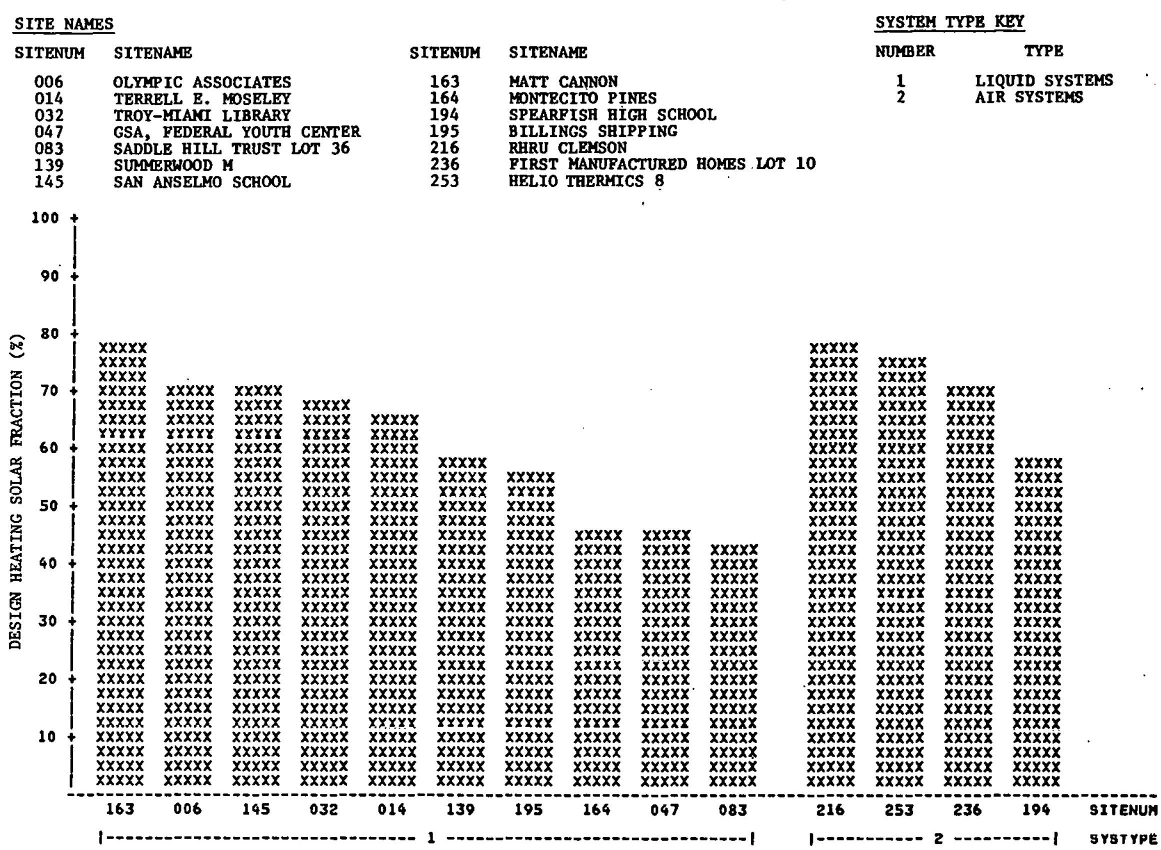

Figure 15. Bar Chart of Design Heating Solar Fraction

Two sites, Terrell E. Moseley (Site Number 014) and First Manufactured Homes Lot 10 (Site Number 236) exceeded their design projections, while three sites, Summerwood M (Site Number 139), Spearfish High School (Site Number 194), and RHRU Clemson (Site Number 216), nearly equaled their design solar fractions.

Terrell E. Moseley (Site Number 014) and Summerwood M (Site Number 139) both have the option of using solar energy directly in a duct heating coil in addition to assisting the heat pump. In the solar-assisted heat pump mode, electrical energy must be expended by the compressor to use solar energy. This fact limits the solar fraction to a value determined by the heat pump's COP. The direct use of solar energy in a duct heating coil allows the heating system to operate at a much higher COP, thus increasing the solar fraction over that possible with solar-assisted heat pump operation only.

First Manufactured Homes Lot 10 (Site Number 236), Spearfish High School (Site Number 194) and RHRU Clemson (Site Number 216) are sites which utilize air as the collection and distribution fluid. These sites deliver solar energy directly, from the collectors or from storage. Building air is heated directly, thus eliminating the need for heat exchangers and the inefficiency associated with them. Substantial portions of the heating loads at these sites were met by solar thermal losses to the building.

3. Percent of Heating Load from Solar Losses. Thermal energy losses occur in ducts, pipes, and from storage vessels in solar heating systems. This loss is due to the nature of solar systems which require that energy be transported relatively long distances and stored to be used when a heating load exists. Conventional heating systems produce and deliver thermal energy only when needed, thus reducing uncontrolled losses.

Depending on the location of ducts, pipes, and storage, thermal losses may occur into conditioned spaces. These losses can contribute to the heating requirement of the building but may result in overheating problems during mild weather.

Six sites, Saddle Hill Trust Lot 36 (Site Number 083), Summerwood M (Site Number 139), First Manufactured Homes Lot 10 (Site Number 236), Helio Thermics 8 (Site Number 253), Spearfish High School (Site Number 194), and RHRU Clemson (Site Number 216), had solar thermal losses which contributed to the heating load. Figure 16 presents the fraction of the heating load met by losses at these sites. All of the systems which utilize air as the collection and distribution medium had significant portions of their heating loads met by uncontrolled losses.

At First Manufactured Homes Lot 10 (Site Number 236), nearly 58% of the load was met by thermal losses. This site has one of the lowest heating loads per square foot of floor area per heating degree-day. Located in Lubbock, Texas, energy requirements for space cooling at this site are probably larger than the space heating requirements. Thermal losses from the solar system will add to this large cooling load, possibly negating the benefits of winter space heating savings.

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006	OLYMPIC ASSOCIATES	163	MATT CANNON
014	TERRELL E. MOSELEY	164	MONTECITO PINES
032	TROY-MIAMI LIBRARY	194	SPEARFISH HIGH SCHOOL
047	GSA, FEDERAL YOUTH CENTER	195	BILLINGS SHIPPING
083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
139	SUMMERWOOD M	236	FIRST MANUFACTURED HOMES LOT 10
145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

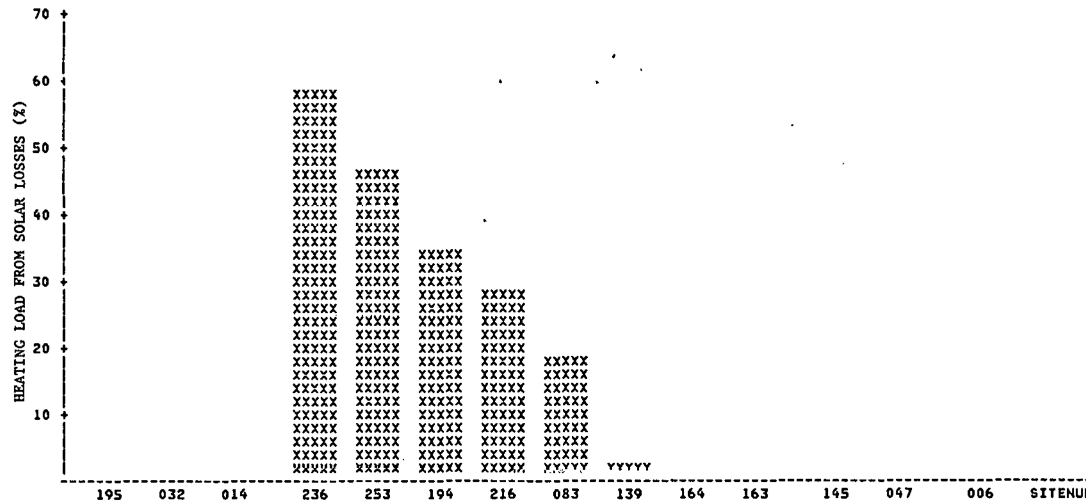

Figure 16. Bar Chart of Percent of Heating Load from Solar Losses

Helio Thermics 8 (Site Number 253) and RHRU Clemson (Site Number 216) both employ under-house gravel beds as storage which provide a large face area across which losses to the building can occur. Both of these sites also utilize storage for space cooling, when needed, by circulating cool night air to the gravel storage. During the day, warm house air is circulated through storage where cooling occurs.

4. Solar Used for Heating Per Square Foot Collector Per Day. Solar energy used for heating per square feet of collector per day is presented in Figure 17. This parameter identifies how effectively each system collected, stored, and transported solar energy to the heating load.

Terrell E. Moseley (Site Number 014) performed quite well, utilizing an average of 330 BTU/ft^2-day. The Summerwood M (Site Number 139) solar site performed second best. This performance shows that solar-assisted heat pump sites effectively utilize available solar energy. Air sites also utilized a high amount of solar energy per square feet per day; however, uncontrolled thermal losses were a substantial portion of this.

5. Overall Solar System COP. The ratio of the total solar energy used to the total solar-specific operating energy is the overall solar system COP. This parameter, presented in Figure 18, provides an indication of the overall benefit of the solar energy system.

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145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

SYSTEM TYPE KEY

NUMBER	TYPE
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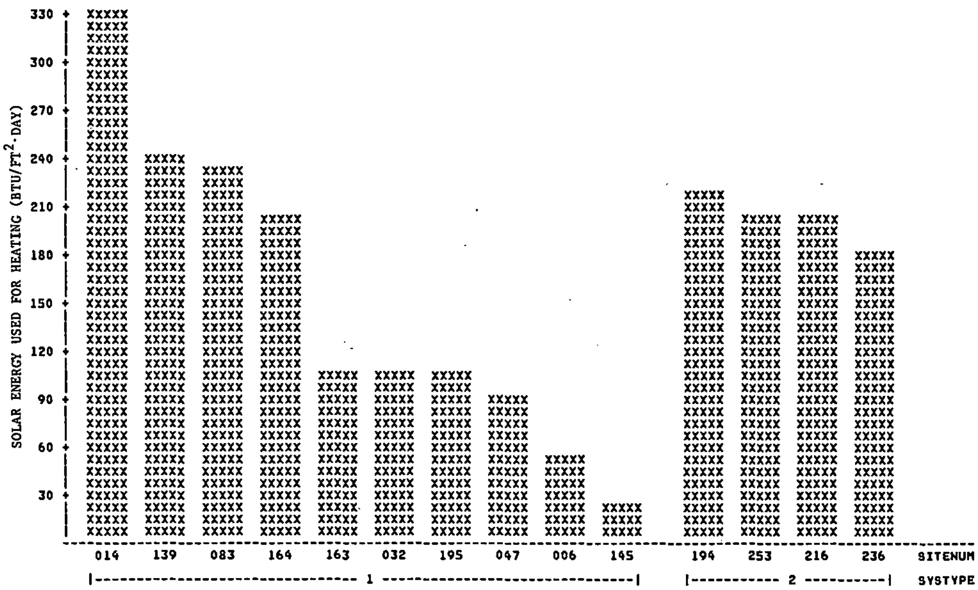

Figure 17. Bar Chart of Solar Energy Used for Heating Per Square Foot of Collector Per Day

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
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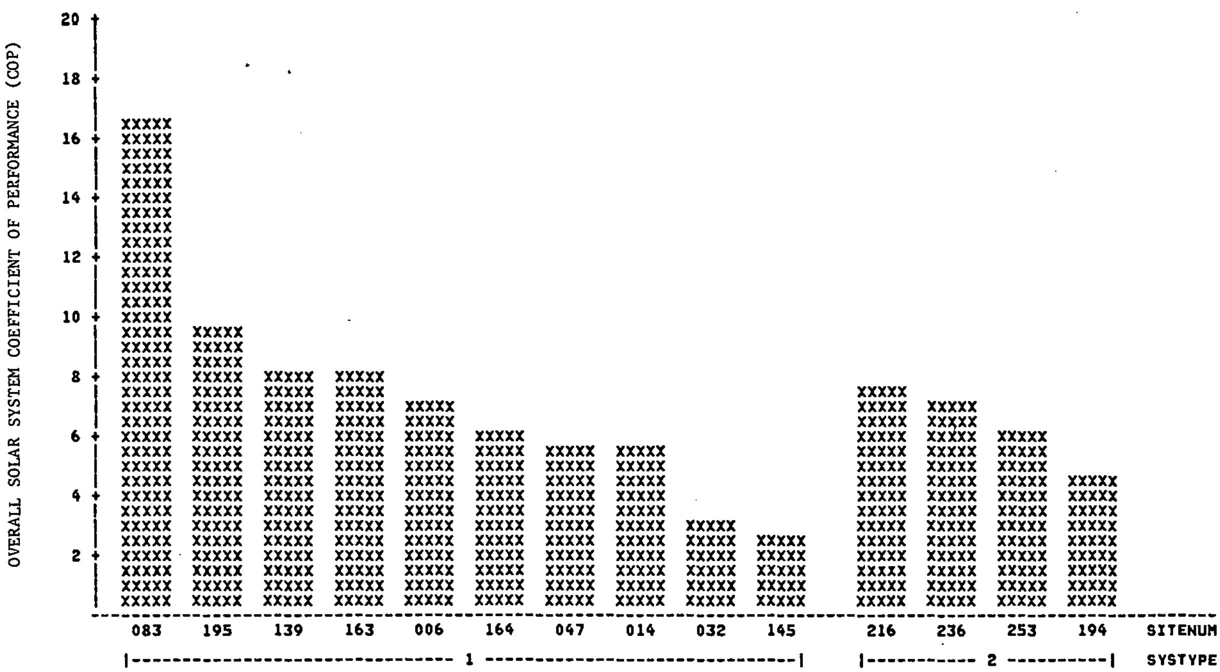

Figure 18. Bar Chart of Overall Solar System COP

Saddle Hill Trust Lot 36 (Site Number 083) supplied over 16 BTU of solar energy to all loads for each BTU of solar operating energy. High thermal losses, which contributed to the heating load at this site, resulted in this high COP value. Considering only the measured solar energy delivered to the loads of 17.34 million BTU, the COP is reduced to 9.58 which is still a very high value. Billings Shipping (Site Number 195) also achieved an excellent COP of 9.74. Proper component sizing and operational control resulted in efficient operation for these two systems.

The poor overall solar system COP evident with San Anselmo School (Site Number 145) and Troy-Miami Library (Site Number 032) is due to excessive consumption of operating energy and poor performance in the collection and delivery of solar energy to the loads. Troy-Miami Library utilizes collector recirculation for freeze protection. This method rejects collected solar energy while unnecessarily utilizing operating energy. A problem with the collector photocell controller caused the collector pumps to operate continuously during a portion of the heating season. Continuous operation of air handling units also wasted operating energy.

6. Overall Solar Heating COP. The overall solar heating COP is presented in Figure 19. This parameter is a ratio of the measured solar energy used for heating to the operating energy required to deliver it. The measured energy does not include solar thermal losses to the load. The operating energy includes a portion of the collector operating energy equal to the ratio of the measured heating solar energy to the total solar energy used in addition to the solar specific heating operating energy.

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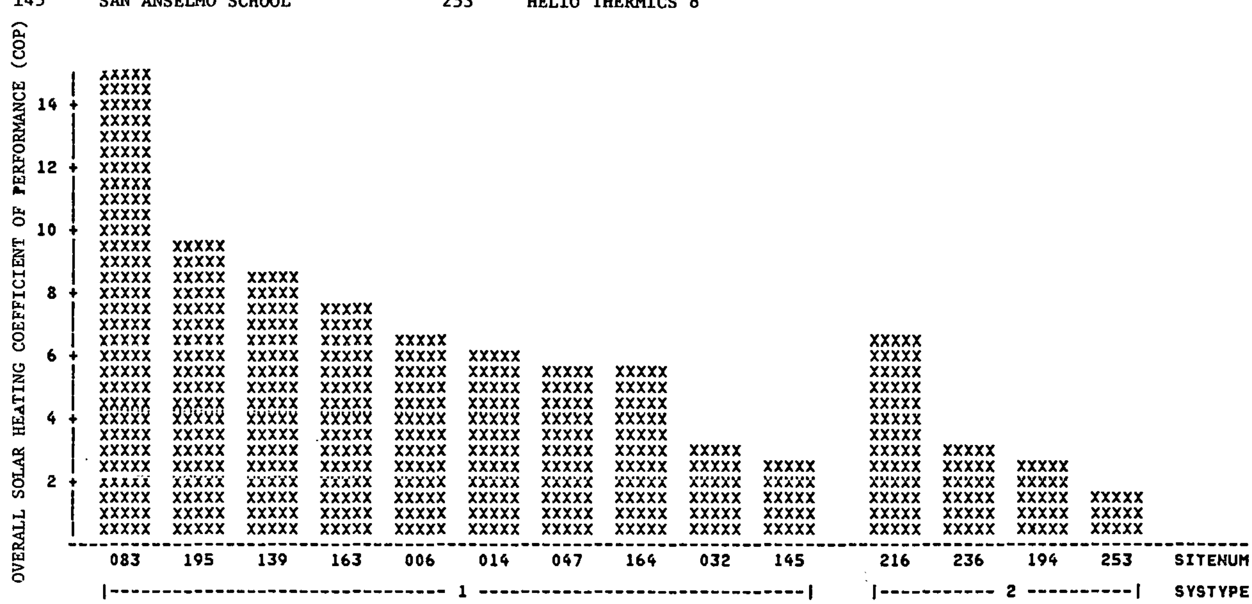

Figure 19. Bar Chart of Overall Solar Heating COP

Figure 19 illustrates that liquid-based systems provided a greater amount of measured solar energy per unit of operating energy than did air systems. Saddle Hill Trust Lot 36 (Site Number 083) substantially out-performed all other systems. This performance can be attributed to simple system design and high storage temperatures which allowed the system to meet the load with less operating time. Billings Shipping (Site Number 195), Summerwood M (Site Number 139) and Matt Cannon (Site Number 163) also exhibited high values for overall solar heating COP for the same reasons.

Three air systems, First Manufactured Homes Lot 10 (Site Number 236), Spearfish High School (Site Number 194) and Helio Thermics 8 (Site Number 253) performed poorly, attaining overall solar heating COPs which are about the same as would be expected from an electric heat pump. These three systems, however, had a high percent of their heating loads met by thermal losses as shown in Figure 16, Page 36.

Troy-Miami Library (Site Number 032) and San Anselmo School (Site Number 145), both liquid sites, performed at a low level of COP. Troy-Miami Library had control problems which caused the expenditure of excess operating energy. At San Anselmo School, poor collector efficiency and continuous collector operation during daylight hours, due to the control method, caused high collector operating energy and a low COP.

7. Percent of Collected Solar Energy Lost. Collected solar energy is delivered to storage and distributed to various loads through ducts, heat exchangers, and pipes. It is important to maximize the efficiency of the storage and distribution system by reducing thermal losses. Effective heat exchangers, short runs of ducts and pipes, adequate insulation, and using the lowest possible fluid temperatures are means with which to obtain the goal of low thermal losses and high system efficiency. Figure 20 presents the percentage of collected solar energy that was lost from the storage and distribution systems. This energy was not available to be delivered directly to the loads. Figure 16 on Page 36 presented the percent of the heating load which was met by solar thermal losses for six applicable sites.

San Anselmo School (Site Number 145) and GSA (Site Number 047) had the highest collected energy losses. Both of these sites use solar energy for cooling, which requires high operating temperatures. The collection system at San Anselmo School uses controls which maintain a minimum outlet temperature of 175°F. This creates a large temperature difference between the working fluid and the ambient environment, causing high thermal losses.

Terrell E. Moseley (Site Number 014) and Helio Thermics 8 (Site Number 253) achieved low collected energy losses while maintaining low average storage temperatures of 100°F and 72°F, respectively.

8. Heating Degree-Days, Measured and Long-Term. Figure 21 presents the measured heating degree-days and Figure 22 gives the expected long-term heating degree-days. Solar energy systems are sized and designed for expected long-term environmental conditions. Very good or poor performance of a particular system, relative to the expected performance, could be explained by a substantial variance from the expected environmental conditions in which the system had to operate.

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047	GSA, FEDERAL YOUTH CENTER	195	BILLINGS SHIPPING
083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
139	SUMMERWOOD M	236	FIRST MANUFACTURED HOMES LOT 10
145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

SYSTEM TYPE KEY

NUMBER	TYPE
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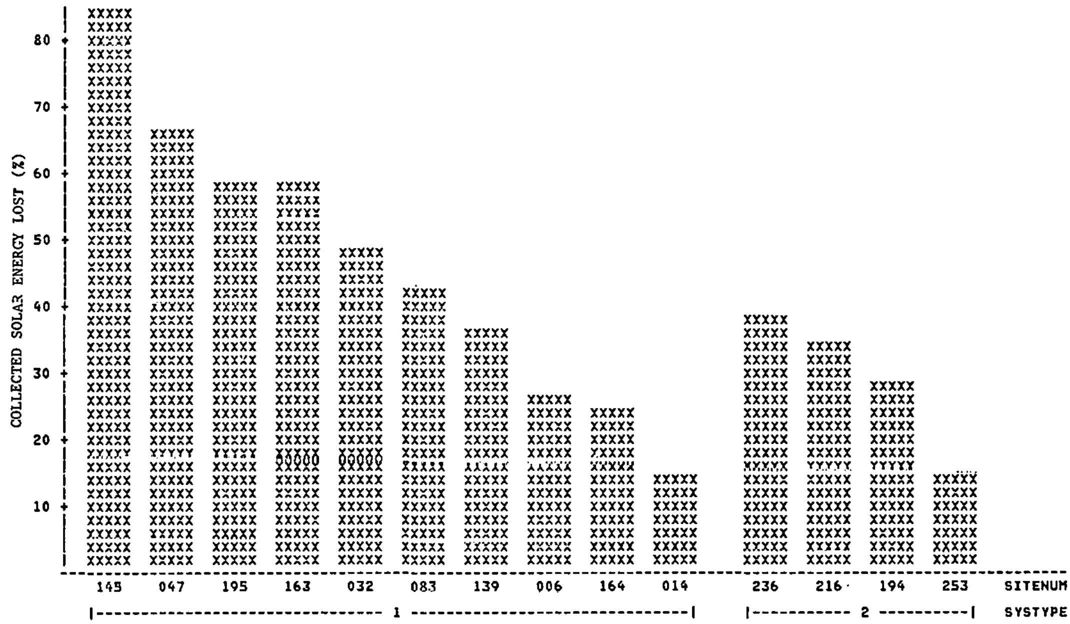

Figure 20. Bar Chart of Percent of Collected Solar Energy Lost

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
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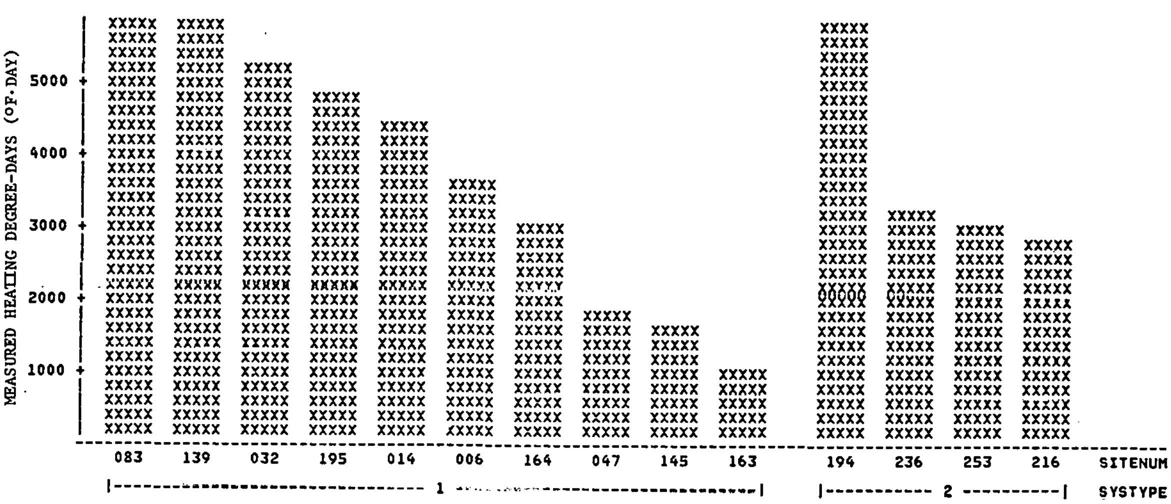

Figure 21. Bar Chart of Measured Heating Degree-Days

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
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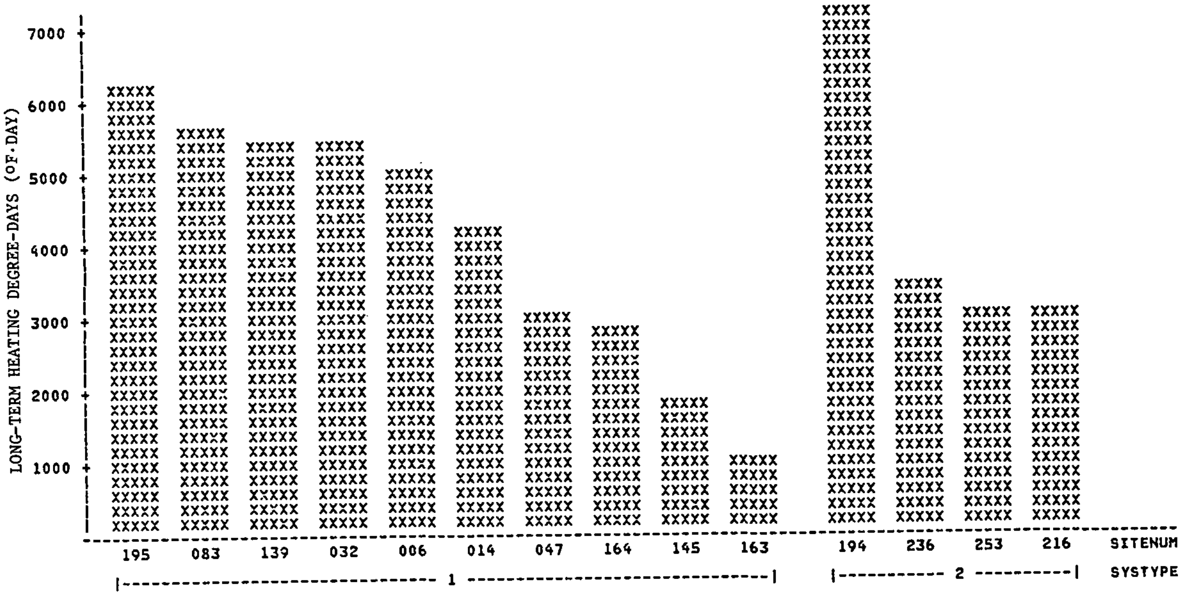

Figure 22. Bar Chart of Long-Term Heating Degree-Days

C. SAVINGS

1. Net Heating Savings Per Square Foot Collector Per Day. Figure 23 presents the net average daily energy savings, in BTU, provided by one square foot of collector area for heating purposes. This value gives a measure of the benefit provided by the solar system for heating, normalized by collector area. As a net value, it includes the solar operating energy expense.

Terrell E. Moseley (Site Number 014) performed quite well, saving a daily average of 487.03 BTU per square foot of collector. This site had one of the highest total collection efficiencies and the lowest amount of collected energy lost, exhibiting the best overall solar system efficiency. Saddle Hill Trust Lot 36 (Site Number 083) provided the second best heating savings. Although the percent of collected energy lost was relatively high at this site, its collection efficiency was good and the percent collected delivered to the load was among the highest. This site utilized solar energy from storage down to a temperature of 70°F. The location of storage at Saddle Hill Trust Lot 36 allowed some of the thermal losses to contribute to the load.

San Anselmo School (Site Number 145) exhibited poor savings due to large collected energy losses. The cooling system operational requirement for high temperature contributed to these high losses. This site also has the highest collector area to storage heat capacity ratio causing high operating point temperatures.

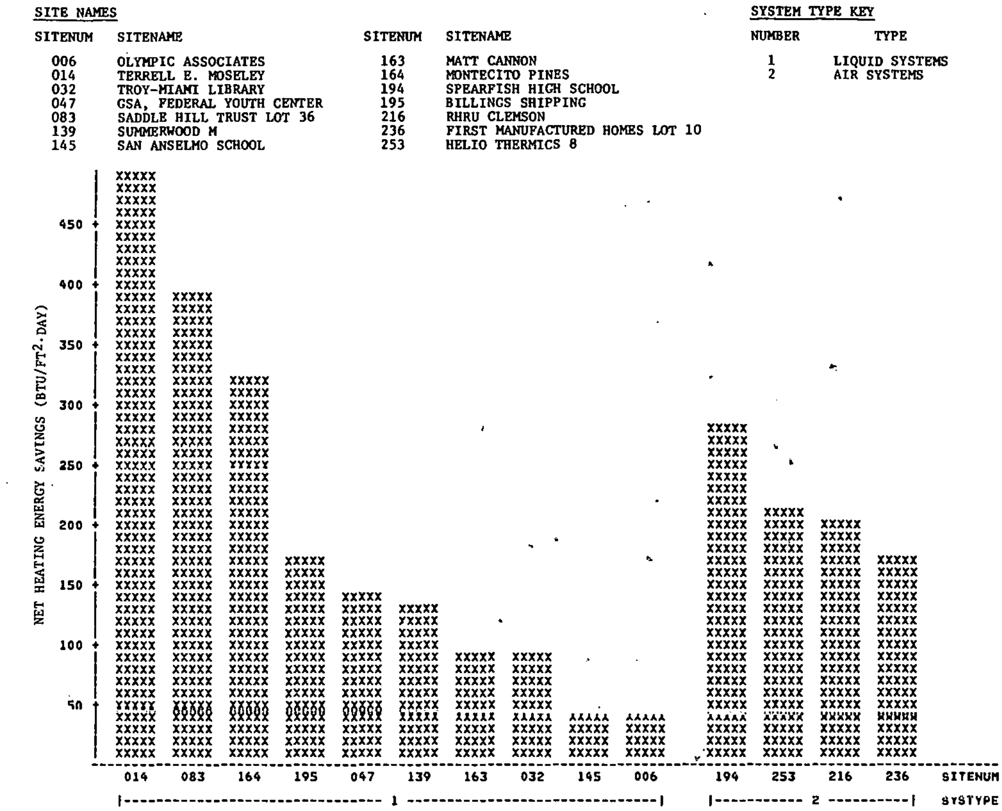

Figure 23. Bar Chart of Net Heating Energy Savings Per Square Foot of Collector Per Day

2. <u>Heating Dollars Saved Per Square Foot Collector Per 1,000 Heating Degree-Days</u>. The heating dollars saved per square foot of collector area per 1,000 heating degree-days are presented in Figure 24. Actual system savings differed from these reported savings due to variations in regional costs. The dollar savings were calculated using the following national average costs for auxiliary fuel:

Electric - 6.06/kwh

Natural Gas - $4.22/1,000 cubic feet

No. 2 Fuel Oil - $1.24/gallon

In dollars per BTU, electricity is the most expensive auxiliary fuel. As would be expected, those sites which provided the greatest dollar savings, RHRU Clemson (Site Number 216), Helio Thermics 8 (Site Number 253), Matt Cannon (Site Number 163) and First Manufactured Homes Lot 10 (Site Number 236), all use electric resistance heating as the auxiliary energy source. Saddle Hill Trust Lot 36 (Site Number 083) uses No. 2 fuel oil, the second most expensive fuel, and this site also achieved good dollar savings. Sites utilizing natural gas as the auxiliary fuel had low dollar savings due to the auxiliary being a relatively inexpensive fuel. Heat pump sites also rated low in dollar savings. At Olympic Associates (Site Number 006), solar energy replaced energy from conventional heat pumps first and electric strips second. This site is a poor performer in every category and is not representative. Terrell E. Moseley (Site Number 014), although a good performing site in almost all categories, did not do well in savings. This performance is due to the particular system configuration where natural gas supplies energy to storage when its temperature is low. In this mode, all energy to the building is supplied through the heat pump. Therefore,

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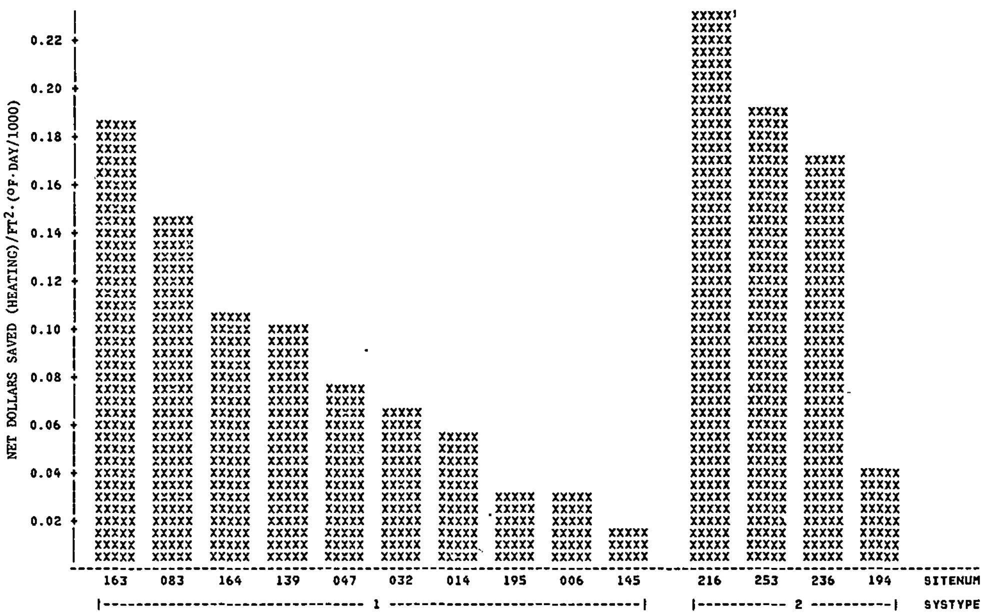

Figure 24. Bar Chart of Heating Dollars Saved Per Square Foot of Collector Per 1,000 Heating Degree-Days

in calculating savings at this site, solar replaces natural gas, not electricity. Summerwood M (Site Number 139) uses a heat pump which is both solar-assisted and conventional. When ambient temperatures are low, however, electric strips are the auxiliary source. Solar primarily replaces electricity, and, therefore, its savings are better than the other heat pump sites.

The cost of auxiliary fuel greatly affects the potential savings a solar site can provide. Although the amount of energy per square foot of collector provided to a building by two solar systems may be similar, its relative value can be greatly different depending on what the replaced auxiliary fuel costs.

3. Net System Energy Savings Per Square Foot Collector Per Day. The net system energy savings per square foot of collector per day are presented in Figure 25. This parameter includes the sum of energy savings provided by the solar system to all loads. Solar-specific operating energy, including the collector operating energy, is counted as a negative electrical energy expense.

4. Net System Dollars Saved Per Square Foot Collector Per 1,000 Heating Degree-Days. The dollar savings provided by the solar system to all loads per square foot of collector per 1,000 heating degree-days are presented in Figure 26. The dollar savings were calculated using the national average fuel costs given previously.

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
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083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
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145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

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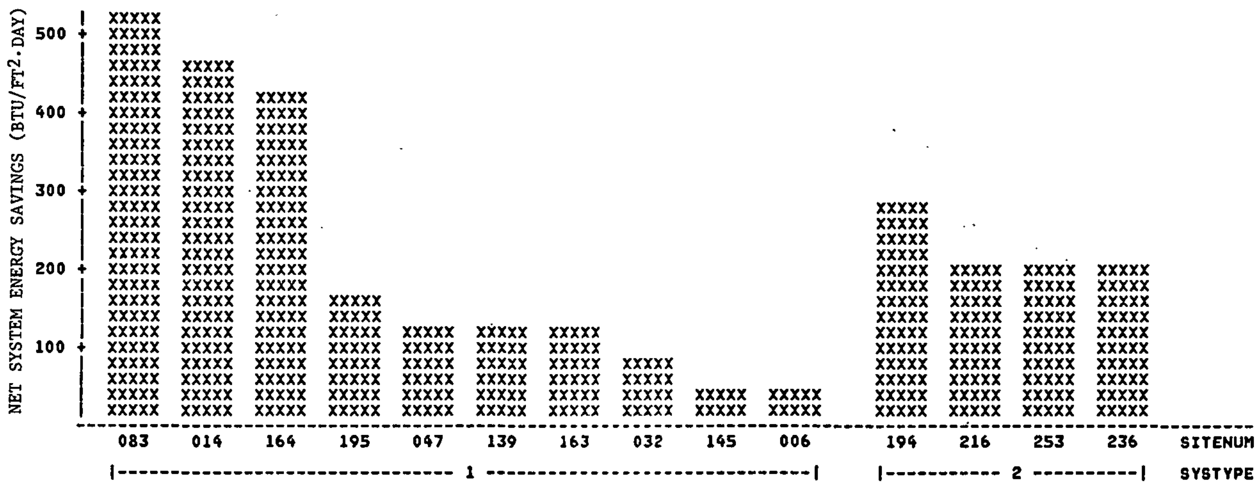

Figure 25. Bar Chart of Net System Energy Savings Per Square Foot of Collector Per Day

SITE NAMES

SITENUM	SITENAME	SITENUM	SITENAME
006	OLYMPIC ASSOCIATES	163	MATT CANNON
014	TERRELL E. MOSELEY	164	MONTECITO PINES
032	TROY-MIAMI LIBRARY	194	SPEARFISH HIGH SCHOOL
047	GSA, FEDERAL YOUTH CENTER	195	BILLINGS SHIPPING
083	SADDLE HILL TRUST LOT 36	216	RHRU CLEMSON
139	SUMMERWOOD M	236	FIRST MANUFACTURED HOMES LOT 10
145	SAN ANSELMO SCHOOL	253	HELIO THERMICS 8

SYSTEM TYPE KEY

NUMBER	TYPE
1	LIQUID SYSTEMS
2	AIR SYSTEMS

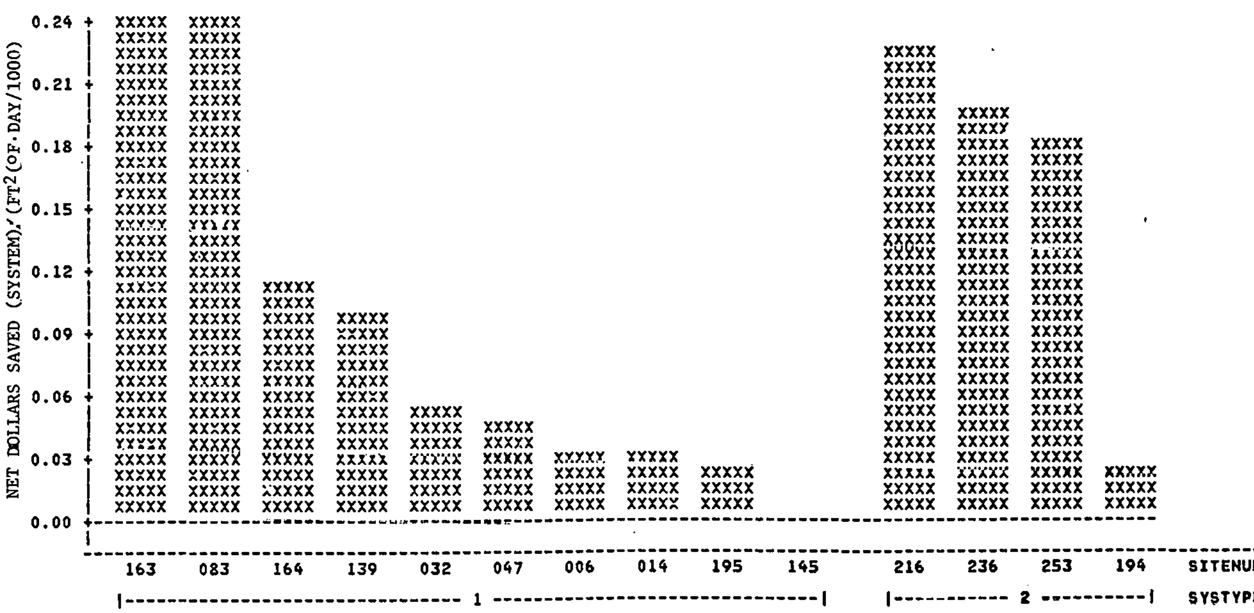

Figure 26. Bar Chart of Net System Dollars Saved Per Square Foot of Collector Per 1,000 Heating Degree-Days

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Section IV

SUMMARY

This section presents a summary of observations made on the various performance indices discussed in Section III. The data presented in the bar charts and tables represents a large volume of information from which general trends can be detected. The intent of this report is to present this data and identify areas of system design and operation which contribute to good or poor solar heating system performance. While an attempt is made to identify obvious aspects of system performance and compare these between different types of sites, it is not possible, within the constraints of this report, to identify and discuss every conceivable relationship. The reader of this report can utilize the large amount of data presented to draw specific conclusions based on experience and special areas of interest.

Energy conservation measures should be the primary consideration before contemplating the installation of a solar heating system to either new or existing buildings. Reduced energy consumption through improved insulation, infiltration control, and energy distribution and management systems will increase the percent contribution of solar energy to the heating load. Those sites which had heating loads of approximately two to eight $BTU/ft^2 \cdot {}^\circ F \cdot Day$ achieved substantially better solar fractions than sites with high heating loads. One site, San Anselmo School (Site Number 145) had a measured heating load of less than two $BTU/ft^2 \cdot {}^\circ F \cdot Day$ but achieved a heating solar fraction of only 13%. System operational control problems prevented the use of available solar energy to meet even this low load.

Large thermal energy losses in air systems are evident. Air leaks from ducts and storage vessels are the major cause of these losses. Losses occurring within conditioned spaces were a substantial contribution of solar energy to heating loads.

Air systems did not perform as well as liquid systems in collector system COP and heating system COP. Fans and blowers use greater amounts of operating energy because they are not as efficient as liquid pumps. This disadvantage may be negated, however, since air systems operate without heat exchangers and generally can deliver solar energy to the building directly from the collectors. These factors eliminate the inefficiency associated with heat exchangers and storage losses. The performance of the air systems was comparable to the best of the liquid systems in the percent of incident and collected solar energy delivered to the loads.

Solar-assisted heat pump sites delivered a high percent of incident solar energy to the loads. The ability of these solar systems to use solar energy at lower temperatures than can be used directly in duct coils allows maximum use of stored solar energy. Low system operating temperatures decrease uncontrolled losses to the environment and increase collection efficiency. The Terrell E. Moseley (Site Number 014) site showed that site-built collectors can operate efficiently when coupled with a solar-assisted heat pump. Substantial cost savings could be realized at solar-assisted heat pump sites if low-cost, low-temperature collectors were employed.

Solar sites which employ absorption chillers had high losses as a percent of the collected energy. The high temperature requirements of these chillers caused low collection efficiency. Attention should be given to the possibility of adding extra insulation to pipes and storage to reduce losses. A summer/winter mode change should be considered to allow the collectors to operate at lower temperatures during the winter. Solar heat exchangers and terminal heating equipment should be sized so that lower temperatures can be utilized.

Recirculation of storage water for freeze protection at Troy-Miami Library (Site Number 032) caused substantial amounts of collected energy to be lost in addition to wasting operating energy. This method of freeze protection is not recommended in geographical locations which experience freezing temperatures often.

Solar systems provided the highest dollar savings at sites which utilize electricity as the auxiliary source of energy, since electricity has the highest cost per BTU. These savings averaged 14.5 cents per square foot of collector per 1,000 heating degree-days. Savings at sites with natural gas auxiliary averaged 5.3 cents per square foot of collector per 1,000 heating degree-days. A solar system is more cost effective when it reduces the use of auxiliary electricity rather than low-cost natural gas.

Many space heating sites experienced system problems which prevented thorough analysis. The misadjustment or failure of collector subsystem controls was a predominant problem resulting in collected energy being rejected, excessive use of operating energy, or the failure of collector operation. Poor control conceptualization and overly complex design contributed to these problems. Mechanical failure of pumps, fans, dampers, and pipes was a common problem. In some cases, collector damage resulted from stagnation and overheating.

Complex system designs which employed three-way valves, tempering valves, and multiple operating modes experienced operational problems. Simple system design and control will result in more dependable operation. Initial system costs can be reduced by eliminating expensive valves and controllers.

Some system designs permit auxiliary energy to be delivered to storage. By maintaining storage at a higher temperature than would normally occur, collection efficiency is lowered. This high temperature prevents the collection of some solar energy which would have been available for the loads.

SECTION V

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APPENDIX A

SITE DESCRIPTIONS

BILLINGS SHIPPING, Site Number 195

The Billings Shipping solar energy site, located in Billings, Montana, is an enclosed freight distribution facility with 4,900 square feet of heated office space. The system has a roof-mounted flat-plate collector array that faces south at an angle of 50 degrees to the horizontal. The collector array is made up of 120 LSC 18-1S collectors made by Lennox Industries. The collector array has a gross area of 2,147 square feet and uses a 50% propylene glycol and water solution for the energy transport fluid.

The collected solar energy is stored in a 2,500-gallon water tank which is insulated with two inches of polystyrene and buried five feet below the surface of the ground. Solar energy may be transferred to the space heating subsystem from this tank or transferred directly from the energy collection subsystem. This solar-heated water passes through the solar portion of the air-handler unit space heating coil to provide space heating. Auxiliary space heating is obtained from heated water flowing through a separate loop of the air-handler unit. Auxiliary energy is supplied by a gas-fired Weil McLain E6H105-W hot water boiler and a separate heat exchanger in the air-handler unit.

The system, shown schematically in Appendix B, has four modes of solar operation.

Mode 1 - Collector-to-Heat Exchanger - This mode activates pump P1 when the collector surface reaches 130°F. Pump P1 circulates the glycol solution through the collectors and the heat exchanger. Pump P1 is turned off whenever the collector surface temperature falls below 110°F. If the temperature of the collector fluid exceeds 195°, the heat rejectors activate to cool the fluid and protect the collectors.

Mode 2 - Heat Exchanger-to-Storage - This mode activates when mode 1 is active and the collector fluid temperature at the collector outlet is higher than the temperature of storage. Water is circulated by pump P2 through the collector heat exchanger, valve V2, storage, and valve V1.

Mode 3 - Heat Exchanger-to-Load - This mode activates when mode 1 is active and a space heating demand exists. Water is circulated by pump P2 through the collector heat exchanger, the air handler space heating coils, and valve V2. When the temperature of the water leaving valve V2 is lower than the storage temperature, V1 bypasses storage; otherwise, the flow passes through storage and then valve V1.

Mode 4 - Storage-to-Load - This mode activates when mode 1 is not active, a space heating demand exists, and the storage temperature is greater than 90°F. Water is circulated by pump P3 from storage through valve V1, the space heating coils, valve V2, and returned to storage.

FIRST MANUFACTURED HOMES LOT 10, Site Number 236

The First Manufactured Homes Lot 10 site is a single family residence located in Lubbock, Texas. The building has 1,280 square feet of living area. Solar energy is used for space heating and preheating domestic hot water. The solar energy system has an array of nine Payne #175A408SCS flat-plate collectors, with a gross area of 288 square feet. The array faces south at an angle of 45 degrees to the horizontal. The collectors use air to collect and deliver solar energy to 20,520 pounds of rock located in a storage bin located within the house. An air-to-liquid heat exchanger, located near the collector array outlet, is used to heat water in an 82-gallon preheat tank.

Solar energy is supplied to meet the space heating requirements either directly from the collector array or from the rock storage bin. Solar heated water from the 82-gallon preheat tank is supplied to the cold water inlet of a 42-gallon domestic hot water tank. Both the space heating system and the domestic hot water system utilize electric resistance heaters for auxiliary energy.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collectors	Payne	175A408SCS
Blower	Payne	520B042BP
Preheat tank	State	SSV82-UT57
Domestic hot water tank	State	V-440T
Domestic hot water circulation pump	Little Giant	CMD-100-3B
Rock storage	Site-built	
Air conditioners	Payne	569A024RCUE
Fan coil	Payne	525A024010HCFC
Water coil	Payne	414B048CCW
Air directors	Payne	481A016SAD

The system, shown schematically in Appendix B, has five modes of operation.

<u>Mode 1 - Collector-to-Storage</u> - When the temperature of the collectors is at least 25°F greater than the bottom of the storage bin and the building is not demanding heat, the controller will energize the solar blower and the collector air director motor. Solar energy will then be supplied to the storage bin until the temperature differential drops below 10°F.

Mode 2 - Direct Solar-to-Space Heating - For this operating mode, three conditions must be met. The first is that a 25°F temperature differential must be maintained between the collector sensor and the sensor in the bottom of the storage bin. The second is that the sensor located near the top of the rock storage bin must measure a temperature of 95°F or higher. The third is that the first stage of the building thermostat must demand heat.

When these three conditions have been met, the controller will energize the space heating blower, the solar blower, the solar air director in the collector ducts, and the solar air director in the space heating ducts.

NOTE: The water heating mode will take place concurrently with mode 1 and mode 2 when the control sensors indicate that solar energy is available to preheat the domestic hot water.

Mode 3 - Storage-to-Space Heating - To heat the indoor conditioned space using stored solar energy, three conditions must be met. The first is that the building thermostat must demand heat. The second is that the sensor in the top of the rock storage bin must have a temperature greater than 95°F, indicating sufficient energy in the storage bin. The third is that the temperature differential between the collector sensor and the sensor in the bottom of the bin must be less than 25°F, indicating that direct solar energy from the collectors is not available.

When these three conditions are met, the controller will energize the indoor space heating air director and blower.

If heat from the storage bin is unable to meet the building demand, the second stage of the building thermostat will energize the electric resistance auxiliary heaters. These will supply auxiliary energy concurrent with the addition of energy from the rock storage bin.

Mode 4 - Preheating Domestic Hot Water - When the temperature of the collectors is at least 25°F greater than the preheat tank, system controls energize the solar blower and domestic hot water pump. This mode will continue until the water temperature in the preheat tank reaches 140°F, or the temperature differential drops below 10°F. The water preheating mode receives the highest priority; therefore, it can activate during the summer when no solar energy is added to the rock storage bin.

Mode 5 - Auxiliary Space Heating - When solar energy is not available from either the collectors or storage, heating will be provided exclusively by the electric resistance heaters.

GSA, Site Number 047

The GSA solar energy site is the Federal Youth Center located is a prison near Bastrop, Texas. This facility consists of youth housing units, administration offices, prison industries, academic and vocational training, a clinic, recreation, and support services. The combination of buildings to which solar energy makes a space heating and cooling contribution has a floor area of approximately 149,671 square feet. The solar energy system is designed to provide 46% of the annual heating demand, nine percent of the annual cooling demand, and 97% of the annual domestic hot water (DHW) demand.

The solar energy system consists of 21,760 square feet of single-glazed, selective-coated collectors manufactured by Cole Solar Systems. Orientation is such that the 1,184 collectors are all located on the roof structures and are connected in a series-parallel arrangement. This results in small groups of collectors (four to ten) connected in parallel which have a common output connected in series to the common input of a second identical group. Solar heated water is stored in two interconnected tanks outside the equipment room. Water returning from the collectors enters a 15,000-gallon storage tank. For freeze protection, the collector loop uses the draindown method.

Domestic hot water (DHW) heating is accomplished by drawing hot water from the smaller, hotter storage tank through a heat exchanger and returning it to the storage tank. The DHW recirculating loop to the other buildings flows through this heat exchanger and the auxiliary DHW heater.

Space heating is provided by pumping water from the smaller storage tank through a separate heat exchanger. The space heating circulating loop from the other buildings flows through this heat exchanger, then to the auxiliary boilers where additional heat is added if necessary.

Space cooling is supported by circulating water from the smaller storage tank through an absorption chiller. Auxiliary energy may supplement or be used in place of the solar energy through use of fossil boilers and a heat exchanger. Further auxiliary cooling is provided through two centrifugal chillers.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturers	Model No.
Collectors	Cole Solar Systems Inc.	306GIS
Absorption chiller	York 120 Ton	ESE-3B3A
Auxiliary chillers	York 250 Ton	HT01-C1-BEC

The system, shown schematically in Appendix B, has four modes of solar operation.

Mode 1 - Collector-to-Storage - This mode is entered when the temperature sensor on the collector absorber plate rises to 20°F above the temperature of storage tank 2. Collection is terminated when the differential temperature falls below 3°F. Collector pump P32 may operate at three possible speeds, depending on the rate of solar energy absorption. As the temperature difference between the collector plate and the storage tank increases, the pump speed increases. Similarly, when possible, the pump speed decreases to the next level as the difference in temperature falls. Whenever storage tank 2 temperature at the pump inlet exceeds 185°F, the pump is turned off.

Mode 2 - Domestic Hot Water Heating - DHW heating is accomplished by circulating water from storage tank 1 by either pump P29 or P30 through heat exchanger HX2. Modulating valves maintain the water leaving the tube section below 145°F and a 3°F temperature loss across the solar side of the heat exchanger. A valve also determines whether larger pump P30 or smaller pump P29 is necessary to provide circulation. Auxiliary DHW heating is supported by boiler 3 and pump P23 which circulate water through a heat exchanger in the DHW heater. DHW heating in the dormitory section is accomplished by means of heat exchangers in the space heating loop in these buildings. The dormitory DHW load is not instrumented, is assumed to be small when compared with the main DHW recirculation loop load, and, therefore, is estimated.

Mode 3 - Space Heating - Space heating is accomplished by circulating water from storage tank 1 by either pump P27 or P28 through heat exchanger HX1. Modulating valves maintain the water leaving the tube section below 145°F and a 3°F temperature loss across the solar side of the heat exchanger. A modulating valve also determines whether larger pump P27 or smaller pump P28 is necessary to provide circulation. Auxiliary space heating during the winter is provided by using pumps P17 and P18 to circulate through boilers 1 and 2. During the summer, boiler 3 is used to provide auxiliary energy instead of boilers 1 and 2. Circulation from the boiler is produced by pump P33 through heat exchanger HX4. A modulating valve maintains a water temperature of 140°F leaving the tube section of the heat exchanger. When boiler 3 is used, circulation in the space heating loop is provided by pump P34. Circulation in this loop is required during the summer since this loop also provides DHW in the dormitory buildings.

Mode 4 - Space Cooling - Space cooling is accomplished by using pump P31 to circulate hot water from the storage tank through the generator of the absorption chiller. The storage tank temperature necessary to start the absorption chiller varies from 182°F to 196°F and is determined from the sunshine forecast and the overnight low forecast. When the storage tank drops below 175°F or the load is not being met, valve V7 opens, V8 closes, and pumps P31 and P26 start. This allows boilers 1 and 2 to supply energy to the absorption chiller. Two centrifugal chillers are also available for auxiliary space cooling. Solar heated water, used in this and the previous two modes, returns to the storage tanks through valve V6. Valve V6 compares the temperature of the returning water with the temperature of tank 1, and, if the temperature of the returning water is below that of tank 1, the water is diverted into tank 2.

HELIO THERMICS 8, Site Number 253

Helio Thermics House Lot 8 is one of two instrumented single family residences in Greenville, South Carolina. The home has approximately 1,086 square feet of conditioned space. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The solar energy system utilizes the attic space as the solar energy collector. The attic roof faces 10 degrees west of south and is pitched at an angle of 51 degrees to the horizontal. Solar energy enters the attic through a 416-square-foot aperture which is double-glazed with corrugated, translucent, fiberglass-reinforced, acrylic panels. The interior of the attic is painted black to maximize the absorption of solar energy. Warm air accumulates in the peak of the attic roof and circulates through the conditioned space or through storage by an air handler. Solar energy is stored in an 870-cubic-foot storage bin containing 85,460 pounds of crushed rock. The bin is located under the house and has two inches of polystyrene insulation. Cold water is preheated in the attic by thermosiphoning water from the 80-gallon preheat tank through a manifold system of copper tubes. These tubes are attached to black sheet-metal plates, thus enhancing absorption of solar radiation for preheating the water as it circulates to and from the preheat tank. Preheated city water is stored in the preheat tank and supplied, on demand, to a conventional 42-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, an electrical heating element in the hot air supply duct provides auxiliary energy for space heating. An electrical heating element in the DHW tank provides auxiliary energy for water heating.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collector	Helio Thermics, Inc.	Site-fabricated
Storage	Helio Thermics, Inc.	Site-fabricated
Solar Heating Subsystem Air Handling Unit Blower Motorized Damper Actuator Dampers Electronic Control System Electric Resistance Duct Heater	Helio Thermics, Inc.	Model 800
Thermostat	Honeywell, Inc.	TH72D and Q672B
DHW Tank	Mor-flo Industries	ER-425
DHW Preheat Tank	Helio Thermics, Inc.	Solar Preheat Tank

The system, shown schematically in Appendix B, has eight modes of operation.

Mode 1 - Collector-to-Space Heating - This mode activates when space heating is required and the collector supply-duct air temperature is 10°F higher than the building ambient temperature. This mode terminates when the temperature difference drops to less than 6°F or the space heating requirement is satisfied.

Mode 2 - Collector-to-Storage - This mode activates when there is no demand for space heating and the collector supply-duct temperature is 26°F higher than the storage temperature. This mode terminates when the temperature difference between the collector and storage is less than 16°F.

Mode 3 - Storage-to-Space Heating - This mode activates when space heating is required (but is not available from the collector) and the storage temperature exceeds the building ambient temperature by 5°F. This mode terminates when the buiding ambient temperature equals the storage temperature or when space heating is no longer required.

Mode 4 - Auxiliary Energy-to-Space Heating - This mode activates when heat is required in the living area and thermal energy is not available from the collectors or storage. An electrical heating element in the hot air supply-duct remains on until the requirement for heat is satisfied.

Mode 5 - Summer Mode, Space Cooling - This mode can be activated when cool air from the outside is desired in the living area. The outside air-intake damper opens, the duct to the living area opens, and the air-handler fan activates.

Mode 6 - Summer Mode, Passive Cooling Storage - This mode can be activated when the residents wish to store cool air in storage for circulation the next day. The air-handler fan activates and an outside air-intake damper opens to allow to cool air to circulate through the attic and storage.

Mode 7 - Summer Mode, Storage-to-Space Cooling - This mode can be activated when cool air from storage is desired in the living area. The outside air-intake damper closes, the duct to the living area opens, and the air-handler fan activates.

Mode 8 - Domestic Hot Water (DHW) Preheating - This mode activates when there is a demand for hot water. Water is drawn from the conventional DHW tank and replenished with heated water from the preheat tank. The DHW subsystem has this one independent mode of operation for preheating.

MATT CANNON, Site Number 163

The Matt Cannon site is a four-unit apartment house in Gainesville, Florida. The building has approximately 2,420 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 597 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. Solar energy is stored aboveground in a 1,000-gallon steel tank with four inches of insulation. Solar-heated water is pumped from storage through an air heat exchanger in the return air-duct of each apartment to satisfy the heating demand. City water is preheated by a heat-exchanger jacket on a 120-gallon preheat tank which supplies preheated DHW, on demand, to a conventional 30-gallon DHW tank in each of the four apartments. When solar energy is insufficient to satisfy the DHW load, an electrical heating element in each DHW tank provides auxiliary energy for water heating. Similarly, an electrical heating element in each apartment air-handler provides auxiliary energy for space heating.

The system, shown schematically in Appendix B, has three modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates when the collector outlet temperature is 16°F higher than that of the water in the bottom of the storage tank. Water circulates from the tank through the collectors until the temperature difference is 2°F or less.

Mode 2 - Storage-to-Space Heating - This mode activates when there is a demand from a manually-preset thermostat in the conditioned space and the temperature of the water in the storage tank is 80°F or higher. Water circulates from the storage tank through a heat exchanger in the air-handler unit in each apartment and returns to the tank when the space heating demand is satisfied.

Mode 3 - DHW Preheating - This mode activates when the temperature of the preheat tank is below the temperature of storage. Water circulates from the storage tank through the heat-exchanger jacket on the preheat tank.

MONTECITO PINES, Site Number 164

The Montecito Pines site is an apartment complex in Santa Rosa, California. It consists of one instrumented unit containing eight apartments. Each apartment has approximately 864 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW). The solar energy system which serves the eight-apartment unit has a Sunburst Solar Energy array of flat-plate collectors with a gross area of 950 square feet. The array faces 23 degrees west of 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 to the space heating and hot water loads. Freeze protection is provided by draindown. Solar energy is stored underground in a 2,000-gallon insulated tank manufactured by the North Coast Tank and Filter Company. Auxiliary energy, in times of low solar energy, is supplied by a gas-fired boiler. City water is circulated through a heat exchanger in the storage tank for preheating before entering the boiler which supplied both space heating water and DHW on demand.

The system, shown schematically in Appendix B, has four modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates collector loop pump P1 when the collector plate temperature exceeds the storage temperature by 17°F and terminates when a temperature difference of 3°F is reached.

Mode 2 - Storage-to-Space Heating - This mode activates space heating pump P2 when there is a space heating demand and the temperature at the top of the storage tank is 105°F or higher. Mode diversion valves are energized to divert the flow to the heat exchanger in the storage tank, bypassing the gas-fired boiler.

Mode 3 - Auxiliary Space Heating, DHW Preheating - This mode activates space heating pump P2 when there is a space heating demand and the temperature at the top of the storage tank is less than 105°F. Mode diversion valves direct the flow through the gas-fired boiler, bypassing the heat exchanger in the storage tank.

Mode 4 - DHW Preheating - This mode activates when there is a demand for DHW. Incoming city water passes through the heat exchanger in the storage tank on the way to the gas-fired boiler which supplies hot water, on demand, to the apartments.

OLYMPIC ASSOCIATES, Site Number 006

The Olympic Associates, Inc. site is a single-story brick office building located in Richland, Washington. Construction was completed and the building occupied in January 1977. The building has 14,000 square feet of conditioned floor area with a capacity of about 100 persons. The solar energy system was designed to annually provide approximately 71% of the space heating, 97% of the space cooling, and 90% of the domestic hot water requirements for year-round operation of the building. A 6,000-square-foot array of 252 General Electric Model FP-2, roof-mounted, double-glazed, flat-plate collectors in 13 rows faces five degrees west of south at an angle of 46 degrees from the horizontal. A solution of 65% water and 35% ethylene glycol provides freeze protection and is the energy transfer medium. This solution is separated by a heat exchanger from the water used in the solar storage tank. Solar energy storage is provided by a 9,000-gallon steel storage tank covered with three inches of foamed urethane and buried outdoors. Solar energy from storage is transferred to the conditioned space by air forced over eight zone heat exchangers in the air ducts. The demand is controlled by zone thermostats. A 25-ton solar hot water driven ARKLA absorption chiller provides chilled water to a 2,000-gallon chilled water storage tank. Chilled water is supplied to the same heat exchangers in the forced air ducts as is the hot water for space heating. A heat pump in each of eight zones is used to augment solar energy for both space heating and cooling. Domestic hot water is preheated by circulating solar heated water through a heat exchanger immersed in the preheat tank.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collectors	General Electric	FP-2
Absorption Chiller (25 ton)	ARKLA	Solaire 300
Heat Pump	Carrier	50D 9006
Storage Tanks	Welk	-
Heat Exchanger	B&G	-
DHW Tank (52 gal)	A.O. Smith	-
DHW Preheat Tank	National Steel	-

The system, shown schematically in Appendix B, has five modes of solar operation.

Mode 1 - Collector-to-Storage - This mode is entered when one or both absorber plate thermal switches close at 180°F for space cooling or 120°F for space heating, respectively, at which time pumps P1 and P2 are energized. The set points are automatically selected by system demand switches on the control panel. The transfer solution is circulated through the collectors, through the main heat exchanger HX2, and back to the collectors until the absorber plate temperature drops to less than 180°F for cooling or 120°F for heating, at which time pumps P1 and P2 are de-energized. Energy is extracted from the collector loop at HX2 under control of valve V2. This valve is set to the position B-AB when the mixture temperature in the collector loop exceeds the solar storage tank temperature by 15°F to 30°F. The system uses energy directly from the main heat exchanger when there is a space heating or space cooling demand. Otherwise the solar energy is routed to the solar storage tank.

Mode 2 - Collector-to-Space Heating - Solar energy from the collection loop is transferred across heat exchanger HX2 to each of the eight zone air-handling units. Pump P3 is energized when any one of the zones has a space heating demand. In the air handling unit, valves V7A, V7B, V7C and V7D provide for either heating or cooling through the same heat exchanger HX4. In the space heating mode, valves V7C and V7D route hot water to HX4, and V7A and V7B inhibit chilled water flow.

Mode 3 - Collector-to-Space Cooling - Solar energy from the collection loop is transferred across heat exchanger HX2, or from storage to the absorption chiller. When 180°F water is available, the chiller will become functional. The absorption chiller will continue to operate after space cooling requirements are met until the chilled water storage tank temperature drops to 44°F. Should the 9,000-gallon solar storage tank reach a temperature greater than 220°F, the ARKLA will continue to operate until the chilled water storage tank temperature drops to 38°F. Pump P4 is energized when any one of the zones has a space cooling demand. In the air handling unit, valves V7A, V7B, V7C, and V7D provide for either heating or cooling through the same heat exchanger, HX4. In the space cooling mode, V7A and V7B route chiller water to HX4, and V7C and V7D inhibit hot water flow.

Mode 4 - Domestic Hot Water Preheat - Solar energy from the solar storage tank preheats the incoming cold water supply through HX3 in the solar preheat tank. Pump P6 is activated when the temperature differential between the solar storage tank and the solar preheat tank has reached a preset temperature. To prevent overheating, P6 is de-energized when the preheat temperature reaches 150°F.

Mode 5 - Excess Energy Rejection - The system enters this mode when the solar storage tank temperature exceeds 230°F. During this mode, the cooling pond water pump P7 will operate until the storage tank temperature decreases by 1.5°F. Heat exchanger HX1 in the collector loop was sized to handle maximum insolation loads and therefore no energy will be added to storage when this mode is active.

Summary - Modes 1 through 5 can be active simultaneously. During transitional periods such as spring or fall, mode 2 and mode 3 are commonly active simultaneously at midmorning.

RHRU CLEMSON, Site Number 216

The Rural Housing Research Unit (RHRU) of the United States Department of Agriculture (USDA) Science and Education Administration solar energy site is an instrumented, combination greenhouse and residence at Clemson University and is sponsored by the Appalachian Regional Commission and South Carolina Agricultural Experimentation Station. The two-story house uses both active and passive solar components for space heating, space cooling, and domestic hot water heating. This site is operated by the South Carolina Agriculture Experimentation Station at Clemson, South Carolina. The active system has 388 square feet of flat-plate collector built by the USDA. The collector faces due south and is tilted at an angle of 60 degrees from the horizontal. Air is used as the transfer medium for delivering solar energy from the collector to storage. The air entering the collector may be preheated by routing it through the greenhouse, which has a projected area of 333 square feet in the plane of the collector.

The energy is stored in 1,161 cubic feet of rock located in a storage bin beneath the house. Space heating is accomplished by circulating warm air from the collector or the rock storage bin through the conditioned spaces. Space cooling is provided by circulating cooled air from outside or from the rock storage bin through the conditioned spaces. Auxiliary heating is furnished by 20-kilowatt electric heat strips, and auxiliary cooling is provided by a 2.5-ton air conditioner. The heat strips and the air conditioner evaporator coils are located in the air-handler unit supply plenum. Domestic hot water (DHW) is preheated by circulating city water in two 42-gallon preheat tanks through an air-to-liquid heat exchanger located in the collector outlet plenum. Auxiliary hot water heating is furnished by a 4.5-kilowatt electrical element in the 30-gallon hot water tank.

The system, shown schematically and pictorially in Appendix B, has three winter modes of operation, three summer modes, and a domestic hot water mode.

A. WINTER OPERATION

Mode 1 - Collector-to-Storage - During periods of adequate insolation when there is no space heating demand, warm air is routed from the collector outlet, through rock thermal storage, and back to the collector. To maintain a greenhouse temperature of 70°F and avoid overheating, air returning to the collector may be circulated through the greenhouse collecting solar heat.

Mode 2 - Collector-to-Space Heating - During periods of adequate solar insolation, space heating is supplied to the conditioned space by drawing warm air directly from the collector outlet plenum. The return air is recycled through the solar collector for reheating and redistribution.

Mode 3 - Storage-to-Space Heating - Air is transferred from the rock thermal storage by the air-handling unit to the house. Return air from the house may be recycled through the greenhouse at night under the control of manual dampers. This maintains the minimum greenhouse temperature at approximately 50°F. When the air temperature of the rock thermal storage is insufficient to satisfy the space heating demand, auxiliary energy is supplied by the electrical heat strips.

B. SUMMER OPERATION

Mode 1 - Purge - Cool air from outside is circulated through the rock thermal storage so that the cooler air will pick up stored energy transferred to storage from the conditioned spaces. The air bypasses the greenhouse and is vented through the solar collector to the outside.

Mode 2 - Storage-to-Space Cooling - Air that had been cooled during the previous purge mode is drawn from storage and distributed to the house. Additional cooling is supplied by the auxiliary evaporator coils located in the air-handler unit supply plenum.

Mode 3 - Outside Air-to-Space Cooling - Cool air is drawn from outside and delivered to the house. The return air is recycled to the solar collector and vented to the outside.

C. DOMESTIC HOT WATER OPERATION

The DHW preheat mode is used in both winter and summer. Water from the preheat tank circulates through the air-to-water heat exchanger, which is located in a plenum at the top of the flat-plate collector. The effective collector area for summer mode operation is 43 square feet. Hot water flow through the heat exchanger begins when the temperature at the heat exchanger is 3°F above the preheat tank temperature, and reaches maximum flow rate when the temperature difference is 23°F. Flow stops when the temperature difference decreases to below 3°F. The proportional control device ensures that the flow rate is proportional to the temperature difference. Whenever the temperature at the heat exchanger decreases to below 35°F, water from the preheat tanks circulates through the air-to-water heat exchanger to protect the system from freezing.

SADDLE HILL TRUST LOT 36, Site Number 083

Saddle Hill Trust Lot 36 is a single family residence in Medway, Massachusetts. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The system has an array of 14 liquid flat-plate Daystar model 2001 collectors with a gross area of 315 square feet. The array faces south at an angle of 58 degrees to the horizontal. A 60% glycerol solution is the transfer medium that delivers solar energy from the collector array to storage; water is the transfer medium that delivers solar energy from storage to the space heating and hot water loads. Solar energy is stored in the basement in a 750-gallon storage tank. The tank is made of steel and lined with polyurethane. Preheated city water is supplied, on demand, to a conventional 80-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, a Friedrich model QUA-112-AMA oil furnace provides auxiliary energy for space heating. Similarly, the conventional electric Vaughn Model C8N2 80-gallon DHW heater provides auxiliary energy for water heating. The system, shown schematically in Appendix B, has three modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates the collector pump when the collector temperature is either more than 40°F higher than storage temperature or higher than 150°F. Solar energy transfer takes place through a heat exchanger located inside the storage tank.

Mode 2 - Storage-to-Space Heating - This mode activates the space heating pump when there is a demand for space heating, storage temperature is 70°F or higher, and house temperature is lower than storage temperature. Solar energy transfer takes place through a heat exchanger located inside the air duct.

Mode 3 - Storage-to-DHW Tank - This mode activates the DHW solar pump when storage water is 5°F higher than water in the DHW tank. Solar energy transfer takes place through a heat exchanger located inside the DHW heater.

SAN ANSELMO SCHOOL, Site Number 145

The San Anselmo School is a one-story, brick elementary school, located in San Jose, California. The building contains approximately 34,000 square feet of floor area, and is entirely bound by brick walls except for a small portion of window area. The school is functional all year-round and typically operates between the hours of 8:00 a.m. to 3:00 p.m. on weekdays. The school is usually unoccupied on the weekends.

The solar energy system was added to the existing building, and is interconnected to the original cooling and heating equipment. The system was designed to supply 70% of the annual space heating requirements and 72% of the annual space cooling needs for the school.

The solar energy system incorporates 3,740 square feet of evacuated tubular glass collectors, a heat rejector, an expansion tank, a storage tank, a solar operated absorption chiller, electronic controls, and interconnecting pipelines and hardware between the solar system and original heating and cooling equipment. Existing equipment was unaltered except for controls. These components include two gas-fired absorption chillers, two gas-fired absorption chiller/heaters, a cooling tower, 33 air handling units, heating/cooling coils, and five pumps.

The collector array faces due south at a tilt of 40 degrees to the horizontal for collecting solar energy. The collector system utilizes city water as a transfer medium from collector to storage and back to the collector again to complete the cycle. If solar energy is excessive, then solar energy is dissipated to the environment via a water-to-air heat rejector. When sufficiently higher temperature is reached in the storage tank, hot water is either transferred to the solar chiller during the cooling mode, or is transferred directly to the heating coils during the heating mode. If solar energy is insufficient in meeting the space cooling and heating requirements, then two auxiliary gas-fired absorption chillers and two auxiliary gas-fired absorption chiller/heaters will satisfy the energy demand for the school.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Evacuated Tube Collectors	General Electric	TC-100
Heat Rejector	McQuay-Perfex, Inc.	LHD-217 CH
Storage Tank	Ace Buehler, Inc.	VS72-9A
Absorption Chiller and Chiller/Heaters	ARKLA Corporation	WFB-300
Valves	Barber Colman	-
Controllers	Barber Colman	-

The system, shown schematically in Appendix B, has nine modes for solar operation.

Mode 1 - Collector Freeze Protection - This mode occurs when the outside ambient temperature is below 43°F and the level of insolation is not sufficient for energy collection. Solar pump P8 is activated and valve V3 is opened to allow flow through the heat rejector. Energy from the storage tank maintains the water in the collector loop at 38°F via modulating valve V2. This prevents all equipment from being damaged by freezing.

Mode 2 - Auxiliary Collector Freeze Protection - This is a safety backup freeze protection mode. If the temperature exiting the collectors drops below 34°F, then dump valve V4 directs city water through the collector loop to prevent the collectors from freezing.

Mode 3 - Solar Energy Collection - Solar energy collection is activated whenever insolation levels are sufficient. Pump P8 is turned on and all the flow bypasses the storage tank and returns to the collectors to complete the cycle. Pump P8 is deactivated when insolation levels fall below the set point.

Mode 4 - Collector-to-Storage - This mode occurs when the temperature exiting the collectors is 175°F or above. This closes the bypass port on valve V2 and allows all water to flow through storage. When the temperature falls below 175°F, valve V2 reverses position and allows all water to bypass the storage tank. This assures a positive energy storage into the tank.

Mode 5 - Storage-to-Space Cooling - Whenever space cooling is required and the temperature in the storage tank is above 175°F, then pump P7 is activated, allowing flow from storage to the solar operated absorption chiller. If solar energy is insufficient to meet the cooling demand, then two auxiliary gas-fired absorption chillers and two auxiliary gas-fired absorption chiller/heaters will supply the space cooling requirements.

Mode 6 - Storage-to-Space Heating - Whenever space heating is required and there is sufficient energy in the storage tank, then pump P7 is activated, allowing hot water to flow to the heating coils for distribution to the heating zones via the air handling units. If solar energy is insufficient, then two auxiliary gas-fired absorption chiller/heaters will supply the remaining heating requirements.

Mode 7 - Solar Heat Rejection - This mode occurs when excess solar energy is diverted from the collectors to the heat rejector unit via valve V3. This mode operates when the temperature exiting the collectors is 220°F or above, to reject excess energy to the environment. This deactivates when the temperature exiting the collectors falls below 220°F.

Mode 8 - Auxiliary Heat Protection - This is a safety backup protection to prevent collector damage. This mode activates when the temperature leaving the collectors exceeds 240°F and opens dump valve V4 to allow city water to cool the collectors. This mode deactivates when the water leaving the collectors falls below 232°F.

Mode 9 - Power Failure Protection - This mode activates at any time during a power failure. Dump valve V4 opens to allow city water to the collector loop and remains open until power is restored.

Note: An absorption chiller/heater is an absorption chiller which can be utilized for space heating by deactivating the cooling tower flow.

SPEARFISH HIGH SCHOOL, Site Number 194

The Spearfish High School solar energy system consists of a high volume flat-plate (Solaron, Inc.) collector array of 8,034 square feet mounted at 55 degrees tilt facing due south, operated by a circulating fan on the outlet duct return to the storage air handler. Upstream of the storage rock bin, capacity 4,150 cubic feet, is a damper system which selects solar heated air flow to a domestic hot water (DHW) preheat heat exchanger (36 inches x 68 inches) directly to the space heating load, or to the rock bin for storage. On about November 12, 1980, a mode was configured which allows simultaneous heating of the conditioned space and the storage rock bin with solar energy.

The ducting of the air transfer systems seems to be resistant to air leakage and the installation of the collector array, air handlers, and distribution system is adequate for the region's severe winter climate. Auxiliary energy for space and hot water heating is provided by natural-gas-fired packaged boilers.

The system, shown schematically in Appendix B, has three modes of operation for space heating.

Mode 1 - Collector-to-Storage - The solar energy is transferred to storage after the heating load is satisfied, by repositioning dampers so air flows from the top plenum of the rock box to the bottom plenum and back to the collector array.

Mode 2 - Collector-to-Space Heating - The solar collector air handler circulating fan is activated when the absorber plate temperature reaches 80°F. Solar heated air is moved to the air handler at the storage rock box where control logic, actuated by system demands for heat or DHW or both, determines damper positions. Mode 2 selects direct solar space heating in which solar heated air is provided to roof-mounted air handlers which make up the required thermal energy from conventional hot water boilers to satisfy the load.

Mode 3 - Collector-to-Space Heating and Storage - The collector circulating fan and the storage delivery fan can operate simultaneously in this new mode to provide both stored and direct heated solar energy to the load. This is accomplished by positioning the storage air handler dampers and opening the damper downstream of the storage air handler.

The domestic hot water (DHW) subsystem is enabled by operation of the main collector circulating fan. Appropriate damper positions are selected by control logic which senses hot water demand and routes water to be preheated into the air-to-water heat exchanger while damper positions are selected to route solar heated air to the heat exchanger.

SUMMERWOOD M, Site Number 139

The Summerwood Associates site is a cluster of condominiums overlooking Long Island Sound. The Summerwood M site is a rowhouse residence in Old Saybrook, Connecticut. The home has approximately 1,375 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 340 square feet. The array faces 12 degrees west of south at an angle of 50 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage and to the space heating and DHW loads. Draindown provides collector freeze protection. Solar energy is stored in a 600-gallon poured concrete insulated tank located in a crawl space. Solar heated water is supplied to a liquid-to-air heat exchanger within the space heating duct and to a heat pump for water-to-air operation. A closed heat transfer loop between the solar storage tank and a 120-gallon DHW tank provides solar energy to the DHW supply. When solar energy is insufficient to satisfy the entire space heating load, the heat pump operates in its water-to-air mode, extracting heat from the solar-heated water. When the storage tank temperature falls below 40°F, the heat pump automatically disconnects from the solar-heated water supply and operates in an air-to-air mode using an outdoor evaporator. An electric heater in the space heating duct provides auxiliary energy for space heating in conjunction with both solar and conventional heating modes. An electrical heating element in the DHW tank provides auxiliary energy for water heating.

The manufacturers of major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collector	Sunworks	Solector IM LC
Solar storage tank	Wormser Scientific Corporation	Site-built concrete
Solar storage tank insulation	Dow Chemical Co.	Polystyrene Styrofoam G
Air-handling system, including blowers, heat exchangers, heat pump and electrical resistance heater	Friedrich Air Conditioning and Refrigeration Co.	Climate Master V-22 12AW
Domestic water heater	Vaughn Corporation	E-120SNR-0
Control mode selector	Johnson Controls	147-1-2-3

The system, shown schematically in Appendix B, has four modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates when collector temperature exceeds the storage temperature by 15°F and terminates when a temperature difference of 2°F is reached. Collector loop pump P1 is operated in this mode.

Mode 2 - Storage-to-Space Heating - Direct Solar Mode - This mode activates when there is a demand for space heating and solar storage temperature is above 85°F. Circulating pump P2 and the air-handling subsystem blower are operated in this mode.

Mode 3 - Storage-to-Space Heating - Solar-Assisted Heat Pump Mode - This mode activates when there is a demand for space heating and the solar storage temperature is less than 85°F and greater than 40°F. Circulating pump P2, the air-handling subsystem blower, and the heat pump are operated in this mode.

Mode 4 - Storage-to-DHW - This mode activates when the temperature difference between solar storage and the DHW tank exceeds 15°F and terminates when the temperature difference drops below 6°F. Pump P3 is operated in this mode.

TERRELL E. MOSELEY, Site Number 014

The Terrell E. Moseley site is a 1,780-square-foot, single-story, commercial office building with attached warehouse in Lynchburg, Virginia. The solar energy system is designed to provide approximately 70% of the space heating and hot water energy requirements of the office building. Because the hot water consumption is very low, only the space heating system is monitored for performance evaluation. The site has a collector array of 16 flat-plate collectors built by T. E. Moseley, Inc. The collector array has a gross area of 400 square feet, and faces south at a tilt angle of 50 degrees from the horizontal. Water is the heat transfer medium throughout the solar energy system. Collected solar energy is delivered to the 2,000-gallon storage tank, which is in an unheated attached warehouse building. The insulation on the tank is four inches of fiberglass.

When solar energy is insufficient to maintain 55°F storage temperatures, a gas-fired boiler (auxiliary heater) provides additional energy to storage. Space heating is provided by circulating storage water through a heat exchanger located in the air distribution system of the building. In addition, a solar-assisted heat pump is employed to provide auxiliary energy to the space heating demand. Since the collector fluid automatically drains into storage after each solar energy collection operation, additional collector freeze protection measures are not required.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collectors	400 ft^2 of site-built collectors	-
Heat Pump	York Triton water-to-air heat pump	DW30H
Controller	Rho Sigma Controller	102

The system, show schematically in Appendix B, has three modes of solar operation, which are described below.

Mode 1 - Collector-to-Storage - This mode is entered when the collector absorber plate temperature exceeds the middle storage temperature by 20°F. The transfer fluid is circulated from storage through the collectors and back to storage until this temperature differential drops to less than 3°F.

Mode 2 - Storage-to-Space Heating - This mode is entered when there is a demand for space heating and the sensed temperature of the storage water is greater than 85°F. Water is circulated between storage and liquid-to-air heat exchanger HX1 in the air-handling unit distribution duct until the space heating demand is satisfied, or the sensed storage temperature drops below 85°F.

Mode 3 - Storage-to-Heat Pump - This mode of operation provides space heating when mode 2 operation is not available. This mode is entered when there is a demand for space heating and the temperature of the storage water is below 85°F. Energy input to the heat pump is supplied by opening the normally closed valve V2, closing the normally open valve V1, and circulating storage water through heat pump evaporator HX2. This mode is terminated when either the sensed storage temperature rises above 90°F, or when no space heating demand exists.

TROY-MIAMI LIBRARY, Site Number 032

The Troy-Miami Library site is a county library located in Troy, Ohio. The building is a one-story structure with very high ceilings and a basement containing offices and meeting rooms. The total floor area is 23,000 square feet, which is divided into five zones for heating and cooling. The solar energy system is designed to supply 69% of the space heating requirements. No domestic hot water or space cooling is provided by solar energy. Auxiliary energy is provided by electric heating coils in the air-handling units, supplemented by electric baseboard heaters and unit heaters near entryways and in the garage area. The solar heating system and the central chilled water system share common piping through the air handlers, and are isolated from each other by three-way valves which are controlled automatically according to heating or cooling demands.

The 102 collectors are Owens-Illinois Sunpak, evacuated glass tube type. The collectors face 27 degrees west of south and are tilted 40 degrees from the horizontal. The gross collector area is 3,264 square feet. The collector fluid medium is water with anticorrosion additives. No collector draindown is utilized, and the collector pumping system is controlled by the tube temperature set point method.

Storage consists of a 5,000-gallon water tank buried outside the building. The tank is insulated by three inches of expanded urethane foam and enclosed in a water-resistant fiberglass jacket.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Component	Manufacturer	Model No.
Evacuated Tube Collectors	Owens-Illinois	Sunpak Series
Water Storage Tank	Owens-Corning	Noncorroding underground storage tank
Controls	Honeywell	Pneumatic
Air Handling Units	Chrysler Corp.	Airtemp
Circulation Pump	Thrush	F
Electric Duct Heaters	Thermatrol Chromalox	MF (open coil) DHOC1 (open coil)
Electric Chiller	Chrysler Corp.	HAW 75-1

The system, shown schematically in Appendix B, has three primary modes of operation using solar energy. In addition to these primary modes, there are three collector conditioning/protection modes. Also, space heating can be provided by a conventional heating mode which uses electrical power. The solar modes are described in the following paragraphs.

Solar collection is enabled when the water temperature inside the evacuated tubes is raised above 80°F by insolation to the array. The following modes are then selected by control logic.

Mode 1 - Collectors-to-Space Heating - Mode 1 is activated whenever the temperature at T1 is at or above 120°F and the heating mode has been selected. Once entered, this mode continues until the temperature at T1 drops to 80°F or until heating requirements are met. In this mode, the water from the collectors is delivered by pumps P2 and P3 through valves V13, V8, and V6 to air handlers AHU1 through AHU5. The return water passes through V1, V9 and V12 and back to the collectors. Mode 1 incorporates two submodes which differ by the path of the heating return water. In submode 1A, the return water bypasses storage, flowing straight through valve V12 back to the collectors. In submode 1B, return water is directed to the water thermal storage through V10, then through V11, the bottom port of V12, and back to the collectors. The selection of submode 1A or 1B is determined by the difference between temperatures at T5 and T6. Submode 1B is entered when the temperature at T5 exceeds T6 by at least 5°F, and continues as long as T5 is at least 2°F greater than T6. In submode 1B, valves V10 and V11 are set to deliver water to the storage tank at the upper level and extract water from storage at the lower level.

Mode 2 - Storage-to-Space Heating - This mode is entered when the temperature at T1 drops below 80°F. The system continues in this mode as long as T1 is less than 120°F, temperature at T4 is greater than 75°F, and heating is selected. In mode 2, pump P1 is on and pumps P2 and P3 are off. Flow for this mode goes from the upper level of water thermal storage through valves V11, V12, V13, and V8, through pump P1 to the air handlers, and returns to the lower level of storage through valves V9 and V10. If temperature at T1 again rises to 120°F, mode 1 is reactivated by opening valve V6, turning off pump P1, turning on pumps P2 and P3, and repositioning valve V13. If temperature at T4 drops below 75°F, valve V8 is closed, pump P1 is turned off, and valve V9 is repositioned to block return flow from the air handlers. In the latter condition, conventional electric heat is used to support the heating load.

Mode 3 - Collectors-to-Storage - This mode is entered when the temperature at T1 is at or above 120°F and the heating mode has not been selected. The mode is terminated when the controller-sensed temperature at T1 drops below 120°F or when the heating system is activated.

In mode 3, valve V8 is closed and valve V9 is repositioned so that water from the collectors (after passing valve V13) flows through the top port of valve V9.

As in the case of mode 1, there are two submodes for mode 3. The selection of the submodes is determined by the difference between temperatures at T5 and T6. If the temperature at T5 exceeds the temperature at T6 by at least 5°F, the flow passes through valve V10, into storage, and returns to the collectors through valves V11 and V12. When the temperature at T5 no longer exceeds the temperature at T6 by at least 2°F, the water thermal storage is bypassed.

Collector Array - Freeze Protection-Conditioning

The collector conditioning/protection modes are used to prevent freezing of the collectors in the winter and overheating of the collectors during summer or other high collection/low load times.

Freeze Protection Mode A - When the outside air temperature falls below 40°F while valve V13 is set to bypass the collectors, valve V14 opens and pumps P2 and P3 run for ten minutes out of every four hours. This mode continues until the collector discharge temperature (T2) cannot be maintained above 40°F. Under that condition, Freeze Protection Mode B is entered.

Freeze Protection Mode B - This mode is entered when the collector discharge temperature cannot be maintained above 40°F by Freeze Protection Mode A. When this mode is entered, valve V13 is positioned to allow flow straight through toward valve V8, valve V8 is closed, and valve V9 is positioned to accept flow through its top port and return the flow to the water thermal storage through valve V10. Storage tank water is then drawn through valves V11 and V12 and through the collectors by pumps CP2 and CP3. This mode remains in operation until the collector discharge temperature (T2) reaches 55°F. The system then returns to the normal operating sequence, with Freeze Protection Mode A enabled if adverse conditions still prevail.

Collector Heat Purge Conditioning Mode - This mode is entered when collector discharge temperature (T2) rises to 220°F. At this point, the purge fan is turned on, and its exhaust dampers are opened. This reduces excessive heat buildup in the collection system, preventing damage to the collector array and/or venting of steam to the atmosphere.

APPENDIX B

SITE SCHEMATICS

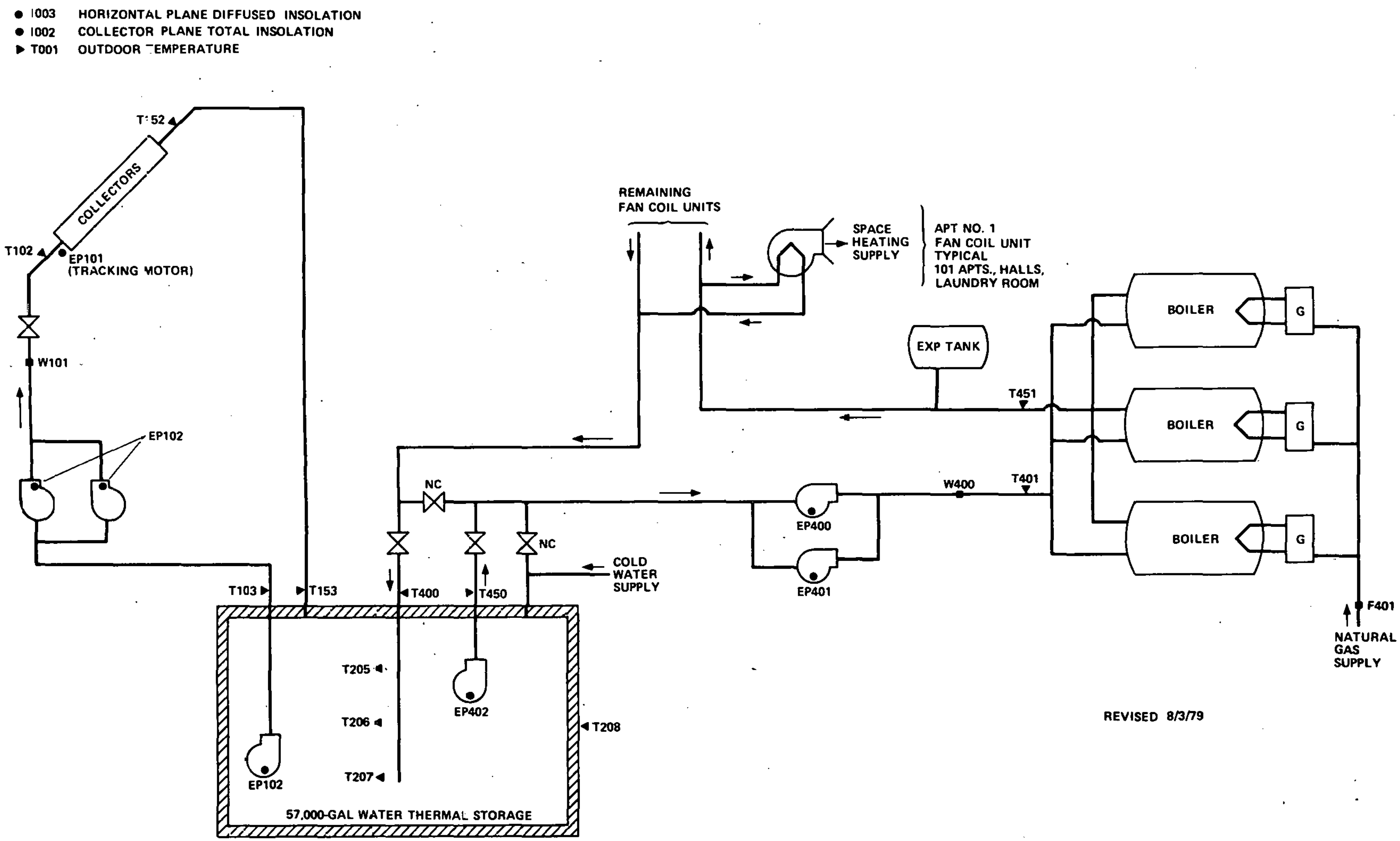


Figure B-1. Albuquerque Western II Solar Energy System Schematic

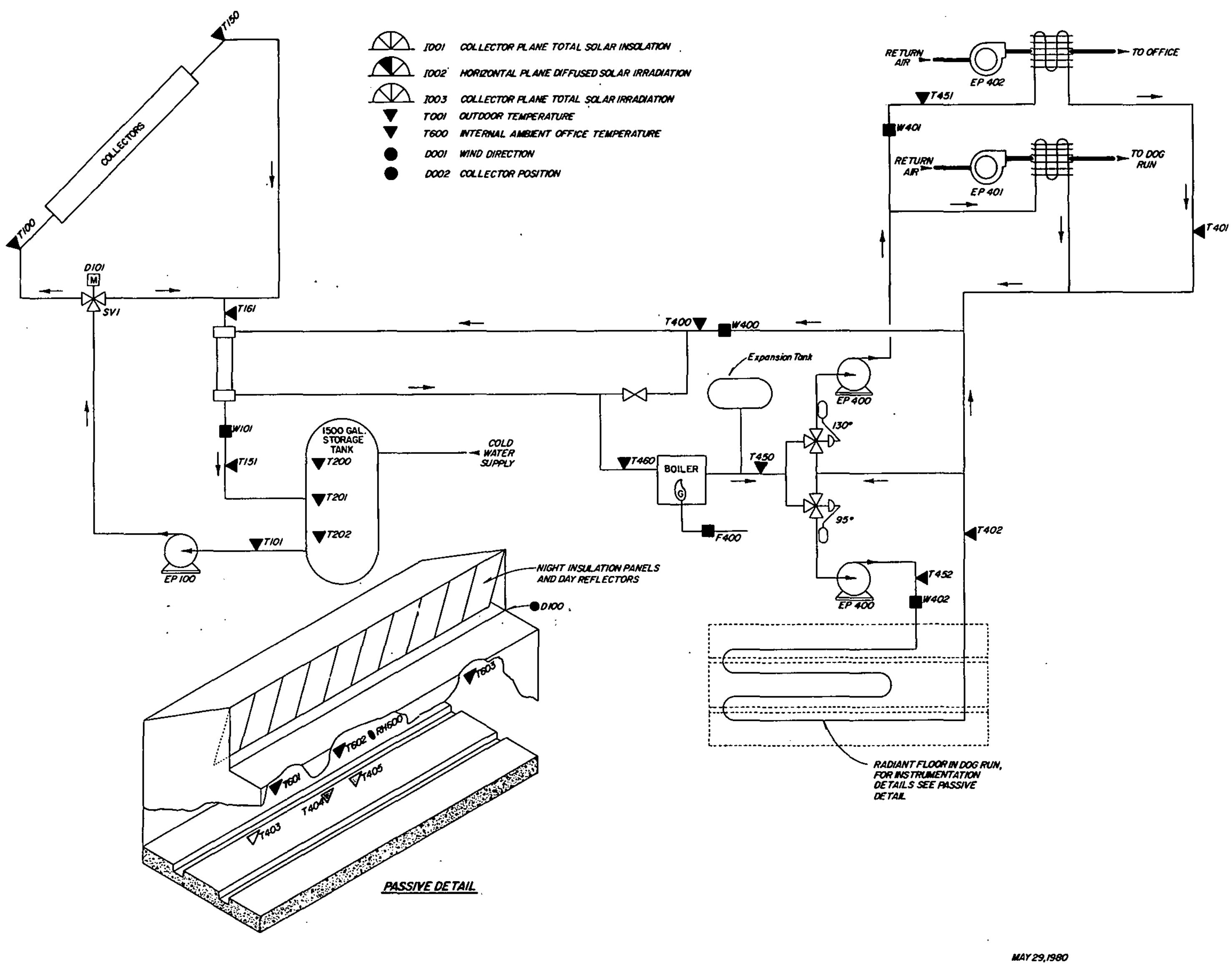


Figure B-2. Animal Control Center Solar Energy System Schematic

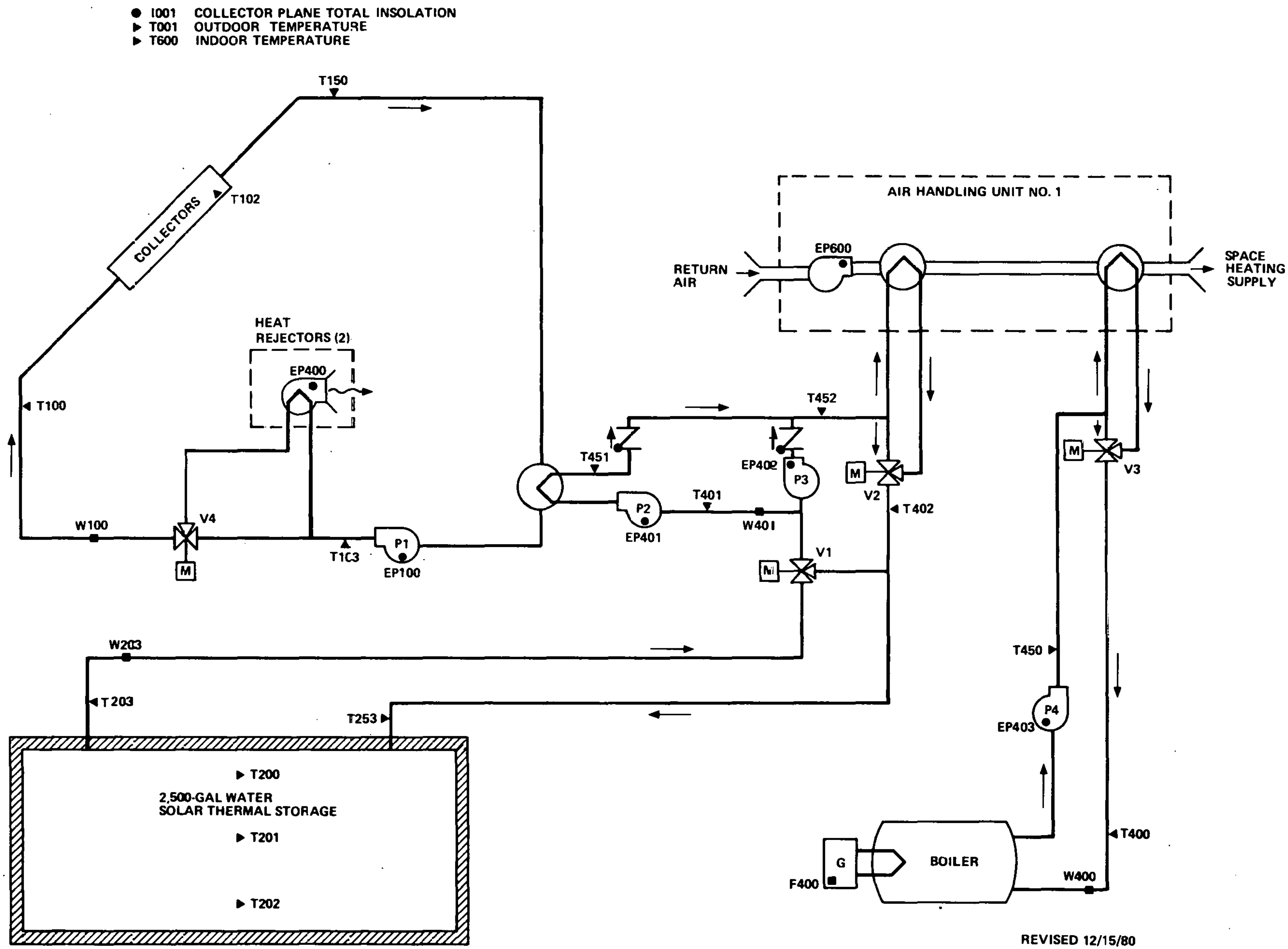


Figure B-3. Billings Shipping Solar Energy System Schematic

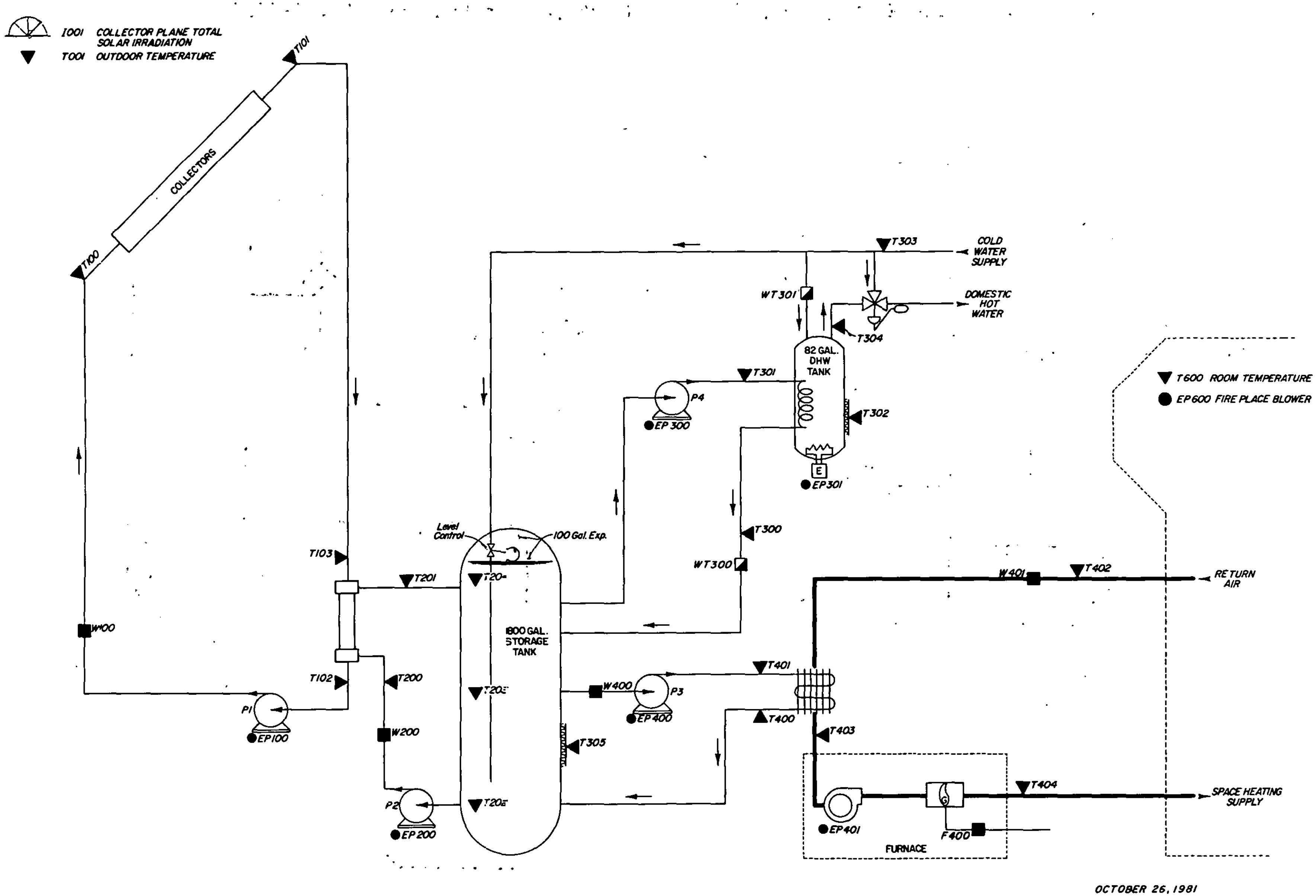


Figure B-4. Bond Construction Solar Energy System Schematic

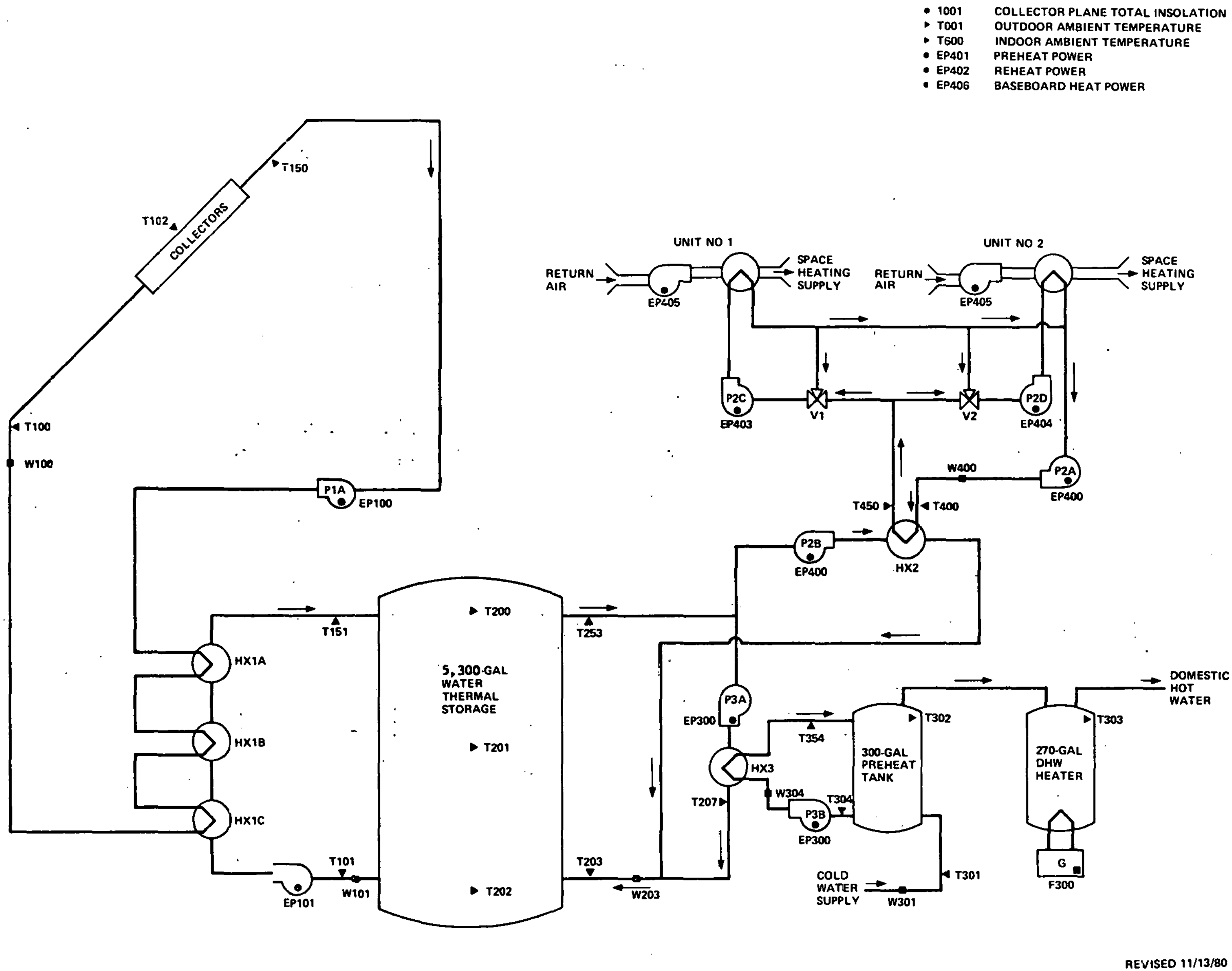


Figure B-5. Brookhaven National Laboratory Solar Energy System Schematic

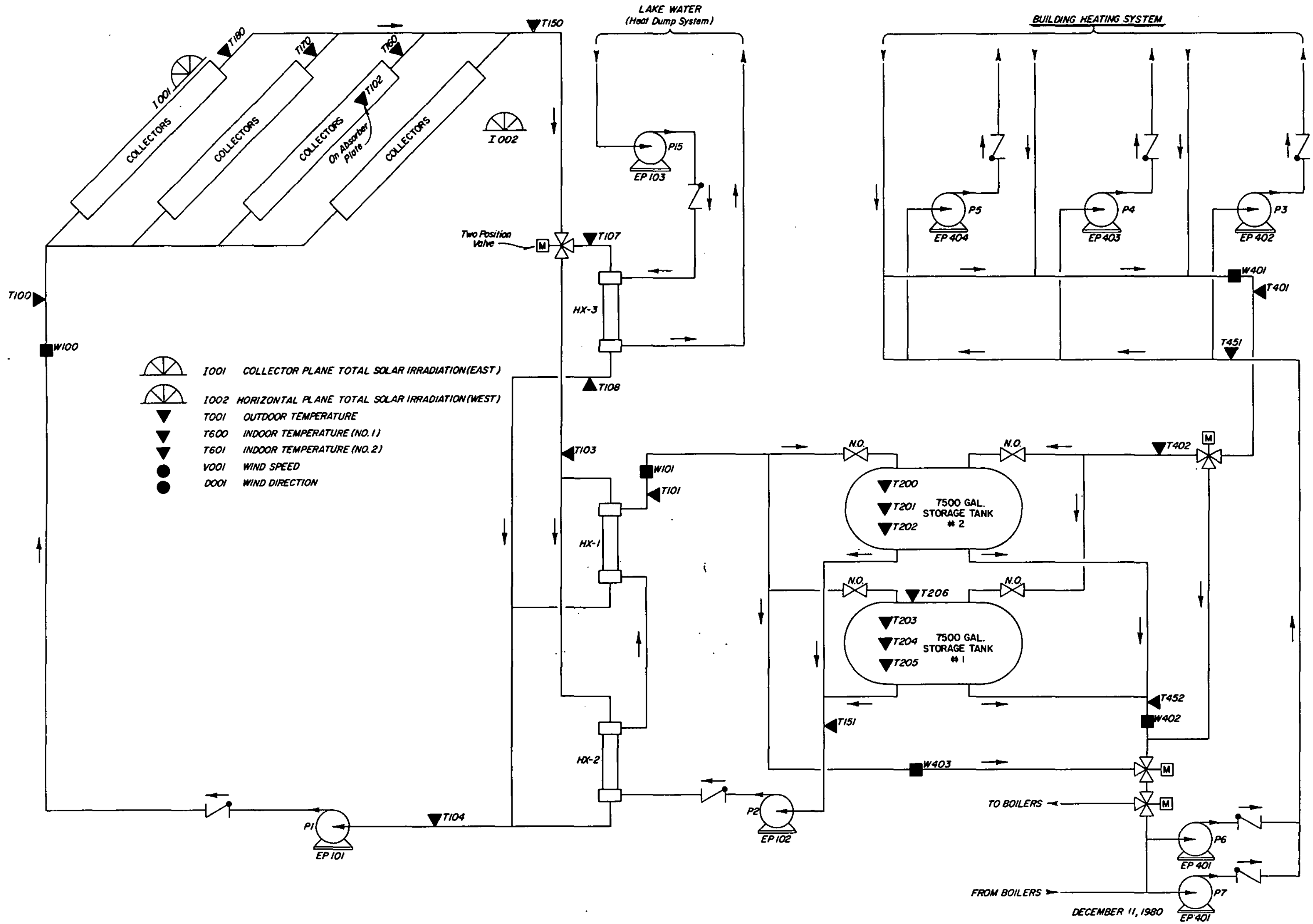


Figure B-6. Chicago Navy Pier Solar Energy System Schematic

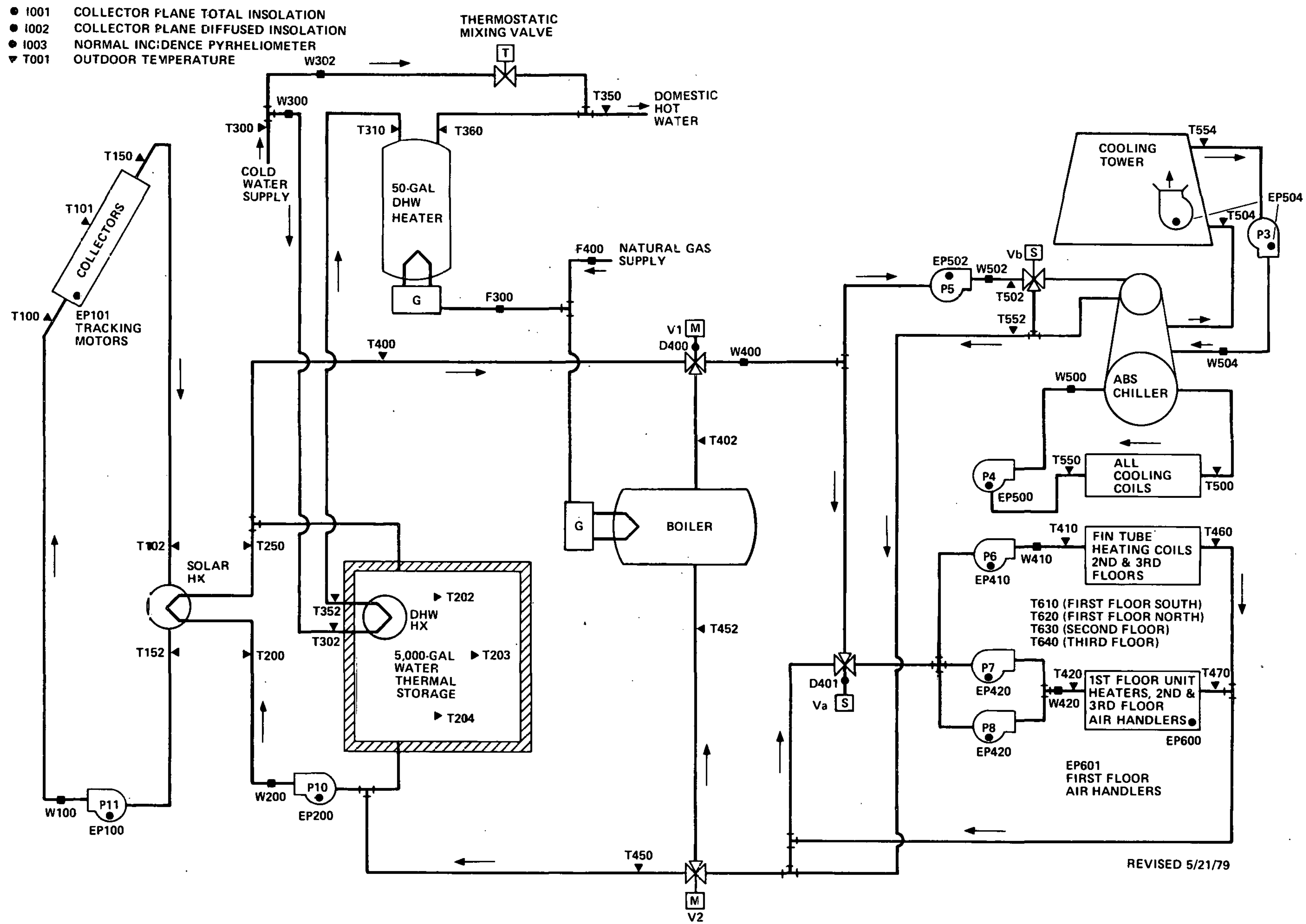


Figure B-7. Columbia Gas Solar Energy System Schematic

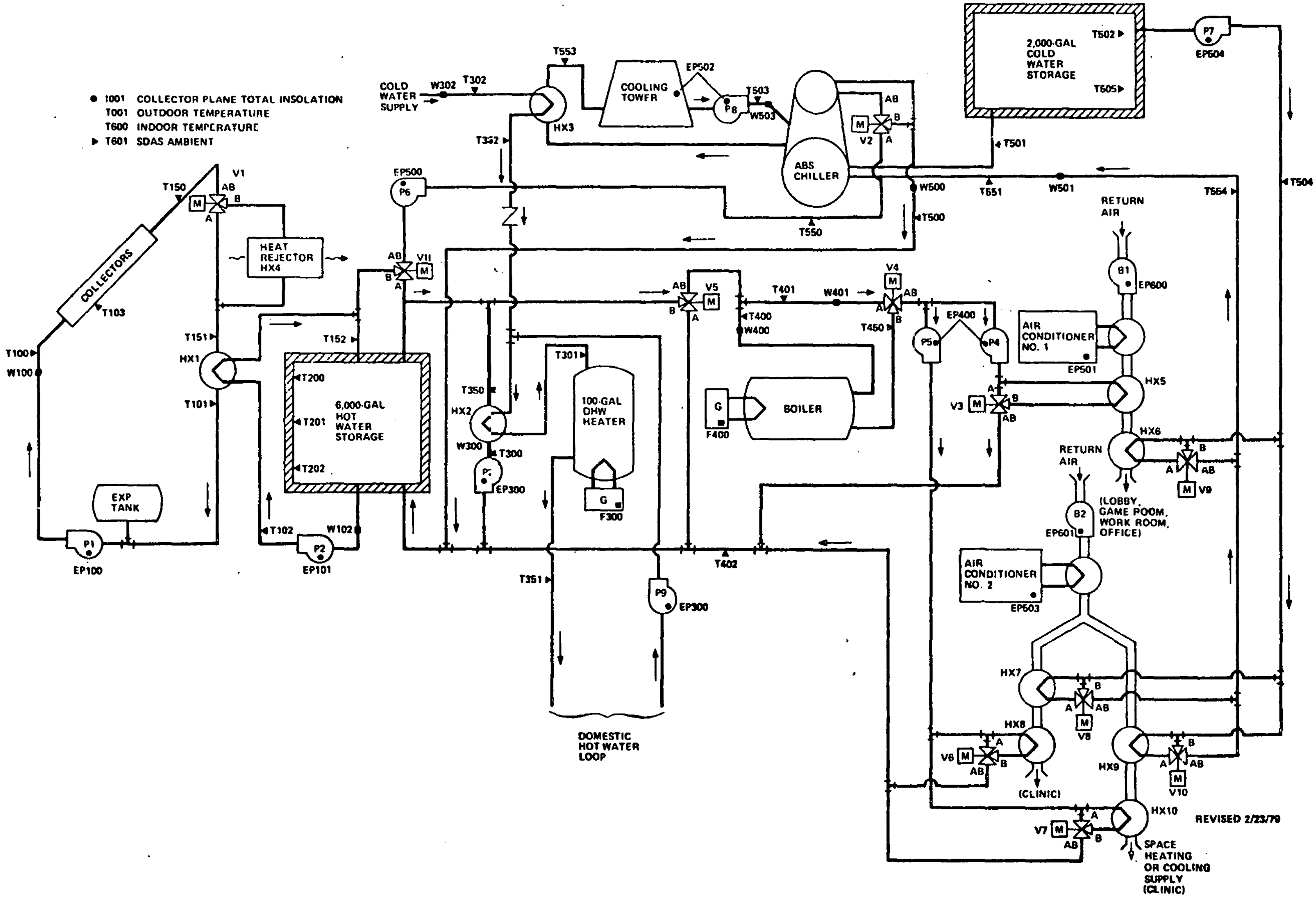


Figure B-8. Dallas Recreation Center Solar Energy System Schematic

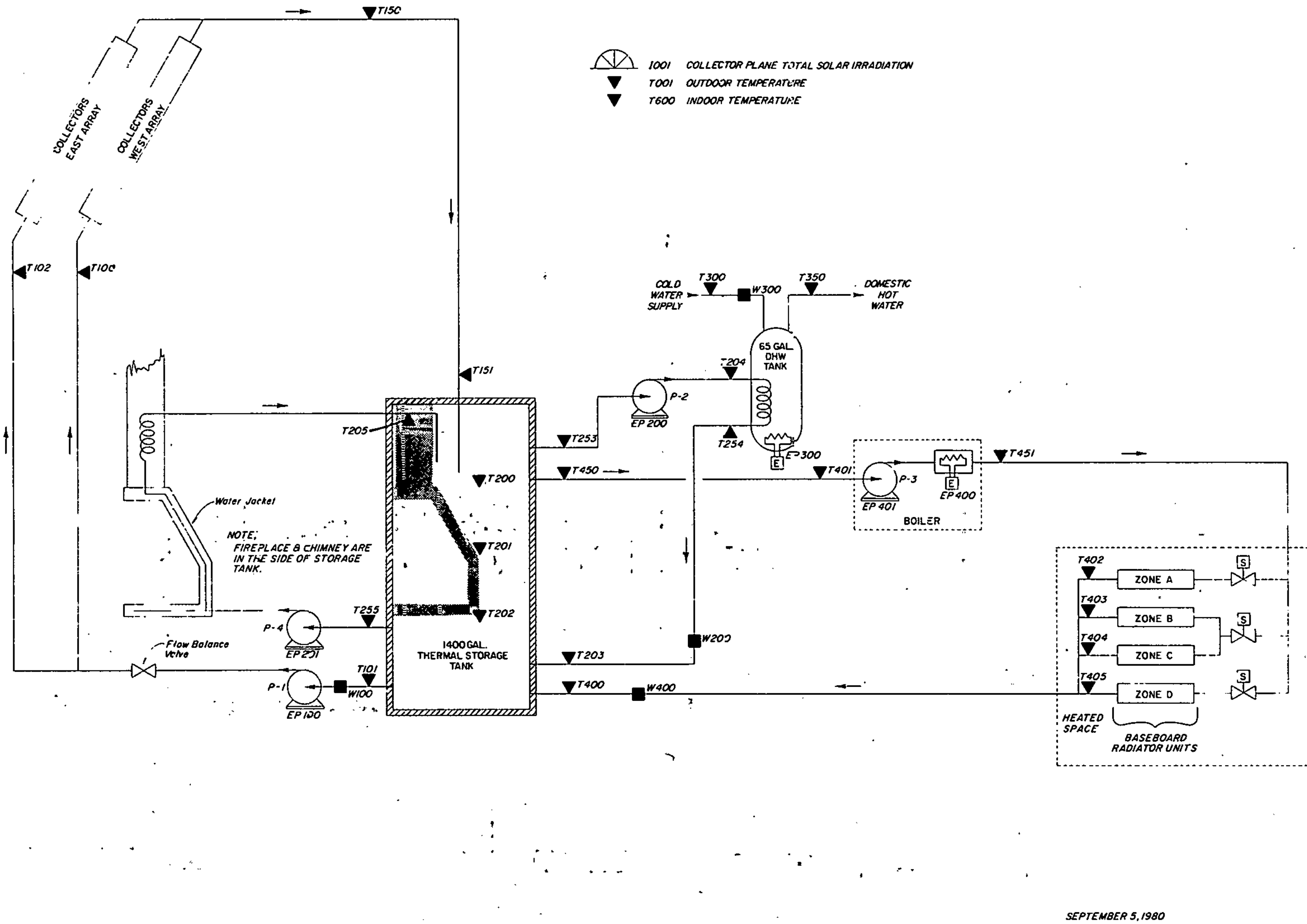


Figure B-9. Design Construction Solar Energy System Schematic

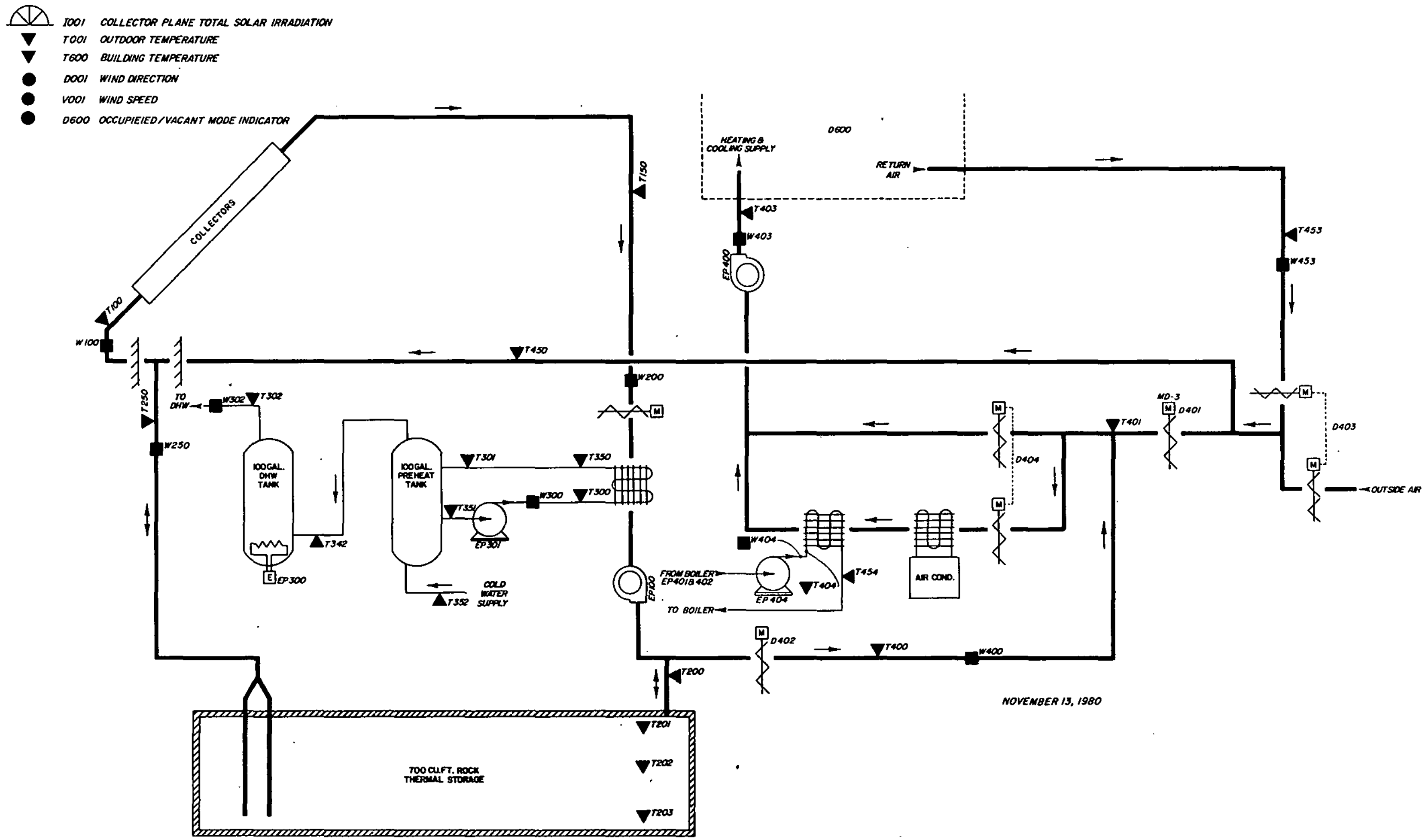


Figure B-10. First Baptist Church Solar Energy System Schematic

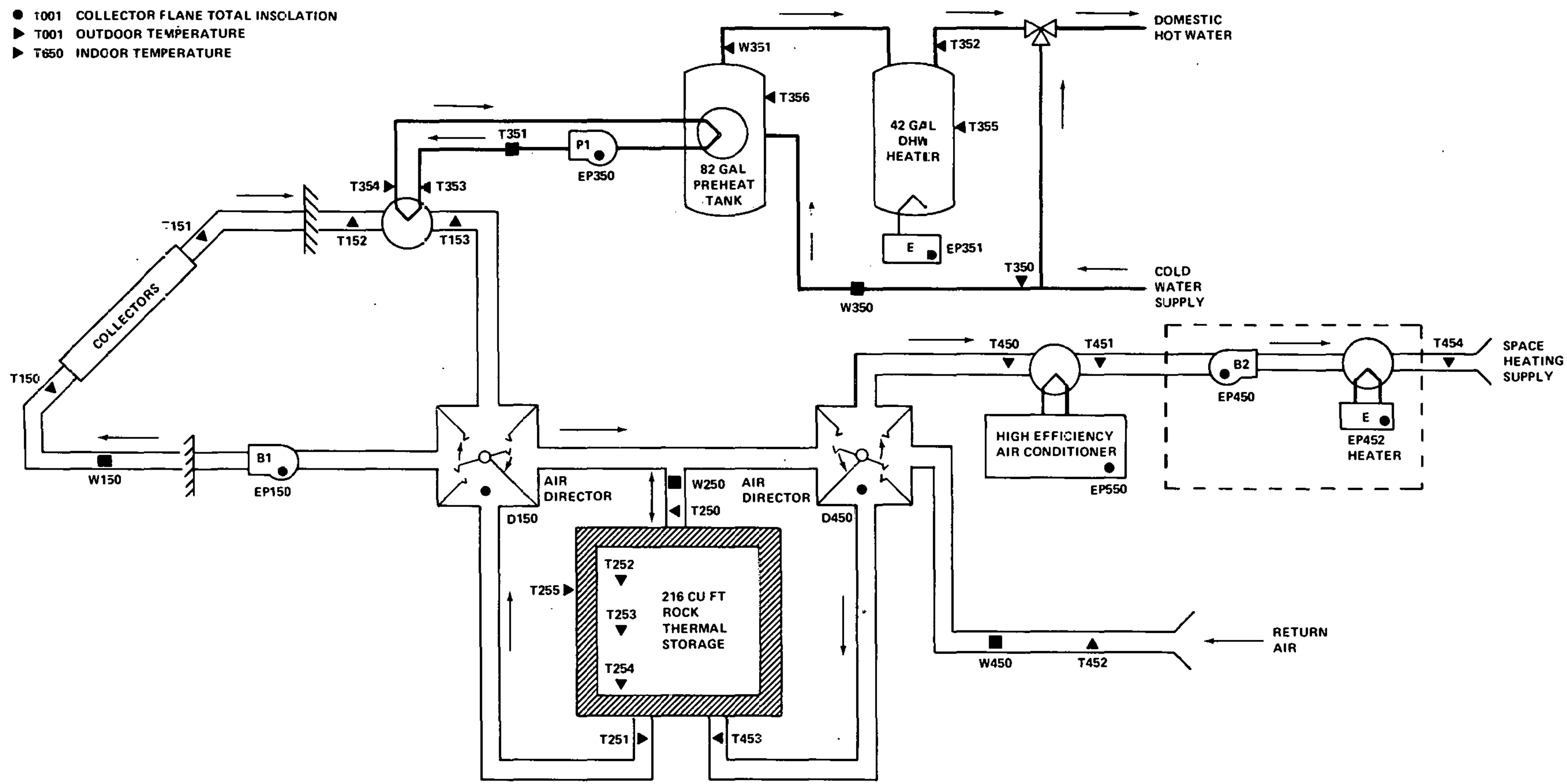


Figure B-11. First Manufactured Homes Lot 10 Solar Energy System Schematic

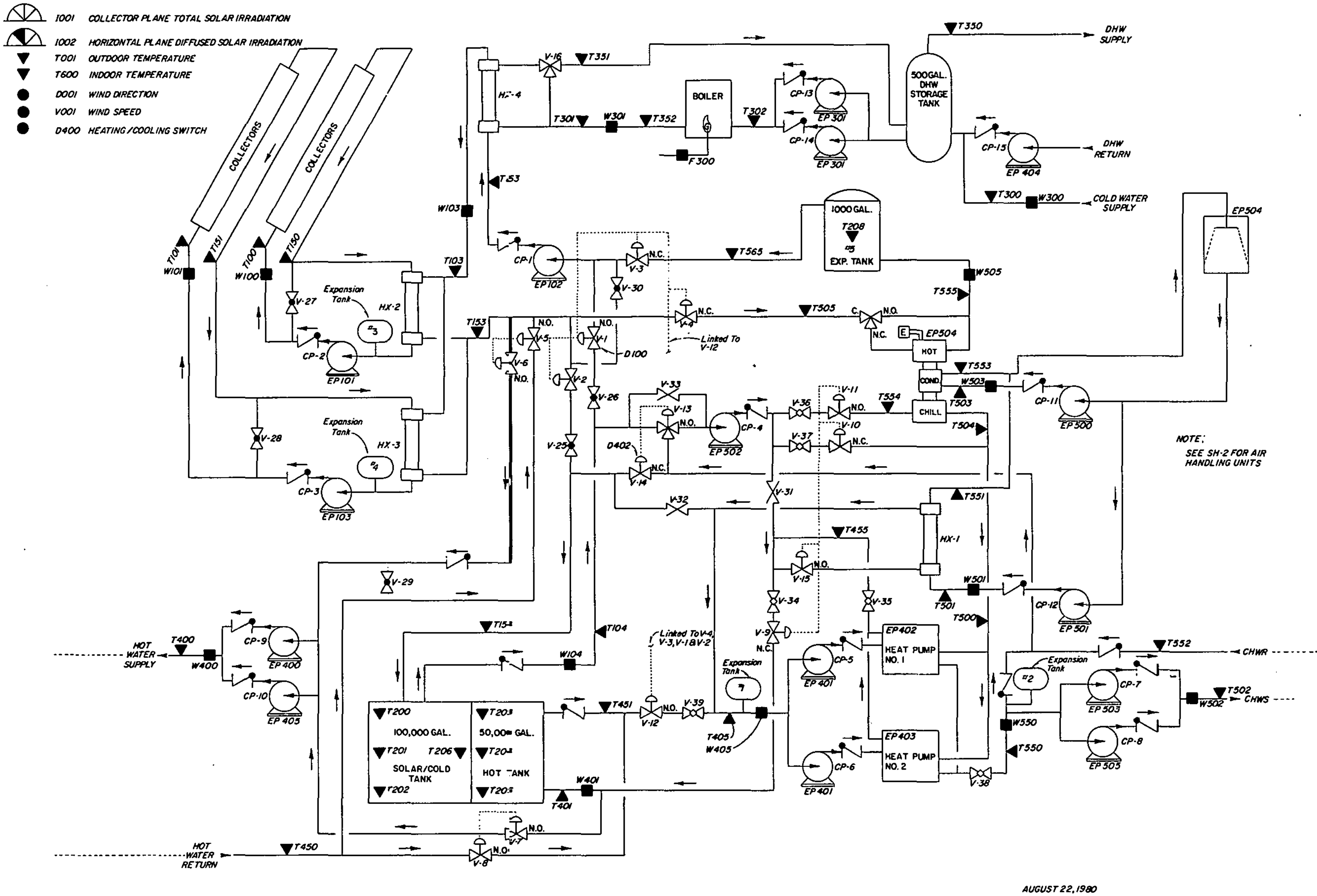


Figure B-12a. Fort Polk Exchange Solar Energy System Schematic

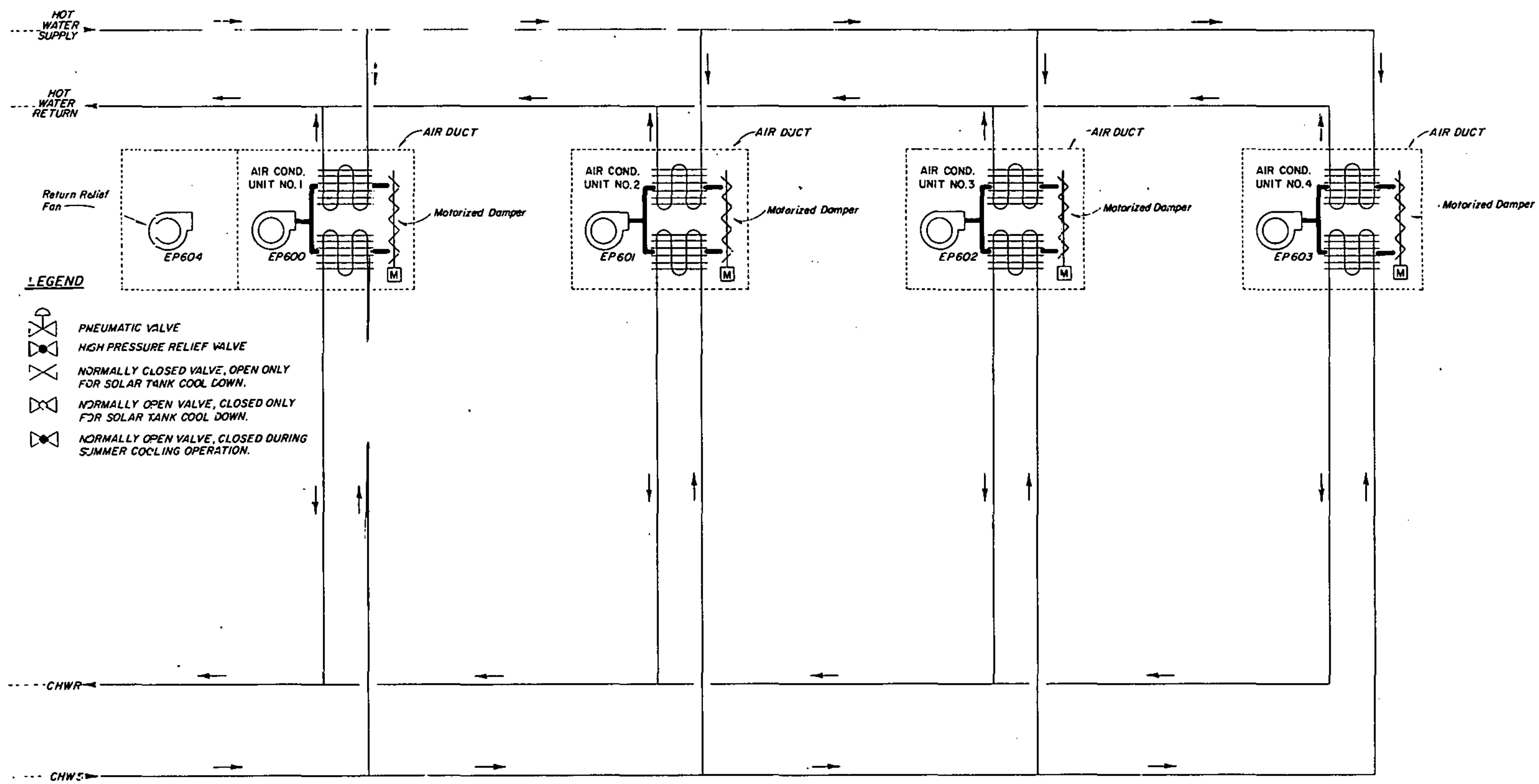


Figure B-12b. Fort Polk Exchange Solar Energy System Space Cooling and Heating Units

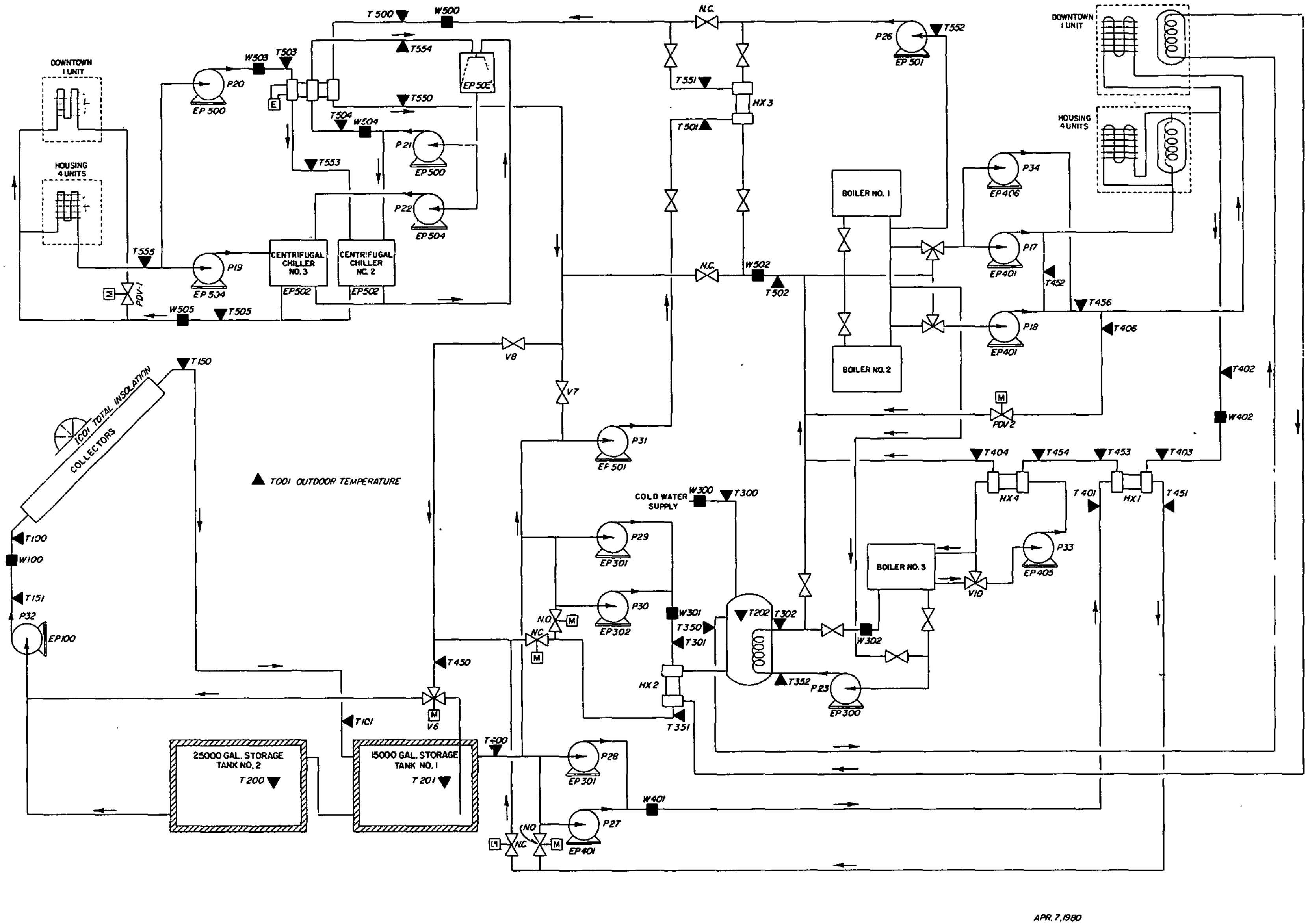


Figure B-13a. GSA, Federal Youth Center, Solar Energy System Schematic

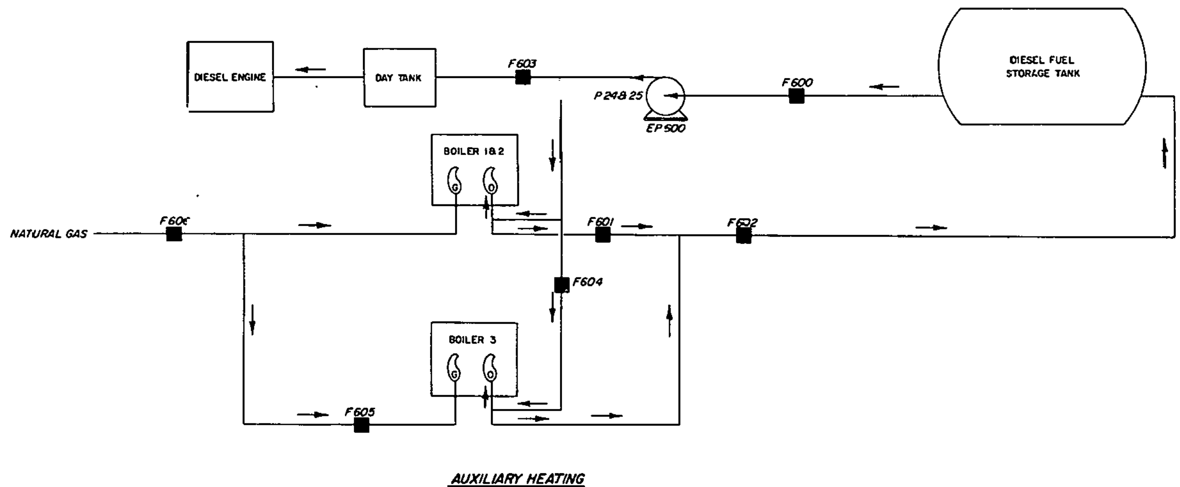


Figure B-13b. GSA, Federal Youth Center, Solar Energy System Auxiliary Heating Schematic

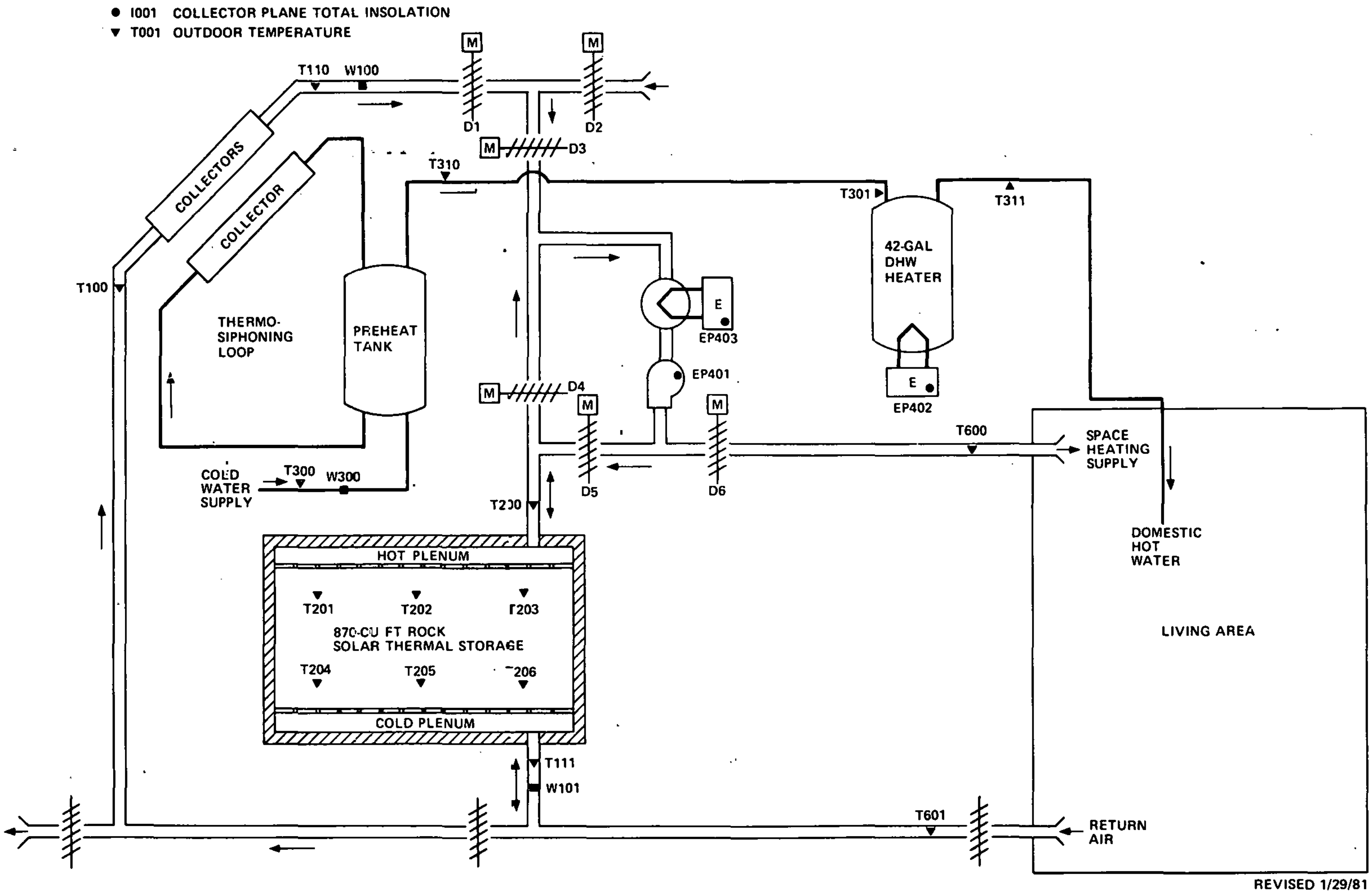


Figure B-14. Helio Thermics 8 Solar Energy System Schematic

● I001 COLLECTOR PLANE TOTAL INSOLATION
● I002 COLLECTOR PLANE DIFFUSED INSOLATION
▼ T001 OUTDOOR TEMPERATURE
▼ T600 INDOOR TEMPERATURE

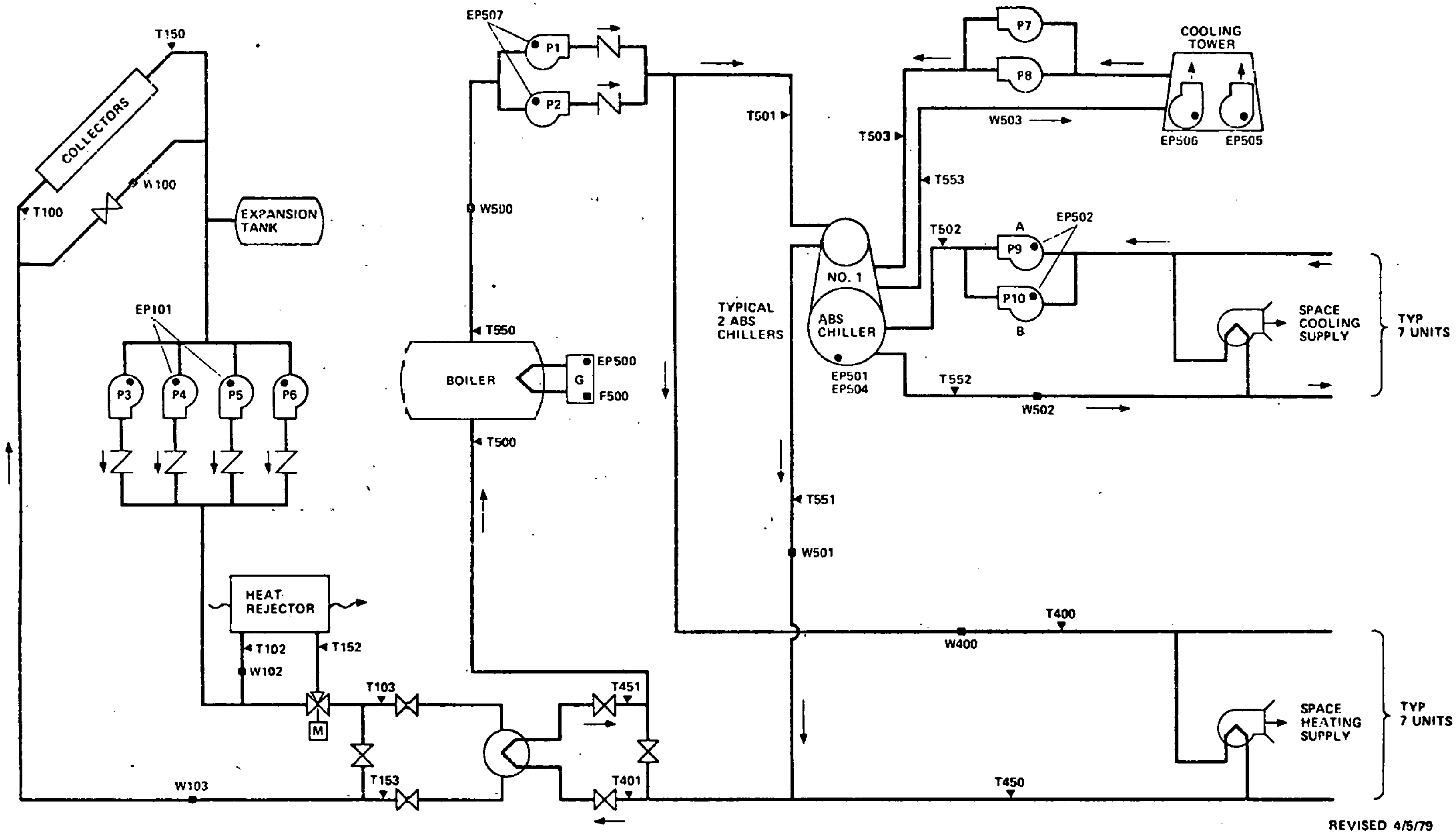


Figure B-15. Irvine School Solar Energy System Schematic

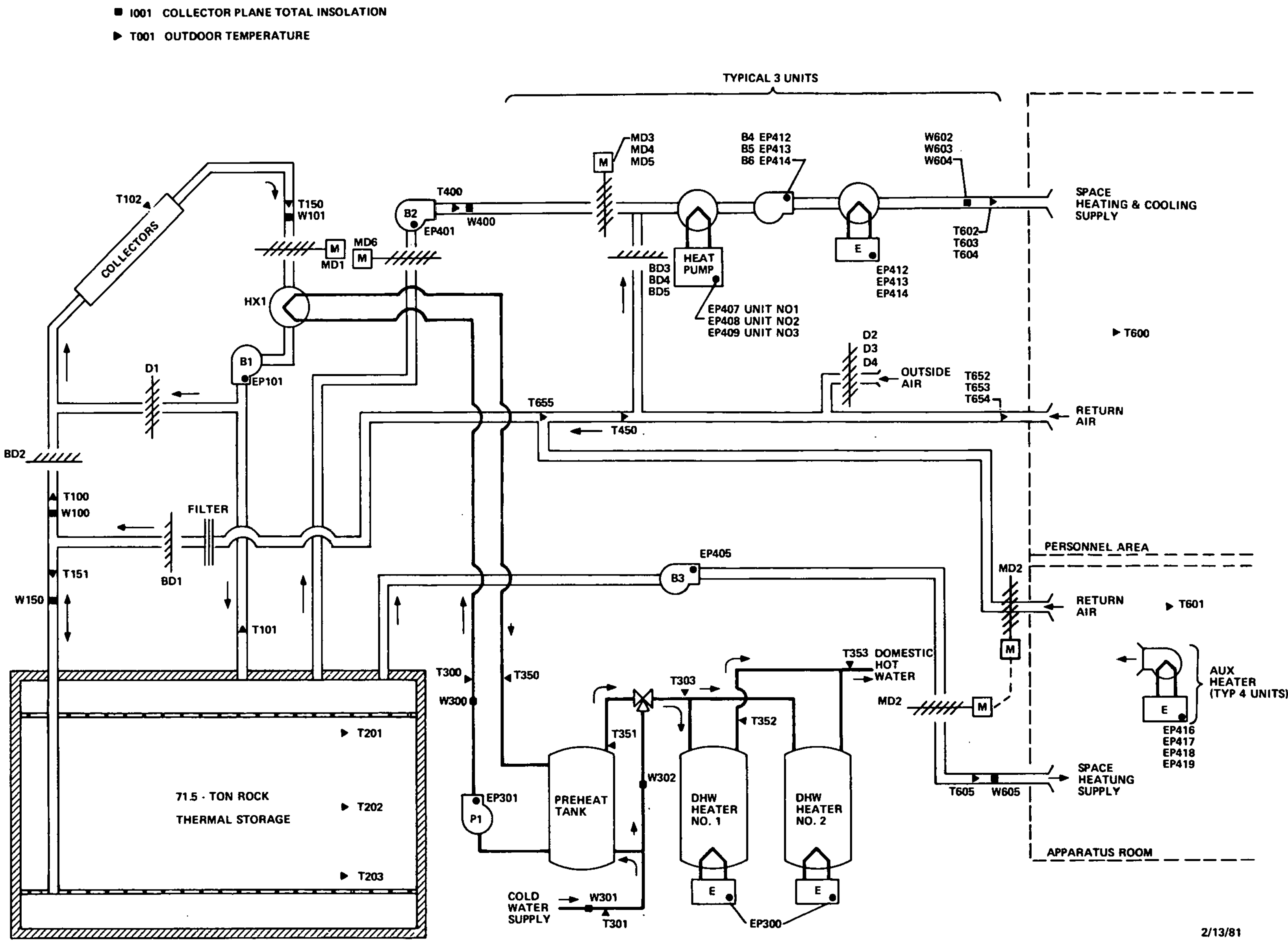


Figure B-16. Kansas City Fire Station Solar Energy System Schematic

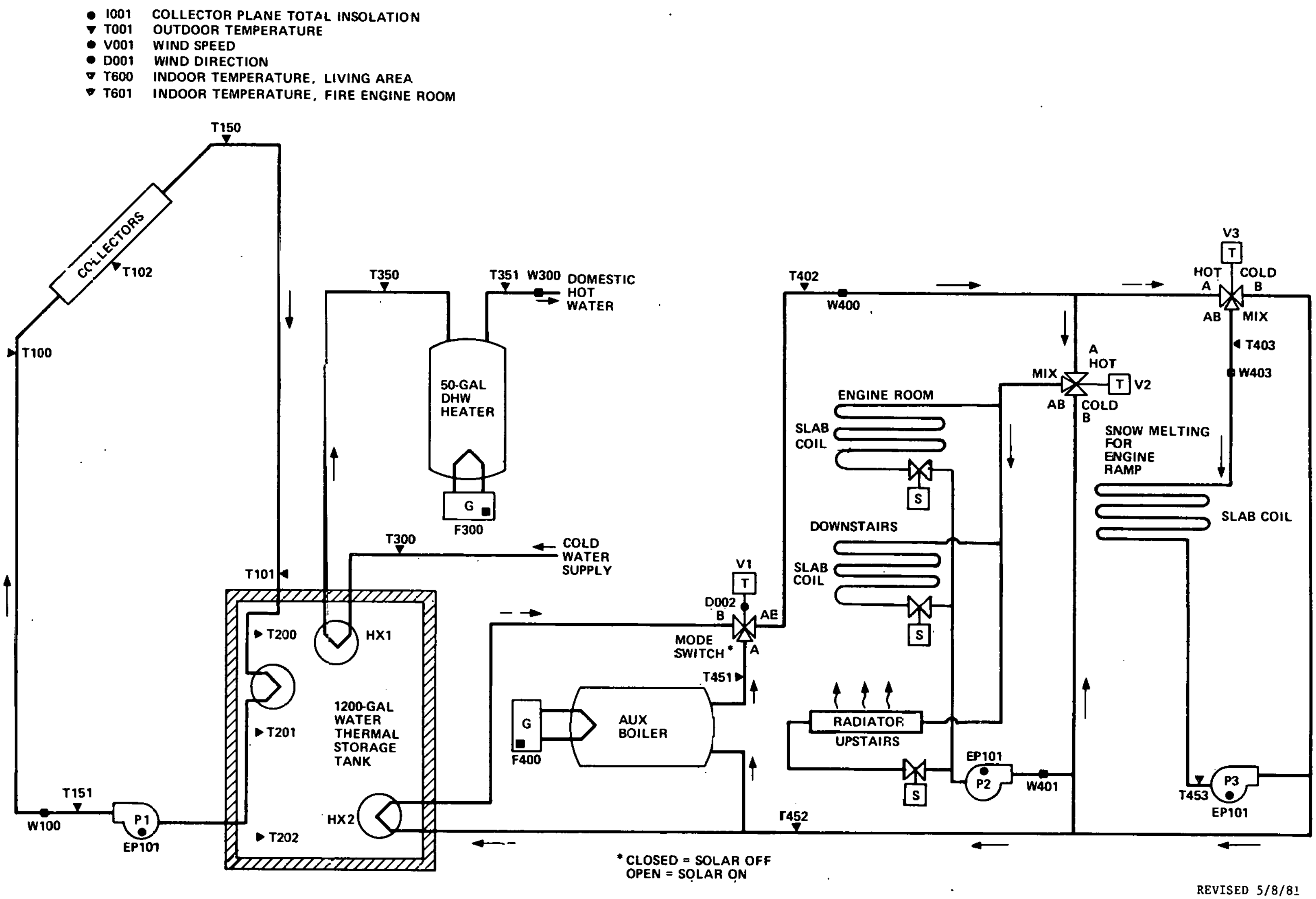


Figure B-17. Lake Valley Firehouse Solar Energy System Schematic

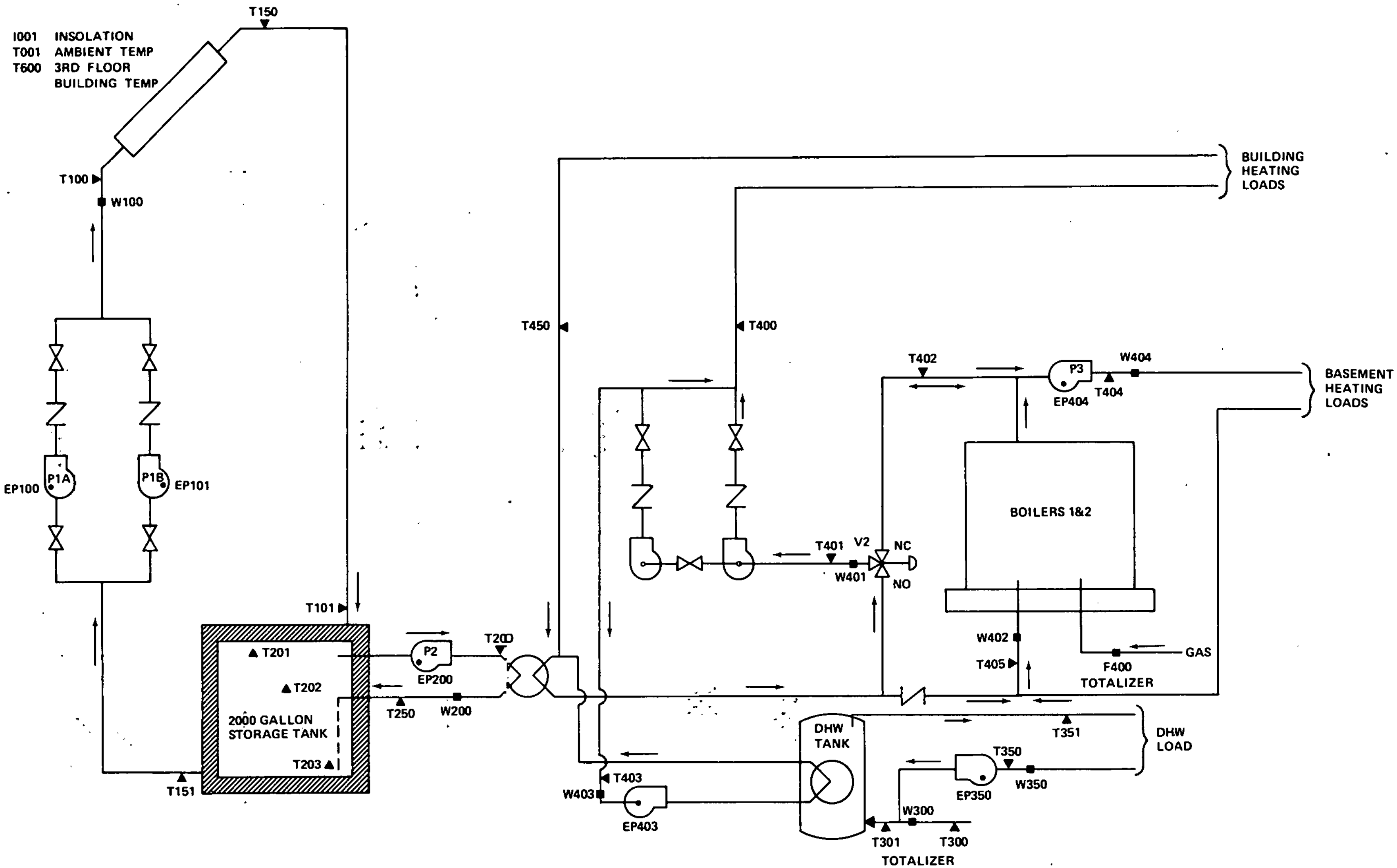


Figure B-18. Lawrence Berkeley Laboratory Solar Energy System Schematic

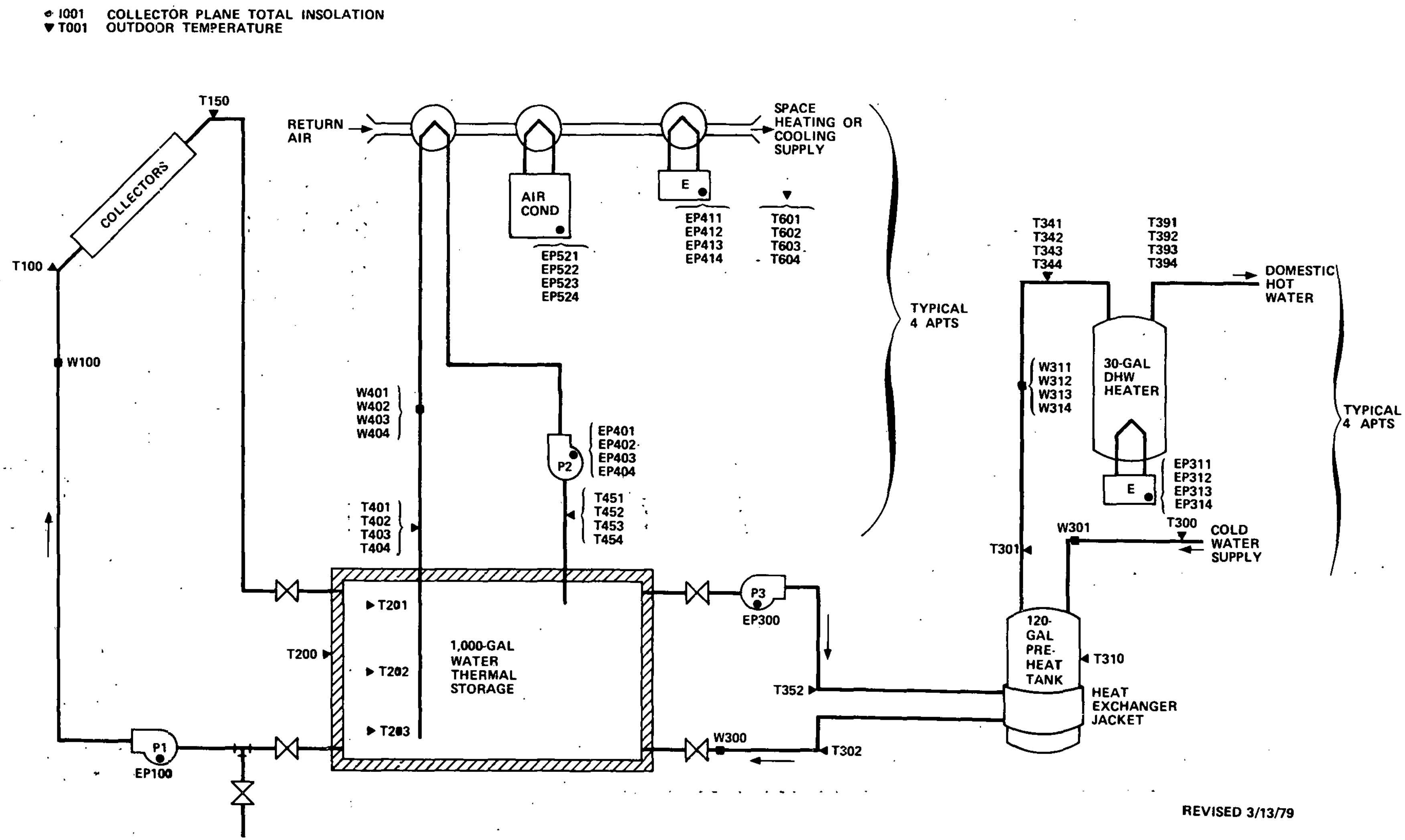
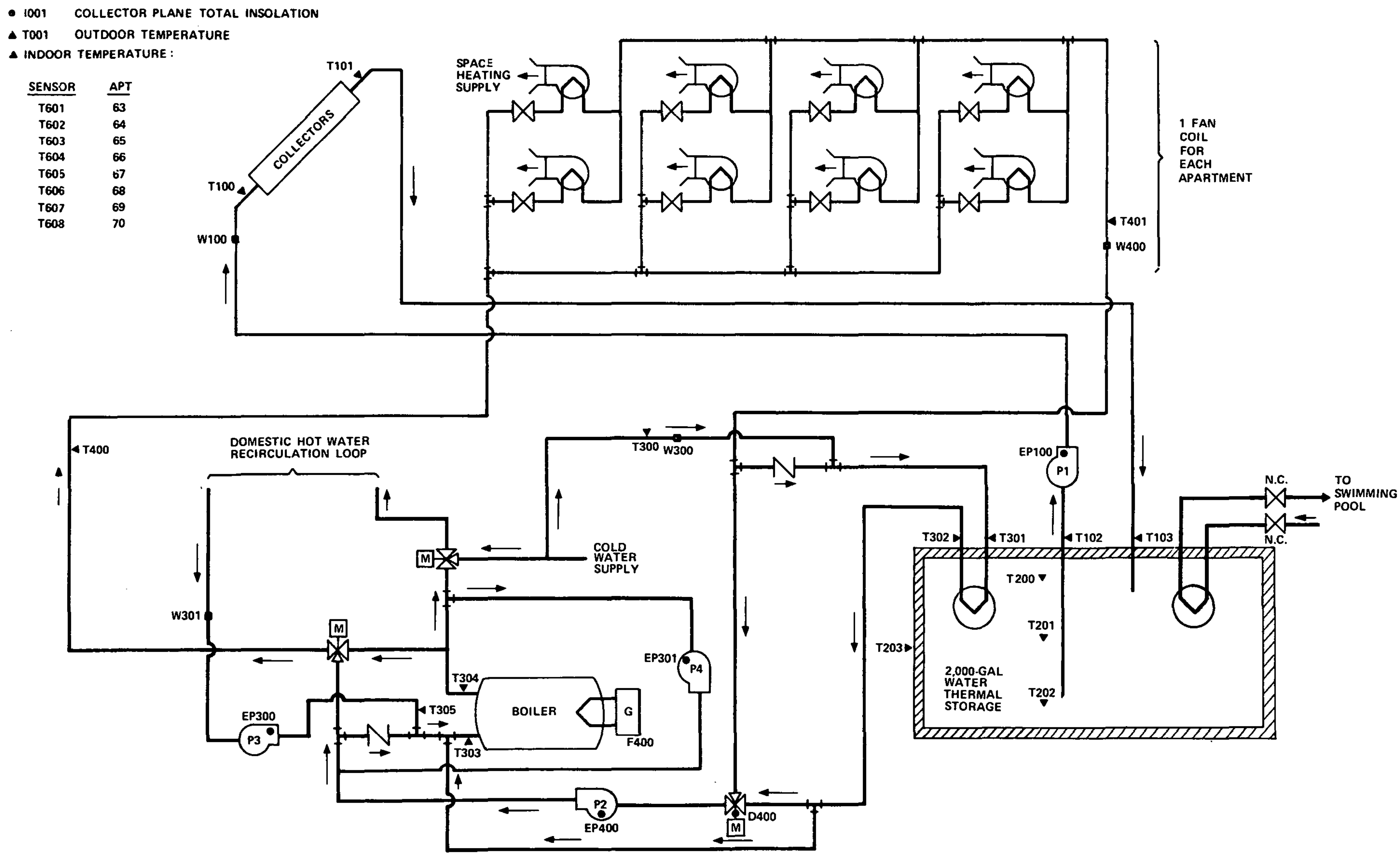


Figure B-19. Matt Cannon Solar Energy System Schematic



REVISED 11/10/80

Figure B-20. Montecito Pines Solar Energy System Schematic

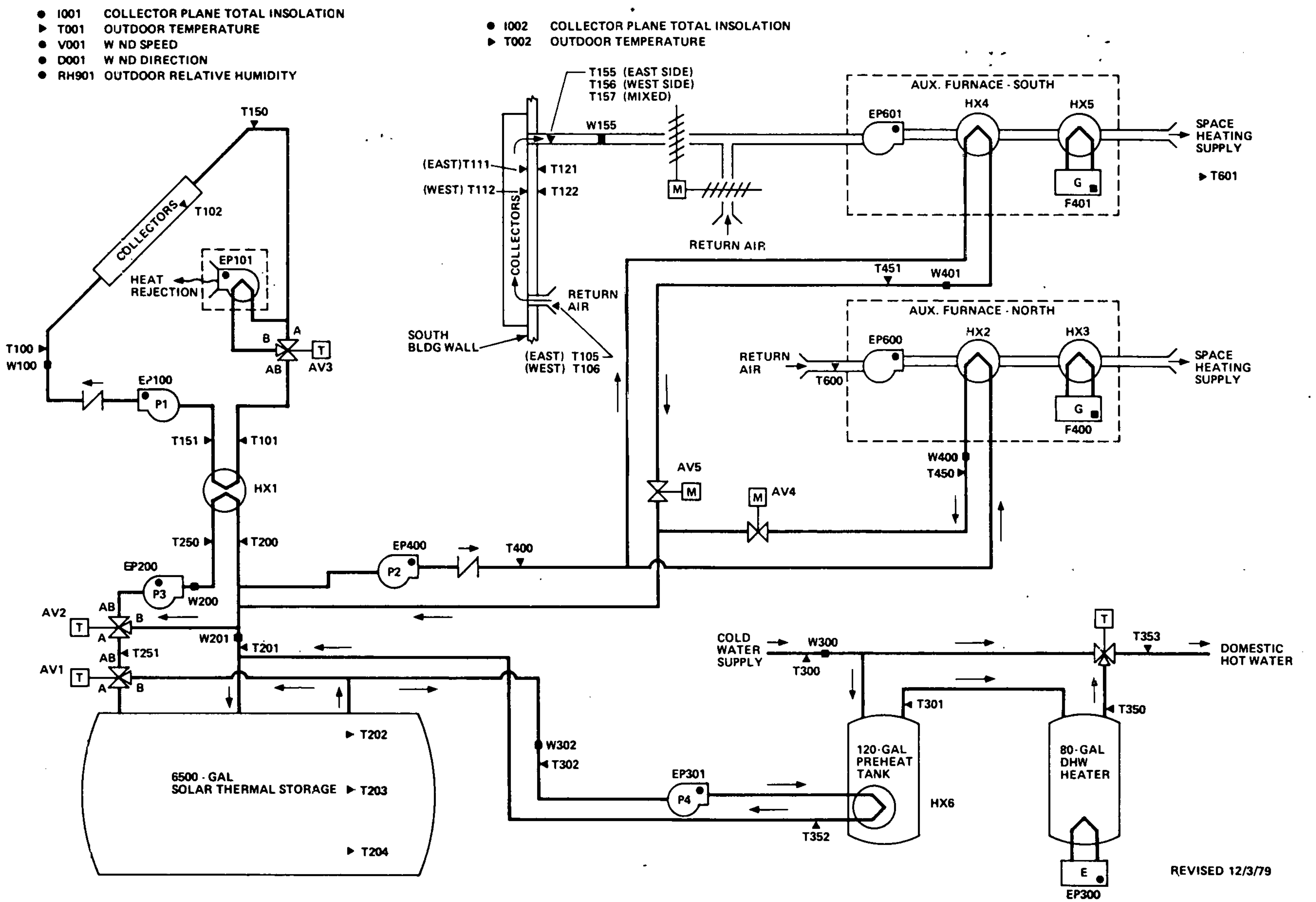


Figure B-21. Oakmead Industries Solar Energy System Schematic

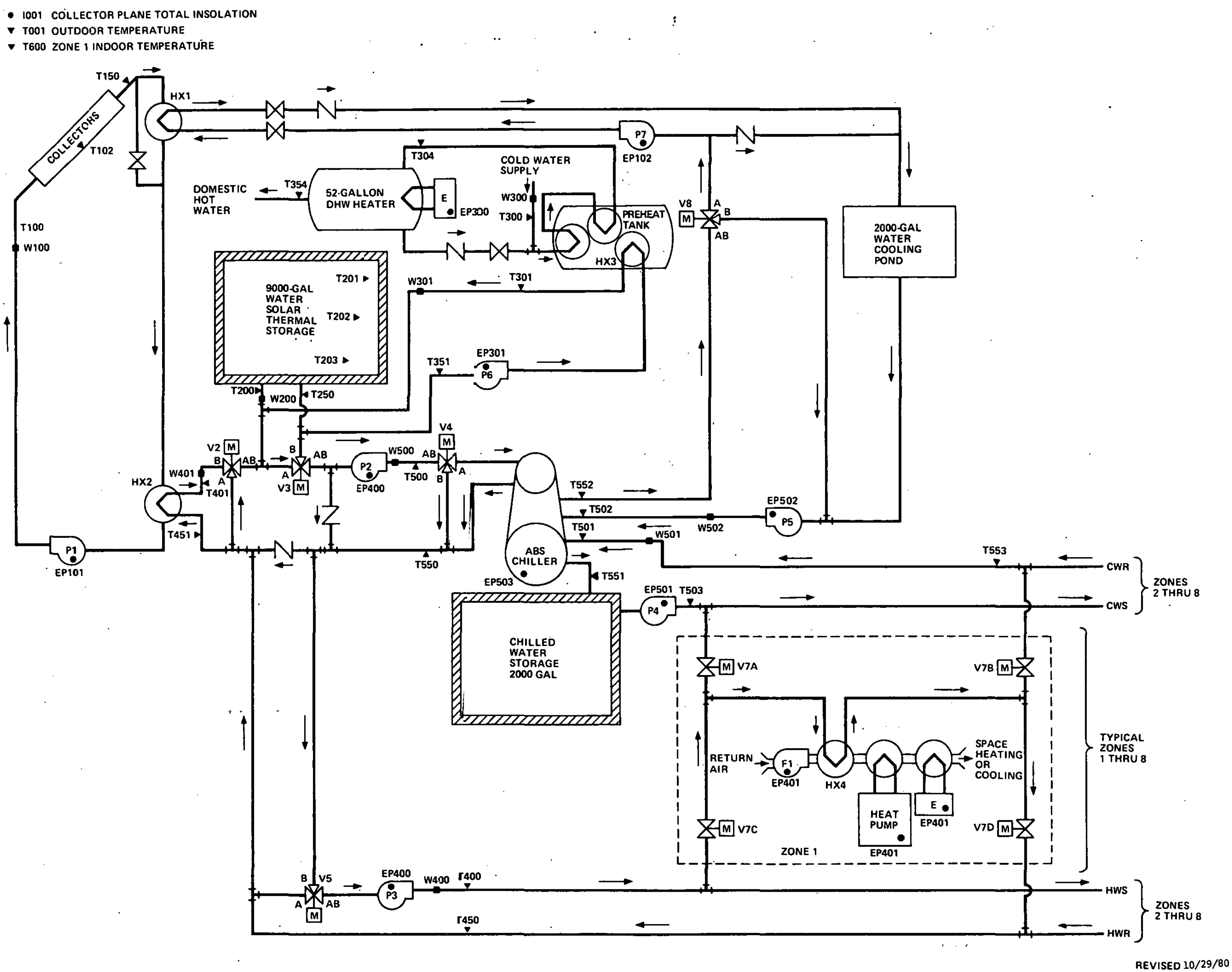


Figure B-22. Olympic Associates Solar Energy System Schematic

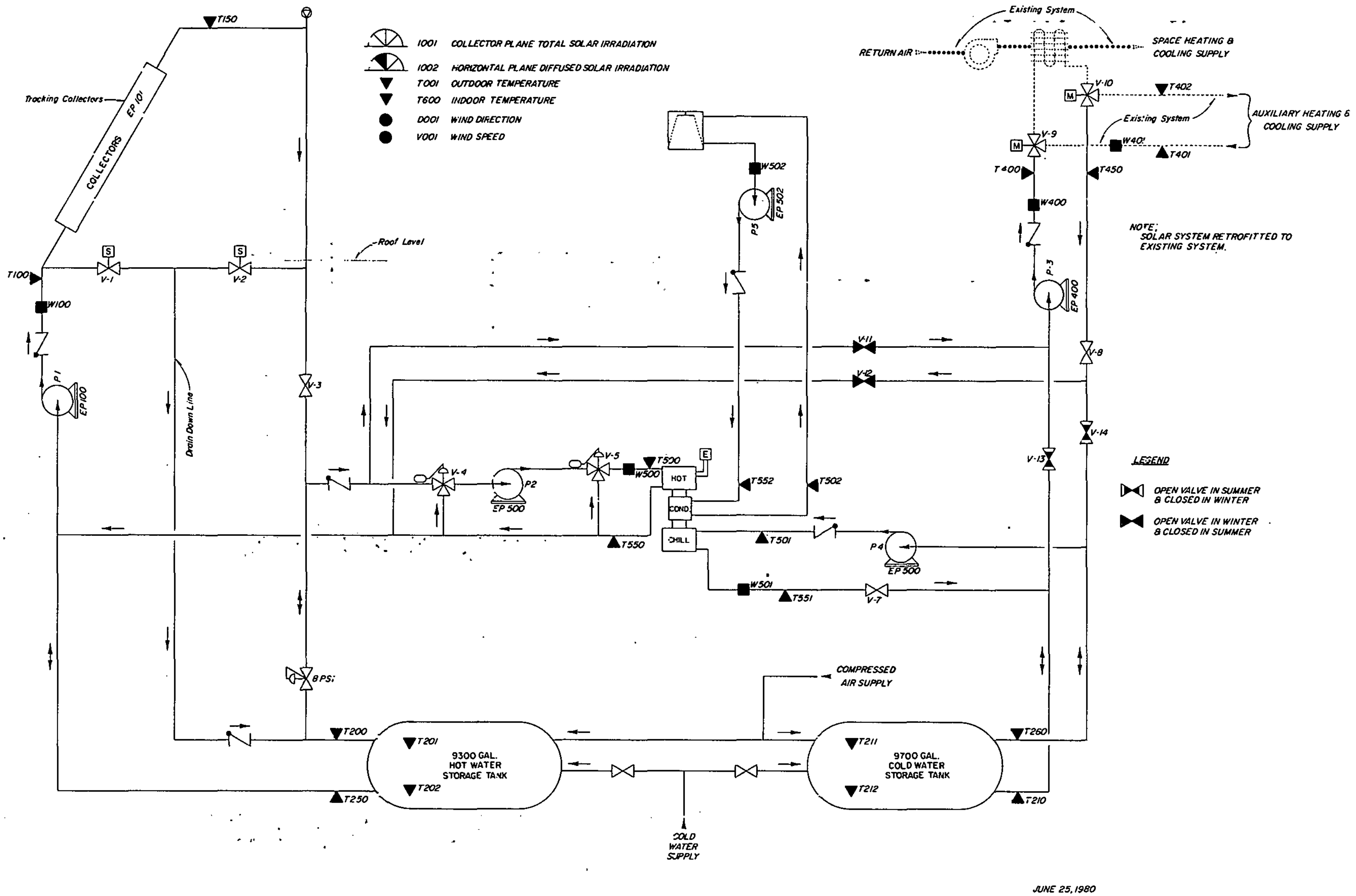


Figure B-23. Padonia Elementary School Solar Energy System Schematic

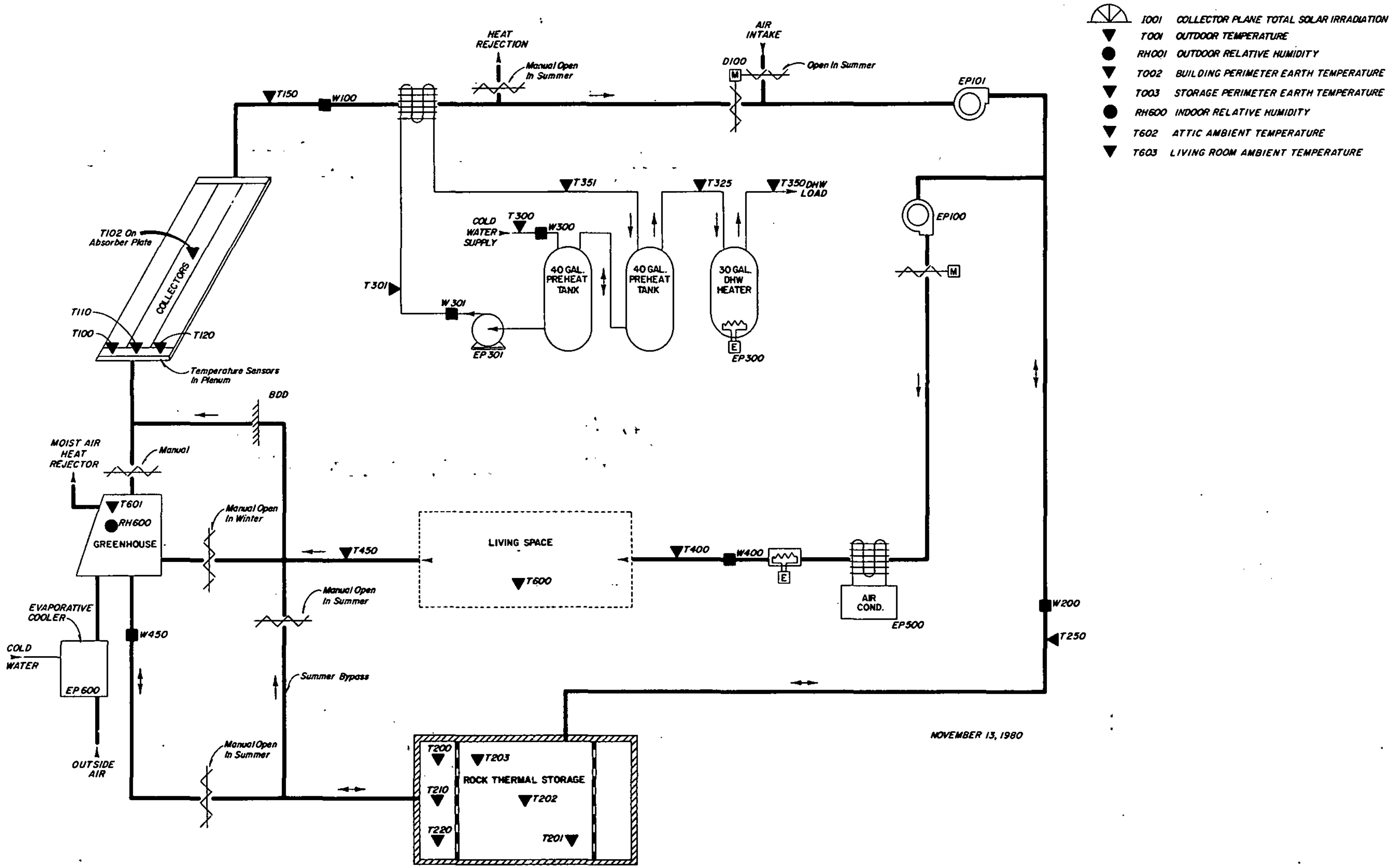


Figure B-24a. RHRU Clemson Solar Energy System Schematic

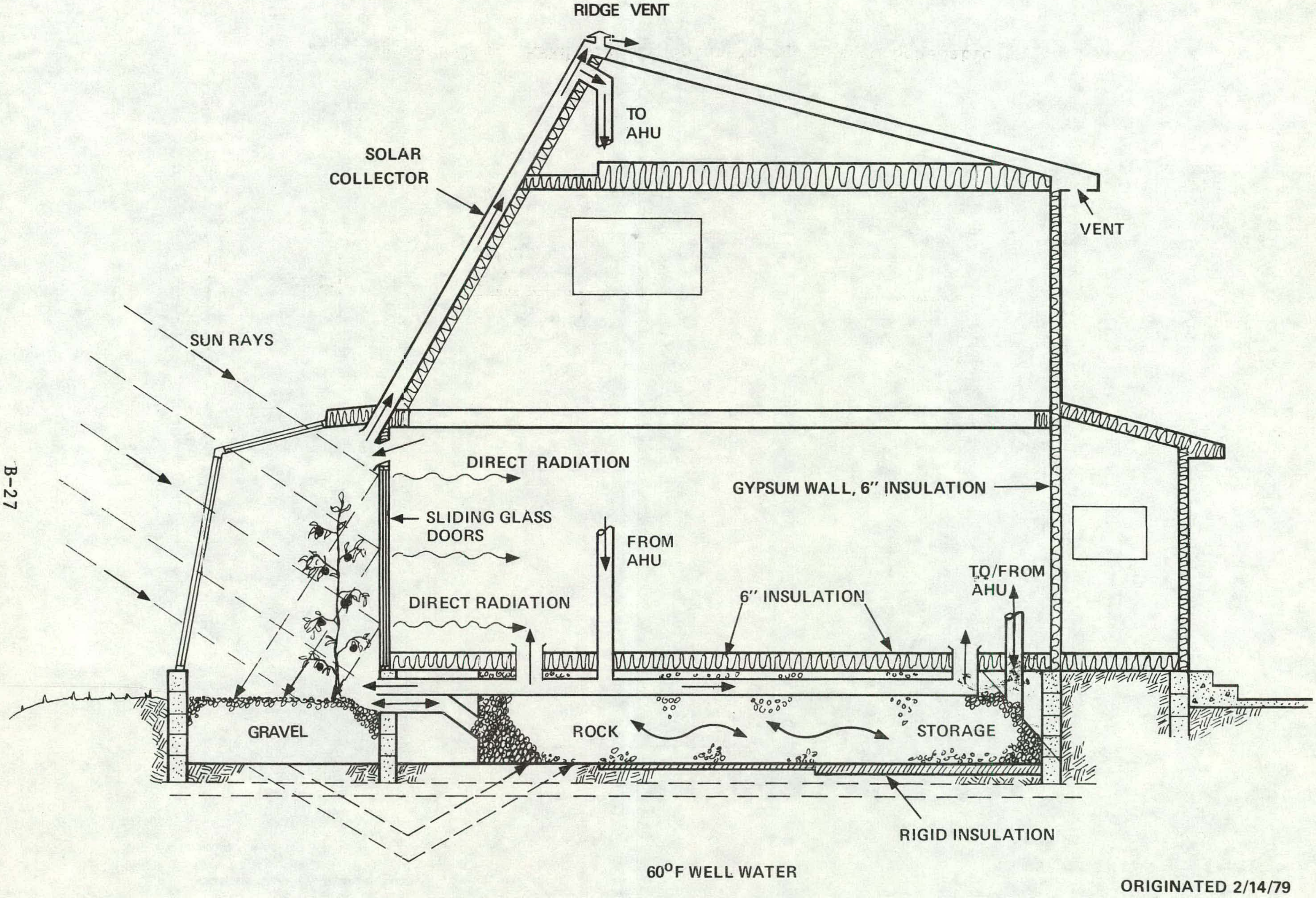


Figure B-24b. RHRU Clemson Solar Energy System Pictorial

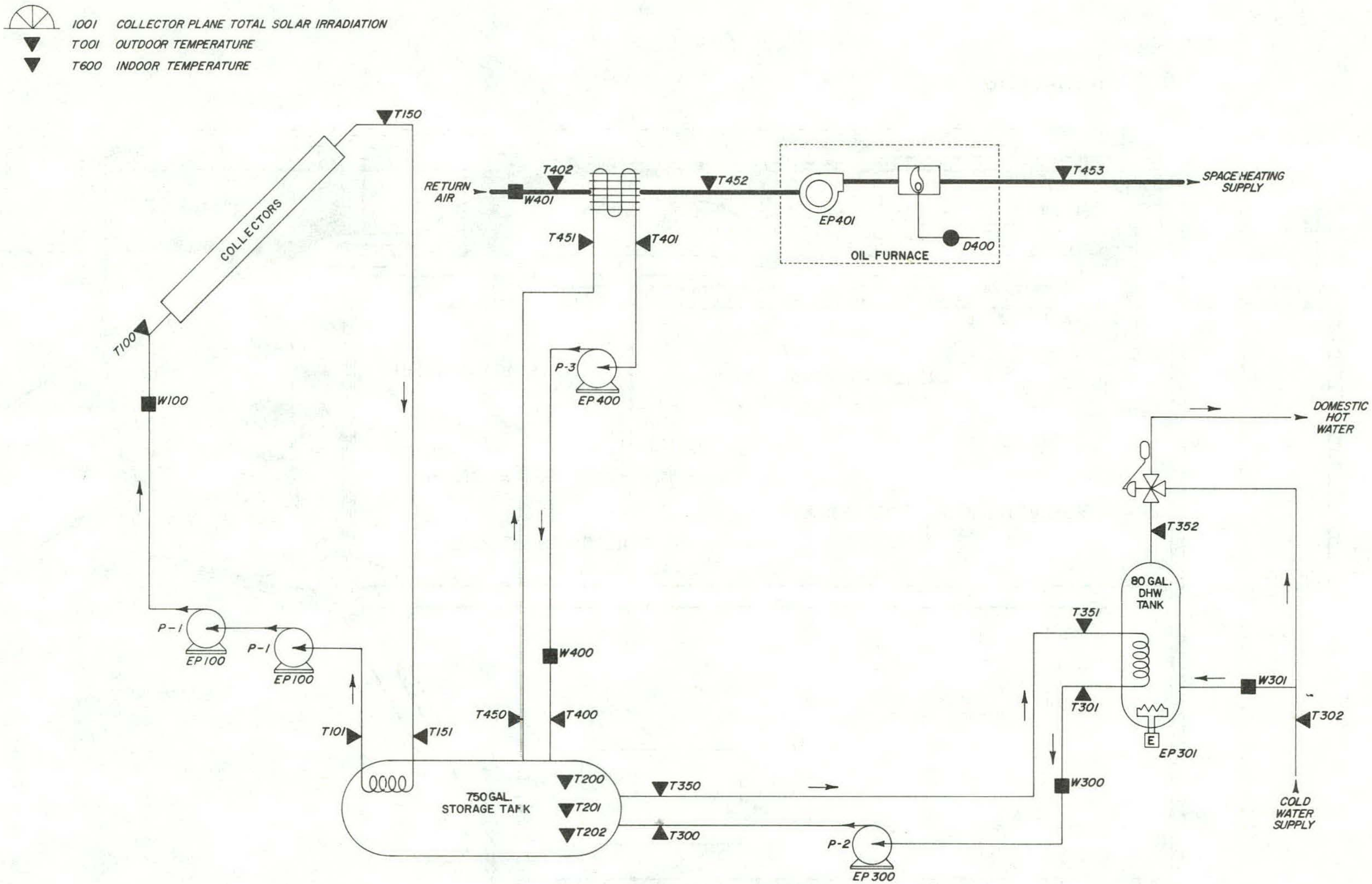


Figure B-25. Saddle Hill Trust Lot 36 Solar Energy System Schematic

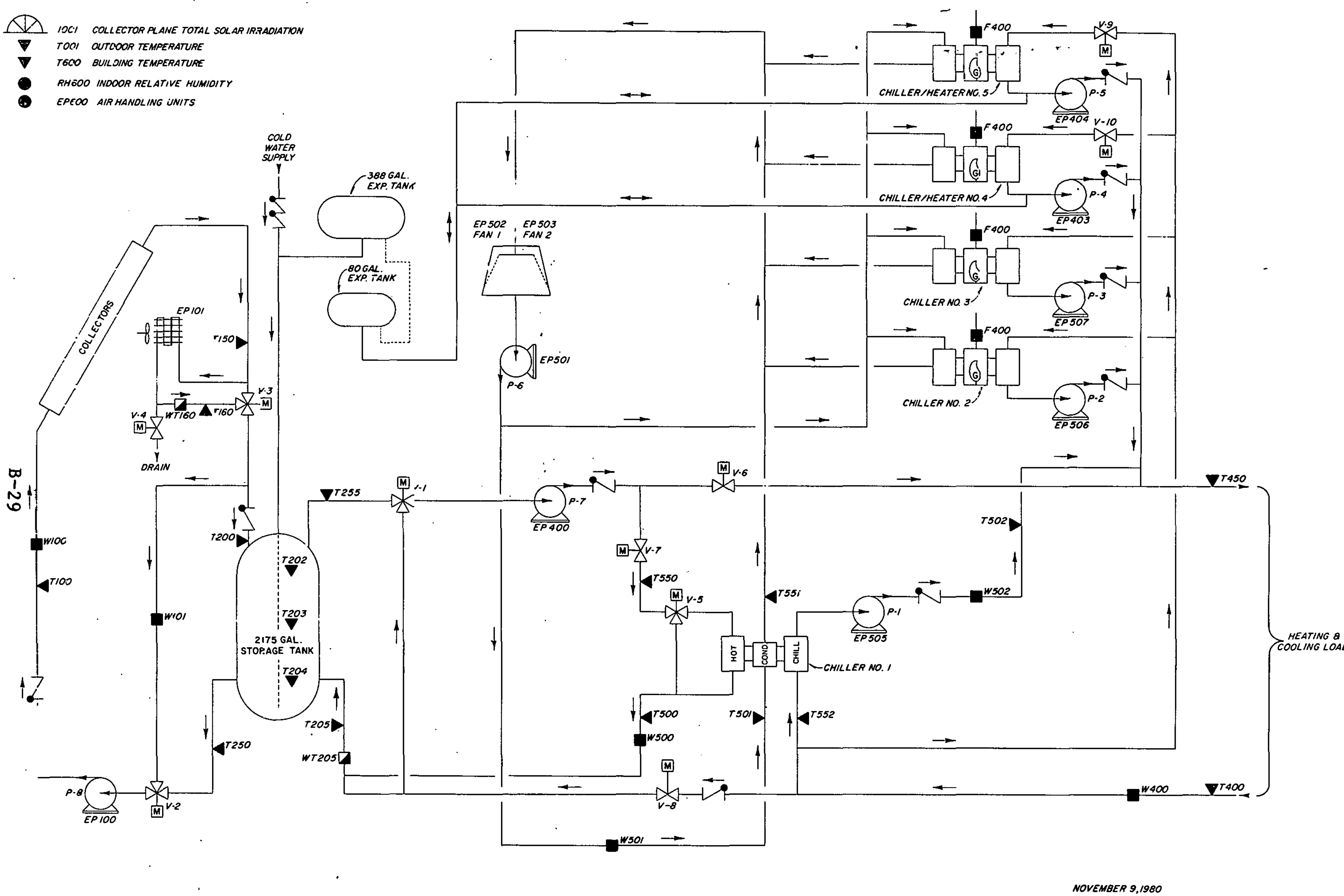
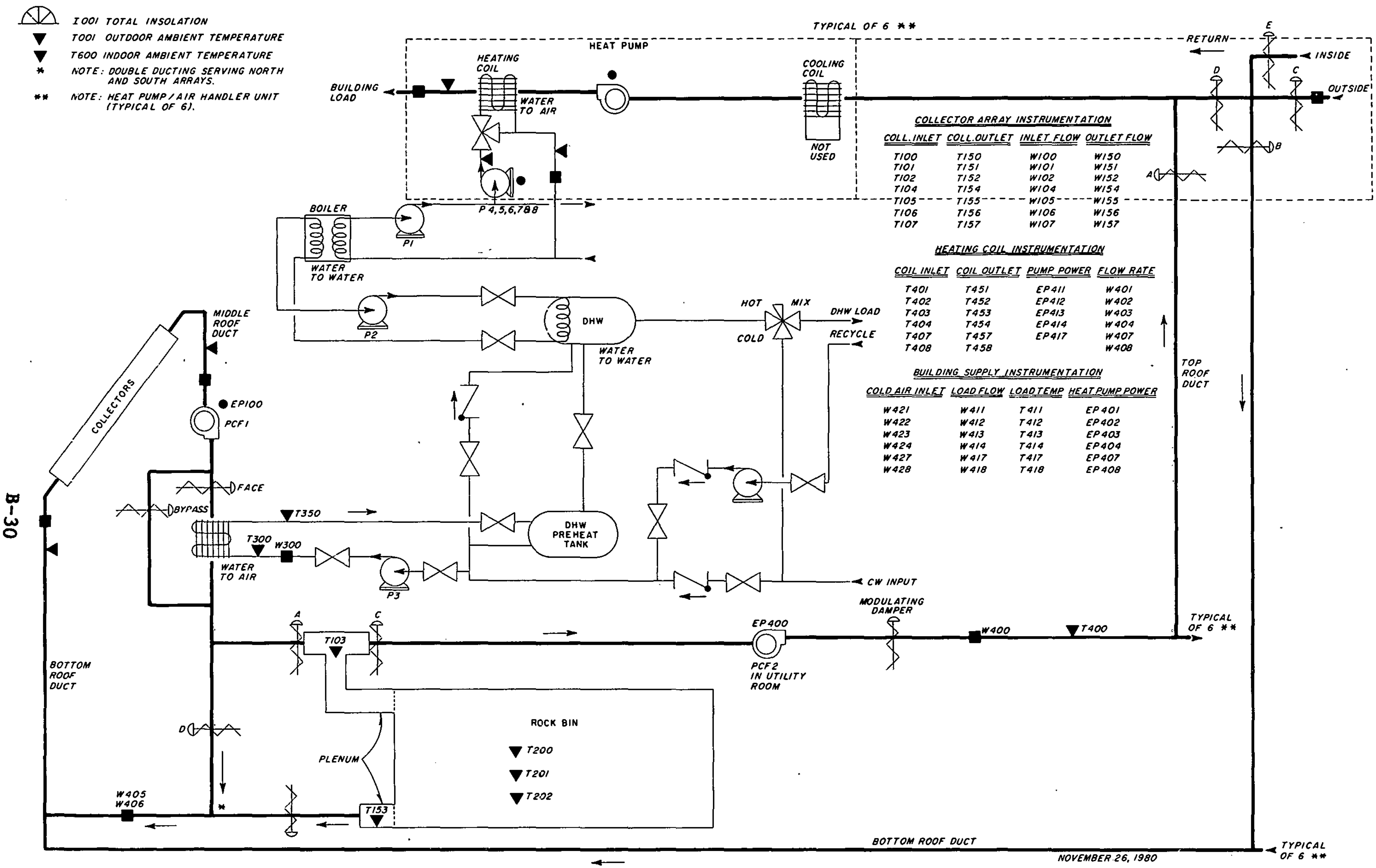


Figure B-26. San Anselmo School Solar Energy System Schematic



COLLECTOR ARRAY INSTRUMENTATION

COLL. INLET	COLL. OUTLET	INLET FLOW	OUTLET FLOW
T100	T150	W100	W150
T101	T151	W101	W151
T102	T152	W102	W152
T104	T154	W104	W154
T105	T155	W105	W155
T106	T156	W106	W156
T107	T157	W107	W157

HEATING COIL INSTRUMENTATION

COIL INLET	COIL OUTLET	PUMP POWER	FLOW RATE
T401	T451	EP411	W401
T402	T452	EP412	W402
T403	T453	EP413	W403
T404	T454	EP414	W404
T407	T457	EP417	W407
T408	T458		W408

BUILDING SUPPLY INSTRUMENTATION

COLD AIR INLET	LOAD FLOW	LOAD TEMP	HEAT PUMP POWER
W421	W411	T411	EP401
W422	W412	T412	EP402
W423	W413	T413	EP403
W424	W414	T414	EP404
W427	W417	T417	EP407
W428	W418	T418	EP408

Figure B-27. Spearfish High School Solar Energy System Schematic

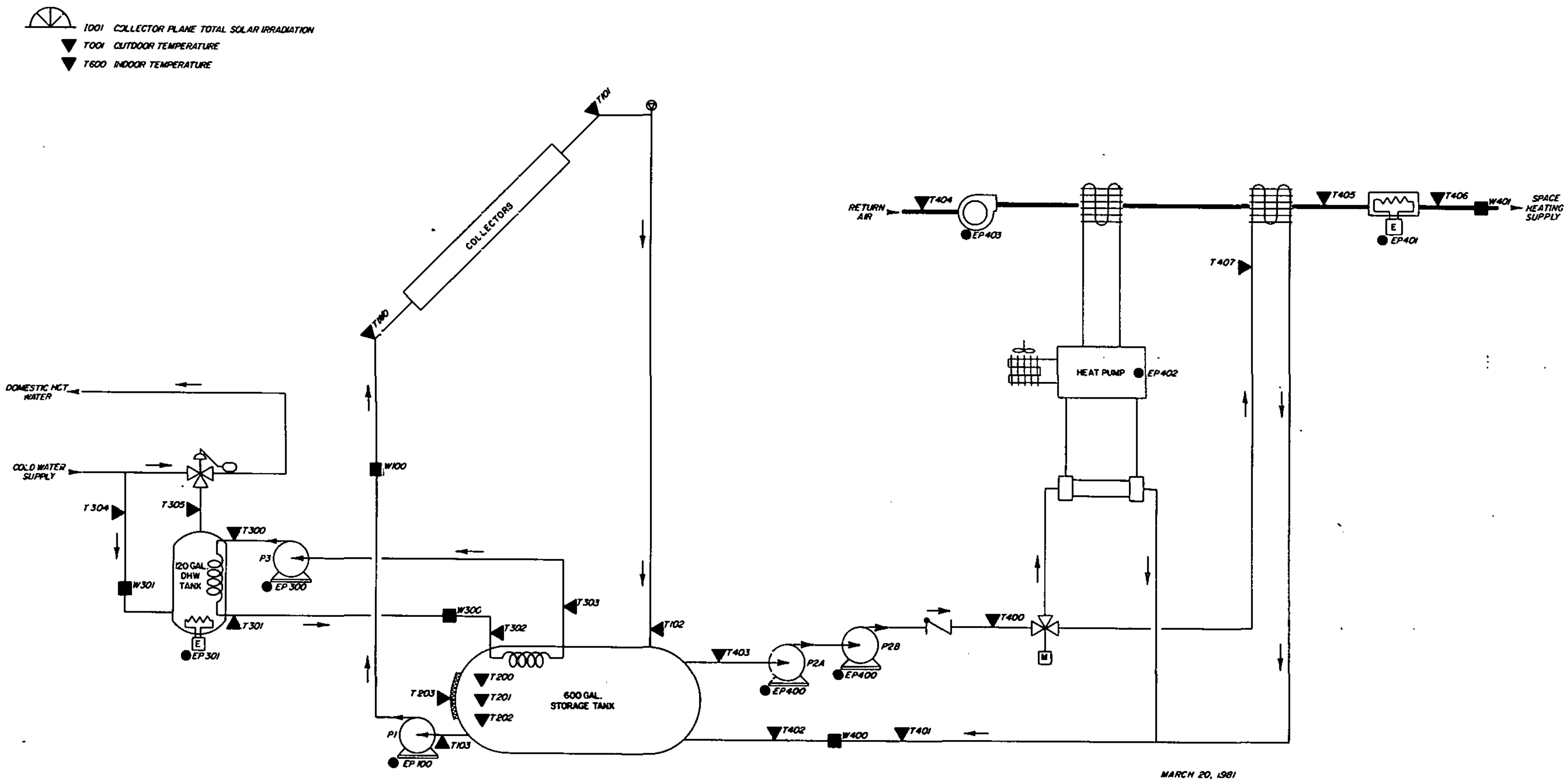


Figure B-28. Summerwood M Solar Energy System Schematic

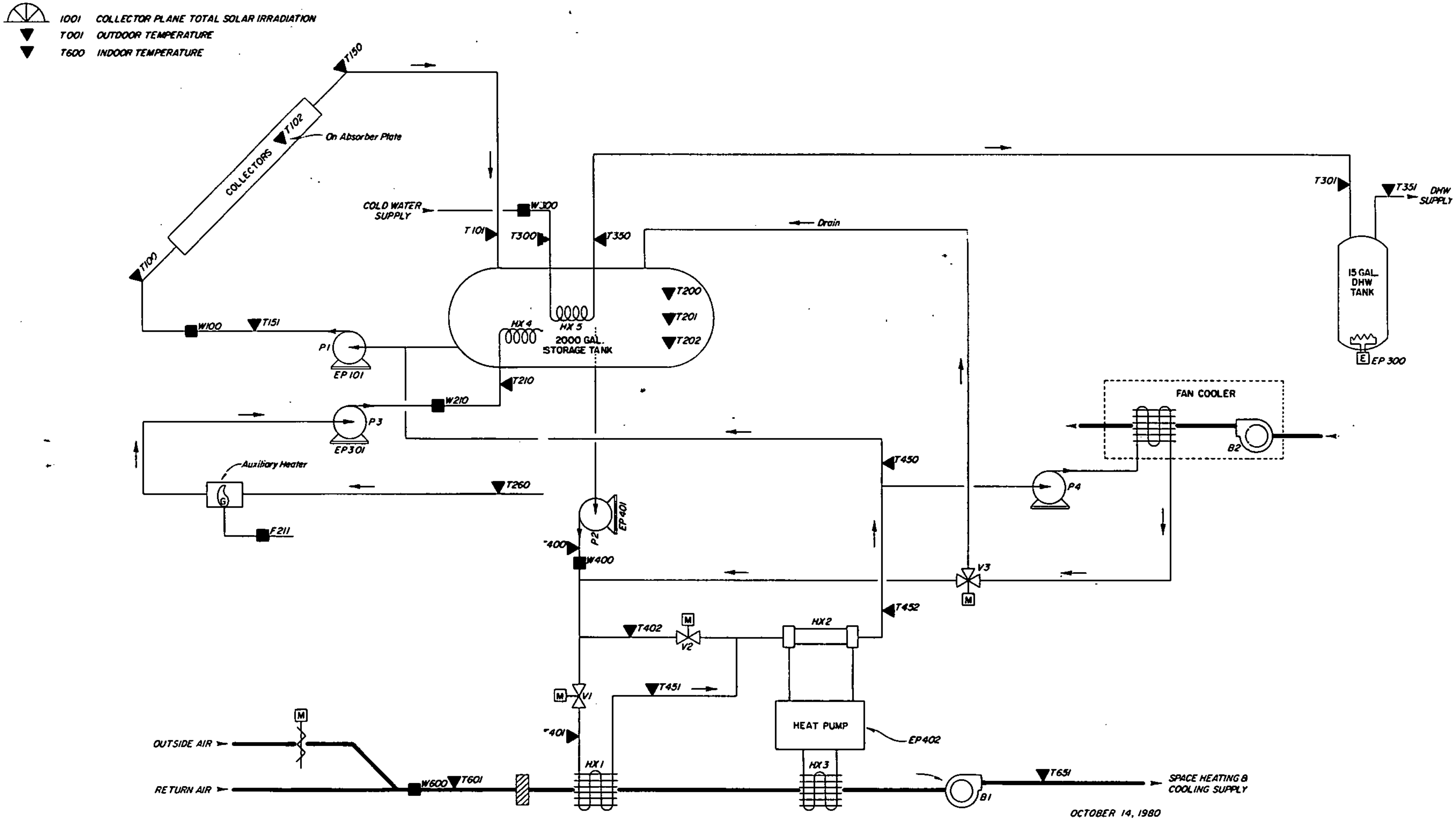


Figure B-29. Terrell E. Moseley Solar Energy System Schematic

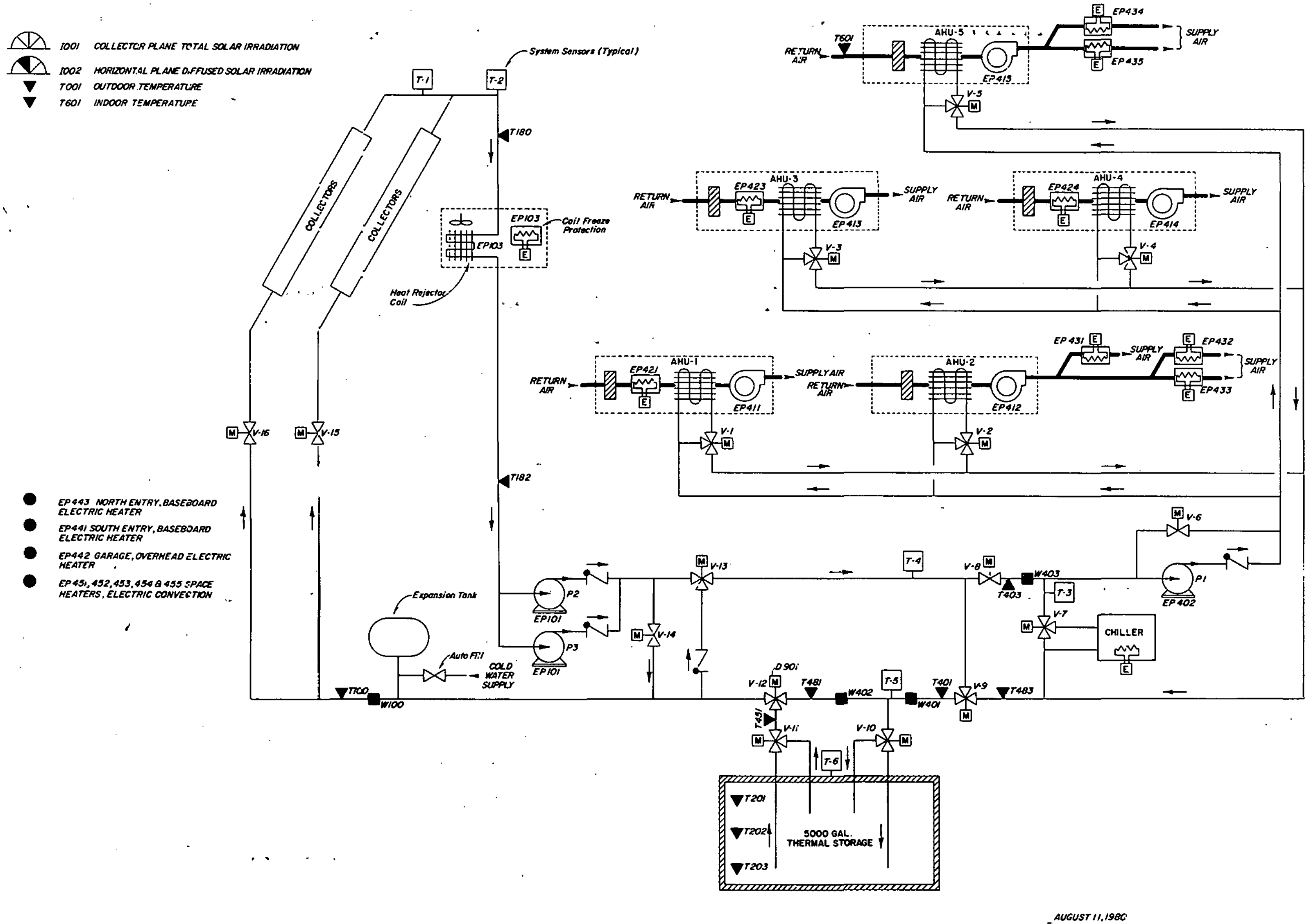


Figure B-30. Troy-Miami Library Solar Energy System Schematic

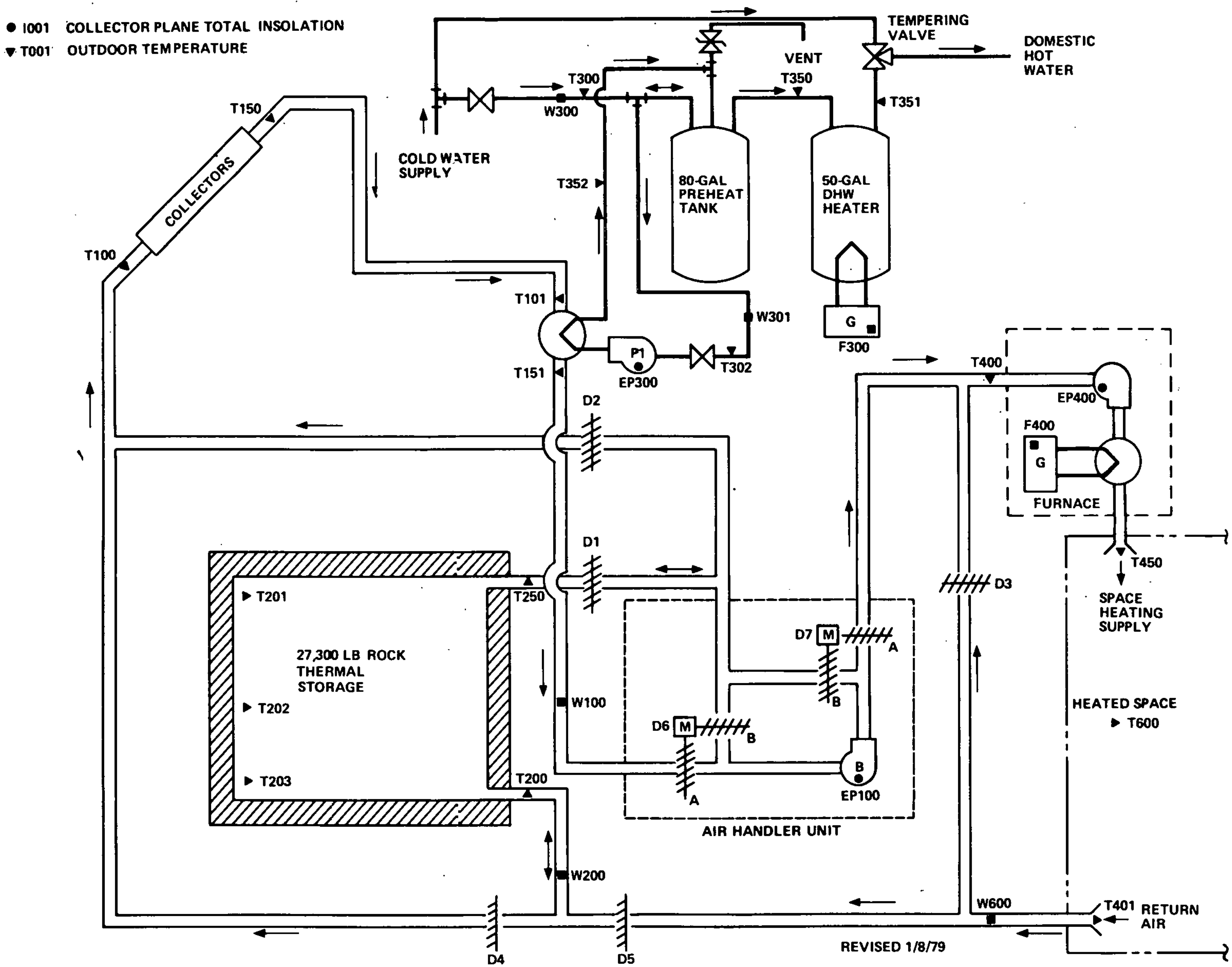


Figure B-31. Washington Natural Gas Solar Energy System Schematic

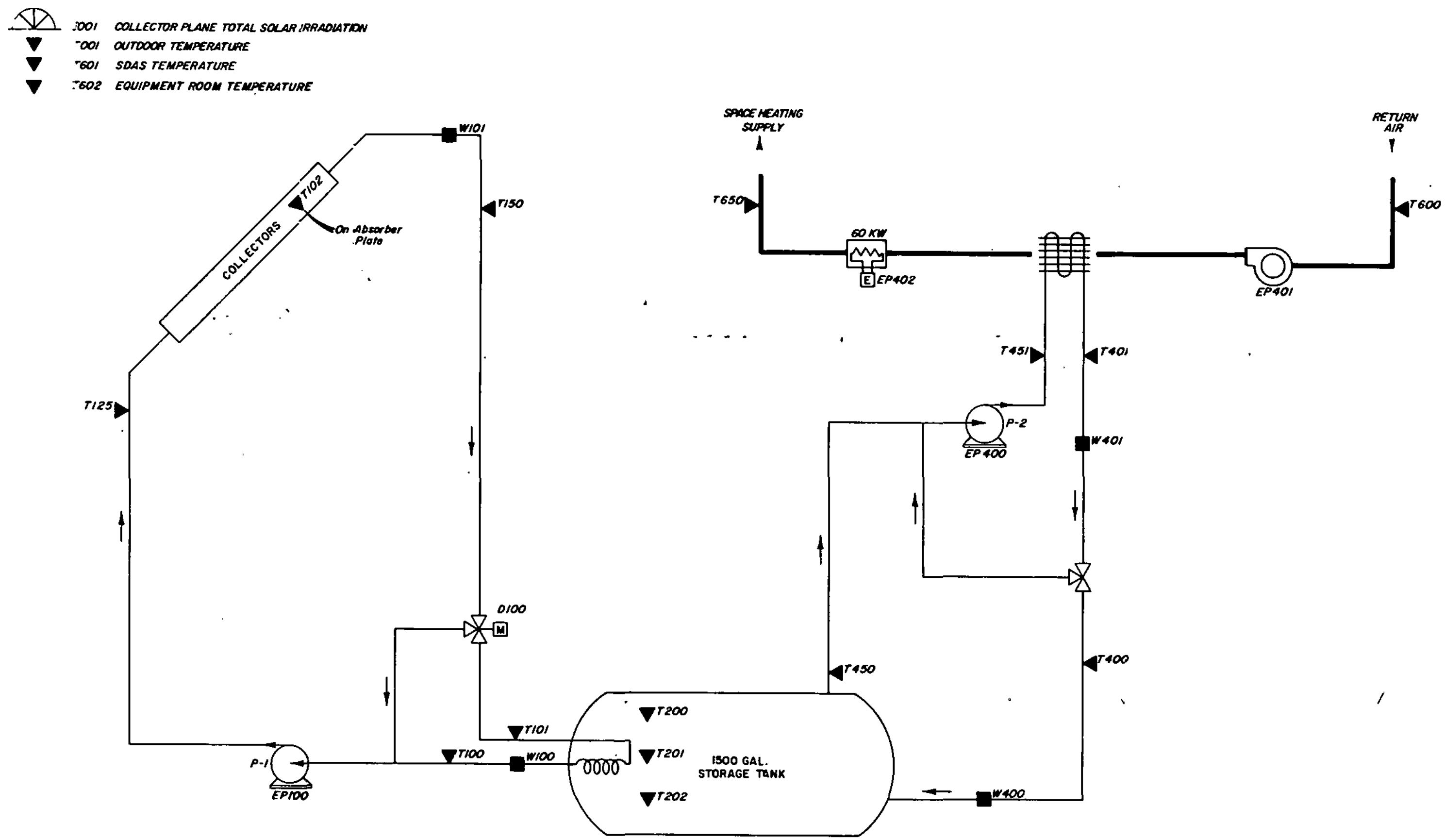


Figure B-32. Wyoming Rural Electric Solar Energy System Schematic

APPENDIX C

ENERGY FLOW DIAGRAMS

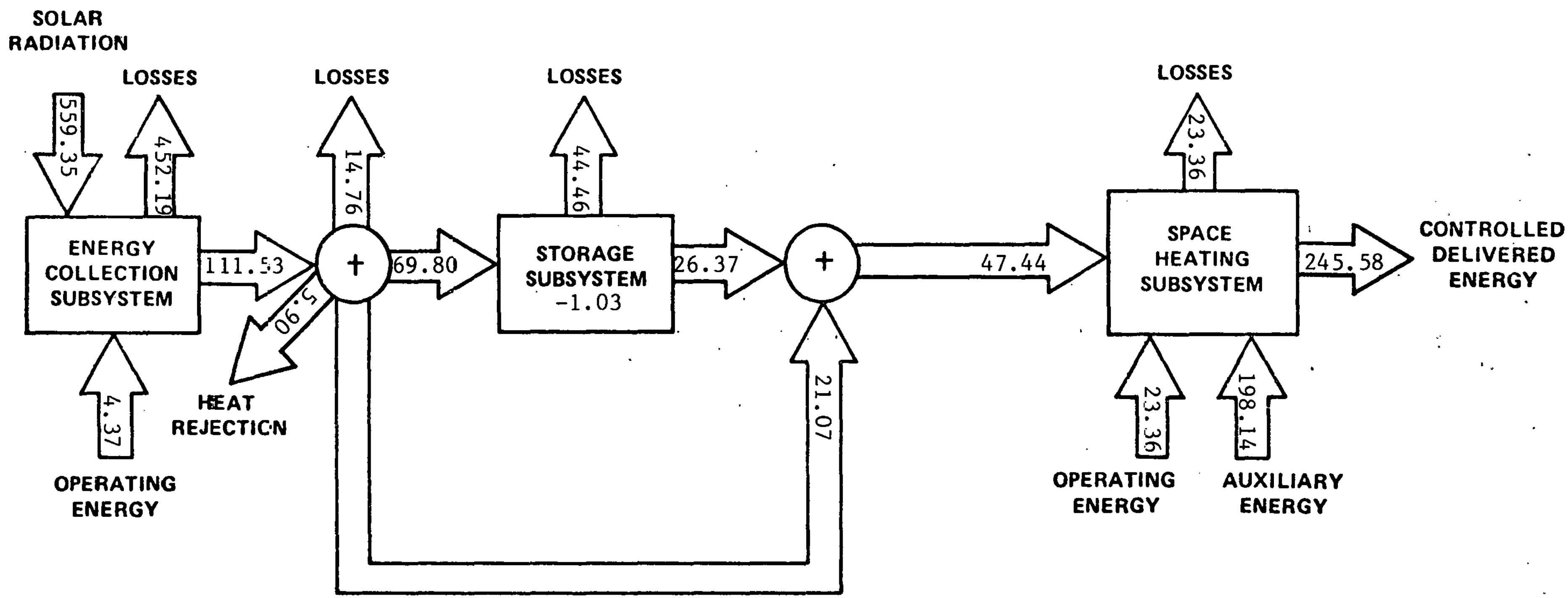
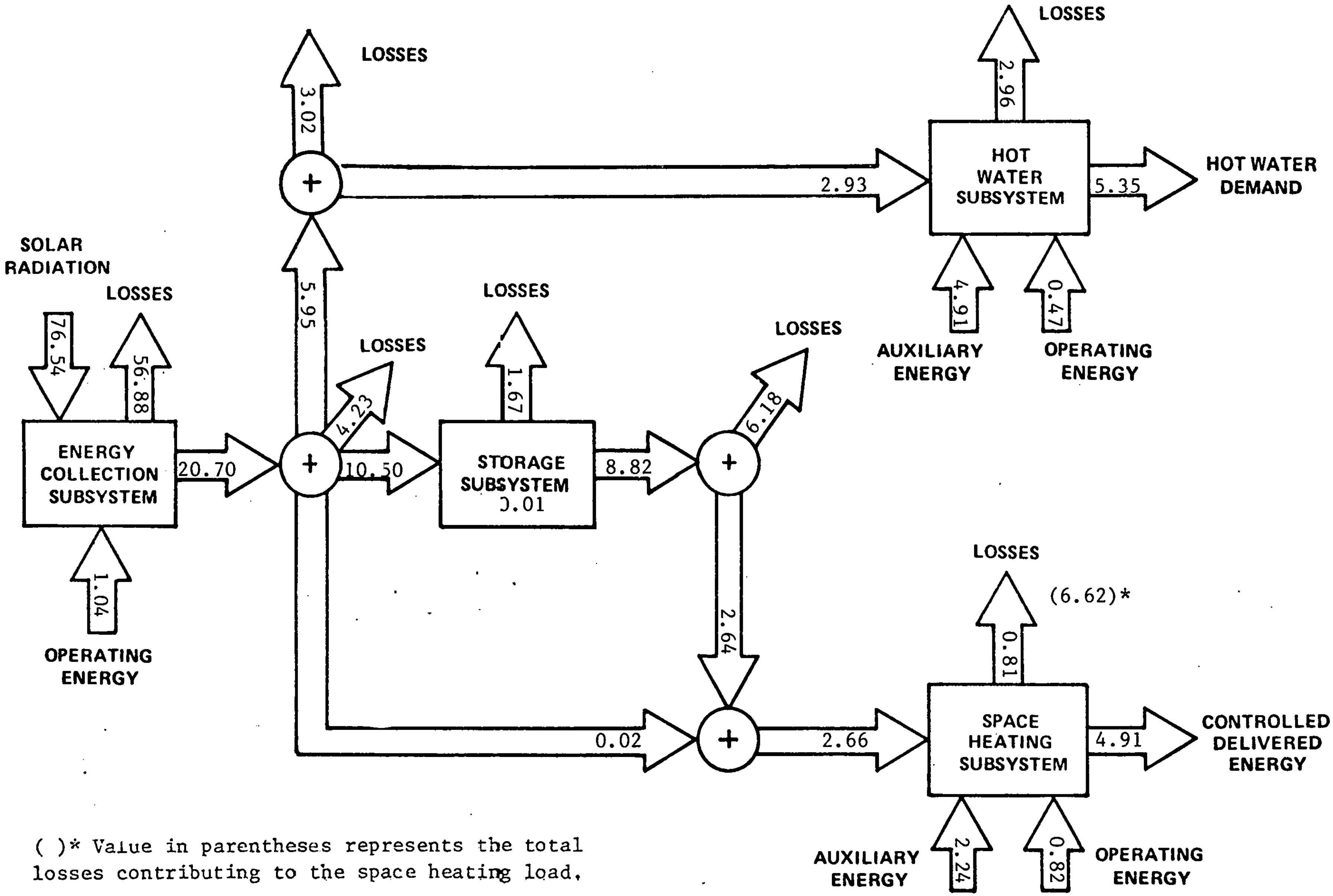


Figure C-1. Energy Flow Diagram for Billings Shipping
September 1980 through March 1981
(Figures in Million BTU)



( )* Value in parentheses represents the total losses contributing to the space heating load.

Figure C-2. Energy Flow Diagram for First Manufactured Homes Lot 10
November 1980 through April 1981
(Figures in Million BTU)

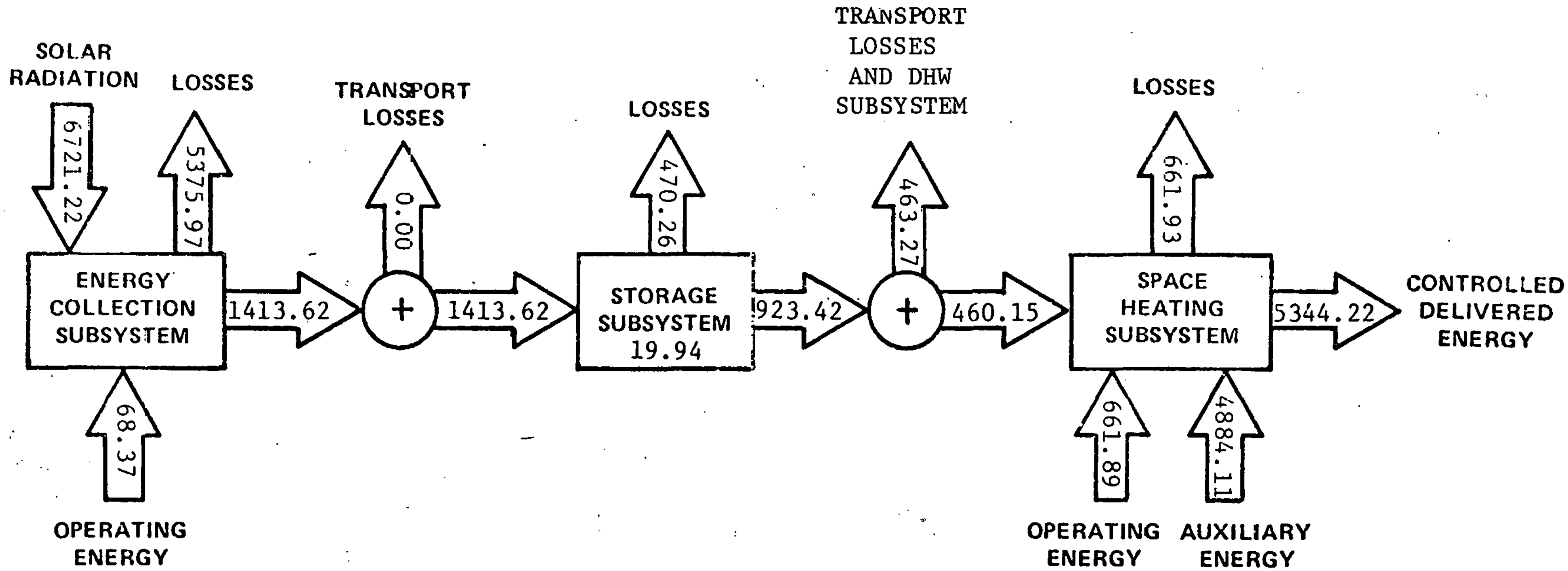
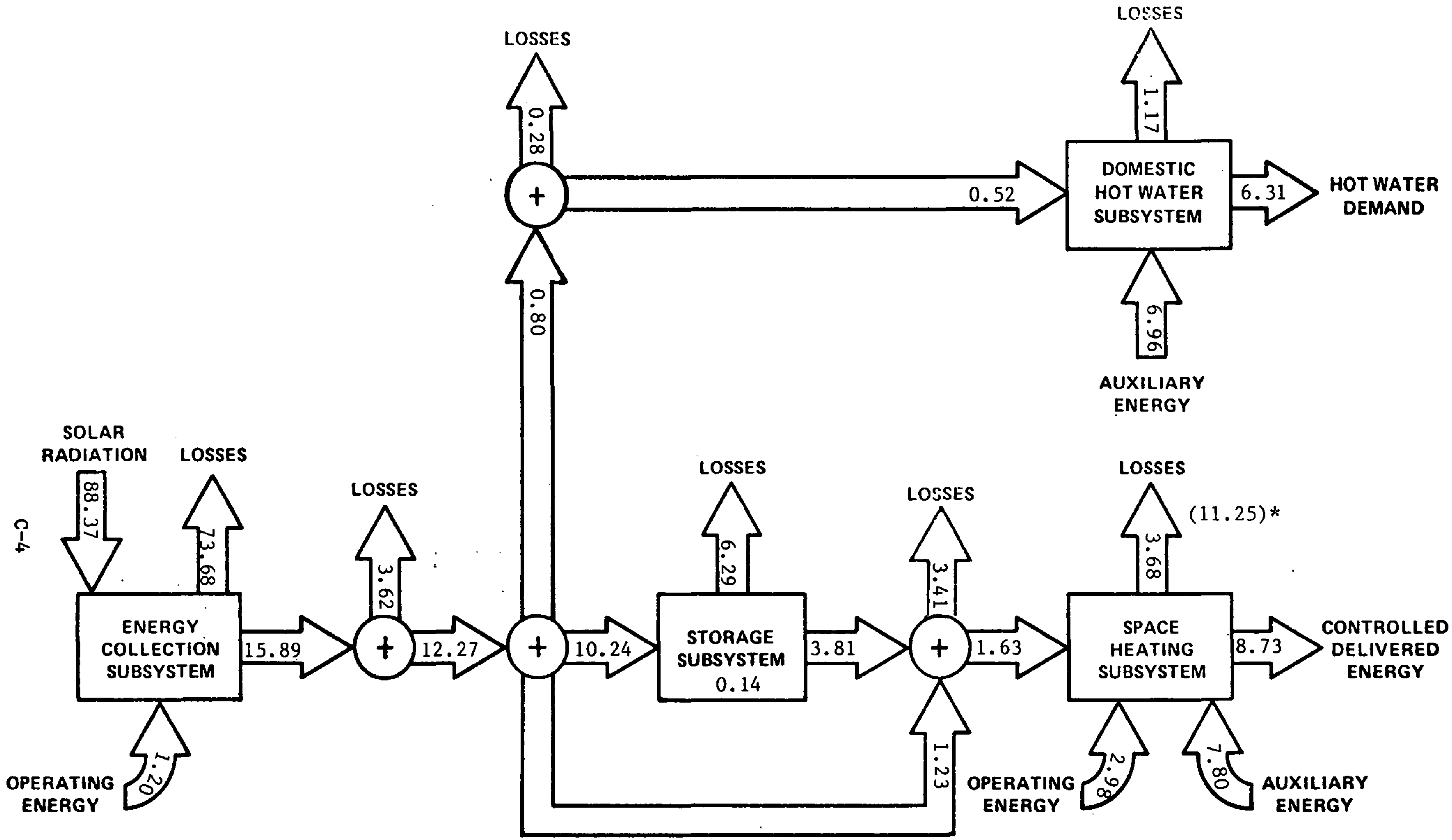


Figure C-3. Energy Flow Diagram for GSA, Federal Youth Center,
October 1980 through May 1981
(ECSS and Space Heating Subsystems only)
(Figures in million BTU)



C-4

( )* Value in parentheses represents the total losses contributing to the space heating load.

Figure C-4. Energy Flow Diagram for Helio Thermics 8
October 1980 through February 1981
(Figures in Million BTU)

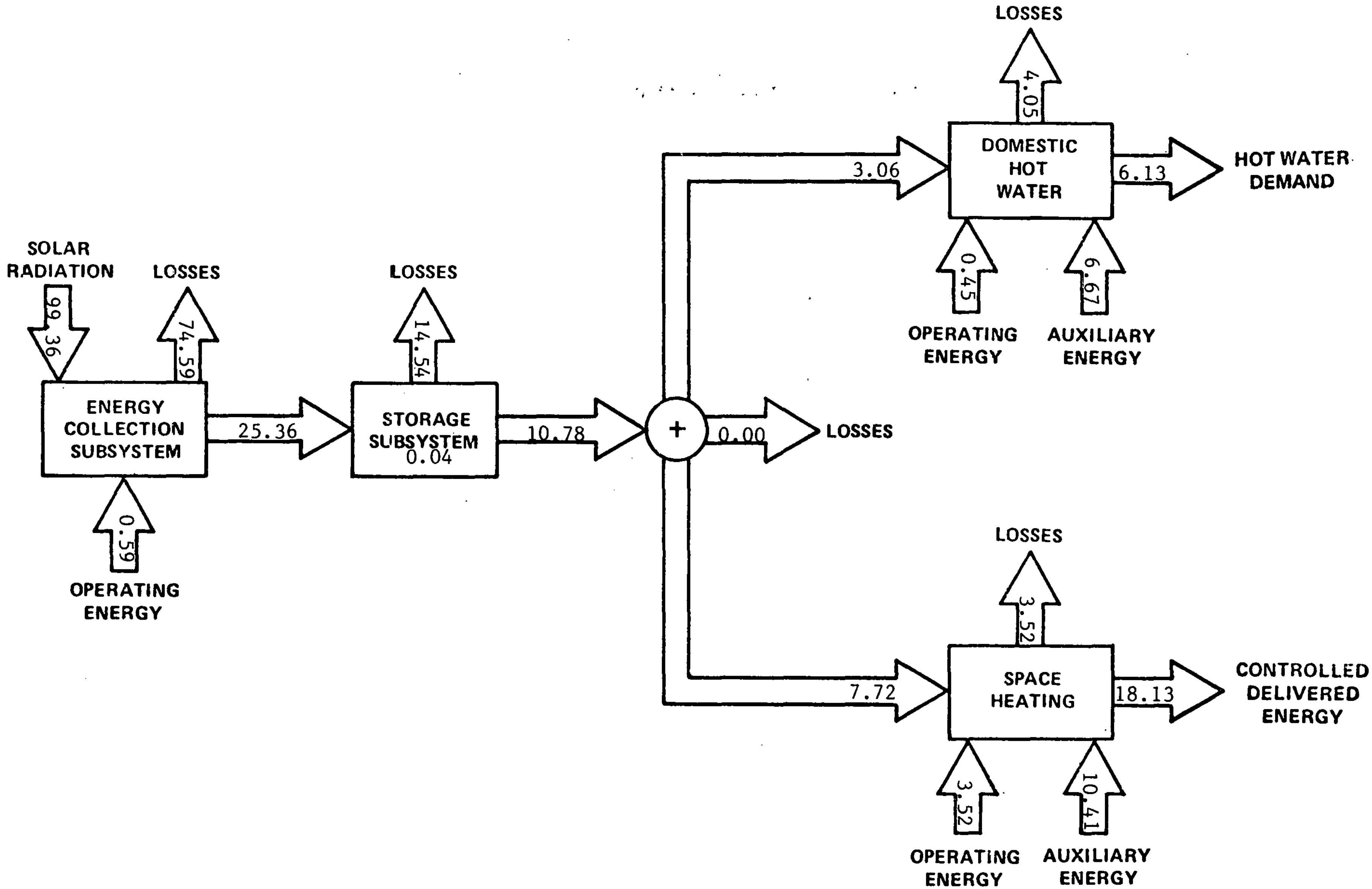


Figure C-5. Energy Flow Diagram for Matt Cannon
December 1980 through March 1981
(Figures in Million BTU)

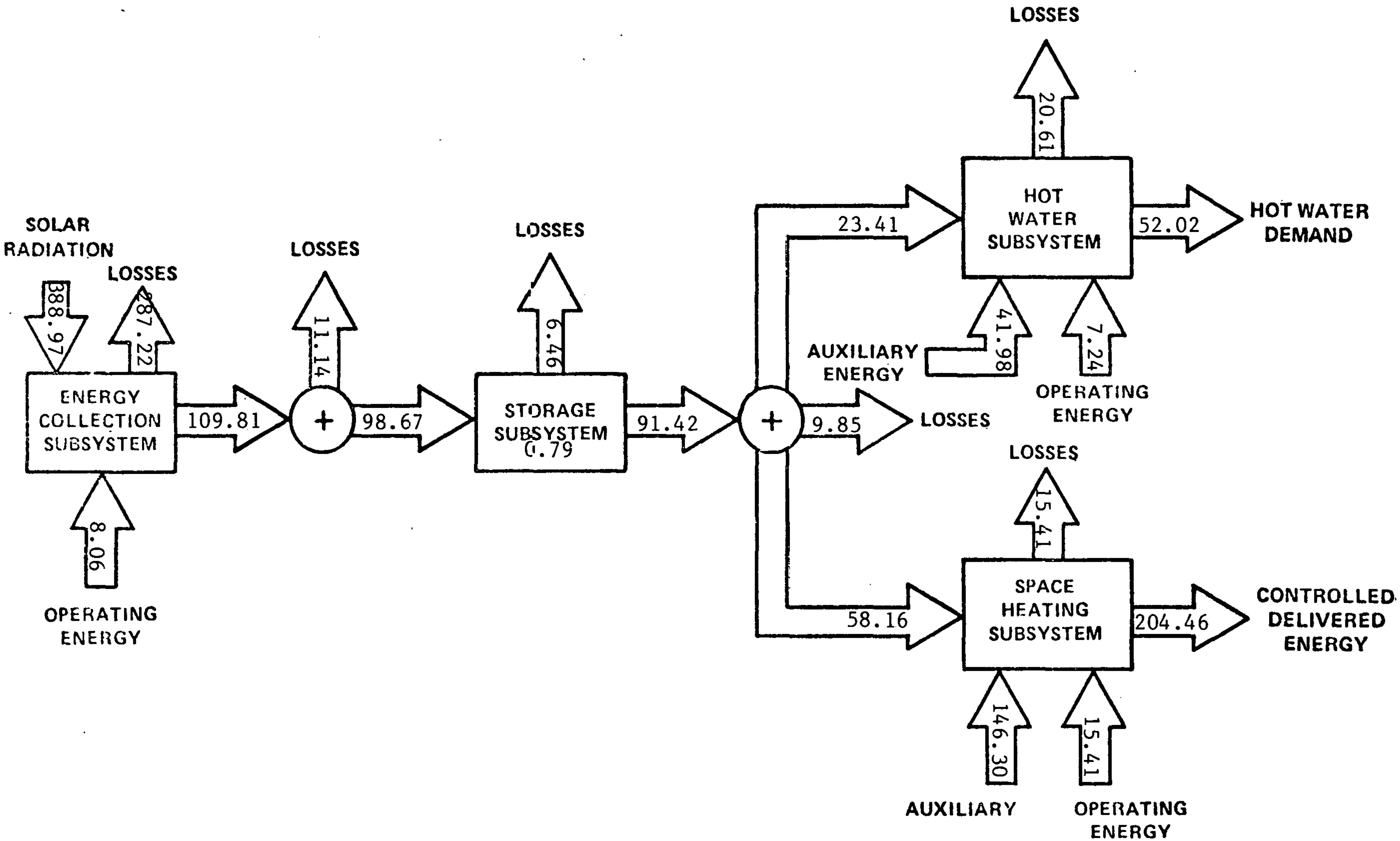


Figure C-6. Energy Flow Diagram for Montecito Pines
July 1980 through April 1981
(Figures in Million BTU)

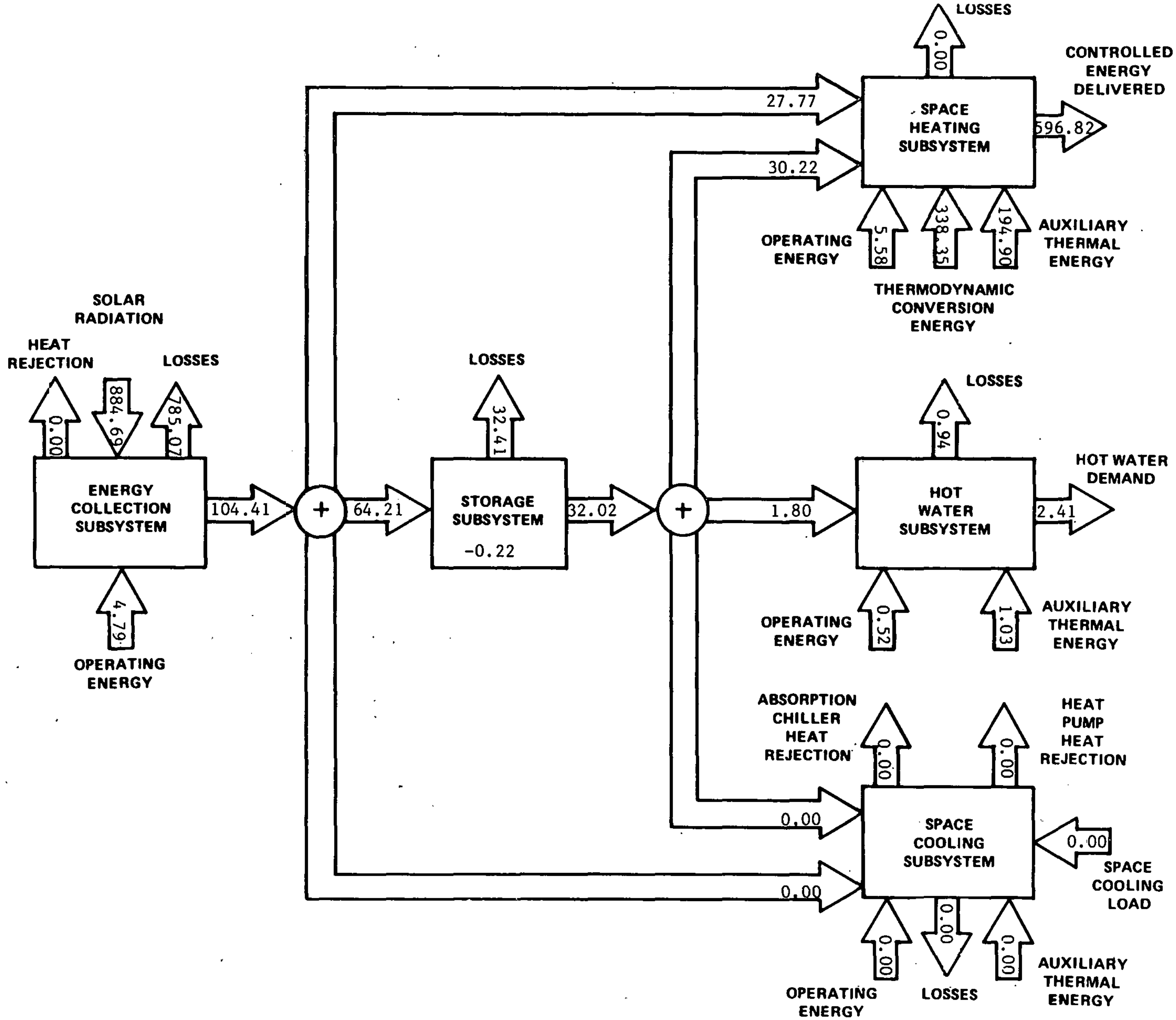
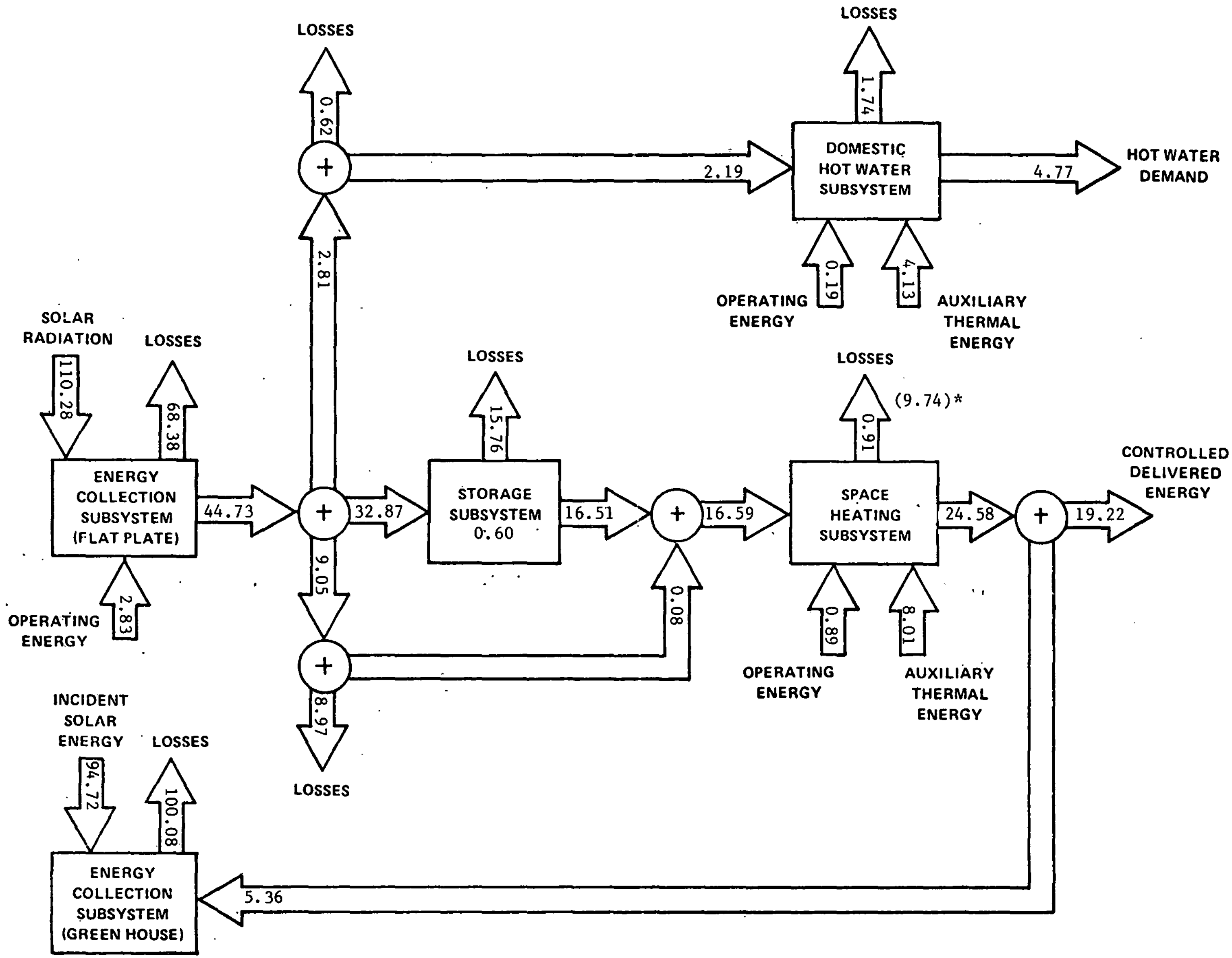
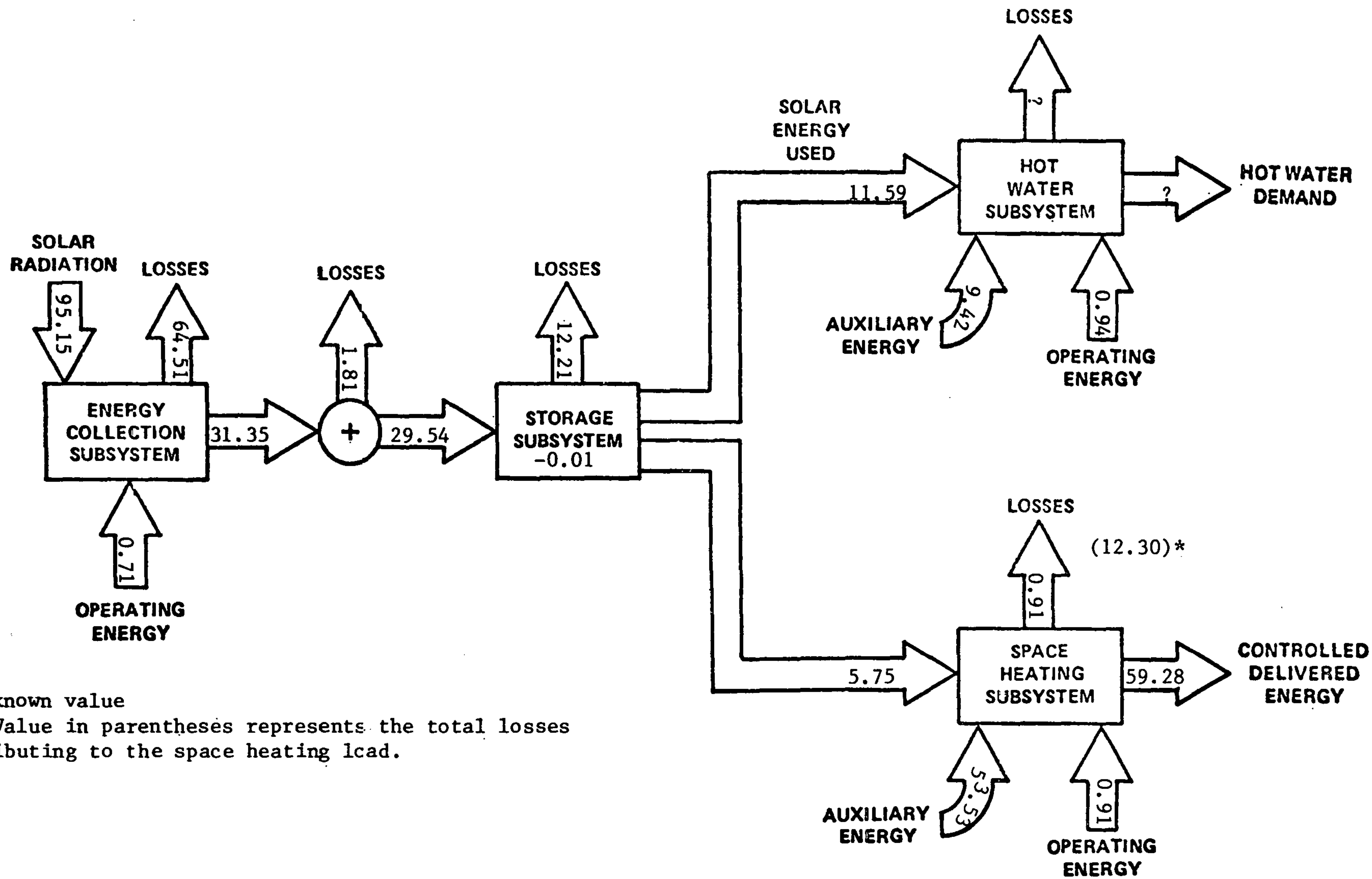


Figure C-7. Energy Flow Diagram for Olympic Associates
October 1980 through March 1981
(Figures in Million BTU)



( )* Value in parentheses represents the total losses contributing to the space heating load.

Figure C-8. Energy Flow Diagram for RHRU Clemson November 1980 through April 1981 (Figures in Million BTU)



? Unknown value
( )* Value in parentheses represents the total losses contributing to the space heating lcad.

Figure C-9. Energy Flow Diagram for Saddle Hill Trust Lot 36
October 1980 through May 1981
(Figures in Million BTU)

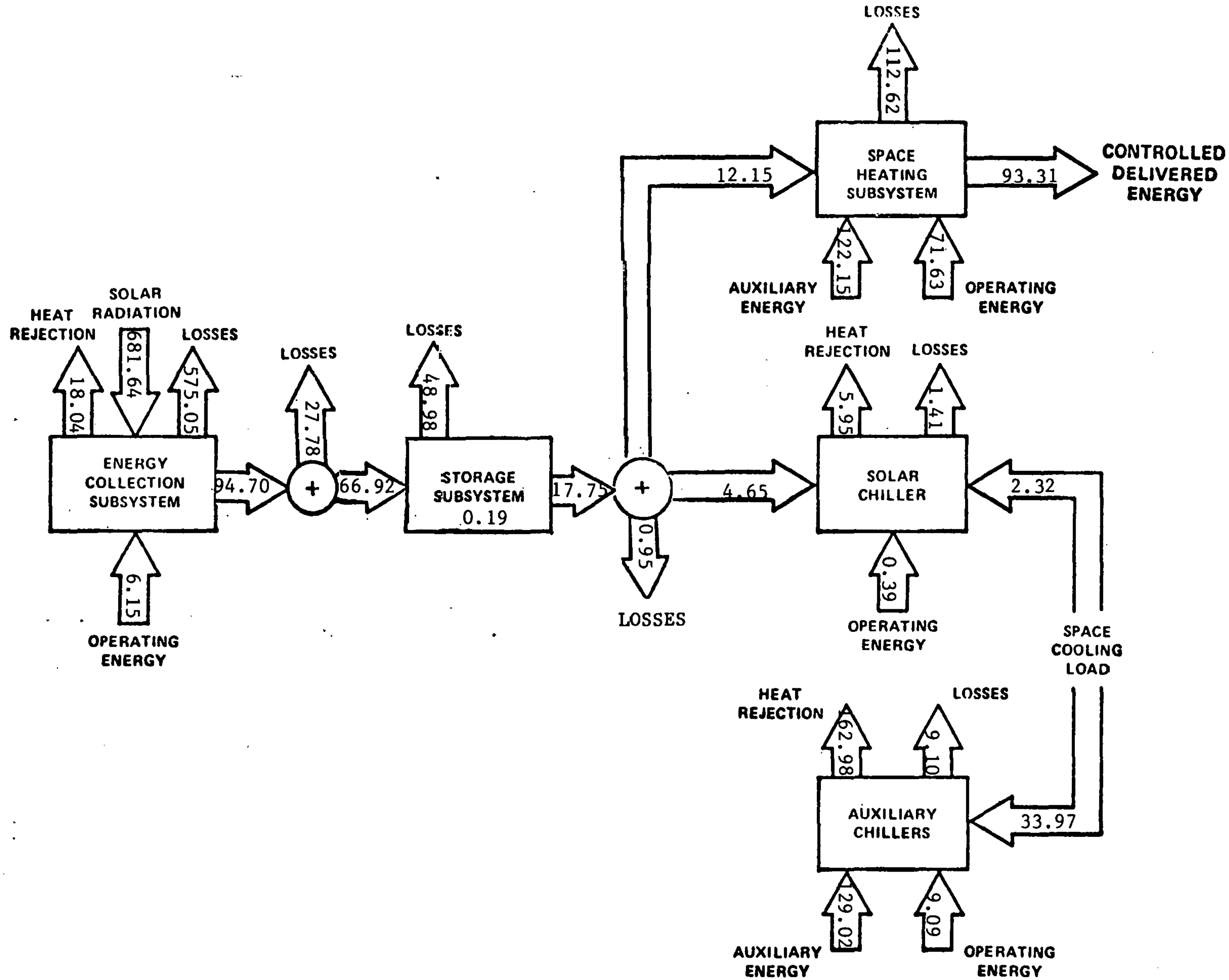
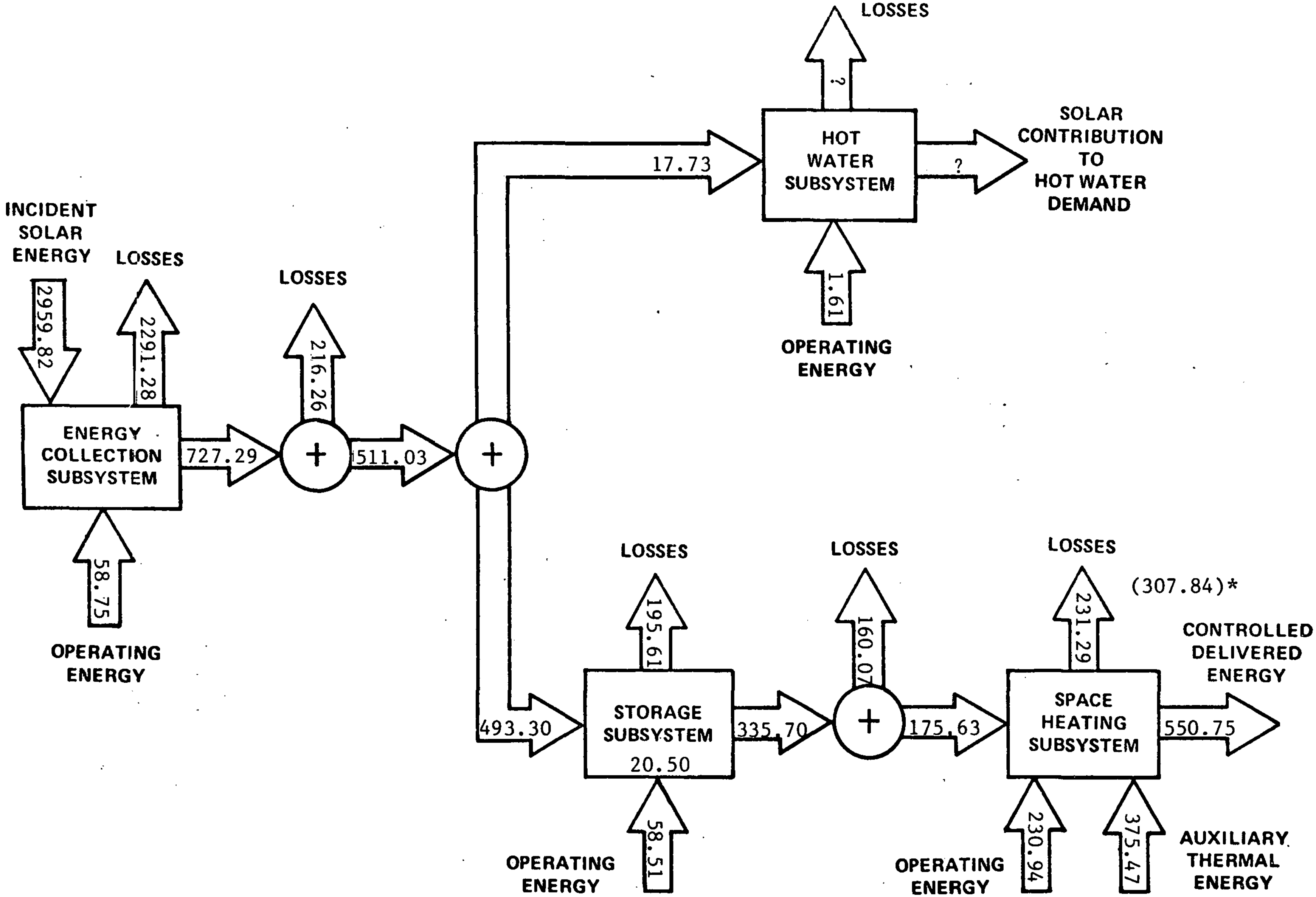
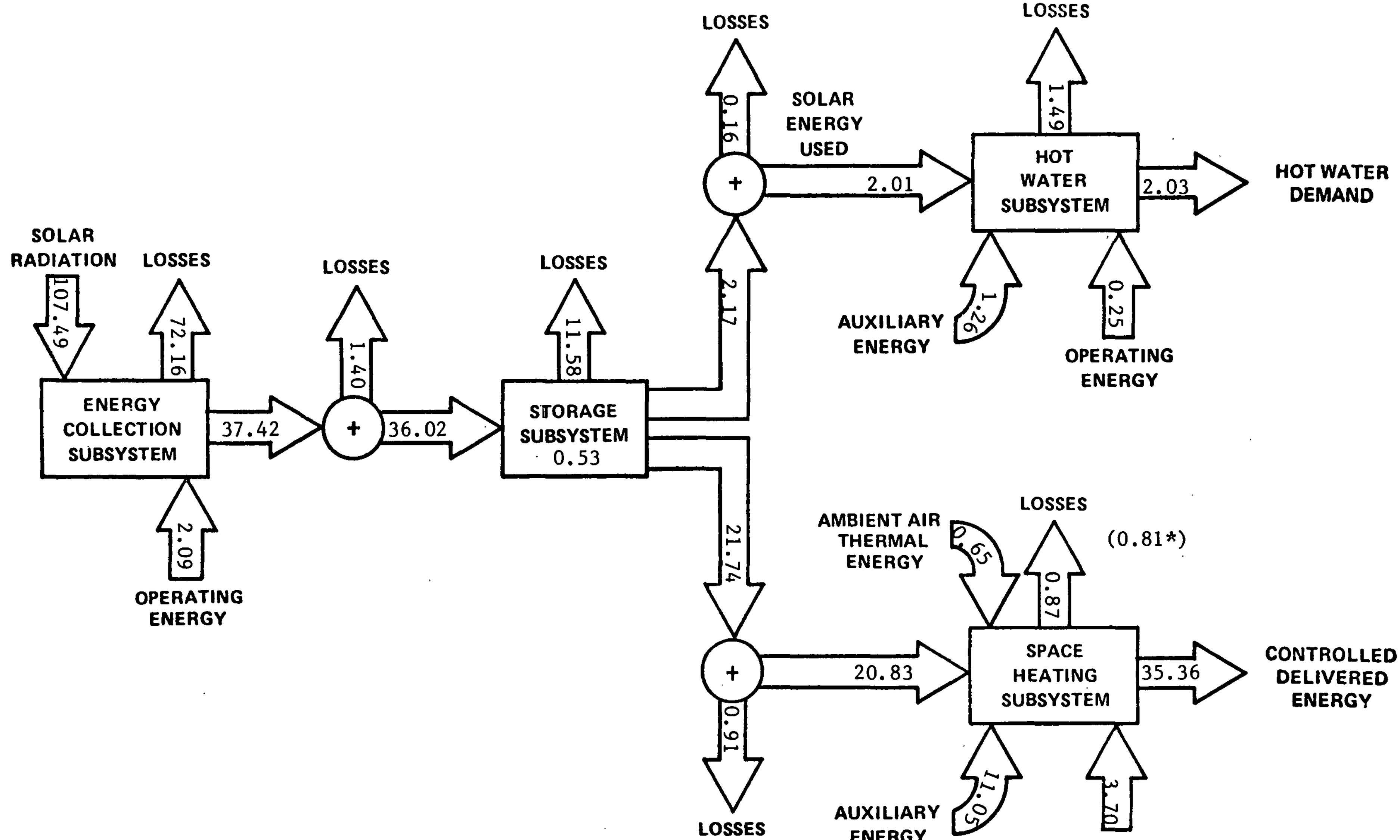


Figure C-10. Energy Flow Diagram for San Anselmo School
November 1980 through March 1981
(Figures in Million BTU)



? Unknown value
( )* Value in parentheses represents the total losses contributing to the space heating load.

Figure C-11. Energy Flow Diagram for Spearfish High School
September 1980 through May 1981
(Figures in Million BTU)



( )* Value in parentheses represents the total losses contributing to the space heating load.

Figure C-12. Energy Flow Diagram for Summerwood M
October 1980 through May 1981
(Figures in Million BTU)

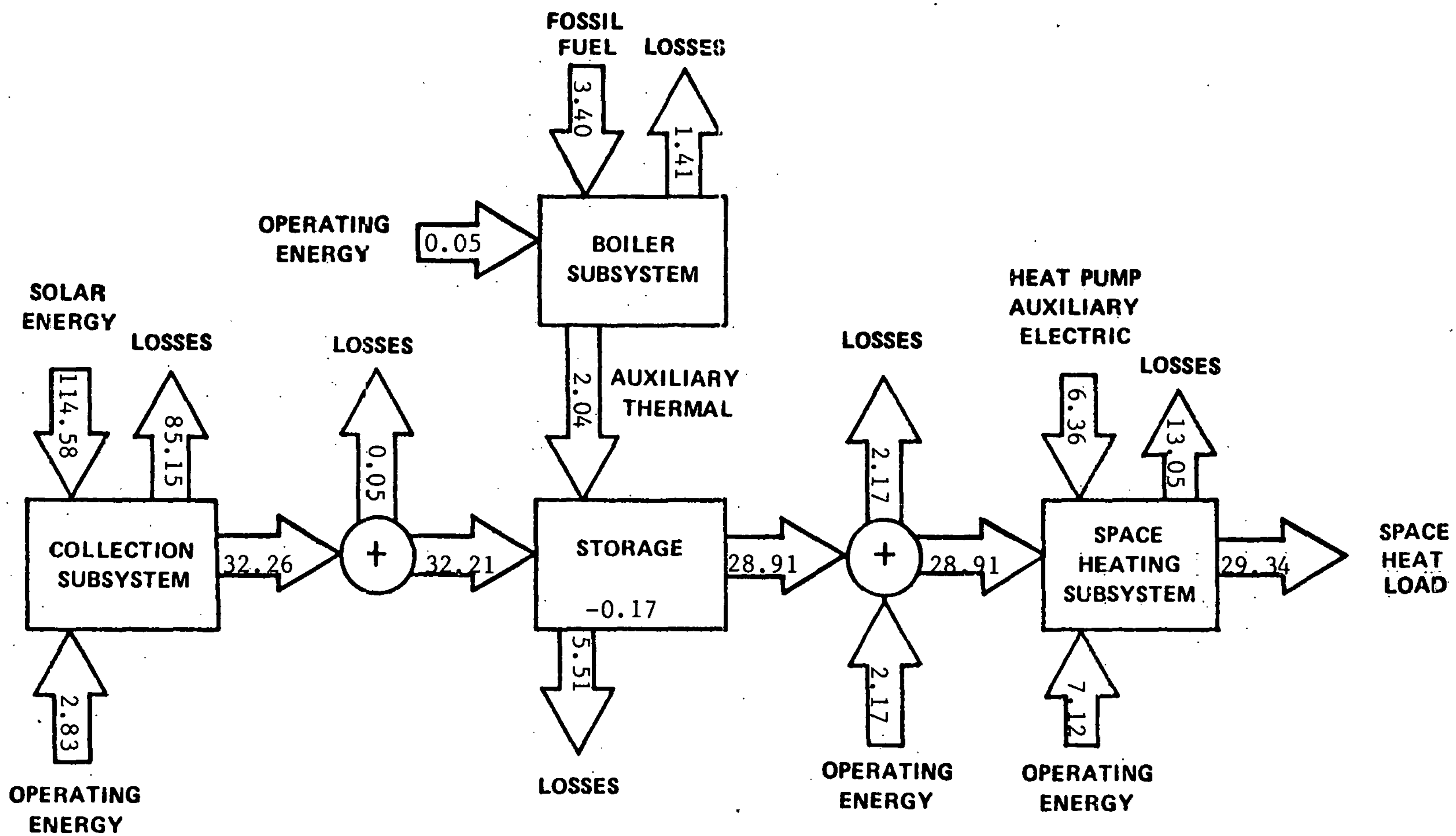


Figure C-13. Energy Flow Diagram for Terrell E. Moseley
October 1980 through April 1981
(Figures in Million BTU)

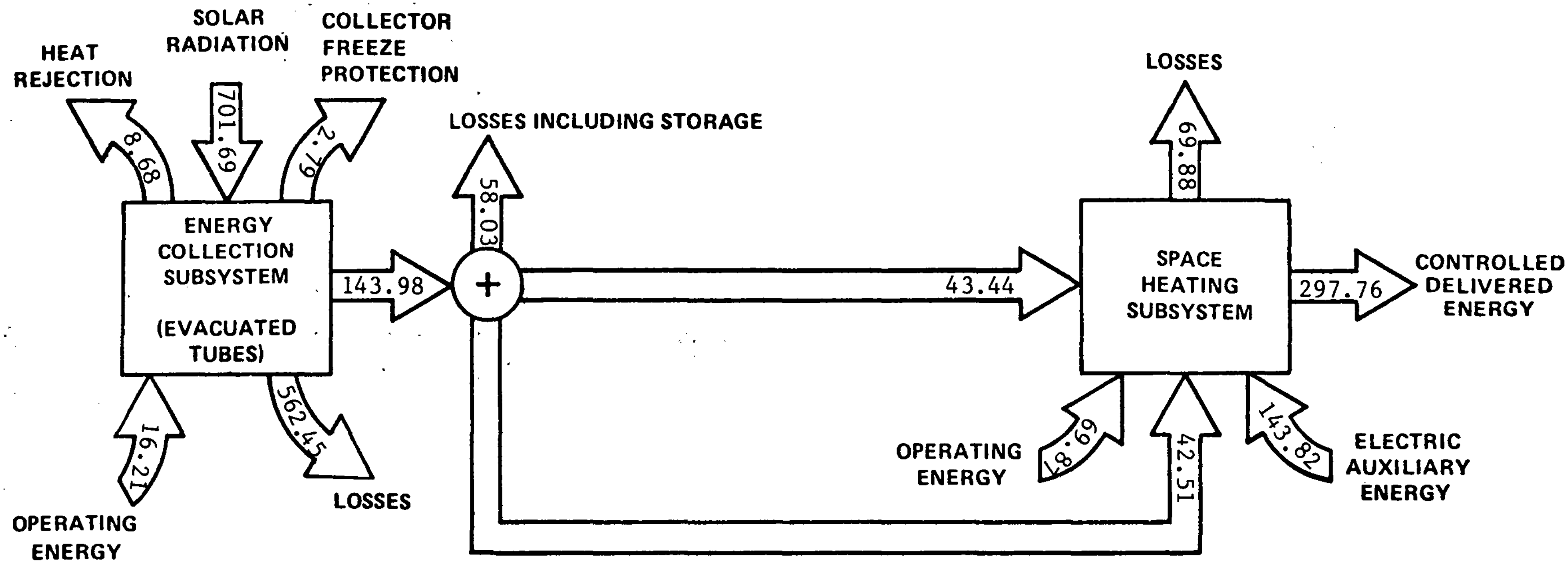


Figure C-14. Energy Flow Diagram for Troy-Miami Library
October 1980 through April 1981
(Figures in Million BTU)

APPENDIX D

PERFORMANCE EVALUATION TECHNIQUES

The performance of a solar energy system is evaluated by calculating a set of primary performance factors which are based on those in the intergovernmental agency report Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program (NBSIR-76/1137).

An overview of the NSDN data collection and dissemination process is shown in Figure D-1.

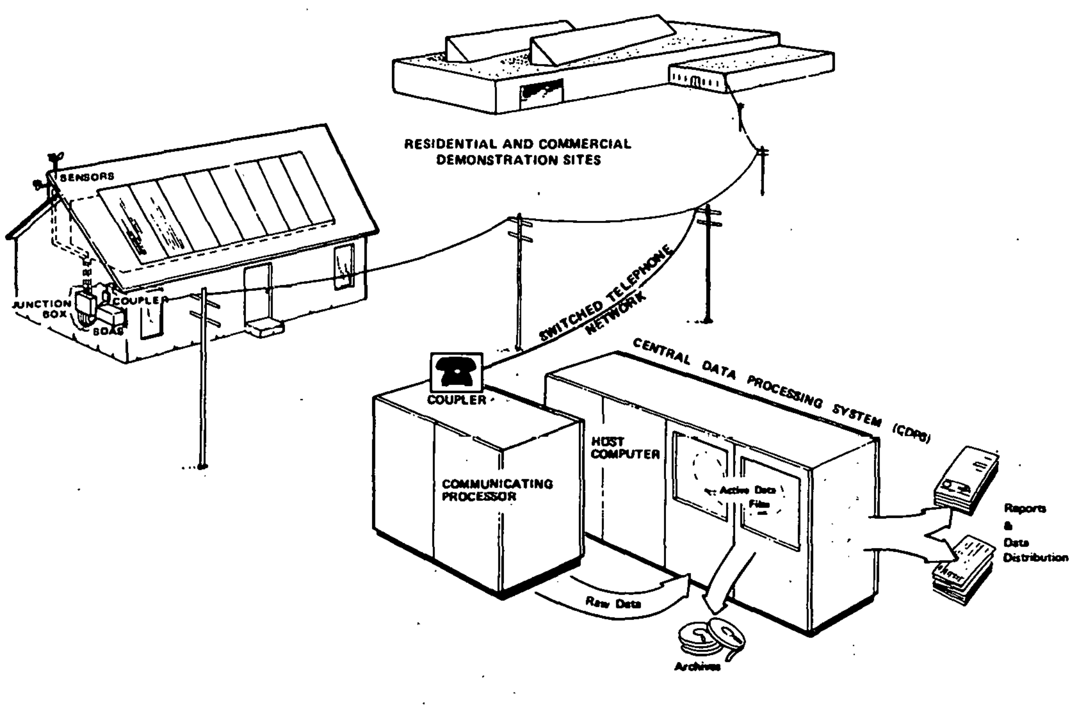


Figure D-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of every 320 seconds, the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each 320 second interval, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain data by contacting Vitro Laboratories.

DATA ANALYSIS

The analyst develops a unique set of "site equations" for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each scan interval. The site software produces as output a set of performance factors; on an hourly, daily, and monthly basis.

These performance factors quantify the thermal performance of the system by computing energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors, comparative evaluation of the wide variety of solar energy systems would be impossible. An example of a primary performance factor is "Solar Energy Collected by the Array." This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any real time data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

APPENDIX E

SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin; i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree-Days	The sum over a specified period of time of the number of degrees the average daily temperature is above 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings — The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.

Expansion Tank — A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.

F-Curve — The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).

Fixed Collector — A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.

Flat-Plate Collector — A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).

Focusing Collector — A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.

Fossil Fuel — Petroleum, coal, and natural gas derived fuels.

Glazing — In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.

Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree-Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	Incoming solar radiation.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.
Microclimate	Highly localized weather features which may differ from long-term regional values due to the interaction of the local surface with the atmosphere.

Nocturnal Radiation — The loss of thermal energy by the solar collector to the night sky.

Operating Energy — The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.

Operating Point — A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as:

$$\frac{Ti-Ta}{I} \left(\frac{°F \times hr. \times sq.\ ft.}{BTU} \right)$$

Operational Collector Efficiency — Ratio of collected solar energy to incident solar energy only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.

Outgassing — The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.

Passive Solar System — A system which uses architectural components of the building to collect, distribute, and store solar energy.

Pebble Bed (Rock Bed) — A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.

Reflected Radiation — Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.

Rejected Energy — Energy intentionally rejected, dissipated, or dumped from the solar system.

Retrofit — The addition of a solar energy system to an existing structure.

Selective Surface — A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

APPENDIX F

CONVERSION FACTORS

Energy Conversion Factors

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[1]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[2]	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/BTU
Electricity	3,413 BTU/kilowatt-hour	292.8×10^{-6} kwh/BTU

[1] No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

[2] No. 5 and No. 6 fuel oils

APPENDIX G

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally-conductive grease is used between the probe and the thermowell to assure faster temperature response.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph
	± 3% above 25 mph
Time Constant:	0.145 second

HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the polymer thin film capacitor. A one-micron-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H. ± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 μ V/W/m^2
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M^2
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle ± 3% 70-80° zenith angle

LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel Body - Brass or stainless steel Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% (½" to 3½" line size) ± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body - bronze Measuring chamber - plastic
Accuracy:	± 1.5%

AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C ± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature:	100°C (max)
Flow Range:	0.6 to 48 gph
Accuracy:	± 1% of full scale

FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity:	175 cubic ft/hr
Max Working Pressure:	5 psi

ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range:	1 to 0 (lead or lag)
Response Time:	250 ms
Temperature Effect:	1% of reading
Accuracy:	0.5% of full scale

HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature:	-50° to 200°F
Response Time:	6 seconds
Linearity:	2%
Repeatability:	0.5%
Sensitivity:	2 mv/BTU/ft^2-hr
Size:	2" X 2"

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