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SANTA CLARA, CALIFORNIA, COMMUNITY CENTER COMMERCIAL SOLAR DEMONSTRATION DESIGN AND CONSTRUCTION REPORT

September 1977

Work Performed Under Contract No. EY-76-C-03-1083

The Lockheed Palo Alto Research Laboratory
Palo Alto, California

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Contract No. EY-76-C-03-1083

Prepared by

THE LOCKHEED PALO ALTO RESEARCH LABORATORY
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For

CITY OF SANTA CLARA
1500 WARBURTON AVENUE
SANTA CLARA, CALIFORNIA 95050

And the

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
DIVISION OF SOLAR ENERGY

FOREWORD

The City of Santa Clara, California, has a unique combination of characteristics: it is located in the San Francisco Bay area and therefore is in an urban location; it is in the Santa Clara Valley, which is a growth environment; and it has a city government that emphasizes utility services and public works for its residential and commercial/industrial populace. These characteristics attracted the attention of the National Science Foundation and subsequently the Energy Research and Development Administration relative to the potential benefits to be derived from the installation of a solar heating and cooling system on the City's Community Recreation Center.

The effort to bring Santa Clara into the National Solar Heating and Cooling Demonstration Program began in November 1974. This document discusses the evolution of the heating and cooling system from concept to detailed design and specification, and finally to hardware mechanization and installation of a successful system. The system became operative in the Spring of 1977.

ABSTRACT

The Community Recreation Center is owned and operated by the City of Santa Clara; it is located in the Central Park area. The facility has a solar driven heating and cooling system which is part of the National Solar Heating/Cooling Demonstration Program planned and directed by the ERDA Division of Solar Energy.

The Community Recreation Center is a one story 27,000-sq-ft multiuse facility providing day and night, year around service to the government and residents of the city.

The City of Santa Clara is located in Santa Clara County in the San Francisco Bay Area at 37° 20' North latitude. The prevailing climate can be generalized as Mediterranean in nature characterized by approximately 2,500 degree-days – (heating). In comparison with many regions of the country, this is an "easy" air conditioning area because humidity levels are seldom outside the comfort range.

Size, shape, form, materials of construction, and usage indicated that the facility would represent a cooling-dominated load with peak cooling requirements of 5.9×10^6 Btu per day versus peak winter heating requirements of 2.9×10^6 Btu per day.

The installed liquid solar heating and cooling system is characterized by:

a) Roof-mounted fixed-flatplate solar collectors.
b) Collector array consisting of 436 individual modules, for a total array area of 7085 sq ft. The array is South facing at an 18-deg tilt.
c) Collector design is optimized for minimum losses and thus, high temperature operation – utilizing a high fin efficiency copper absorber plate, with selective coating and two cover glasses of tempered high transmission glass.

d) Cooling is achieved by two 25-ton lithium-bromide absorption chillers, ARKLA Model WF-300 and a single cooling tower.

e) Underground storage consists of:

   1) One 10,000 gallon insulated steel tank for hot water – operating range 115°F to boiling.

   2) One 50,000 gallon insulated steel tank for chilled water – operating range 42° – 55°F.

f) Auxiliary Energy Source – Natural Gas.

g) Building interior is divided into 11 zones, each zone having its own fixed-air volume, two-coil air handler.

h) Interior space conditioning is based on utilization of an outdoor air economizer.

i) Solar System has fully automatic electronic controls with multimodes of operation selected by a roof-mounted pyranometer.

j) The installed system coupled to an on-site data system for acquisition and formating of overall system performance.

This project was initiated in the Fall of 1974 and came on-line in the Spring of 1977. The solar system is sized to provide 80 percent of the total annual energy requirements for the Community Recreation Center in connection with its intended activities.

ACKNOWLEDGMENTS

The following design and construction report describes the solar heating and cooling system now installed and operational on the Community Recreation Center Building of the City of Santa Clara, California. The Lockheed Palo Alto Research Laboratory working for the City of Santa Clara was responsible for the creation of the system design concept and reduction of that concept through building architect/mechanical engineer team to an appropriate set of engineering drawings and specifications sufficient for the City's general contractor and supporting trades and crafts to procure and install the defined system. This report is prepared as partial fulfillment of the City's obligations under the provisions of ERDA, Division of Solar Energy, Contract EY-76-C-03-1083.

At the Palo Alto Research Laboratory, Energy Programs assembled a design team to execute this project; the following are recognized as the principal members of that effort:

L. B. Anderson, Project Manager	C. F. Kooi
F. J. Brown	S. L. Leacock
A. B. Burns, Project Engineer	K. N. Marshall
R. J. Conti	W. E. Shannon, Mgr, Energy Programs
R. E. Damon	R. K. Wedel

In preparing the original proposal and subsequent amendments, Lockheed recognizes the following for their important contributions:

D. R. Von Raesfeld, Santa Clara City Manager and members of his staff
Norman P. Ingraham, Executive Director, Northern California Power Agency
D. M. Delabarre, Director, California Innovation Group

Mr. R. Bezerra, Water Maintenance Foreman, for field direction of the City-of-Santa-Clara-executed portions of the system installation and startup

Mr. Roger Val, Building Manager, Community Recreation Center

Mr. J. N. Davis, Science Advisor, City Manager's Staff

The National Science Foundation/ERDA Oversight Committee – and the following individuals who throughout the term of the program provided valued insight and suggestions that were key to the final design selections:

Mr. Douglas M. Jardine, General Contractor, Colorado Springs, Colorado

Prof. J. I. Yellott, Visiting Professor of Architecture, Arizona State University

Dr. John C. Ward, Solar Energy Application Laboratory, Colorado State University, Fort Collins, Colorado

In developing the original concept of the project and the subsequent program plan for bringing the Community Recreation Center of the City of Santa Clara into the National Solar Heating and Cooling Demonstration Program, Lockheed recognizes the following:

At the National Science Foundation, Washington, D. C. – Mr. Alex Schwarzkopf (NSF, PTP, Project Engineer)

Dr. Charles S. Chen

At ERDA Headquarters, the Division of Solar Energy:

Mr. Raymond A. Fields

Mr. Ronald A. Scott

Mr. Eugene Doering (ERDA Project Engineer)

At the ERDA San Francisco Operations Office:

Mr. Robert Hughey

Ms. Marilyn Eggers

The following are due special recognition for their participation by interacting with Lockheed throughout the evolutionary design and specification of the solar heating and cooling system. This group includes:

D. C. Thimgan, Architect, Santa Clara, California – the City's architect for the Community Recreation Center

P. R. McCoy, and Associates – the architect's mechanical engineer and the designer of the mechanical systems

G. J. Yamas Company, Inc., South San Francisco, California, and Mr. Gordon T. Walker, and Mr. Edward E. Davis – for their innovative contributions in reducing Lockheed control concepts to hardware reality

The University of Santa Clara, Santa Clara, California – Prof. Richard Pefley of the School of Engineering and graduate students William A. Niemeyer and Stephen L. Ayraud, for their participation in the data monitoring system design and programming of the Lockheed developed algorithms for data acquisition and reduction.

Mr. John C. Bowen, Manager, AMETEK, Power Systems Group, Hatfield, Pa. – director of the AMETEK program which created a product-engineered, flat plate collector, from the specification developed for this system by Lockheed.

This program was authorized in late 1974 with design and hardware related activities beginning in 1975, extending through 1977. Lockheed recognizes the following individuals and groups for their important contributions relative to the successful implementation and startup of the system:

The City of Santa Clara, California, and the City Manager's staff including:

Mr. Earl R. Carmichael, Director, Parks and Recreation

Mr. Robert R. Mortenson, Director of Water and Sewer Utilities, and Project Director for the Solar Program

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INTRODUCTION
by
W.E. Shannon

1.1 SANTA CLARA COMMUNITY RECREATION CENTER

The Community Recreation Center, owned and operated by the City of Santa Clara, California, is part of the nationwide network of buildings and facilities participating in the ERDA-sponsored Solar Heating and Cooling Demonstration Program. The solar-driven heating and cooling system installed on this facility began full operation in the second quarter of 1977, thereby completing construction of a project that was formulated in late 1973.

The Community Recreation Center is a one-story facility with a 27,000-sq-ft net interior area that is used by both the City Government and its residents for a variety of purposes, which may be summarized as follows:

- City staff offices
- Storage and files
- General lobby
- Multipurpose/stage
- Multipurpose/arts and crafts
- Preschool and handicapped services
- Teenage recreation
- Food preparation

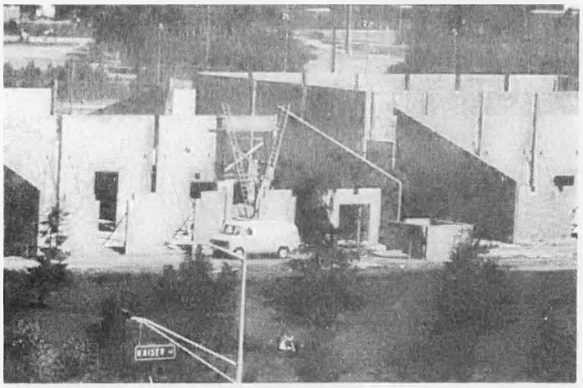
The facility serves the community on a year-round basis, with both day and evening schedules. Because of the prevailing local climate (Mediterranean) and the variety of uses for which the facility is used, it is an ideal application for a solar-driven heating and cooling system.

The building is constructed as a slab on grade, with tilt-up precast concrete walls, using Glulam prefabricated roof truss members with sloping roof areas finished in red Spanish style consistent with the theme of the City of Santa Clara – the "Mission City." The building is generally of rectangular shape with the long dimension running in an east-west direction, thereby making the sloping roof areas on the south side of the building ideal placement areas for solar collectors. The size, shape, orientation, materials of construction, and intended use were evaluated to develop anticipated time-varying heating and cooling loads for the facility. This particular building is a cooling-dominated design with the peak summer cooling load (5.9×10^6 Btu per day) being approximately twice the peak winter heating load. The maximum cooling load for design-day conditions was calculated to be 65 tons. The building under construction, the facility prior to installation of solar arrays, and the completed installation are shown in Fig. 1-1. Highlights of the installed solar heating and cooling system are presented in Table 1-1.

Fixed flat-plate roof-mounted collectors provide heat to underground storage via an intermediate heat exchanger; or, when the incident solar insolation permits, drive one or both of the installed absorption chillers to produce chilled water for underground storage. Placement of major solar system components on or within the building is shown in Fig. 1-2. Figure 1-3 schematically depicts operation in the high solar mode.

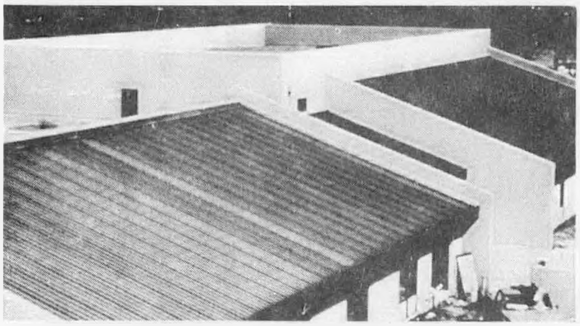
The building interior is divided into eleven zones, each served by a fixed air volume fan coil unit of the two-coil design having both a hot and cold coil. In each zone, depending upon sensed requirements for heating or cooling, hot or chilled water is brought to the individual air handler from underground storage to condition air being exhausted into the zone volume. The floor plan of the building is shown in Fig. 1-4, and interior views in Fig. 1-5.

System controls are electronic and system control valves are electric or electro-hydraulic with all components being industrial quality, readily available in the commercial market, and in this instance supplied by the Barber-Coleman Company.



a. Early Stage of Construction

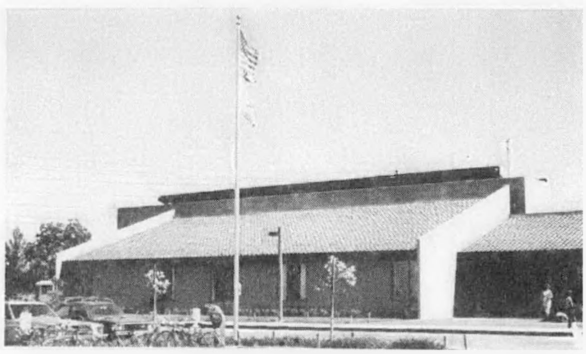
b. Outer Shell Completion



c. South Roof, With CORTEN Steel Installed

d. Completed Facility, South Facade

e. Lower Roof Array and MER Entrance



f. Completed Facility, Entrance and North Facade

Fig. 1-1 Community Recreation Center, Construction to Completion

Table 1-1

SOLAR HEATING AND COOLING SYSTEM CHARACTERISTICS

Building Location	969 Kiely Blvd., Santa Clara, California
Building Area	27,000 sq ft floor space, single story
Interior Space Conditioning	Heating and cooling, water-to-air heat exchanger via fan coils, constant volume air handling system
Primary Energy Source	Solar, 80 percent (on an annual basis)
Auxiliary Energy Source	Gas-fired boiler
Solar Cooling System	
• Cooling Units	Two 25-ton lithium bromide, absorption cycle, water chillers fired by hot water from solar collectors
• Cold Water Storage	50,000 gal at 40° to 55°F, ambient pressure, underground
• Other	Outdoor air economizer
Solar Heating System	
• Heating Units	Solar collectors; primary/secondary circulating loops operate as closed, pressurized system – energy storage via heat exchanger to hot tank
• Hot Water Storage	10,000 gal at 120° to 212°F, ambient pressure, underground
Service Hot Water	Line pressure to faucets via heat exchanger, with blending loop for temperature control
Ametek Solar Collector	
• Type	Flat-plate, self-contained modules, vented through dessicant
• Total Absorber Plate Area	7,085 sq ft (nominal)
• Absorber Plate Material	Copper
• Working Fluid	Water plus 10 percent propylene glycol (freeze protection)
• Selective Coating	"Ametek Black"; solar absorptance $\geq$ 98 to 99 percent, infrared emittance $\approx$ 0.20 to 0.40
• Cover	Two glass covers with transmission $\geq$ 90 percent net
• Insulation	Fiberglass and mineral wool with no organic binders
Building Loads	
• Peak Winter Heating Load	2.9×10^6 Btu/day
• Peak Summer Cooling Load	5.9×10^6 Btu/day

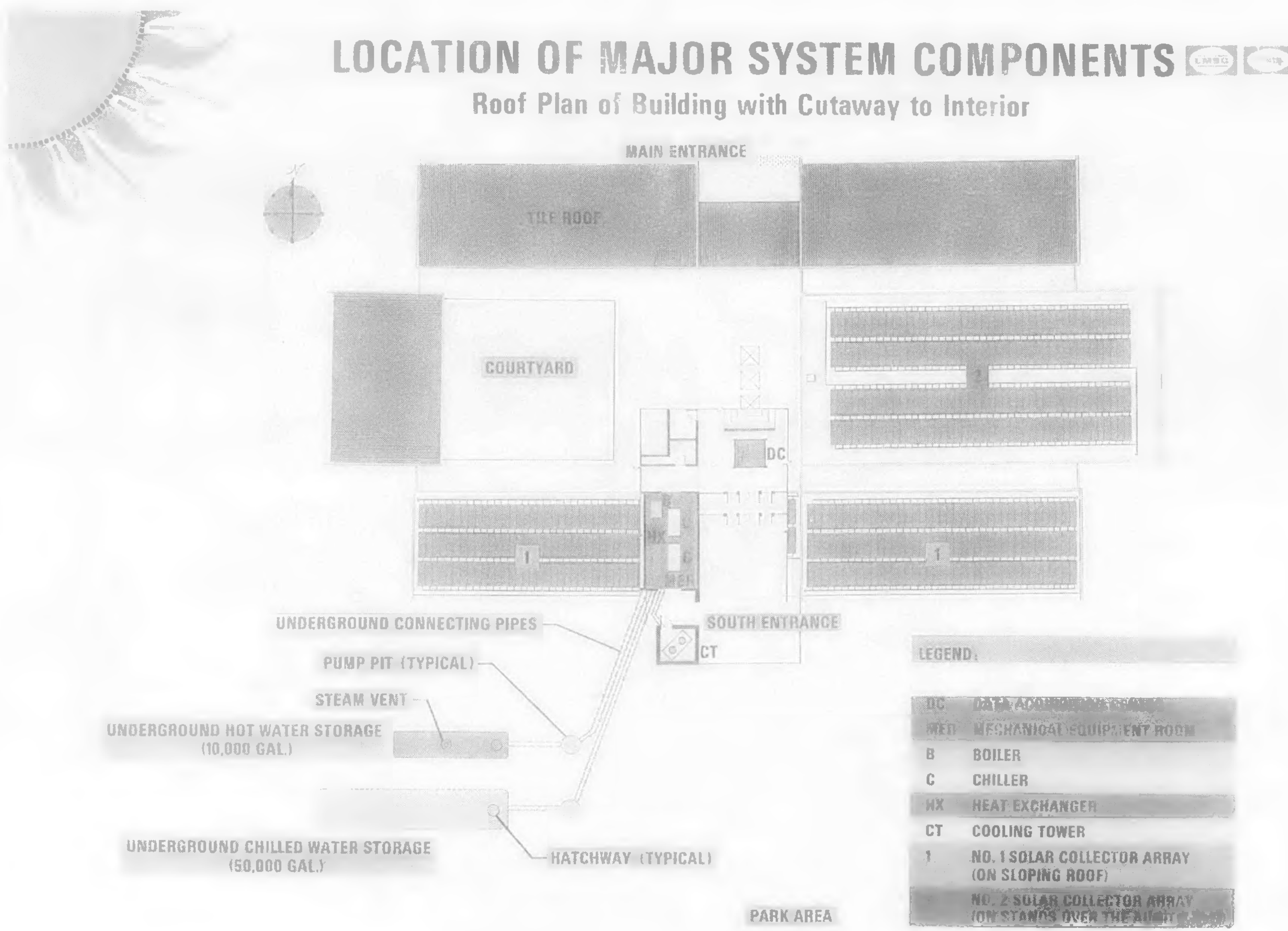


Fig. 1-2 Location of Major System Components

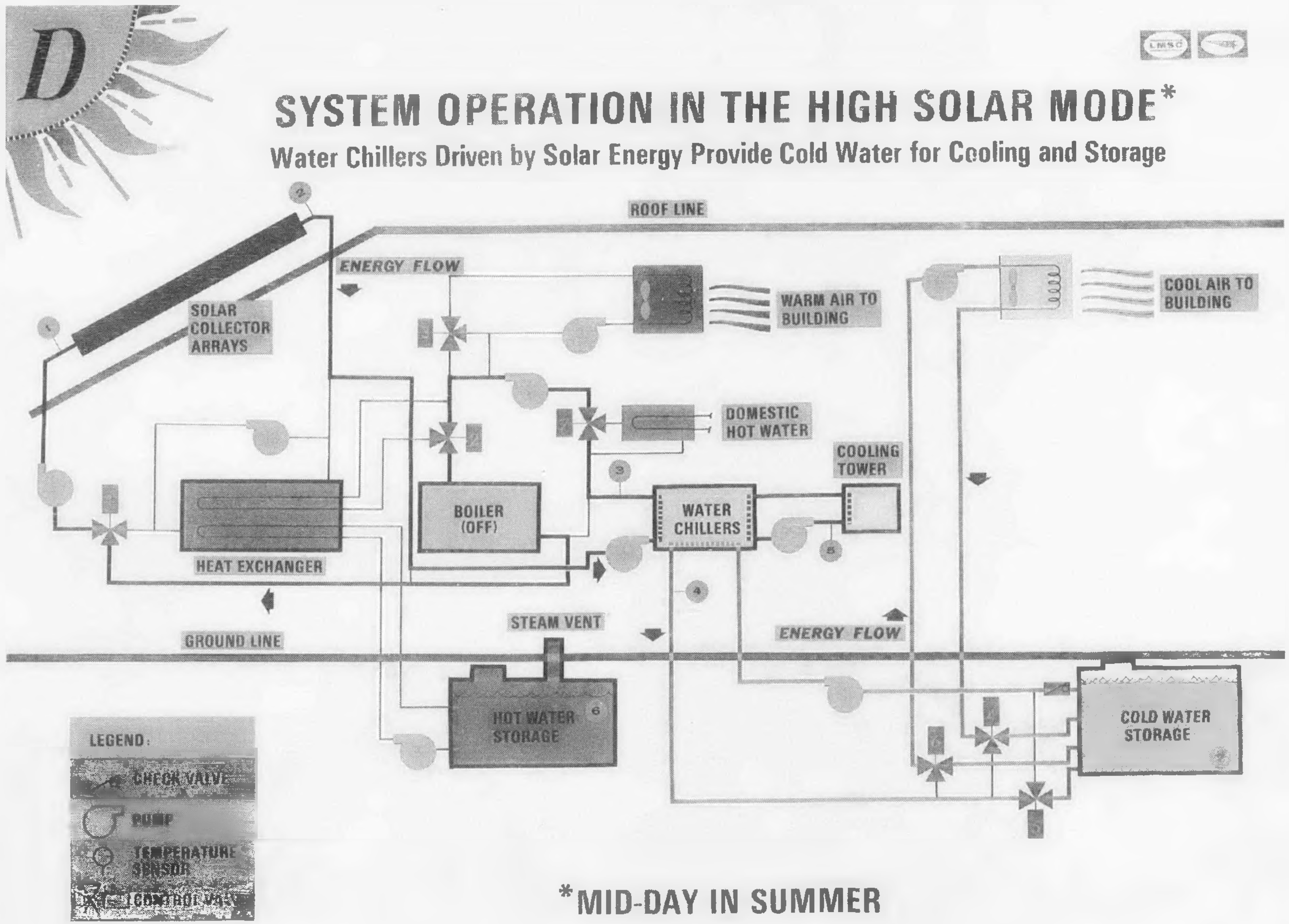


Fig. 1-3 System Operation in the High Solar Mode

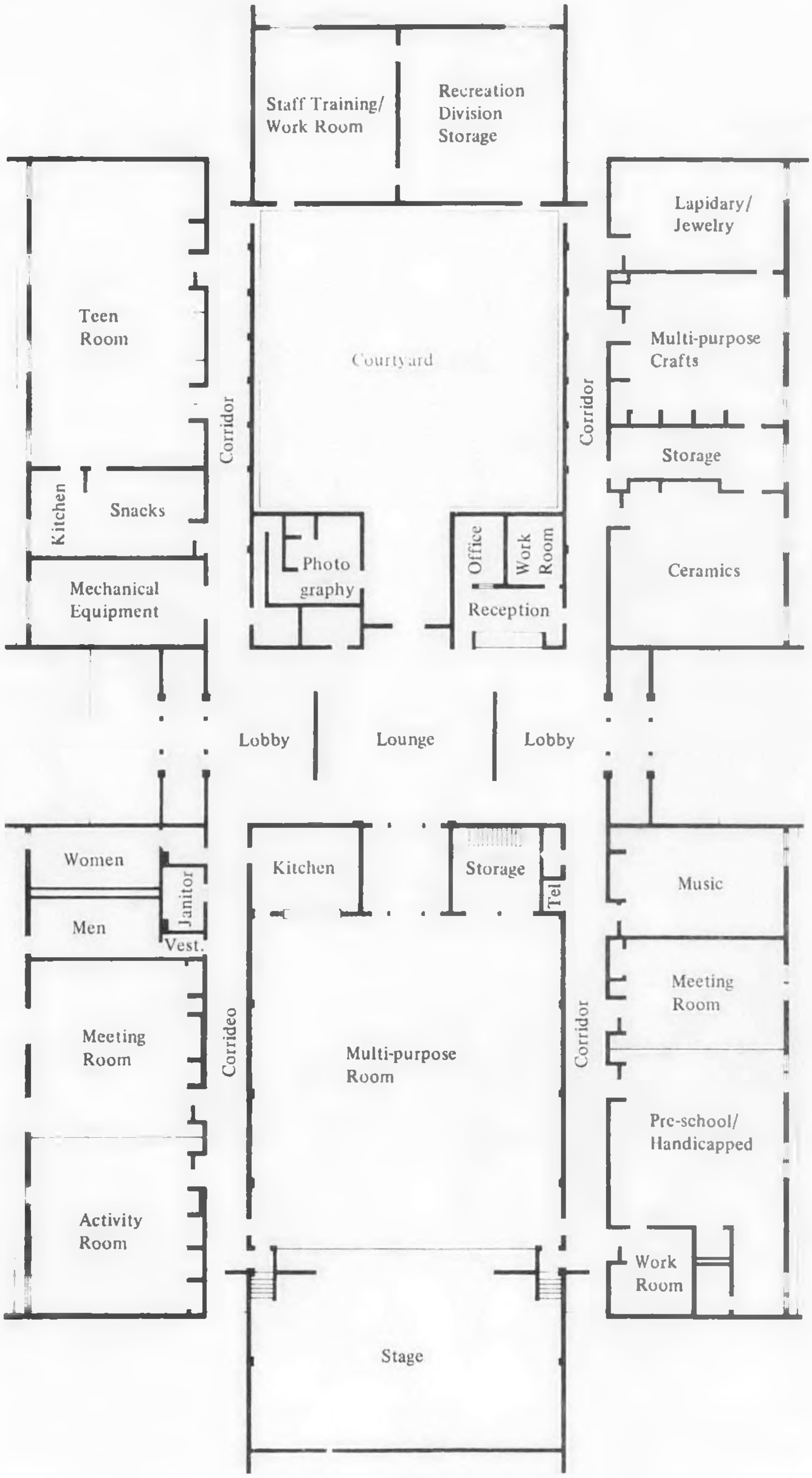
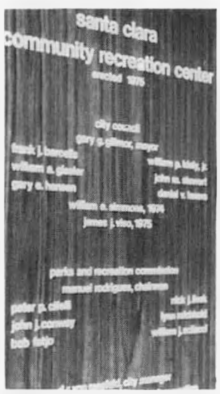


Fig. 1-4 Community Recreation Center Floor Plan

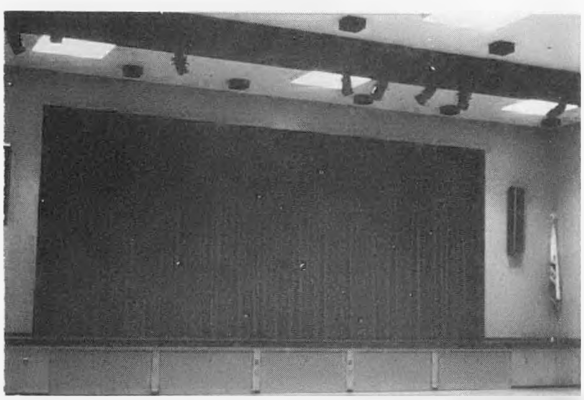
a. Lobby and Lounge

b. Lobby

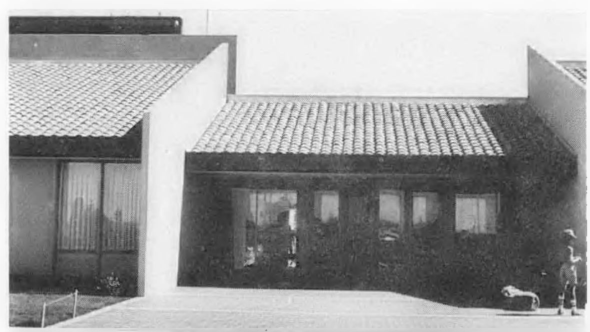


c. Building Sponsors

d. Courtyard



e. Multipurpose Room



f. Main Entrance

Fig. 1-5 Building Details

Building cooling requirements are met by lithium bromide absorption water chillers; the building has two 25-ton ARKLA units installed in the mechanical equipment room. The system operating logic is one in which at all times when the incident solar insolation is sufficient, the collector array drives one or both absorption chillers simultaneously producing chilled water for underground storage. Building cooling is then accommodated by drawing chilled water from underground storage and delivering it to the appropriate heat exchange surfaces in the individual fan coil units. In those situations when there is inadequate chilled water storage in reserve, the control system directs the auxiliary natural gas fired boiler to produce hot water which is then piped directly to the input side of the water chillers providing either 25 or 50 tons of chilled water production capability on an instantaneous basis.

Building heating functions similarly to cooling in that hot water from underground storage is piped to the heat exchange surface of the individual air handler to satisfy zone heating requirements.

Underground storage tanks are made from steel plate and are treated on both interior and exterior surfaces. In this system design, the hot tank as well as the cold tank operate at ambient pressure. This approach was chosen to avoid the expense of fabricating a pressure vessel for hot storage. Tank exteriors are coated with a sprayed urethane foam insulation followed by the application of a vapor barrier coating. Tanks were placed in specially prepared direct burial pits having self-draining fields achieved through the use of pea gravel and an outer vinyl vapor barrier. The internal surface of the cold storage tank is treated with a bitumen coating equivalent to that commonly utilized in potable water storage tanks. The hot water storage tank has a special ceramic liner, "feroline," to provide corrosion protection at the air-water interface at the top of the tank. Figure 1-6 shows the placement of the buried hot and cold tanks on the southside of the building along with the hot tank vent, access to the tanks, and access to the pump wells.

The fixed flat plate solar collector array is fabricated from individual collector modules (Fig. 1-7) with each module approximately 26 in. × 100 in. The collector design specification was structured to maximize the performance of this type of collector design in

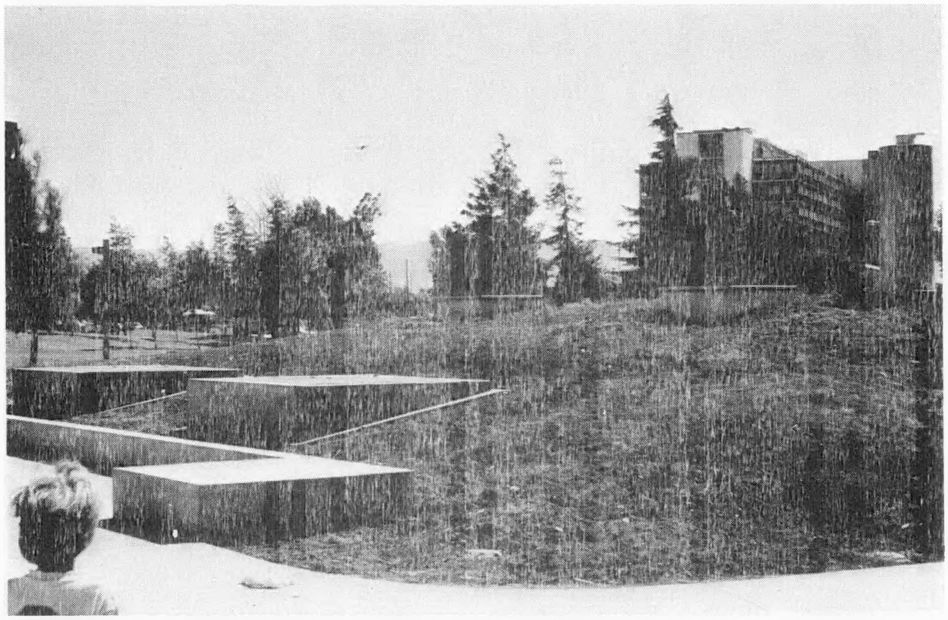


Fig. 1-6 Underground Hot and Cold Water Storage Installation

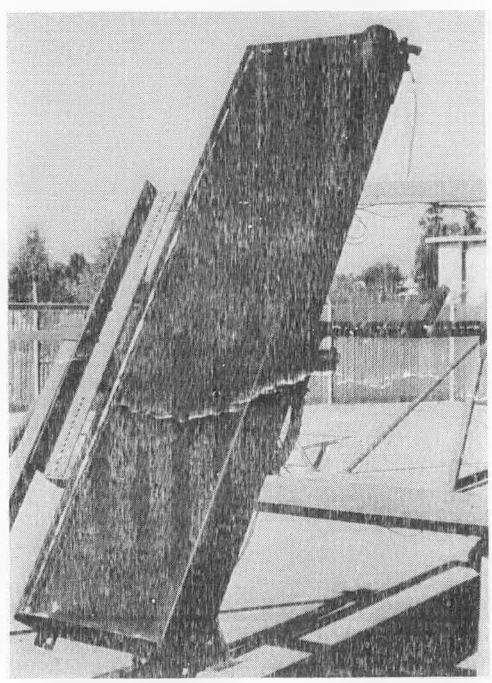


Fig. 1-7 Fixed Flat-Plate Solar Collector Array Module

order to attain fluid temperatures adequate to drive the absorption water chillers in the system. The collector uses two cover glasses of high-transmission glass made by Fourco and a copper roll bond absorber plate from Olin with a special fluid passage design to maximize the absorber plate fin efficiency (approximately 99%). The upper (bright) side of the absorber plat is treated with a selective coating. This selective coating is a proprietary process developed by the collector manufacturer, Ametek, and features high absorptivity with infrared emissivities in the range of 0.25 to 0.30. The cover glass spacing and spacing of cover systems on the surface of the absorber panel were optimized by a solar collector computer program in order to minimize conduction, convection, and radiation losses. (See Appendix H.) Conduction losses are further reduced by the extensive use of thermal stops at all points of contact between the cover system and the absorber plate with the collector case, as well as the use of a back surface insulation, all contained in an airtight enclosure that is permitted to breathe through a dessicant pack which is recharged during daylight hours by incident solar energy.

The collector array (consisting of 436 modules, for a total of 7,085 sq ft) is mounted on the sloping south facing roof as well as the roof of the multipurpose room. Both arrays are installed at a slope of 18 deg, and since this building is a cooling-load dominated design, analysis showed that this collector tilt would be appropriate for system operation, when evaluated on an annual basis.

The use of individual collector modules to form the roof weather element was considered; however, the City decided that a full roof and weather seal independent of the collector structure should be created with individual collectors fastened thereto. In keeping with the mission style of design, the south facing sloping roofs were finished in CORTEN steel and allowed to achieve their natural iron oxide coloration, which closely resembles the remaining tiled roofs. The collector modules were then provided with mounting feet and attached to lateral rails which in turn are fastened to the CORTEN roof.

In keeping with the characteristics of the local climate, provision for full outdoor air usage (economizer) is also included. The climate is characterized by large temperature swings, day to night, in both winter and summer. Thus, the economizer has an important impact upon satisfying building cooling requirements during the frequent evening/night time utilization.

1.2 PROJECT HISTORY

The Community Recreation Center is owned and operated by the City of Santa Clara, California, which is located in the county of Santa Clara. The City is one of the high-growth-rate urban industrial cities of the San Francisco Bay Area, geographically positioned as shown on Fig. 1-8. The City covers an area of 18.6 square miles and has a 1977 population of 90,000. Chartered some 125 years ago, the city currently operates with a Council-City Manager form of government. The mayor and six councilmen are elected for 4-year terms; the City Manager is an appointive position.

The City owns and operates its own water, sanitary and electrical utilities. The Santa Clara utility system provides electric power to approximately 36,700 customers and water and sewer to 21,700 customers. City utility services are shown on Table 1-2.

Table 1-2
CITY OF SANTA CLARA UTILITY SERVICES
(June 1976 Data)

	Electric	Water	Sewer
Consumers	36,700	21,700	21,700
Total Usage	1,138,360 MWH	7,017 Million Gallons	–
Plant Capacity	374 Megawatts	56.7 Million Gallons/Day	–
Miles/System	514.4	263.5	239.8
Employees	97	39	9

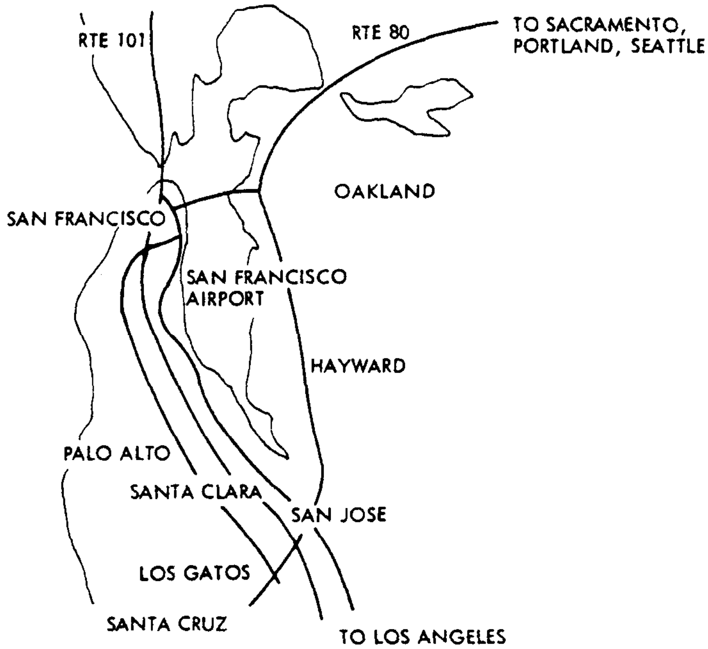


Fig. 1-8 Geographic Location of Santa Clara, California, in the San Francisco Bay Area

The master plan for the City of Santa Clara enacted several years ago made provision for a 52-acre Central Park to be located in the heart of the city. Major facilities included in the Central Park plan include the International Swim Center, Central Library, tennis courts, and multiuse athletic fields. In the Fall of 1973 the City Council initiated action to implement the next planned addition to Central Park – the Community Recreation Center. This facility and its projected use were described in the preceding section.

Planning for the Community Recreation Center occurred in a time period when the city staff recognized the desirability of creating a structure that would be fully consistent with evolving national objectives in energy conservation. At the direction of the City Manager, staff personnel surveyed then existing concepts for the design and construction of energy-efficient buildings and further explored the available technology for using solar energy to provide interior space heating and/or cooling. Such issues were most appropriate for exploration by the City Manager's staff since Santa Clara is a "utility oriented" city. By operating its own municipal electric department, Santa Clara provided the potential setting to evaluate both problems and benefits to be derived from the use of solar energy considering the viewpoints of both supplier and user.

In the fall of 1973, the Arab oil embargo was in effect and this nation was just beginning to experience a rapid escalation of energy prices. Municipal utilities, Santa Clara included, began to consider both short-term and long-term issues relative to satisfying demands for energy. As a part of this consideration, the issue was raised as to what role if any solar energy might play in the City's future planning. At this point, the Palo Alto Research Laboratory was approached by City personnel soliciting the firm's views on both the state of the art as well as the feasibility of including some form of solar-driven system on the Community Recreation Center facility, then in its final planning stages.

Aware of the available technology, the federal program for solar energy being formulated by the National Science Foundation and the initiation of the widely referenced NSF Phase Zero Studies on solar heating/cooling, it was Lockheed's suggestion to the City that some form of solar energy usage be an integral part of the planned new facility.

From these early discussions between the City and the Palo Alto Research Laboratory, a joint effort was undertaken to prepare and submit to the National Science Foundation a proposal for the inclusion of solar-driven heating and cooling on the Community Recreation Center, with that facility to be added to the network of solar demonstrations then in the planning stage as a part of the NSF proof of concept experiments (POCE).

1.3 PROJECT ORGANIZATION

Before proceeding with the description of the project organization, it should be noted that the City of Santa Clara has some 90,000 residents and an annual operating budget of 88 million dollars. As a municipality, it has a fully structured set of City services and administrative capabilities.

The Community Recreation Center was initiated by the City, engaging a project architect – David C. Thimgan of Santa Clara – to create a design along with the supporting drawings and specifications. Upon completion of this data, the City advertised for bids from general contractors and ultimately selected Welch Construction Inc. as general contractor for the building construction program.

With reference to the solar heating/cooling system for the Community Recreation Center, the Palo Alto Research Laboratory assisted the City in planning, preparing, and submitting a proposal for the design, hardware acquisition, installation, and performance monitoring of such a system. Upon the acceptance of this proposal by the National Science Foundation (NSF) and subsequently the Energy Research and Development Administration (ERDA), the award was made in the name of the City of Santa Clara.

As shown in Table 1-3, the program awarded to the City of Santa Clara is officially known by the title "Solar Heating and Cooling as a Public Utility,"* with D. R. Von Raesfeld, the City Manager, as principal investigator. The City Manager in turn structured the organization as shown in Fig. 1-9, with Robert R. Mortenson, City staff member, and Director of the City's Water and Sewer Departments, designated full-time project director. This selection was based on his familiarity and experience with municipal utility (water) operations along with prior experience in federally sponsored grant programs.

The assignment for the Lockheed Palo Alto Research Laboratory was to create a solar heating/cooling system concept, this to be followed by preparation of engineering drawings, memos, and specifications with appropriate hardware and material callouts which could then be utilized by the architect (D. C. Thimgan, AIA) and his supporting mechanical engineer (P. R. McCoy Associates) to prepare drawings and specifications in the conventional CSI** format for the solar-peculiar additions to the facility. City departments were involved for procurement, legal, and as subsequently developed,

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*ERDA contract EY-76-C-03-1083
**Construction Specification Institute

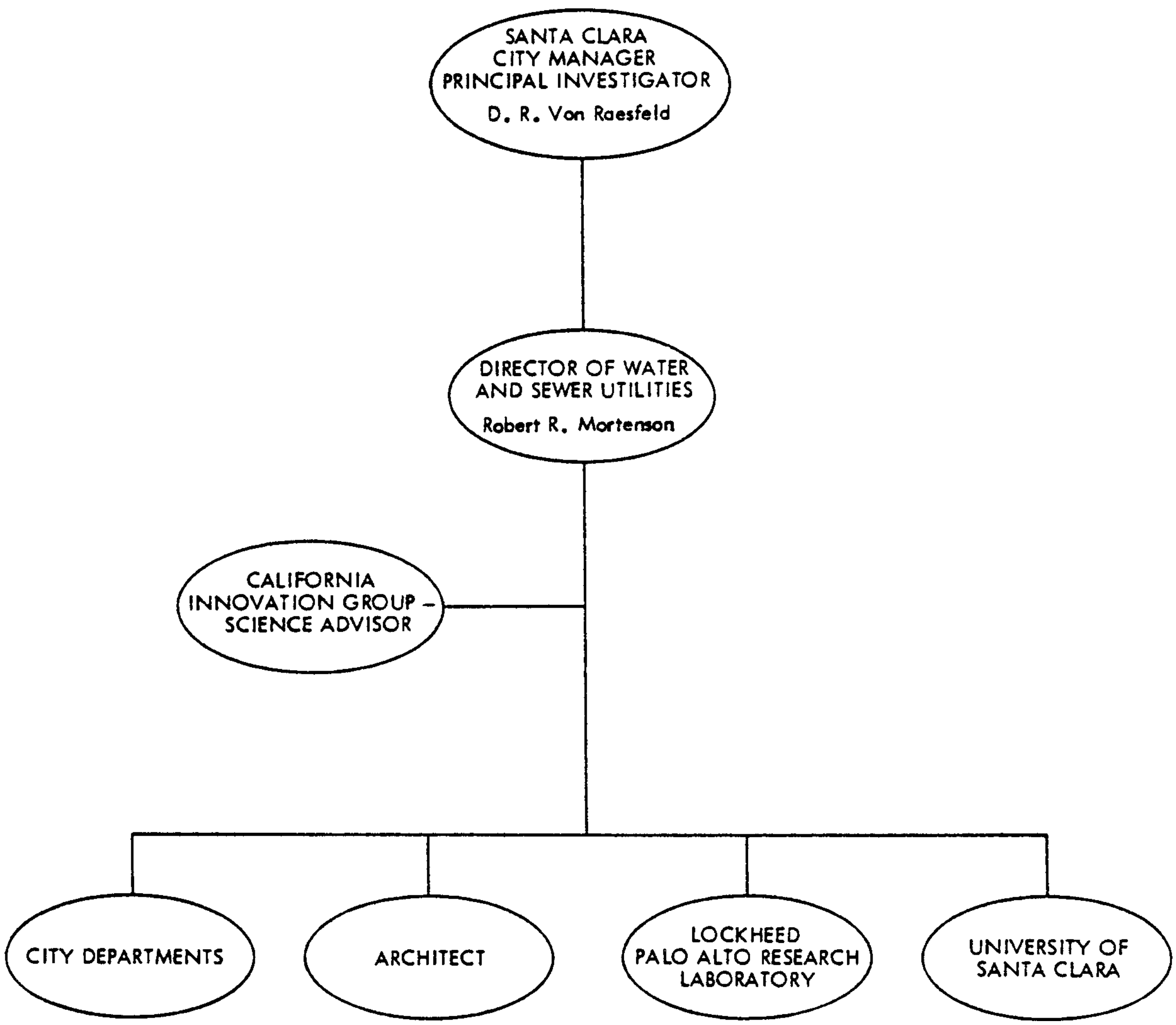

Fig. 1-9 Program Organization

Table 1-3

SOLAR HEATING AND COOLING AS A PUBLIC UTILITY

PHASE I SOLAR HEATING AND COOLING SYSTEM CONSTRUCTION

- SOLAR SYSTEM DESIGN
  - SPACE CONDITIONING
  - CONTROL STRATEGY
  - MONITOR INSTRUMENTATION
  - PREPARATION OF DRAWINGS AND SPECIFICATIONS
  - HARDWARE ACQUISITION, FABRICATION AND INSTALLATION
  - SYSTEM START-UP AND CHECK-OUT

PHASE II PUBLIC UTILITY APPLICATION STUDY ("UTILITY BLUEPRINT")

- SOLAR ENERGY UTILIZATION BY PUBLIC ENTITIES
  - HOW TO?
  - WHY TO?
  - THE ECONOMIC VIABILITY
- AN EXAMINATION OF MAJOR ISSUES
  - NORMALIZED COMMUNITY CENTER PERFORMANCE
  - AUXILIARY ENERGY PROJECTIONS – COST & AVAILABILITY
  - CODES
  - LEGAL ALTERNATIVES
  - IMPLEMENTATION
- PREPARATION OF DECISION LOGIC

providing the major portion of labor and services for installation and startup of portions of the total system. The University of Santa Clara, working under Lockheed's direction, prepared detailed programming for the solar data acquisition system, implementing the system-level algorithms developed by Lockheed. This would provide the basis for the University subsequently undertaking a task to collect, reduce, and interpret performance data acquired during operation of the fully installed system.

1.4 SCHEDULE

As originally conceived the program for designing and installing solar heating and cooling on the Community Recreation Center would proceed concurrently with the construction of the facility. This planned schedule is shown in Fig. 1-10. As events later dictated, the goals of this schedule were in no way attained. While the contracting

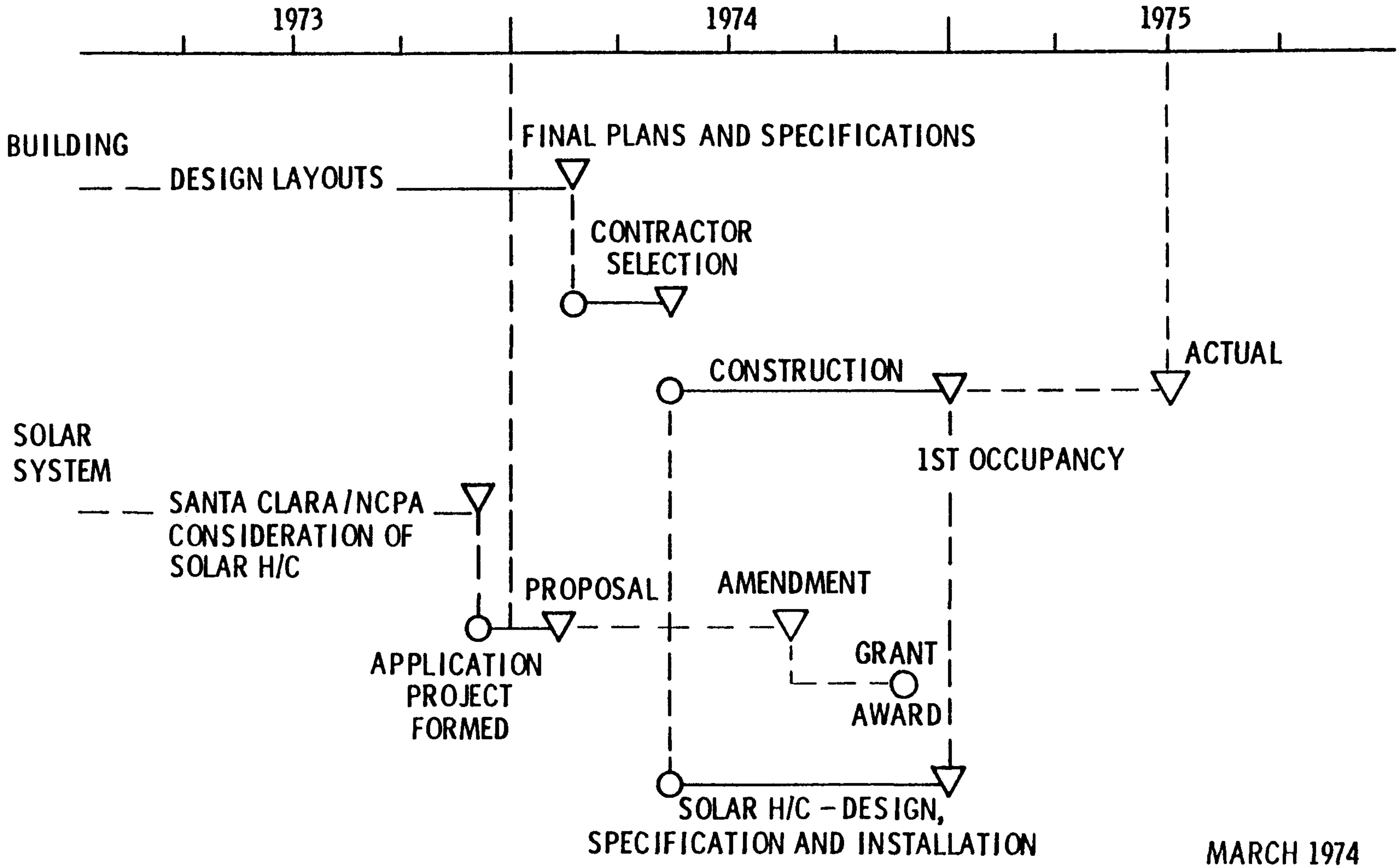

Fig. 1-10 Planned Schedule (Proposed March 1974)

and construction of the facility proceeded generally according the plan with the City taking first occupancy in July of 1975, the schedule of activities related to the solar system was totally different.

The chronology of major events from project initiation in 1973 through project completion in 1977 is shown in Table 1-4.

For design and construction activities, (Phase I) experience has shown that the project took approximately twice as long to implement as initially planned and from a cost standpoint, was twice as expensive as initially estimated. Further details on actual costs of solar-peculiar hardware acquisition, installation, and distribution by major category are presented in Section 6 of this report.

1.5 OBJECTIVES

The contract awarded to the City of Santa Clara for installing solar heating and cooling on the Community Recreation Center was in fact a program which contained two major phases. These phases, I and II, were described in highlight fashion in Table 1-3. Phase I concentrated entirely on the engineering details and hardware mechanization of the system with Phase II to examine much broader issues of future potential solar energy utilization by public entities.

Solar energy utilization for heating and cooling at the Community Recreation Center has multiple values for ERDA, in that it provides:

- A case study in building design considering energy conservation and solar system installation and operation
- Comprehensive performance evaluation of solar driven heating and cooling

The City of Santa Clara as a local government is "public utility oriented." The City is acutely aware of current and projected demands on utilities within its consumer areas. Equating demand to supply in a cost realistic manner represents a continuing challenge. Thus, the dual interests of being able to assure customer service but at a projected future cost of such services that are realistic was one of the underlying motivations that prompted Santa Clara to undertake this program.

Table 1-4

CHRONOLOGY

Year	Month	Event
1973	Jul	NSF Phase 0 Heating/Cooling Studies awarded
	Nov	City Manager invites Lockheed views on solar energy potential
	Jan	Santa Clara/Lockheed joint effort formed to seek NSF sponsorship for POCE
1974	Mar	Solar Energy Proposal submitted to NSF
	Apr	Community Center construction starts
	Nov	Solar Energy Grant awarded to City by NSF
1975	Jan	Project funds transferred from NSF to ERDA
		Lockheed given go-ahead for system design of specification
	Jun	Community Center construction completed (W/O solar)
	Jul	Solar collectors ordered; first bids received on solar additions
		Additional ERDA funding requested, for solar hardware
	Oct	Additional ERDA funding received
1976	Feb	Hot and cold storage reservoirs installed; solar plumbing installation started
	Mar	First collector shipments
	Jul	Electrician's strike
	Aug	Balance of solar collectors delivered and installed
	Sep	Water circulated through collectors – malfunctions noted in collectors
	Oct	Final shipment of collectors installed
1977	Jan	Repairs to collectors completed by manufacture
	Feb	Data system purchase vs lease negotiated; header insulation started
	Mar	Energy balance obtained via data acquisition system
	Apr	Both absorption chiller units powered by solar array
	May	Full operation of installed solar system

Cities such as Santa Clara are in a position to accomplish what would otherwise be totally impractical in the private sector. The usual connotations of profit or return on investments did not apply in this particular project. Therefore, ERDA was assured from the beginning of a project planning and management attitude which had as its central motivation the thorough and unbiased evaluation of solar energy utilization in the context of identifying practical ways in which to apply or promote its introduction. Santa Clara as a utility operator is motivated to find ways in which to equate energy demand to supply, for both present and future time periods, achieving this desired equality at acceptable economic costs.

1.6 PREDICTED PERFORMANCE

Computer modeling of system performance was done by several techniques, which varied one to the other by the rigor of representing the dynamic real-time performance of the final system configuration. Modeling was used as an important tool in the evolution, refinement, and ultimate selection of the solar system concept and its several principal operating modes.

As the design of the system evolved, it became apparent that we would need to use a real-time dynamic simulation of the system — building utilization and installed solar system — if we were to optimize the design and at the same time make reasonably accurate suggestions of anticipated performance. Our initial plan was to utilize the University of Wisconsin developed TRNSYS program for this effort. As one of the original users of TRNSYS, we soon found, like others, that it was a program still in its evolutionary stages and as such could not satisfy our needs in terms of a design tool. This led us to develop our own modeling and real-time simulation of the Santa Clara system, by a program which we have identified as SOLARDYN, a computer modeling capability which has its origins in TRNSYS-Mod. II.

A description of the SOLARDYN program along with an example of the simulation printout is presented in Appendix G. Table 1-5 and Fig. 1-11 present an annual prediction of expected Santa Clara Community Recreation Center solar heating/cooling system performance.

Table 1-5

AVERAGE DAILY TOTALS FROM MONTHLY CUMULATIVE TOTALS

(KJ × 10^{-6})

	QU Solar	0.65 QU	Aux Htr	0.65 Aux	Htg Coils	Clg Coils	Bldg Load
Jan	2.201		0.390		2.504	0	2.514
Feb	2.482		0.071		2.089	0	2.101
Mar	3.145		0		1.447	0	1.457
Apr	4.154		0.126		0.926	0.621	0.313
May	3.582		0.322		0.426	1.154	0.720
Jun	4.688	3.047	1.575	1.024	0	3.030	3.025
Jul	4.958	3.223	2.271	1.476	0	3.944	3.941
Aug	4.670	3.036	3.248	2.111	0	4.681	4.677
Sep	3.775	2.454	2.137	1.389	0	3.316	3.302
Oct	4.244		0.755		0.617	1.592	0.966
Nov	1.686		0.538		0.832	0.682	0.160
Dec	2.441		0.772		2.710	0	2.720

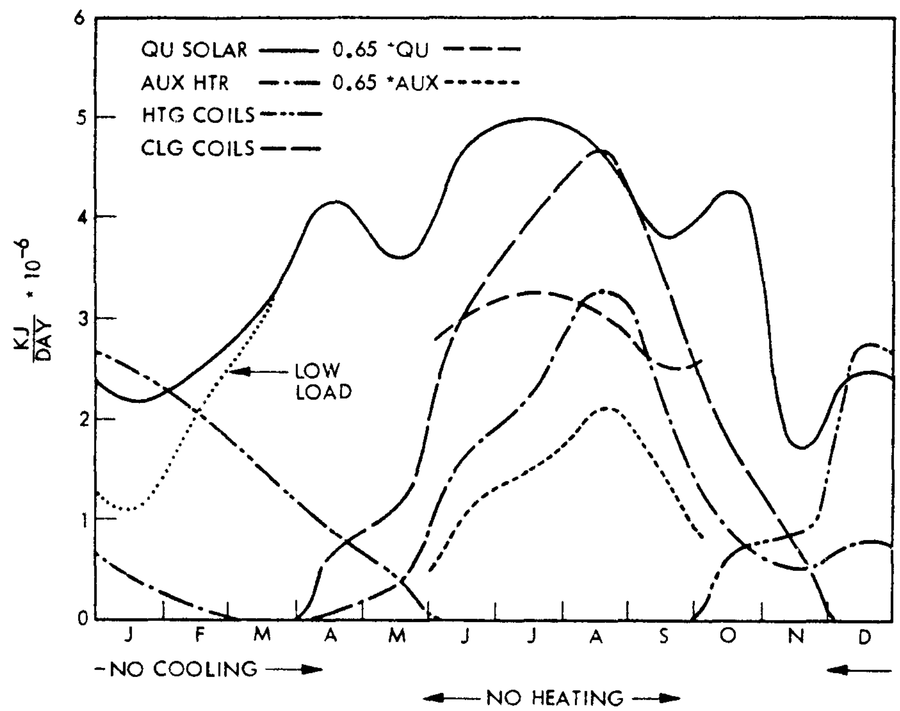

Fig. 1-11 Plot of Expected Solar Heating/Cooling System Performance

Section 2
SOLAR SYSTEM DESIGN

by

W. E. Shannon

2.1 CONSTRAINTS

As owner and operator of the Community Recreation Center, the City of Santa Clara — while interested in obtaining first-hand experience with solar heating and cooling systems — was at the same time concerned that its public facility not be converted into a research laboratory. Lockheed was admonished early in our association with the City to keep in mind that the task was creation of a capable, reliable interior space-conditioning system for the building. The City outlined its requirements and desires as being a solar system having minimum complexity; minimum maintenance; as fault-free as possible; and, wherever possible, fabricated from commercially available materials and components whose expected lifetime would be of the same order as that of the basic building (in excess of 30 years).

As Lockheed described various concepts and systems designs, the City's concern immediately focused on the principal nonstandard component — the solar collector array. The collector was given special attention, and Lockheed was assigned added responsibility to assure that this component would not be a problem in terms of short life time or excessively high cost as part of the total installed system.

Since the building was of significant size (27,000 square feet), Lockheed recognized the opportunity to provide (at minimum cost) some added flexibility in the plumbing and system interconnection to allow a variety of experiments and system evaluations to be performed on this solar heated and cooled facility. Such suggestions were acceptable to the City with the proviso that any such activities should not in any way impact the normal usage proposed for the Community Recreation Center.

As outlined in the Section 1, initial planning and design of the building preceded the decision to seek federal support for the installation of solar heating and cooling. As a consequence, the fundamental initial building design – size, shape, orientation, and materials of construction – was developed by the architect and the City without considering the impact of their design on subsequent installation of solar heating and cooling. As the building design developed, provision was made for adding a solar system in selected areas, but construction was initiated well before the National Science Foundation decided to accept the City's proposal. While this system cannot be called a retrofit installation, one would have taken different design approaches if the solar system had been fully integrated into the original planning for the facility.

An issue given extensive consideration by Lockheed and the City dealt with location of the collector array. On examining the architect's original plans, recommendations had been made that the collector array could be placed ajacent to the building. The array could have been installed in such a fashion as to provide the facility with a covered parking lot. It is of interest to note that it was a National Science Foundation decision that the collector array be placed on the roof. The NSF was influenced by critics of the then evolving solar heating and cooling program and questions about the compatibility between solar collector arrays and building roof structures. Once that decision was made by NSF, Lockheed suggested that the collector array be fabricated in the form of individual collector modules, designed in such a way that they would form the outer roof element. As a municipal facility, the building was patterned after other mission-style City facilities. Accordingly, its low-sloping outer roofs were finished in red Spanish tile. The City was reluctant to accept the thought that an adequate and dependable roof member could be created from the individual collector modules, and because of their concern about this system component, Lockheed was directed to plan on a collector array that would mount on top of a weather-sealed roof membrane. It was at this point that the architect recommended that the low south-facing sloping roofs be finished in CORTEN steel where the coloration of this material, when it naturally oxidizes, closely resembles the tile used on the balance of the roof areas. This choice was accepted by the City and in turn was the guideline for Lockheed in selecting CORTEN material as the outer case structure for individual collector modules.

Recalling that the issue of off-roof versus on-roof placement of the collector array was decided in favor of on-roof placement, a related and major impact of that decision was that we were then constrained to available south-facing roof areas as a finite limit on the maximum size of the installed collector array. The roof-mounted array consists of two segments – one being those collector modules mounted on the low sloping roof (18-deg tilt) and the balance or second area consisting of those collectors mounted on the roof of the multipurpose room, also at an 18-deg tilt. One additional aspect of collector placement encountered in the early conceptual design stages was the architect's concern about the external appearance of any roof-mounted collectors. With some reluctance he was finally convinced that collectors mounted on the low south-facing sloping roofs would not be objectionable, but he insisted that the collector array be mounted on the roof of the multipurpose room in such a manner that it would not be visible from street level.

In developing the original building concept to satisfy the functional requirements as defined by the City for the Community Recreation Center, the architect, his mechanical engineer, and other professionals working on the project did not emphasize energy conservation. As Lockheed became involved with the project and was introduced to the preliminary design concepts then in existence for the building, it found that none of the several techniques then available to minimize the annual energy demands to heat and cool a facility (as described in numerous National Bureau of Standards, GSA, and ASHRAE publications) were being considered. Rather, one of the primary design objectives was to meet a City-defined construction cost target.

Through Lockheed interaction with the architect and the City staff, a number of design changes were made to facilitate the addition of the solar system and at the same time reduce the building's annual energy demands. Some of the significant changes included:

- Increased roof insulation, all areas
- Increased multipurpose area roof strength to accommodate the installation of collectors and supporting racks
- Modification of the HVAC system to incorporate an outdoor air economizer

With these issues in mind, the guidelines for developing the initial Community Recreation Center solar system concept were as follows:

- Solar system to provide heating, cooling, and domestic hot water
- Solar system to deliver a significant portion of annual energy requirements, equal to or greater than 70 percent
- The solar system to be able to achieve the same type of interior space conditioning as would have been achieved by a conventional HVAC installation.
- Solar system to connect to multizone air handlers of fixed air volume type with independent hot and cold coils
- Collector array to be roof mounted
- Solar-peculiar equipment to be located in the existing mechanical equipment room
- Energy storage (liquid) hot and/or cold to be located underground on the south side of the building
- Auxiliary energy source – natural gas
- Solar system controls – electronic (this was the basis for the original building HVAC system control)
- System controls and solar data acquisition system to be independent, stand alone systems
- A computer-aided data acquisition system to be provided

2.2 SYSTEM DESIGN EVOLUTION

Heating and cooling load data had to be developed for initial sizing of the system. To begin this effort, Lockheed started with the load calculations of P. R. McCoy and Associates, the mechanical engineer, who had examined winter- and summer-design-day requirements using the classical ASHRAE computation procedure. It is of interest to note that his initial work confirmed our assumptions that the HVAC system design for the facility would be cooling-dominated and that the summer-design-day peak cooling demand was something in excess of 60 tons. We later returned to this same ASHRAE type load data and by our own techniques made an approximation where we converted fixed-point load calculations into 24-hour time-varying heating and cooling load estimates. These were required as input routines in connection with the more detailed dynamic modeling of the building and its installed solar heating and cooling system that we were to later perform.

For system design we also needed climatic and solar insolation data, and it was our approach that this information should be used in terms of the day-to-day, hour-to-hour variations instead of attempting to develop averages or degree-day approximations. In our search for an applicable data base, we were extremely fortunate to find that the Meteorology Department of California State University-San Jose had developed a 10-year file of accurate solar insolation data of which Fig. 2-1 is representative. They additionally had climatic data (Fig. 2-2) and in this latter category we also drew upon climatic data from the San Jose Airport and from Moffett Field Naval Air Station. Our objective was to create an annual day-by-day, hour-by-hour climatic and solar insolation data merge to support our system-sizing and performance-evaluation-modeling activities. Such a data merge was created in the form of a computer tape which combined solar insolation and climatic data appropriate to the micro climate associated with the geographic location of the Community Recreation Center. Figures 2-3 and 2-4 show January through June total insolation and monthly average temperatures from that tape, identified as "South Bay Area – 1971 Profile."

In order to be conservative in the design and specification of the solar system, we purposely selected data from calendar year 1971 because that year had a summer period with several unusually long and hot periods.

For a solar system to provide heating, cooling, and domestic hot water, we recognized that the collector array would have to be capable of the following:

• Heating	110° F
• Domestic hot water	130° F
• Cooling	Equal to or greater than 200° F (for rated or near rated operation of absorption chillers)

SAN JOSE STATE COLLEGE
METEOROLOGICAL OBSERVATORY

LOCATION - 37° 20'N, 121° 53'W

MONTH - AUG YEAR - 1971

SOLAR and SKY RADIATION (cal./cm²)

DAY \ HOUR ENDING PST		05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	TOTAL
1			2.4	13.2	27.6	42.0	55.2	65.4	71.4	73.8	69.0	60.0	46.3	32.4	17.4	4.2	T		580.9
2			1.2	10.2	27.0	41.4	54.6	64.2	70.2	72.0	67.8	57.4	43.0	34.2	19.6	5.4	T		574.2
3			1.2	7.8	24.6	42.0	55.8	66.6	73.2	74.4	69.6	59.4	48.6	33.6	18.0	5.4	T		580.2
4			0.6	3.0	9.0	33.0	54.6	66.0	73.2	74.4	[illegible]	60.0	43.0	33.0	18.0	5.4	T		473.8
5			T	3.0	9.0	23.2	[illegible]	66.0	72.0	73.8	[illegible]	69.0	[illegible]	32.4	17.4	4.5	T		528.6
6			1.2	6.6	17.4	41.4	[illegible]	64.8	70.5	74.4	[illegible]	59.4	48.0	33.6	17.4	5.4	T		564.0
7			1.8	11.4	26.4	41.4	55.2	[illegible]	[illegible]	[illegible]	70.2	[illegible]	44.8	33.4	[illegible]	6.0	T		591.0
8			1.2	16.2	[illegible]	42.0	55.2	[illegible]	71.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.4	T		532.0
9			1.2	15.3	25.2	40.8	[illegible]	64.8	71.4	[illegible]	[illegible]	65.4	[illegible]	[illegible]	[illegible]	4.5			574.3
10			1.2	7.6	23.4	33.4	50.4	61.8	65.4	70.3	[illegible]	61.2	47.4	34.2	16.3	3.6			553.3
11			1.2	9.0	23.4	[illegible]	52.8	[illegible]	[illegible]	63.4	[illegible]	56.4	45.6	30.6	15.6	3.6			539.4
12			0.6	7.0	[illegible]	[illegible]	55.2	63.0	[illegible]	70.2	66.6	53.3	46.8	31.2	16.2	4.2			555.6
13			0.6	4.2	21.0	39.0	[illegible]	63.6	[illegible]	71.4	[illegible]	[illegible]	47.4	32.4	[illegible]	4.8			550.8
14			1.2	10.2	25.2	41.4	55.2	64.2	[illegible]	[illegible]	67.2	59.4	43.0	31.2	15.6	3.6			[illegible]
15			0.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72.6	[illegible]	59.4	[illegible]	30.0	15.6	3.6			[illegible]
16			1.2	[illegible]	[illegible]	[illegible]	[illegible]	64.2	[illegible]	72.6	[illegible]	59.4	[illegible]	31.3	16.2	3.6			[illegible]
17			[illegible]	[illegible]	24.6	[illegible]	[illegible]	[illegible]	73.2	74.4	[illegible]	60.0	43.0	32.4	15.6	[illegible]			574.2
18			1.2	10.2	[illegible]	43.2	[illegible]	[illegible]	72.6	73.2	[illegible]	[illegible]	45.6	[illegible]	15.0	[illegible]			[illegible]
19			[illegible]	12.0	[illegible]	[illegible]	[illegible]	65.4	71.4	72.0	[illegible]	[illegible]	45.6	30.6	15.0	3.0			562.2
20			0.6	5.4	[illegible]	34.2	[illegible]	[illegible]	[illegible]	72.0	[illegible]	[illegible]	47.4	30.6	[illegible]	3.0			[illegible]
21			T	3.0	[illegible]	[illegible]	[illegible]	57.0	[illegible]	[illegible]	67.2	[illegible]	[illegible]	[illegible]	13.2	[illegible]			[illegible]
22			0.6	4.2	7.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.4			[illegible]
23			0.6	5.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.4	2.4			[illegible]
24			[illegible]	[illegible]	[illegible]	30.0	[illegible]	[illegible]	[illegible]	37.5	[illegible]	17.4	[illegible]	7.2	1.8	1.2			[illegible]
25			1.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.0	1.8			[illegible]
26			T	7.2	22.2	37.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.2	12.0	2.4			505.8
27			T	7.4	14.4	39.0	51.6	[illegible]	[illegible]	[illegible]	[illegible]	56.4	45.0	[illegible]	13.2	2.4			[illegible]
28			0.6	6.6	15.6	[illegible]	[illegible]	61.5	68.4	69.0	[illegible]	[illegible]	43.2	27.6	12.6	1.8			502.2
29			0.6	7.5	22.8	[illegible]	[illegible]	63.0	[illegible]	70.2	[illegible]	56.4	43.3	27.6	12.0	1.8			[illegible]
30			0.6	9.0	22.2	36.6	51.0	[illegible]	[illegible]	67.2	[illegible]	[illegible]	42.0	[illegible]	10.2	0.6			[illegible]
31			T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.3			[illegible]
TOTAL			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
AVERAGE			[illegible]	[illegible]	20.2	[illegible]	[illegible]	61.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30.1	[illegible]	[illegible]			[illegible]

REMARKS

Fig. 2-1 Solar and Sky Radiation

SAN JOSE STATE COLLEGE METEOROLOGICAL OBSERVATORY

LOCATION: 37°20'N - 121° 53' W   MONTH AUG   YEAR '71

✓ SE "DRA[illegible]" [illegible] LATE EVENING [illegible]

SURFACE METEOROLOGICAL OBSERVATIONS

DAY	OBS. TIME	W.X. OBST. TO VSBY.	VSBY.	CLOUD TYPES and AMOUNTS	CEIL-ING	STA. PRESS. (mb)	T	T_W	T_{DP}	RH.	MAX. TEMP	MAX. TIME	MIN. TEMP	MIN. TIME	WIND DIR. (Deg)	WIND SPEED (mph)	24HR WIND RECORD TOTAL	PREV. DIR.	MAX. VEL.	REMARKS	OBS. INIT.
1	1500		30	0		1004.5	87.0	[illegible]			84.5	1400	[illegible]	0500	290	11		NW	17		
2	1502		25	0		[illegible]	[illegible]	[illegible]		26	79.2	[illegible]	[illegible]	0530	[illegible]	12		NW	15	VIS [illegible]	[illegible]
3	1504		25	250 ⦶ (4CC, 1CS)		[illegible]	73.5	63.0		37	[illegible]	1200	57.3	0500	300	14		NW	18	[illegible]	[illegible]
4	1513		50	0		[illegible]	78.2	65.0		52	79.3	1400	58.5	0500	300	12		NW	19	[illegible]	[illegible]
5	1508		50	0		[illegible]	81.5	64.7		41	81.5	[illegible]	55.1	0500	330	10		NW	20	[illegible]	[illegible]
6	1501		35	0		1004.1	85.6	66.9		33	86.3	1500	57.2	0400	300	11		[illegible]	17	[illegible] LYRS W[illegible]	[illegible]
7	1500		50+	0		1004.7	84.0	64.5		34	86.5	1400	57.5	0500	340	10		NW	19	FEW CI[illegible] E	[illegible]
8	1500		50+	0		1006.2	85.0	64.0		34	90.0	1300	61.9	0500	320	13		NW	22		[illegible]
9	1507		40	0		[illegible]	84.7	65.5		43	89.1	1400	61.2	0500	300	10		NW	23	[illegible]	[illegible]
10	1504	HK	-X12	150 ⦶ (4ACCAS)		1001.7	92.5	70.4		34	95.2	1430	62.1	0530	330	9		NW	16	[illegible]	[illegible]
11	1500		15	0		1002.9	82.2	67.8		49	85.6	1400	59.1	0400	310	11	✓	NW	19	[illegible]	[illegible]
12	1514		18	0		1004.7	75.6	64.7		61	82.2	1130	57.2	[illegible]	290	13	✓	NW	16	VIS LWR N	[illegible]
13	1513		25	0		1005.4	75.0	64.0		54	[illegible]	1230	55.5	0600	310	11	✓	NW	23	[illegible]	PG
14	1500		30	180 ⦶ (1AC)		1005.4	78.0	63.5		38	83.9	1230	54.2	0530	310	7	✓	NW	18	[illegible]	[illegible]
15	1510		35	0		[illegible]	[illegible]	61.7		45	76.0	[illegible]	[illegible]	0530	270	13		NW	13	[illegible]	[illegible]
16	1501		40	0		1007.9	[illegible]	[illegible]		34	83.0	1400	54.5	0530	320	16G25		NW	[illegible]	[illegible] LYRS [illegible]	[illegible]
17	1510		30	0		1007.6	76.1	61.4		43	81.5	[illegible]	55.9	0530	[illegible]	13		[illegible]	23	[illegible]	[illegible]
18	1512	HK	-X12	0		1004.4	81.0	64.8		39	86.4	1230	52.0	0700	300	10	✓	NW	16	[illegible]	[illegible]
19	1509		15	0		[illegible]	73.5	62.9		55	82.9	1230	53.4	0600	290	18G22	✓	SE	22	[illegible]	[illegible]
20	1500		60	0		1008.1	73.7	63.4		[illegible]	75.7	[illegible]	[illegible]	[illegible]	310	12G18		[illegible]	[illegible]	[illegible]	[illegible]
21	1500		40	250 ⦶ 250 ⦶ (2CC, 1CI)		1008.4	72.5	66.2		69	76.5	1330	57.2	[illegible]	330	12G18		NW	25	[illegible]	[illegible]
22	1500		60	250 ⦶ (3CI)		[illegible]	75.0	61.7		55	[illegible]	1300	[illegible]	[illegible]	330	16		NW	21	[illegible]	[illegible]
23	1500		25	250 ⦶ (7CI)		[illegible]	88.7	65.0		[illegible]	[illegible]	1500	55.4	[illegible]	330	9		NW	21	[illegible]	[illegible]
24	1511	HK	15	E120 ⦶ 250 ⦶ (3 ACCAS [illegible])		1005.6	74.2	64.0		57	81.1	1230	63.1	0600	300	7		NW	18	[illegible]	[illegible]
25	1510		20	250 ⦶ (2CI)		1005.4	81.7	65.6		45	85.0	[illegible]	61.5	0500	300	12	✓	NW	15	[illegible]	[illegible]
26	1506	HK	-X12	180 ⦶ (1AC)		1005.4	77.3	64.8		51	[illegible]	1130	[illegible]	0500	[illegible]	14	✓	SE	20	[illegible]	[illegible]
27	1500		20	0		[illegible]	74.5	62.1		50	76.3	1400	56.5	0400	[illegible]	10	✓	NW	15		[illegible]
28	1500		50	250 - ⦶		1009.3	72.0	59.9		42	73.7	1300	55.8	[illegible]	310	15		NW	[illegible]		[illegible]
29	1500		30	250 ⦶		[illegible]	70.0	59.4		49	71.6	1330	54.4	0530	330	16		NW	22		[illegible]
30	1500		50	0		1007.5	76.0	62.2		45	78.2	1330	53.2	[illegible]	330	15		NW	20	[illegible]	[illegible]
31	1500		30	0		*M	71.5	[illegible]		44	72.5	1430	60.3	[illegible]	[illegible]	11G17		NW	22	[illegible]	[illegible]
TOTAL			949			(1781) (30)	(24[illegible])	(1973[illegible])			(2538)	(1107)	(1784)	(157.5)	(937)	373			[illegible]		
AVE.			31			1006.0	78.3	63.7			81.9	1330	57.5	0500	330	12		NW	20		[illegible]

* BAROGRAPH NOT OPERATING CORRECTLY

Fig. 2-2 San Jose Surface Meteorological Observations

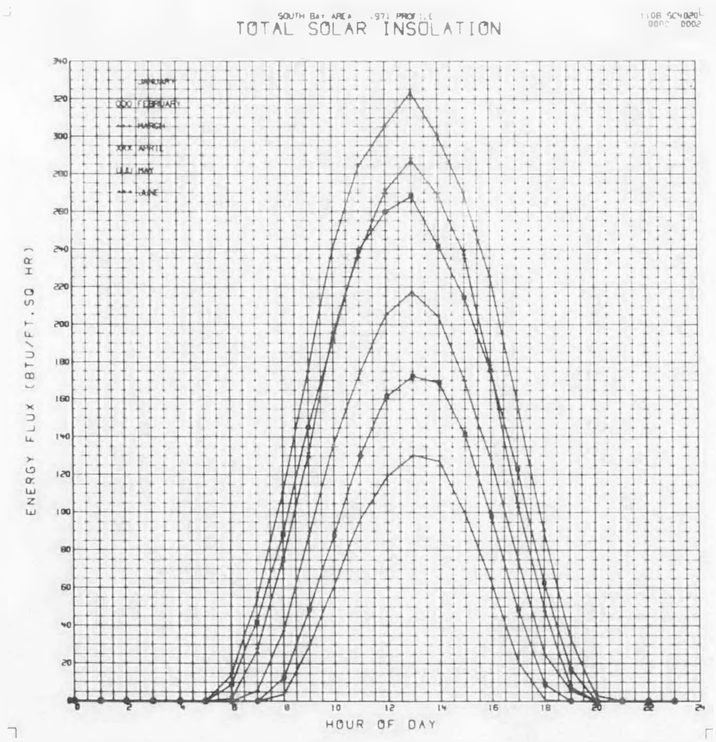

Fig. 2-3 Total Solar Insolation, January Through June 1971

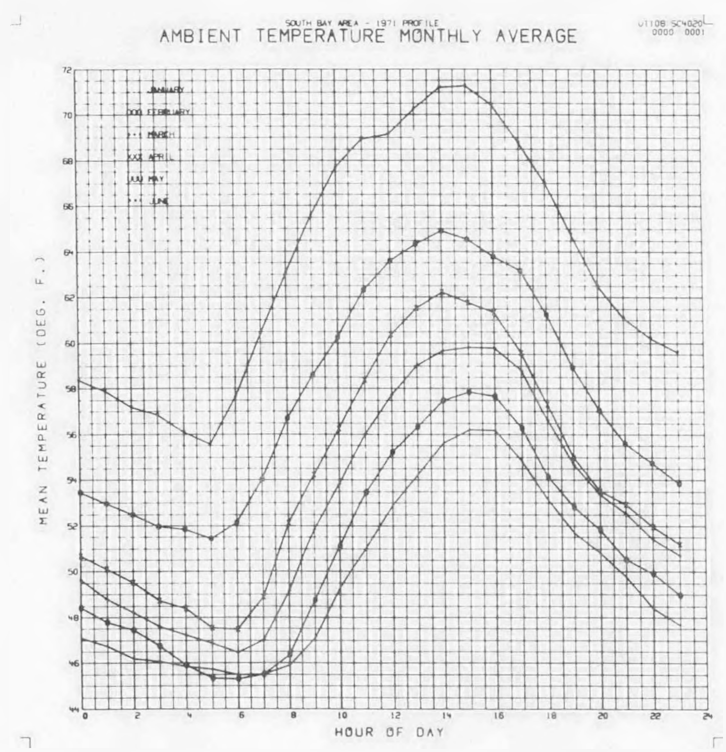

Fig. 2-4 Ambient Temperature Monthly Average, January Through June 1971

As designers we were concerned with identifying either a collector or perhaps two types of collectors that would satisfy this very wide range of exit temperatures in order to satisfy the desired building functions.

The preliminary mechanical system design, which was based on use of a fixed air volume system with individual air handlers having both a hot and cold coil, appeared to be compatible with our evolving solar concepts. Thus, the first issues that were addressed included:

- System interconnection
- Size and type of absorption chiller

An early decision was to utilize hot-water-driven absorption chilling because it recognized that in the 1975 time period there was not an available, reliable or cost effective rankine turbine system, or for that matter any other heat-driven device capable of producing a cooling effect which we could specify for use in this system. While some consideration was given to the electric heat pump, it was recognized that the solar assist to the heat pump was attractive in the heating mode but since this was a cooling-dominated building load situation there was no interest on the part of the National Science Foundation or the City in that type of system.

With this in mind, one of our original proposals contained the installed system concept as shown in Fig. 2-5. This figure is presented to provide a basis for comparison with the final system design and as evidence of our later recognition of what a simplistic as well as totally inadequate system design approach this configuration presented. In this first concept, the collector array provided its energy to hot storage and energy was subsequently moved from hot storage to the input side of a single absorption chiller. Utilizing building load data as well as climatic/solar insolation information developed for this facility, first estimates of energy requirements on an annual basis were developed (Fig. 2-6) by the utilization of a modeling program developed by the Lockheed Huntsville Research and Engineering Center under NSF sponsorship.

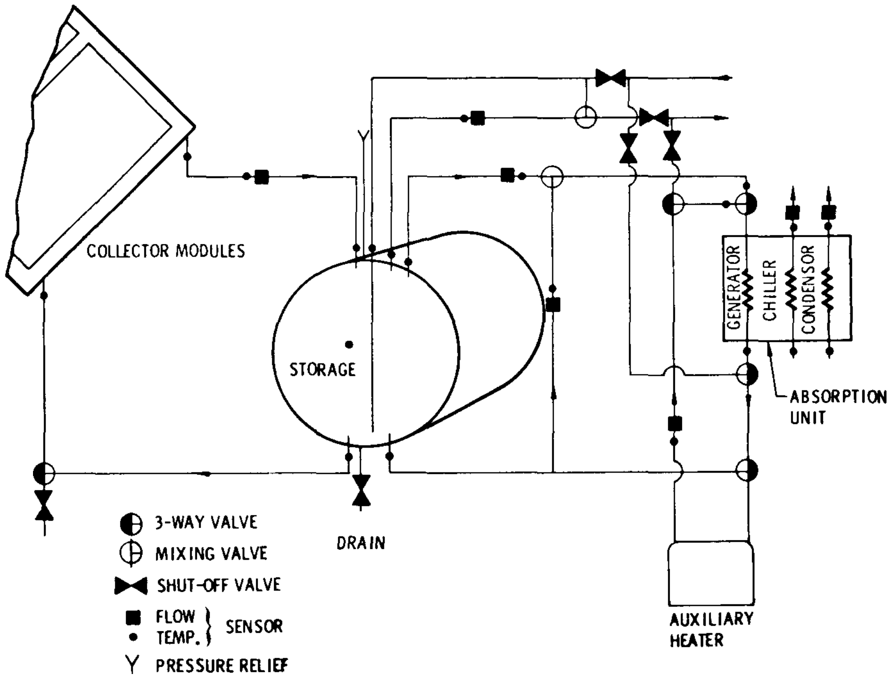

Fig. 2-5 Preliminary Solar System Block Diagram

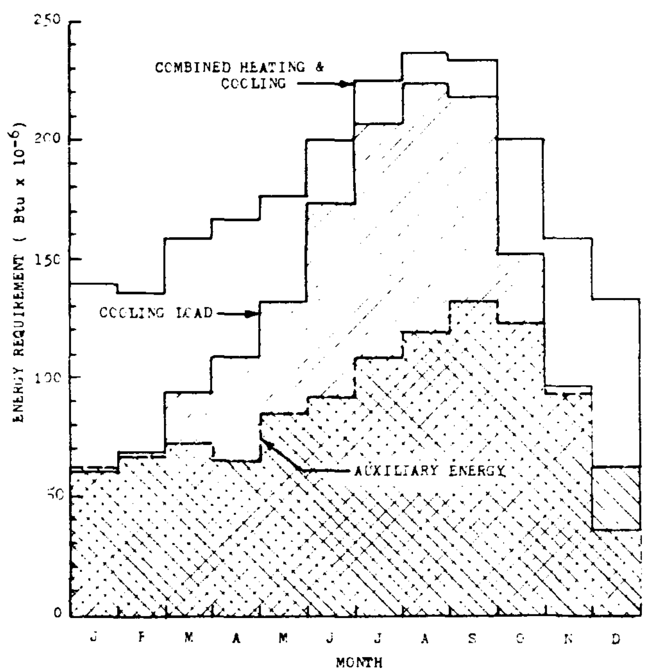

Fig. 2-6 Energy Requirements Analysis

As we evaluated this first concept, we saw that it had the following failings:

- A single large chiller would operate most of the time at other than design conditions, and by investigation we found the performance penalty in both chiller efficiency and in capacity derating to be so excessive as to render the approach impractical.
- The energy output from the collector array was not directly connected to the chiller input but rather got to the chiller via heat exchange in hot storage. As we examined the impact of losses in this concept, we found them to be excessive and unacceptable for practical system operation.
- To fire absorption chillers at or near rated capacity required water temperatures at or above the boiling point. This design would have required pressurized hot storage which we later realized had a major impact upon the storage vessel cost.
- Successful operation of the chiller required that the entire storage volume be at chiller firing temperatures – a condition that we found impractical to attain. Alternatively, we saw that having a large volume of hot storage at some elevated temperature somewhat below the requirements of the chiller input was of no significant value because the added energy input by some auxiliary device (gas, electric, etc.) would, on a total energy basis, equate to providing the full energy demand of the chiller with no net energy taken from storage by the chiller.

At this point in the design evolution, it was a National Science Foundation suggestion that we consider a system that would utilize both hot and chilled water storage. Our first investigations were oriented toward examining how the production of chilled water in daylight hours might satisfy cooling requirements in periods of low solar insolation or at night time, but as we further examined the concept it became apparent that utilization of chilled water storage was the preferred if not optimum way to utilize solar-driven absorption chillers. It was from this suggestion that we turned our attention to a system design which allowed the energy received by the collector array to be piped directly to the input side of the absorption chillers, and the identification of the control logic predicated on producing chilled water at all times when incident solar energy on the collector array is sufficient (above the loss threshold) to allow this function to occur.

These concepts are embodied in the next evolution of the system design presented in simplified form in Fig. 2-7. Note that the total collector array is divided into three areas with areas 1 and 2 being the lower south sloping roofs on the Community Recreation Center and area 3 being the collectors to be installed on the roof of the multipurpose room. Note also that this system design was based on the use of three chillers instead of one, which in this instance were three chillers of 25-tons capacity each. In this system design we would drive one, two, or three chillers, depending on the ability of the collector array to handle them and in turn produce chilled water for reservoir storage. If the array output was insufficient to drive one, two, or three chillers, it would then be channeled through a heat exchanger and by that mechanism provide energy to hot storage. Hot and cold coils of the individual air handlers were then connected to secondary loops connected to hot and cold storage.

In developing this system concept, the inclusion of cold storage added a level of complexity that could not be accommodated by the modeling program previously described and utilized. As a consequence, we went to Solar Environmental Engineering Company of Fort Collins, Colo. We provided them with our South Bay Profile for climatic/solar insolation data and our building load data, and by the use of their model SIMSHAC, examined issues in sizing and optimizing this system concept. Although we were attempting to use the TRNSYS program in house, it was not as yet operational and we were finding that that program was also somewhat lacking in terms of its ability to accurately model the dynamics of the system we were evolving. But by combining the simulation results obtained from SIMSHAC with our own variation on the TRNSYS program, which we identified as SOLARDYN, we were able to recognize the following limitations of the second system design:

- It was not possible to drive three 25-ton chillers with roof-area-limited collector array (an imposed design constraint).
- Cold storage – an appealing concept – would work as planned only if stratification could be developed and maintained in that tank.

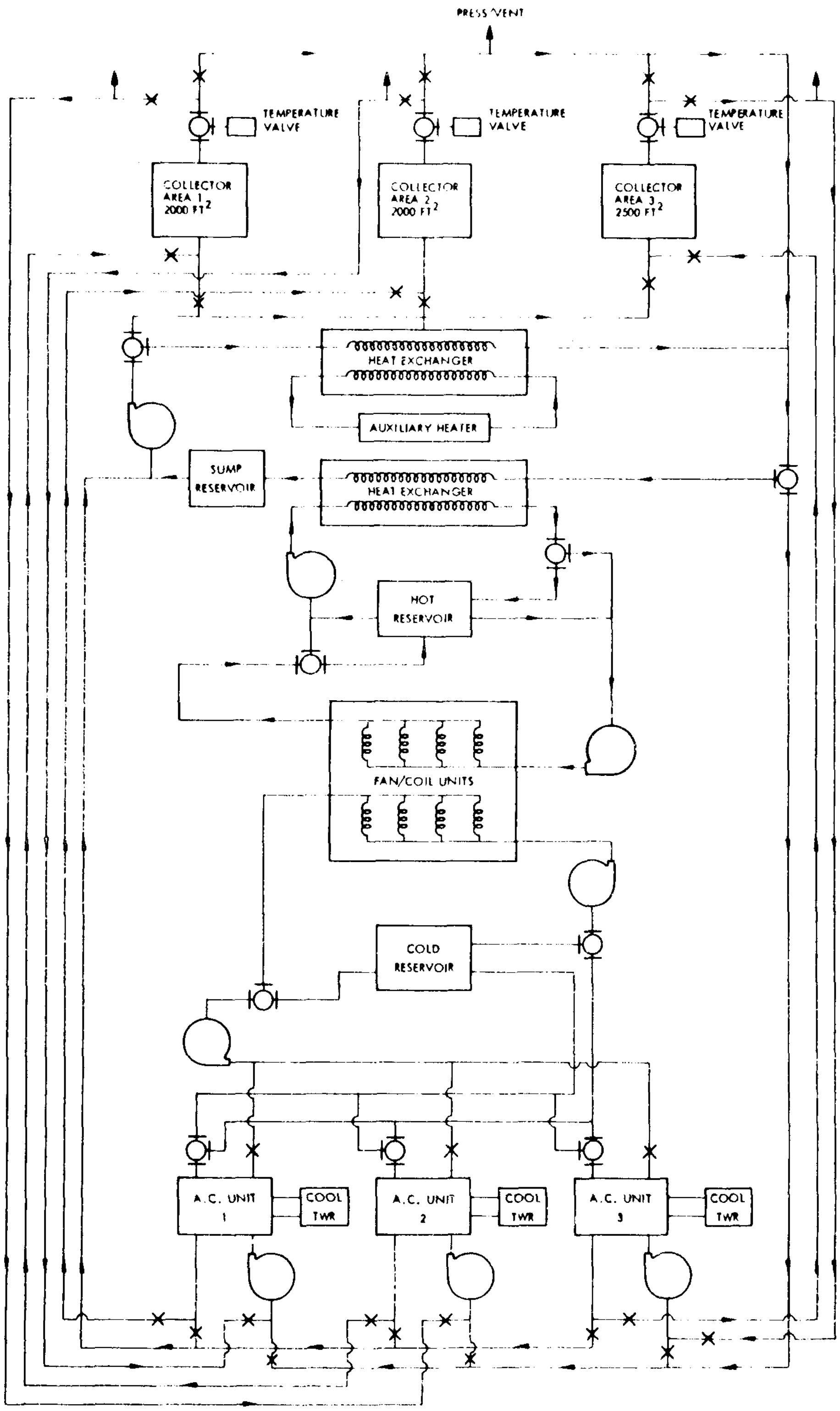

Fig. 2-7 Second Generation System Design

With these results in hand, and with the completion of our SOLARDYN systems simulation program, we were able to create the next and final configuration of the Community Recreation Center solar heating and cooling system. This system is shown schematically in Fig. 2-8. Details of the system and highlights of its several principal modes of operation are fully described in Section 3.

This system had the following significant features:

- Two absorption chillers of 25-ton rating each
- Ambient storage for both hot and chilled water
- Hot water storage: 10,000 gallons
- Cold water storage: 50,000 gallons
- Hot storage isolated from the pressurized collector loop by a heat exchanger
- Provision for the collector array to drive one or both absorption chillers directly and simultaneously, depending on available incident solar insolation
- Array mounted pyranometer, a basic sensor in the control system mechanization
- Gas-fired auxiliary heater capable of providing hot water for direct firing of one or both absorption chillers independent of hot storage

This system configuration in turn has led us to the definition of three primary control algorithms which have been implemented utilizing electronic control hardware. These modes, summarized in Fig. 2-9, recognize that available solar insolation is a time-varying quantity, and that only during limited portions of each day can one or both chillers be direct fired and in turn produce chilled water from the solar input. Thus, the system control priorities call for the production of chilled water from one or both chillers, conditions permitting, in what is identified as the high solar mode. In other periods of moderate intensity solar insolation (the so-called low solar mode), the energy output of the collector array charges hot storage through an intermediate heat exchanger. Schematic indication of system operation in these primary modes is presented in Figs 2-10, 2-11, and 2-12.

For building operation, the interior spaces are divided into individual zones, each with its own sensing and control hardware and individual air handler. As a

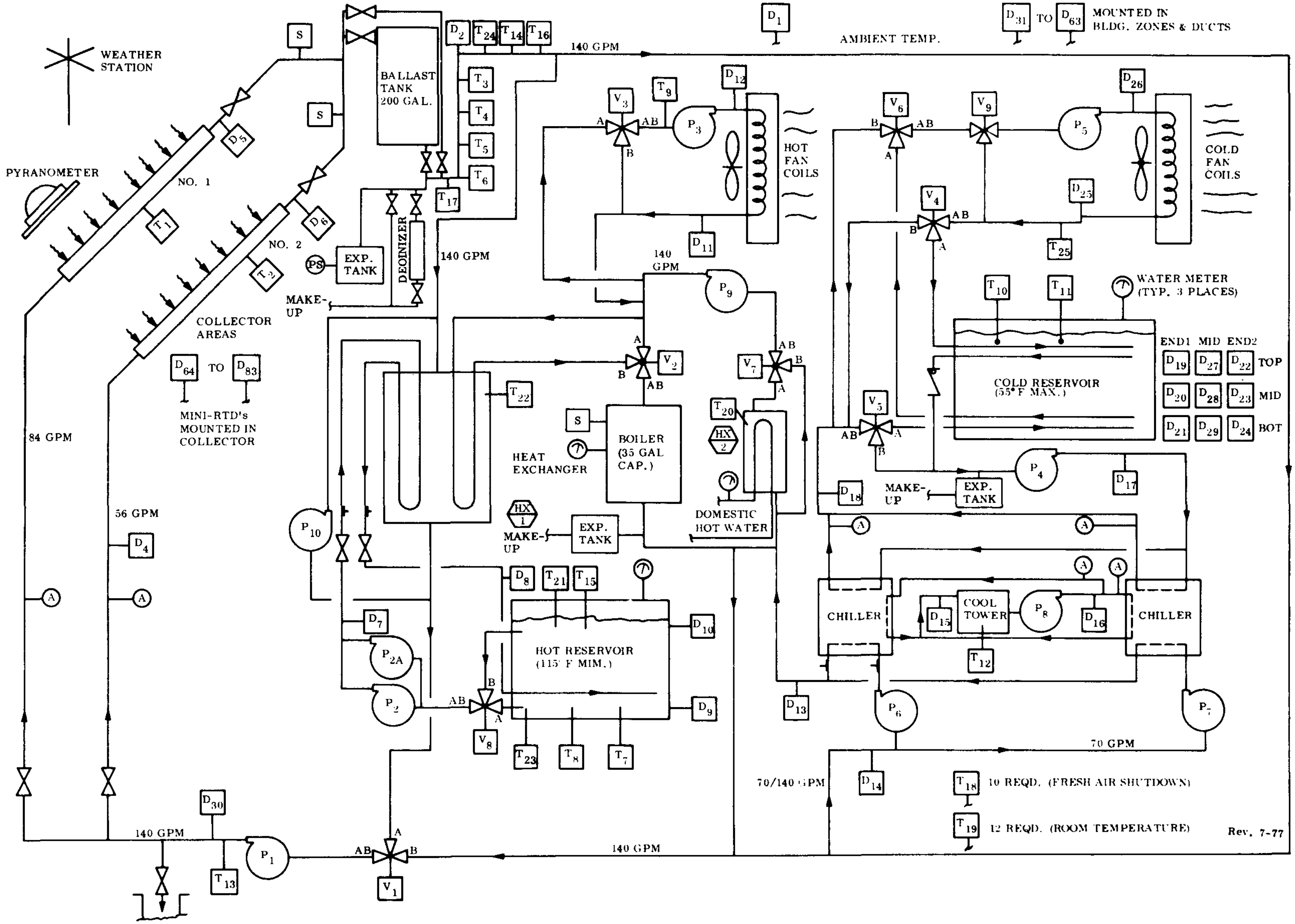

Fig. 2-8 Final System Design Block Diagram

- FULLY AUTOMATIC SENSING AND CONTROL
- THREE MAIN SYSTEM CONTROL MODES DETERMINED BY AVAILABLE SOLAR ENERGY FLUX
  - (1) NO SOLAR INSOLATION DETECTED (MODE 1)
    - DRAWS FROM STORAGE
    - USES BOILER IF STORAGE DEPLETED
  - (2) LOW-SOLAR INSOLATION (MODE 2)
    - COLLECTS SOLAR ENERGY AND USES FOR HEATING OR STORES IN HOT RESERVOIR FOR HEATING AND FAUCET HOT WATER
    - BOILER DRIVES CHILLERS IF COLD STORAGE DEPLETED
  - (3) HIGH SOLAR INSOLATION (MODE 3)
    - SOLAR ENERGY DRIVES CHILLERS TO COOL BUILDING; EXCESS COLD WATER PUT IN STORAGE RESERVOIR
    - ALL REMAINING SOLAR ENERGY STORED IN HOT RESERVOIR
- ECONOMIZER CYCLE DRAWS IN COOL OUTSIDE AIR TO HELP SATISFY COOLING DEMAND

Fig. 2-9 Control System Features

function of demand or the request for heating and/or cooling, hot or chilled water is drawn from storage and brought to that specific air handler. As presented in Section 1.6, with the peak cooling demand being approximately twice the peak heating demand, our estimates are that the building will always have adequate energy in storage for heating. For cooling, instantaneous building demands can be satisfied from storage or if necessary from one or both of the 25-ton absorption chillers which may be instantly brought on line in a direct fired mode by hot water generated from the auxiliary boiler.

The use of detailed dynamic modeling of the proposed system led us to the examination of another issue which might have gone overlooked. This deals with the optimum manner in which to control flow from the collector array as a function of time-varying incident solar insolation in the context of a basic control algorithm that wants to operate one or both chillers whenever conditions permit. In Figs. 2-13 and 2-14 we present actual daily solar insolation data – intensity versus time. For reference we show a typical day (August 27), a day with no cloud cover or other obscuration; then for comparison, two other days (August 22 and August 23), both of which have perturbations to the classical insolation curve but which are highly representative of the local microclimate. August 22 represents a typical summer day in the Bay Area which is overcast

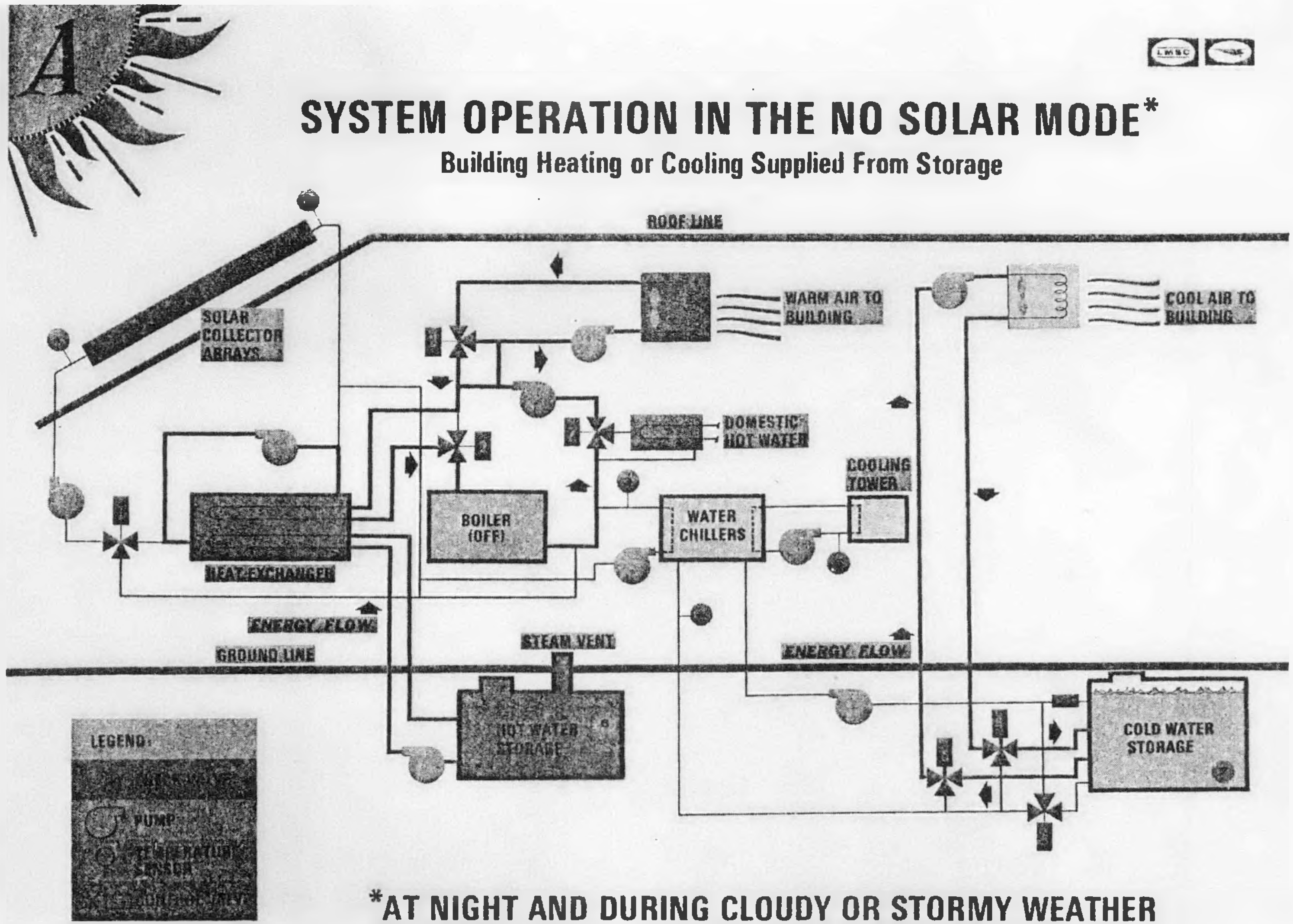

Fig. 2-10 System Operation in the No Solar Mode

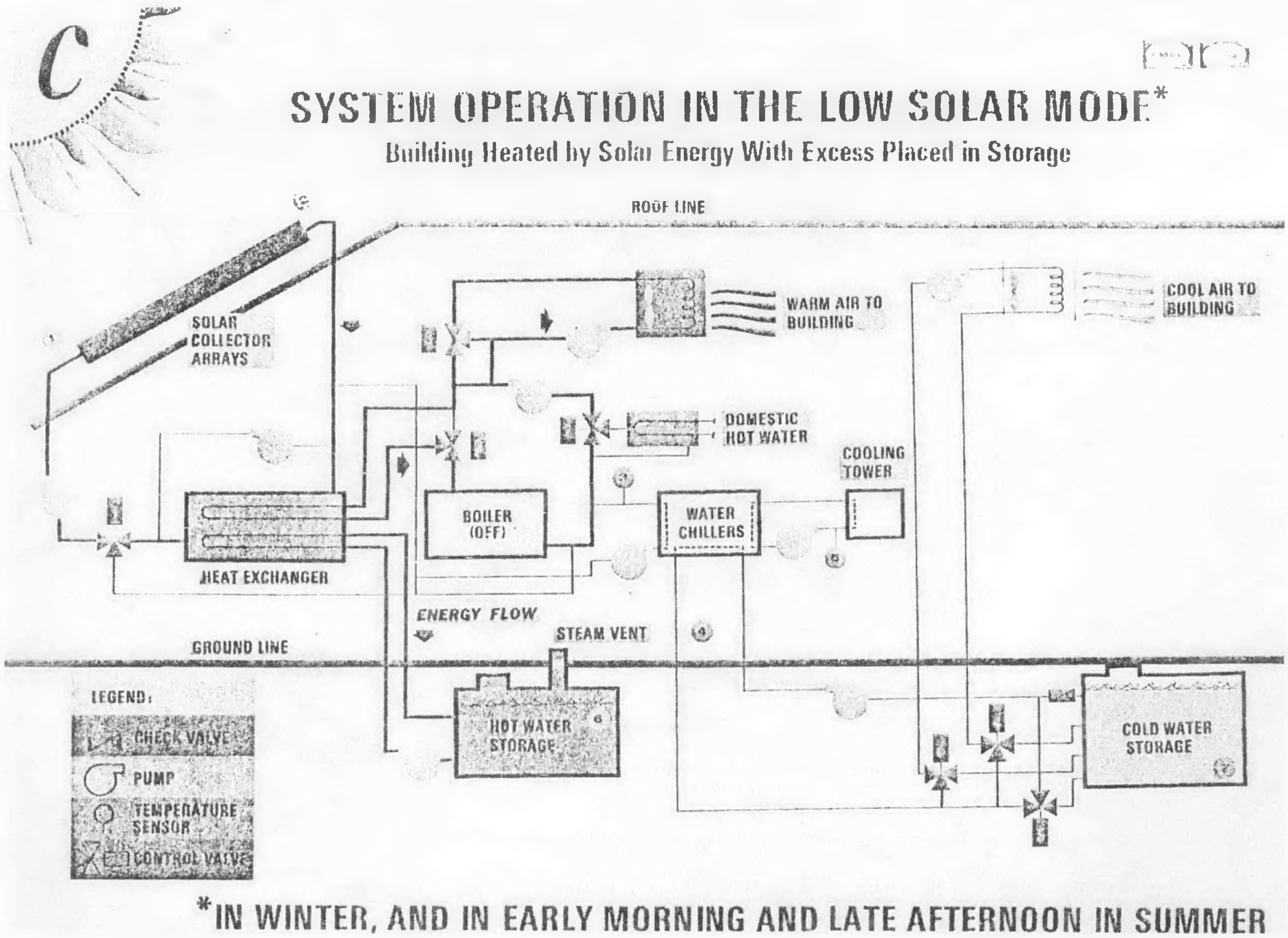

Fig. 2-11 System Operation in the Low Solar Mode

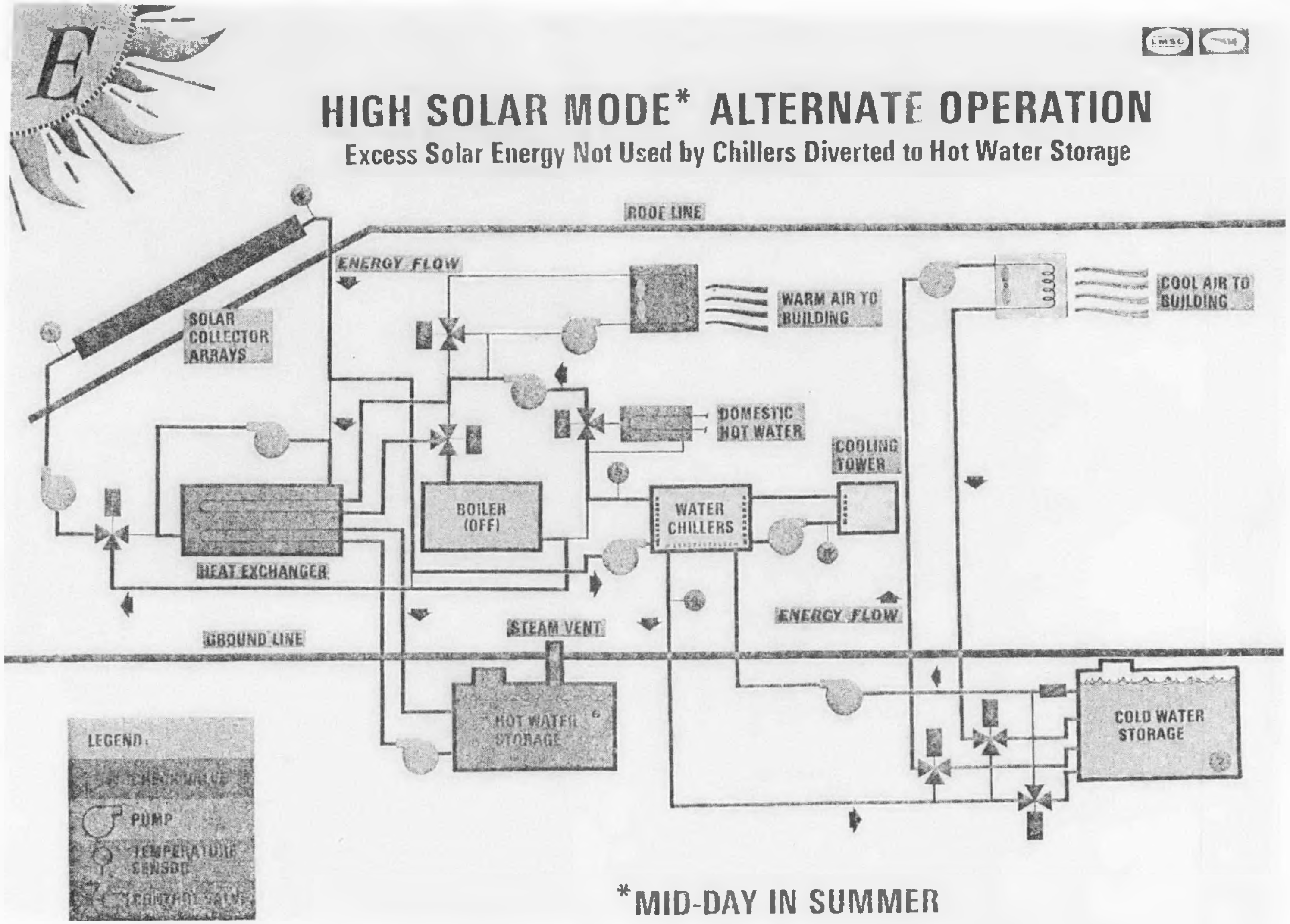

Fig. 2-12 High Solar Mode Alternate Operation

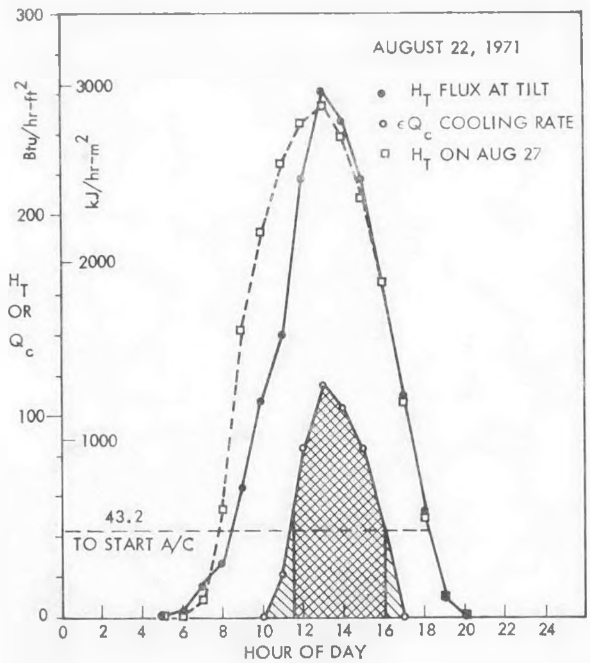

Fig. 2-13 Solar Cooling in Late August

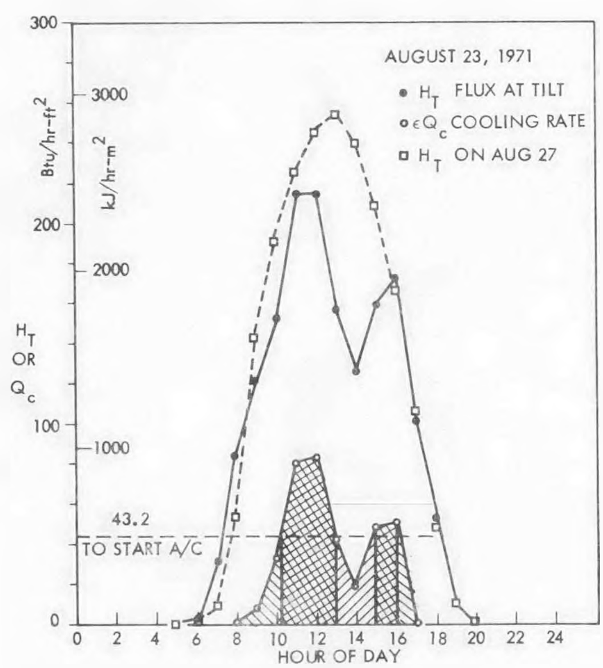

Fig. 2-14 Effect of Mid-Day Cloud Cover on Solar Cooling

from low hanging fog through part or all of the morning hours. August 23 is a day that did not have the classical morning fog but instead had broken cloud coverage with that coverage occurring during mid-day peak insolation.

Our initial approach for interconnecting the array with the chiller inlet is shown in Fig. 2-15. This approach recognizes a threshold of incident energy on the array which must be exceeded in order to overcome losses and provide water temperatures adequate to fire the chillers. In the steady state proportional flow system, the flow would be throttled in order to attain the required operating temperature range. As we became familiar with the operating characteristics of the ARKLA absorption chiller and its susceptibility to short-term on/off cycling, we recognized the need to avoid this mode of operation and as such examined a different type of interconnection which put a tank (a small energy storage capability) between the array outlet and the chiller inlet. In this system approach the array always operates at a constant flow regardless of the incident energy intensity, the objective being to capture the maximum amount of energy. The hot tank (design II of Fig. 2-16), is a volume that is maintained in the temperature range shown, where that temperature range is adequate to fire the absorption chiller. These two design approaches were analyzed for two actual days as portrayed in Figs. 2-13 and 2-14 with the results presented in Fig. 2-17. It was this analysis that led us to drop the proportional flow approach and go to the system design as depicted in Fig. 2-8.

2.3 MAJOR COMPONENT DESIGN AND SELECTION

2.3.1 Solar Collector Array

In specifying the collectors for the array, our first inclination was to use a fixed flat-plate collector design. Such an approach would immediately be in keeping with the architectural constraints imposed on the system design, but more fundamentally we had at that time (early 1975) not seen any collector mechanization reach the point in product development where we were impressed with its combined performance, cost, and potential lifetime. On the basis of the building design, areas available for collector

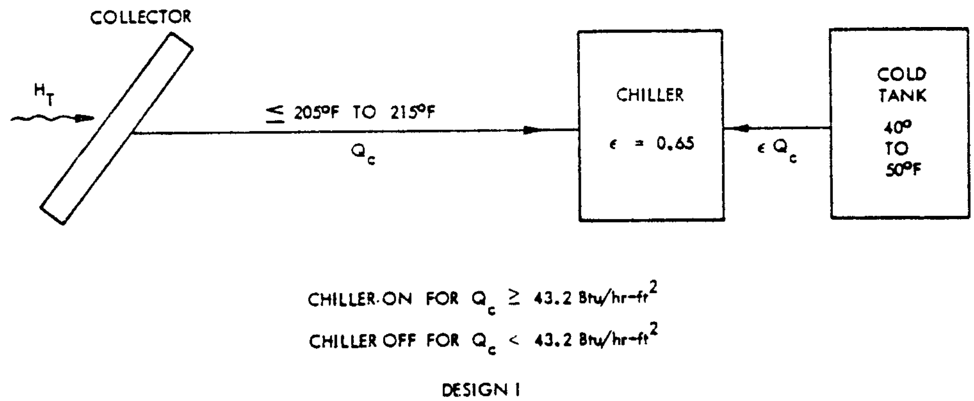

Fig. 2-15 Steady State Proportional Flow System

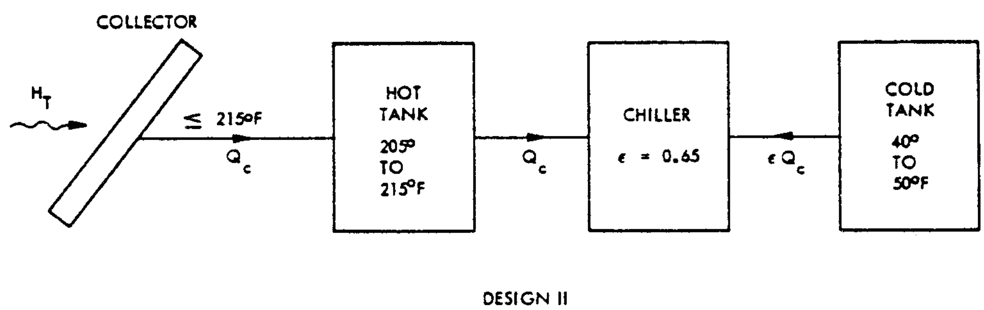

Fig. 2-16 Non-Steady State Integration System

SYMBOL	QUANTITY	DESIGN	AUG 22	AUG 23
$\int H_T \, dt$	TOTAL RADIATION ON COLLECTOR (Btu/ft^2-day)	-	1628	1599
$\int Q_c \, dt$	HEAT AVAILABLE FOR COOLING (Btu/ft^2-day)	I	429	259
		II	450	361
	AVERAGE COLLECTOR EFFICIENCY	I	26.4%	16.2%
		II	27.6%	22.6%
$\epsilon \int Q_c \, dt$	HEAT PUMPED (Btu/ft^2-day)	I	279	168
		II	292	235

Fig. 2-17 Total Heat Incident, Cooling Heat, Efficiency, and Heat Pumped for Two Types of Operation on August 22 and 23, 1971

placement were as shown in Fig. 2-18. From the modeling of the system, we found that a total collector array in the order of 6,500 square feet would be appropriate for the system, and this in turn was very close to the maximum collector area that could be reasonably installed on the designated spaces.

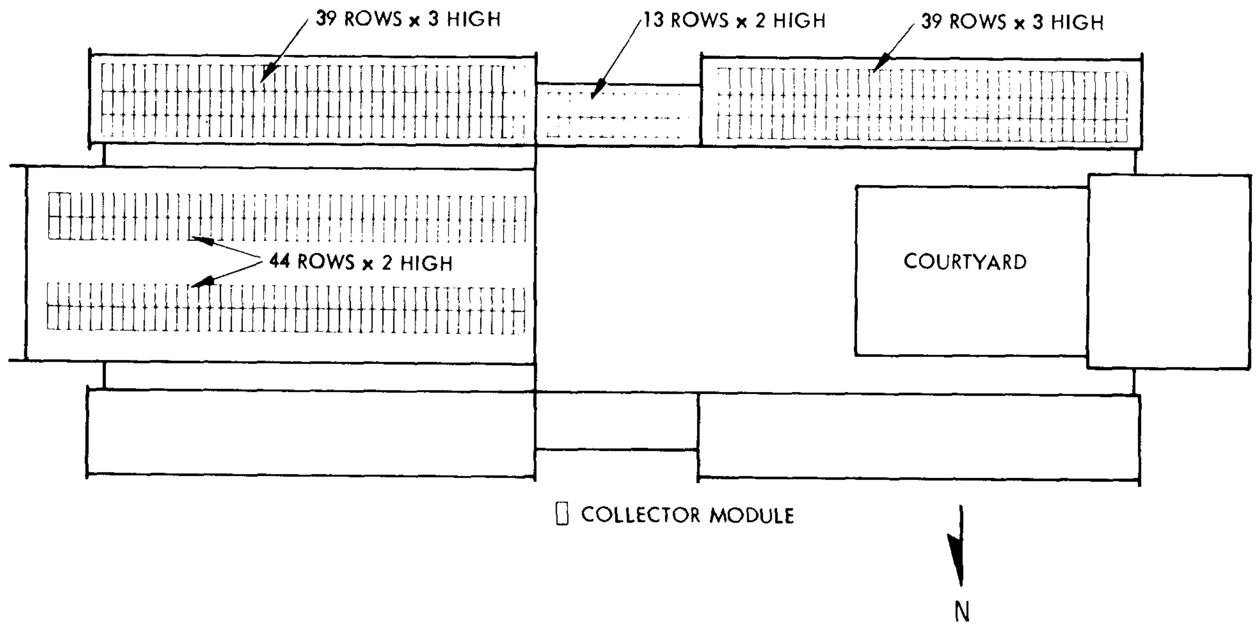

Fig. 2-18 Areas Available for Solar Collector Placement

Our modeling confirmed the magnitude of the cooling-dominated system design, and from this examination we found that having the south tracing collectors mounted at an angle of 18 deg was not a system penalty, but in fact worked to our advantage because of the high sun angles in the hot-weather periods.

As designers and specifiers, our principal concern was whether or not we could identify and select a collector approach that would have the performance capabilities adequate to drive the ARKLA absorption chillers. Further, such collectors had to feature the durability/lifetime characteristics that were so necessary for installation on a public building. While we were initially concerned with the cost of collectors, events subsequently showed that the collector acquisition price was not a dominant element, being in the order of $17.50 per square foot for a two-cover glass/copper absorper design with optically selective coating. What was not recognized until much later in the project was the pending cost impacts associated with collector mounting, collector manifolding and interconnection, and insulation of headers leading to and from the major elements of the collector array.

In examining various options that we might follow to implement the collector array, early design choices made were:

- Water/propylene glycol as the working fluid versus thermal oils
- Cover system of glass versus any of the plastics such as Tedlar, Lexan, etc.
- Fixed flat-plate collector design fully enclosed with backside insulation and closed weather-tight case
- No antireflection coating or infrared mirror coatings to be applied to upper or lower cover glasses

Concurrent with the design of the Community Recreation Center system, Lockheed was pursuing fixed flat-plate solar collector design under both company and ERDA sponsorship. We established at our Palo Alto facility an outdoor test yard for solar system components as shown in Fig. 2-19. This yard subsequently became one of the 20 outdoor facilities selected by the National Bureau of Standards for their "roundrobin" collector test program. This facility was invaluable for this project in that it provided us with experimental data used in the development and verification of our analytic modeling capabilities for fixed flat-plate collectors as defined in Appendix H. Further, it gave us the opportunity to test and evaluate under actual operating conditions various collector concepts and forms of mechanization being considered for use in the Community Recreation Center system.

A wide range of collector concepts were examined in detail for potential utilization. Many of these concepts were tested in our Palo Alto facility and significant among

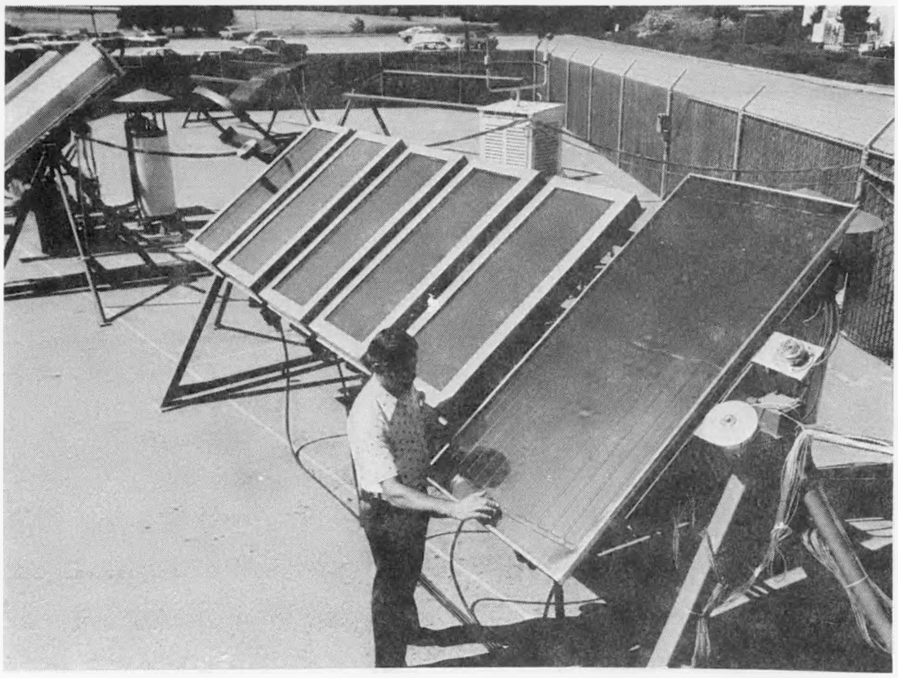

Fig. 2-19 Palo Alto Test Yard for Solar System Components

those tests was the evaluation of an "early" concentration tracking collector. Our Palo Alto experimental data differed by a factor of two (low) with published manufacturers data. We examined absorber selective coatings, internal conduction and radiation losses, and finally concluded that the collector had a performance limitation based on the focusing capability of the lens; as a consequence, it was dropped from further consideration.

In the category of evacuated tubular collectors, we were unable to obtain a sample from Owens-Illinois, but did acquire a Corning collector for test. This Corning collector was the most fundamental of designs, featuring a copper absorber plate mounted on the diameter of the evacuated tube with a selective coating on that absorber. Simple as this design was, our testing showed this approach to be highly effective and its performance equal to the best ever attained in any of our optimized two-cover glass flat-plate collector designs. This data was indicative of the potential now being developed for evacuated tubular collectors utilizing some modest degree of concentration. While attractive in terms of performance, Corning was not in a position to seriously consider supplying collectors for this project.

Since we were unable to find a fixed flat-plate collector sufficiently well along in its development program with performance adequate for the system design that we had in mind, we elected to prepare a design and performance requirements specification and procure such a collector through the purchasing department of the City of Santa Clara.

As the basis for developing collector requirements, we examined various issues in collector design as they influenced total system performance. Figure 2-20 shows the need for a collector utilizing an optically selective coating versus those having only a flat black coating ($\alpha/\epsilon \cong 1$). As a companion issue, there were those who proclaimed that very high α/ϵ ratios of 10 or higher were absolutely mandatory for high-performance fixed flat-plate collector operation. From our analytical modeling and combined experimental verification, we found this not to be the case, but instead saw the need for very high absorptivity; in fact, the higher the better, In the case of infrared emissivity, the tendency had been to achieve as low a value as possible – of 0.10, or less. From an analysis of fixed flat-plate collectors, we developed a relationship between efficiency and emissivity (Fig. 2-21). Thus, for this system we specified emissivity in the range of 0.20 to 0.40.

The cost associated with achieving very low emissivities (and thus high α/ϵ ratios) is disproportionate with the advantage to be attained. Because we planned on the use of a fixed array which would be subjected to widely varying angles of incidence for the arriving solar insolation, one of our early activities was to examine the solar absorptance for a range of selective coatings as a function of angle of incidence, with typical results as shown in Fig. 2-22.

Our concept for the design of an appropriate collector is shown in Fig. 2-23, with basic ideas from that initial concept carried forward to requirements which subsequently appeared in the Lockheed-prepared collector specification (Appendix A). This specification was distributed to potential suppliers, and we assisted the City in screening supplier responses. Suppliers who claimed to have a product in existence were advised that their product would be seriously considered only if they provided a unit for test and evaluation in our Palo Alto solar test yard. That requirement dissuaded most of the

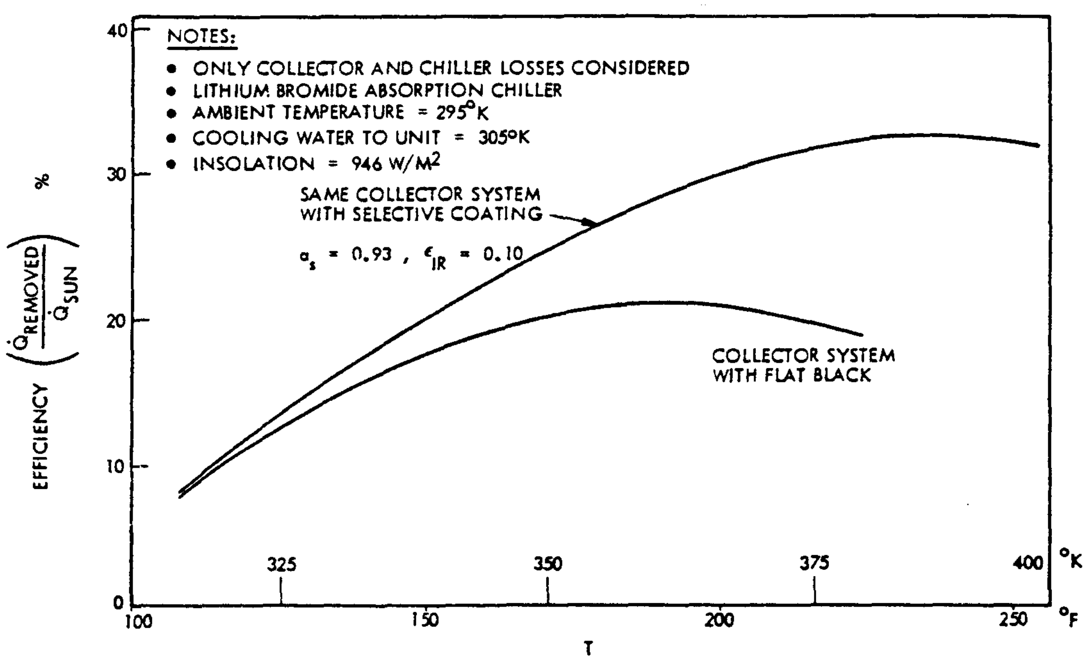

Fig. 2-20 Effect of Absorber Surface Optical Properties on Chiller/Collector System Efficiency

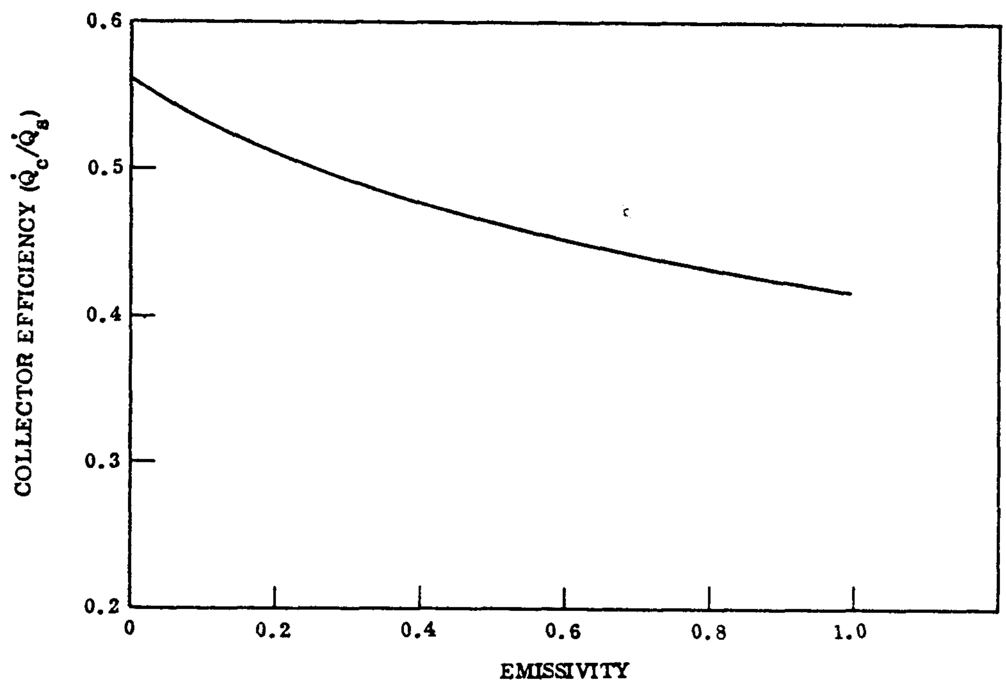

Fig. 2-21 Relationship Between Collector Emissivity and Collector Efficiency

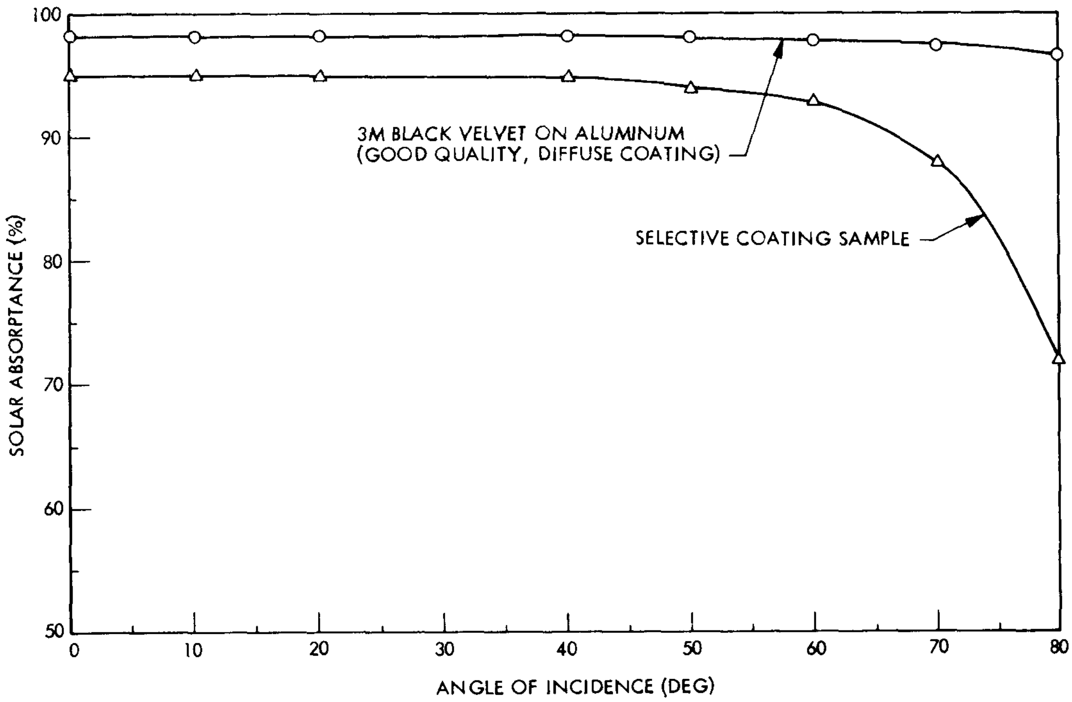

Fig. 2-22 Solar Absorptance as a Function of Incidence Angle

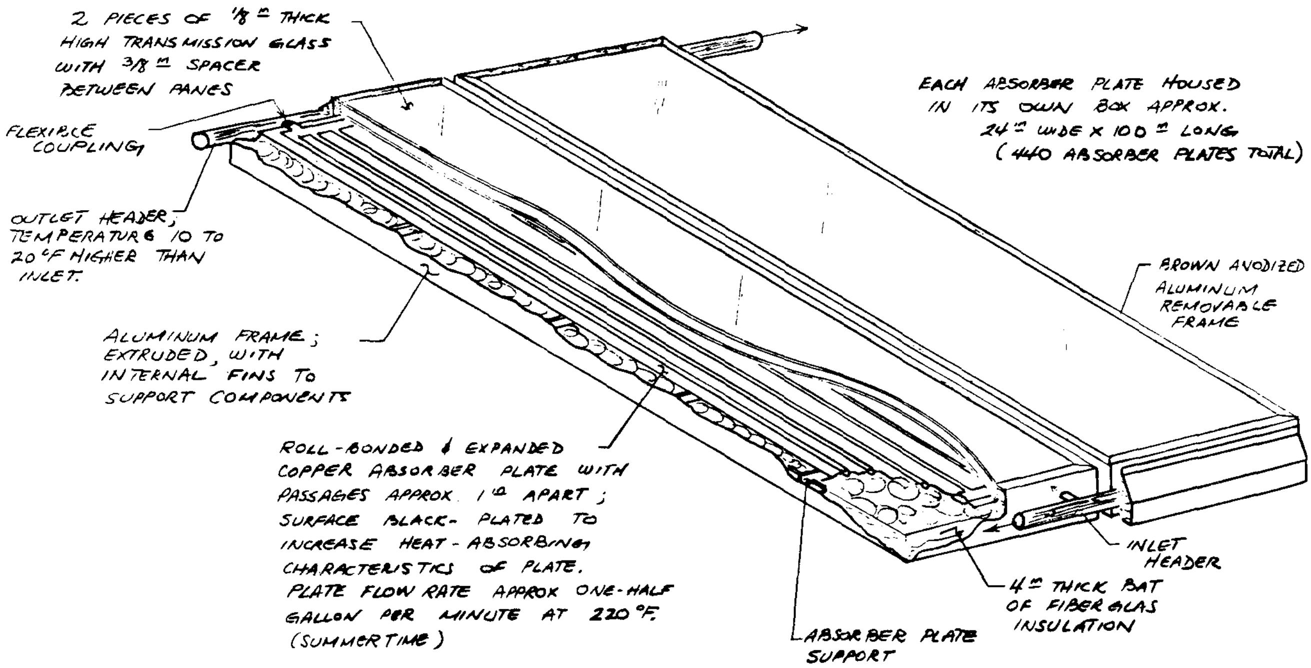

Fig. 2-23 Lockheed Collector Design

potential suppliers from pursuing the opportunity. Among the serious respondents, the City was approached by Ametek's Power Systems Group, who at that time had developed a proprietary selective coating and were planning to create a new solar collector product line. Ametek made a proposal to the City to use the Lockheed collector design and experience in collector materials as a point of departure to product engineer a unit tailored for specific installation on the Community Recreation Center. An understanding was reached and a contract awarded to Ametek. Their first prototype collectors were received in mid 1975 and Fig. 2-24 presents test data on one of the first full-scale prototypes as acquired in our Palo Alto outdoor test facility. Figure 2-25 plots the performance of the Ametek collector at peak solar summer insolation levels (typical) and compares actual experimental data with our theoretical predictions based on our model ing of this class of collector (see Appendix H). Figure 2-26 presents a range of data taken from several Ametek prototypes as well as first production units with the data presented in the classical style.

2.3.2 Absorption Chiller

Having made the decision to use hot water fired absorption chilling for this system, we examined equipment manufactured by York, ARKLA, and Kawasaki Heavy Industries (double effect: COP ≅ approx. 1.2).

In our original design concept, the Community Recreation Center system would have used one large absorption chiller. With the summer design-day load estimated at 60 plus tons, this would have required a 100-ton machine from ARKLA, a 150-ton machine from York, and we could have obtained a machine in the 70- to 80-ton capacity range from Kawasaki. As we examined the hardware possibilities, we decided against the York equipment because they did not have performance data (at varying water temperatures and flow rates) by which to define the operation of the machine at off design or derated conditions. Additionally, as our system concept finally evolved, we elected to use multiple small machines instead of one large machine. In the instance of Kawasaki the potential of a higher COP was very appealing, but we discovered that although

LOCKHEED TEST: A-2 FULL SCALE PROTOTYPE

DATE: 6-3-75

TIME	TEMP (IN) MV	TEMP (IN) °F	TEMP (OUT) MV	TEMP (OUT) °F	FLOW RATE METER	FLOW RATE #/HR	TOTAL SOLAR MV	TOTAL SOLAR BTU/HR-FT²
1228	4.235	210.5	4.544	222	29	162.4	9.032	306.37
1233	4.228	210	4.577	223.5	29	162.4	9.055	307.31
1238	4.275	212	4.594	224	29	162.4	9.123	[illegible]
1243	4.250	211	4.588	224	29	162.4	9.102	308.[illegible]
1248	4.265	211.5	4.605	224.5	29	162.4	9.165	310.91
1253	4.259	211	4.586	224	29	162.4	9.236	313.[illegible]
1258	4.239	210.5	4.596	224.5	29	162.4	[illegible]	[illegible]
1303	4.221	210	4.565	223	29	162.4	9.267	314.54
1308	4.243	210.5	4.568	223	29	162.4	9.281	314.21
1313	4.235	210.5	4.562	223	29	162.4	9.219	312.7[illegible]
1318	4.237	210.5	4.568	223	29	162.4	9.251	313.[illegible]
1323	4.235	210.5	4.572	223.5	29	162.4	9.295	315.2[illegible]
1328	4.243	211	4.568	223	29	162.4	9.266	[illegible]
1333	4.243	211	4.546	222.5	29	162.4	9.233	313.[illegible]
1338	4.281	212	4.554	222.5	29	162.4	9.212	313.49
1343	4.302	213	4.616	225	29	162.4	9.255	313.93
1348	4.405	217	4.653	226.5	29	162.4	9.130	309.[illegible]
1353	4.383	216	4.671	227	29	162.4	9.110	309.01
1358	4.405	217	4.665	227	29	162.4	9.127	309.59

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Fig. 2-24 Palo Alto Outdoor Test Facility Data on Ametek Full-Scale Prototype Solar Collector

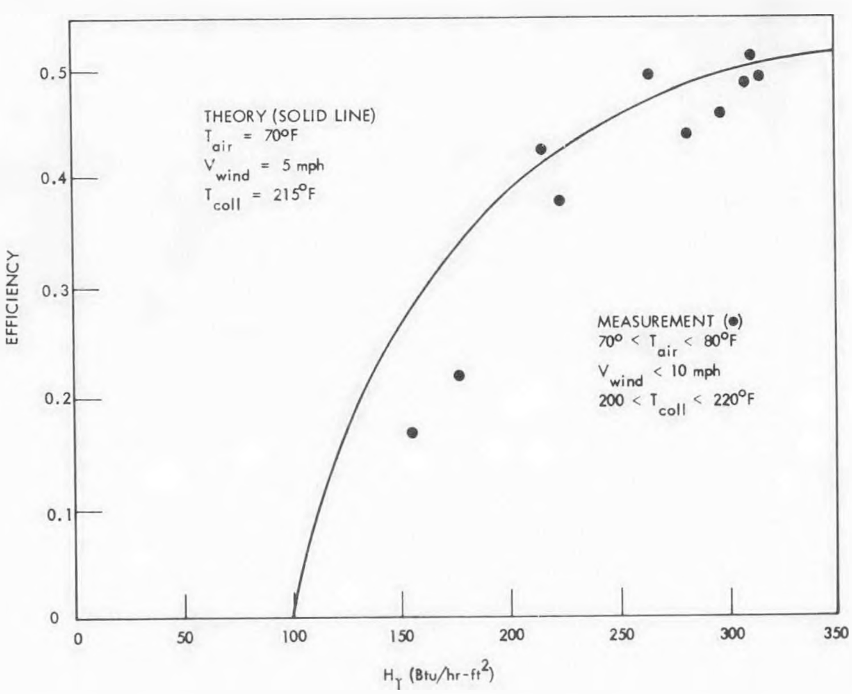


Fig. 2-25 Performance of Ametek Collector at Peak Summer Insolation Levels

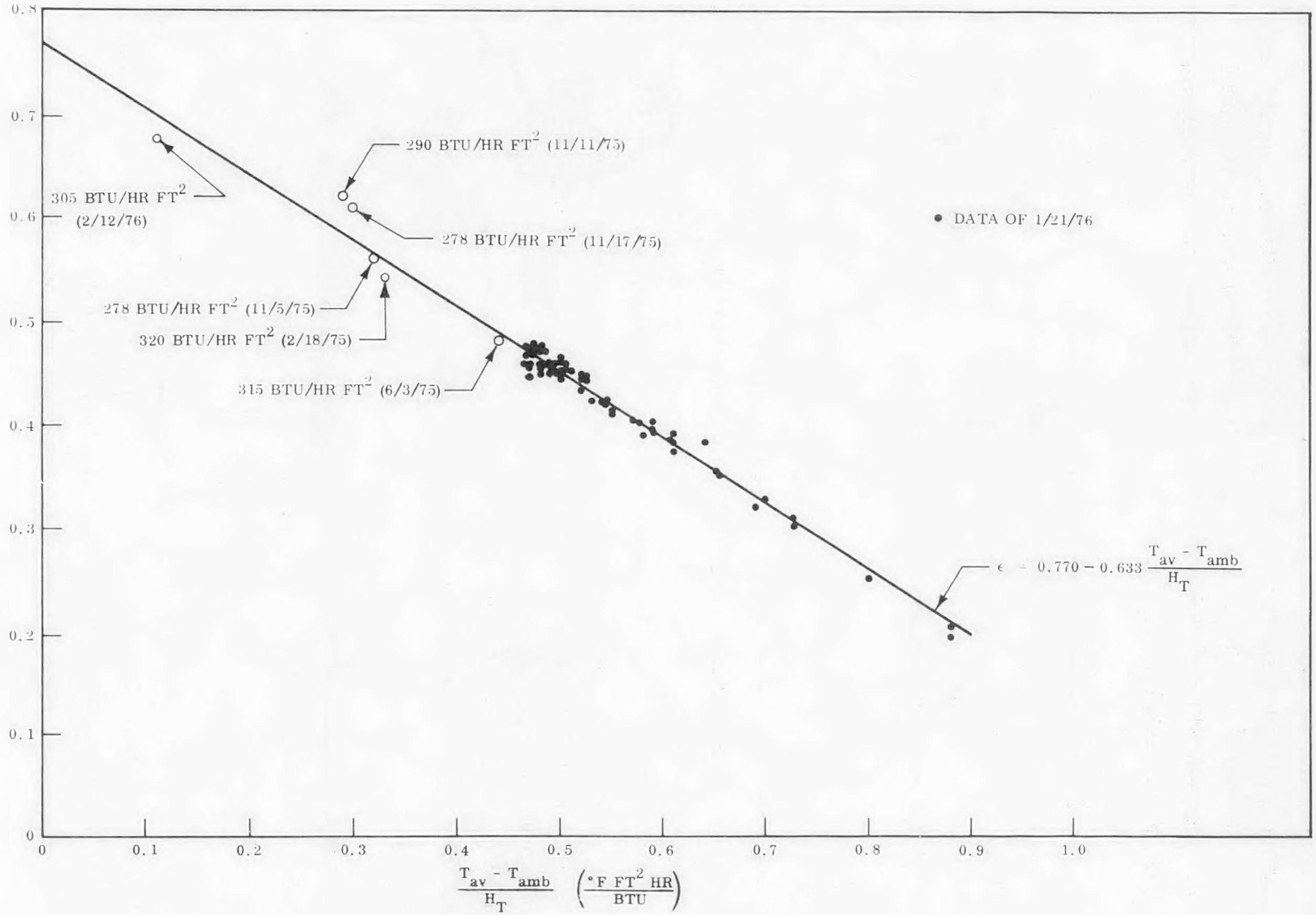


Fig. 2-26 Ametek Collector Efficiency vs. Average Plate Temperature Divided by Total Radiation

Kawasaki had a major portion of the air conditioning market in Japan, it did not have a market in the United States; and therefore no basis for distribution, repair, or maintenance. It was these latter issues that deterred us from further consideration of their equipment. This left ARKLA, and we settled on their 25-ton size machine, the water-fired version known as Model WF300.

After selecting this type of absorption chiller, later design and definition of the system revealed that we had to cope with such real operating problems as elimination of short time cycling, addition of internal insulation to the machines to eliminate heat losses, and accommodating the characteristic operation of the chiller which does not produce water at temperatures lower than 40° to 42°F.

2.3.3 Storage

The system concept that we developed for mechanization was based on the use of hot and cold storage. Hot storage in this instance means water from a low temperature of approximately 110° F up to the boiling point of water, because the hot storage tank and its atmospheric vent is the mechanism by which we dump excess energy collected by the array. Cold storage represents water temperatures that at the low end are limited by the capability of the absorption chiller characteristics, which in this instance means temperatures in the order of 40° to 42°F. On the upper end, cold storage does not exceed a temperature of 55°F because this is the practical upper limit at which water supplied to the zone air handlers can still produce some degree of effective air cooling.

On the basis of the mechanizations elected, we were able to use unpressurized tanks for both hot and cold storage, which then gave us the option of examining a variety of storage mechanizations.

The issue of storage was the subject of many discussions between Lockheed, the architect, and City personnel. One of our initial suggestions was the use of above-ground storage. The idea offered was to construct rectangular rooms sized to storage volume, insulate the exterior and place a vinyl liner on the interior, and provide an insulated roof.

We found this idea appealing from both a cost and performance standpoint; however, it was rejected by the architect and the City because of appearance. This decision then led us to examine the full spectrum of opportunities for underground storage.

To analyze underground storage options we first had to examine costs associated with rectangular concrete tanks formed and poured in place. This is a practical approach; however, it is very expensive. Next we examined the products available from a variety of precast concrete vault manufacturers in both four- and five-sided configurations. The four-sided versions are four adjoining walls which require the addition of a top and bottom slab, and that addition is the design weakness of the approach; namely, in attaining a joint or bond of any long-time integrity. In all of the vault options we finally concluded that a mechanization by that approach would require some specially prepared vinyl or hypalon liner to assure a water-tight interior barrier. While we examined high vermiculite loadings in concrete to reduce its as-poured thermal conductivity, there was no way to reduce the thermal conductivity to desired levels while retaining adequate cured strength. Thus, all of these designs would require some type of insulation applied to outer surfaces, with a major problem being how to apply the insulation on the bottom of a concrete rectangular structure, plus providing a long lifetime moisture barrier.

Also examined were specially fabricated (i.e., thin wall) reinforced lined concrete pipe available from several manufacturers in the Bay Area. The concept was to use pipe sections installed vertically in the ground, forming a right circular storage cylinder. While this idea was manageable in terms of size, cost, weight, and over-highway transport, we found that to accommodate the storage volumes required for the system would have demanded very deep burial of the tanks, which in turn was considered impractical by the general contractor and City personnel.

Fiberglass tanks from various manufacturers were examined and what we immediately found was that although we could get a warranted product for cold water storage, we could not get any warranty for the hot water requirement. Generally, the fiberglass tanks available were not warranted at storage temperatures above 140°F. Since our system requires that the hot water tank be capable of boiling, that class of tank could not be used for hot storage. One added issue was the fact that fiberglass tanks were found to be very expensive.

The end result of our explorations was to select tanks fabricated of rolled and welded steel plate. In the final detailed design of our tanks, we had a number of problems that had to be solved which are summarized in Fig. 2-27. We again made important use of our system sizing and modeling capability, looking at the payoff options for various sizes of storage and developed trend curves from which the final sizing of hot and cold storage was finally selected. The trend for cold storage is shown in Fig. 2-28. Because of the large volumes involved and the correspondingly large surface areas of both hot and cold tanks, we specified insulation for both tank exteriors. As shown in Fig. 2-29 and as further defined in Appendix K, we conducted a limited trade study to determine the optimum characteristics of applied insulation.

Attention was also given to interior treatment of both tanks. On the cold tank, the inner surface is lined with a bitumin coating typical of that used by the Santa Clara Water Department for storage of potable water. This tank has a normal temperature operating range between 40° and 55° F. One other internal feature of the cold tank has to do with the special manifolds and diffuser system developed as a result of an experimental program conducted by Lockheed in order to achieve thermal stratification. The details of this discharge manifold system appear in Section 3.1.3 and a review of our experimental program and modeling of thermal stratification is presented in Appendix J.

For the hot tank, the discharge of excess heat energy is achieved by allowing the tank to boil since it is vented to the atmosphere. The hot tank experiences continuing changes in its water level and thus has a potentially severe corrosion problem at the air-water interface over a wide range of internal tank surfaces. To protect the tank, a special ceramic coating was applied to the interior once it was in place in the ground. This lining is designed to provide the desired corrosion protection, at the air/water interface, for a surface level that continually changes.

HOT TANK PROBLEMS

- HEAT EXCHANGERS REQUIRED TO ISOLATE AMBIENT PRESSURE TANK FROM PRESSURIZED FIRING WATER SYSTEM AND TO PREVENT DRAIN DOWN OF FAN/COIL UNITS IF TANK IS UNDERGROUND
- THERMAL CYCLING STRESSES CONCRETE
- SPECIAL RESINS NEEDED FOR COMPOSITE HOT WATER TANKS
- CORROSION IN METAL TANKS: SPECIAL HOT WATER RESISTANT COATINGS REQUIRED FOR STEEL
- NO SEEPAGE: INSULATION MUST BE KEPT DRY FROM BOTH SIDES
- VENT REQUIRED FOR BOILING OFF EXCESS ENERGY
- AUTOMATIC FILL/LEVEL CONTROL REQUIRED

COLD TANK PROBLEMS

- CANNOT USE HEAT EXCHANGERS: EFFICIENCY LOSS TOO GREAT
- SPECIAL VALVES AND CONTROLS NEEDED TO PREVENT FAN/COIL DRAIN DOWN TO UNDERGROUND TANK
- NO SEEPAGE OR CONDENSATION: INSULATION MUST BE KEPT DRY
- STRATIFICATION MUST NOT BE DISTURBED: FOUR DIFFUSER PIPES NEEDED
- SMALL RANGE OF USE TEMPERATURES NECESSITATES LARGE VOLUME OF STORAGE

Fig. 2-27 Design Problems for Hot and Cold Tanks

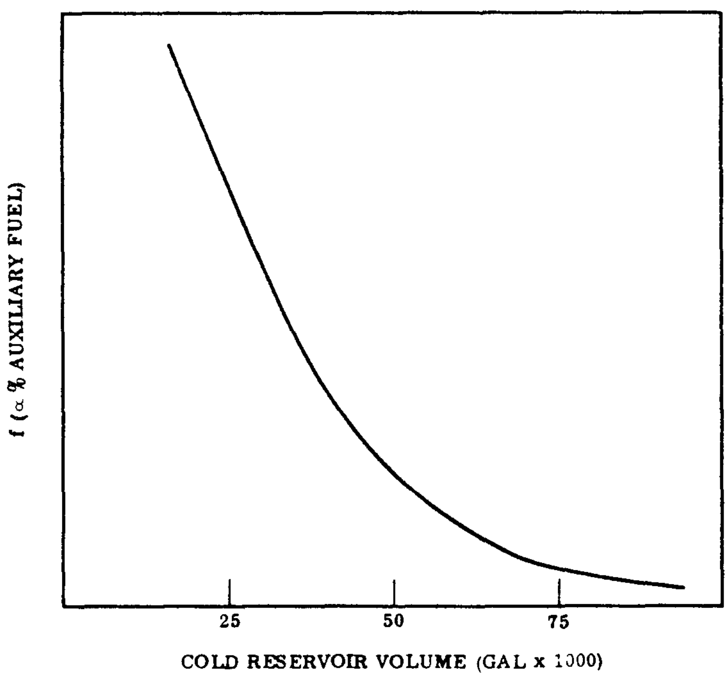


Fig. 2-28 Cold Storage Trend

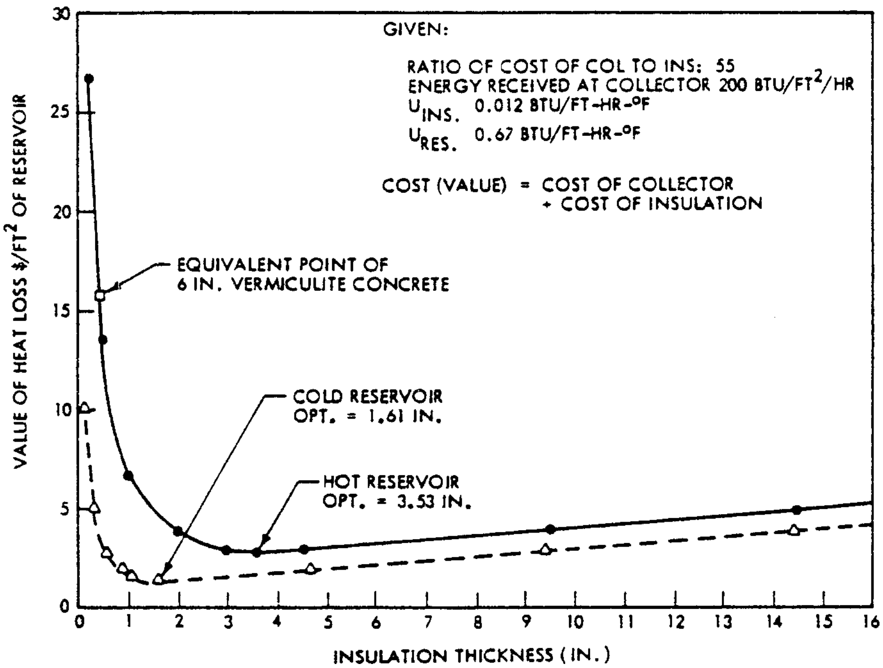


Fig. 2-29 Optimum Characteristics for Tank Insulation

Section 3
HARDWARE DESCRIPTION AND INSTALLATION

3.1 MAJOR COMPONENTS

The following subsections discuss the design of the major system components:

- Absorption chillers
- Collectors
- Storage
- Mechanical arrangement
- Controls
- Piping and plumbing
- System layout and component locations

3.1.1 Absorption Chillers

The 25-ton, hot-water fired, absorption-cycle chillers were specified for this project, based upon their commercial availability in the capacities desired. The principle of operation for these units is well established.

The cooling performance of the 25-ton unit manufactured by Arkla Industries, Inc., the Model WF-300, is given in Table 3-1* as a function of firing water inlet temperature and rate of flow, and condensing water temperature supplied to the chiller. A companion table, Table 3-2, presents compatible data on firing water outlet temperatures. The data in Table 3-1 show that the unit operates at a derated capacity unless the firing water is a minimum of 220°F. When operating at rated capacity, the COP (coefficient of performance) is a maximum of 0.67; thus, 445,000 Btu/hr must be

*Tables 3-1 through 3-3 taken from Arkla Industries product literature

Table 3-1 WF-300 COOLING CAPACITY (TONS)

Hot Water Temp °F	200°F			205°F			210°F			215°F			220°F			225°F			230°F			245°F			Hot Water Temp. °F
Hot Water Flow GPM	70			70			70			70			70			60			50			30			Hot Water Flow GPM
Cooling Water Flow GPM	90			90			90			90			90			90			90			90			Cooling Water Flow GPM
Cooling Water Temp. °F	80°	85°	90°	80°	85°	90°	80°	85°	90°	80°	85°	90°	80°	85°	90°	80°	85°	90°	80°	85°	90°	80°	85°	90°	Cooling Water Temp. °F
Chilled Water °F from Unit 50	19.0	16.5	14.5	19.5	17.0	14.0	20.5	18.0	15.0	22.0	19.5	18.0	25.5	23.3	19.2	25.5	25.5	22.0	25.5	25.5	22.0	25.5	25.5	22.0	50
48	19.0	16.2	13.5	19.4	17.0	13.7	20.5	18.0	14.8	22.0	19.3	17.5	25.5	23.0	19.0	25.5	25.5	21.2	25.5	25.5	21.2	25.5	25.5	21.2	48
46	18.7	16.0	12.3	19.2	16.7	13.2	20.3	18.0	14.4	21.5	19.0	16.5	25.1	22.5	18.4	25.1	25.1	20.5	25.1	25.1	20.5	25.1	25.1	20.5	46
45	18.5	15.6	11.7	19.0	16.5	13.0	20.1	17.7	14.2	21.4	18.7	16.3	25.0	22.0	17.9	25.0	24.9	19.8	25.0	24.9	19.8	25.0	24.9	19.8	45
44	18.2	15.2	11.0	18.6	16.2	12.5	19.9	17.4	13.6	21.0	18.5	16.0	24.5	21.7	17.5	24.6	24.5	19.0	24.6	24.5	19.0	24.6	24.5	19.0	44
42	17.2	14.4	9.3	17.5	15.5	11.5	19.3	16.5	12.5	20.5	17.5	14.5	24.0	20.6	16.0	24.8	23.1	17.7	24.3	23.1	17.0	24.3	23.1	17.7	42
40	16.0	13.0	7.5	16.5	14.0	10.0	18.6	15.5	10.5	19.0	16.5	12.8	23.3	19.0	13.5	23.6	20.5	16.0	23.6	20.5	16.0	23.6	20.5	16.0	40

Table 3-2 FIRING WATER TEMPERATURE AND FLOW RATE

80°F CONDENSING WATER			85°F CONDENSING WATER			90°F CONDENSING WATER		
HOT WATER °F			HOT WATER °F			HOT WATER °F		
GEN. IN	GEN. OUT	GPM	GEN. IN	GEN. OUT	GPM	GEN. IN	GEN. OUT	GPM
200	190	70	200	191	70	200	194	70
205	194	70	205	195	70	205	197	70
210	198	70	210	199	70	210	201	70
215	202	70	215	203	70	215	204	70
220	205	70	220	208	70	220	209	70
225	209	60	225	210	60	225	211	60
230	210	50	230	212	50	230	213	50
235	211	40	235	213	40	235	214	40
240	213	35	240	214	35	240	216	35
245	214	30	245	215	30	245	217	30

extracted from the firing water to produce a cooling effect of 300,000 Btu/hr (25 tons) in the chilled water. Firing water input can be modulated down to a minimum of 222,500 Btu/hr with a proportional decrease in refrigeration capacity. If the demand for refrigeration drops below one-half of the rated capacity of the unit, the firing water input requirement remains at 222,500 Btu/hr; consequently, the COP drops below 0.67 under these conditions.

The chilled water flow rate can be varied from 40 to 90 gpm as shown in Table 3-3 with the temperature differential across the chilled water side of the unit decreasing in direct proportion to the increase in flow rate. All of the combinations shown in the table are based upon unit operation at rated refrigeration capacity (300,000 Btu/hr). The temperature for chilled water leaving which is presented in the table is merely an example temperature; a range of obtainable exit temperatures is shown in Table 3-1.

The solar-powered heating and cooling system incorporates chilled water storage to cool the building during periods when solar energy is inadequate to fire the chillers. The chillers normally supply the cold storage reservoir, and the building load demand is met by drawing chilled water from the reservoir. The chilled water coils in the building are designed for an entry temperature of 45°F and a leaving temperature of 59°F. In view of these requirements and the performance characteristics of the chillers themselves, the chilled water controllers on the chillers have been set for the lowest possible outlet temperature, 40°F, and a relatively high flow rate, 75 gpm. Consequently, the inlet temperature is 48°F when the outlet temperature is at the minimum,

Table 3-3

CHILLED WATER FLOW VERSUS CHILLED WATER RETURN TEMPERATURES

GPM	40	45	50	55	60	65	70	75	80	85	90
Chilled Water Return Temperature	60	58.3	57	55.9	55	54.2	53.6	53	52.5	52.1	51.7
Chilled Water Leaving Temperature	45	45	45	45	45	45	45	45	45	45	45

and the COP of the unit does not drop below 0.67 until the inlet temperature drops below 44°F. These settings maximize the operating temperature range in the cold storage reservoir over which the chillers operate at maximum COP. Installed chillers, located in the mechanical equipment room, are shown in Figs. 3-1 and 3-2.

3.1.2 Collectors

The primary energy demand in the building is for cooling. Given the chiller performance specifications noted in the previous section, the primary requirement for the collector array is to supply firing water to the chillers at temperatures of 220°F or higher. The solar energy conversion efficiency required of the collector at these temperatures may be estimated as follows. Using a nominal collector area of 6,500 ft^2 installed on roof areas of the building, approximately 3,900 ft^2 are located on the south-facing, sloping roof having a tilt angle of 18 deg. The remaining 2,600 ft^2 are situated on the flat roof above the multipurpose room. Taking the flux of the sun on a south-facing surface with a tilt of 18 deg with the horizontal being approximately 300 Btu/ft^2/hr in the vicinity of solar noon at a latitude of 37°20' N in summer, the solar energy conversion efficiency required of the collector is approximately 45 percent:

$$\eta = \frac{445000\ (2)}{6500\ (300)} \times 100 = 45 \text{ percent}$$

The performance equation for the collector specified for this project is shown in Fig. 3-3, together with test results from three independent sources. If the average collector temperature is 225°F, the ambient temperature is 75°F, and the flux normal of the sun to the collector is 300 Btu/ft^2/hr, the abscissa value is 0.5. Efficiency of the collector under these conditions is somewhat above the estimated requirement of 0.45. Note that the efficiency of the unit at lower collector temperatures, which are suitable for meeting building heating loads, is considerably higher.

The collector used is a product of Ametek Power Systems Group, Hatfield, Pa. (Fig. 3-4). It was designed by Ametek to specifications prepared by the Lockheed Palo Alto Research

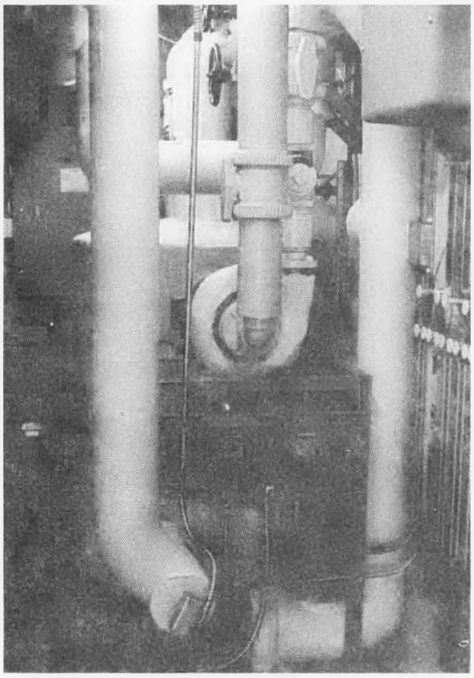


Fig. 3-1 Absorption Chiller in MER

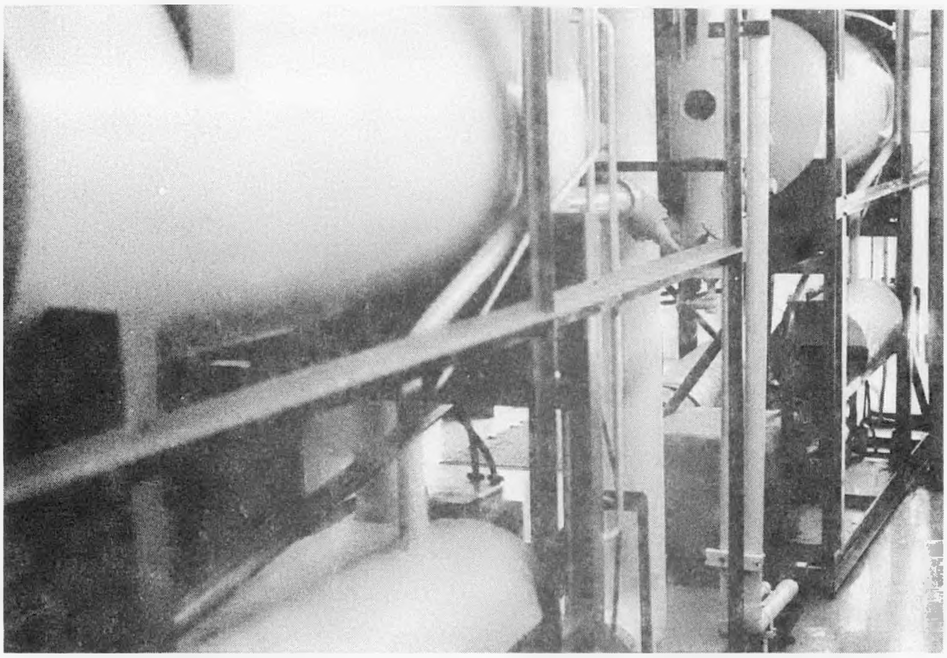


Fig. 3-2 Absorption Chiller in MER

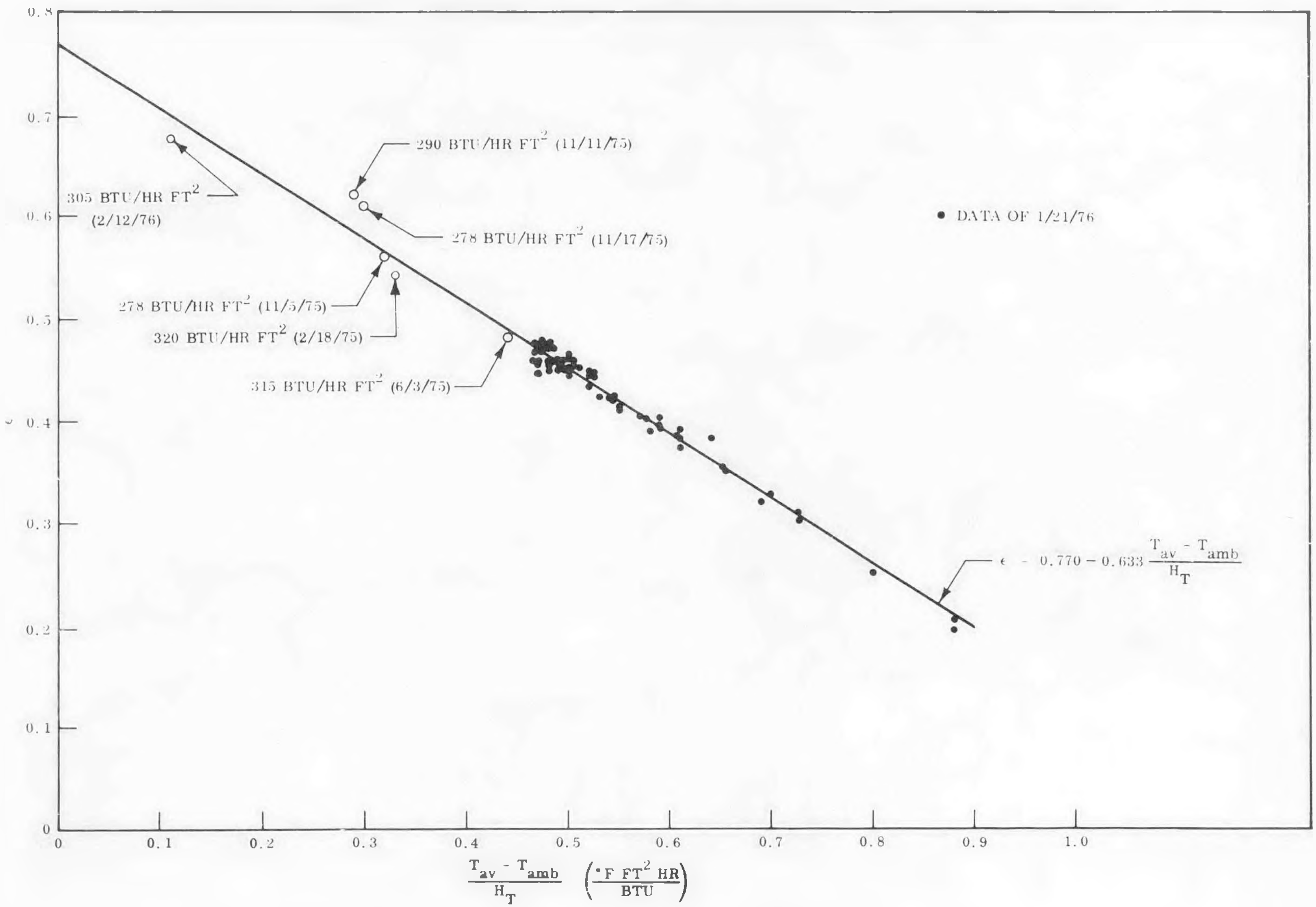


Fig. 3-3 Performance Equation for AMETEK Flat Plate Solar Collector at the City of Santa Clara Community Recreation Center

Fig. 3-4 Collector Assembly

Laboratory (see Appendix A). The collector is specifically designed to meet or exceed a noontime efficiency rating of 45 percent when the difference between the mean fluid temperature in the collector and ambient temperature is approximately 150°F and the solar flux is 300 Btu/ft^2 hr. Efficiency is calculated on the basis of the solar flux measured normal to the surface of the collector and collector aperture area (16.25 ft^2).

The outer enclosure is fabricated from Corten steel with continuous welds at all joints. There are only three penetrations into the box: inlet and outlet pipes to the absorber plate and a vent to the desiccant. The pipes are fitted with grommets at the box wall, and a sealant is used at all mating surfaces. Consequently, the outer enclosure is weathertight; moisture cannot enter the box to dampen the insulation or fog the glazing and reduce the efficiency of the unit.

The vent to the desiccant is located inside one of the box feet on the inlet end of the box. A tube connects the vent to the desiccant container which is located adjacent to the bottom of the absorber plate in approximately the center of the unit. In this location, the desiccant is heated sufficiently during the day to vaporize and expel any moisture that may have entered the desiccant tube during the night with cool night air. The desiccant, therefore, is self-regenerative and does not require replacement.

Two tempered glass plates are used in each box. The upper piece is sealed into a specially designed synthetic rubber gasket which in turn is sealed to the lip of the outer enclosure. The gasket employs an integrally molded glazing zipper to facilitate replacement of the cover or access to the interior of the box. The two glass plates are one inch apart, and the bottom plate is one inch above the surface of the absorber plate.

The glazing is a product of the Fourco Glass Company, Clarksburg, West Virginia, and carries the commercial designation "Clearlite." It is a low-iron glass (0.59 percent) with 90-percent average transmission. Specific transmission data are:

Millicron Range	Transmission (Percent)
400 – 700	90 – 91.5
1050	86.5 – 87

The absorber plate is a Roll-Bond product with integral riser and header design manufactured in copper no. 122 by Olin Brass, East Alton, Illinois. The absorber plate and the bottom glazing are both held in place with clips that prevent vertical movement of these components but allow movement in the plane of the components caused by thermal expansion. The absorber plate, however, is fixed at the outlet end so that all thermal expansion takes place toward the inlet. This movement is accounted for at the inlet end of the box by providing the inlet tube with a crossover equipped with an expansion joint. The inlet and outlet pipes are in-line on the right side of the box.

The interior design of the box has been carefully executed to minimize conductive and convective losses through the bottom and sides of the outer enclosure. Interior structure is supported on rigidized or board insulation, and insulators are used between all mating metal surfaces. A loose, fibrous insulation fills the bottom of the box.

The board and loose insulation used in the collector boxes are products of Eagle-Picker Industries, Inc., Cincinnati, Ohio. The insulation board is MT-8 Mineral Fiber board with a nominal density of 8 lb/ft^3 and the following conductivity values:

Mean Temperature (°F)	K (Btu - in./hr/ft^2/°F)
100	0.220
200	0.255
300	0.315
400	0.385

Binders used in the fabrication of this product do not out-gas below 550°F. The loose fiber insulation is H-2 Mineral Fiber with essentially the same conductivity values as are noted above. This particular material was specially processed for this program because a very small amount of oil spray used to control airborne particles during manufacturing vaporized in the collector under stagnant conditions and deposited out on the absorber plate and the surfaces of the glazing. The special processing consisted of eliminating the oil spray. Other organic materials in the collector box – for example, the gasket for the top glass and fiberglass cloth used to contain the loose insulation in the bottom of the box – were also carefully evaluated or processed to ensure that no out-gassing occurs at stagnation temperatures to 400°F.

Each collector box has four 1-in.-high feet that are designed to lock the box in place conveniently when it is placed on a properly prepared roof. The design is illustrated in Fig. 3-5. Each foot has a metal tab facing in the downhill direction. This tab slips over the free flange of a zee stiffener mounted to the roof or to collector stands. Once installed, hook bolts and oversized rectangular washers are used to lock the feet to the zee stiffener as shown in Figs. 3-6 and 3-7. This locking feature was specifically designed for lateral earthquake loads which could jar the boxes free of the zee stiffener flange. Special precautions have been taken to provide a protective interface between the Corten foot and the zee stiffener. To avoid any possible accelerated corrosion at this joint, the tab on the foot is coated with silicone paint; further, the rectangular washer is drilled through in two places to prevent entrapment of moisture in the foot adjacent to the washer. Placement of collectors on roof areas to form the array and interconnection to headers is shown in Figs. 3-8, 3-9, 3-10, and 3-11.

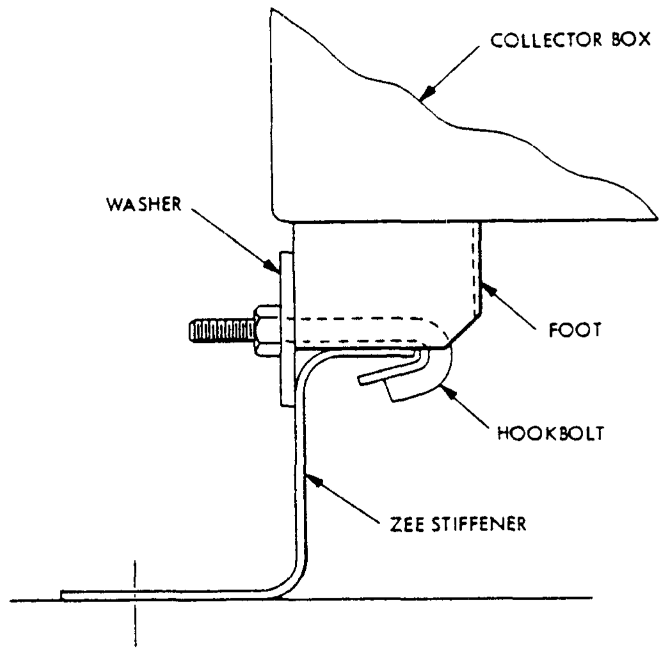


Fig. 3-5 Collector Foot to Zee Stiffener Locking Assembly

The absorber plate has 21 risers over the 22-in. plate width. Both the risers and the headers are hydraulically inflated to the same overall height, which is approximately 0.16 in. Therefore, to maintain a greater pressure drop in the risers than in the headers, which ensures that all of the risers will be filled during operation, the headers are approximately 4-in. wide and have a waffle, spot-bond pattern to sustain a design pressure of 40 psi at 450°F without failure. The inlet to the plate is at bottom left, and the exit is diagonally across the panel at top right. Consequently, all fluid travels the same distance in moving through the plate. The headers have a position slope away from the inlet and to the outlet to avoid trapped air and also to ensure complete drainage. The headers are placed as close as possible to the ends of the plate, considering roll-bonding tolerance, to minimize the dead area at the ends of the plate. During trimming operations, the dead area at the top of the plate is held to a prescribed dimension, and the dead area at the bottom of the plate is allowed to vary within the tolerance of the roll-bonding process. All plumbing connections to the absorber plate are brazed

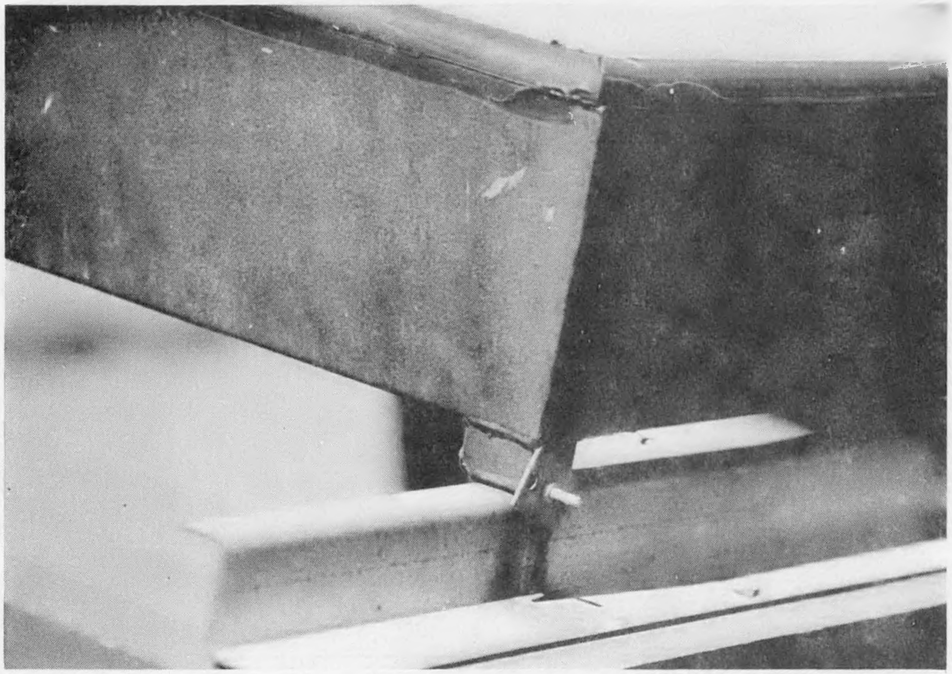


Fig. 3-6

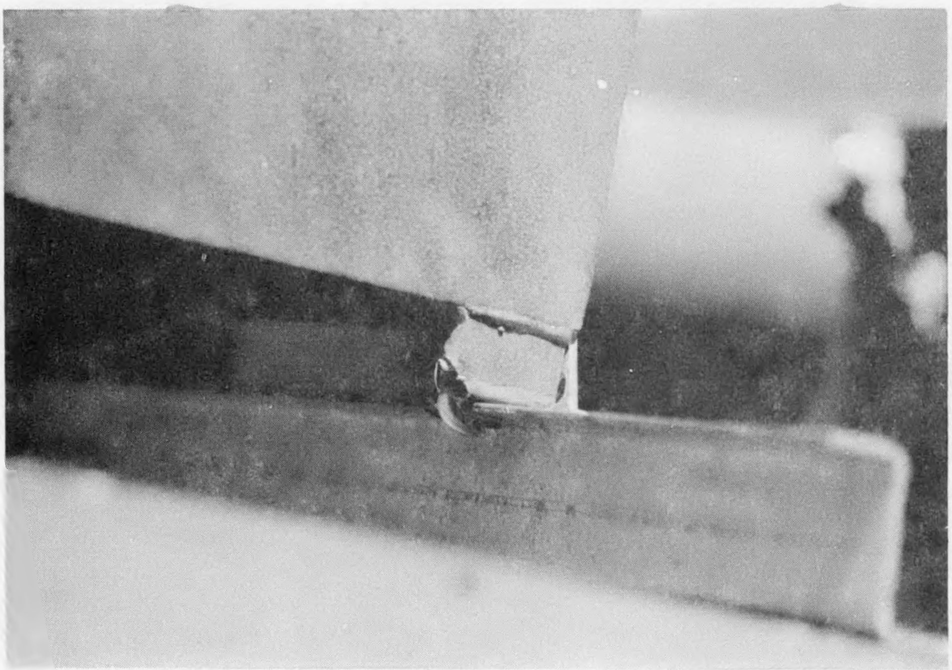


Fig. 3-7

Collector Mounting Foot

Fig. 3-8

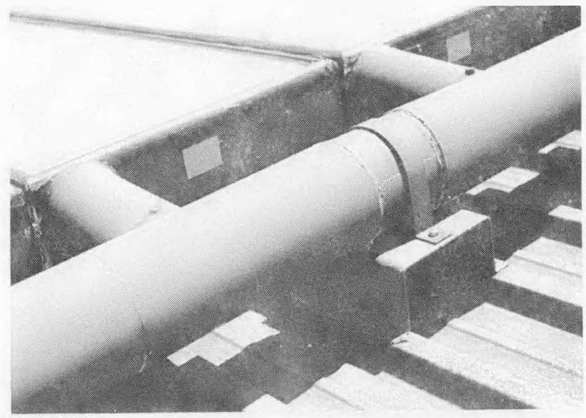


Fig. 3-9

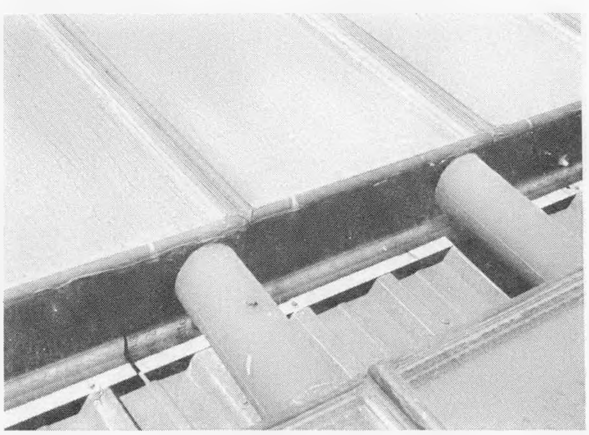


Fig. 3-10

Fig. 3-11

Collectors on Roof

to withstand stagnation temperatures to 450° F. Pressure drops across a single panel using water as the working fluid have been recorded by Ametek as follows:

Flow Rate (lb/hr/ft^2)	Flow Rate (gpm/panel)	Pressure Drop (psi)
10	0.293	0.026
20	0.586	0.08
30	0.879	0.16

At these flow rates, maximum fluid velocity is well below the maximum permissible to prevent erosion of the copper, and the flow is laminar.

The upper side of the copper absorber plate is treated with a proprietary selective coating developed by Ametek that has the following optical properties:

	Range
Absorptivity	0.97 – 0.99
Emissivity	0.22 – 0.40

Durability and performance degradation of the coating are unknown at this time. However, the coating has been subjected to temperatures of 450° F under stagnation conditions with minimum property change.

Two stands were built on the flat roof over the multipurpose room to support collectors. These stands are constructed from Douglas fir and are protected with two coats of stain to preserve the wood against the weather. The support stands are shown in Figs. 3-12 and 3-13.

The multipurpose room roof is surrounded by a 5-ft-high parapet. The two collector stands are positioned so that the collectors on the south stand are in full sun at solar noon on December 21; i.e., the sun just clears the parapet to strike the bottom edge of the collectors at solar noon on the shortest day of the year. The collectors on the

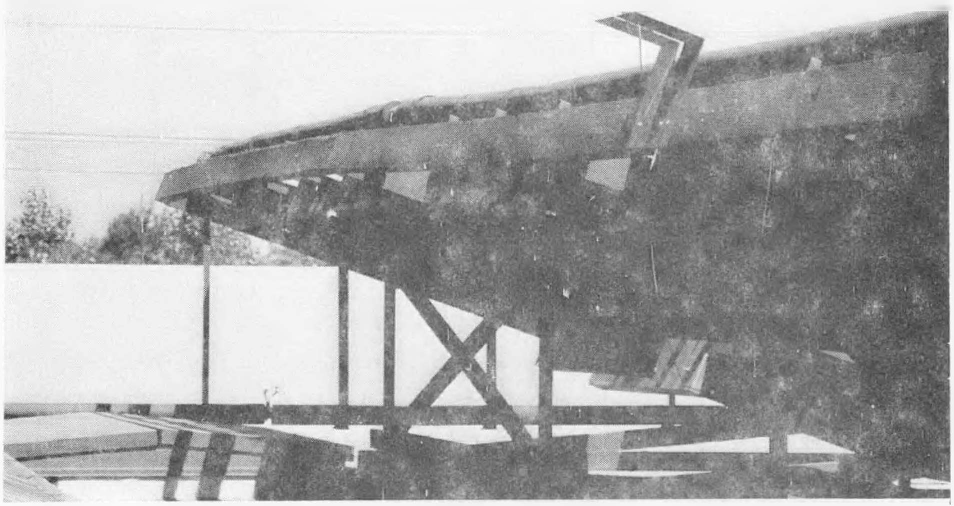


Fig. 3-12

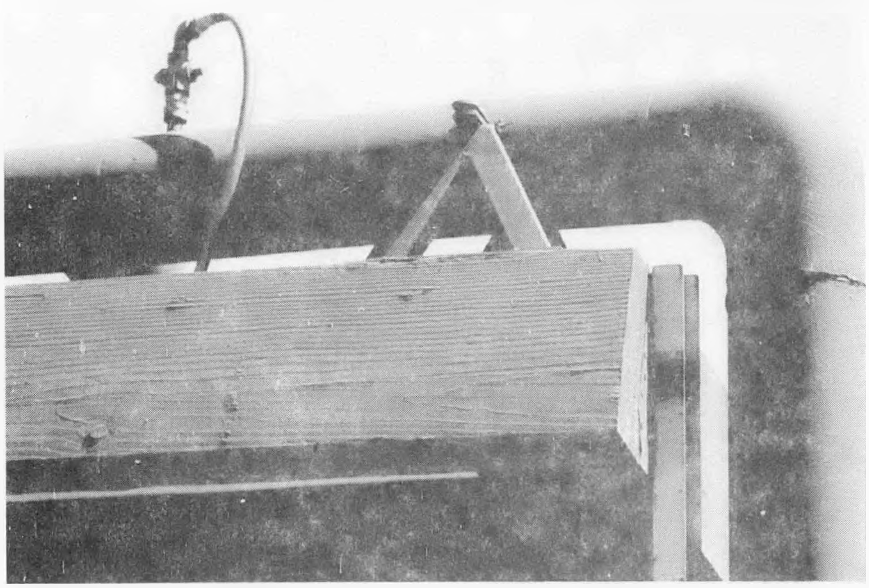


Fig. 3-13

Multipurpose Roof Array and Stand

north stand receive the same solar exposure, except for shadowing caused by the outlet header on the south stand. Vertical elevation of the north stand to eliminate this shadowing in winter was ruled out in favor of minimizing the visual profile of the stands from ground level.

3.1.3 Storage

The solar system design features both hot and cold water storage reservoirs that provide heating and cooling energy respectively to meet building demands. Cold water storage was selected over hot storage of chiller firing water because of requirements in the latter case for a pressurized tank to store water at temperatures of 220°F or greater, the need for a large storage volume because of the small range of useful temperatures, the significantly greater requirement for tank insulation, and problems associated with corrosion protection of the reservoir and internal hardware at temperatures above 200°F.

Both the hot and cold water storage reservoirs operate at ambient pressure. The hot storage reservoir has a capacity of 10,000 gal. The temperature of the hot reservoir is allowed to fluctuate with building demand and the availability of solar energy for hot storage up to a maximum of 212°F. The heating coils inside the building are designed for an inlet temperature of 105°F; consequently, the hot storage reservoir cannot be utilized whenever the reservoir temperature falls below approximately 115°F. Because the hot storage reservoir is capable of a large temperature range, the reservoir is relatively small. Energy stored in the hot storage reservoir can supply average building demand for up to four days during stormy weather, depending upon the initial temperature status of the reservoir and the magnitude of the building demand.

The cold storage reservoir has a capacity of 50,000 gal. This large storage volume is required because of the small operational temperature range that is possible. The chillers supply chilled water to the reservoir at a minimum temperature of 40°F at the maximum COP of 0.67 while the design entry temperature to the cold coils of ind vidual air handlers in the building is 45°F. The reservoir provides a one-day reserv to the building under average summer building load demand conditions, a capability dependent upon diffusers that ensure cold tank stratification. Lines from the chillers and to the building cold fan coils are located in the bottom of the reservoir while lines to the chillers and from the building cold fan coils are located in the top of the reservoir.

The hot water storage reservoir is a welded, cylindrical A36 steel tank that is 8 ft in diameter and 34 ft in length. Its capacity is 10,000 gal, and it has an air space at the top of the tank for the collection of steam. The tank has a 3.5-ft-diam hatchway and a 10-in.-diam steam vent. The tanks as delivered to the site are shown in Fig. 3-14. Note that the ends of the tank are reinforced with two stiffeners to carry bending moments across this flat surface. These stiffeners are welded to straps at either end which distribute the end reactions into the cylindrical wall of the tank. The tank is fabricated from 0.25-in.-thick steel plate. Lifting eyes are provided at the top centerline of the tank for ease of handling.

Fig. 3-14 Fabricated Steel Tanks, as Delivered

The exterior surface of the tank is insulated with Owens-Corning Urethane Spray System No. 304. This is a 4-lb-density material that was applied after the tank surfaces had been descaled and primed. The application of the material is illustrated in Figs. 3-15 and 3-16. A total thickness of 3.5-in. of insulation was laid down in passes which included a 0.25-in.-thick initial pass and subsequent passes 0.5-in. thick. This technique results in the desired density and also prevents cracking and splitting within the foam. Properties of the material as defined by the manufacturer are given in Table 3-4.

Table 3-4

TYPICAL PHYSICAL PROPERTIES[(a)] OF URETHANE SPRAY SYSTEM NO. 304

Property	Unit	Value
Density	lb/ft^2	4.0 to 4.4
Compressive Strength: Parallel Perpendicular	psi	75 70
Thermal Conductivity[(b)]: As sprayed. Aged (3 mo. at 140 F)	Btu in./hr ft^2 deg F	0.12 0.16
Permeability	perm-in	< 2.0
Open Cell Content	Percent by volume	<10
Recommended Temperature Range – Constant Temperature		-30°F to +225°F

(a) Properties shown are for materials sprayed onto a surface at room temperature and removed for physical testing.
(b) 0.14 Average "k" at 75°F mean temperature.

The compressive strength of the material after a one-day cure was sufficient to support the weight of the empty tank. Therefore, the tank was rotated after the upper half had been sprayed to provide access to the lower half of the tank. No crushing of the foam was observed as a result of this procedure. The work was performed only when the application surfaces were dry and the ambient temperatures were above 60°F.

Fig. 3-15 Spray Application of Insulation to Tank

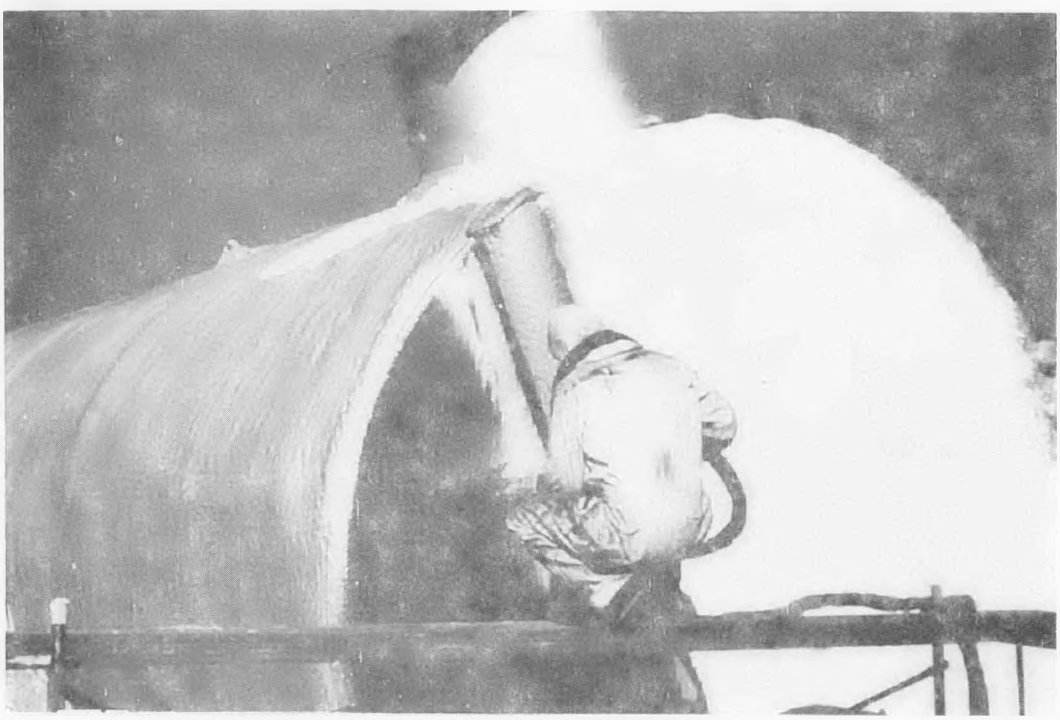


Fig. 3-16 Spray Application of Insulation to Tank End

Following the application of the urethane spray foam insulation, a waterproof barrier was applied to seal the external surface of the foam against moisture (Fig. 3-17). The system specified for this program was Foster Monolar White Sprayable Mastic No. 60-36. This is a tough, flexible, fire-resistant material based on duPont Hypalon. It is intended for the protection of thermal insulation. Service temperature limits are -20 to +250°F, and water vapor transmission is 0.04 perm at 30 mils dry. In this particular case, the material was applied with a mop because the viscosity of the system at approximately 65°F did not permit spraying.

Fig. 3-17 Application of Moisture Seal

The 3.5-in. thickness of urethane foam insulation results in an R factor of 25 when the average thermal conductivity of the material is taken to be 0.14 Btu-in/hr ft^2 °F. Taking the temperature of the ground in winter to be 60°F and the average operational temperature of the reservoir in winter to be 180°F, the daily heat loss from the reservoir is 110,000 Btu. This is about 2 percent of the useful energy capacity of the reservoir, taking 115°F as the lowest useful temperature in the reservoir for meeting building heating demand. The urethane foam, besides being a very efficient insulating material, is ideal for the insulation of curved surfaces. In addition, the compressive strength of the 4-lb-density material is adequate when cured to support the filled tank and earth burden without crushing. Finally, the insulation and the waterproof barrier are both capable of withstanding tank temperatures to 212°F without property degradation.

The interior of the tank is lined with a minimum 0.5-in. thickness of a rust-proof, nonsoluble, silicious material carrying the commercial designation "Feroline." This product was selected because of its ability to prevent corrosion in the tank wall at continuous tank temperatures of 212°F, particularly at the waterline and those areas above the waterline subjected to continuous hot vapor. Strengths of the material as a function of age at test as provided by the supplier are:

Age at Test (days)	Compressive Strength (psi)
3	5,890
7	9,580
14	10,100
28	12,420

This material was applied to the interior walls of the tank after the tank had been set in position, back filled, and all piping connections made. The material was applied directly to the cylindrical walls of the tank, but the flat end closures were first covered with a wire mesh tack-welded into place. Following application of the material, the tank was filled with water and the material was allowed to cure for 30 days. The tank was then drained and internal piping, controls, and instrumentation installed prior to refilling. The material characteristically has a slight but continuous expansion during its first year of setting up, which forces the lining firmly against the walls of the tank, while the strength of the material prevents chipping.

This particular tank does not have a built-in ladder for access. Corrosion protection of the ladder was not considered feasible; consequently, access to the tank is gained by manually inserting a ladder whenever the tank is entered. Unistrut hangers are provided in the bottom of the tank for pipe supports. Two such hangers are located in the top of the tank to support instrumentation.

The cold water storage reservoir is also a welded, cylindrical A36 steel tank that is 12 ft in diameter and 58 ft in length. The capacity of the tank is 50,000 gal with a small air space at the top of the tank. This tank also has a 3.5-ft-diam hatchway which is located off the centerline of the tank to clear the diffuser pipes and shrouds that run the length of the tank at both top and bottom centerline. The tank is fabricated from 5/16-in.-thick steel plate, and lifting eyes are provided at top centerline for handling purposes.

Stratification of the fluid in the cold water storage reservoir is necessary for successful operation of the system. This stems from the fact that the chillers cannot supply the tank at their design COP once the input to the chillers from the tank drops below 44°F. On the other hand, the cold fan coils in the building are designed for an inlet temperature of 45°F. Thus, it is important to segregate the supply to the chillers and the return from the cold fan coils at the top of the tank while the return from the chillers and the supply to the cold fan coils is confined to the bottom of the tank.

In the design of the stratified cold storage tank uniform and smooth water deposition is needed near the top and bottom of the tank to maintain proper temperature stratification. Appreciation of this problem can be gained by considering the lopsided ratio of water deposition speed to mean tank speed. In the cold storage tank, the mean particle advection speed (due to source and load flows) is roughly 0.5 in. per min. In this quiet environment, even a modest jet with a speed of a few inches per second creates a significant disturbance. Therefore, a water diffusion system is needed to bring the speed down to tank values from the 45 ips or so that prevail in the inlet plumbing. Such a system was developed by means of laboratory experiments.

The Hydrodynamics Facility at the Lockheed Palo Alto Research Laboratory (see Appendix J) was used to simulate the bottom section of the cold storage tank, including full-size inlet and outlet piping. The discharge orifices followed a pattern that was calculated to give uniform water deposition and withdrawal along the 60-ft length of the tank. Water was pumped through the pipes at the same rate (per unit length of simulated tank) as in the actual storage tank. Dye injection was used to visualize the resulting water flow.

A straightforward arrangement of the pipes resulted in the flow pattern shown in Fig. 3-18. Jets from the discharge orifices created a pair of wall jets that climbed up the tank walls and generated considerable mixing. These jets proved to be persistent, and various baffles on the floor and walls of the tank were ineffective in dissipating them. After systematic testing of various alternatives, a new concept was developed. The pipes were arranged as shown in Fig. 3-19 with a partial baffle around them. A new discharge orifice pattern incorporated side-thrusting jets, which created pairs of counterrotating vortices located between the pipes and baffle, running parallel to the pipes. Water deposition into the tank occurred by detrainment from the vortices and therefore through a much larger area than the original jets. As a consequence, the deposition process was much smoother, and no wall jets or rapid mixing were observed, as shown in Fig. 3-20. This design was adopted for the inlet diffusion system of the cold water tank at Santa Clara.

The exterior surface of the cold water storage reservoir is insulated with the same urethane spray system and waterproof barrier used on the hot-water storage reservoir, except in this case the thickness of the insulation is 2 in. In spite of the substantially larger size of the cold water reservoir, the insulation supports the weight of the filled tank without crushing.

The 2-in. thickness of urethane foam insulation represents an R factor of 14 when the average thermal conductivity of the material is taken to be 0.14 Btu-in./hr ft^2 °F. Assuming the temperature of the ground in summer to be 65°F and the average

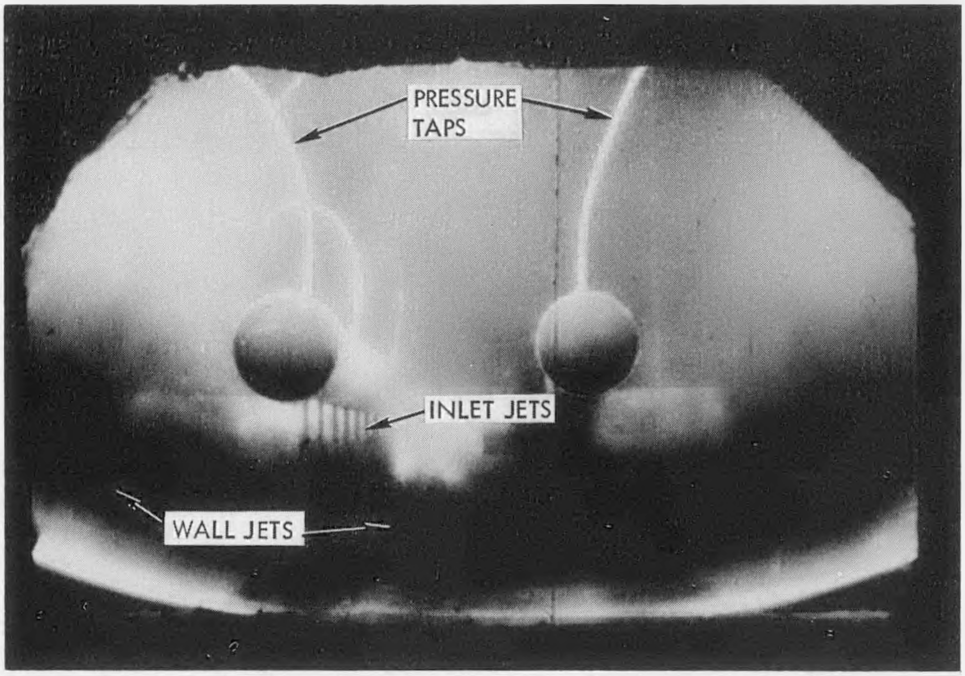


Fig. 3-18 Straightforward Piping Arrangement (Note Formation of Wall Jets and Mixing.)

operational temperature of the reservoir in summer to be 45°F, the daily energy loss from the reservoir is 83,000 Btu. This again represents about 2 percent of the useful energy capacity of the reservoir, taking 12°F as the design temperature differential in the reservoir for meeting building cooling demand.

The interior of the tank, the permanent access ladder, and the top and bottom shrouds are coated with 16 mil of Koppers Bitumastic Super Tank Solution. This material was applied to prevent corrosion after initially preparing the surfaces by sandblasting them to near-white. Typical ground preparation for the tanks and placement is given in Figs. 3-21 and 3-22.

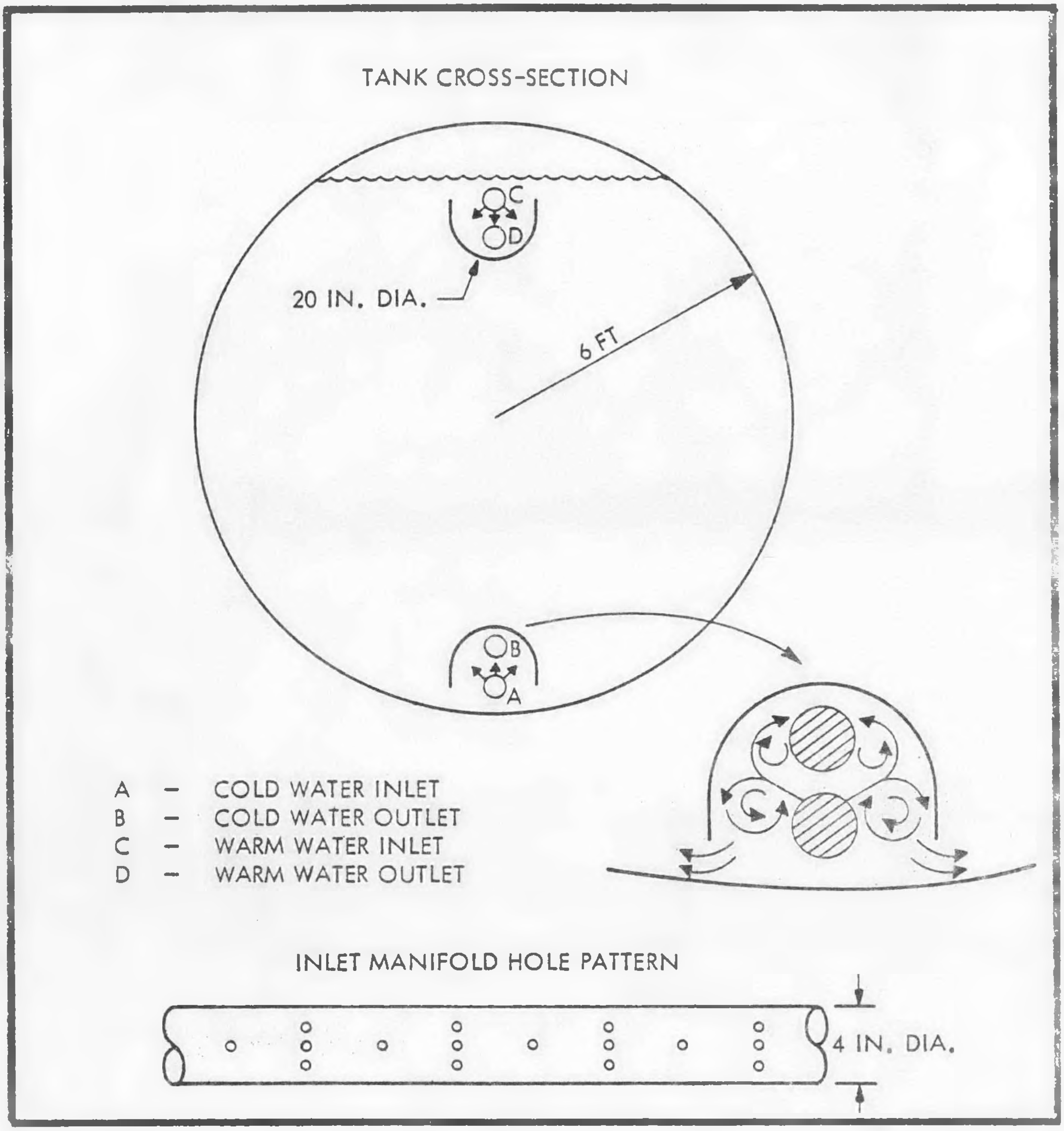


Fig. 3-19 Lockheed's Design of Baffle System to Minimize Mixing due to Water Deposition

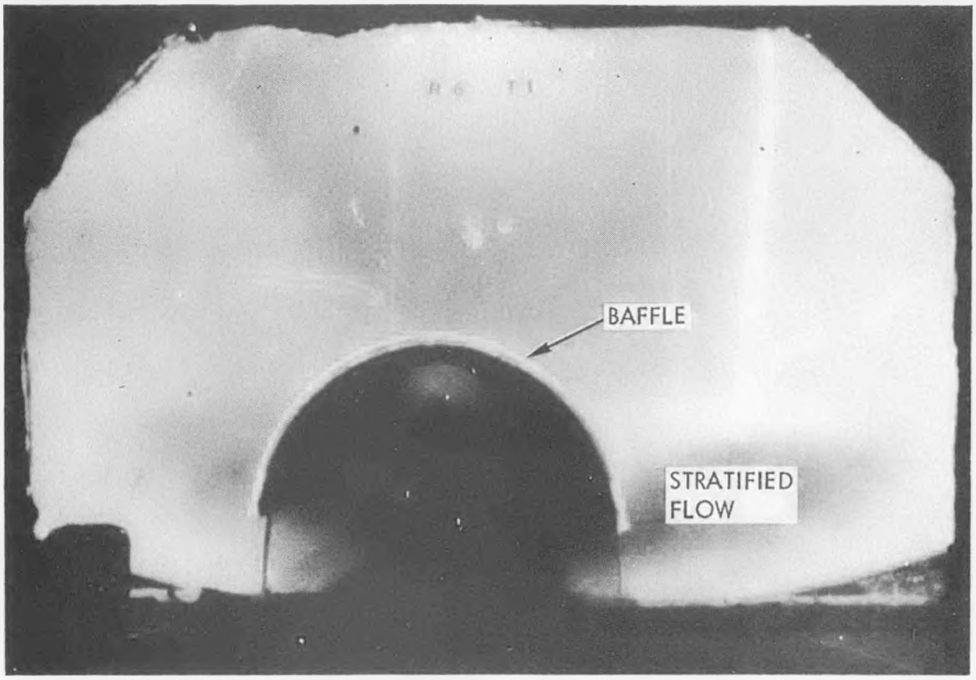


Fig. 3-20 Lockheed Baffle System in Operation

Fig. 3-21 Ground Preparation for Tank

Fig. 3-22 Ground Placement of Tank

3.1.4 Mechanical Arrangement

The mechanical arrangment of the solar-powered heating and cooling system is shown in schematic form in Fig. 3-23. Basically, when valve V_1 is in the A → AB position, solar energy is used for heating; when valve V_1 is in the B → AB position, solar energ is used to produce cooling via the chillers. These two piping loops are interconnected to an auxiliary boiler loop that can be used as an energy source to either heat or cool the building if solar energy in either direct or stored form is unavailable. This particular arrangement was also chosen because it allowed the solar-related piping to be added on after the boiler had been operational in first heating and then cooling the building.

The piping system features a number of secondary pumping loops that allow various building demands to be met in an efficient manner with a minimum of equipment and control complexity. The hot fan coils in the building are served by such a loop, and

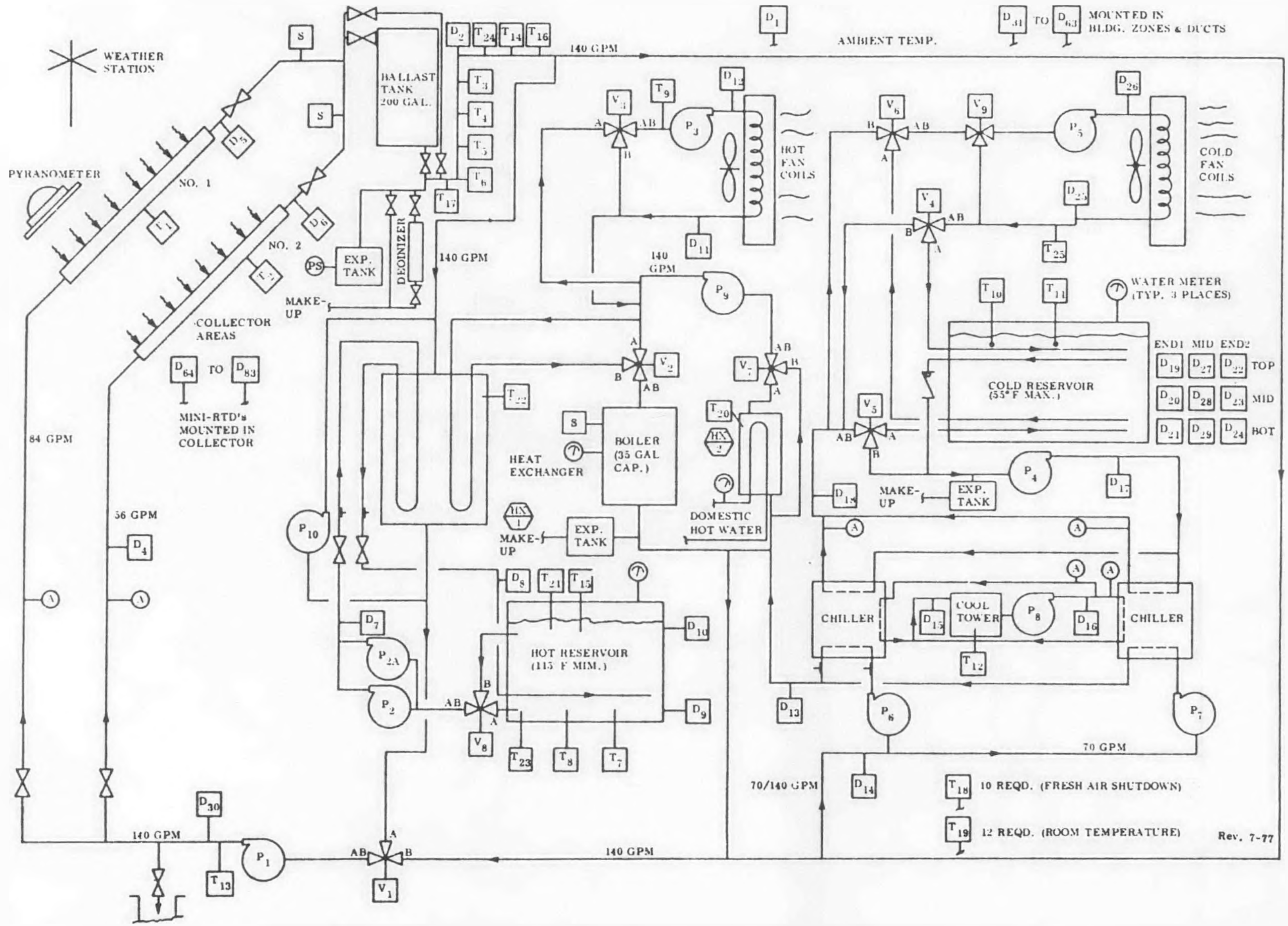


Fig. 3-23 Piping Schematic for Santa Clara Community Center

the cold fan coils can be served in a like manner. In the latter case, chilled water is supplied directly to the cold fan coils via the secondary pumping loop, and the cold storage reservoir is bypassed. Firing water to the two chillers connected in parallel is also provided from a secondary pumping loop whether the firing water is heated by solar energy or the auxiliary boiler. Either one or both chillers can be fired as requirements demand.

Ten constant flow pumps and six two-position, motor-driven, three-way valves are used in the system. In addition, there are two modulating three-way valves that are used to control to preset values the temperature of (1) the fluid to the hot fan coils (V_3) and (2) the domestic hot water (V_7).

There are four independent fluid loops in the system. Fluid heated in the collector may be passed through any of the pipes that appear as darkened lines in Fig. 3-24. The chilled water side of the chillers, the cold storage reservoir and the cold fan coils form a second fluid loop while the cooling tower has its own fluid loop. The fourth loop is the hot storage reservoir loop, which communicates with the rest of the system through heat exchanger HX-1. As a result of this arrangement, only the fluid in the collector loop requires freeze protection, and the volume of fluid requiring treatment both for freeze protection and purity is relatively small.

Because the storage reservoirs are at ambient pressure, pump pits are located adjacent to both the hot and cold storage reservoirs so that the pumps can be ensured of a positive head on the suction side by locating them below the fluid level of the tanks. During heat exchange operations into the hot reservoir, water is drawn from the bottom of the reservoir at one end and is deposited at the bottom of the reservoir at the other end. Heat exchange out of the hot reservoir is achieved by drawing fluid from the top of the reservoir and returning it to the bottom of the reservoir. Pump P_2 is used for normal heat exchange operations. However, in the event that the water temperature in the bottom of the hot reservoir approaches boiling during heat exchange into the reservoir, a larger pump, pump P_{2A}, is energized (and pump P_2 is deenergized) to prevent cavitation of the suction side of the pump or flashing in the heat exchanger.

SANTA CLARA SOLAR PROJECT

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

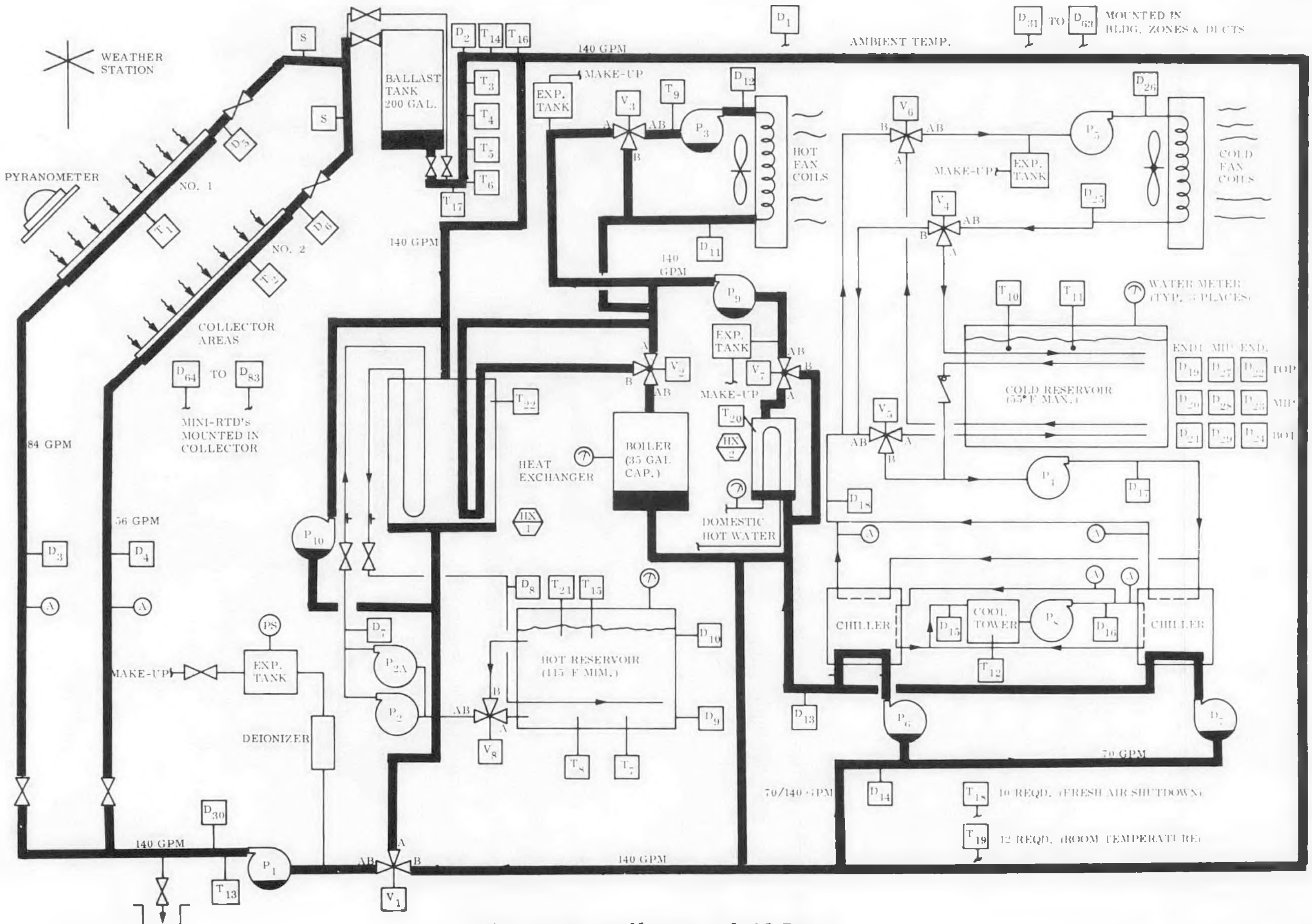


Fig. 3-24 Collector Fluid Loop

Heat exchanger HX-1 has two tube bundles plus a pumping loop (pump P_{10}) to provide circulation in the shell when pump P_1 is off. The primary bundle communicates with the hot storage reservoir as discussed previously while the secondary bundle communicates with the hot fan coils via the boiler loop. Consequently, solar energy may be used to meet the building heating demand, and any excess may be simultaneously stored in the hot reservoir. The secondary tube bundle in HX-1 may also be used to heat domestic hot water with solar energy via heat exchanger HX-2. This small heat exchanger is used to supply domestic hot water, rather than a more conventional small storage tank, because of the low anticipated usage of domestic hot water in the building. The heat exchanger will always be served by solar energy in either a direct or stored form except when the chillers are being fired from the auxiliary boiler, or the building is being heated by the boiler.

A special mechanical situation exists in the chilled water loop as a result of cooling the building with chilled water storage. Pump P_5, which serves the cold fan coils, is located in the mechanical equipment room, well above the surface of the water in the cold storage reservoir. Thus, provisions to pressurize the suction side of the pump must be made to prevent draining to the cold storage reservoir. This is accomplished by automatically switching valves V_4 and V_6 to the $B \rightarrow AB$ position whenever pump P_5 is de-energized and simultaneously pressurizing the lines with city water pressure via a suitable pressure reduction valve to account for possible leakage through pump seals. In the event that pump P_4 is also deenergized, valve V_5 is also switched to the $B \rightarrow AB$ position to maintain a pressurized fluid loop.

A 200-gal ballast tank is located at the exit to the collector arrays (in the MER) to provide the system with a short-duration fly-wheel effect in the event of scattered cloud cover. Rapid temperature drops in the collector fluid due to a passing cloud are counteracted by the hotter fluid in the ballast tank; consequently, short-cycling of the chillers due to rapid variations in the temperature of the firing water is eliminated. This results in more effective use of solar energy to fire the chillers and an extension of chiller life.

3.1.5 Controls

The solar-powered heating and cooling system is managed automatically with solid state controllers operating in conjunction with resistance temperature devices (RTDs) and a pyranometer. The pyranometer is the primary sensing device used to determine the appropriate conditions for initiating the various solar operating modes because it eliminates the time lag involved in heating fluid in the collector array. However, the pyranometer is backed up with resistance temperature devices in case of malfunction.

The solid-state controllers and RTDs are used both in the building air system and in the piping. Signals from the control devices are fed back to a master control panel located in the mechanical equipment room where the system may be adjusted according to the options available. A detailed review of the control system and its several modes of operation is presented in Section 4.

3.1.6 Piping and Plumbing

Details in the piping throughout the solar-powered heating and cooling system parallel in most cases standard practice in conventional heating and cooling systems. Manually operated shut-off valves are installed on either side of major pieces of equipment so that they can be serviced or replaced with a minimum loss of fluid. Included in this category are all pumps, tanks, motor-driven valves, chillers, the boiler, the cooling tower, and collector arrays. In addition, by-passes are provided for some components to allow the system to continue to operate when these components are undergoing maintenance. The boiler, ballast tank, cold water storage reservoir, and deionizers are equipped with by-pass piping, and one chiller may be operated independently of the other because of the parallel piping hook-up for these units.

Where necessary to prevent backflow, check valves are used. Flow rates in pipes are regulated with balance cocks or circuit setters. Divisions of flow throughout the piping system are balanced with circuit setters with Annubar measuring devices employed to accurately check the settings. Where possible, valves have been specified that perform multiple functions. Most balance cocks also serve as shut-off valves. Some triple-duty valves that combine check valve, balance cock, and shutoff valve functions are specified. Air bleed valves are located at high points in the piping to expel air from the system during fill operations, and blow-down valves are located as necessary on the condensing and chilled water sides of the chillers.

Expansion tanks are located in the system fluid loops as required to absorb the expansion and contraction of the working fluid with changing temperatures. Pressure to the system (nominally 20 psi) is maintained by city water pressure, and the same lines are utilized to admit make-up water to the system. These lines are equipped with pressure reducing valves, check valves, and shut-off valves.

The schematic drawing of the piping system as drawn by the mechanical engineer for this program to reflect the details discussed above is shown in Appendix L, Drawing L-13. This was the top drawing used by the plumbing subcontractor in piping the system.

Water in the collector fluid loop contains a 10-percent-by-volume concentration of propylene glycol to prevent freezing. The water used to fill the system was bottled water with minimal impurities, and make-up water admitted from city water lines passes through cartridge-type deionizers to ensure chemically pure water in the collector fluid loop and in the hot storage reservoir fluid loop. A chemical feeder is also installed to the make-up line for the cooling tower. Float valves are used in the hot and cold storage reservoirs to regulate the make-up water to the tank.

The hot water piping in the system is copper with appropriate dielectric isolation with dissimilar materials as required. The chilled water piping is schedule 80 PVC pipe with socket weld fittings. Schedule 40 PVC pipe with socket weld fittings is used in the cooling tower piping.

Joints in the hot water piping throughout the system are standard soldered joints except in the collector arrays. These joints are silver soldered to provide adequate joint integrity at collector stagnation temperatures (450° F).

All piping within the fluid loops of the system is insulated with the exception of the cooling tower lines. In the latter case, the difference between the temperature of the fluid and ambient temperature is small, and the only advantage of insulation is some slight cooling effect within the mechanical equipment room. The insulation for the collector loop is designed to keep the rate of total pipe heat loss at no more than approximately 3 percent of the total energy being extracted from the loop under the most stringent of normal operating conditions. These conditions are experienced when the collector is supplying fluid at 220 F to fire both chillers at full load. Energy required at the chillers, therefore, is approximately 890,000 Btu/hr. The length of piping on the loop between the chillers and the collector arrays is approximately 1,500 ft. Therefore, a 3 percent loss rate results in a requirement for the collector arrays to deliver approximately 920,000 Btu/hr, and the loss per lineal foot of pipe may not exceed 18 Btu/hr. The details of the insulation designs that have been used to meet this requirement in the collector loop are presented in the following subsections.

In the case of the hot water storage loop, the pipe insulation is designed to keep the loss rate at less than one-half percent. The most severe normal operating condition involves moving fluid through heat exchanger HX-1 at the exchange capacity of the unit (1×10^6 Btu/hr). The length of piping in the loop between HX-1 and the hot storage reservoir is approximately 200 ft. Therefore, the loss per lineal foot of pipe may not exceed 25 Btu/hr. The fluid temperature in this condition may reach 212° F. The pipes are underground, and the temperature differential is approximately 150° F. See Subsection 4.3.3 for design details.

The insulation for the chilled water loop is similarly designed, with the loss rate restricted to less than one percent. Here, the most severe normal operating condition occurs with the two chillers operating at full load, 600,000 Btu/hr. In the event that this energy is used to meet building demand directly (i.e., the cold storage reservoir is by-passed), the fluid moves to the cold jump pit and returns to the MER prior to entering pump P_5. The length of piping in the loop is approximately 500 ft. Therefore, the loss per lineal foot of pipe may not exceed 12 Btu/hr. The piping is underground. The maximum temperature differential between the ground and the fluid temperature is 25° F (65° to 40° F). Details of the pipe insulation design meeting this requirement are given in Subsection 4.3.4. Note that the design criteria for the hot and cold storage loops do not include losses in the building piping which serves the hot and cold fan coils. These lines were existing in the building prior to the initiation of the design of the solar-powered heating and cooling system. The low loss rates in the hot and cold storage loops are obtainable primarily because of the relatively short pipe lengths in these loops. The loss rates are, of course, higher when the loops are operating at less than maximum energy transfer; i.e., the absolute loss per lineal foot of pipe remains approximately constant whether the transfer is equal to or only half of the maximum transfer.

Insulation of collector array headers is shown in Figs. 3-25 and 3-26. The insulation of lines leading from underground storage to the building is shown in Fig. 3-27 and 3-28, and insulation of lines and components in the mechanical equipment room is shown in Figs. 3-29 and 3-30.

3.2 SYSTEM LAYOUT AND COMPONENT LOCATIONS

A series of isometric drawings is presented in this section to describe the actual locations of the piping, equipment, and sensors in the solar-powered heating and cooling system. An index to the drawings is presented in Table 3-5 and the drawings, numbered SCP-PC1 through SCP-PC18, follow.

Piping in the MER has been fitted into a relatively small space and as a consequence it is impossible to clearly show this piping in one drawing. Instead, the MER piping has been divided here into six functional subsystems and a drawing prepared for each subsystem. These are drawings SCP-PC1 through SCP-PC6.

The drawings show the locations of the control sensors and a cross-index to locate a particular sensor is given in Table 3-6. This table also identifies the function of each sensor and its preliminary set point as defined in the Control System Specification. The Control System Specification is included in this report as Appendix A.

The drawings show additionally the locations of the data sensors that measure fluid temperature ($D_1 \rightarrow D_{30}$). A cross-index for locating these sensors is presented in Table 3-7.

A cross-index for locating the motor-driven valves is given in Table 3-8, and a similar index for locating the manual valves in the system is presented in Table 3-9. Table 3-9 includes all gate valves (either cast iron or PVC), balance cocks, check valves, and circuit setters. Note that the manual valves have all been tagged with numbered brass discs that correlate back to the numbers assigned in the table. The motor-driven valves are labeled with plastic tape, as are both the data and control sensors.

The system includes thirteen annubar devices, and an index to their locations as indicated on the drawings is shown in Table 3-10. The table also presents the design gpm rating for pipe flow at each annubar location. The annubars are physically labeled the same as the equipment previously described.

An index to the pumps in the system appears as Table 3-11. This table gives design gpm rates and also lists the pump function. All pumps are labeled on adjacent structure or electrical boxes, as well as at remote power switches in the MER.

Finally, Table 3-12 presents the locations of the data sensors in the air ducts in the building ($D_{31} \rightarrow D_{63}$). Drawings illustrating the locations of all of these sensors are not given; however, an example ac unit installation is shown in Fig. 3-31. The sensors are labeled where installed for quick identification.

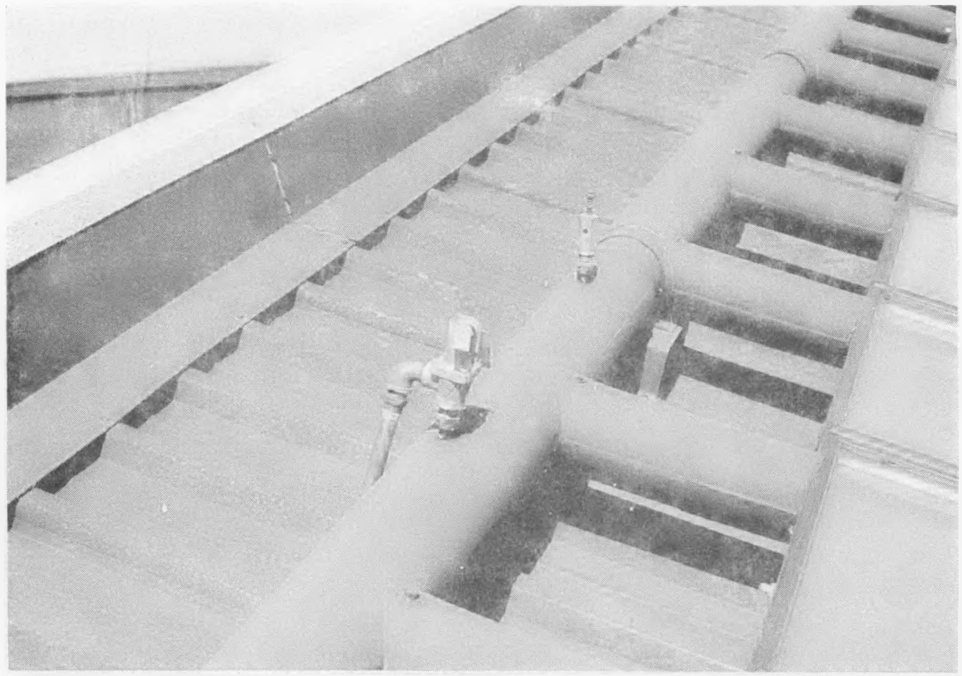


Fig. 3-25 Insulation of Collector Array

Fig. 3-26 Insulation of Collector Array

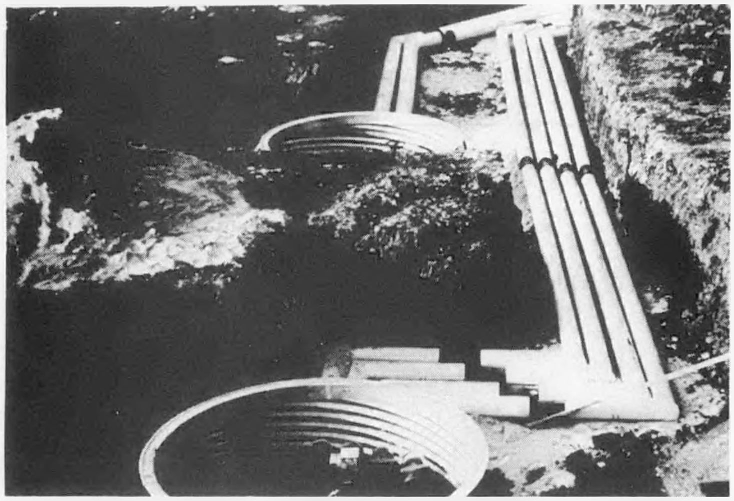


Fig. 3-27 Insulation of Lines From Storage

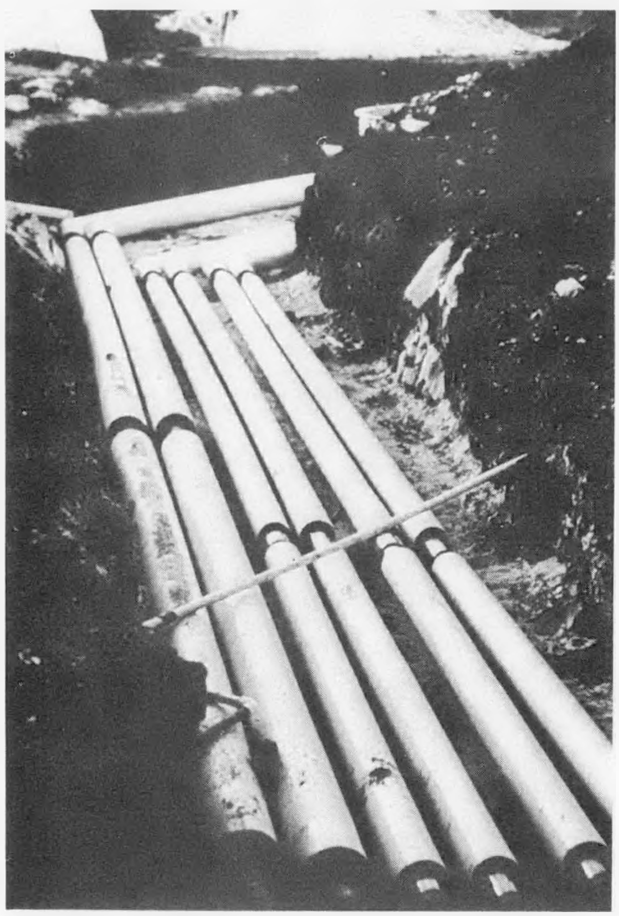


Fig. 3-28 Insulation of Lines From Storage

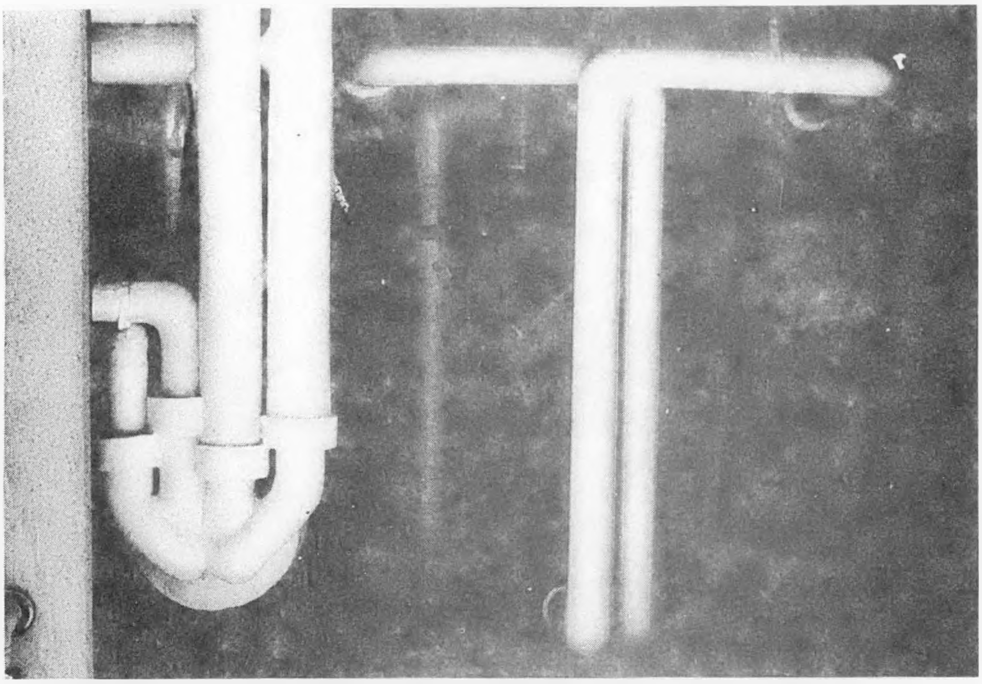


Fig. 3-29 Component Insulation, Mechanical Equipment Room

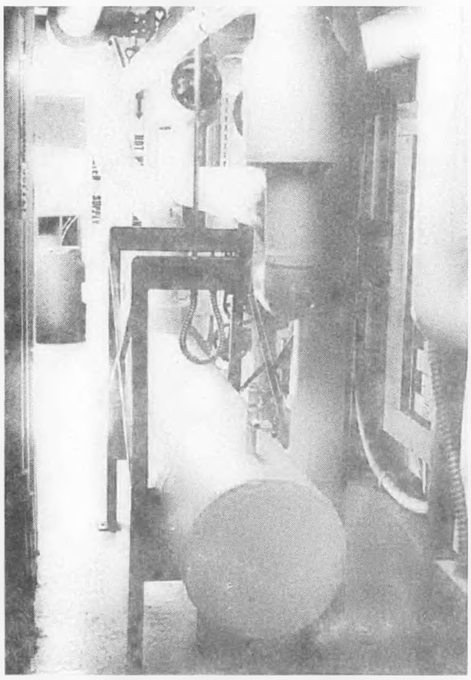


Fig. 3-30 Component Insulation, Mechanical Equipment Room

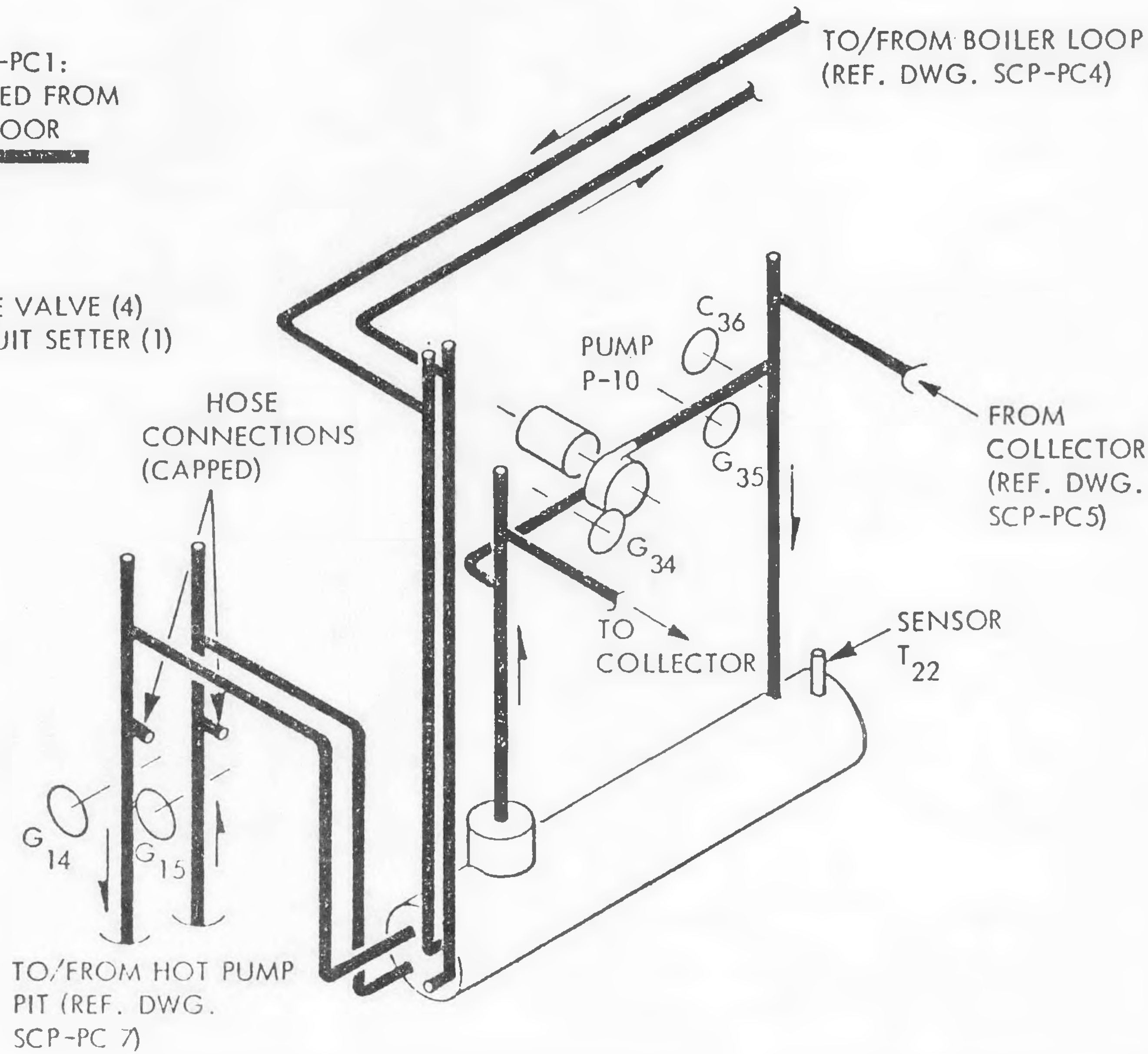
TABLE 3-5

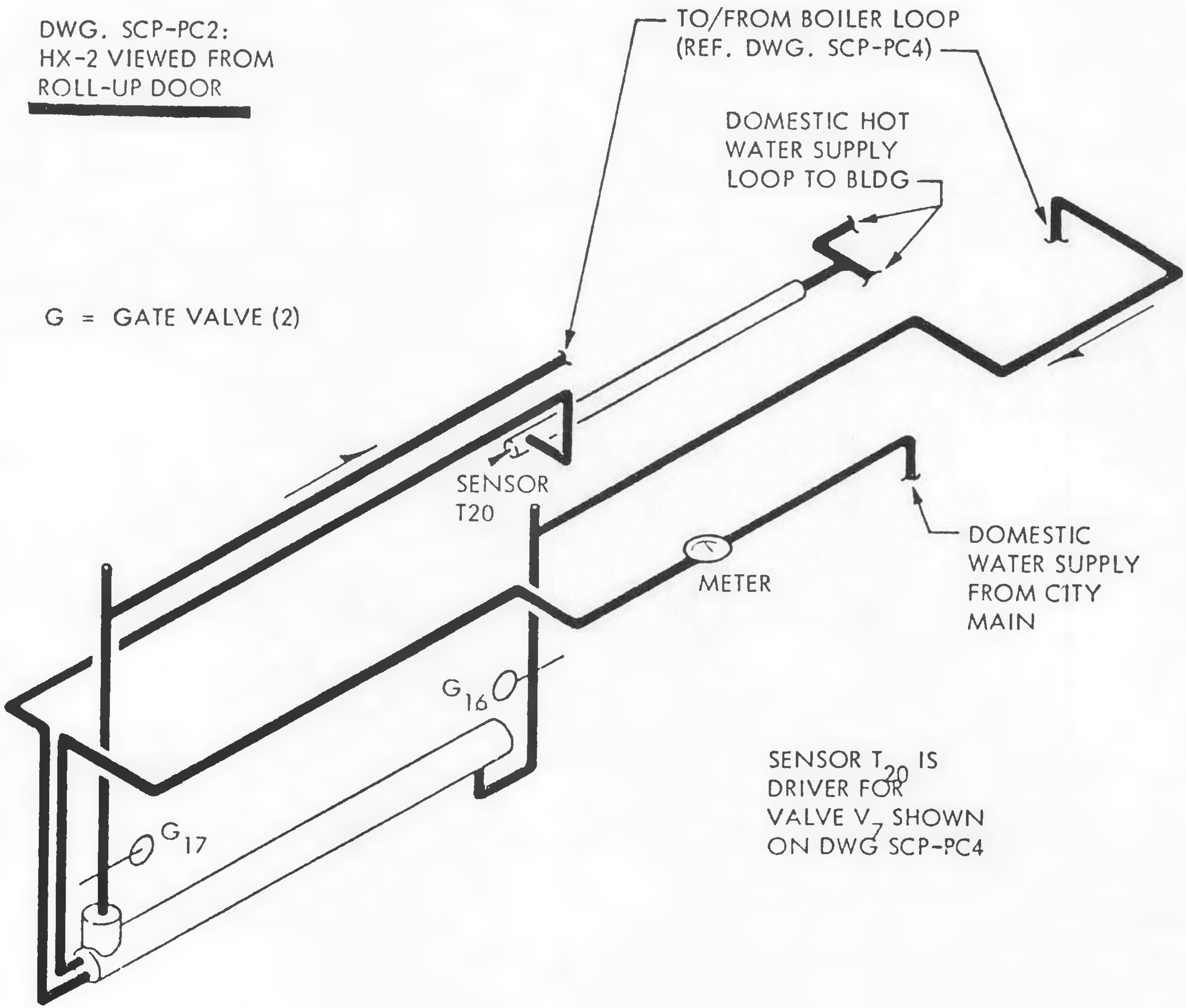
INDEX TO ISOMETRIC DRAWINGS OF MECHANICAL SYSTEM

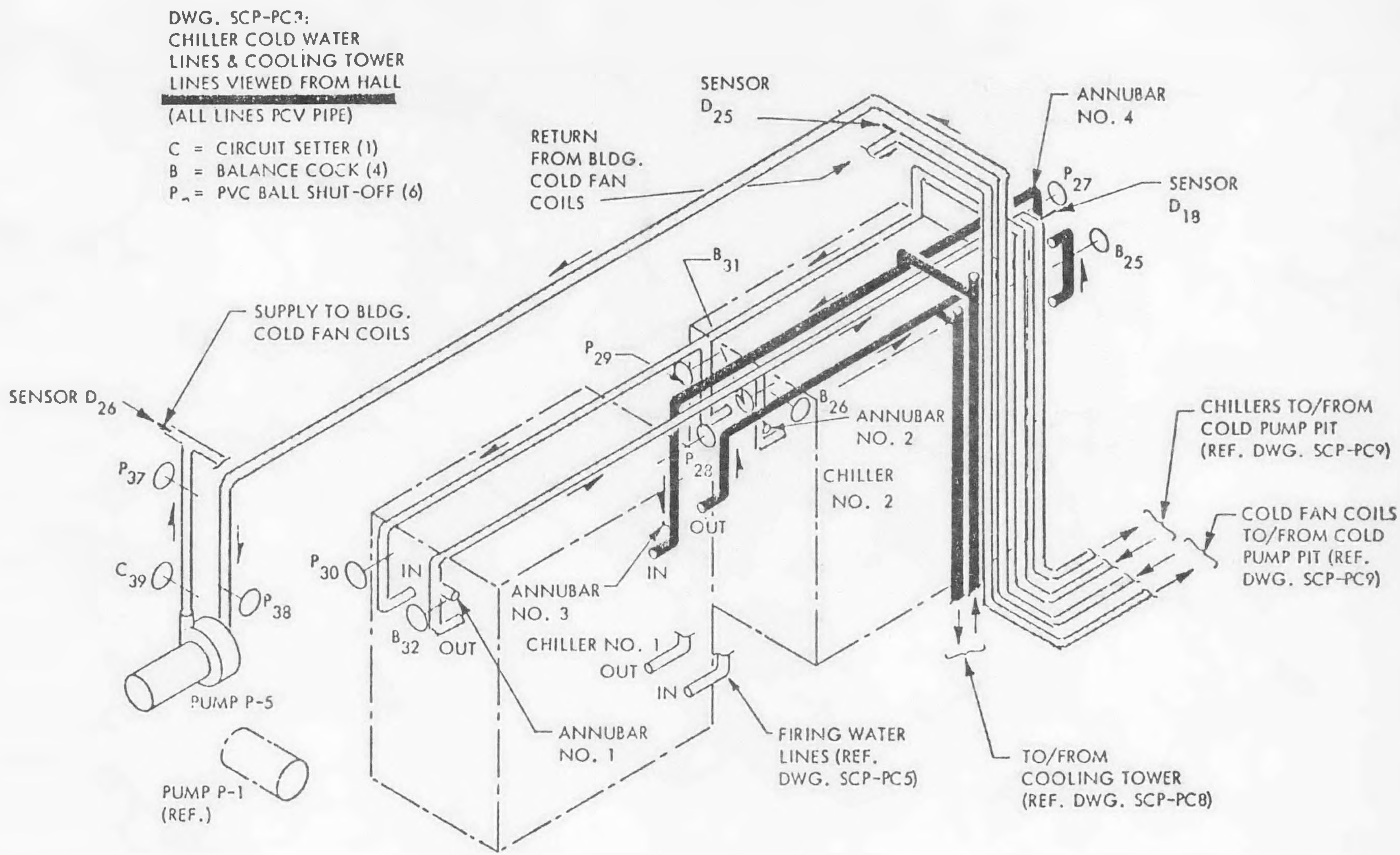
Drawing	Title
SCP-PC1	HX-1 Viewed from Roll-Up Door
SCP-PC2	HX-2 Viewed from Roll-Up Door
SCP-PC3	Chiller Cold Water Lines and Cooling Tower Lines Viewed from Hall
SCP-PC4	Boiler Viewed from Chillers
SCP-PC5	Collector-to-MER (Supply) Lines Viewed from Door
SCP-PC6	MER-to-Collector (Return) Lines Viewed from Door
SCP-PC7	Hot Reservoir Pump Pit Viewed from Ladder
SCP-PC8	Cooling Tower Viewed from Enclosure Door
SCP-PC9	Cold Reservoir Pump Pit Viewed from Ladder
SCP-PC10	Cold Reservoir Lines Viewed from Ladder
SCP-PC11	Hot Reservoir Lines Viewed from Tank Neck
SCP-PC12	Lines to/from Collector Not shown on Other Drawings
SCP-PC13	Location of Sensors in Cold Water Reservoir
SCP-PC14	Location of Sensors in Hot Water Reservoir
SCP-PC15	Revised Collector Loop Make-Up
SCP-PC16	Make-Up Water in Cold Pump Pit
SCP-PC17	Make-Up Water in Hot Pump Pit
SCP-PC18	Make-Up Water to Pump Pits

DWG. SCP-PC1:
HX-1 VIEWED FROM
ROLL-UP DOOR

G = GATE VALVE (4)
C = CIRCUIT SETTER (1)



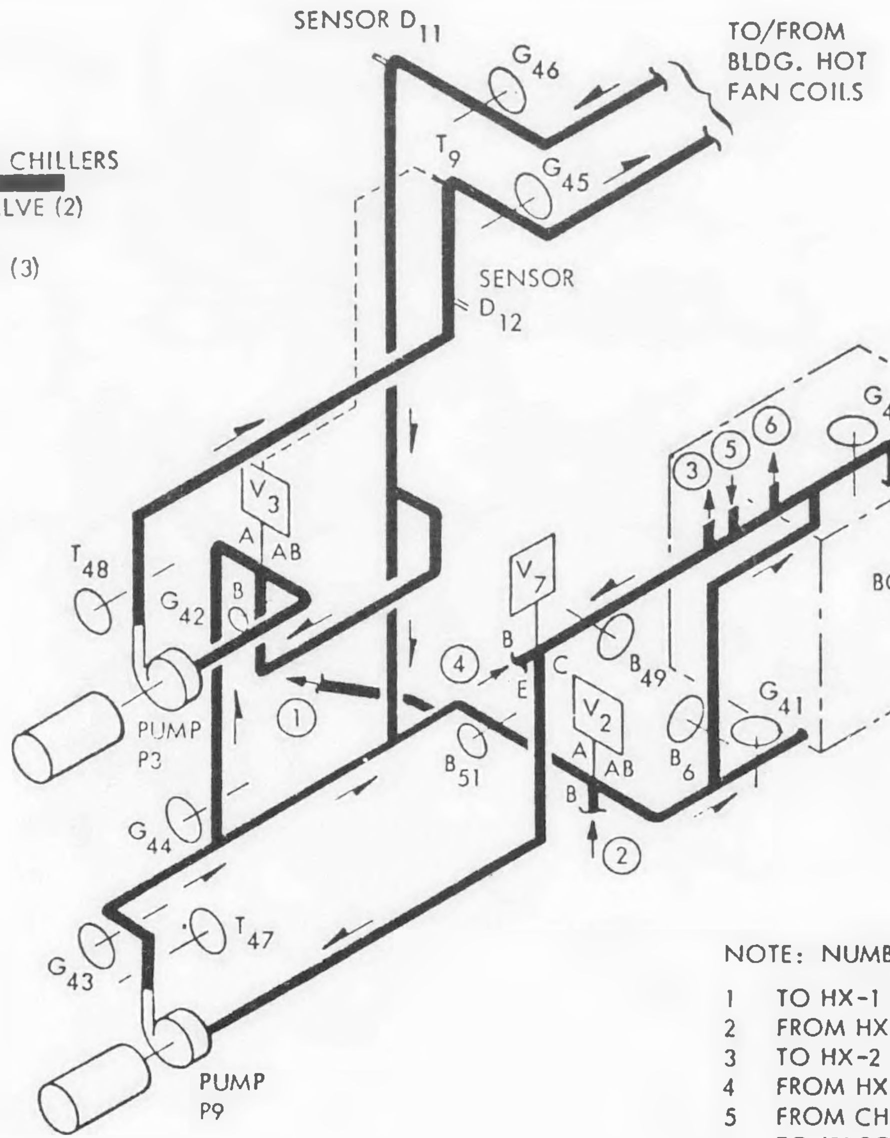

DWG. SCP-PC2:
HX-2 VIEWED FROM
ROLL-UP DOOR
TO/FROM BOILER LOOP
(REF. DWG. SCP-PC4)
DOMESTIC HOT
WATER SUPPLY
LOOP TO BLDG
G = GATE VALVE (2)
SENSOR
T20
DOMESTIC
WATER SUPPLY
FROM CITY
MAIN
METER
G16
G17
SENSOR T20 IS
DRIVER FOR
VALVE V7 SHOWN
ON DWG SCP-PC4


DWG. SCP-PC?:
CHILLER COLD WATER
LINES & COOLING TOWER
LINES VIEWED FROM HALL
(ALL LINES PCV PIPE)
C = CIRCUIT SETTER (1)
B = BALANCE COCK (4)
P = PVC BALL SHUT-OFF (6)
SENSOR D_{25}
RETURN FROM BLDG. COLD FAN COILS
ANNUBAR NO. 4
P_{27}
SENSOR D_{18}
B_{25}
B_{31}
SUPPLY TO BLDG. COLD FAN COILS
P_{29}
SENSOR D_{26}
B_{26}
ANNUBAR NO. 2
P_{28}
CHILLER NO. 2
CHILLERS TO/FROM COLD PUMP PIT (REF. DWG. SCP-PC9)
P_{37}
OUT
IN
COLD FAN COILS TO/FROM COLD PUMP PIT (REF. DWG. SCP-PC9)
P_{30}
IN
ANNUBAR NO. 3
C_{39}
P_{38}
B_{32}
OUT
CHILLER NO. 1
OUT
IN
PUMP P-5
ANNUBAR NO. 1
FIRING WATER LINES (REF. DWG. SCP-PC5)
TO/FROM COOLING TOWER (REF. DWG. SCP-PC8)
PUMP P-1 (REF.)

DWG SCP-PC4:

BOILER VIEWED FROM CHILLERS

T = TRIPLE-DUTY VALVE (2)
G = GATE VALVE (7)
B = BALANCE COCK (3)



SENSOR T_9 IS DRIVER FOR VALVE V_3

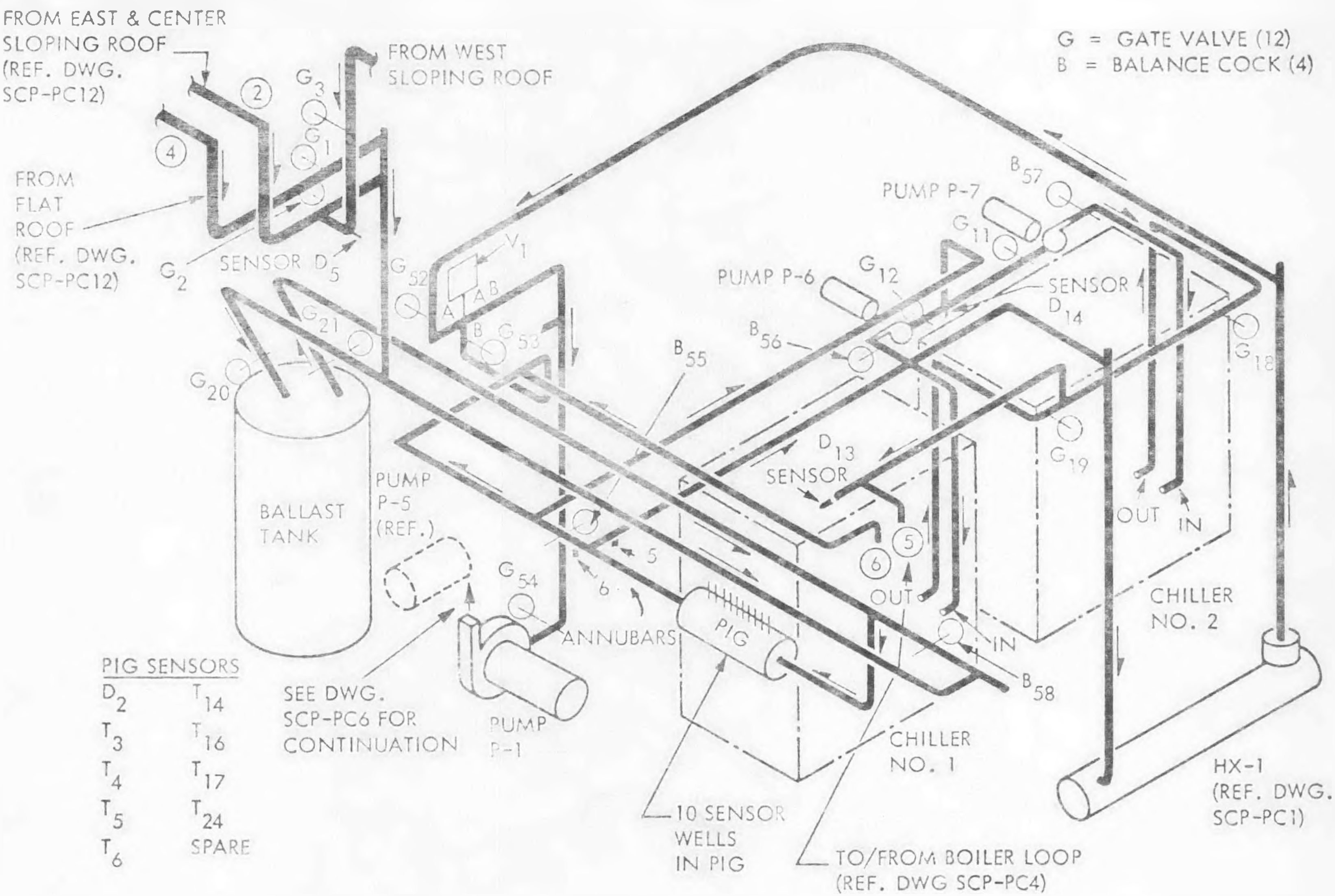
NOTE: NUMBERED LINES ARE:

1 TO HX-1 (REF. DWG. SCP-PC1)
2 FROM HX-1
3 TO HX-2 (REF. DWG. SCP-PC2)
4 FROM HX-2
5 FROM CHILLERS (REF. DWG. SCP-PC5)
6 TO 'B' PORT OF VALVE V_1

DWG. SCP-PC5:

COLLECTOR-TO-MER (SUPPLY) LINES VIEWED FROM DOOR

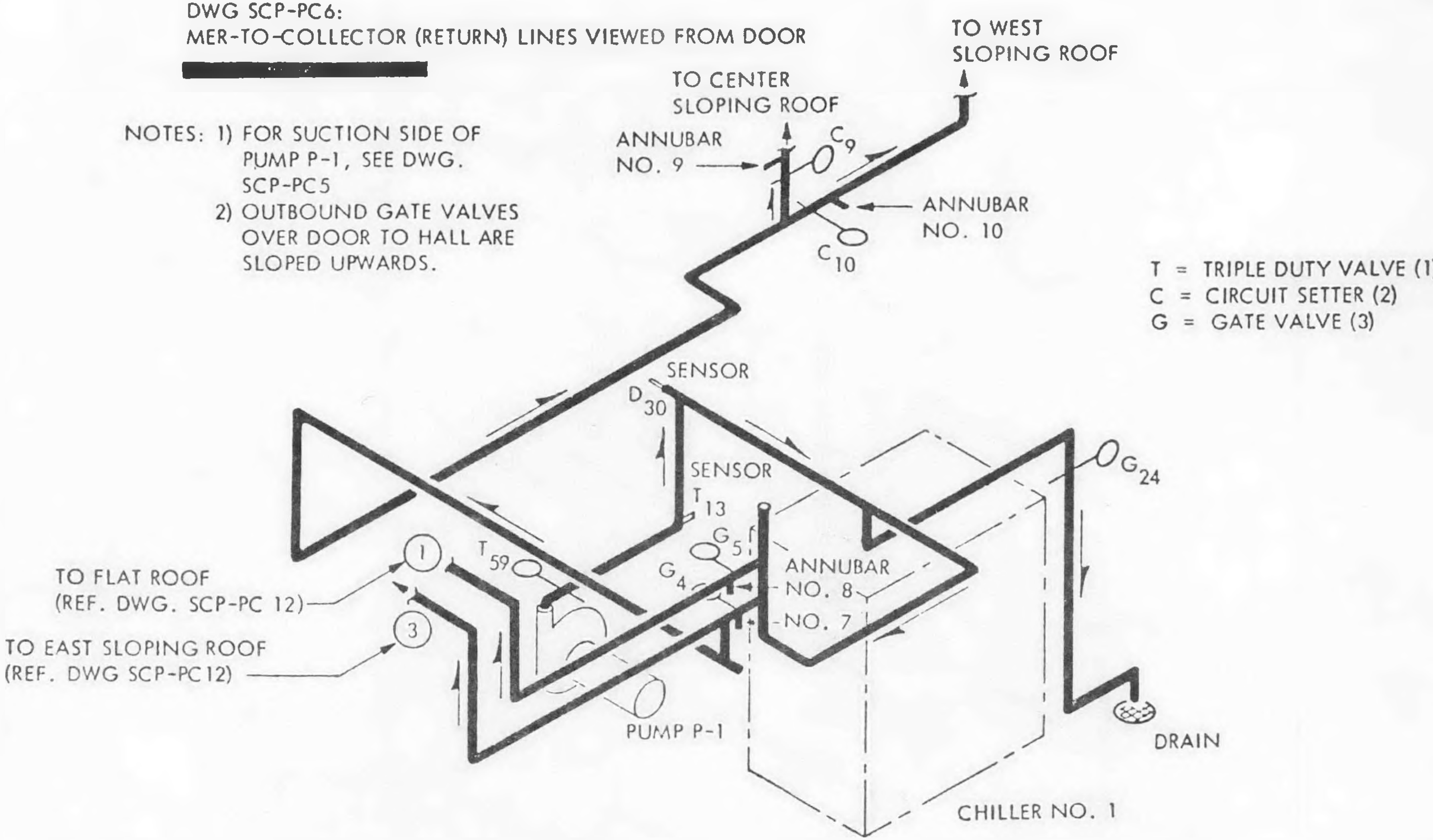
[redacted]



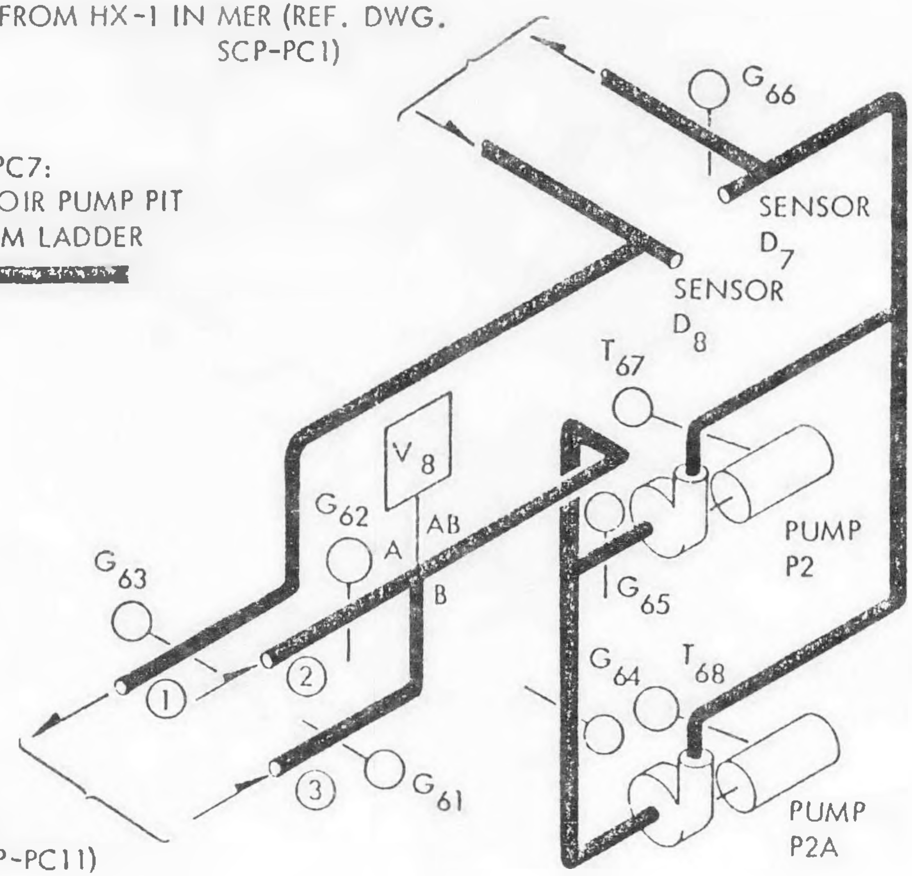
DWG SCP-PC6:
MER-TO-COLLECTOR (RETURN) LINES VIEWED FROM DOOR

[redacted]

NOTES: 1) FOR SUCTION SIDE OF PUMP P-1, SEE DWG. SCP-PC5
2) OUTBOUND GATE VALVES OVER DOOR TO HALL ARE SLOPED UPWARDS.



DWG. SCP-PC7:
HOT RESERVOIR PUMP PIT
VIEWED FROM LADDER
[redacted]



G = GATE VALVE (6)
T = TRIPLE DUTY VALVE (2)

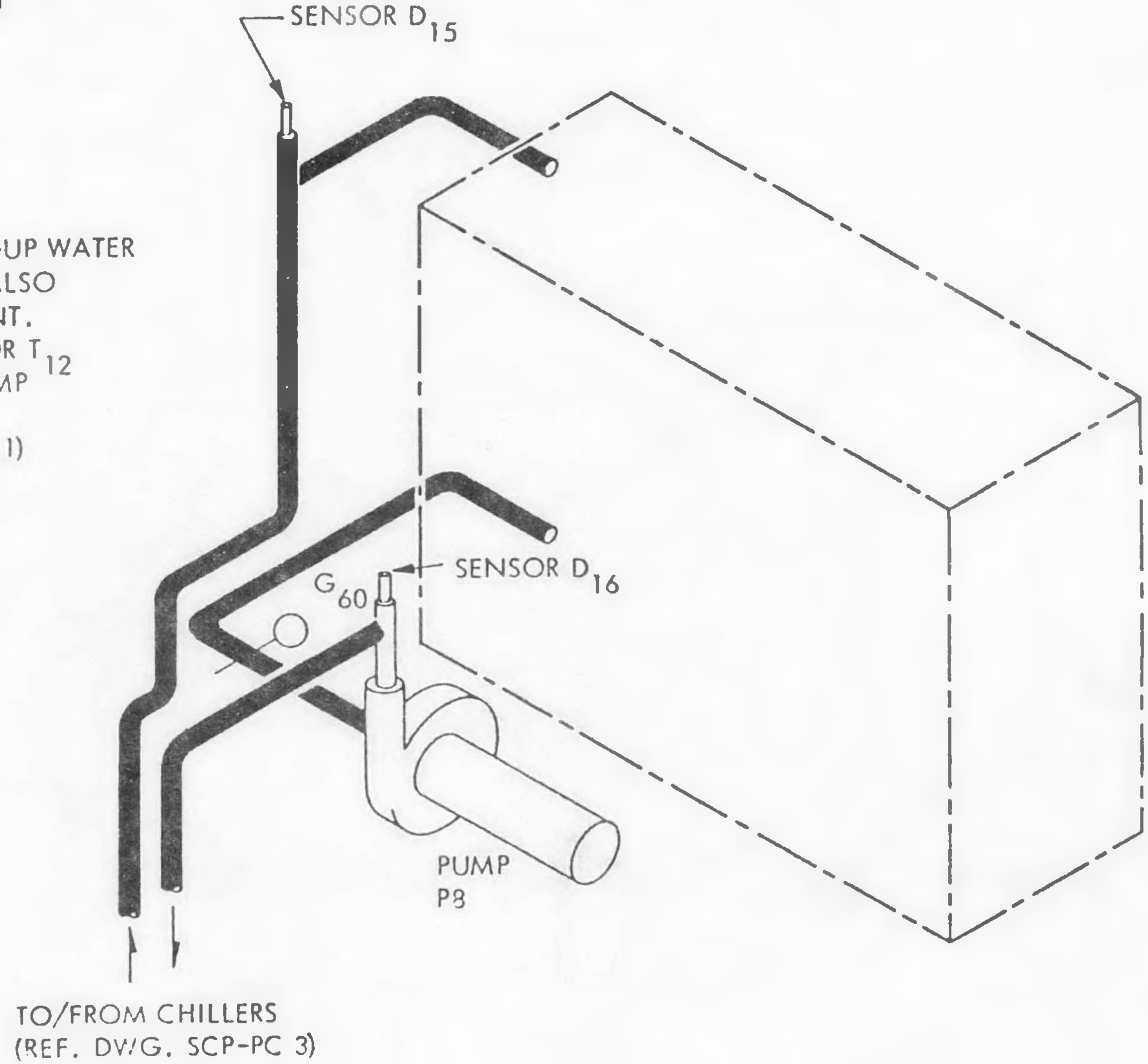
NOTES:
1) PIT ALSO CONTAINS DOMESTIC WATER LINE WITH RETRANSMITTING WATER METER & DEIONIZER
2) VALVE V_8:
'A' PORT TO BOTTOM OR TANK
'B' PORT TO TOP OF TANK

DWG. SCP-PC8:

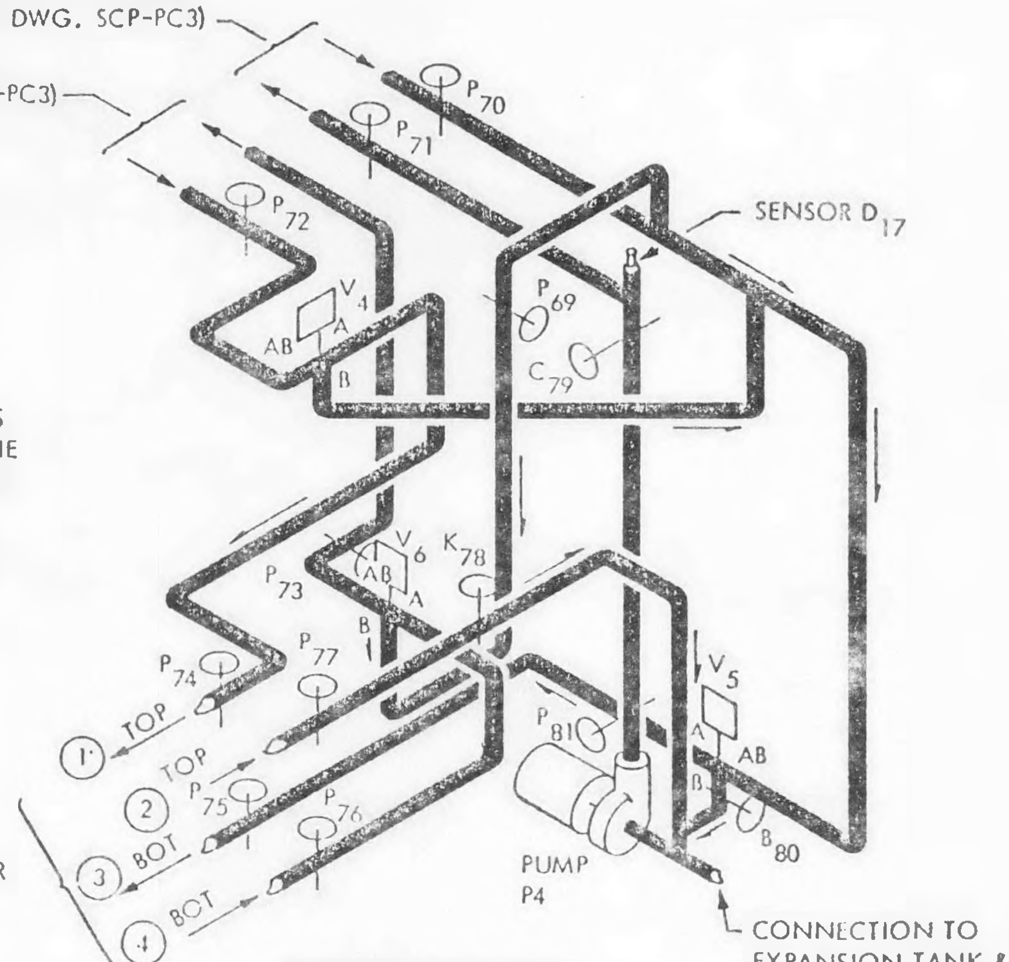
COOLING TOWER VIEWED FROM ENCLOSURE DOOR

NOTES: 1) MAKE-UP WATER LINE ALSO PRESENT.
2) SENSOR T_{12} IN SUMP

G = GATE VALVE (1)



DWG. SCP-PC9:
COLD RESERVOIR
PUMP PIT VIEWED
FROM LADDER

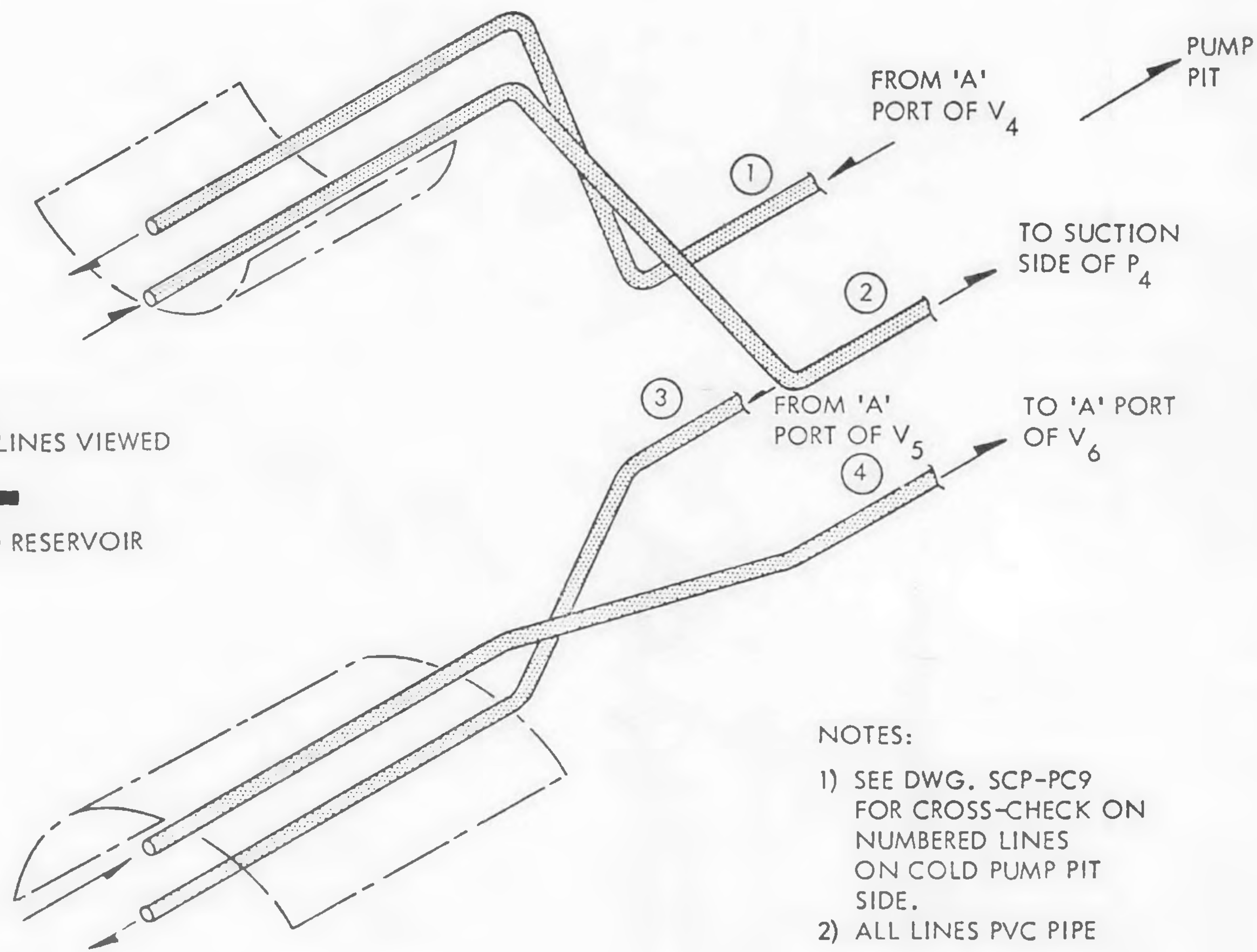


NOTES: 1) PIT ALSO CONTAINS MAKE-UP WATER LINE WITH MANUAL READ WATER METER & EXPANSION TANK
2) ALL LINES PVC PIPE

P = PVC BALL SHUT-OFF (10)
C = CIRCUIT SETTER (1)
B = BALANCE COCK (1)
K = CHECK VALVE (1)

NUMBERED LINES ARE:

1. FROM COLD FAN COILS
2. TO CHILLERS
3. FROM CHILLERS
4. TO COLD FAN COILS



DWG. SCP-PC 10:
COLD RESERVOIR LINES VIEWED FROM LADDER

[redacted]

SENSORS IN COLD RESERVOIR

D_{19}	D_{27}
D_{20}	D_{28}
D_{21}	D_{29}
D_{22}	T_{10}
D_{23}	T_{11}
D_{24}	

NOTES:

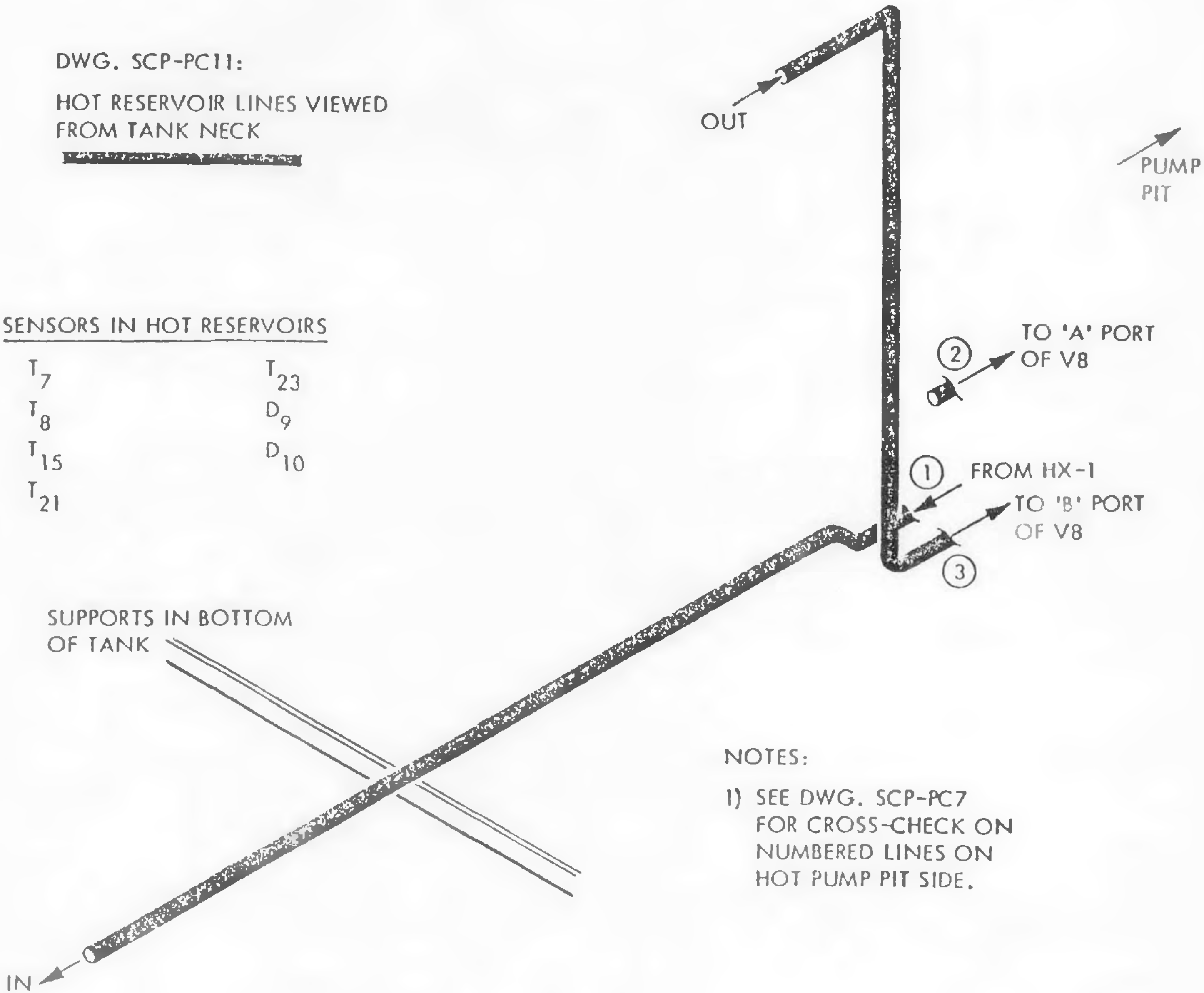
1) SEE DWG. SCP-PC9 FOR CROSS-CHECK ON NUMBERED LINES ON COLD PUMP PIT SIDE.
2) ALL LINES PVC PIPE

DWG. SCP-PC11:

HOT RESERVOIR LINES VIEWED FROM TANK NECK

SENSORS IN HOT RESERVOIRS

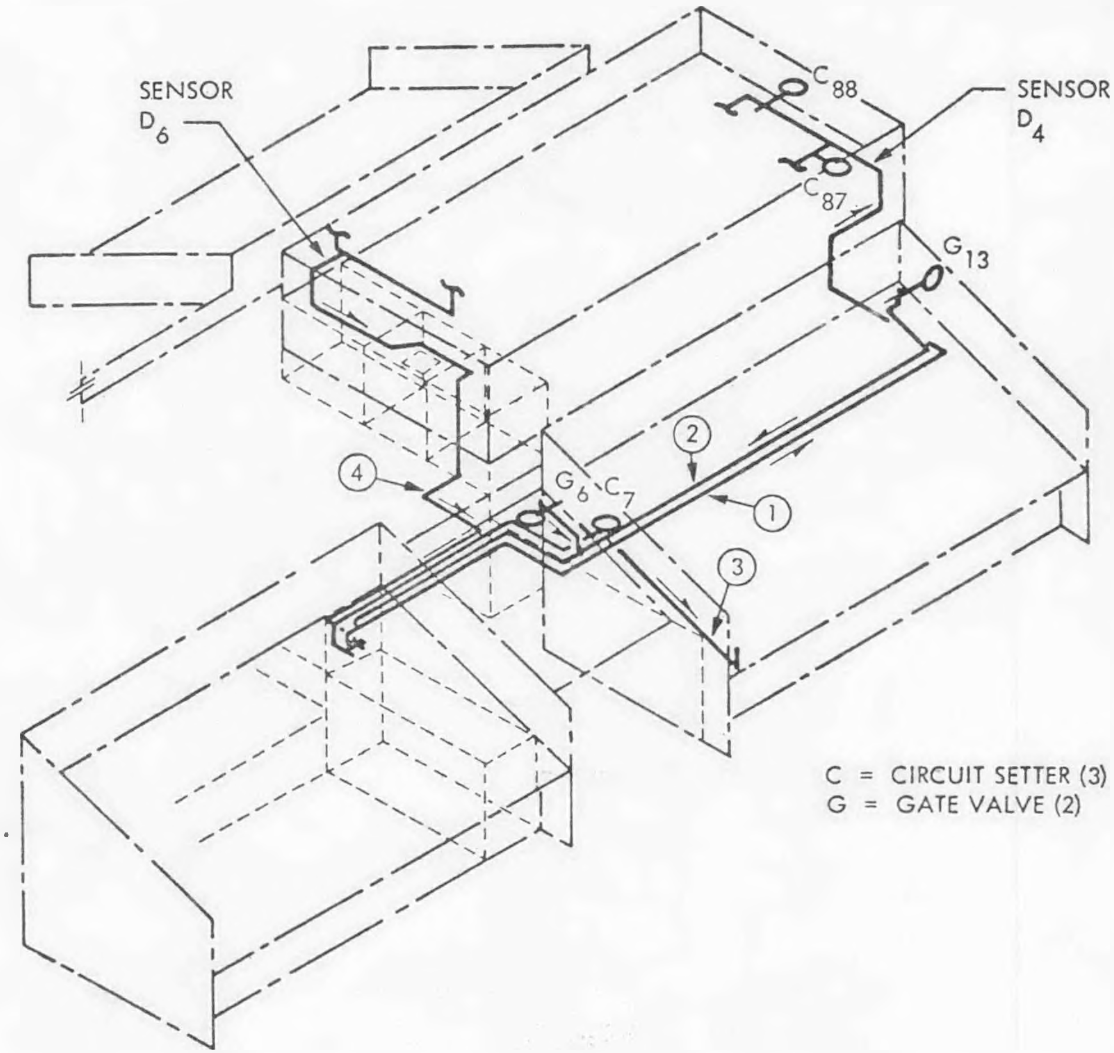
T_7	T_{23}
T_8	D_9
T_{15}	D_{10}
T_{21}	



NOTES:

1) SEE DWG. SCP-PC7 FOR CROSS-CHECK ON NUMBERED LINES ON HOT PUMP PIT SIDE.

DWG. SCP-PC 12:
LINES TO/FROM
COLLECTOR NOT
SHOWN ON OTHER
DRAWINGS



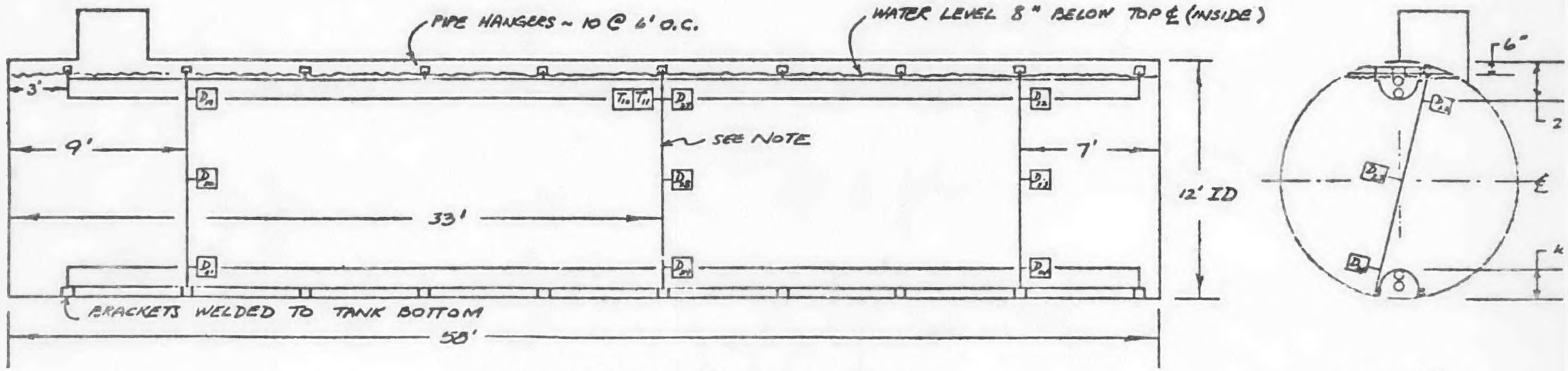
NOTES:

1) SENSORS D_4 & D_6 ARE ON TOP OF FLAT ROOF IN TEES AT ROOF PENETRATIONS
2) ANNUBARS NO. 12 & NO. 13 ON TOP OF FLAT ROOF ADJACENT TO CIRCUIT SETTERS
3) FOR CROSS-CHECK TO NUMBERED LINES TO/FROM MER SEE DWGS. SCP-PC 5 & PC-6.
4) RETURN FROM WEST SLOPING ROOF NOT SHOWN; FOR SUPPLY TO CENTER & WEST SLOPING ROOF SEG DWG. SCP-PC6.
5) ANNUBAR NO. 11 ADJACENT TO CIRCUIT SETTER C_7

DWG. SCP - PC 13:

LOCATION OF SENSORS IN COLD WATER RESERVOIR

SANTA CLARA SOLAR PROJECT



LONGITUDINAL SECTIONAL VIEW

END VIEW
SHOWING TYPICAL SENSOR ARRANGEMENT

NOTES: SENSORS ANCHORED TO STEEL WIRE CABLE COATED WITH TAR BASE PAINT. CABLE MAY BE LOOPED OVER PIPE HANGER @ TOP; USE TURNBUCKLE AT OTHER END TO REMOVE SLACK. PAINTED STEEL TUBE OR ∠ MAY REPLACE CABLE (ATTACH WITH STAINLESS STEEL WIRE).

PROVIDE 2 FT COIL OF WIRE WITH EACH SENSOR FOR POSSIBLE LOCATION ADJUSTMENT.

LOCKHEED PALO ALTO RESEARCH LAB
A. B. BURNS 2-23-76

SCP- 0223761

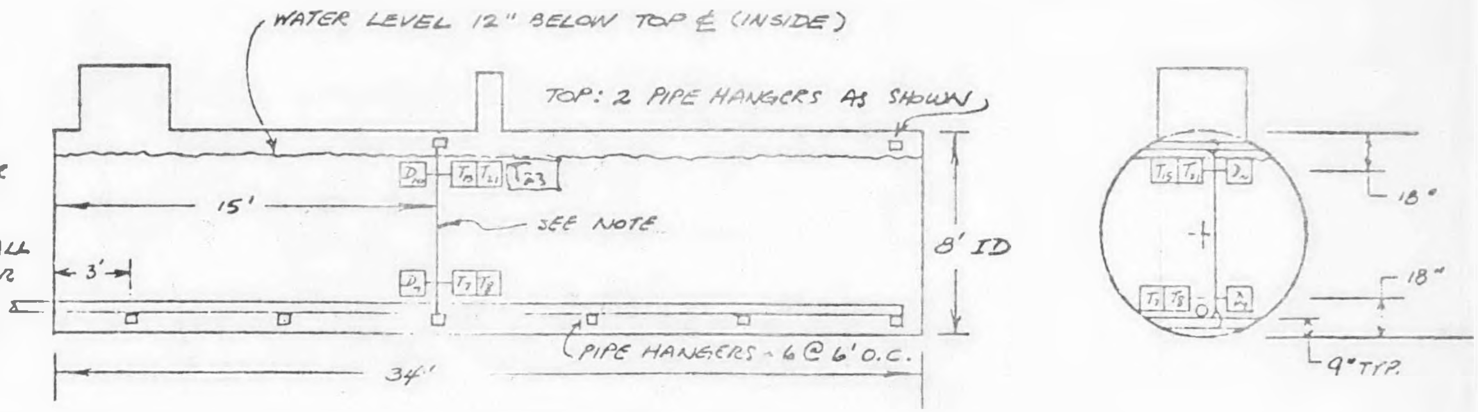
DWG. SCP-PC14:

LOCATION OF SENSORS IN HOT WATER RESERVOIR

SANTA CLARA SOLAR PROJECT

NOTES: SENSORS ANCHORED TO STAINLESS STEEL WIRE CABLE. CABLE MAY BE LOOPED OVER PIPE HANGER AT ONE END; USE TURN-BUCKLE AT OTHER END TO REMOVE SLACK. INSTALL CABLE AS CLOSE TO CENTER OF TANK AS POSSIBLE. STAINLESS STEEL TUBE OR ℄ MAY REPLACE CABLE. (ATTACH WITH STAINLESS STEEL WIRE.)

PROVIDE 2 FT. COIL OF WIRE WITH EACH SENSOR FOR POSSIBLE LOCATION ADJUSTMENT.



LONGITUDINAL SECTIONAL VIEW

END VIEW

LOCKHEED PALO ALTO RESEARCH LAB.

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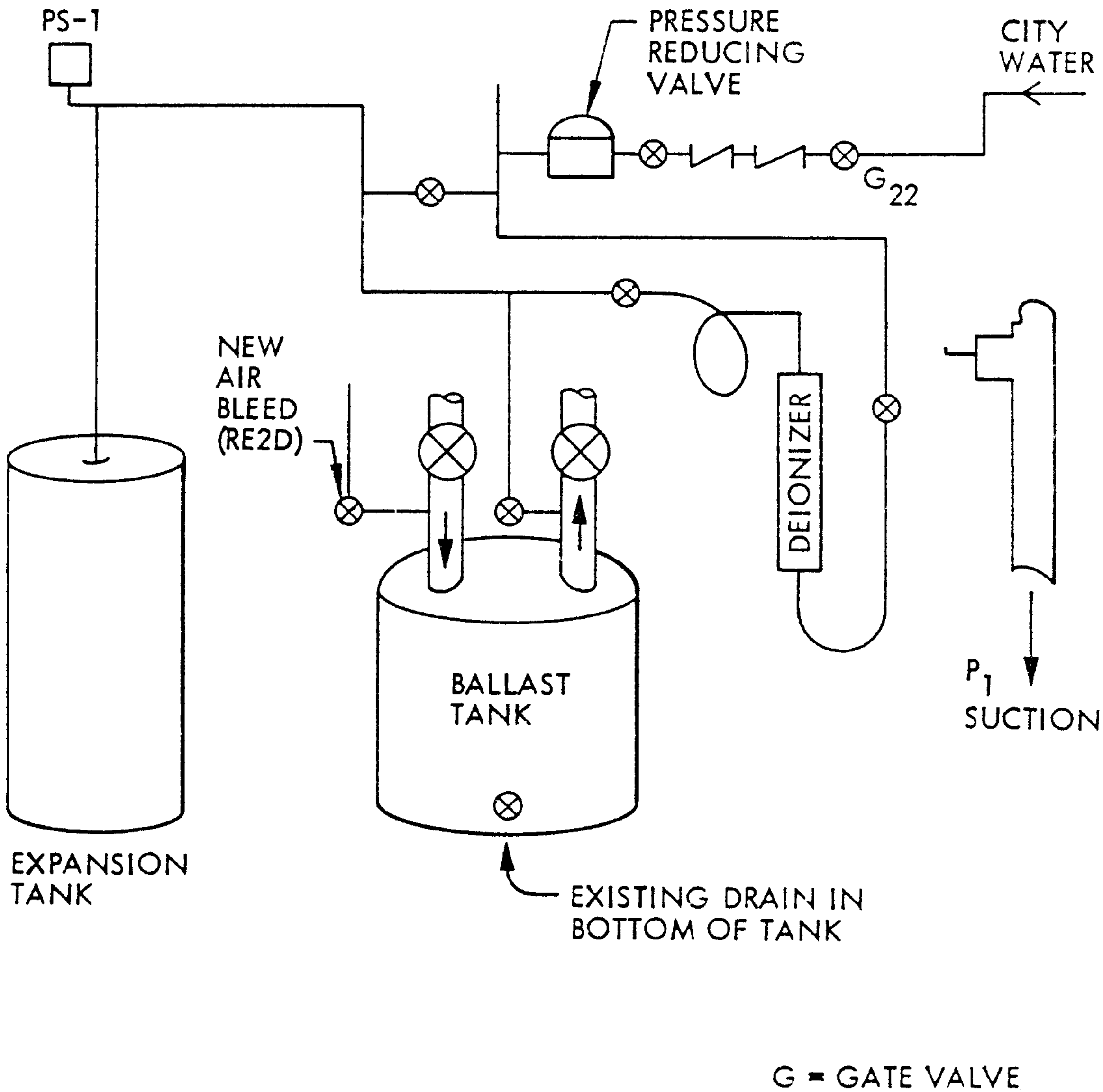
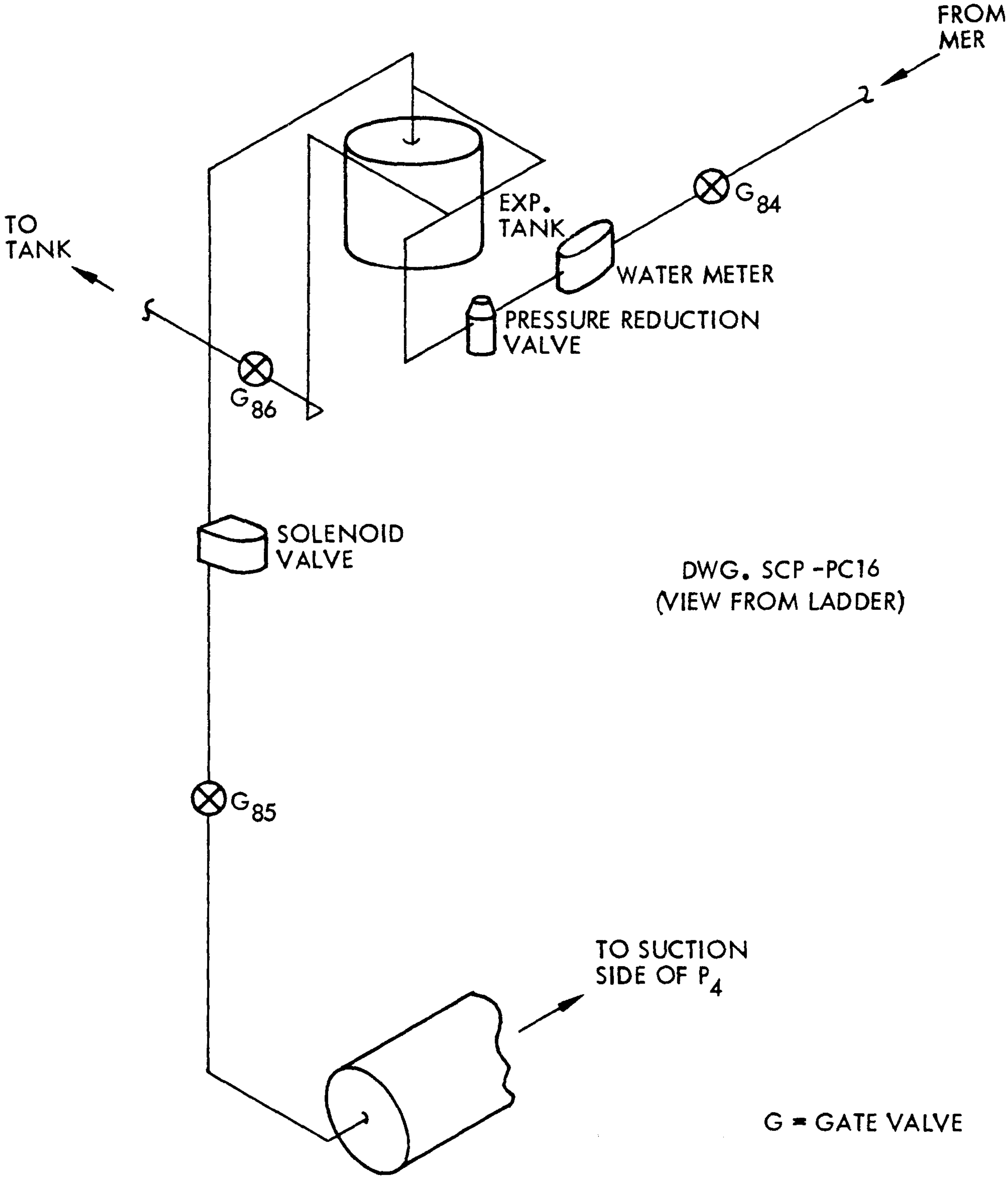
SCP-0223762

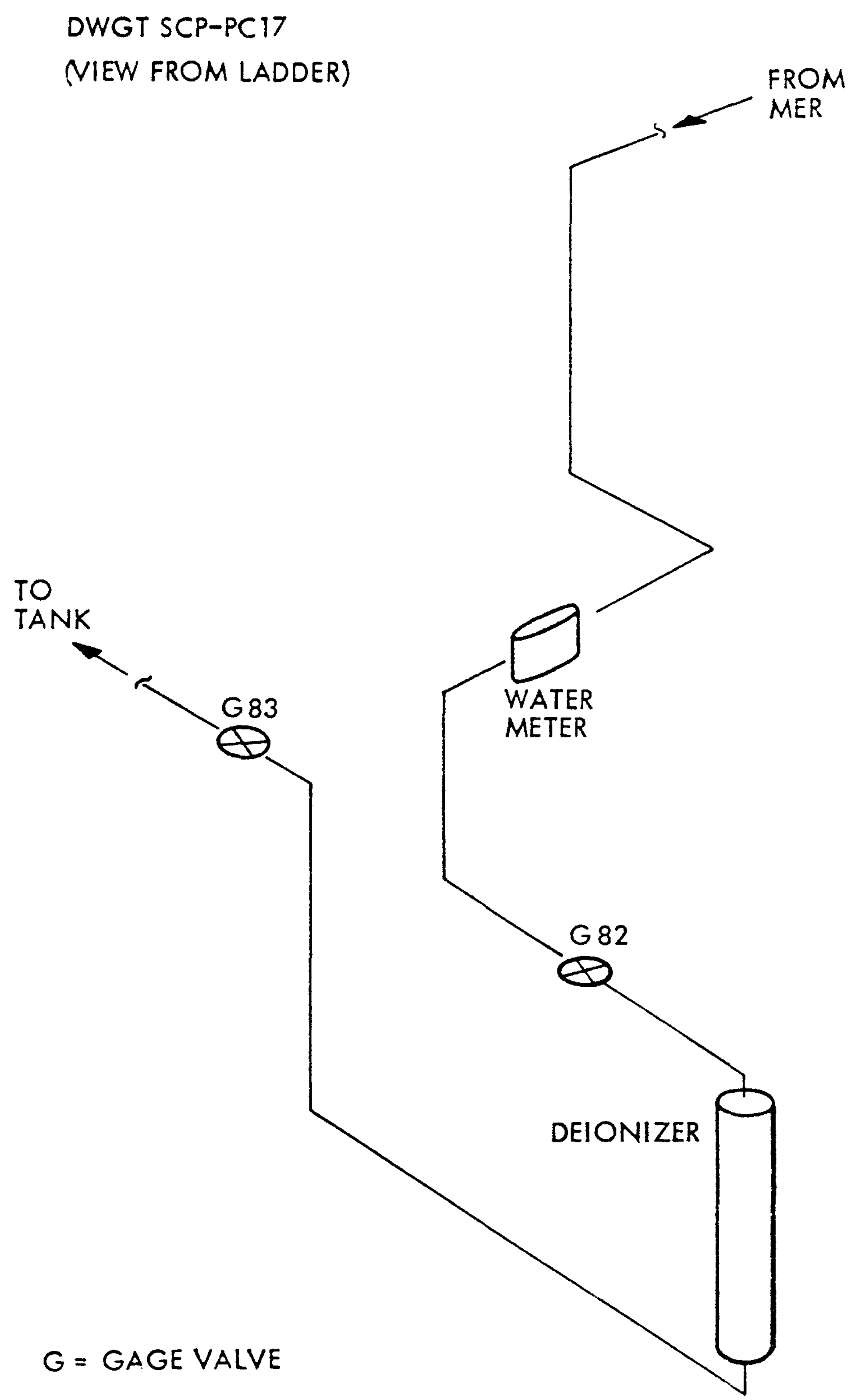
DWG SCP-PC15



Revised Collector Loop Make-up



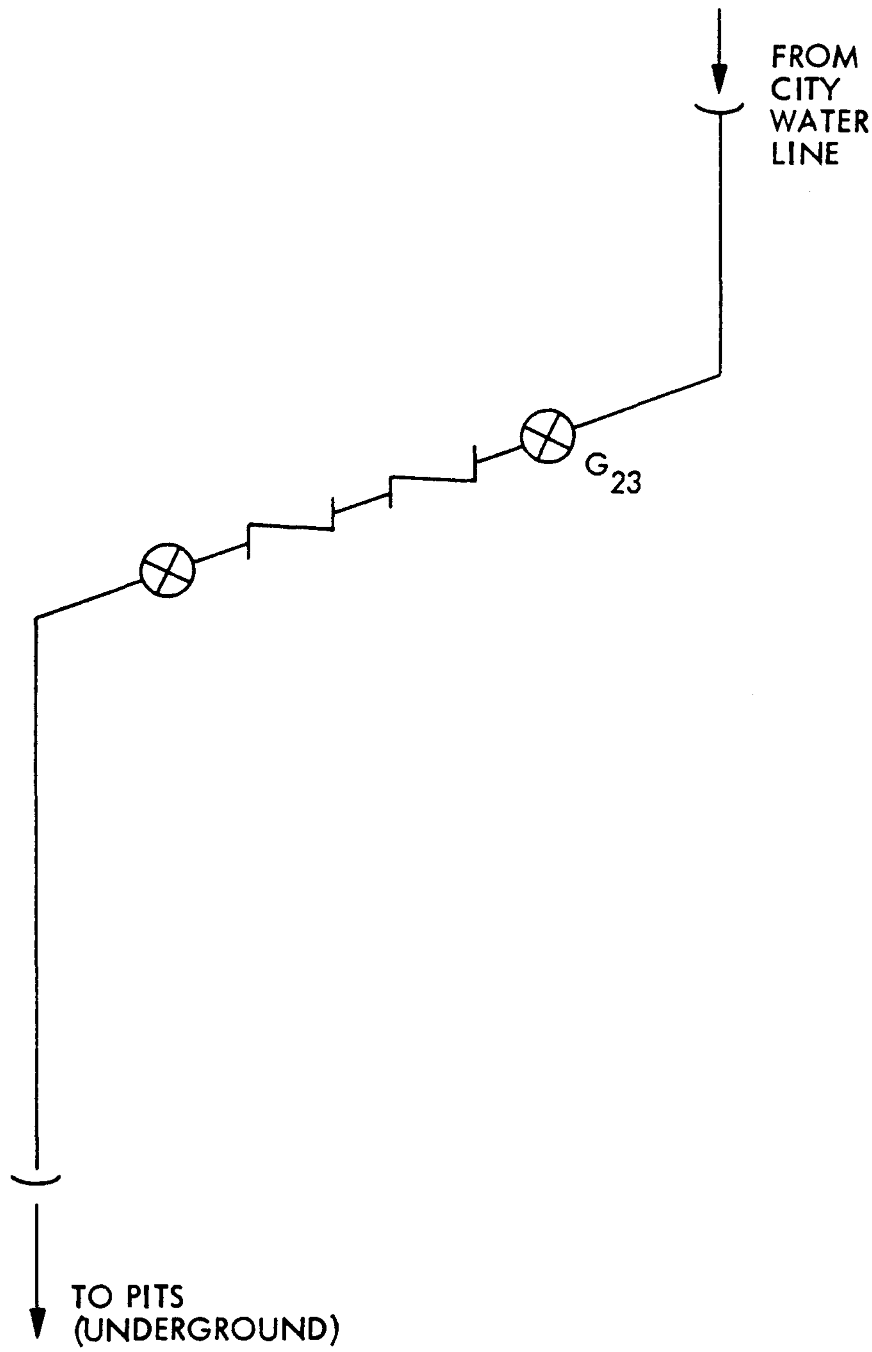
Make-up Water in Cold Pump Pit



Make-up Water in Hot Pump Pit

DWG SCP-PC18

(VIEW IN SW CORNER OF MER)



Make-up Water to Pump Pits

TABLE 3-6

INDEX TO CONTROL SENSOR FUNCTIONS & LOCATIONS

Sensor	Dwg.	
T_1		Collector back-up signal to pyranometer for no & low solar modes (140°F); located in collector on flat roof.
T_2		Collector back-up signal to pyranometer for no & low solar modes (140°F); located in collector on west sloping roof.
T_3	PC 5	Sensor in pig which with T_7 determines whether to heat exchange to hot reservoir.
T_4	PC 5	Sensor in pig giving back-up signal to pyranometer for hi solar mode (195°F)
T_5	PC 5	Sensor in pig which with T_{13} determines 10°F differential for shutting down 2nd ARKLA
T_6	PC 5	Sensor in pig to activate 2nd ARKLA (220°F)
T_7	PC 14	Sensor in hot tank pump pit which with T_3 determines whether to heat exchange to hot reservoir. Prelim. set: If $T_3 > T_7$, start heat exchange to hot reservoir
T_8	PC 14	Hot reservoir min. spec. sensor (115°F @ bottom)
T_9	PC 4	Controls V_3 mix to HFC @ 105°F (in MER)
T_{10}	PC 13	Cold reservoir min. spec. sensor (55°F @ top)
T_{11}	PC 13	Cold reservoir signal to shut down ARKLA's (44°F @ top)
T_{12}	PC 8	Cycles cooling tower fan to maintain condensing water temp.
T_{13}	PC 6	Sensor in main line to collector which with T_5 determines 10°F diff. for shutting down 2nd ARKA; in MER.
T_{14}	PC 5	Sensor in pig to activate one ARKA (210°F)
T_{15}	PC 14	Controls pump P_{2A}, 210° set point, located in hot reservoir
T_{16}	PC 5	Bleed-Off mode control sensor in pig (230°F)
T_{17}	PC 5	Dump mode control sensor in pig (240°F)
T_{18}	-	Fresh air shutdown elements (economizer); total of 10 elements
T_{19}	-	Room sensing elements; total of 12 elements
T_{20}	PC 2	Sensor in DHW line to activate boiler when DHW temperature falls below 120°F
T_{21}	PC 14	Sensor in top of hot reservoir set at 115°F; controls use of hot reservoir to heat bldg.
T_{22}	PC 1	Sensor in jacket of HX-1 heat exchanger; used to determine if DHW can be heated from HX-1 (set point = 105°F)

TABLE 3-6 (Continued)

Sensor	Dwg.	
T_{23}	PC 14	Sensor in bottom of hot tank; used with T_{24} to determine if reservoir temperature is greater than collector temperature for reverse heat exchange
T_{24}	PC 5	Sensor in pig; used with T_{23} to determine if reservoir temperature is greater than collector temperature for reverse heat exchange Preliminary set for T_{23} and T_{24}: If $T_{23} < T_{24}$, terminate reverse heat exchange.

TABLE 3-7

INDEX TO DATA SENSOR FUNCTIONS & LOCATIONS

Sensor	Dwg.	
D_1		Ambient temperature (on roof)
D_2	PC 5	With D_{30} measures ΔT across entire collector (in pig in MER)
D_3	-	Eliminated; use D_{30} with D_5 to measure ΔT across collector #1
D_4	PC 12	With D_6 measured ΔT across collector #2 (on flat roof)
D_5	PC 5	See D_3 (in MER above door)
D_6	PC 12	See D_4 (on flat roof)
D_7	PC 7	With D_8 measured ΔT being exchanged to/from hot tank (in hot tank pump pit)
D_8	PC 7	See D_7 (in hot tank pump pit)
D_9	PC 14	Temp. @ bottom of hot tank
D_{10}	PC 14	Temp. @ top of hot tank
D_{11}	PC 4	With D_{12} measured ΔT across hot fan coils (in MER)
D_{12}	PC 4	See D_{11} (in MER)
D_{13}	PC 5	Temperature of ARKLA firing water @ outlet (in MER)
D_{14}	PC 5	Temperature of ARKLA firing water @ inlet (in MER)
D_{15}	PC 8	With D_{16} measures energy dissipated by cooling tower (in cooling tower enclosure)
D_{16}	PC 8	See D_{15} (in cooling tower enclosure)
D_{17}	PC 9	With D_{18} measures cold energy delivered to cold tank from ARKLA's (in cold tank pump pit)
D_{18}	PC 3	See D_{17} (in MER)
D_{19}	PC 13	Temperature @ top, near end of cold tank
D_{20}	PC 13	Temperature @ center, near end of cold tank
D_{21}	PC 13	Temperature @ bottom, near end of cold tank
D_{22}	PC 13	Temperature @ top, far end of cold tank
D_{23}	PC 13	Temperature @ center, far end of cold tank
D_{24}	PC 13	Temperature @ bottom, far end of cold tank
D_{25}	PC 3	With D_{26} measures ΔT across CFC (in MER)
D_{26}	PC 3	See D_{25} (in MER)

TABLE 3-7 (Continued)

Sensor	Dwg.	
D_{27}	PC 13	Temperature @ top, middle of cold tank
D_{28}	PC 13	Temperature @ center, middle of cold tank
D_{29}	PC 13	Temperature @ bottom, middle of cold tank
D_{30}	PC 6	With D_2 measures ΔT across entire collector (in MER)
$D_{31} \rightarrow D_{63}$	-	In air ducts; see Table 3-8 and Fig. 3-1
$D_{64} \rightarrow D_{83}$	-	Mini-PRT's in collector; movable.

TABLE 3-8

INDEX TO MOTOR-DRIVEN VALVE LOCATIONS

VALVE	DWG.	
V_1	PC 5	Primary Solar Control Valve (in MER)
V_2	PC 4	Hot Water Control Valve (in MER)
V_3	PC 4	HFC Modulating Valve (in MER)
V_4	PC 9	Chilled Water Control Valves (in cold pump pit)
V_5	PC 9	Chilled Water Control Valves (in cold pump pit)
V_6	PC 9	Chilled Water Control Valves (in cold pump pit)
V_7	PC 4	DHW Modulating Valve (in MER)
V_8	PC 7	Hot Tank Control Valve (in Hot Pump Pit)

TABLE 3-9

INDEX TO MANUAL VALVE LOCATIONS

Manual Valve	Dwg.	Notes
1	PC 5	
2	PC 5	
3	PC 5	
4	PC 6	
5	PC 6	
6	PC 12	
7	PC 12	Circuit Setter
8	-	Domestic water adjacent to boiler
9	PC 6	Circuit Setter
10	PC 6	Circuit Setter
11	PC 5	
12	PC 5	
13	PC 12	
14	PC 1	
15	PC 1	
16	PC 2	
17	PC 2	
18	PC 5	
19	PC 5	
20	PC 5	
21	PC 5	
22	PC 15	Collector make-up line adjacent to ballast tank
23	PC 18	Make-up line adjacent to HX-1
24	PC 6	
25	PC 3	Balance Cock
26	↓	Balance Cock
27	↓	
28	↓	
29	↓	
30	↓	
31	↓	
32	PC 3	Balance Cock
33	-	Domestic water adjacent to boiler
34	PC 1	
35	PC 1	
36	PC 1	Circuit Setter
37	PC 3	
38	PC 3	
39	PC 3	Circuit Setter

TABLE 3-9 (Continued)

Manual Valve	Dwg.	Notes
40	PC 4	
41	↓	
42	↓	
43	↓	
44	↓	
45	↓	
46	↓	
47	↓	Triple-Duty Valve
48	↓	Triple-Duty Valve
49	↓	Balance Cock
50	↓	Balance Cock
51	PC 4	Balance Cock
52	PC 5	
53	↓	
54	↓	
55	↓	Balance Cock
56	↓	Balance Cock
57	↓	Balance Cock
58	PC 5	Balance Cock
59	PC 6	Triple-Duty Valve
60	PC 8	
61	PC 7	
62	↓	
63	↓	
64	↓	
65	↓	
66	↓	
67	↓	Triple-Duty Valve
68	PC 7	Triple-Duty Valve
69	PC 9	
70	PC 9	
71	↓	
72	↓	
73	↓	
74	↓	
75	↓	
76	↓	
77	↓	
78	↓	Check Valve
79	↓	Circuit Setter
80	↓	Balance Cock
81	PC 9	
82	PC 17	Domestic water make-up in Hot Pump Pit upstream of deionizer

TABLE 3-9 (Continued)

Manual Valve	Dwg.	Notes
83	PC 17	Domestic water make-up in Hot Pump Pit upstream from Hot Tank
84	PC 16	Domestic water make-up in Cold Pump Pit upstream from pressure reduction valve
85	PC 16	Domestic water make-up in Cold Pump Pit upstream of suction side to Pump P_4
86	PC 16	Domestic water make-up in Cold Pump Pit upstream from Cold Tank
87	PC 12	Circuit Setter
88	PC 12	Circuit Setter

Note: Valves are gate valves unless otherwise specified.

TABLE 3-10

INDEX TO ANNUBAR LOCATIONS

Annubar	Dwg.	GPM	Notes
1	PC 3	75	Chiller #1 Cold Water Output Line
2	↓	75	Chiller #2 Cold Water Output Line
3	↓	90	Cooling Tower Line to #1 Chiller
4	↓	90	Cooling Tower Line to #2 Chiller
5	PC 5	140	Collector Loop thru HX-1
6	↓	140	Collector Loop to Chiller Firing Sides
7	PC 6	84	Flow Outbound to Collector #1 (Sloping)
8	↓	56	Flow Outbound to Collector #2 (Flat)
9	↓	8.4	Flow Outbound to Center Sloping Area (#1)
10	↓	37.8	Flow Outbound to West Sloping Area (#1)
11	PC 12	37.8	Flow Outbound to East Sloping Area (#1)
12	PC 12	28.	Flow Outbound to South Rack (#2)
13	↓	28.	Flow Outbound to North Rack (#2)

TABLE 3-11

INDEX TO PUMP FUNCTIONS AND LOCATIONS

Pump	Dwg.	GPM	
P_1	PC 5	140	Primary Pump (in MER)
P_2	PC 7	140	Hot Reservoir Pump (in Hot Pump Pit)
P_{2A}	PC 7	180	Dump Mode Pump (in Hot Pump Pit)
P_3	PC 4	94	HFC Pump (in MER)
P_4	PC 9	150	Cold Reservoir Pump (in Cold Pump Pit)
P_5	PC 3	148	CFC Pump (in MER)
P_6	PC 5	70	#1 Chiller Pump (in MER)
P_7	PC 5	70	#2 Chiller Pump (in MER)
P_8	PC 8	180	Cooling Tower Pump (in Cooling Tower Enclosure)
P_9	PC 4	140	Boiler Loop Pump (in MER)
P_{10}	PC 1	140	Heat Exchanger Circulating Pump (in MER)
P_{11}	-	8	Sump Pumps; in Hot and Cold Pump Pits
P_{12}	-	-	DHW Circulating Pump

TABLE 3-12

LOCATIONS OF DATA SENSORS IN BUILDING AIR DUCTS

Building Zone or AC Unit Number	Sensor Location/Number		
	Supply Duct		Return Duct
	Upstream from Coils	Downstream from Coils	
1	32	33	31
2	35	36	34
3	38	39	37
4	41	42	40
5a	59 & 63 *	60	58
5b	"	61	58
5c	"	62	58
6	44	45	43
7	47	48	46
8	50	51	49
9	53	54	52
10	56	57	55

* Zone 5 may call for reheat; PRT #63 measures temperature downstream from the cold coils but upstream from all three hot coils. See Fig. 3-1.

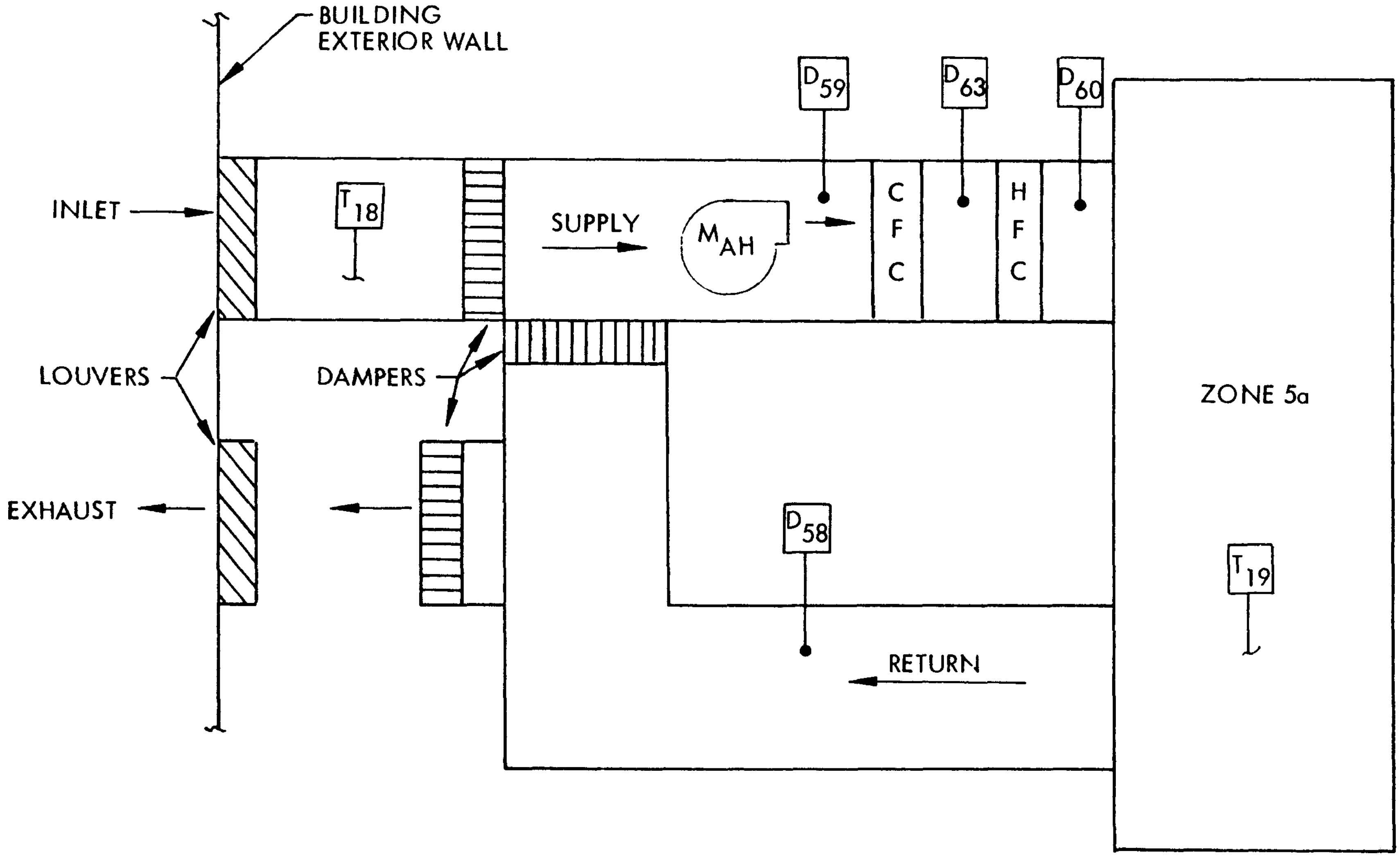


Fig. 3-31 Example of Duct Data Sensor Installation

Section 4
CONTROL SYSTEM

by A. Bruce Burns, Lockheed Palo Alto Research Laboratory, and Edward E. Davis, G. J. Yamas Company, Inc.

4.1 GENERAL

The system design objective is to maximize utilization of solar energy to meet building heating and cooling demands. Because of the mild winter climate in the Santa Clara Valley, the primary building load is cooling. Consequently, the first use of available solar energy is always to drive the chillers whenever the solar insolation is sufficiently high, and the second use is to provide heating energy to the building at all other times.

The control system has two basic functions. First, it manages the distribution of solar energy that is collected according to control logic built into the system. Second, it manages the supply of energy to the building zones to meet building energy demands. The supply and demand for energy is, of course, not often balanced; therefore, the control system is designed to a logic matrix of situations in order to provide uninterrupted service to the building with the minimum use of auxiliary energy.

The Low Solar Mode is in effect when the solar insolation is sufficient to provide building heating and hot storage, but insufficient to fire the chillers. In general, the system operates in this mode during winter, and in summer during early morning and late afternoon.

The High Solar Mode is initialized when the solar insolation is adequate to fire one or both chillers. Active periods center about solar noon in summer.

In the NO Solar Mode, the control system draws upon underground storage of hot and/or chilled water to satisfy building demands for heating and cooling, respectively. If underground storage cannot satisfy the demand, then auxiliary energy (natural gas) is used to fire a hot water boiler, the output of which is used for heating or direct firing of the absorption chiller(s).

The various combinations of events that may occur in any of these three primary solar modes are presented separately. Note that each combination of events carries a characteristic designation (such as HS-11: High Solar Mode, eleventh combination of events) and that these designations have been programmed into the computer in the Data Acquisition System (DAS) via a program called MODE 1. Using this program, the DAS senses the status of the system and identifies the operational mode (for example, HS-11). Once this has been determined, the charts and tables in Section 3 can be used to check the position/status of the valves, pumps and equipment in the system.

No Solar, Low Solar, and High Solar are automatically selected during normal operations, but they may also be manually selected by moving one of the switches on the front of the Control Panel in the MER. The physical locations and markings of these switches are shown in Fig. 4-1. In the following discussion, these switches are referenced as override switches S_1 through S_{12}; Fig. 4-2 shows a correlation between this designation and the locations of Fig. 4-1. For example, the manual switch for selecting No Solar, Low Solar or High Solar is override switch S_8. Locations of other pertinent switches that are positioned inside the control panel are shown in Figs. 4-3 and 4-4.

The control functions served by the override switches are defined in Table 4-1. It can be seen that the switches control a number of manual operations. This information should be referenced in determining the effect upon the system operation of component failure or change in override switch position.

In the following discussion, mention will be made of several temperature sensors and controllers that initiate specific control functions. Table 4-2 is a summary of these devices and their functions in the system.

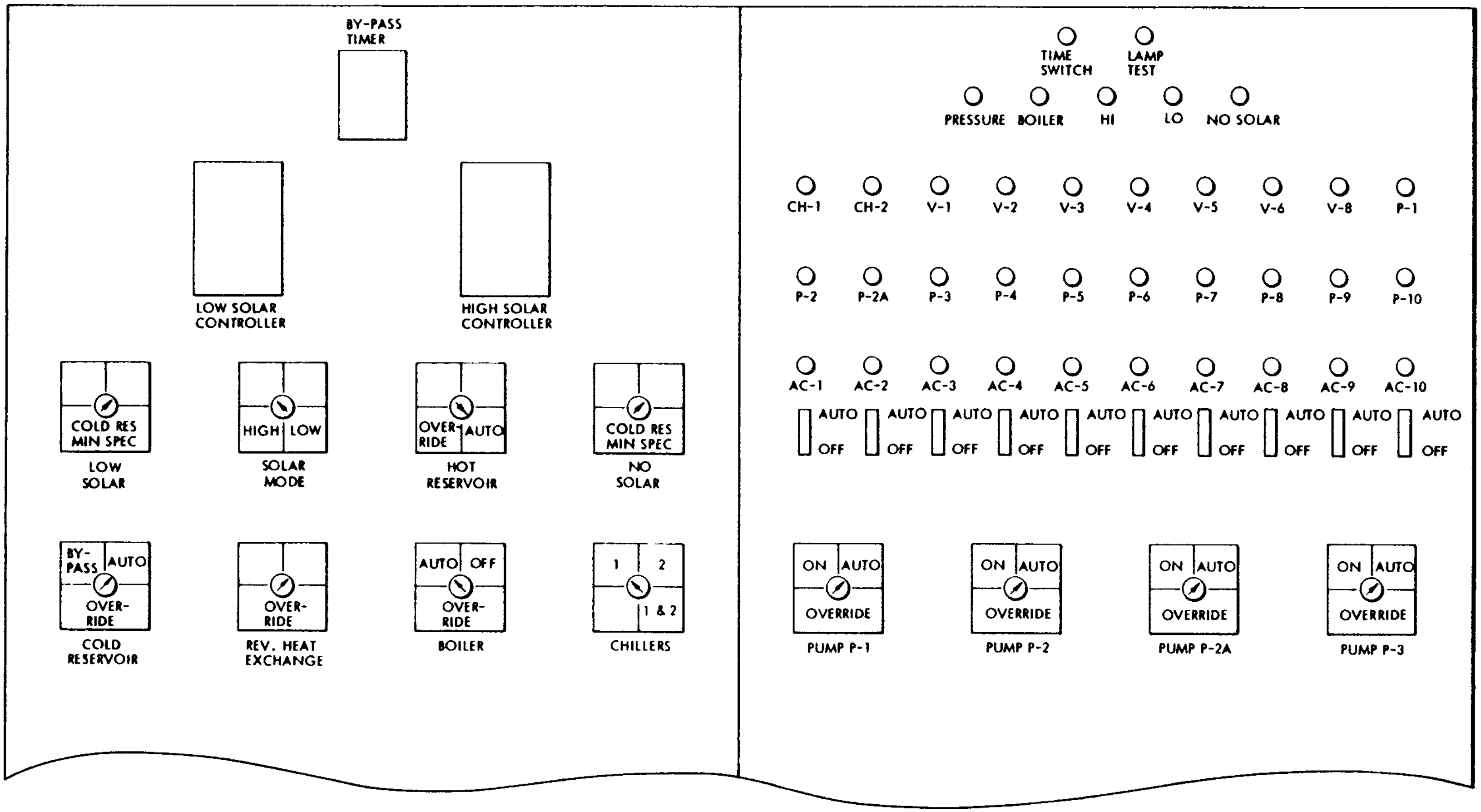


Fig. 4-1 Location of Switches in Exterior Doors of Control Panel for Solar-Powered Heating & Cooling System

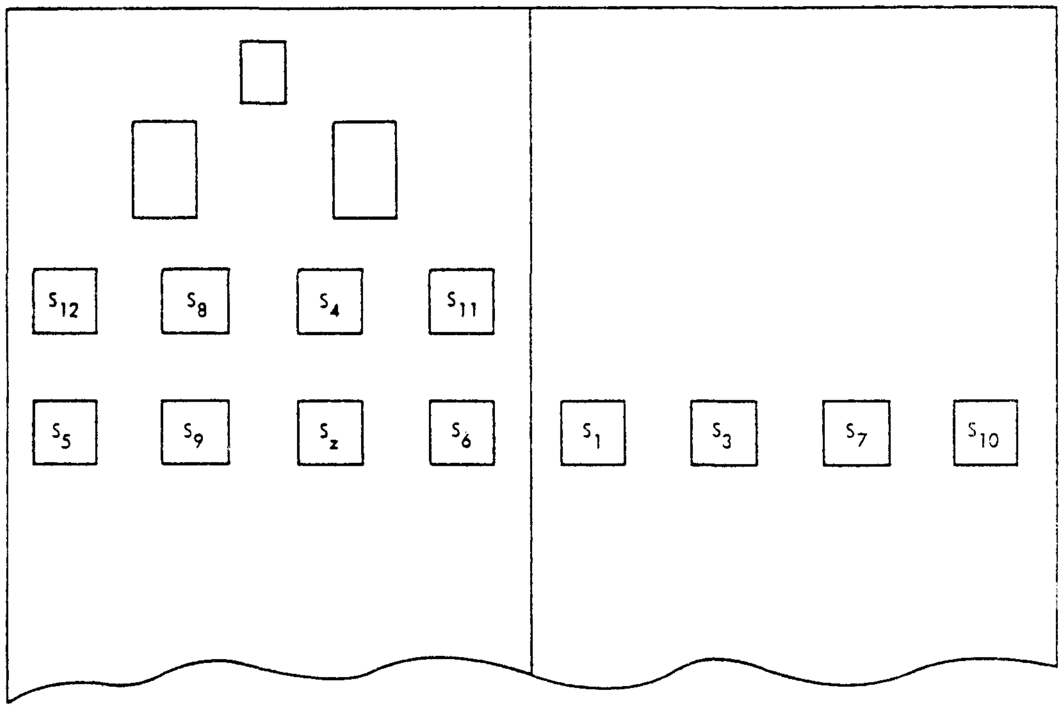


Fig. 4-2 Correlation of Switches in Exterior Doors of Control Panel to Override Switch Numbers

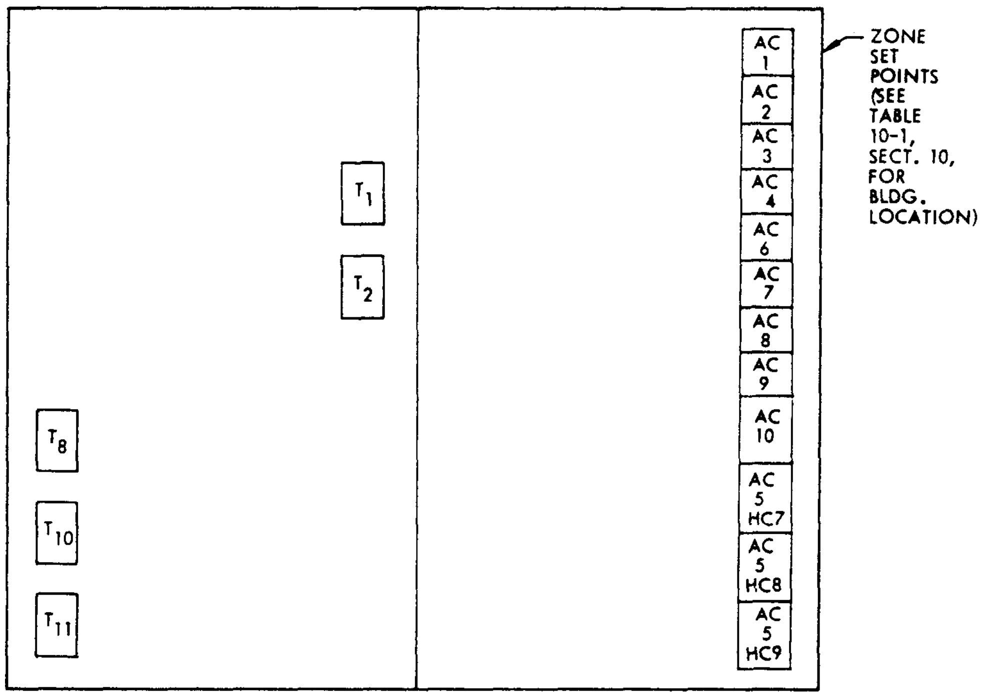


Fig. 4-3 Location of Switches in Interior Doors of Control Panel for Solar-Powered Heating & Cooling System

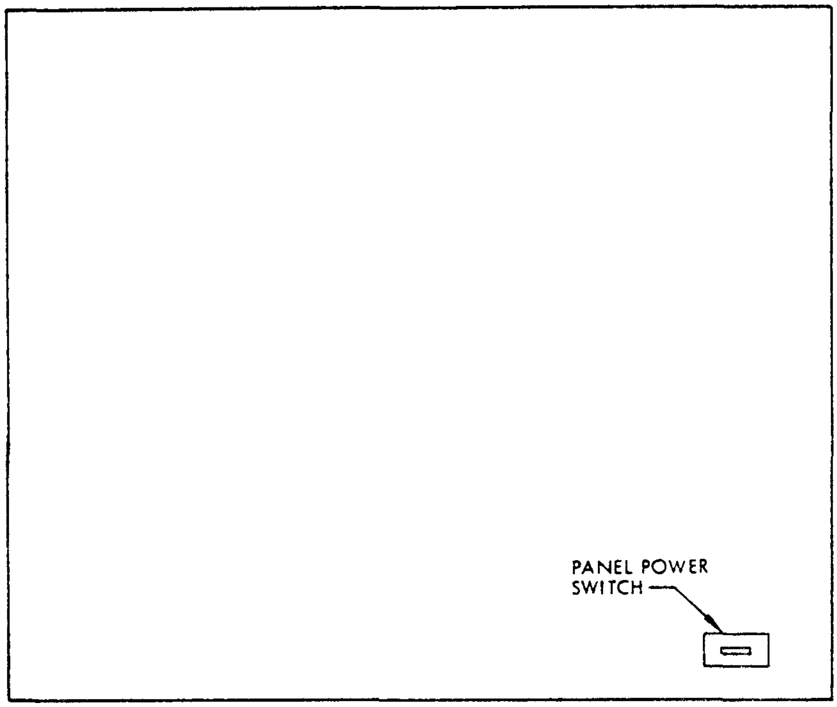


Fig. 4-4 Location of Panel Power Switch Behind Internal Doors of Control Panel

Table 4-1

OVERRIDE SWITCHES AND THEIR CONTROL FUNCTIONS

SWITCH	DESCRIPTION/FUNCTION
S_1	A micro-switch series 910, "ON-AUTO", P_1 override switch is provided to: (a) "ON" position – overrides pump P_1 controls and allows P_1 to run continuously. (b) "AUTO" position – allows P_1 to cycle automatically during normal operation. S_1 should normally be left in the "AUTO" position.
S_2	A micro-switch series 910, "ON-AUTO", Boiler override switch is provided to: (a) "ON" position – overrides boiler mode controls and allows boiler to run continuously. (b) "AUTO" position – allows boiler to cycle automatically during normal operation. S_2 should normally be left in the "AUTO" position.
S_3	A micro-switch series 910, "ON-AUTO", P_2 override switch is provided to: (a) "ON" position – overrides pump P_2 controls and allows P_2 to run continuously. (b) "AUTO" position – allows P_2 to cycle automatically during normal operation. S_3 should normally be left in the "AUTO" position.
S_4	A micro-switch series 910, AUTO-BYPASS-MIN SPEC hot reservoir mode switch S_4, is provided to: (a) "BYPASS" position – system heating demands will be met by means other than by hot water from the hot storage reservoir. (b) "MIN. SPEC." position – when S_4 is in this position, optional hot reservoir min spec will be accomplished by T_8 and its associated controls. (c) "AUTO" position – when S_4 is in this position, the system will operate under normal operating conditions. S_4 is normally left in the "AUTO" position.
S_5	A micro-switch series 910, "AUTO-BYPASS", cold reservoir mode switch S_5 is provided to: (a) "BYPASS" position – cooling for the building demand is supplied directly via the chillers and the cold storage reservoir is isolated. (b) "AUTO" position – when S_5 is in this position the system will operate under normal operating conditions. S_5 is normally left in the "AUTO" position.
S_6	A micro-switch series 910, "CH-1, CH-2, CH-1 & CH-2", chiller selector switch S_6 is provided to: (a) "CH-1" position – upon a call for cooling, chiller 1 will be the first chiller to be energized. (b) "CH-2" position – upon a call for cooling, chiller 2 will be the first chiller to be energized. (c) "CH-1 & CH-2" position – upon a call for cooling, both chillers will be energized.

Table 4-1 (Cont.)

SWITCH	DESCRIPTION/FUNCTION
S_7	A micro-switch series 910, "ON-AUTO", P_{2A} override switch is provided to: (a) "ON" position – overrides pump P_{2A} controls and allows P_{2A} to run continuously. (b) "AUTO" position – allows P_{2A} to cycle automatically during normal operation. S_7 should normally be left in the "AUTO" position.
S_8	A micro-switch series 910, "NO-LOW-HIGH-AUTO", mode control switch is provided to: (a) "NO" position – the primary system will switch to the NO Solar Mode of operation, bypassing automatic mode controls. (b) "LOW" position – the primary system will switch to the LOW solar mode of operation, bypassing automatic mode controls. (c) "HIGH" position – the primary system will switch to the HIGH solar mode of operation, bypassing automatic mode controls. (d) "AUTO" position – the primary system will switch automatically between modes according to demands from the pyranometer, T_1 and/or T_2 and T_4. S_8 should normally be left in the "AUTO" position.
S_9	A micro-switch series 910, "OFF-AUTO", reverse heat exchange switch is provided to: (a) "OFF" position – locks out ability to reverse heat exchange. (b) "AUTO" position – allows system to reverse heat exchange automatically as controlled by T_{23} and T_{24} and their associated controls. S_9 should normally be left in the "OFF" position.
S_{10}	A micro-switch series 910, "ON-AUTO", P_3 override switch is provided to: (a) "ON" position – overrides pump P_3 controls and allows P_3 to run continuously. (b) "AUTO" position – allows P_3 to cycle automatically during normal operation. S_{10} should normally be left in the "AUTO" position.
S_{11}	A micro-switch series 910, "AUTO-OFF", NO solar min. spec. switch is provided to: (a) "AUTO" position – allows T_{10} and its associated controls to min. spec. the cold reservoir automatically in the NO solar mode. (b) "OFF" position – locks out cold reservoir min. spec. operation in NO solar mode.
S_{12}	A micro-switch series 910, "AUTO-OFF", LOW solar min. spec. switch is provided to: (a) Same as S_{11} (a) except LOW solar. (b) Same as S_{11} (b) except LOW solar.

Table 4-2

TEMPERATURE SENSORS AND CONTROLLERS AND THEIR CONTROL FUNCTIONS

SENSOR	DESCRIPTION/FUNCTION
T_1 & T_2	Electronic temperature sensors T_1 and T_2 located in the collector array in conjunction with CP8102 solid state controllers, AT8155 setpoint adjusters and a CC8101 electronic relay are provided to back up pyranometer operation in the event of failure or malfunction. T_1 and T_2 and their associated controls will switch the system between NO and LOW solar modes of primary system operation. Setpoint for both sensors is 140°F.
T_3 & T_7	Electronic temperature sensors T_3 located in the collector exit water and T_7 located in the hot reservoir in conjunction with a CP8102 solid state controller and a CC8101 electronic relay are provided to measure the temperature differential between the solar loop and hot reservoir. When the reservoir temperature is 10°F lower than the collector loop temperature, pump P_2 will be energized and heat will be exchanged via HX-1.
T_4	A TC205 remote bulb thermostat with its bulb located in the collector exit, T_4 is provided as a pyranometer backup and will switch the system between LOW solar and HIGH solar modes of primary system operation. Setpoint is 195°F.
T_5 & T_{13}	Electronic temperature sensors T_5, located in the collector exit and T_{13}, located in the collector input water, in conjunction with a CP8102 solid state controller and a CC8101 electronic relay are provided to measure the temperature differential across the collector array and will deenergize the second chiller whenever the differential drops below 10°F.
T_6	A TC205 remote bulb thermostat with its bulb located in the collector exit water, T_6 is provided to energize the second chiller whenever the collector exit water temperature is greater than the setpoint on T_6 (220°F).
T_8	Electronic temperature sensor T_8, located in the hot reservoir, in conjunction with a TP8101 bridge and amplifier, an AT8122 setpoint adjuster and a CC8102 two-stage electronic relay is provided to verify that the hot reservoir is within min. spec. (115°F) and will control min. spec. of hot reservoir if optional min. spec. is desired.
T_9	A TP307 remote bulb microtherm, T_9, with its bulb in the hot water supply to the fan coil units is provided to modulate valve V_3 to maintain a predetermined hot water temperature (105°F).
T_{10}	Electronic temperature sensor T_{10}, located in the cold reservoir, in conjunction with a TP8101 bridge and amplifier, an AT8122 setpoint adjuster and a CC8101 electronic relay, is provided to control cold reservoir min. spec. whenever the reservoir temperature rises above the setpoint (55°F).
T_{11}	Electronic temperature sensor T_{11}, located in the cold reservoir, in conjunction with a TP8101 bridge and amplifier, an AT8122 setpoint adjuster and a CC8101 electronic relay, is provided to lock out chiller operation whenever the temperature is lower than the setpoint (44°F).
T_{12}	A TC203 remote bulb thermostat with its bulb in the condenser water supply to the chillers, T_{12} is provided to cycle the tower fan to maintain condenser water temperature (80°F).

Table 4-2 (Cont.)

SENSOR	DESCRIPTION/FUNCTION
T_{14}	A TC205 remote bulb thermostat with its bulb located in the collector exit water, T_{14} is provided to energize the first chiller whenever the collector water temperature is equal to or greater than 210°F.
T_{15}	Electronic temperature sensor T_{15}, located in the hot reservoir, in conjunction with a CP8102 solid state controller and a CC8101 electronic relay, is provided to energize pump P_{2A} and deenergize pump P_2 whenever the temperature rises above the setpoint (210°F).
T_{16}	A TC233 remote bulb thermostat with its bulb located in the collector exit water, T_{16} is provided to allow heat exchange via HX-1 to the hot reservoir whenever the collector exit water temperature exceeds the setpoint (230°F). This is the "Bleed-Off" mode.
T_{17}	A TC223 remote bulb thermostat with its bulb located in the collector exit water, T_{17} is provided to place the system into the "DUMP MODE" thus heat exchanging to the hot reservoir via heat exchanger HX-1 if the collector exit temperature exceeds the setpoint (240°F).
T_{18}	A TC210 remote bulb thermostat with its bulb in the outside air T_{18} is provided to close the fresh air dampers to minimum whenever the outside temperature is above the setpoint (75°F).
T_{19}	A TS8131 wall-mounted electronic temperature sensing element, in conjunction with a TSP8101 indication and control transmitter, a TP8101 bridge and amplifier, an AT8158 zone setpoint adjuster and an AD8101 sequence adapter, T_{19} is provided to modulate the zone controllers and activate the primary equipment to maintain zone temperature.
T_{20}	A TC204 remote bulb thermostat with its bulb located in the domestic hot water, T_{20} is provided to start the boiler whenever the domestic hot water temperature is below the setpoint (120°F).
T_{21}	Electronic temperature sensor T_{21}, located in the hot reservoir, in conjunction with a CP8102 solid state controller and a CC8101 electronic relay is provided to allow the hot reservoir to supply building heating demands in the NO solar mode if the hot reservoir temperature exceeds the setpoint (115°F).
T_{22}	A TC203 remote bulb thermostat with its bulb in the jacket of heat exchanger HX-1, T_{22} is provided to lock out boiler operation (in any mode) if HX-1 temperature exceeds setpoint (105°F).
T_{23} & T_{24}	Electronic temperature sensing elements T_{23}, located in the hot reservoir, and T_{24}, located in the collector exit water, in conjunction with a CP8102 solid state controller and a CC8101 electronic relay are provided to measure the temperature differential between collector exit and hot reservoir temperatures, and will initiate reverse heat exchange from the hot reservoir to the collector array whenever the reservoir temperature exceeds the collector temperature by 10°F.

4.2 AUTOMATIC MODES OF OPERATION

4.2.1 General Description

The primary system runs continuously in the automatic modes of operation and is only interrupted by pressure loss in the system or whenever the manual control disconnect switch is turned off. Fan coil operation is controlled by a Vertrex EM II variable start timeswitch which varies the starting time of the units depending upon outside ambient conditions, but always starts the units prior to building occupancy. A 12-hour bypass timer provides for OFF-hours of system operation. Manual override switches located at the temperature control panel are provided to interrupt fan coil unit operation if desired and are normally left in the "Automatic" position.

Zone Control

A TS8131* wall-mounted electronic temperature sensing element, in conjunction with a TSP8101 indication and control transmitter, a TP8101 bridge and amplifier, an AT8158 zone setpoint adjuster, and an AD8101 sequence adapter located in the temperature control panel sequence the operation of a VP3142 heating valve, a VP3142 cooling valve, an MP2110/CP8301 mixed air damper actuator to maintain zone temperature. A TC210 remote bulb thermostat with its bulb located in the air is provided to close the outside air damper to minimum whenever the outside air temperature exceeds 75°F. AD8201 high and low signal selectors and a CC8102 solid state heating/cooling relay energize the appropriate primary equipment upon zone demand to provide heat and chilled water to the zone valves in accordance with zone demand.

Solar Modes

The system can be in only one solar mode at any given time and will switch from one mode to the next during normal system operation. Mode selector switch S_8 must be left in the "AUTO" position during this time.

*These callouts denote specific types of Barber-Coleman equipments used in the control system.

An Eppley pyranometer mounted on the roof is provided to sense the solar flux and its output is coupled to B-C 520A controllers which will switch the primary system into either LOW or HIGH solar modes, depending upon the signal produced by the pyranometer. Temperature sensing elements T_1 and T_2, located in the collector array in conjunction with CP8102 solid state controllers and AT8155 set point adjusters and CC8101 electronic relay located at the control panel, are provided to switch the system from the NO solar mode to the LOW solar mode if the temperature of T_1 and/or T_2 exceeds the setpoints (140°F). A TC205 remote bulb thermostat, T_4, with its bulb located in the collector exit water, switches the system from the LOW solar mode to the HIGH solar mode whenever the collector exit water temperature exceeds the T_4 setpoint (195°F). Temperature sensors T_1, T_2, and T_4 and their associated controls are provided as a backup to the pyranometer in the event of failure or malfunction.

Mode selection can also be accomplished by manual override switch S_8 located at the control panel. Normally, this switch will be left in the AUTO position in order to allow the system to operate automatically but NO solar, LOW solar and HIGH solar positions are available whenever manual override is desired.

4.2.2 Automatic No Solar Mode of Operation

The system operates automatically in the Low Solar Mode whenever the pyranometer signal is less than 1.5 millivolts and/or sensors T_1 and T_2 sense temperatures that are less than 140°F. To meet building heating demand from the hot storage reservoir, the system controls place the motor driven valves in these positions:

V_1	A → AB
V_2, V_4, V_5, V_6, V_8	B → AB

and start the following pumps:

P_2, P_3, P_9, P_{10}

The positions of valves V_1, V_4, V_5 and V_6 are shut-down positions; i.e., these valves do not pass fluid in this particular sequence, but they have a preferred position when they are inactive. Figure 4-5 shows fluid flows for this condition.

This transfer of energy continues as long as the building heating demand exists, or until the reservoir energy is depleted; sensor T_{21}, located at the top of the hot storage reservoir, senses the latter event and signals the control system to switch to the auxiliary boiler whenever $T_{21} < 115°F$. Note that an interlock between valve V_2 and the boiler has been provided so that the boiler cannot fire whenever valve V_2 is in the $B \rightarrow AB$ position. This feature prevents heat exchange from the boiler to the hot storage reservoir except when manual override switch S_4 at the master control panel has been thrown.

Building cooling demand is met with energy from the cold storage reservoir when the valves are in these positions:

V_1, V_4, V_6	$A \rightarrow AB$
V_2, V_5, V_8	$B \rightarrow AB$

and pump P_5 is energized. Figure 4-6 gives fluid flows for this case.

In the event that the building demand involves heating in some zones and cooling in other zones simultaneously, the valve positions for cooling only prevail, but in this case, the following pumps are started:

$$P_2, P_3, P_5, P_9, P_{10}$$

See Fig. 4-7 for fluid flows.

A complete listing of the automatic, steady-state operations that can be experienced in the No Solar Mode is presented in Table 4-3.

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

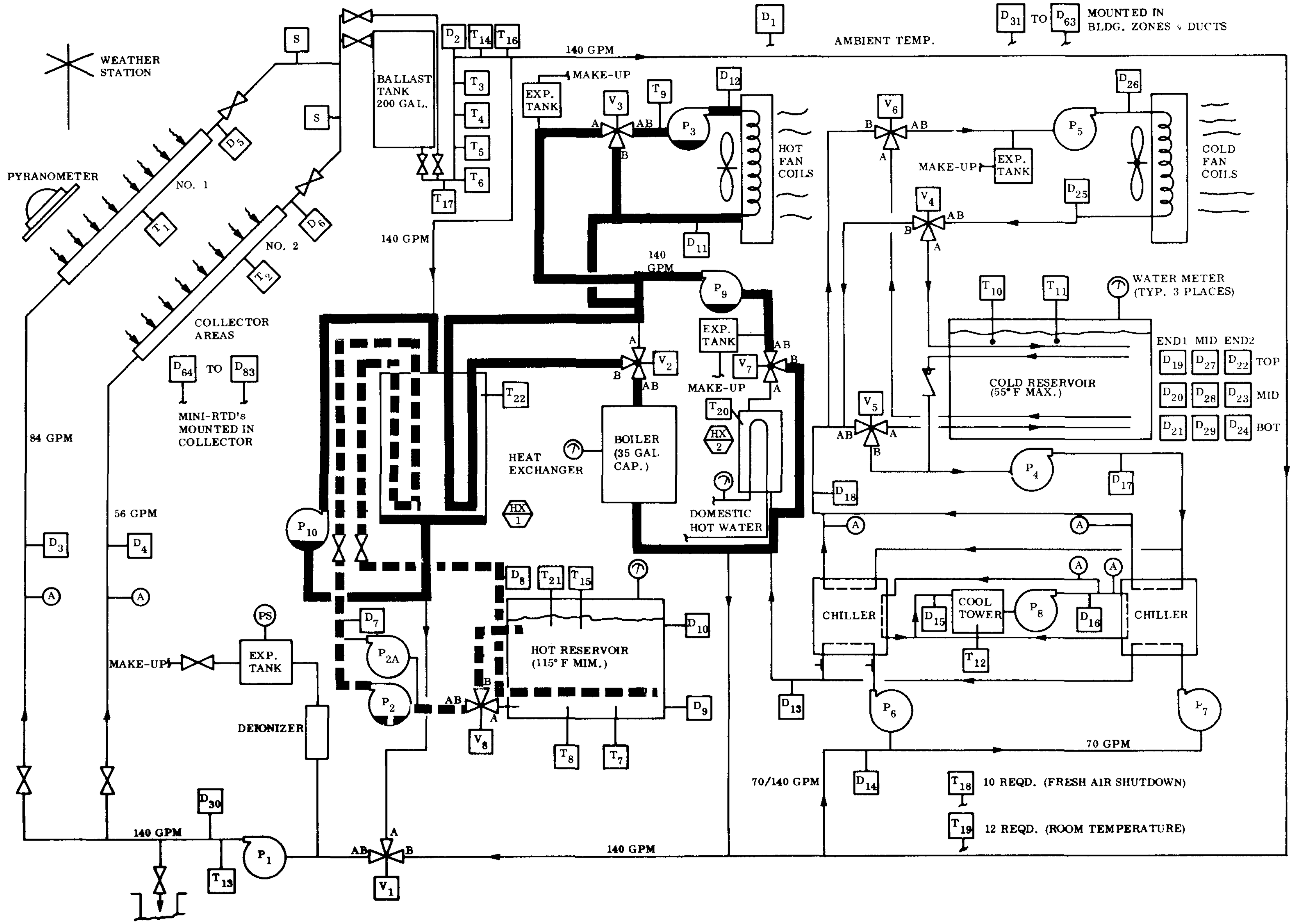

Fig. 4-5 No Solar Mode NS-1a: Heating and DHW From Hot Reservoir; No Cooling Required. ($T_{21} \geq 115°$ F)

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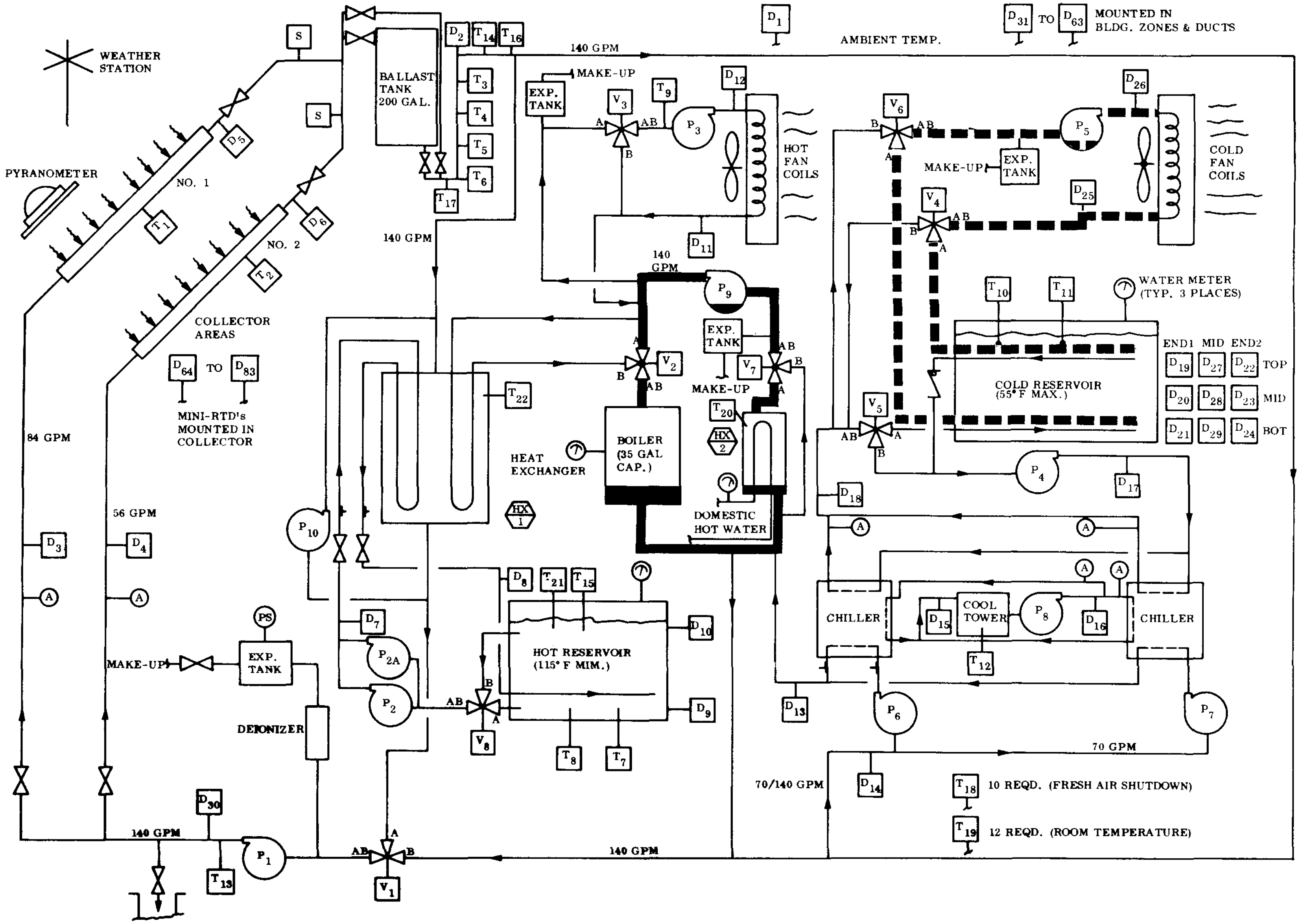

Fig. 4-6 No Solar Mode NS-6a: Cooling From Cold Reservoir; DHW From Boiler; No Heating Required

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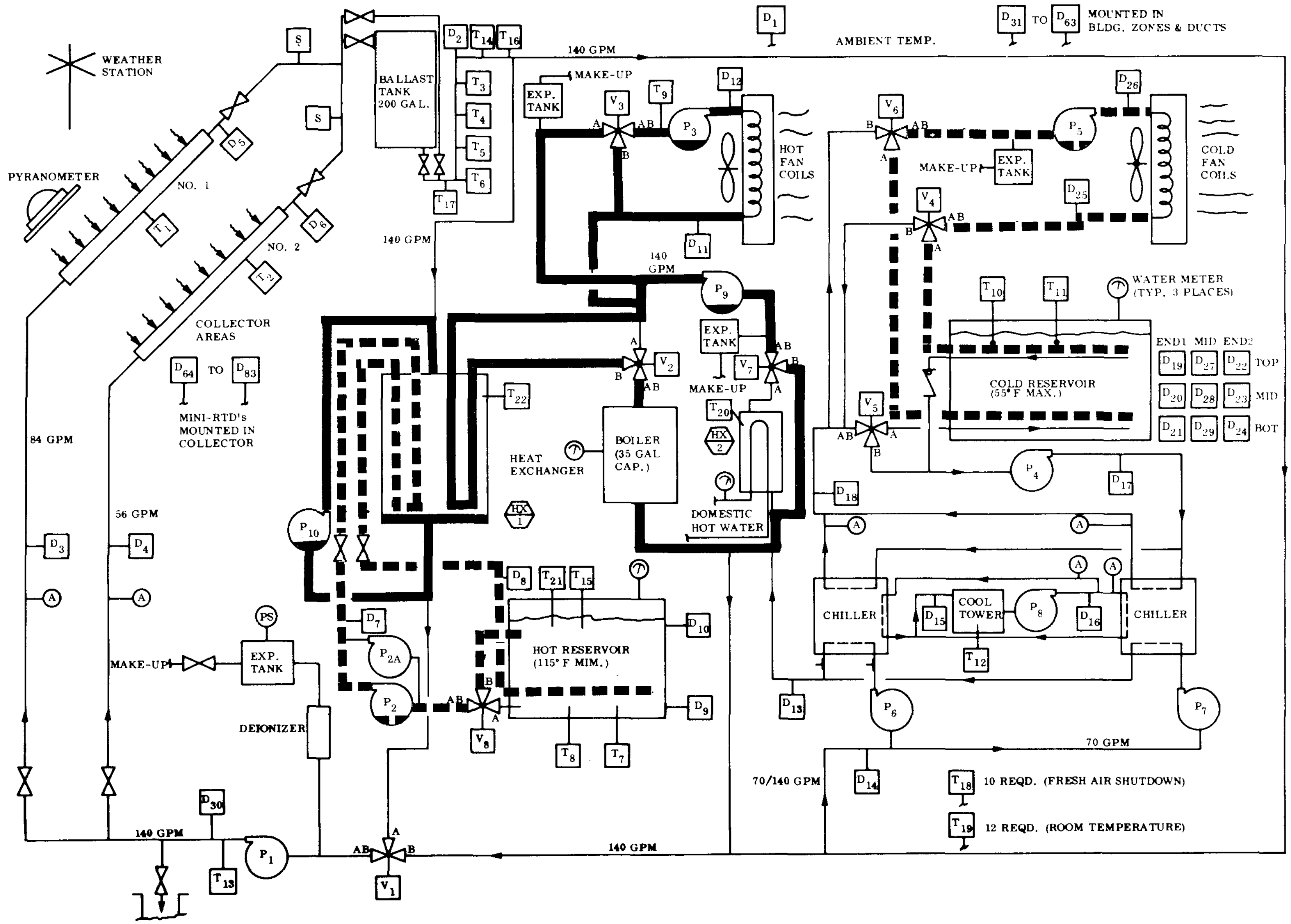

Fig. 4-7 No Solar Mode NS-10a: Cooling From Cold Reservoir; Heating and DHW From Hot Reservoir

Table 4-3

MATRIX OF SYSTEM AUTOMATIC, STEADY-STATE OPERATING MODES AS A FUNCTION OF ENERGY SOURCE: NO SOLAR MODE

ID	Fig.	Energy Destination: Heating	Cooling	Domestic Hot Water	Hot Storage	Cold Storage	Collector	Clock	Condition
NS-1a	2-1	R		R				ON	Heating
NS-2a	2-2	B	-	B				ON	Heating
NS-3	2-3	B	-	B	B			ON	Heating + Opt. Hot Res. Min Spec.
NS-4a	2-4	B	-	B	-	B		ON	Heating + Cold Res. Min Spec.
NS-5	2-5	B	-	B	B	B		ON	Heating + Opt. Hot Res. Min Spec. + Cold Res. Min Spec.
* NS-6a	2-6	-	R	B				ON	Cooling
* NS-7	2-7	-	R	B	B			ON	Cooling + Opt. Hot Res. Min Spec.
* NS-8a	2-8	-	R	B	-	B		ON	Cooling + Cold Res. Min Spec.
* NS-9	2-9	-	R	B	B	B		ON	Cooling + Opt. Hot Res. Min Spec. + Cold Res. Min Spec.
NS-10a	2-10	R	R	R				ON	Heating & Cooling
NS-11a	2-11	B	R	B				ON	Heating & Cooling
NS-12	2-12	B	R	B	B			ON	Heating & Cooling + Opt. Hot Res. Min Spec.
NS-13a	2-13	B	R	B	-	B		ON	Heating & Cooling + Cold Res. Min Spec.
NS-14	2-14	B	R	B	B	B		ON	Heating & Cooling + Opt. Hot Res. Min Spec + Cold Res. Min Spec.
* NS-15a	2-15	-	-	B				ON	Domestic Hot Water Only
NS-16a	2-15	-	-	B				OFF	Domestic Hot Water Only
NS-17	2-16	-	-	B	B			ON/OFF	Opt. Hot Res. Min Spec.
NS-18a	2-17	-	-	B	-	B		ON/OFF	Cold Res. Min Spec.
NS-19	2-18	-	-	B	B	B		ON/OFF	Opt. Hot Res. Min Spec. + Cold Res. Min Spec.
NS-1b to NS-18b	2-19		(See Note 4)				R	ON/OFF	Opt. Hot Res. Reverse Heat Exch. to Collector (Override Switch S_9)

Notes:
1. Constant demand assumed for domestic hot water except as noted.
2. Notation: S=Solar, R=Reservoir, B=Boiler
3. If P_3 "on" with clock, eliminate modes marked *.
4. Optional reverse heat exchange from hot reservoir to collector permissible in all modes except those involving optional hot reservoir spec. by boiler. Conditions: $T_{23} - T_{24} \geq \Delta T_{min}$. & exchange timer "on". (Total of 11 "b" modes.)
5. The override switch for optional hot reservoir min spec. is S_4.

4.2.3 Automatic Low Solar Mode of Operation

System control shifts up from the No Solar Mode to the Low Solar Mode when the pyranometer signal is greater than 1.5 millivolts; it shifts down from the High Solar Mode to the Low Solar Mode when the pyranometer signal is less than 4.4 millivolts. The shift from No Solar to Low Solar is backed up by T_1 and T_2 (set at 140°F) as noted previously. The backup for the shift from High Solar to Low Solar is T_4 which is set at 195°F.

The boiler may fire in the Low Solar Mode in order to satisfy the cold storage reservoir temperatures, but only when valve V_2 is in the A → AB position; i.e., when solar energy is not being heat exchanged into the building.

If the system is moving from the No Solar Mode to the Low Solar Mode, the signal to initiate the Low Solar Mode energizes pump P_1. Valve V_1, which has been in shutdown position, A → AB, remains in this position during the Low Solar Mode. Energy transfer to the hot storage reservoir via heat exchanger HX-1 begins when the differential $T_3 - T_7$ is 10°F. The fluid flows for this condition are shown in Fig. 4-8.

Building heating demand in this mode is met directly with solar energy via the secondary tube bundle in heat exchanger HX-1 with valve V_2 in the B → AB position. Control sensor T_{22} located in the shell of heat exchanger HX-1 provides control for this operation and is set at 105°F. The schematic piping diagram representing this operation is given in Fig. 4-9. The valve positions are:

V_1, V_8	A → AB
V_2, V_4, V_5, V_6	B → AB

and the following pumps are energized:

P_1, P_2, P_3, P_9

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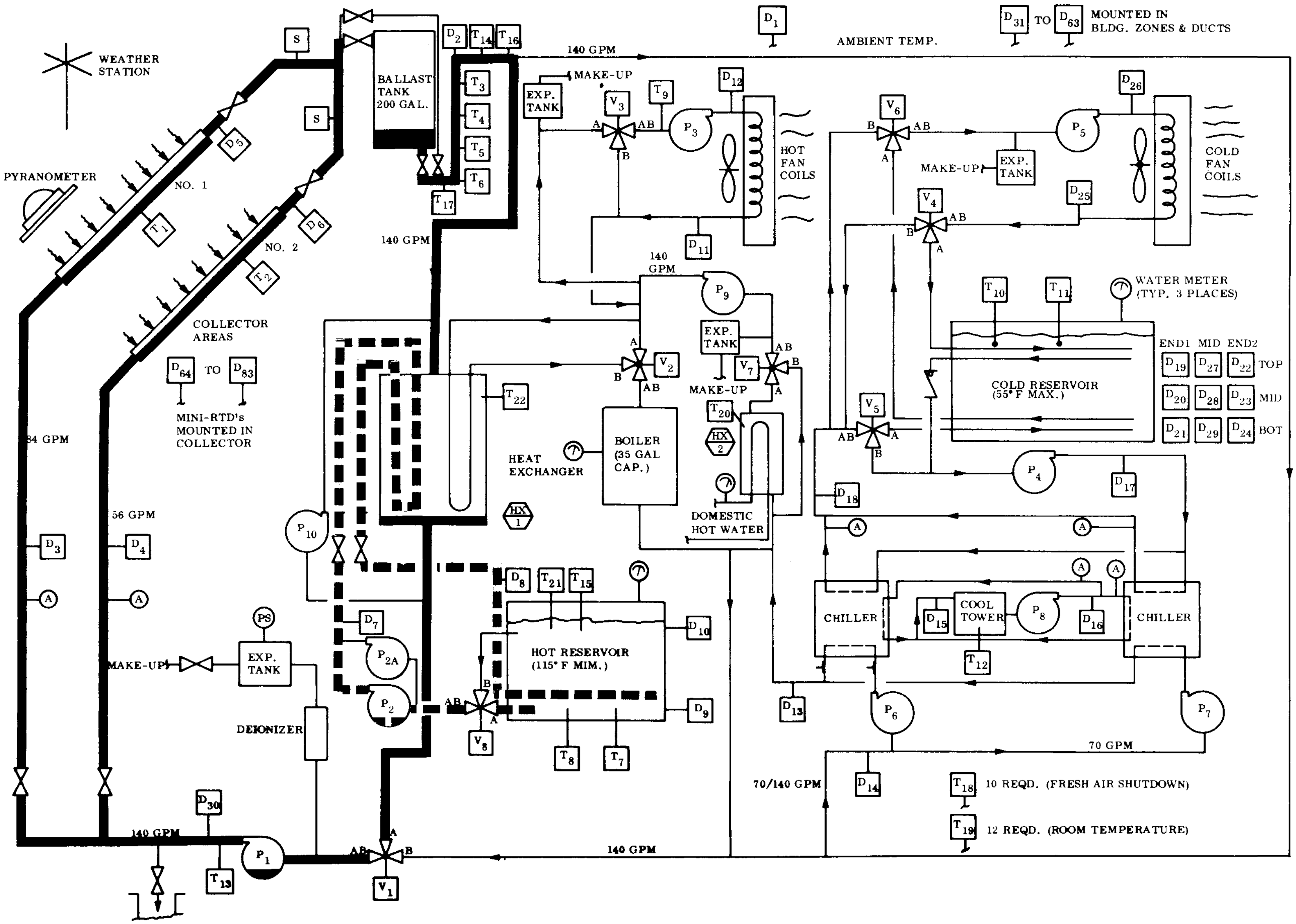

Fig. 4-8 Low Solar Mode LS-9a: Hot Storage From Solar; No Heating, Cooling or DHW Required (Clock On or Clock Off)

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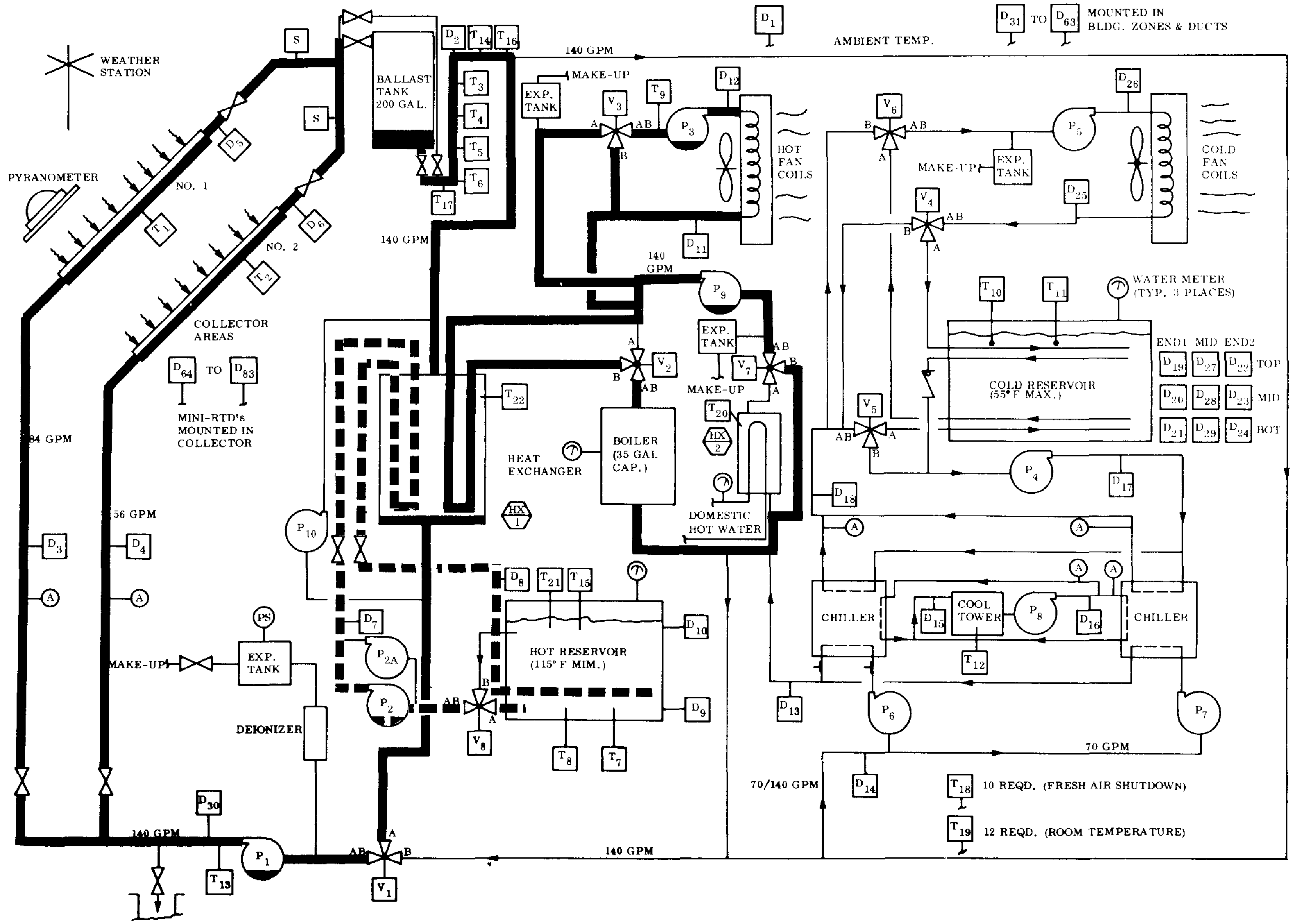

Fig. 4-9 Low Solar Mode LS-1a: Heating, DHW and Hot Storage From Solar; No Cooling Required

Building cooling demand in the Low Solar Mode is supplied from the cold storage reservoir, the same as in the No Solar Mode. The valve positions are:

V_1, V_4, V_6, V_8	A → AB
V_2, V_5	B → AB

and these pumps are energized:

$$P_1, P_2, P_5, P_9$$

The schematic piping diagram for this operation is shown in Fig. 4-10.

Building demand involving heating in some zones and cooling in other zones requires the same valve positions as noted above for cooling (only) demand, but with the following pumps in operation:

$$P_1, P_2, P_3, P_5, P_9$$

The schematic piping diagram for this situation is presented in Fig. 4-11.

This discussion treats the case where control of the system is moving from the No Solar Mode to the Low Solar Mode. The same discussion applies in the case of system control moving from the High Solar Mode to the Low Solar Mode, except that in this event, pump P_1 is already running, and valve V_1 must be moved to the A → AB position.

A complete list of the automatic, steady-state operations possible in the Low Solar Mode appears in Table 4-4.

4.2.4 Automatic High Solar Mode of Operation

The High Solar Mode is initiated when the pyranometer signal is equal to or greater than 4.4 millivolts. The back-up control temperature sensor is T_4.

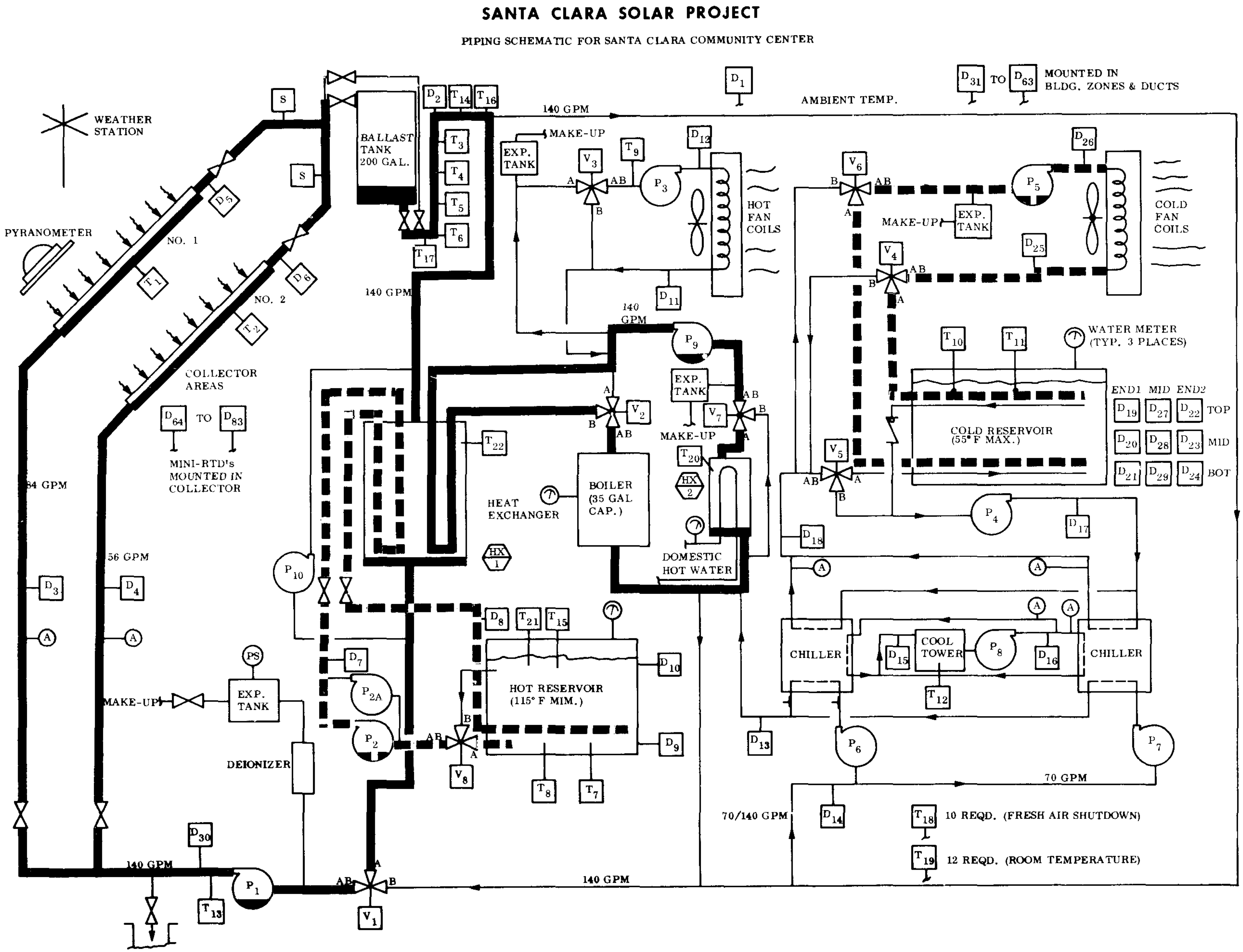

Fig. 4-10 Low Solar Mode LS-3a: Cooling From Cold Reservoir; No Heating Demand; Hot Storage and DHW From Solar

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

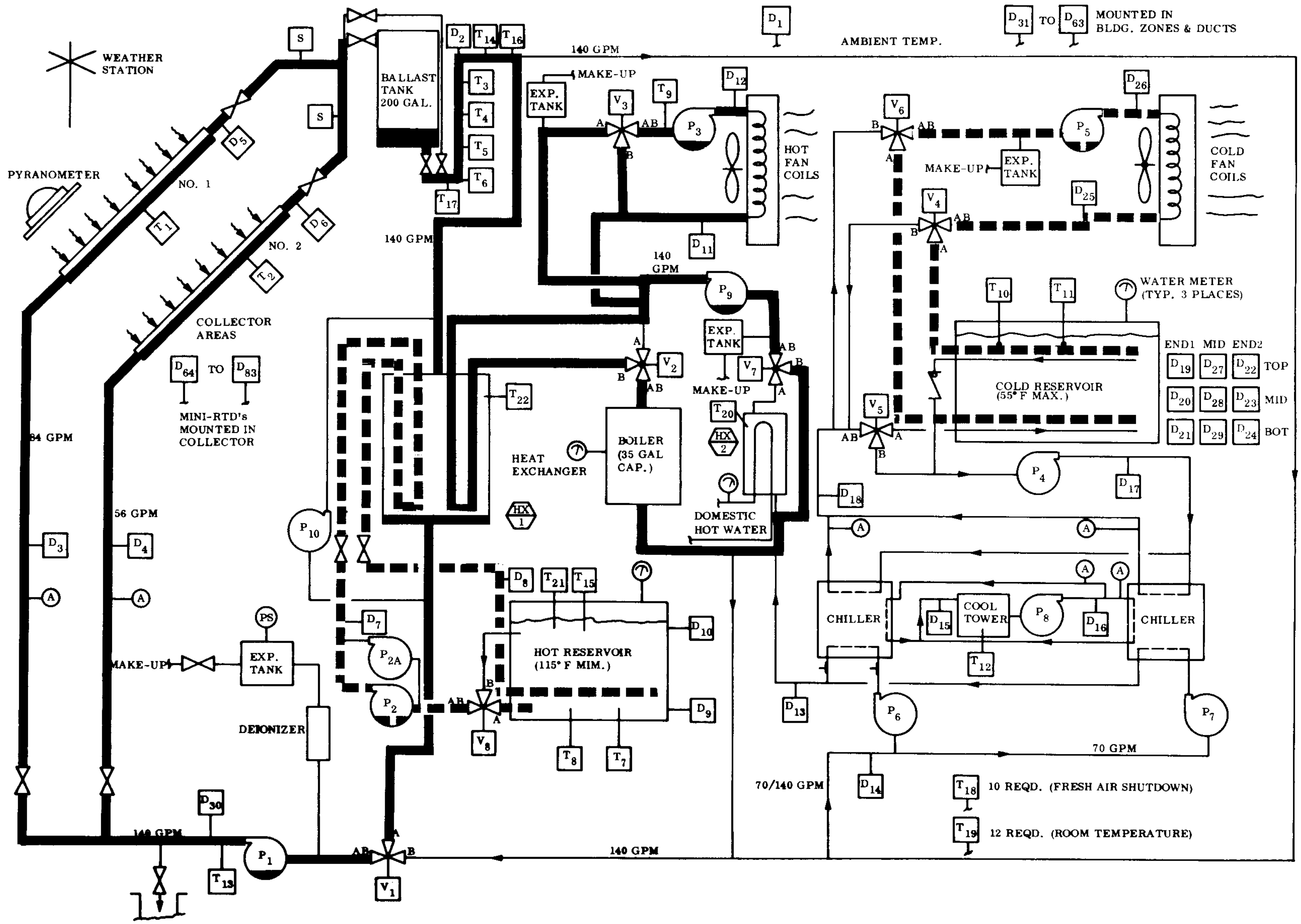

Fig. 4-11 Low Solar Mode LS-5a: Heating, Hot Storage and DHW From Solar; Cooling From Cold Reservoir

Table 4-4

MATRIX OF SYSTEM AUTOMATIC, STEADY-STATE OPERATING MODES AS A FUNCTION OF ENERGY SOURCE: LOW SOLAR MODE ($D_2 \geq 140°F$)

ID	Fig.	Energy Destination: Heating	Cooling	Domestic Hot Water	Hot Storage	Cold Storage	Collector	Clock	Condition
LS-1a	3-1	S	-	S	S	-		ON	Hot Storage + Heating
LS-2a	3-2	B	-	B	S	B		ON	Hot Storage + Heating + Cold Res. Min Spec.
* LS-3a	3-3	-	R	S	S	-		ON	Hot Storage + Cooling
* LS-4a	3-4	-	R	B	S	B		ON	Hot Storage + Cooling + Cold Res. Min Spec.
LS-5a	3-5	S	R	S	S	-		ON	Hot Storage + Heating & Cooling
LS-6a	3-6	B	R	B	S	B		ON	Hot Storage + Heating & Cooling + Cold Res. Min Spec.
* LS-7a	3-7	-	-	S	S	-		ON	Hot Storage + Domestic Hot Water Only
LS-8a	3-7	-	-	S	S	-		OFF	Hot Storage + Domestic Hot Water Only
LS-9a	3-8	-	-	-	S	-		ON/OFF	Hot Storage Only
LS-10a	3-9	-	-	B	S	B		OFF	Hot Storage + Cold Res. Min Spec.
LS-1b to LS-10b	3-10							-	Same as LS-1a to LS-10a Without Hot Storage ($T_3-T_7 < \Delta T_{min}$)
LS-1c to LS-10c	3-11	(See Note 4)					R	ON/OFF	Optional Hot Reservoir Reverse Heat Exchange to Collector (Override Switch S_9)

Notes:
1. Constant demand assumed for domestic hot water except as noted.
2. Notation: S=Solar, R=Reservoir, B=Boiler.
3. If P_3 "on" with clock, eliminate modes marked *.
4. Optional reverse heat exchange from the hot reservoir to the collector replaces hot storage in modes LS-1a to LS-10a if $T_{23}-T_{24} \geq \Delta T_{min}$. & exchange timer is "on".

The signal to initiate this mode causes valve V_1 to be switched to the B → AB position. As a result, the collector fluid is made available to the chiller secondary pumping loop, and heat exchange into the hot storage reservoir is stopped. The fluid is allowed to circulate through the system until the temperature of the collector fluid on the exit side of the arrays reaches 210°F. At this point, T_{14} causes the controls to energize one chiller via pump P_6 and allow it to operate on its own controls provided that the temperature at the top of the cold storage reservoir has not dropped to or below the set point of T_{11}, namely, 44°F. When the collector array fluid exit temperature is equal to or greater than 220°F, T_6 signals the control system to energize the second chiller via pump P_7. Operations continue in this mode until either T_{11} senses its 44°F set point, or the solar flux begins to diminish. In the former case, the chillers are de-energized by stopping pumps P_6 and P_7. In the latter case, the temperature differential across the collector arrays is sensed by T_5 and T_{13} and when this differential $\ll$ 10°F, the second chiller is de-energized. Operations with one chiller continue until T_4 senses a temperature less than 195°F. The first chiller is then de-energized, and system control reverts to the Low Solar Mode. The cooling tower is energized via pump P_8 when either chiller unit is in operation. The cooling tower fan is cycled to maintain condensing water temperature via T_{12}.

If the building demand is for heating during the High Solar Mode, the piping schematic is as shown in Fig. 4-12. This schematic shows both chillers energized; i.e., the collector exit fluid temperature exceeds 220°F. As a consequence, the secondary pumping loop serving the two chillers is drawing all 140 gpm from the collector loop to supply the two chillers.

To serve the hot fan coils, pump P_9 is energized to supply fluid to the boiler loop, and the hot fan coils draw fluid from the boiler loop via pump P_3. The valve positions for this condition are:

V_5	A → AB
V_1, V_2, V_4, V_6, V_8	B → AB

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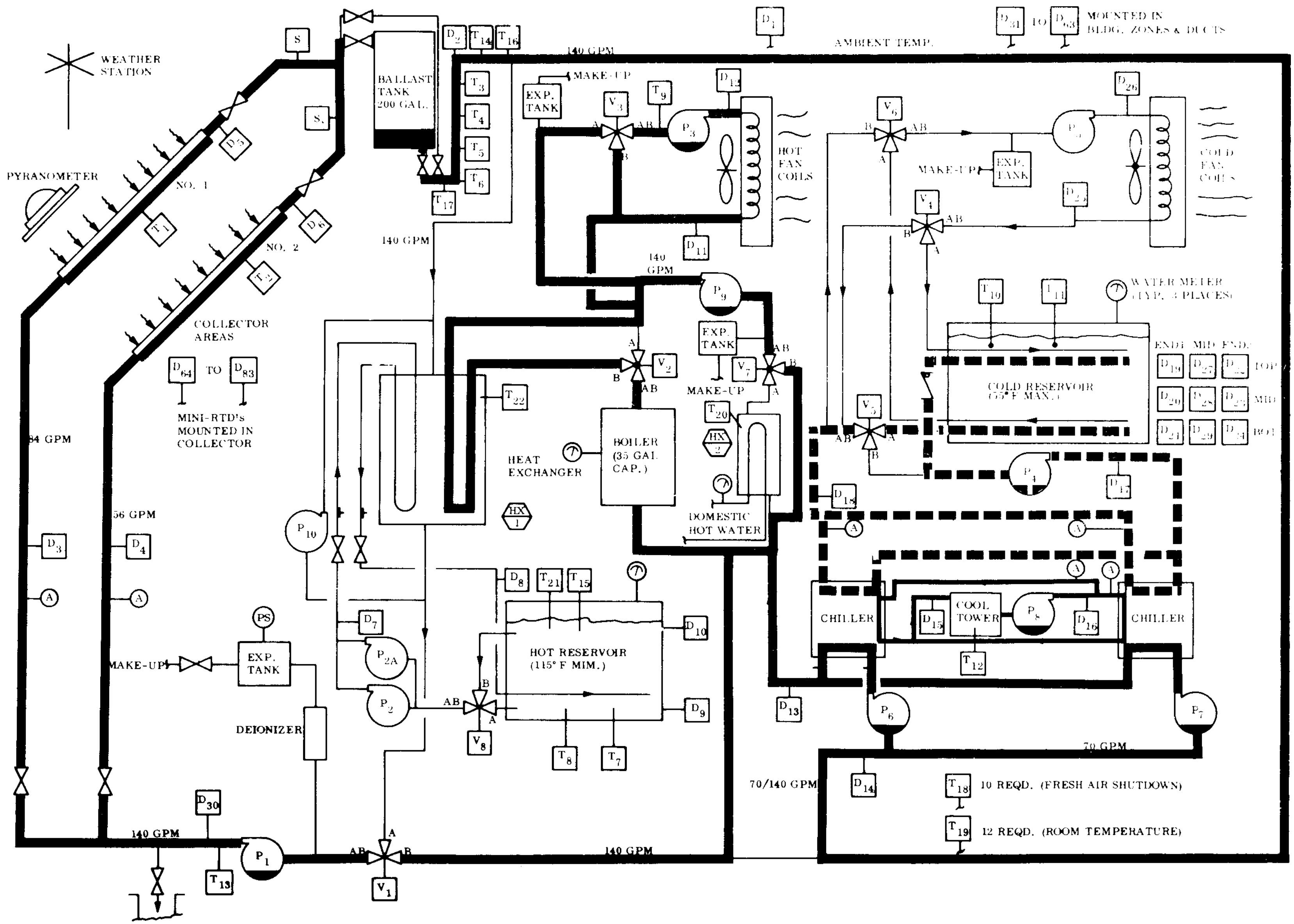

Fig. 4-12 High Solar Mode HS-1: Cold Storage, Heating and DHW From Solar; No Cooling Required

and the following pumps are energized:

$$P_1, P_3, P_4, P_6, P_7, P_8, P_9$$

The building cooling (only) demand is met with energy from the cold storage reservoir. In this situation the piping schematic is as shown in Fig. 4-13 and the valve positions are:

V_4, V_5, V_6	A → AB
V_1, V_2, V_8	B → AB

The pumps that are in operation are:

$$P_1, P_4, P_5, P_6, P_7, P_8, P_9$$

where pump P_9 cycles with the demand for domestic hot water via heat exchanger HX-2. Note that the boiler is locked out whenever valve V_1 is in the B → AB position; i.e., whenever system control is in the High Solar Mode.

Building demand requiring both heating and cooling is met with the valves in the same positions as noted above for cooling only with the following pumps energized:

$$P_1, P_3, P_4, P_5, P_6, P_7, P_8, P_9$$

The schematic diagram representing this condition is given in Fig. 4-14.

A complete list of the automatic, steady-state operations possible in the High Solar Mode is shown in Table 4-5.

4.2.5 Auxiliary (Boiler) Modes of Operation

The auxiliary boiler is employed in either the No Solar Mode or the Low Solar Mode to serve any combination of three functions during normal operations. These functions

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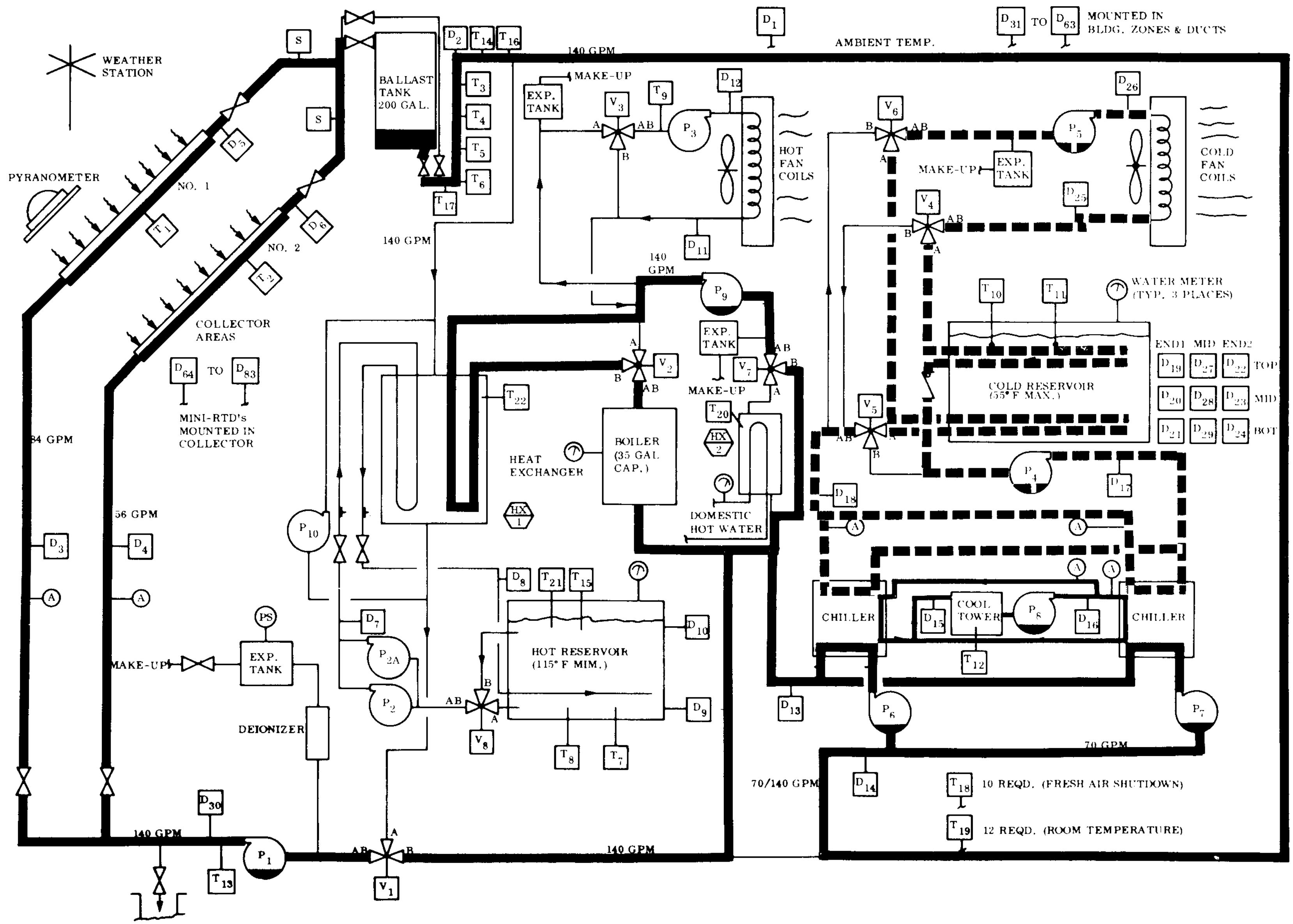

Fig. 4-13 High Solar Mode HS-3: Cold Storage and DHW From Solar; Cooling From Cold Reservoir; No Heating Required

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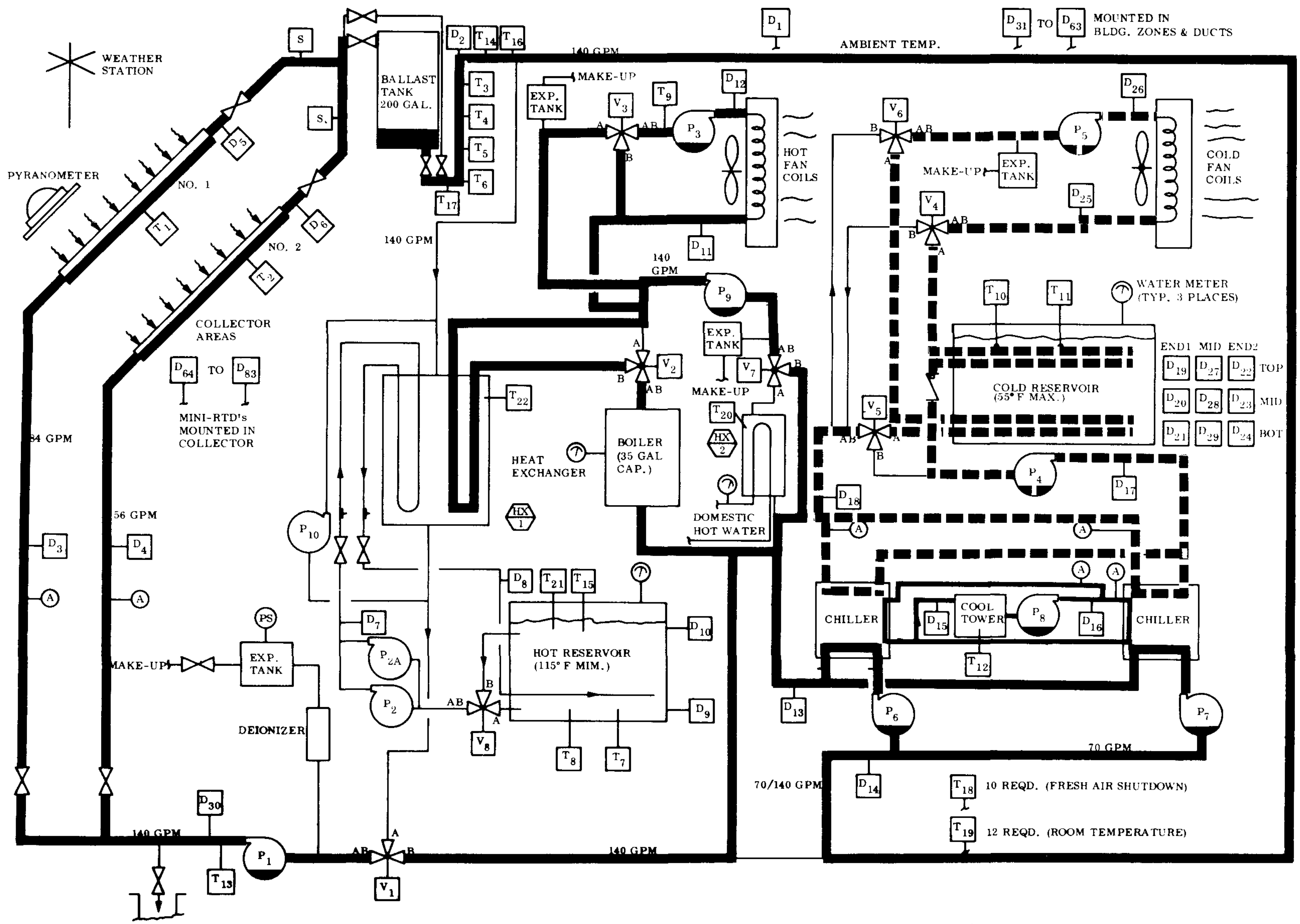

Fig. 4-14 High Solar Mode HS-7: Cold Storage, Heating and DHW From Solar; Cooling From Cold Reservoir

Table 4-5

MATRIX OF SYSTEM AUTOMATIC, STEADY-STATE OPERATING MODES AS A FUNCTION OF ENERGY SOURCE: HIGH SOLAR MODE

ID	Fig.	Energy Destination: Heating	Cooling	Domestic Hot Water	Hot Storage	Cold Storage	Collector	Clock	Condition
HS-1	4-1	S	-	S	-	S		ON	Cold Storage + Heating
HS-2	4-2	S	-	S	S	S		ON	Cold Storage + Heating + Bleed-off
* HS-3	4-3	-	R	S	-	S		ON	Cold Storage + Cooling
HS-4	4-4	-	R	S	-	S		ON	Cold Storage + Cooling with 1 Chiller
* HS-5	4-5	-	R	S	S	S		ON	Cold Storage + Cooling + Bleed-off
* HS-6	4-6	-	R	-	-	S		ON	Cold Storage + Cooling without Domestic Hot Water Demand
HS-7	4-7	S	R	S	-	S		ON	Cold Storage + Heating & Cooling
HS-8	4-8	S	R	S	S	S		ON	Cold Storage + Heating & Cooling + Bleed-off
* HS-9	4-9	-	-	S	S	S		ON	Cold Storage + Bleed-off
HS-10	4-10	-	-	S	S	S		OFF	Cold Storage + Bleed-off
* HS-11	4-11	-	-	S	-	S		ON	Cold Storage + Domestic Hot Water Only
HS-12	4-11	-	-	S	-	S		OFF	Cold Storage + Domestic Hot Water Only
HS-13	4-12	-	-	-	-	S		ON/OFF	Cold Storage Only
HS-14	4-13	-	-	S	S	-		OFF	Dump + Domestic Hot Water Only
* HS-15	4-13	-	-	S	S	-		ON	Dump + Domestic Hot Water Only
HS-16	4-14	S	-	S	S			ON	Dump + Heating
* HS-17	4-15	-	R	S	S	-		ON	Dump + Cooling
HS-18	4-16	S	R	S	S	-		ON	Dump + Heating & Cooling

Notes:
1. Constant demand assumed for domestic hot water except as noted.
2. Notation: S=Solar, R=Reservoir, B=Boiler
3. If P_3 "on" with clock, eliminate modes marked *.
4. The two chillers normally come on and go off in sequence; override switch S_6 permits alternating this sequence.

are: 1. satisfy building heating demand in the absence of adequate direct or stored solar energy. 2. maintain the stored energy level in the cold storage reservoir by supplying firing water to the chillers and 3. meet domestic hot water demand. The boiler is always locked out in the High Solar Mode. The boiler set point is 220°F.

The temperature of the hot water storage reservoir is allowed to swing with supply and demand. Therefore, it is possible that there is insufficient energy in the hot storage reservoir to meet building heating demand. This condition is signaled by sensor T_{21}, which is set to 115°F. When the temperature at the top of the reservoir drops below 115°F, valve V_2 is switched to the A → AB position and the boiler fires to meet building demand. If this event occurs during energy transfer from the reservoir, the action also includes de-energizing pump P_2. The active fluid lines are illustrated in the piping schematic presented in Fig. 4-15.

In general solar energy is adequate in the Low Solar Mode to meet building heating demand, and solar energy has priority in the control system when available. If, however, the energy level in the cold storage reservoir requires replenishing $T_{10} > 55°F$, the boiler will fire to meet this requirement and thereby block the access of direct solar energy to the hot fan coils. Consequently, the boiler will meet any building heating demand that occurs while the boiler is firing. The fluid flows representing this condition are shown in Fig. 4-16. Note that solar energy collected during this operation is stored in the hot storage reservoir.

The domestic hot water demand is, of course, met automatically by the boiler if the boiler is firing to meet the other demands outlined above. However, the boiler does fire solely to meet the domestic hot water demand in the No Solar Mode even if useful energy is available in the hot storage reservoir. This occurs, for example, when the clock is off, i.e., after building occupancy hours, when hot water is needed for cleaning. Firing the boiler is preferred to starting pump P_2 and heat exchanging through HX-1 principally because of the time lag involved in bringing energy from the reservoir to the user, and the relatively small energy demand involved.

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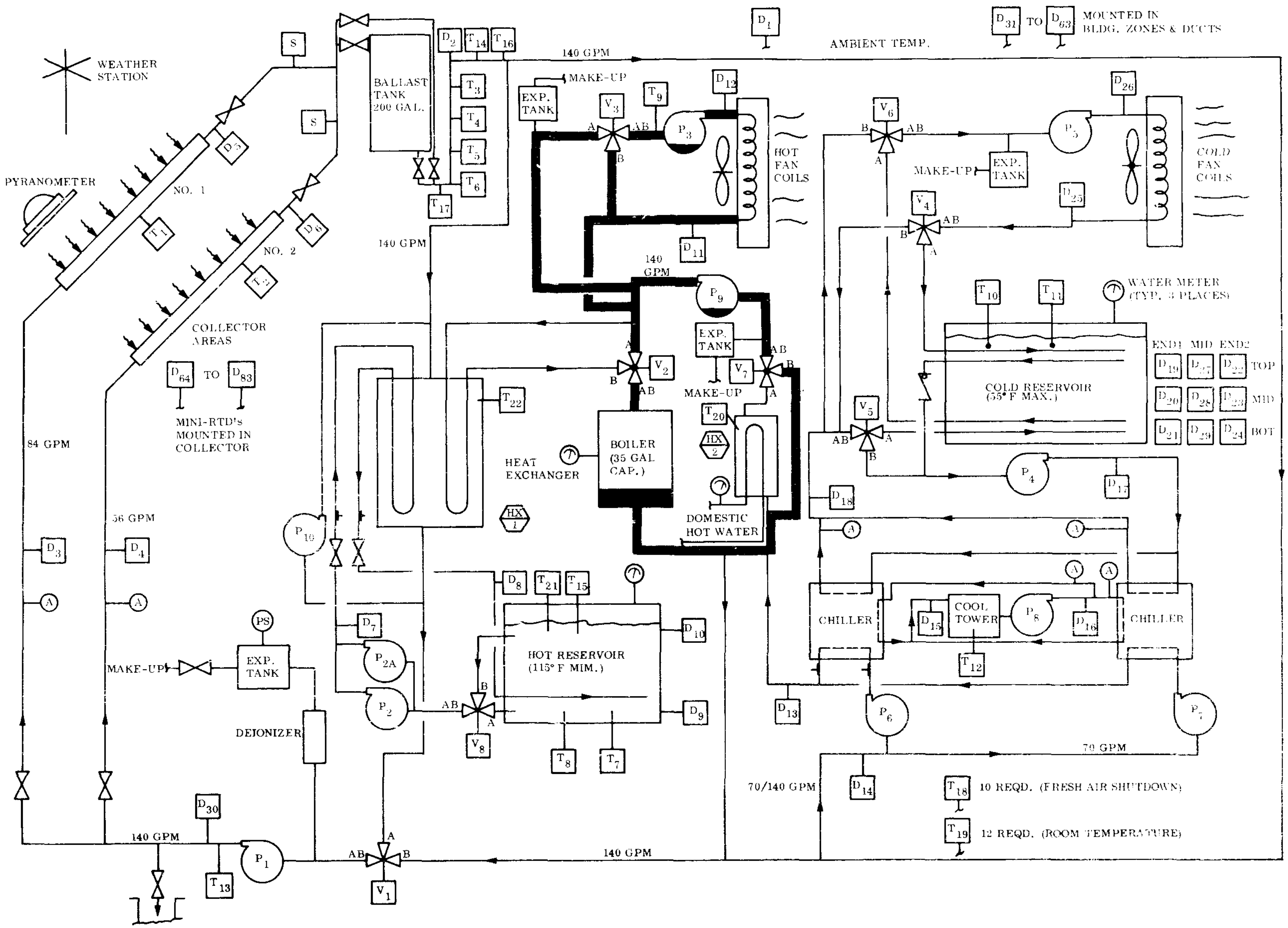

Fig. 4-15 No Solar Mode NS-2a: Heating and DHW From Boiler; No Cooling Required ($T_{21} < 115°$ F)

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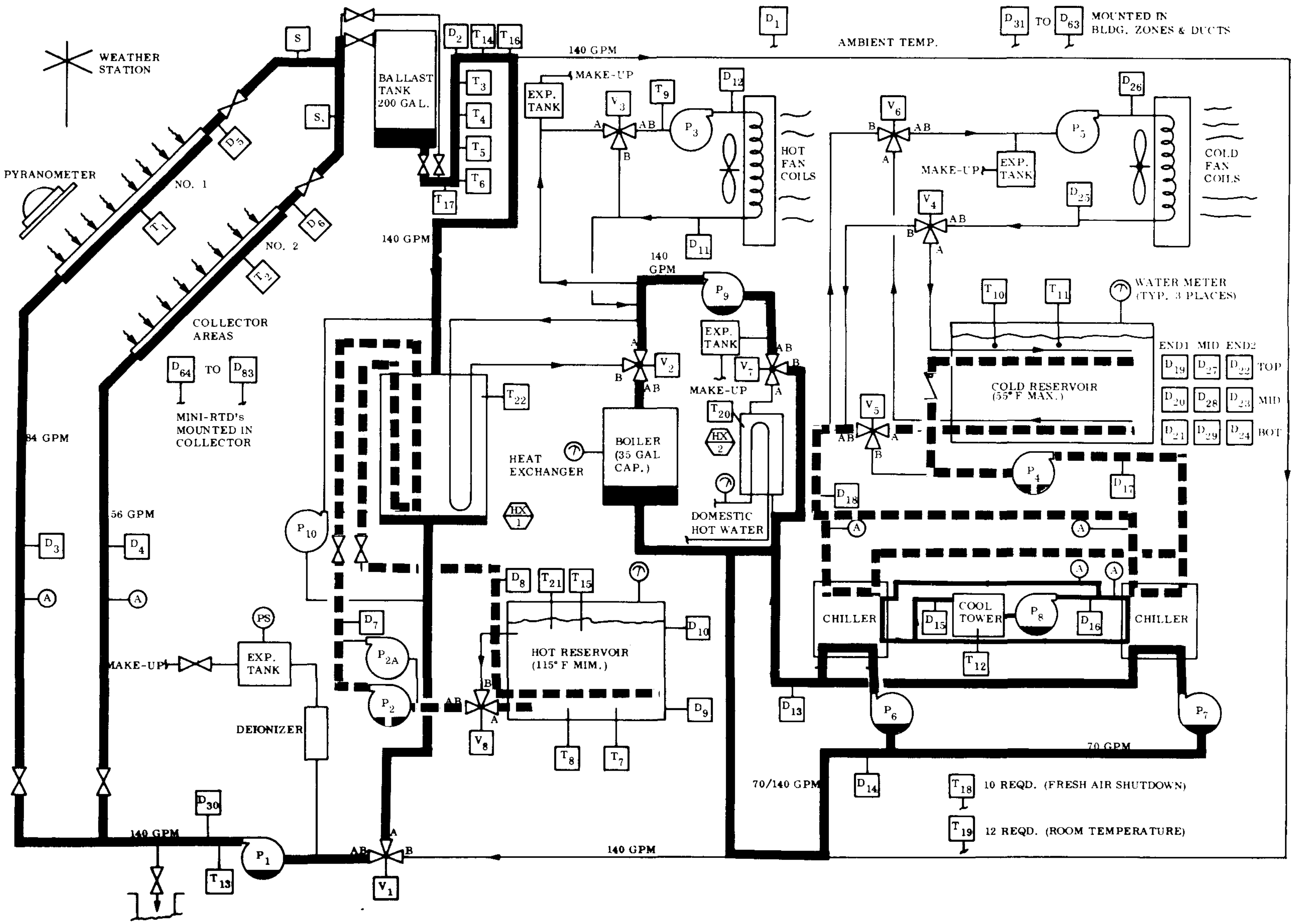

Fig. 4-16 Low Solar Mode LS-10a: Min Spec of Cold Reservoir and DHW From Boiler; Hot Storage From Solar (Clock Off)

Tables 4-3 and 4-4 include a complete matrix of automatic, steady-state operating modes in which the boiler fires during normal operations.

4.2.6 Storage (Reservoir) Control

The control system includes provisions for the maintenance of specified temperature levels in both the hot and cold storage reservoirs (min. spec.). The controls for the maintenance of a hot storage reservoir minimum temperature are optional and are discussed in Section 4.2.8.

Under normal operating conditions, the cold storage reservoir always supplies the building cooling demand. The cold storage reservoir temperature at the top of the tank is controlled by T_{10} to a temperature of 55° F. When the temperature of the fluid at this location exceeds 55° F, the boiler fires the chillers to lower the temperature to the specified level. As noted in the previous section, this can only be done during the No Solar Mode or the Low Solar Mode so that there is no interference with solar energy firing the chillers in the High Solar Mode. This control is assured by locking out the boiler whenever valve V_1 is in the B → AB position.

4.2.7 Domestic Hot Water Heating

The domestic hot water demand is supplied from a tube bundle inside the shell of heat exchanger HX-2. The shell has access to the boiler loop via modulating valve V_7 and this valve is controlled by T_{20}, set to 120° F. The sensor is located in the domestic hot water supply line in the MER, which is part of a recirculating system.

The temperature of the domestic hot water may drift below 120° F under certain conditions. Whenever valve V_2 is in the B → AB position, the boiler is locked out. The valve is in this position when the building heating demand is being met either by the hot storage reservoir or directly by the collector array with the control system in the Low Solar Mode. Under these conditions, valve V_2 remains in the B → AB position as long as the temperature of the fluid in the shell of HX-1 is equal to or greater than

105°F, the set point for T_{22}. The temperature of the fluid in the shell of HX-2, therefore, may drop to 105°F before T_{22} signals the control system to switch valve V_2 to the A → AB position and fire the boiler to meet building heating demand.

4.2.8 Options

The control system permits several options to be selected that deviate from normal, automatic operations. In general, these options permit control system flexibility to modify normal operations as it becomes apparent during the initial use of the solar hardware that changes are desirable from either an energy conservation or economy point of view. The options are controlled by a series of override switches located on the front of the control panel in the MER.

Reverse Heat Exchange Option (S_9)

The purpose of this option is to preheat the collector arrays in the morning in summer, using excess energy stored in the hot-storage reservoir, so that the time of day at which the collector fluid is hot enough to drive the chillers in the High Solar Mode is moved forward; the total operational period of the chillers is thus lengthened each day with solar energy. This option is accomplished with the following controls.

The option is activated by override switch S_9, which has three positions: ON, AUTO and OFF. In the automatic position, operations begin with a timer that starts pump P_1 at a preset time. (Note: Valve V_1 is already in the proper position, A → AB, since this is the shut-down position.) Pump P_1 is allowed to run from 0 to 5 min via a time-delay device to ensure valid temperature readings in the collector fluid loop. The temperature differential between the collector array fluid and the fluid in the top of the hot storage reservoir is then determined via T_{24} and T_{23}, respectively. If $T_{23} - T_{24} \geq \Delta T$ min, heat exchange begins via pump P_2 with valve V_8 in the B → AB position. Heat exchange continues until $T_{23} - T_{24} < \Delta T$ min, or the preset elapsed time on the timer expires. Should $T_{23} - T_{24} < \Delta T$ min initially, no heat exchange takes place. The control is essentially the same when override switch S_9 is in the ON position, except that in this case the timer is bypassed.

Chiller Priority Option (S_6)

Because the solar system will frequently activate a single chiller, it is desirable to be able to designate either chiller 1 or chiller 2 for this service so that cumulative operational time is approximately equal for the two units. Override switch S_6 provides this capability.

Pump P_3 ON Option (S_{10})

Override switch S_{10} provides the control system with the option to energize pump P_3 either with clock on or only with building heating demand.

Cold Reservoir Bypass Option (S_5)

The cold-storage reservoir may be bypassed so that the chillers supply chilled water directly to the cold fan coils. This is accomplished by override switch S_5, and the active piping is as shown typically in Fig. 4-17. The valve positions are:

V_1, V_2	A → AB
V_4, V_5, V_6, V_8	B → AB

The energized pumps are:

$$P_4, P_5, P_6, P_7, P_8, P_9$$

The cold reservoir bypass option can be operated in a number of other modes, which are summarized in Table 4-6.

Cold Reservoir Minimum Specification Option (S_{11} & S_{12})

The cold-storage reservoir minimum specification provisions may be negated in the No Solar Mode or in the Low Solar Mode with override switches S_{11} and S_{12}, respectively. Only one switch should be activated at a time; otherwise, the cold reservoir

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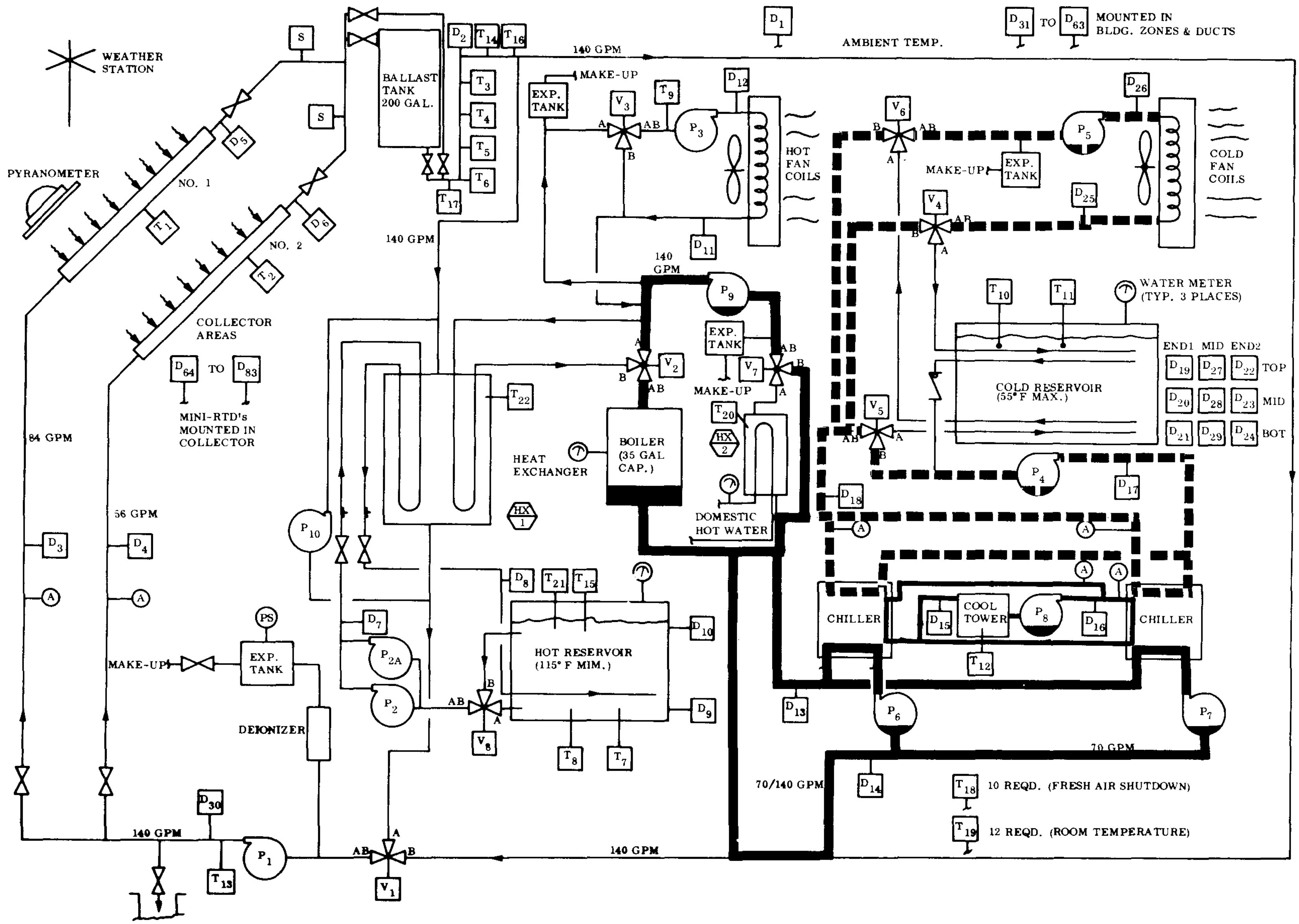

Fig. 4-17 Manual Operation MO-1 (Cold Reservoir By-Pass in No Solar Mode): Cooling and DHW From Boiler; No Heating Required (Override Switch S_5)

Table 4-6

INSTRUCTIONS FOR FILLING THE COLLECTOR WITHOUT SHUTTING DOWN THE SYSTEM (MAKE-UP IN BALLAST TANK)

1. Pump P_1 must be off. Cut power to this pump. (See Section 6).
2. Close gate valve #21 above ballast tank.
3. Close balance cock #55 overhead near ballast tank.
4. Valve V_1 must be in A → AB position; close gate valve #53 as a precaution.
5. Temporarily turn off make-up water supply at ballast tank.
6. Open bleed valve(s) at top of collector array(s).
7. Turn on make-up water supply at ballast tank.
8. As water flows from bleed valve(s) turn off make-up water supply.
9. Close bleed valves.
10. Turn on make-up water supply.
11. Return valves #21, 53, and 55 to original positions. Be sure balance cock #55 is returned to its original setting.
12. Bleed air from bleed valves in the lines that are located either in the MER or elsewhere beneath the roof.
13. Return power to pump P_1.

will not be minimum specified at all and the system will attempt to meet building cooling demand with water from the storage tank that is too warm.

Negating cold-storage-reservoir minimum specifications in the Low Solar Mode removes the possibility that the boiler will fire for minimum specification purposes and thereby block the access of direct solar energy to supply the hot fan coils. This causes all minimum specifications to be performed in the No Solar Mode – which under most conditions is expected to be sufficient time to recharge the reservoir to the specification level, particularly in any season except summer. Minimum specification in only one mode also minimizes short cycling of the chillers to meet minimum-specification requirements.

Hot Reservoir Minimum Specification Option (S_4)

Controls are provided in the system for an option to provide minimum specifications in the hot-storage reservoir to a minimum temperature at the bottom of the tank. The purpose of this option is to provide capability for future need, which might involve the use of natural gas only during off-peak hours, possibly at lower rates.

Override switch S_4 controls this option. Sensor T_8 signals the control system to fire the boiler, switch valve V_2 to the B → AB position, and start pumps P_2, P_9 and P_{10} for heat exchanging through HX-1 whenever the temperature drops below 115°F in the bottom of the hot-storage tank. This action takes place only when the system is in the No Solar Mode.

4.2.9 Automatic Protection Features

The control system and solar hardware incorporate several automatic system protection features. These features prevent a system runaway, thereby preventing possible equipment damage and providing for personnel safety.

Bleed-Off Mode

If the collector arrays supply more solar energy to the system in the High Solar Mode than the chillers can use, the Bleed-Off Mode is automatically implemented to control the temperature of the fluid in the collector loop without interrupting the operation of the chillers. This is done by activating heat exchange to the hot-storage reservoir via the boiler loop and the secondary tube bundle in heat exchanger HX-1.

The control sensor for this mode is T_{16}, which has a set point of 230°F. If the temperature of the fluid exceeds 230°F, the control system switches (or verifies) valve V_2 in the B — AB position and valve V_8 in the A — AB position, and energizes/verifies pumps P_{2A}, P_9, P_{10}. The active system piping is shown typically in Fig. 4-18. Other operational modes involving bleed-off are also possible, as noted in Table 4-5. Pump P_{2A} is activated in this mode, rather than pump P_2, because of the possibility of flashing in the heat exchanger. The Bleed-Off Mode is in effect until the collector fluid loop temperature drops to 230°F.

Dump Mode

There may be situations when the Bleed-Off Mode operation is unable to control the temperature of the fluid in the collector loop in the High Solar Mode. For example, the cold-storage reservoir may be fully charged and the chillers have throttled back or stopped, or the cold reservoir is being bypassed and the chillers have throttled back because of no demand for building cooling. In this event, the Dump Mode is automatically implemented and all solar energy is diverted to heat exchanger HX-1 for storage or release in the hot-storage tank.

The control sensor for the Dump Mode is T_{17}, which has a set point of 240°F. Should the temperature of the fluid exceed 240°F, the control system calls for (or verifies) shutdown of the chillers and associated pumps and valves, switches valve V_1 to the A — AB position, and verifies valve V_8 in the A — AB position. Pump P_{2A} is energized, and heat exchange to the hot storage reservoir begins. The system remains

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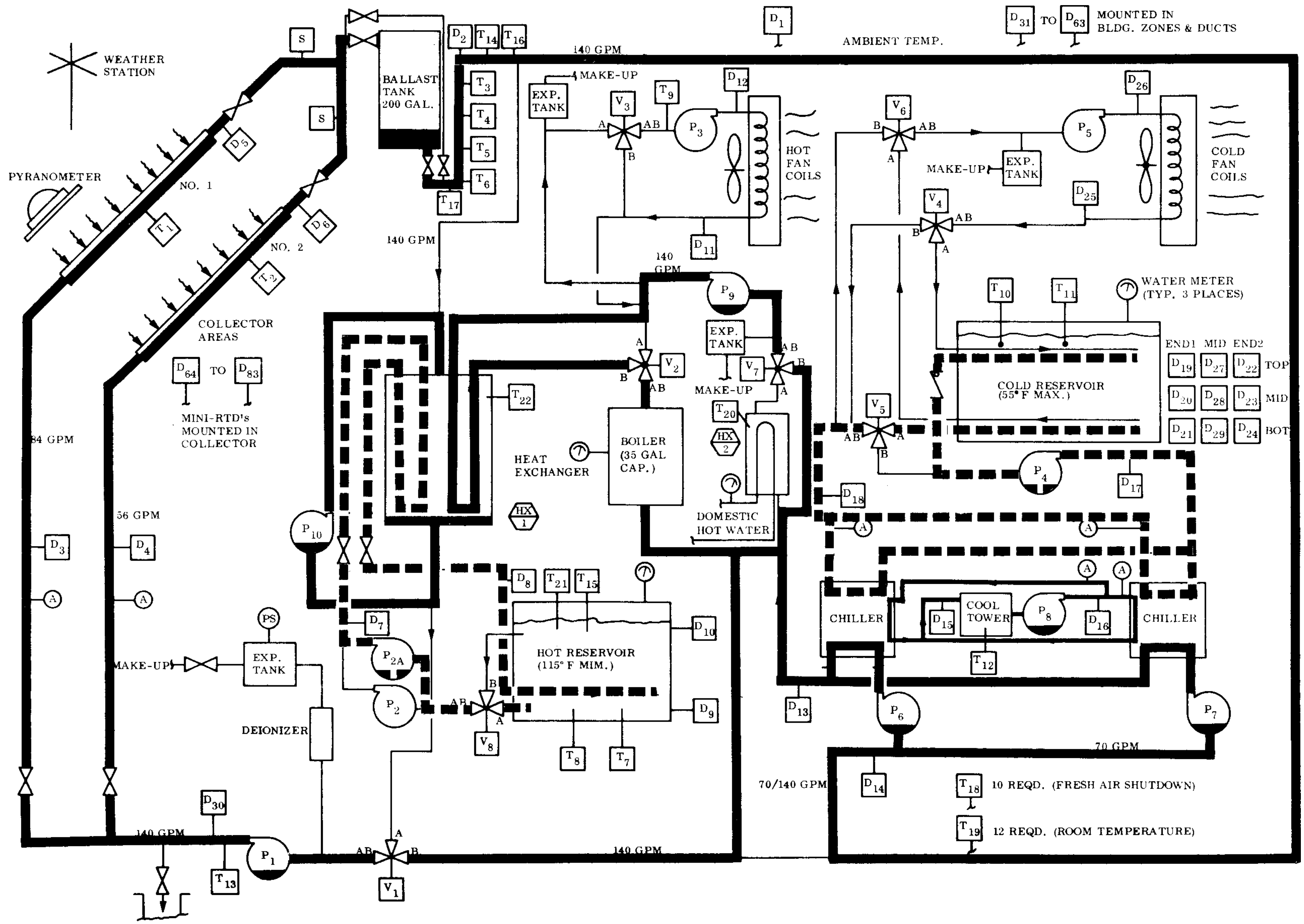

Fig. 4-18 High Solar Mode HS-9: Cold Storage and DHW From Solar; Hot Storage From Solar Via Bleed-Off; No Heating or Cooling Required

in this mode until the temperature in the collector fluid loop drops to 240°F. At this point, valve V_1 is switched to the B → AB position and Bleed-Off Mode Operations resume, provided that the system is still in the High Solar Mode. The active piping for this mode is shown typically in Fig. 4-19. Other operational modes involving dump are also possible as noted in Table 4-5.

Pump P_2 Protection

The effects of the Bleed-Off Mode and Dump Mode may be to leave the fluid in the hot-storage reservoir at or very near its boiling point. Consequently when system control returns to normal operations, there is a possibility that pump P_2 may cavitate on the suction side. To prevent this occurrence, the fluid temperature at the top of the tank is sensed; if it is equal to or greater than 210°F, T_{15} signals the control system to energize pump P_{2A} rather than pump P_2 for all operations involving heat exchange either to or from the tank. Control returns to pump P_2 when the temperature falls below 210°F.

Safety Valves

Safety valves are located in both collector arrays to relieve system pressure if the Bleed-Off and Dump Modes are unsuccessful in controlling the temperature of the fluid in the collector loop. Nominal system pressure is 20 psig, and the equivalent steam temperature is approximately 260°F. The safety valves open automatically when the system pressure is 30 psig, and the equivalent steam temperature is approximately 275°F. The safety valves are located in the outlet headers to each array. When the safety valves open, the system pressure switch senses loss of pressure and immediately shuts down electricity to the system. The collector loop must then be refilled, the safety valves reset, and the system restarted.

Pressure Switch

A pressure switch is located in the collector loop expansion tank which automatically turns off electrical power to the system if the system pressure falls to 17 psi. This

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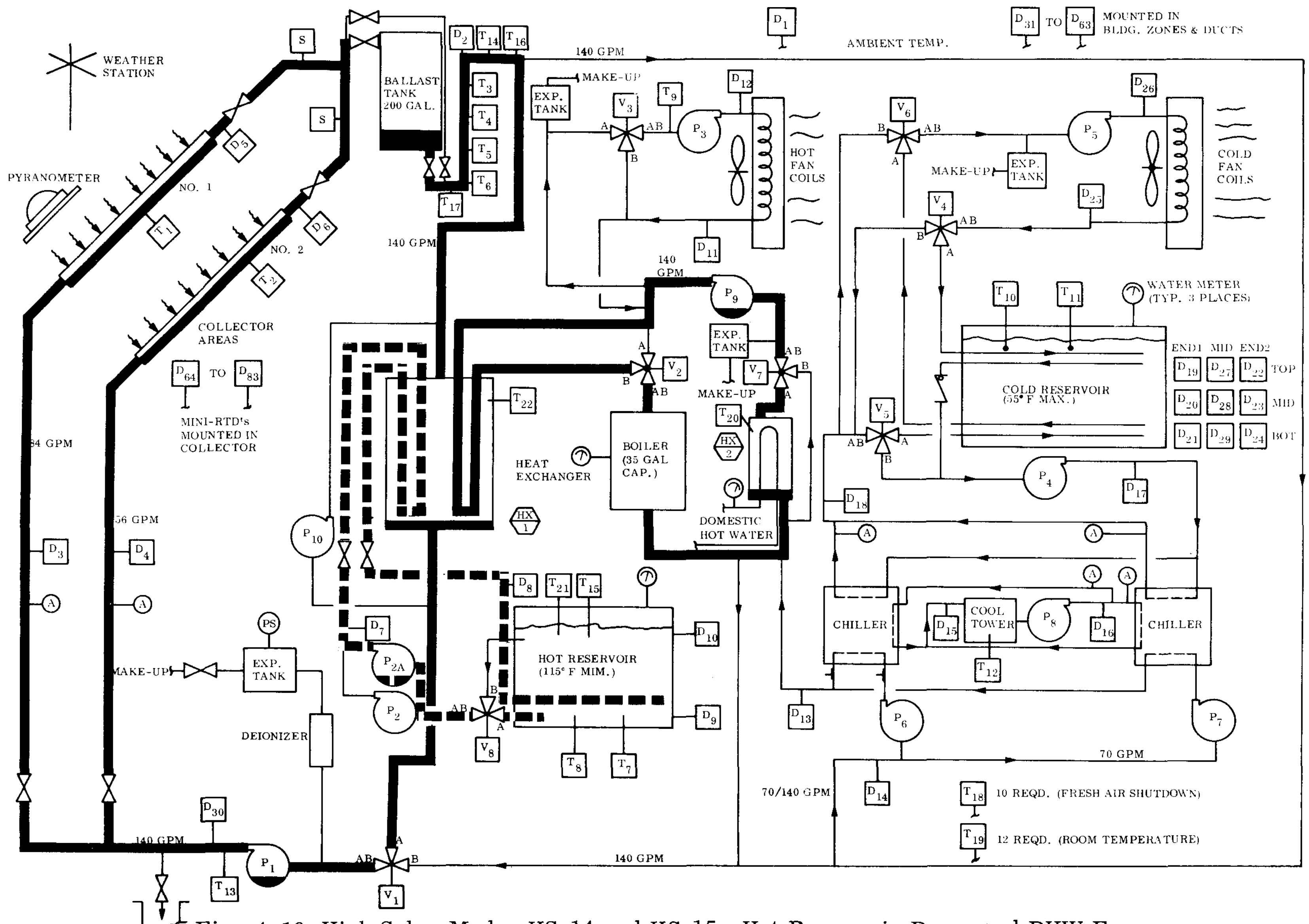

Fig. 4-19 High Solar Modes HS-14 and HS-15: Hot Reservoir Dump and DHW From Solar; No Heating or Cooling Demand (Clock On: Mode HS-15; Clock Off: Mode HS-14)

event could occur in conjunction with the opening of the safety valves, as noted above, or with the development of a leak in the system piping. Restart is manual.

Expansion Tanks

Expansion tanks are specified in the various fluid loops within the system to automatically account for fluid expansion. This, of course, is conventional practice not unique to the solar energy system. However, because of the possible wide swing of temperatures in the collector fluid loop, the expansion tank required is relatively large.

Freeze Protection

The collector fluid loop has a 10-percent concentration of prophylene glycol to reduce the freezing point of the fluid to approximately 25° F. This is slightly below the lowest temperature ever recorded in the Santa Clara Valley. In the event of anticipated lower temperatures, the collector fluid loop may be manually opened to the drain that has been provided, or, alternately, the reverse heat exchange option may be activated by resetting the clock.

Protection of Domestic Hot Water Supply

The prophylene glycol noted under freeze protection has been specially selected for this system because of its nontoxic properties. In the event of leakage in the tube bundle in heat exchanger HX-2, which serves the domestic hot water demand, the 10-percent prophylene glycol concentration will not contaminate the domestic hot water supply.

The control valve for HX-2, valve V_7, also has features for system protection. If this valve fails, a spring return automatically closes the valve and prevents superheating of the domestic hot water supply.

Chiller Time Delays

The control system includes automatic 3-min minimum time delays for each of the two 25-ton chillers before their pumps (P_6 and P_7) are turned off. This arrangement minimizes "short-cycling" the chiller units whenever there are intermittent solar conditions caused by clouds that cannot be absorbed by the ballast tank.

Deionizer

A Cartridge-type deionizer is provided in the collector fluid loop to automatically neutralize make-up water to the system.

Interlocks

Interlocks as discussed in previous sections are provided in the control system to prevent the boiler from firing when solar energy is available. The interlock prevents excess fluid temperatures, which can result when the two energy sources are added together.

System Drain-Down Protection

The control system provides for automatically shutting down valves V_4, V_5 and V_6 in the B $\rightarrow$ AB position when the chilled water system is not in operation in order to avoid drain-down on the suction side of pump P_5. A solenoid valve simultaneously opens to city water pressure (reduced to 12 psi by a pressure-reduction valve) to overcome pressure losses through pump and valve seals.

4.2.10 Manual System Protection Features

The principal manual system protection feature in the solar energy system is hot-storage-reservoir bypass. Bypass of the hot-storage reservoir is prohibited during normal operations because the reservoir acts as a sump for excess solar energy;

without this sump the collector fluid loop temperatures cannot be controlled and the safety valves are activated (in the High Solar Mode).

If it is necessary to bypass the hot-storage reservoir, fittings have been provided across the lines to the primary tube bundle in heat exchanger HX-1 so that the reservoir can be manually isolated and city water may be pumped through the tube bundle to drain. The process must be manually supervised during the time that it is activated.

4.2.11 Corrective Actions

If the automatic system controls fail to function, the collector array may be protected by manually operating the system in the following manner:

- Put the system in the manual No Solar Mode by override switch S_8.
- Turn pump P_1 on by override switch S_1.
- Turn pump P_{2A} on by override switch S_7. If this pump fails to come on, throw S_7 back to its original position and turn pump P_2 on by override switch S_3.
- Check to see that valve V_1 is in the A → AB position.

This procedure sends all solar energy to the hot reservoir, thereby ensuring that the temperatures in the arrays do not rise to levels high enough to open the safety valves.

It should be noted that power switches for the pumps are between the Control Panel and the pumps. Therefore, the Control Panel may be indicating that a pump is on, but the power switch may in fact be off. Power switches should be checked when investigating system malfunctions related to flows. Locations of the power switches appear in Section 6 of this Manual. Conversely, if the controls malfunction to keep a pump running when it should be off, the power switches can be thrown to deenergize the pump.

If the total system requires deenergizing, the power switch shown in Fig. 4-4 can be thrown. This stops everything in the building. It should not be thrown during sunny periods except for very short times, in order to keep temperatures in the arrays under control.

4.3 MANUAL MODES OF OPERATION

4.3.1 General

Options have been designed into the system for both safety and maintenance. For example, if the storage reservoirs require maintenance, a means is provided for operating the system in a reservoir bypass mode. This necessity is brought about by the fact that the solar collectors continue to collect solar energy when the sun is shining regardless of the status of the reservoirs, and this energy cannot be left to accumulate in the collectors for fear of damage and/or events leading to system down-time. Definitions of the optional modes that may be selected by manually throwing switches in the system control panel located in the Mechanical Equipment Room (MER) are presented in Section 4.3.2.

The solar-powered heating and cooling system is an assemblage of components that carry and direct the sun's energy to its point of usage or storage. Each of these components is subject to malfunction or failure. Failure analyses are presented in Section 4.4. The principal aim of this section is to define the critical components, that is, components whose failure results in a hazardous situation with possible damage to the system. The override switches mounted in the system control panel in the MER control the options discussed previously and also permit corrective action in certain operating situations. However, some switch positions are hazardous and should be avoided when the system is operating in the High Solar Mode. The switch positions and their effect on system operation are discussed in Section 4.5.

Valve shut-down positions are discussed in Section 4.6.

4.3.2 Mode Descriptions

The term manual operations is used here to denote other-than-normal operations that are initiated by manually throwing selected override switches in the system control panel located in the MER. Once the switch has been moved, the system in most cases operates automatically in the new mode until the switch is returned to its original position.

The majority of the override switches do not involve any significant changes in flow patterns in the system; these switch positions are analyzed in Section 4.5. The present section deals only with single positions on three override switches that do involve major changes in flow pattern. They are:

- Switch S_5: cold reservoir, bypass position
- Switch S_4: hot reservoir, bypass position
- Switch S_9: reverse heat exchange, on position

Switch S_5 in the bypass position isolates the cold-storage reservoir from the rest of the solar-powered heating and cooling system. There are no safety problems when the reservoir has been bypassed, and the system may operate in any of the three major modes. However, since the cold reservoir is unavailable as an energy source to meet building cooling demand, this demand must always be met by the boiler in the No Solar and Low Solar Modes, and by solar in the High Solar Mode. The various combinations of these two energy sources for satisfying building cooling demand and the energy destinations that are permissible under the system controls are given in Table 4-6, modes MO-1 through MO-10. Mode diagrams for these combinations are presented in Figs. 4-17 and Figs. 4-20 through 4-28.

The likelihood of dump in the High Solar Mode is much greater when the cold reservoir is bypassed, because the building cooling demand may be significantly less than the capacity of the two chillers. Thus, solar energy may be mismanaged if not wasted. Likewise, the two chillers are not adequate to cool the building if the design cooling conditions occur. In this event, building temperatures cannot be maintained at the zone set points, and discomfort may result.

Switch S_4 in the bypass position isolates the hot-storage reservoir from the rest of the system. This event involves safety procedures to protect the system – and these must be strictly followed. The switch should never be in this position while the system is in the High Solar Mode unless city water has been connected to one of the hot reservoir lines leading to heat exchanger HX-1 and a hose to drain connected across the other line.

SANTA CLARA SOLAR PROJECT

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

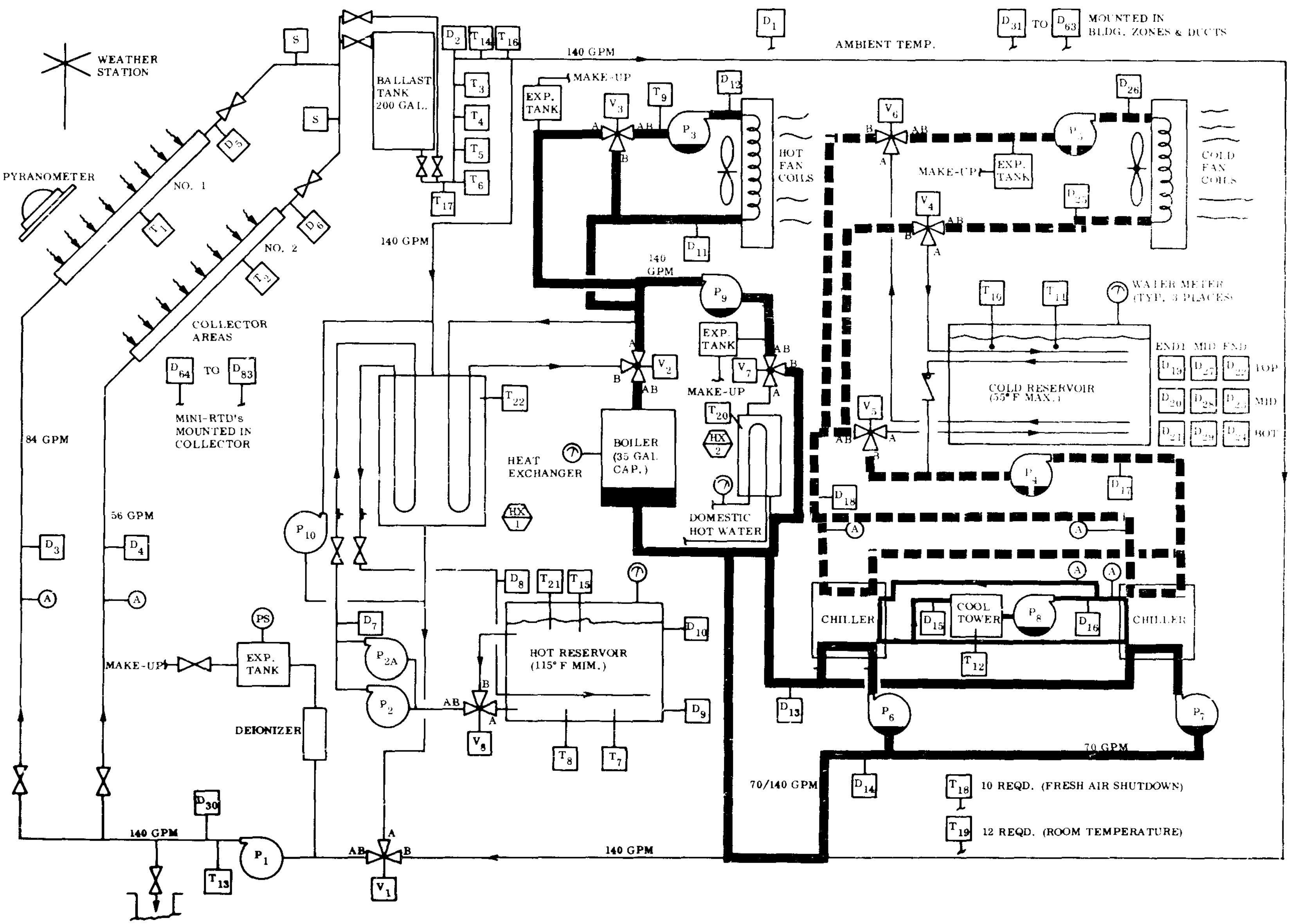

Fig. 4-20 Manual Operation MO-2 (Cold Reservoir By-Pass in No Solar Mode): Cooling, Heating and DHW From Boiler (Override Switch S_5)

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

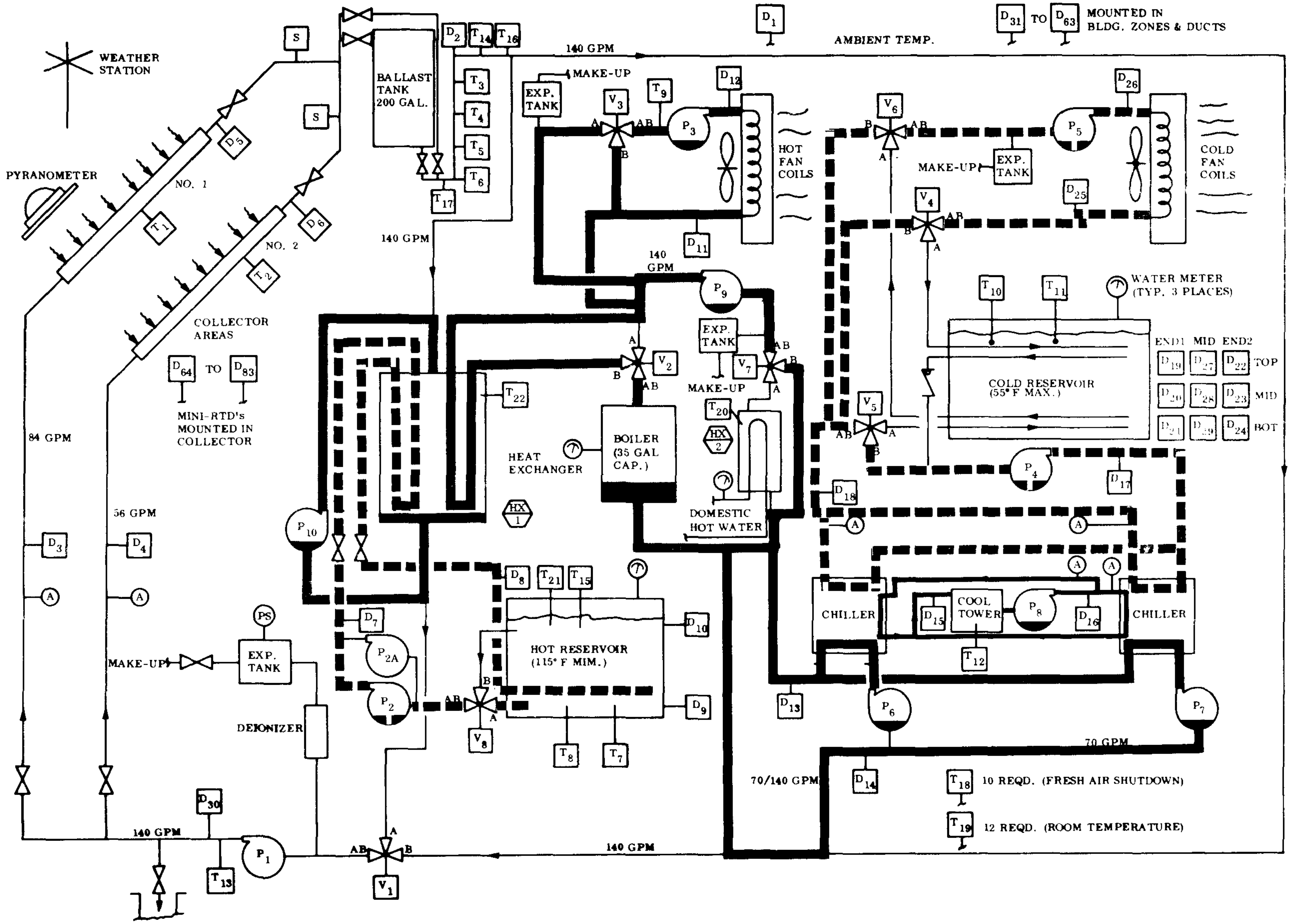

Fig. 4-21 Manual Operation MO-3 (Cold Reservoir By-Pass in No Solar Mode): Cooling, Heating, DHW and Optional Min Spec of Hot Reservoir From Boiler (Override Switch S_5)

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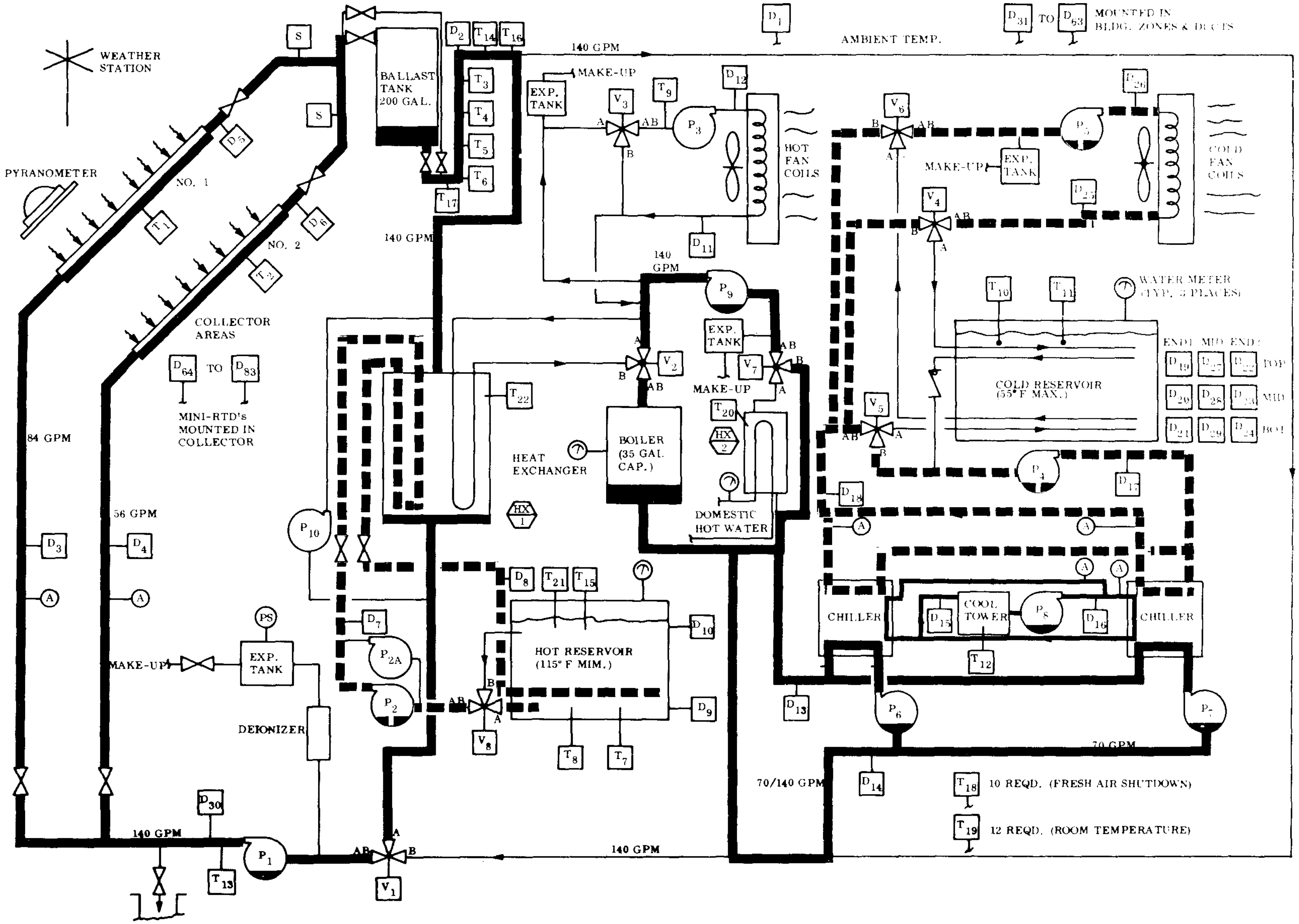

Fig. 4-22 Manual Operation MO-4 (Cold Reservoir By-Pass in Low Solar Mode): Cooling and DHW From Boiler; Hot Storage From Solar; No Heating Required (Override Switch S_5)

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

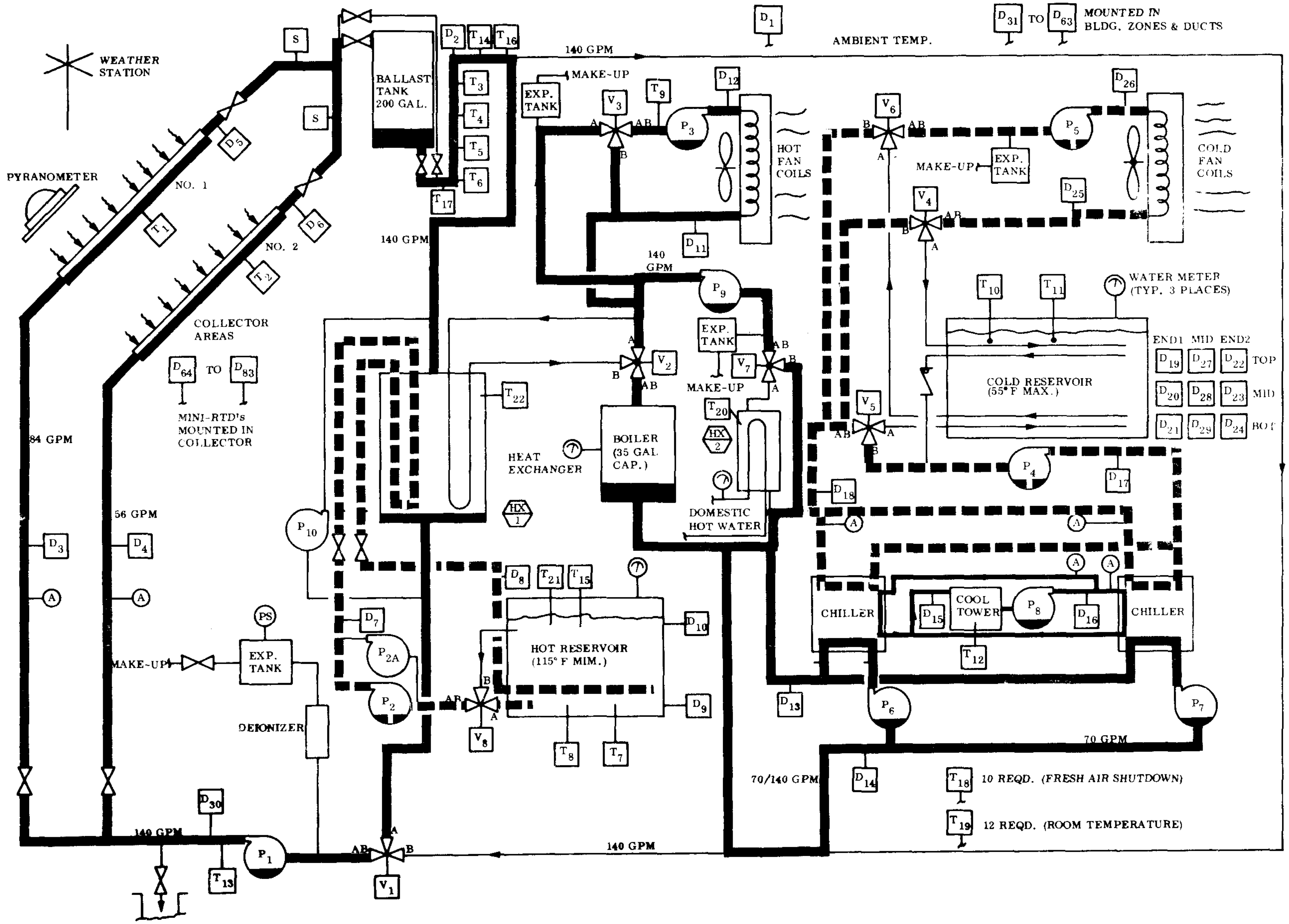

Fig. 4-23 Manual Operation MO-5 (Cold Reservoir By-Pass in Low Solar Mode): Cooling, Heating and DHW From Boiler; Hot Storage From Solar (Override Switch S_5)

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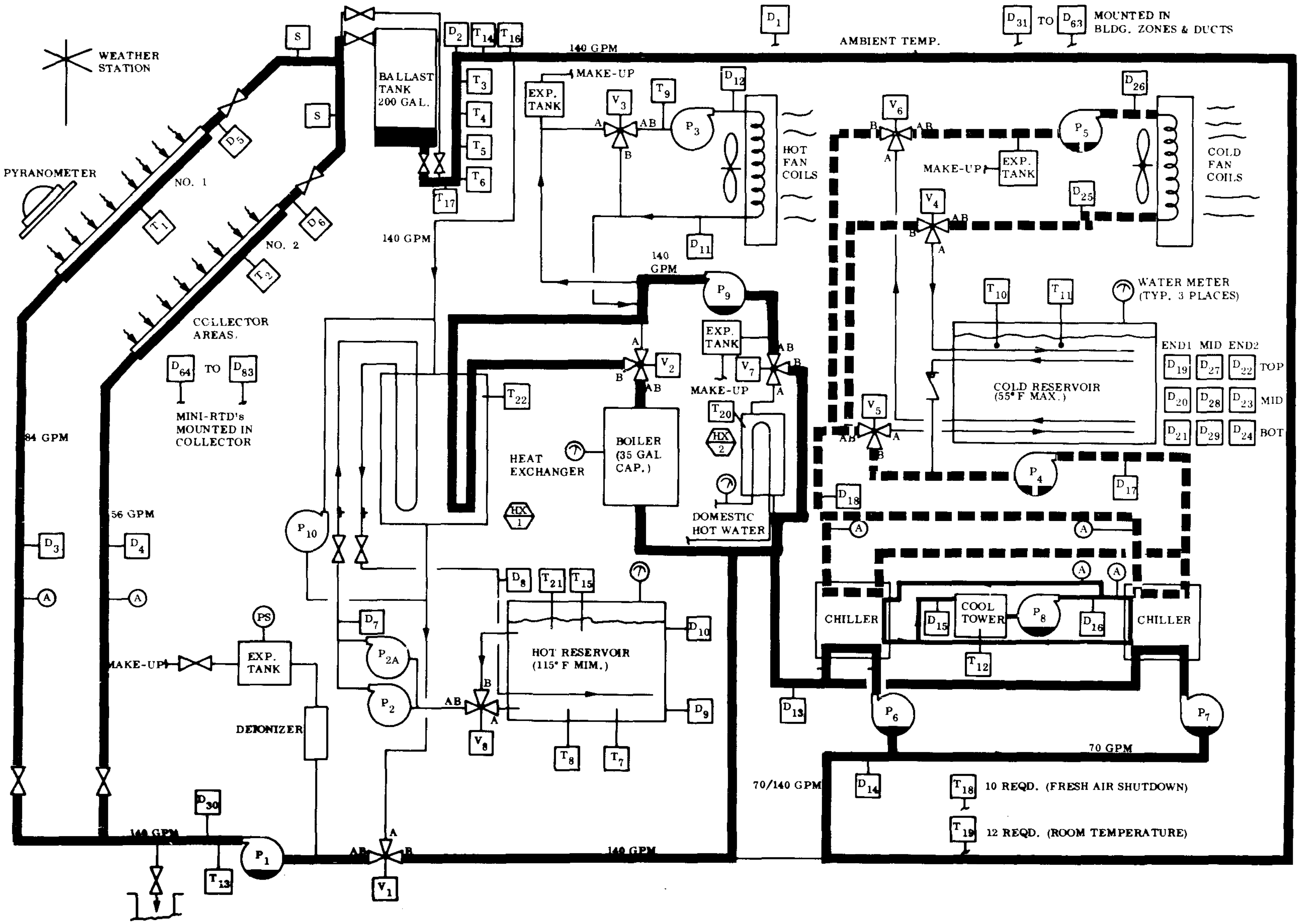

Fig. 4-24 Manual Operation MO-6 (Cold Reservoir By-Pass in High Solar Mode): Cooling and DHW From Solar; No Heating Required (Override Switch S_5)

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

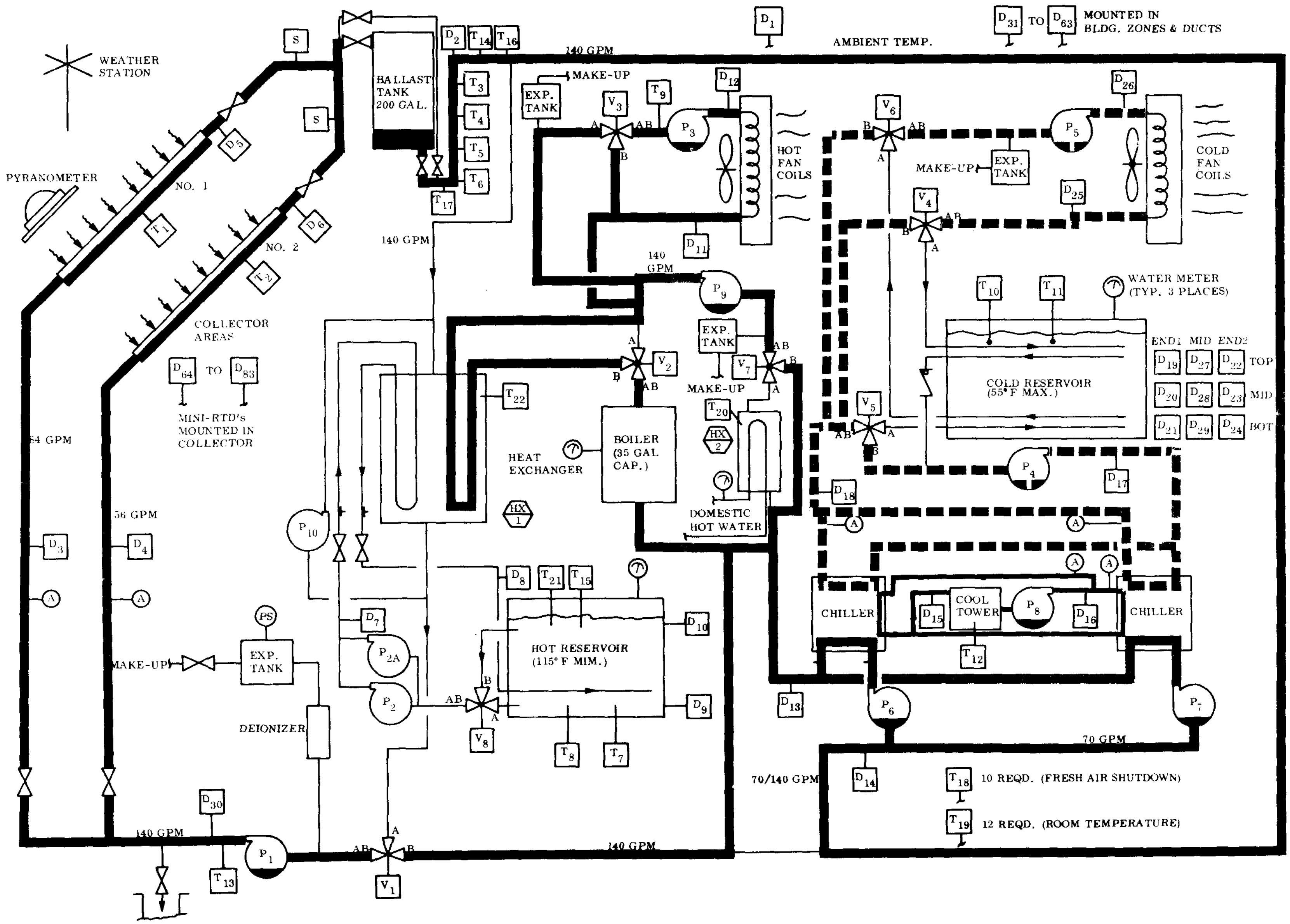

Fig. 4-25 Manual Operation MO-7 (Cold Reservoir By-Pass in High Solar Mode): Cooling, DHW and Heating From Solar (Override Switch S_5)

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

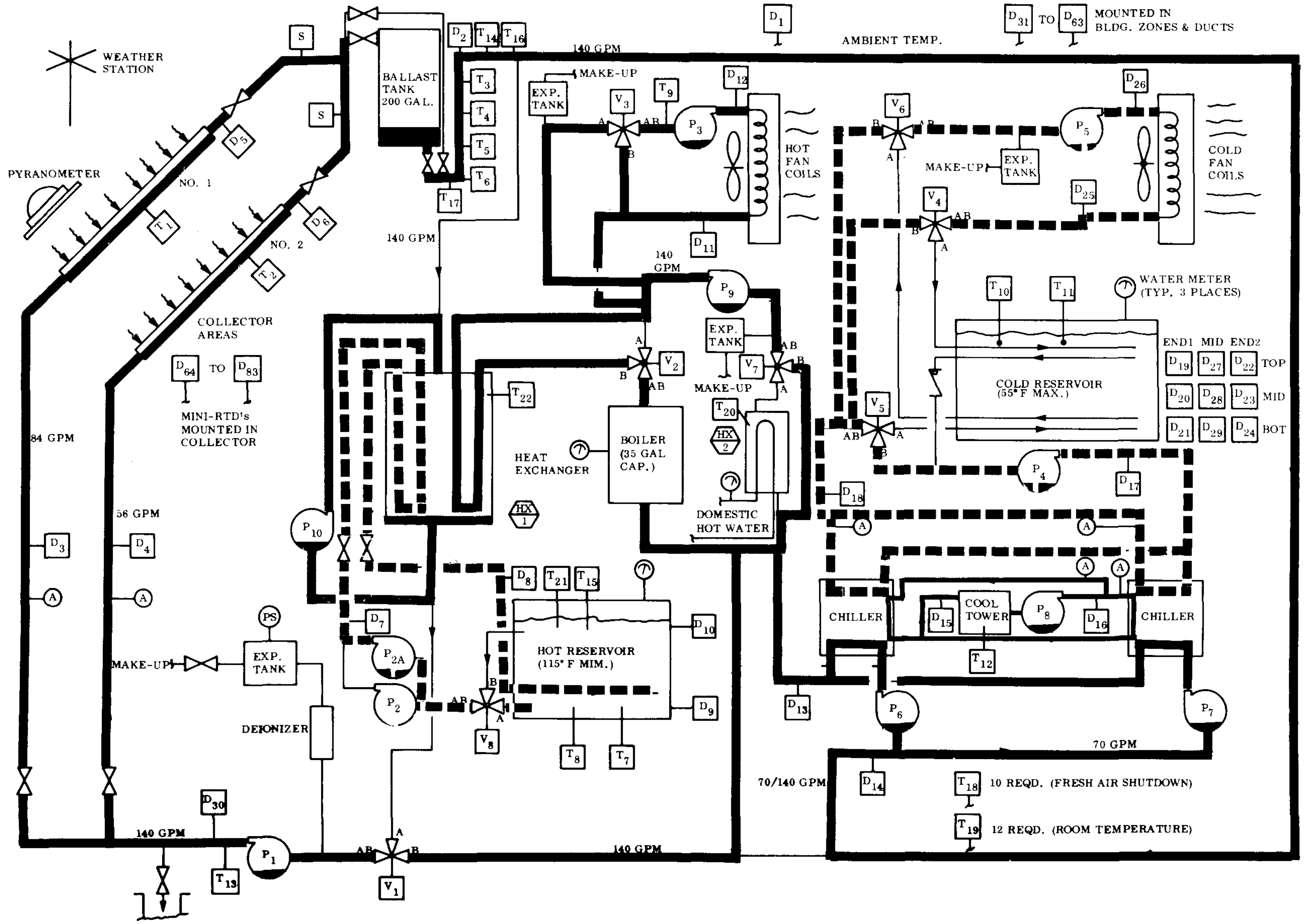

Fig. 4-26 Manual Operation MO-8 (Cold Reservoir By-Pass in High Solar Mode): Cooling, Heating and DHW From Solar; Hot Storage From Solar Via Bleed-Off (Override Switch S_5)

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PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

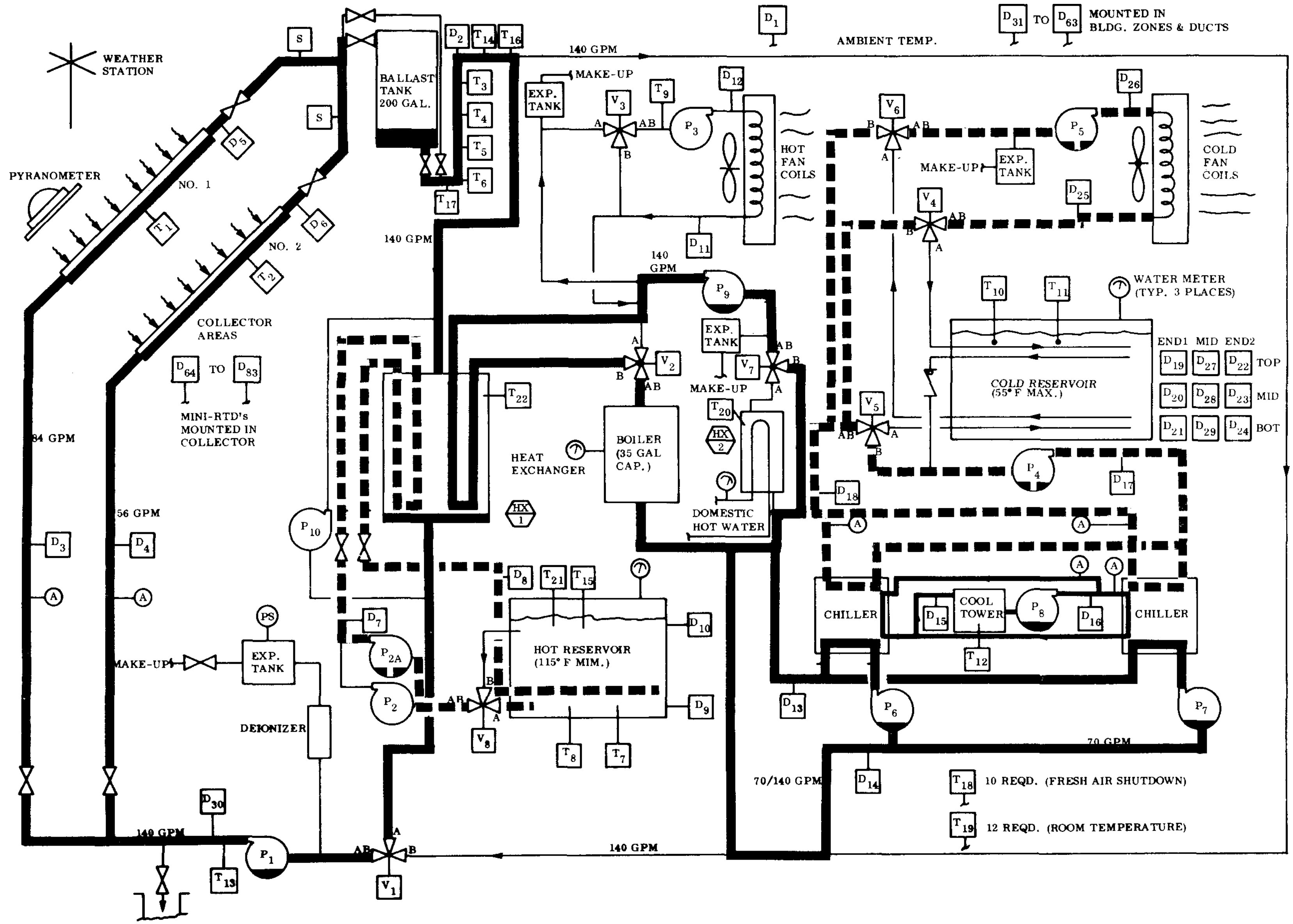

Fig. 4-27 Manual Operation MO-9 (Cold Reservoir By-Pass in High Solar Dump Mode): Cooling, DHW and Hot Storage From Solar; No Heating Required (Override Switch S_5)

SANTA CLARA SOLAR PROJECT

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

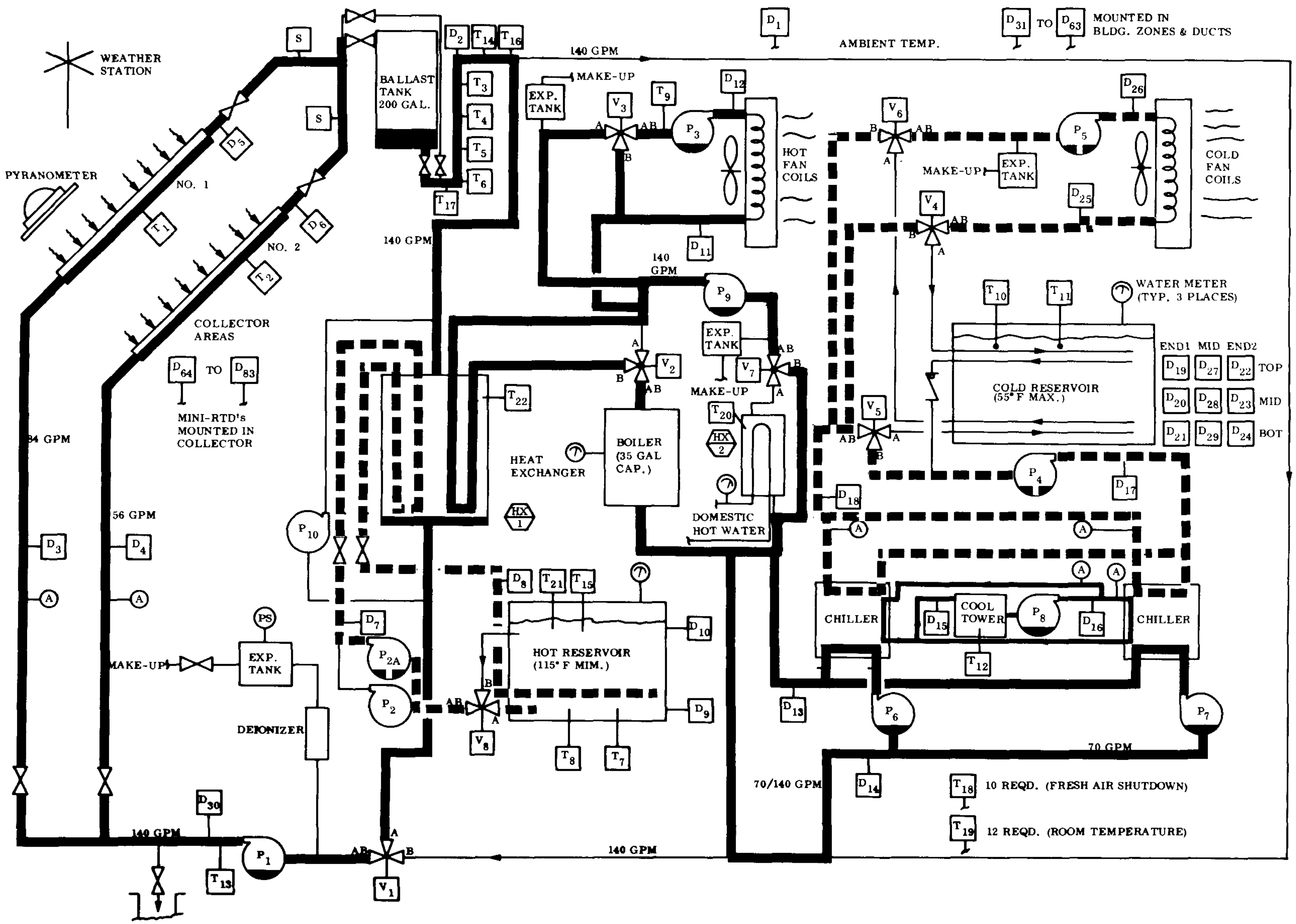

Fig. 4-28 Manual Operation MO-10 (Cold Reservoir By-Pass in High Solar Dump Mode): Cooling, Heating, DHW and Hot Storage From Solar (Override Switch S_5)

The gate valves in the hot reservoir lines between these connections and the reservoir must be closed and a minimum flow of 50 gpm maintained whenever a heat exchange sequence to the hot reservoir is attempted.

Failure to take these steps results in the inability of the system to relieve itself of excess solar energy; the collector fluid loop temperatures rise until the safety valves on the roof are activated. The system pressure is relieved, and the pressure switch shuts off power to the system. The safety valves vent high pressure (high-temperature steam) and the collector absorber plates are subject to damage by the high temperatures possible if the plates boil dry. Refill of the system is later necessary. The mode diagram for this mode, MO-11 (Fig. 4-29) illustrates only the hookup; this should be superimposed upon any High Solar Mode involving heat exchange to the hot reservoir.

Switch S_9 in the on position initiates reverse heat exchange from the hot reservoir to the collector. As noted in Section 7.2, this event is intended specifically for experimentation and it should be activated by engineering personnel. The on position is effective in the No Solar and Low Solar Modes when the condition $T_{23} - T_{24} \geq \Delta T_{min}$ has been met. Inasmuch as a readout from control sensors is not available, this condition may be replaced by the condition $D_9 - D_2 \geq \Delta T_{min}$, where D_9 and D_2 may be read at the data center. The same modes listed in Sections 7.2 and 7.3 for automatic operation of this event (modes NS-1b through NS-18b, total of eleven modes; and modes LS-1c through LS-10c, total of ten modes) are possible for manual operation. The mode diagram for this mode, MO-12 (Fig. 5-12) illustrates only reverse heat exchange from the hot reservoir to the collector; Figs. 4-29 and 4-30 contain complete information.

As in previous tables, the asterisks in Table 4-6 indicate modes that can be eliminated if pump P_3 is always on with the clock.

SANTA CLARA SOLAR PROJECT

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

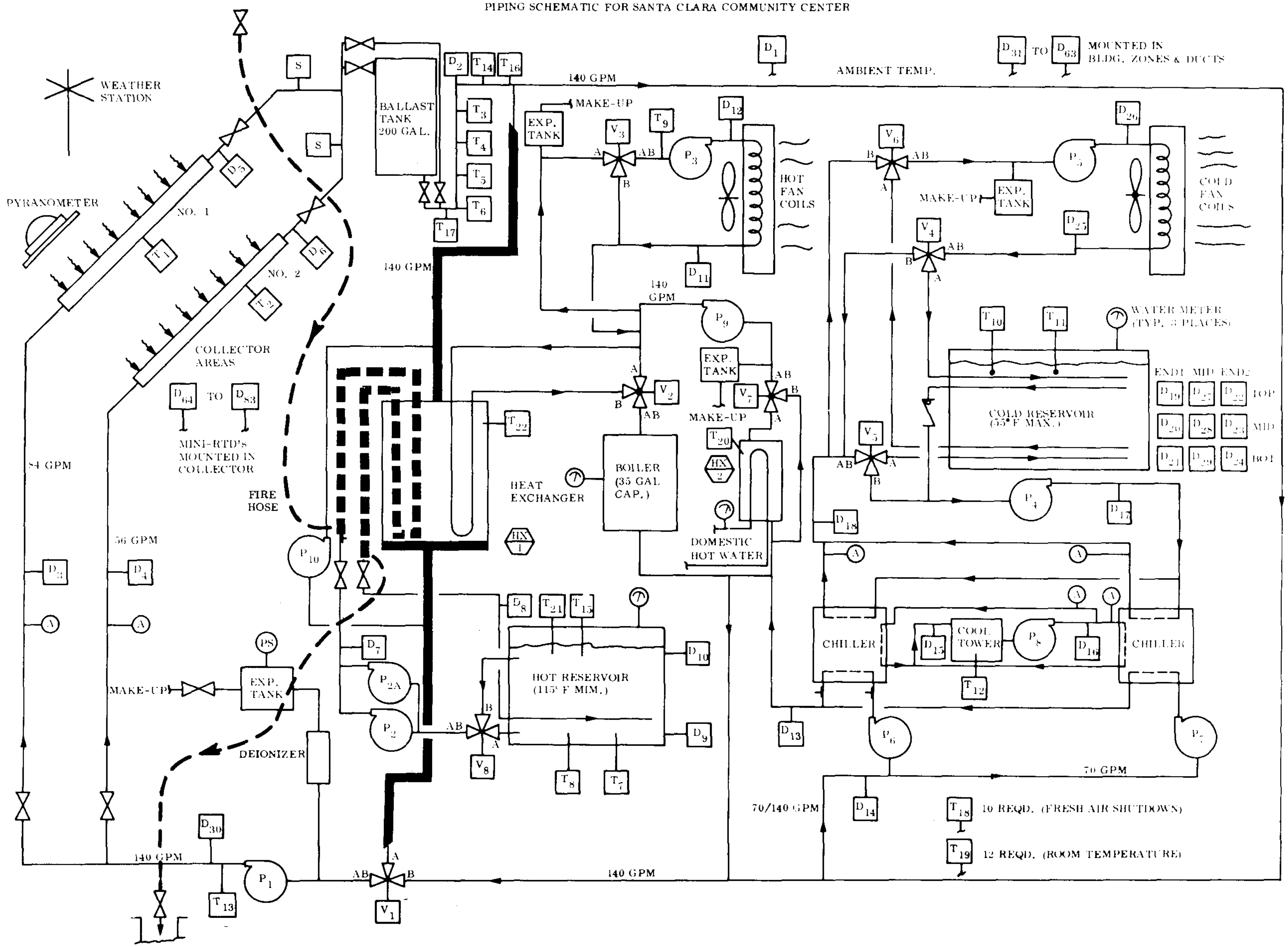

Fig. 4-29 Manual Operation MO-11 (Hot Reservoir By-Pass): City Water @ 50 gpm Min "On" During Any Heat Exchange to Hot Reservoir in High Solar Mode; Dump to Sewer; Pumps P_2, P_{2A} and P_{10} Off for All Modes (Override Switch S_4)

PIPING SCHEMATIC FOR SANTA CLARA COMMUNITY CENTER

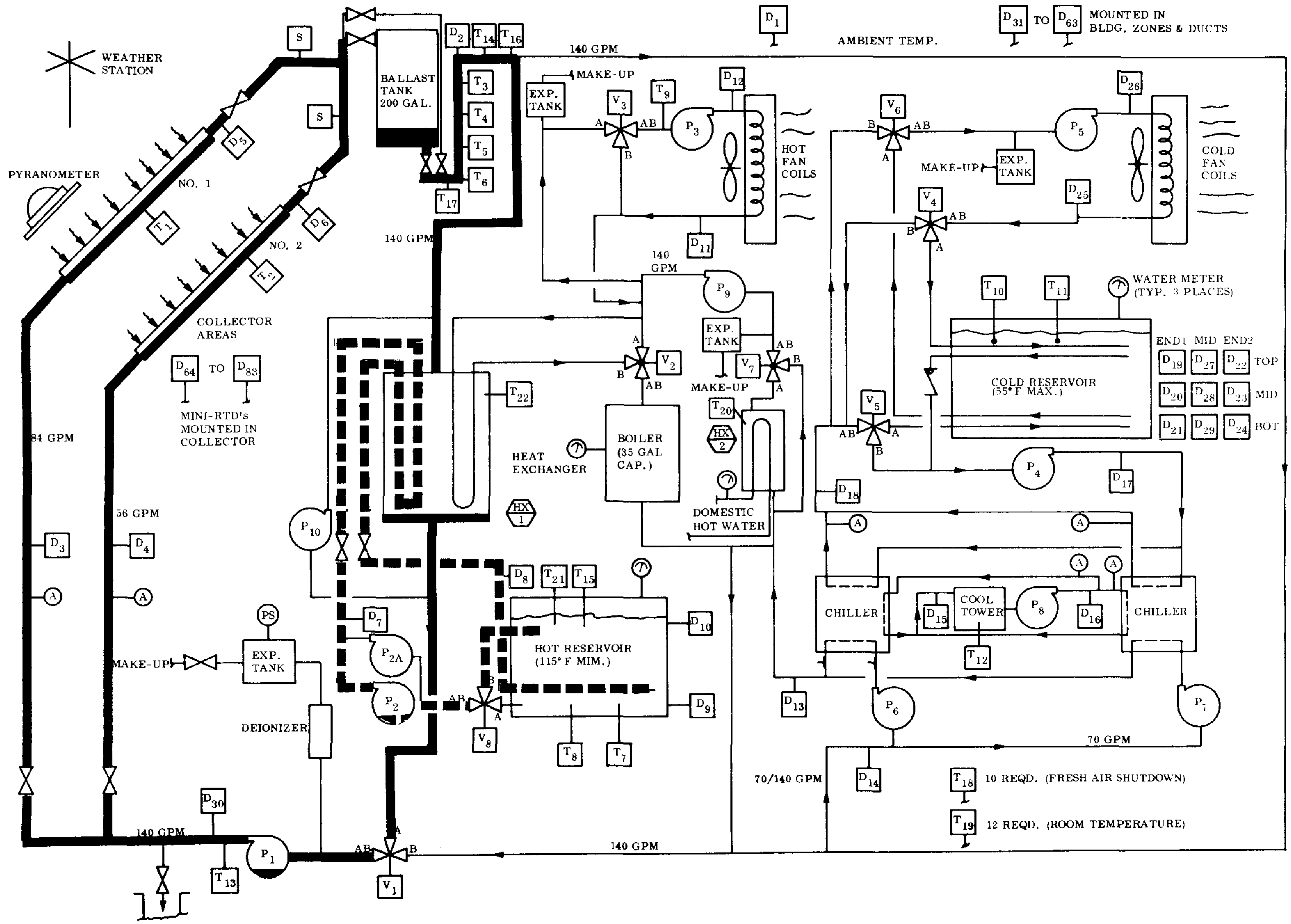

Fig. 4-30 Manual Operation MO-12 (Preheating of Collectors): Only in No Solar and Low Solar Modes When $T_{23} - T_{24} \geq \Delta T_{min}$ and Timer "On" (Override Switch S_9)

4.4 FAILURE ANALYSIS

In this section, the various components of the solar-powered heating and cooling system are evaluated in terms of the effect of their malfunction or failure upon the operation of the system as a whole. Pumps are analyzed in Table 4-7, valves are analyzed in Table 4-8, other equipment is analyzed in Table 4-9, and control sensors are analyzed in Table 4-10. The tables identify the condition and major mode combination (No Solar, Low Solar, or High Solar) that may result in a situation to be avoided because the tolerance of the system will be affected. Recommended corrective procedures to alleviate or avoid hazardous situations are also presented.

A review of the tables shows that malfunction or failure of the majority of components does not affect the safety of the system, but results in energy waste or mismanagement, or discomfort to occupants of the building. Malfunction or failure of the remaining components that can affect the tolerance of the system if corrective measures are not taken may be divided roughly into two groups: for the present discussion, these are called active components and backup components.

The active components are devices activated daily in the operation of the system. In this group are:

- Pump P_1
- Pump P_{2A}
- Valve V_1
- Heat exchanger HX-1
- Temperature control sensor T_{15}
- Temperature control sensor T_{17}

Failure or malfunction of any of these components becomes a problem only in the High Solar Mode, which in general will be reached only during warmer months. The immediate system problem in all cases is overheating in the collector, leading to high pressures and temperatures that activate the system safety valves. This in turn relieves

Table 4-7

FAILURE ANALYSES – PUMPS

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Pump P_1	Stops	No Solar	--	P_1 usually off	None	--
		Low Solar	--	Energy will not be removed from collector	Energy waste	--
		High Solar	Avoid	Collector overheats; safety valves open; system down	Damage to collectors possible; system refill required	Cover collectors with heat barrier
Pump P_2	Stops	Any	--	Heat exchange into or out of tank stops in all except high solar bleed and dump modes	Energy waste	Provide capability with pump P_{2A} by manual control
Pump P_{2A}	Stops	High Solar	Avoid	Dump or bleed to hot tank stops; collector overheats; safety valves open; system down	Damage to collectors possible; system refill required	Pump P_2 no help; go to hot reservoir by-pass mode; connect hoses across HX-1 lines to reservoir, flush heat with City water
Pump P_3	Stops	Any	--	Building cannot be heated	Discomfort	None
Pump P_4	Stops	Any	--	Chilled water output from chillers cannot be moved	Cold reservoir cannot be spec'd.	Shut down chillers
Pump P_5	Stops	Any	--	Building cannot be cooled	Discomfort	None
Pumps P_6, P_7	Stop	Any	--	Firing water input to chillers cannot be moved	Cold reservoir cannot be spec'd.	Shut down chillers
Pump P_8	Stops	Any	--	Condensing water cannot be moved to chillers	Cold reservoir cannot be spec'd.	Shut down chillers
Pump P_9	Stops	Any	--	Pump P_3 cannot be supplied; boiler water cannot be moved	Building cannot be heated; boiler cannot be used; no DHW available	None
Pump P_{10}	Stops	Any	--	Building cannot be heated from reservoir in no solar mode; heat cannot be exchanged in high solar bleed mode	Poor energy management	None

Table 4-8

FAILURE ANALYSES – VALVES

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Valve V_1	Freezes in A→AB	Low Solar	--	Usual position	None	--
		High Solar	--	Energy is dumped to hot reservoir	Poor energy management	--
	Freezes in B→AB	Low Solar	--	Energy exchange to building or hot reservoir is locked out	Energy waste	
		High Solar	Avoid	Cannot go to high solar dump mode; collector overheats; safety valves open; system down; boiler locked out	Damage to collectors possible; system refill req'd; no boiler heat or min. spec.	Cover collectors with heat barrier
Valve V_2	Freezes in A→AB	No Solar	--	Hot reservoir locked out from heating building	Energy waste	--
		Low Solar	--	Building cannot be heated from solar or hot reservoir	Energy waste	--
		High Solar	--	High solar bleed mode cannot function; solar can't heat bldg. during dump	Poor energy management	--
	Freezes in B→AB	No Solar	--	Boiler locked out from heating building; cold res. cannot be min. spec'd. by boiler; building may lack cooling	Discomfort possible	Optional min. spec. of hot reservoir allows boiler "on" with valve in this position
		Low Solar	--	Cold res. cannot be min. spec'd.; building may lack cooling	Discomfort possible	Same as "no solar" notation above
		High Solar	--	Usual position	None	--
Valve V_3	Freezes	Any	--	Modulation to 105°F impaired	Discomfort	--

Table 4-8

FAILURE ANALYSES – VALVES (Cont.)

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Valve V_4	Freezes in A→AB	Any	Marginal	Valve will not provide head against draindown of P_5; building will not be cooled. Valves V_4, V_5 & V_6 must all be in same position; if not, flow balances will be upset	Discomfort; pump P_5 will require priming for restart; system in unidentified mode	Shut down P_5 and chillers until repaired
	Freezes in B→AB	Any	--	Cold reservoir partially by-passed. Valves V_4, V_5 & V_6 must all be in same position to avoid flow imbalances	System may be in unidentified mode	Go to cold reservoir by-pass mode to insure V_4, V_5 & V_6 in same position
Valves V_5, V_6				(See Valve V_4)		
Valve V_7	Freezes	Any	--	Designed to spring to B→AB position in case of failure	No DHW	--
Valve V_8	Freezes in A→AB	No or low solar	--	Hotter water at top of tank inaccessible to heat bldg. or collector	Poor energy management	--
	Freezes in B→AB	Low or High Solar	Marginal	Poor heat exchange into hot reservoir, particularly during high solar bleed and dump modes, and opt. hot reservoir min. spec.	Flashing in heat exchanger a greater possibility	Stand by for hot reservoir by-pass mode if flashing occurs

Table 4-9

FAILURE ANALYSES – EQUIPMENT

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Chiller	Stops	Any	--	Cold res. cannot be cooled	Bldg. may lack cooling	--
Boiler	Stops	Any	--	No auxiliary energy supply	Bldg. may lack heating, cooling & DHW	--
Ballast Tank	Leaks	Any	--	Tank can be isolated; flywheel effect in system absent	Cycling of chillers, modes may occur	--
Hot and/or cold reservoirs	Out of service	Any	--	See "Manual Modes"	--	--
HX-1 heat exchanger	Out of service	No Solar	--	Bldg. heating from hot reservoir prevented; collector pre-heat prevented	Energy waste	--
		Low Solar	--	Heat exchange into hot reservoir or to heat bldg. prevented	Energy waste	--
		High Solar	Avoid	Heat exchange into hot reservoir prevented; collector overheats; safety valves open; system down	Damage to collectors possible; system re-fill required	Cover collectors with heat barrier
HX-2 heat exchanger	Out of service	Any	--	Prophylene Glycol in collector fluid loop is non-toxic in the event of a leak	No DHW	--
Cooling tower	Stops	Any	--	Condensing water from chillers can-not be cooled	Chillers may not be driven; bldg. may lack cooling	Shut down chillers
Pressure switch	Mal-functions tions	Any	Avoid	Loss of system pressure not sensed; system power not cut. Pressure loss may be caused by system leak.	Loss of fluid, possibly very hot; flashing may occur in parts of the system	If leaks are detected and power is on, cut power and cover collectors with heat barrier

Table 4-9

FAILURE ANALYSES – EQUIPMENT (Cont.)

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Expansion Tanks	Mal-function	Any	Avoid	May not control fluid expansion; pressure may exceed 20 psi; safety valves open; system down	Damage to collectors possible; system refill req'd.	Cover collectors with heat barrier
		Any	--	May not provide head to pump P_5; cooling may be interrupted	Discomfort; pump P_5 will require priming	Shut down P_5 and chillers until repaired
Deionizer	Needs recharg-ing	Any	--	pH of water uncontrolled	May lead to pipe corrosion	Replace cartridge
Hot or cold coils	Mal-function	Any	--	Building heating/cooling affected	Discomfort	--
Air Handlers	Stop	Any	--	Building heating/cooling affected	Discomfort	--
Dampers	Mal-function	Any	--	Economizer malfunctions	Energy waste	--
Safety valves	Mal-function	High solar	Avoid	Valves do not open at 260°F	Damage to collectors and piping; possible extensive rework	Cover collectors with heat barrier
Sump pumps	Mal-function	Any	Avoid	Pump pits may flood and short equip; heat exchange to hot reservoir prevented; collector overheats; safety valves open; system down	Loss of bldg. cooling; may result in damage to collectors; system refill req'd.	Bring in other sump pumps and drain pit
Float valves	Mal-function	Any	Avoid	Hot and/or cold tanks overflow; reservoir control sensors shorted; control logic may be voided	Possible danger to public; system temporarily in unidentified mode	Switch to by-pass for cold reservoir and/or hot reservoir
Vacuum breakers	Mal-function	Any	Avoid	Drain-down prevented and/or leakage; leakage may cause system pressure loss; system down; collector overheats	Damage to collectors possible	Cover collectors with heat barrier

Table 4-10

FAILURE ANALYSES – CONTROL SENSORS

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
Pyranometer	Out of service	Any	--	Signals backed up by T_1, T_2 and/or T_4	None	--
T_1, T_2, T_4	Malfunction	Low or high solar	--	Signals backed up by Pyranometer	None	--
T_3, T_7	Malfunction	Low solar	--	Heat exchange to hot reservoir may not start	Energy waste	Not imperative; but pump P_2 can be started manually based on data sensors
		High solar	--	Bleed or dump to hot reservoir not dependent upon T_3, T_7	None	--
T_5, T_{13}	Malfunction	High solar	--	2nd chiller may not be turned off efficiently	Chillers may cycle	Not imperative; 2nd chiller may be turned off manually based on data sensors
T_6	Malfunction	High solar	--	2nd chiller may not be turned on	Energy waste; premature dump	Not imperative; 2nd chiller may be turned on manually based on data sensors
T_8	Malfunction	No solar	--	Hot reservoir may not be optionally min. spec'd.	Neglibible	None
T_9	Malfunction	Any	--	Valve V_3 may not modulate to 105°F	Discomfort	--
T_{10}	Malfunction	Any	--	Cold reservoir may not be min. spec'd.	Building may lack cooling	Go to cold-reservoir bypass mode
T_{11}	Malfunction	Any	--	Chillers may not shut down at 44°F at top of cold reservoir	Energy waste; chillers operate at low COP	None; chillers can be turned off manually but will do so automatically at a temperature less than 44°F

Table 4-10

FAILURE ANALYSES – CONTROL SENSORS (Cont.)

Item	Condition	Mode	System Safety	Failure Analysis	Effect	Immediate Corrective Procedure
T_{12}	Mal-function	Any	--	Cooling tower fan may not cycle properly	Energy waste; chillers may operate at low COP or shut down	None
T_{14}	Mal-function	High solar	--	1st chiller may not be turned on	Energy waste; see Mode LTH -1 to -4	Not imperative; 1st chill-er may be turned on man-ually based on data sensors
T_{15}	Mal-function	High solar	Avoid	Pump P_{2A} may not come on for bleed & dump operations	Can't rid system of excess heat	Manually turn on P_{2A} (turn P_2 off) based on data sensor readings
T_{16}	Mal-function	High solar	--	Bleed action may not start	System may go to dump action	Not imperative
T_{17}	Mal-function	High solar	Avoid	Dump action may not start; collec-tor overheats; safety valves open; system down	Damage to collectors possible; system refill req'd.	Cover collectors with heat barrier. Alternately, move switch S_8 to Mode #2 position
T_{18}	Mal-function	All	--	Fresh air shutdown may be off	Discomfort	--
T_{19}	Mal-function	All	--	Room temperatures may be incorrectly sensed	Discomfort	--
T_{20}	Mal-function	All	--	DHW temp. may be incorrectly sensed; safety feature activated	Spring return assures valve V_7 in B→AB position	None
T_{21}	Mal-function	No solar	--	Hot reservoir may not be called to heat building	Energy waste	--
T_{22}	Mal-function	Any	--	Energy in heat exchanger may not be used to heat building or DHW	Energy waste	--

system pressure, as sensed by the pressure sensor, and power to the system is shut down. The collector array may then boil dry, leading to very high temperatures in the collector absorber plates that may result in physical damage.

Prevention of this hazardous condition generally involves having this equipment onsite and readily available:

- Covers or whitewash for the collector array to act as a heat barrier (P_1, V_1, HX-1, and T_{17} failures)
- Hoses to connect city water to hot reservoir lines into HX-1 and thence to drain (P_{2A} failure)

The practicality of covers for the collector array may be questioned; however, in some cases, such as a malfunction in heat exchanger HX-1, there is no alternative. In other cases, alternatives are available, for example, replacement pumps and motors. These items, in general, are not readily available upon short notice.

Backup components are devices activated only occasionally in the operation of the system. In general, they are off-the-shelf items that are more readily available upon short notice. In this group are:

- Pressure switch PS-1
- Expansion tanks
- Safety valves
- Vacuum breakers
- Sump pumps
- Float valves

Malfunction or failure of these components can result in the same hazards discussed previously, namely, possible damage to the collectors (or other equipment) when the system is in the High Solar Mode. With the exception of the safety valves, which are activated only in the High Solar Mode, these components may be activated, and therefore malfunction, in any of the three major solar modes. In other words, a hazardous condition may not develop with a malfunction unless the system shifts into the High Solar Mode. Preventative action in this event is to cover the collector array with a h barrier, except for failure of a sump pump or float valve.

This discussion assumes some indication of malfunction or failure before the hazard becomes evident in the form of damaged equipment or leakage. With the pressure switch, expansion tanks, and safety valves, this may be difficult; safety depends upon a systematic program of preventive maintenance.

Malfunction or failure of the sump pumps in the hot and/or cold reservoir pits, and the float valves in the hot and/or cold reservoirs may be counteracted by bypassing the reservoirs. In the case of the hot reservoir, this involves the use of the technique previously discussed in Section 4.3.2. Bypassing the cold reservoir does not involve any problems; however, if the pits are flooded, the controls for accomplishing the bypass may be shorted, and drainage of the pits will be necessary before building demand can again be met.

4.5 CONTROL SYSTEM OVERRIDE

Twelve override switches are mounted in the control panel in the mechanical equipment room. The mechanical equipment room is normally locked to prevent access to unauthorized personnel. Consequently, it is assumed that the override switches will not be reset in indiscriminate combinations – of which there are hundreds. The present analysis does not investigate all switch position combinations, on the premise that no override switch will be reset without prior judgment as to individual effect.

Analyses of the positions available on all twelve override switches are presented in Table 4-11 as a function of the three major solar modes. An evaluation of system safety is also included for each switch position. Switches S_4, S_5, S_9, and S_{10} have been covered in previous sections of this manual, as noted in the table.

Table 4-11

ANALYSES OF OVERRIDE SWITCH POSITIONS

Switch	Position	Mode	System Safety	Analysis	Effect
S_1	$P_1 \rightarrow$ on	No solar	--	V_1 in A → AB position; may reverse heat exchange to collector if P_2 is on	May waste energy
		Low solar	--	P_1 should be on continuously	None
		High solar	--	P_1 should be on continuously	None
S_2	Boiler → on	No solar	--	Boiler is locked out when V_2 in B → AB; boiler required when V_2 in A → AB	None
		Low solar	--	Same as no solar	None
		High solar	Avoid	Boiler is locked out when V_1 in B → AB; when V_1 in A → AB (dump), V_2 in B → AB & boiler still locked out	None
S_3	$P_2 \rightarrow$ on	No solar	--	Heat exchange in HX-1 may not be called for	May waste energy
		Low solar	--	If $T_3 - T_7 < \Delta T_{min}$, may reverse heat exchange to collector	May waste energy
		High solar	--	If P_{2A} is off, may heat exchange to hot reservoir	Energy draw may force system into low solar mode
S_4			--	See manual modes (Section 8.2) and no solar modes (Section 7)	--
S_5			--	See manual modes (Section 8.2)	--

(continued)

Table 4-11

ANALYSES OF OVERRIDE SWITCH POSITIONS (Cont.)

Switch	Position	Mode	System Safety	Analysis	Effect
S_6	Chillers → on	No solar	--	Prevents use of stored energy for heating	Poor energy management
		Low solar	--	Prevents use of solar energy for heating	Poor energy management
		High solar	--	Boiler locked out in this mode; if solar cannot maintain energy supply, units automatically shut down	May lock out bldg. heating & DHW
		High solar	Avoid	In high solar dump mode, boiler may override V_2 in B → AB position interlock and fire to supply chillers	Energy waste
	Chillers → alt	High solar	--	See high solar mode HS-4	May waste cooling energy
S_7	P_{2A} → on	All	--	Same as for S_3	--
S_8	Mode #1	Low solar	--	With P_1 off, energy will not be removed from collector	Energy waste
		High solar	Avoid	With P_1 off, system safety valves will open. Safety valves may not open prior to damage in collector due to lack of flow	May damage collectors; system refill required
	Mode #2	No solar	--	With P_1 on, reverse heat exchange to collector may occur	Energy waste
		High solar	--	With V_1 in A → AB position, system dumps all energy in hot reservoir	Waste of cooling energy
	Mode #3	No solar	--	With V_1 in B → AB, boiler locked out	Cannot min. spec. either reservoir; bldg. may go without heat
		Low solar	--	With V_1 in B → AB, boiler locked out; solar energy cannot be stored or used to heat bldg.	Cannot min. spec. cold reservoir; energy waste; bldg. may go without heat

(continued)

Table 4-11

ANALYSES OF OVERRIDE SWITCH POSITIONS (Cont.)

Switch	Position	Mode	System Safety	Analysis	Effect
S_9			--	See manual modes (Section 8.2)	--
S_{10}	P_3 → on			See no, low & high solar modes (Section 7)	--
S_{11}	Min. Spec → off	No solar	--	Cold reservoir min. spec. by boiler negated	None
S_{12}	Min. Spec → off	Low solar	--	Cold reservoir min. spec. by boiler negated	None

In general, the override switch positions available for other-than-normal (that is, other-than-automatic) operations do not involve hazards to the system. There is one exception, S_8 in Mode 1 position. Should the solar insolation be sufficient for the system to be in the High Solar Mode, pump P_1 would be off with switch S_8 in the Mode 1 position, leading to the same hazards discussed in Section 4.4 with reference to the failure of pump P_1.

Additionally, four other switches with on positions should be avoided during the High Solar Mode: S_2, S_3, S_6, and S_7, representing, respectively, the boiler, pump P_2, the chillers, and pump P_{2A}. These switch positions represent conflicts with higher-priority control logic that may result in energy waste and/or system malfunction. For example, it is not permissible to have the boiler on in the High Solar Mode, and having switch S_2 in the ON position in this mode serves no useful purpose.

It has been shown in Section 4.4 that certain override switch positions are useful in alleviating system conditions brought about by malfunction or failure of components. A discussion is provided in that section.

4.6 SYSTEM SHUTDOWN

When the solar-powered heating and cooling system is completely shut down, some of the motor-driven valves have a preferred position. Valves V_4, V_5, and V_6 are always in the B → AB position whenever pumps P_5 and P_4 are off, in order to prevent drain-down of P_5 to the (ambient pressure) cold reservoir. Pump P_5 is located in the mechanical equipment room.

Valve V_1 is in the A → AB position at shutdown. This is the normal position for this valve in both the No Solar and Low Solar Modes; thus, the valve shuts down in the proper position for startup the next day. Valve V_2 is normally in the B → AB position unless the boiler is on, and therefore it is in this position at shutdown. Valves V_3 and V_7 are modulating valves with no preferred shutdown position. Valve V_8 has a preferred shutdown position of A → AB.

Section 5

DATA ACQUISITION SYSTEM

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5.1 GENERAL DESCRIPTION

The data acquisition system (DAS) consists of various types of sensors located throughout the solar-powered heating and cooling system and a computer system that processes the sensor signals. The computer and its associated equipment are resident in the lobby of the Community Recreation Center.

The data acquisition system does not control any operation of the solar-powered system. However, because the computer is equipped with an CRT terminal unit for displaying the sensor signals, the DAS does provide the operational status of the solar system at programmed intervals.

The computer is used to perform a building energy balance at the end of each day. The amount of solar energy collected is calculated, and the distribution of this energy to the building or to storage is tabulated. The status of the storage reservoirs is determined, and the percentage of the total building energy demand supplied by solar energy is calculated. These results are printed out for hardcopy and also stored on magnetic tape for a permanent record.

5.2 EQUIPMENT

Descriptions of the equipment in the Data Acquisition System are presented below. Each piece of hardware is referenced by letter to Fig. 5-1 to identify its location.

A. 2748B – Tape Reader
   – reads information from punched paper tape to the CPU

B. 21MX Computer
   – the CPU (central processing unit) contains the 24K core storage

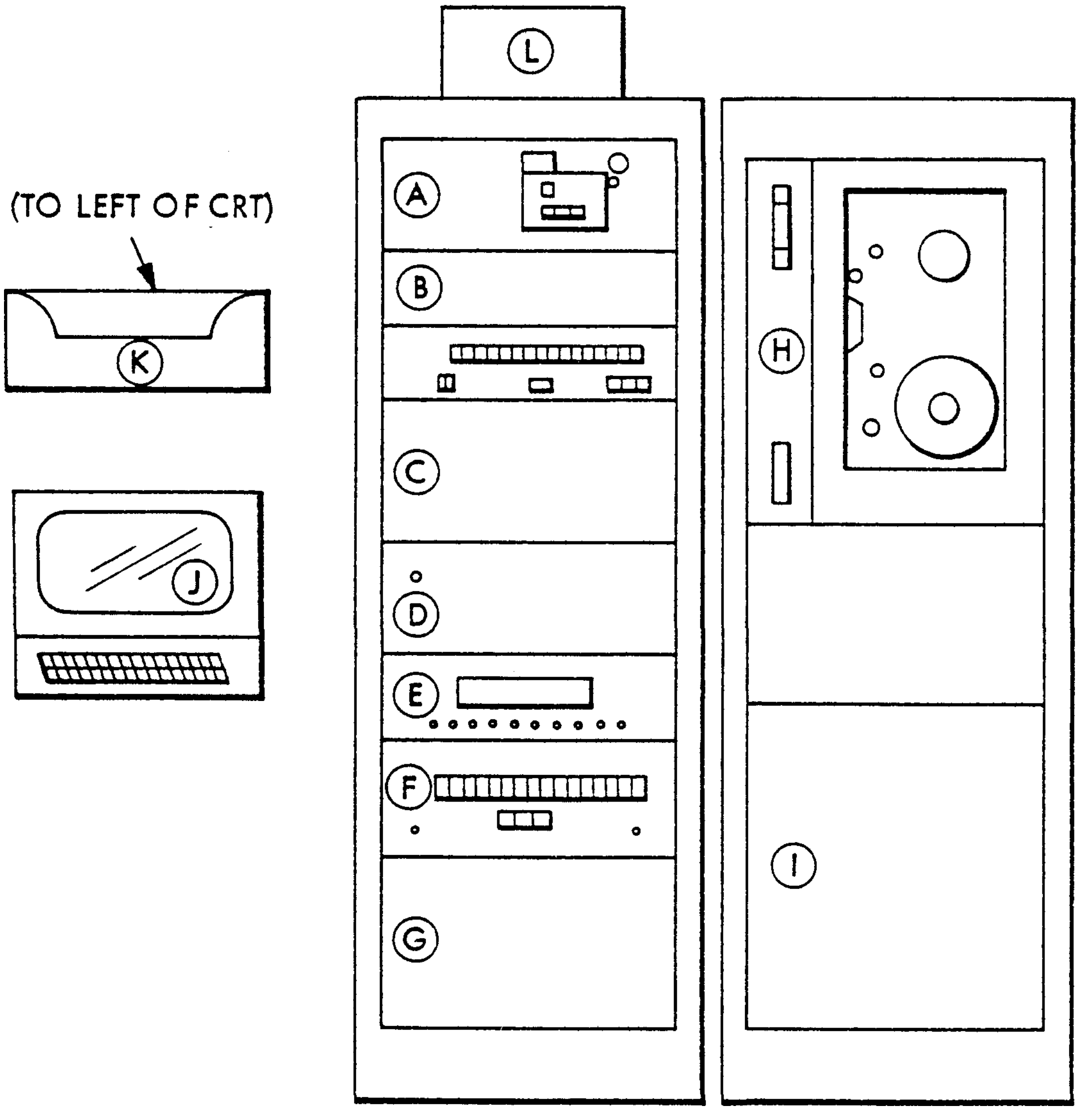


Fig. 5-1 Diagram of Location of DAS Computer Hardware Within Lobby Enclosure

Interface Cards Slot Locations (located in rear of CPU)

Slot No. (bottom to top)

10	Time Base Gen
11	+8 Bit Dup Reg (for Tape Punch)
12	7970 Mag Tape 1
13	7970 Mag Tape 2
14	CRT Interface
15	+8 Bit Dup Reg (for Tape Reader)
16	2313 Interface
17	GRD True In/Out (for Multiprogrammer)
20	GRD True In/Out (for Real Time Clock)

C. 2313 – Analog/Digital Converter

– translates voltage signals into numerical information and inputs it into the CPU

Table of 2313 cards within 12768A Mainframe (read left to right).

A	DAS Control
0	Prog Pacer (Programmable Pacer)
1	ADC (Analog/Digital Converter)
2	S/H AMP (Sample/Hold Amplifier)
3	HLMPX (High-Level Multiplexer)
4-10	LLMPX (Low-Level Multiplexer), 7 cards
11	Dual DAC (Dual Digital/Analog Converter)

– connected to "2313 Interface" interface card in CPU and "DAS Control" card in 2313 via "02313-60001 Control-A" cable

– for input connections to 2313 see Section 10

D. 12769A Power Supply

– provides power to the A/D converter

E. K21-5321B Digital Clock

– inputs real time to CPU

F. 6940B Multiprogrammer

– contains event sense logic and controls their interaction with the CPU

G. 2895B Tape Punch

– outputs data from the CPU to punched paper tape

H. 7970B Digital Tape Unit

– inputs or outputs information to/from the CPU on magnetic tape

I. Hy-Cal ESD-9025-C-85-B Resistance Bridge

– provides voltage signals which vary with the resistance of each of the PRTs

J. 2640A CRT Terminal

– an interactive display between the CPU and an operator

K. 9866A Thermal Printer

– prints all information stored in CRT memory when commanded by CRT, using the "PRINT" button

L. Weather Translator

– translates signals from weather sensors to linear 0-5V signals

5.2.1 Displays

Programs are available to display information relative to the operation and status of the solar-powered heating and cooling system. This information is displayed on the CRT and can be printed on the thermal printer upon request. The two major programs providing this capability are LOOK and MODE.

5.2.1.1 LOOK. This program outputs: 1) internal system arrays for use in checkout of the software and 2) data sensor conversions for use in operator monitoring of energy system operation.

5.2.1.2 MODE. MODE provides a display that identifies the mode the system is operating in. The program operates by using the information in core on the statuses of the on/off devices and performance calculations, then displaying the mode designation and other relevant information on the CRT.

5.3 DATA SENSORS

5.3.1 General Description

Approximately 154 different data sensor signals are monitored and interpreted to provide information to the computer about virtually all aspects of the solar-powered heating and cooling system operations. The signals are classified as: (1) low level (800 m Volt d.c. max.), (2) high level (10.24 Volt d.c. max.), and (3) on-off (resistance greater than or less than 100 ohms).

The bulk of the low-level signals consist of temperature indicators. Platinum resistance temperature (PRT) sensors are used for the temperature measurements. There are a total of 83 PRT sensors throughout the system, thirty of which are used for water temperature measurements in either the piping or water storage tanks. Schematic locations of these sensors can be found in Fig. 5-2. The actual physical locations can be found in the piping drawings and tables in Section 3.

Thirty-three are located in the air ducts throughout the building. A typical zone duct arrangement can be seen in Fig. 5-3 (note that the sensor between the cold fan coil and hot fan coil exists only in zone 5 because of reheat considerations).

Twenty sensors are mini-sensors used to measure temperatures at various locations throughout the collector array. The specific location of these sensors will vary since they can easily be moved depending on the information desired.

With the exceptions of the minis and those sensors in the storage tank, the sensors are ceramic encased, having three wire PRTs with an outside diameter of 3/16 in. These sensors are mounted by slipping them into a stainless steel well which projects into the liquid or air flow.

Sensors in the two water storage tanks are also ceramic enclosed and have three wire PRTs, but they have an outside diameter of 1/8 in. These sensors have special extra long leads to reach the junction box located in the neck of the tank. Mounting

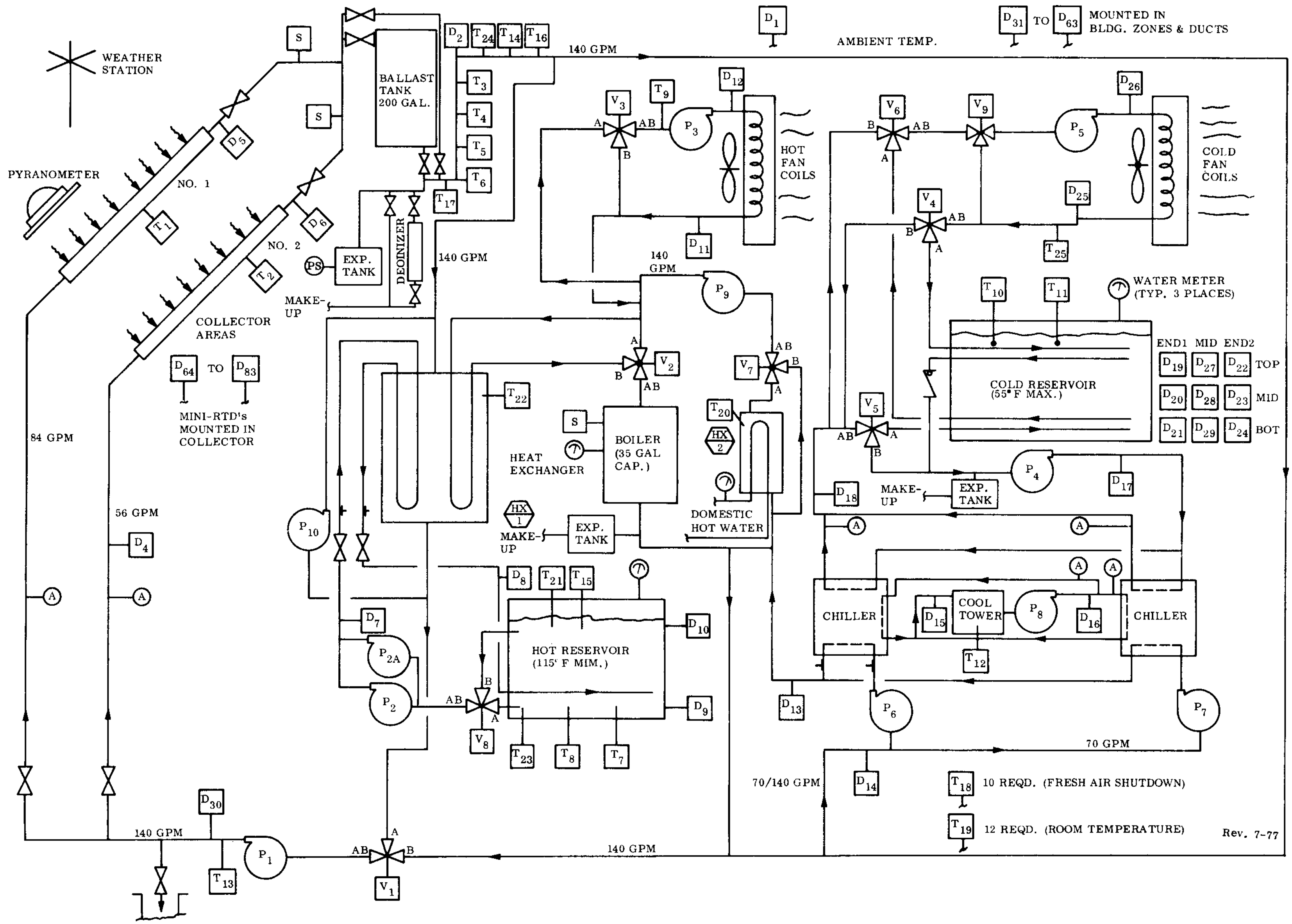


Fig. 5-2 Piping Schematic

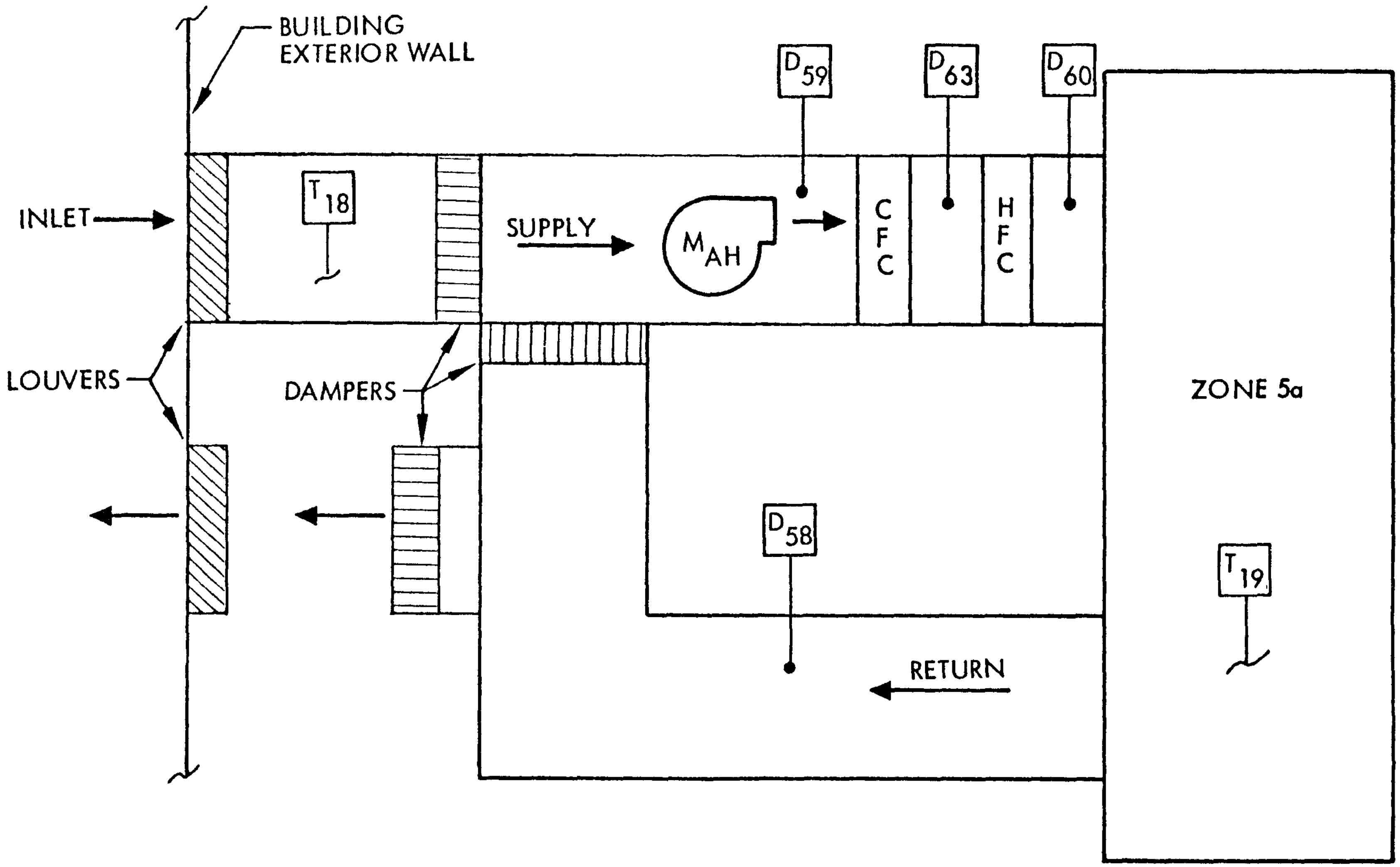


Fig. 5-3 Typical Zone Duct Arrangement

is accomplished by threading the sensor into a small copper pipe with a sealed cap on the end that extends to the junction box in the neck of the tank.

The mini-sensors are the only group that is inserted directly into the fluid flow. Consequently, these sensors are metal clad, and also have an outside diameter of 1/8 in., and are six inches in length.

To allow the sensors to be shifted to various locations in the collector array (and to enable pressure measurements to be made), a special fitting called a Pete's Plug has been installed throughout the system. Installation of the sensor at a specific location simply involves insertion of the sensor body through the rubber seal and down into the fluid stream.

Since the operating characteristics of PRT sensors involved a change of resistance with a change in temperature, a balancing bridge arrangement is necessary to give a temperature proportional voltage. This voltage is measured by the analog-to-digital equipment and sent to the computer.

The bridge arrangement used is a Hy-Cal model ESD-9025-C. It is a self-contained unit with provisions for handling 85 low-level sensor-signal inputs. Each sensor is connected to a separate bridge network which has calibration adjustments to compensate for variations in resistance values and for lead wire resistance effects.

An additional low-level signal provides an indication of solar intensity. This is accomplished by the use of a pyranometer manufactured by Eppley Laboratory, Inc. This instrument is designed for the measurement of global sun and sky radiation and develops an emf of 9.03×10^{-6} volts/watt-meter^2. It is located in the plane of the collectors, at the top edge of the wooden collector supporting structure on the flat roof.

The next group of signals, the high-level ones, are made up of zone setpoint and temperature readings along with wind information. Zone setpoint information (i.e., the desired temperature in the zone) is relayed to the computer in conjunction with the control system equipment. Inside the temperature control panel, there are twelve setpoint controls which determine whether heating or cooling is needed in that zone of the building. Mounted on the shaft of each setpoint control is a separate potentiometer used to relay the setting of the control to the computer. This is done by applying 10 volts d.c. across the potentiometer and measuring the voltage, corresponding to the setpoint present on the wiper.

Zone temperature readings are also detected in conjunction with the control system. In this case, the zone temperature signal that is used for control purposes is passed through an amplifier and then to the data system. The purpose of the amplifier is to raise the level of the signal so as to make it easily and accurately measurable by the analog-to-digital circuitry in the DAS computer system.

Wind information is gathered by a Weather Measure W101-P wind sensor and the associated signal conditioning equipment, and the WTB101-HF wind translator. The wind sensor, located on the flat roof is capable of measuring both wind speed and direction. Signals from the wind sensor are fed into the wind translator located in the data system enclosure, which delivers a calibrated d.c. voltage to the analog-to-digital circuitry. Both wind speed and direction signals provide voltages that are proportional to the quantities being measured.

The final group of data signals represents the current status of various pieces of equipment in the system. The information monitored in this way includes pump on/off status, valve positions, boiler status, chiller status, solar mode, loss of system pressure, time clock status, and override switch positions.

This is accomplished with a group of relays located in the temperature control panel that have open or closed contacts depending on the status of the equipment. Such an open or closed contact can be detected by the event-sense equipment located in the HP Multiprogrammer. By continuously monitoring these relay closures, the computer is aware of any changes in the system status due to control system operation.

Also monitored by the event sense equipment are the contact closures for the two flow indicators. These are retransmitting water meters determining the amount of domestic hot water and hot storage makeup water that is used. These flow indicators are Neptune impulse switches, Model 31, which make and break a switch contact for every gallon of water that passes through the pipe. Through the event-sense equipment, the computer can count the number of gallons of water being used over any desired time period.

5.3.2 Data Signal Connections

Specific information concerning wiring between each data sensor and the associated measurement circuitry can be found in Tables 5-1, 5-2, and 5-3. With the exception of the weather station and PRT wiring on the roof, all signals are wired into numbered terminal strips in the control panel. The numbers are referenced in the signal connection tables and the G. J. Yamas Company control system schematics.

Coming into the data system enclosure, the wiring separates into two groups. PRT signals go to the bridge box and then to the low-level multiplex cards. The event sense and high-level signals pass through another numbered terminal strip mounted on the inside of the computer chassis and then on to the computer. The numbering for the connections to this terminal strip is also referenced in the signal connection tables.

Low-level signals are connected in a differential mode to the HP computer low-level multiplex cards. This simply involves the connection of the negative and positive wires from the bridge box output to two separate inputs on the multiplexer card.

High-level and event-sense signals, are connected in a different manner. These signals are connected in a single-ended manner which is realized by a common input connection for one of the two input wires corresponding to each signal source. The other wire is then assigned to an input pin according to the computer connecting instructions.

Table 5-1

LOW LEVEL MUX SIGNALS

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D1	-	3-50	Row 1-1	CON-1	CON-1
			A	A+	2
			B	B-	1
			C		
D2	577	1-35	Row 1-2	CON-1	CON-1
	578		A	C+	A
	579		B	D-	B
	580		C		
D3	581	1-36	Row 1-3	CON-1	CON-1
	582		A	E+	5
	583		B	F-	4
	584		C		
D4	-	3-49	Row 1-4	CON-1	CON-1
			A	H+	D
			B	J-	E
			C		
D5	589	1-38	Row 1-5	CON-1	CON-1
	590		A	K+	8
	591		B	L-	7
	592		C		
D6	-	3-48	Row 1-6	CON-1	CON-1
			A	M+	H
			B	N-	J
			C		
D7	597	1-40	Row 1-7	CON-1	CON-1
	598		A	P+	11
	599		B	R-	10
	600		C		
D8	601	1-41	Row 1-8	CON-1	CON-1
	602		A	S+	L
	603		B	T-	M
	604		C		
D9	605	1-42	Row 1-9	CON-1	CON-1
	606		A	U+	14
	607		B	V-	13
	608		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D10	609	1-43	Row 1-10	CON-1	CON-1
	610		A	W+	P
	611		B	X-	R
	612		C		
D11	613	1-44	Row 1-11	CON-1	CON-1
	614		A	Y+	17
	615		B	Z-	16
	616		C		
D12	617	1-45	Row 1-12	CON-1	CON-1
	618		A	a+	T
	619		B	b-	U
	620		C		
D13	621	1-46	Row 1-13	CON-1	CON-1
	622		A	c+	20
	623		B	d-	19
	624		C		
D14	625	1-47	Row 1-14	CON-1	CON-1
	626		A	f+	W
	627		B	g-	X
	628		C		
D15	629	1-48	Row 1-15	CON-1	CON-1
	630		A	h+	23
	631		B	i-	22
	632		C		
D16	633	1-49	Row 1-16	CON-1	CON-1
	634		A	j+	Z
	635		B	k-	AA
	636		C		
D17	637	1-50	Row 1-17	CON-1	CON-2
	638		A	m+	2
	639		B	n-	1
	640		C		
D18	641	2-1	Row 1-18	CON-1	CON-2
	642		A	p+	A
	643		B	q-	B
	644		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.- Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D19	645	2-2	Row 1-19	CON-1	CON-2
	646		A	r+	5
	647		B	s-	4
	648		C		
D20	649	2-3	Row 1-20	CON-1	CON-2
	650		A	t+	D
	651		B	u-	E
	652		C		
D21	653	2-4	Row 1-21	CON-1	CON-2
	654		A	v+	8
	655		B	w-	7
	656		C		
D22	657	2-5	Row 2-22	CON-1	CON-2
	658		A	x+	H
	659		B	y-	J
	660		C		
D23	661	2-6	Row 2-23	CON-1	CON-2
	662		A	z+	11
	663		B	AA-	10
	664		C		
D24	665	2-7	Row 2-24	CON-1	CON-2
	666		A	AB+	L
	667		B	AC-	M
	668		C		
D25	669	2-8	Row 2-25	CON-1	CON-2
	670		A	AD+	14
	671		B	AE-	13
	672		C		
D26	673	2-9	Row 2-26	CON-2	CON-2
	674		A	A+	P
	675		B	B-	R
	676		C		
D27	677	2-10	Row 2-27	CON-2	CON-2
	678		A	C+	17
	679		B	D-	16
	680		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D28	681	2-11	Row 2-28	CON-2	CON-2
	682		A	E+	T
	683		B	F-	U
	684		C		
D29	685	2-12	Row 2-29	CON-2	CON-2
	686		A	H+	20
	687		B	J-	19
	688		C		
D30	689	2-13	Row 2-30	CON-2	CON-2
	690		A	K+	W
	691		B	L-	X
	692		C		
D31	440	1-1	Row 2-31	CON-2	CON-2
	441		A	M+	23
	442		B	N-	22
	443		C		
D32	444	1-2	Row 2-32	CON-2	CON-2
	445		A	P+	Z
	446		B	R-	AA
	447		C		
D33	448	1-3	Row 2-33	CON-2	CON-3
	449		A	S+	2
	450		B	T-	1
	451		C		
D34	452	1-4	Row 2-34	CON-2	CON-3
	453		A	U+	A
	454		B	V-	B
	455		C		
D35	456	1-5	Row 2-35	CON-2	CON-3
	457		A	W+	5
	458		B	X-	4
	459		C		
D36	460	1-6	Row 2-36	CON-2	CON-3
	461		A	Y+	D
	462		B	Z-	E
	463		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D37	464	1-7	Row 2-37	CON-2	CON-3
	465		A	a+	8
	466		B	b-	7
	467		C		
D38	468	1-8	Row 2-38	CON-2	CON-2
	469		A	c+	H
	470		B	d-	J
	471		C		
D39	472	1-9	Row 2-39	CON-2	CON-3
	473		A	f+	11
	474		B	g-	10
	475		C		
D40	476	1-10	Row 2-40	CON-2	CON-3
	477		A	h+	L
	478		B	i-	M
	479		C		
D41	480	1-11	Row 3-41	CON-2	CON-3
	481		A	j+	14
	482		B	k-	13
	483		C		
D42	484	1-12	Row 3-42	CON-2	CON-3
	485		A	m+	P
	486		B	n-	R
	847		C		
D43	488	1-13	Row 3-43	CON-2	CON-3
	489		A	p+	17
	490		B	q-	16
	491		C		
D44	492	1-14	Row 3-44	CON-2	CON-3
	493		A	r+	T
	494		B	s-	U
	495		C		
D45	496	1-15	Row 3-45	CON-2	CON-3
	497		A	t+	20
	498		B	u-	19
	499		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D46	500	1-16	Row 3-46	CON-2	CON-3
	501		A	v+	W
	502		B	w-	X
	503		C		
D47	504	1-17	Row 3-47	CON-2	CON-3
	505		A	x+	23
	506		B	y-	22
	507		C		
D48	508	1-18	Row 3-48	CON-2	CON-4
	509		A	z+	Z
	510		B	AA-	AA
	511		C		
D49	512	1-19	Row 3-49	CON-2	CON-4
	513		A	AB+	2
	514		B	AC-	1
	515		C		
D50	516	1-20	Row 3-50	CON-2	CON-4
	517		A	AD+	A
	518		B	AE-	B
	519		C		
D51	520	1-21	Row 3-51	CON-3	CON-4
	521		A	A+	5
	522		B	B-	4
	523		C		
D52	524	1-22	Row 3-52	CON-3	CON-4
	525		A	C+	D
	526		B	D-	E
	527		C		
D53	528	1-23	Row 3-53	CON-3	CON-4
	529		A	E+	8
	530		B	F-	7
	531		C		
D54	532	1-24	Row 3-54	CON-3	CON-4
	533		A	H+	H
	534		B	J-	J
	535		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.–Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D55	536	1-25	Row 3-55	CON-3	CON-4
	537		A	K+	11
	538		B	L-	10
	539		C		
D56	540	1-26	Row 3-56	CON-3	CON-4
	541		A	M+	L
	542		B	N-	M
	543		C		
D57	544	1-27	Row 3-58	CON-3	CON-4
	545		A	S+	14
	546		B	T-	13
	547		C		
D58	548	1-28	Row 3-57	CON-3	CON-4
	549		A	P+	P
	550		B	R-	R
	551		C		
D59	556	1-30	Row 3-60	CON-3	CON-4
	557		A	W+	17
	558		B	X-	16
	559		C		
D60	560	1-31	Row 3-59	CON-3	CON-4
	561		A	U+	T
	562		B	V-	U
	563		C		
D61	560	1-31	Row 4-62	CON-3	CON-4
	561		A	a+	20
	562		B	b-	19
	563		C		
D62	564	1-32	Row 4-61	CON-3	CON-4
	565		A	y+	W
	566		B	z-	X
	567		C		
D63	568	2-14	Row 4-64	CON-3	CON-4
	569		A	f+	23
	570		B	g-	22
	571		C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D64	-	3-26	Row 4-63	CON-3	CON-4
			A	c+	Z
			B	d-	AA
			C		
D65	-	3-27	Row 4-65	CON-3	CON-5
			A	h+	2
			B	i-	1
			C		
D66	-	3-28	Row 4-66	CON-3	CON-5
			A	j+	A
			B	k-	B
			C		
D67	-	3-29	Row 4-67	CON-3	CON-5
			A	m+	5
			B	n-	4
			C		
D68	-	3-30	Row 4-68	CON-3	CON-5
			A	p+	D
			B	q-	E
			C		
D69	-	3-31	Row 4-69	CON-3	CON-5
			A	r+	8
			B	s-	7
			C		
D70	-	3-32	Row 4-70	CON-3	CON-5
			A	t+	H
			B	u-	J
			C		
D71	-	3-33	Row 4-71	CON-3	CON-5
			A	v+	11
			B	w-	10
			C		
D72	-	3-34	Row 4-72	CON-3	CON-5
			A	x+	L
			B	y-	M
			C		

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.-Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D73	-	3-35	Row 4-73 A B C	CON-3 z+ AA-	CON-5 14 13
D74	-	3-36	Row 4-74 A B C	CON-3 AB+ AC-	CON-5 P R
D75	-	3-37	Row 4-75 A B C	CON-3 AD+ AE-	CON-5 17 16
D76	-	3-38	Row 4-76 A B C	CON-4 A+ B-	CON-5 T U
D77	-	3-39	Row 4-77 A B C	CON-4 C+ D-	CON-5 20 19
D78	-	3-40	Row 4-78 A B C	CON-4 E+ F-	CON-5 W X
D79	-	3-41	Row 4-79 A B C	CON-4 H+ J-	CON-5 23 22
D80	-	3-42	Row 4-80 A B C	CON-4 K+ L-	CON-5 Z AA
D81	-	3-43	Row 5-81 A B C	CON-4 M+ N-	CON-6 2 1

Table 5-1 (Continued)

Data Sensor	Control Panel No.	Data Cable No.–Control Panel	Bridge Terminal Input	Bridge Connector Output	Data System Input
D82	-	3-44	Row 5-82 A B C	CON-4 P+ R-	CON-6 A B
D83	-	3-45	Row 5-83 A B C	CON-4 S+ T-	CON-6 5 4
Pyran.	351 352	2-42	T.B. #72, 73	-	CON-6 D E

Table 5-2

HIGH LEVEL MUX SIGNALS

Signal Name	Control Panel No.	Data Cable No.–Control Panel	Terminal Board No.	Data Cable No.–Data System	Data System Connector Number
Z.S.P. #1	304	2-19	1	1-grn. w. yllw.	1
Z.S.P. #2	308	2-21	2	1-brn. w. yllw.	3
Z.S.P. #3	312	2-23	3	1-orng. w. yllw.	4
Z.S.P. #4	316	2-25	4	1-yllw. w. brn.	6
Z.S.P. #5	320	2-27	5	1-yllw. w. grn.	7
Z.S.P. #6	325	2-29	6	1-gray. w. yllw.	9
Z.S.P. #7	329	2-31	7	1-white w. grn.	10
Z.S.P. #8	333	2-33	8	1-blue w. violet	12
Z.S.P. #9	337	2-35	9	1-orng. w. violet	13
Z.S.P. #10	341	2-37	10	1-violet w. orng.	15
Z.S.P. #11	345	2-39	11	1-violet w. blue	16
Z.S.P. #12	349	2-41	12	1-red w. orng.	18
WINDD			13	1-red w. grn.	19
WINDV			14	1-grn. w. red	21
D84	302	2-18	15	1-orng. w. red	22

Table 5-2

HIGH LEVEL MUX SIGNALS (Continued)

Signal Name	Control Panel No.	Data Cable No.–Control Panel	Terminal Board No.	Data Cable No.–Data System	Data System Connector Number
D85	306	2-20	16	1-yllw. w. orng.	24
D86	310	2-22	17	1-red w. gray	A
D87	314	2-24	18	1-grn. w. violet	C
D88	318	2-26	19	1-violet w. grn.	D
D89	323	2-28	20	1-brn. w. violet	F
D90	327	2-30	21	1-white w. blue	H
D91	331	2-32	22	1-grn. w. white	K
D92	335	2-34	23	1-grey w. red	L
D93	339	2-36	24	1-blue w. white	N
D94	343	2-38	25	1-red w. brn.	P
D95	347	2-40	26	1-white w. orng.	S
Common			27	1-blue w. red	2,5,11,14,17,20, 23,B,E,J,M,R

Table 5-3

EVENT-SENSED SIGNALS

SIGNAL NAME	CONTROL PANEL NUMBER	DATA CABLE NO. – CONTROL PANEL	TERMINAL BOARD NUMBER	DATA CABLE NO. – DATA SYSTEM	DATA SYSTEM CONNECTOR NUMBER
BOILER	379	4	28	2 – grn. w. blck.	CON-1 NO. 1
AC NO. 1	432	4	29	2 – blck. w. grn.	CON-1 NO. 2
AC NO. 2	434	4	30	2 – yllw. w. blue	CON-1 NO. 3
PS NO. 1	377	4	31	2 – brn. w. blck.	CON-1 NO. 4
NSM	364	4	32	2 – gray w. violet	CON-1 NO. 5
LSM	360	4	33	2 – blck. w. brn.	CON-1 NO. 6
HSM	362	4	34	2 – violet w. brn.	CON-1 NO. 7
V_1	384	4	35	2 – orng. w. blck.	CON-1 NO. 8
V_2	386	4	36	2 – brn. w. violet	CON-1 NO. 9
V	396	4	37	2 – blck. w. orng.	CON-1 NO. 10
V_4	388	4	38	2 – white w. brn.	CON-1 NO. 11
V_5	390	4	39	2 – gray w. blck.	CON-1 NO. 12
V_6	392	4	40	2 – yllw. w. orng.	CON-2 NO. 1
V_8	394	4	41	2 – blck. w. gray	CON-2 NO. 2
P_1	401	4	42	2 – blue w. yllw.	CON-2 NO. 3
P_2	406	4	43	2 – gray w. white	CON-2 NO. 4
P_{2A}	411	4	44	2 – white w. gray	CON-2 NO. 5
P_3	416	4	45	2 – orng. w. yllw.	CON-2 NO. 6

Table 5-3 (cont.)

SIGNAL NAME	CONTROL PANEL NUMBER	DATA CABLE NO. – CONTROL PANEL	TERMINAL BOARD NUMBER	DATA CABLE NO. – DATA SYSTEM	DATA SYSTEM CONNECTOR NUMBER
P_4	418	4	46	2 – red w. blue	CON-2 NO. 7
P_5	420	4	47	2 – orng. w. white	CON-2 NO. 8
P_6	422	4	48	2 – white w. orng.	CON-2 NO. 9
P_7	424	4	49	2 – blue w. red	CON-2 NO. 10
P_8	426	4	50	2 – grn. w. yllw.	CON-2 NO. 11
P_9	428	4	51	2 – yllw. w. grn.	CON-2 NO. 12
P_{10}	430	4	52	2 – brn. w. yllw.	CON-3 NO. 1
FCU	300	II-17	53	2 – gray w. yllw.	CON-3 NO. 2
S_1(on)	398	4	54	2 – yllw. w. gray	CON-3 NO. 3
S_2(on)	382	4	55	2 – orng. w. red	CON-3 NO. 4
S_3(on)	403	4	56	2 – red w. orng.	CON-3 NO. 5
S_4(bypass)	369	4	57	2 – white w. grn.	CON-3 NO. 6
S_4(min spec)	368	4	58	2 – grn. w. white	CON-3 NO. 7
S_5(bypass)	372	4	59	2 – white w. blue	CON-3 NO. 8
S_6(No. 1)	436	4	60	2 – brn. w. red	CON-3 NO. 9
S_6(No. 2)	437	4	61	2 – blue w. white	CON-3 NO. 10
S_7(on)	408	4	62	2 – grn. w. red	CON-3 NO. 11
S_8(mode No. 1)	354	4	63	2 – red w. grn.	CON-3 NO. 12

Table 5-3 (cont.)

SIGNAL NAME	CONTROL PANEL NUMBER	DATA CABLE NO. – CONTROL PANEL	TERMINAL BOARD NUMBER	DATA CABLE NO. – DATA SYSTEM	DATA SYSTEM CONNECTOR NUMBER
S_8(mode No. 2)	355	4	64	2 – gray w. red	CON-4 NO. 1
S_8(mode No. 3)	356	4	65	2 – violet w. blue	CON-4 NO. 2
S_9(on)	707	4	66	2 – blue w. violet	CON-4 NO. 3
S_{10}(on)	413	4	67	2 – orng. w. violet	CON-4 NO. 4
S_{11}(on)	706	4	68	2 – red w. gray	CON-4 NO. 5
S_{12}(on)	705	4	69	2 – blue w. blck.	CON-4 NO. 6
W. M. No. 1	569 570	1–33	76	2 – blck. w. blue	CON-4 NO. 7
W. M. No. 2	573 574	1–34	77	2 – grn. w. violet	CON-4 NO. 8
Common (card No. 1)	–	4	71	2 – yllw. w. brn.	CON-1 NO. 15
Common (card No. 2)	–	4	71	2 – brn. w. white	CON-2 NO. 15
Common (card No. 3)	–	4	71	2 – violet w. orng.	CON-3 NO. 15
Common (card No. 4)	–	4	71	2 – violet w. grn.	CON-4 NO. 15

5.3.3 Sensor Calibration Procedures

Calibration of the bridge circuitry involves the simulation of the sensor by a decade resistance box installed at the sensor connections. By adjusting the decade box according to the resistance-temperature specifications supplied with each sensor, the bridge circuit for that sensor can be adjusted until the measurement circuitry indicates a temperature corresponding to that resistance value.

Each PRT sensor was originally supplied with a calibration tag attached to the wires. These tags show actual resistance versus temperature measurements for that particular sensor.

A special group of computer programs is needed for calibration purposes. One program, gives a listing of the high-level and low-level signal voltages. Another program repeatedly samples a desired channel and prints out the voltage measured. A third program is used in conjunction with the above two programs to specify the gain used in the low-level measurements.

Once the voltage measurement takes place, the corresponding temperature must be found. This table specifies the PRT defining equation for temperature-resistance correlations using the bridge circuitry. The goal of calibration, therefore, is to line up the sensor response (by the use of the decade box) with the defining equation response. This can be done by setting the decade box controls to the interpolated resistance value of the sensor at 0° F. If the voltage level does not correspond to the 0° F voltage level as specified in the bridge output table (namely 0.0 mV), then adjust the zero set control until the readings do correspond.

Usually the 212 deg point on the sensor specifications is chosen as the other data point needed to line up the response curves. The resistance corresponding to this temperature is set on the decade box and the above procedure is followed. Any adjustments are made with the full-scale adjust control. Once this point is correctly adjusted, the zero point should be rechecked to verify that no changes have occurred.

Note that any open channel will cause all of the signals on the corresponding low level multiplex card to be inaccurate. Therefore, any channels without sensors connected to the inputs will have the input terminals shorted together.

Calibration of the zone set point and zone temperature signals is fairly straightforward since both are adjusted to give a 5-volt output for a temperature setting, or reading, of 70° F. The above calibration programs are once again used for measurement by choosing the appropriate channel number (Note: the channels are assigned according to the signal listings in Tables 5-1 and 5-2 with high-level signals coming before low level).

Adjustments are made to the zone set point signals by using the zero set point control on a remaining bridge circuit. The zone temperature is calibrated by measuring the temperature of the zone with a thermometer and adjusting the corresponding zone transmitter within the Control Panel to give a signal that is equal to 5 volts at 70° F.

The wind direction circuitry is adjusted for a full scale (i.e., 360 deg.) output of 5 volts d.c. while the wind speed indicator is adjusted to give a 5 volt d.c. signal for a wind speed of 50 mph (range switch in low position).

5.4 SOFTWARE

A software system has been written to program the DAS computer hardware to achieve the stated objectives. This system inputs, converts, and stores solar energy system and building data. It does on-site, real-time calculations of performance and daily energy balances of the energy system and building. The resulting information can then be displayed on the CRT or printed on the thermal printer.

The basis of this system is the operating system software supplied by Hewlett-Packard. This provides the environment in which the user-written programs run. The operating system used is the RTE-C (Real Time Editor-Core based) system written by Hewlett-Packard. In this system, multiple programs reside in core and are scheduled to be run in flexible, real-time dependent, interactive manner. Using the features of RTE-C, the DAS operates unattended except for changing of the magnetic tape (on which data & calculations are stored) once a week. Programs communicate data with each other using common storage. The RTE-C system is generated for each particular use by the user using Hewlett-Packard-supplied software. User-written programs are written in FORTRAN and are prepared for use in the system using Hewlett-Packard-supplied compilers and loaders.

The operating system uses about 10,000 of the 24,000 words of computer memory in core. 5,000 is allotted for common area storage. This leaves about 9,000 for user programs. Each of the various main tasks of the DAS software system is assigned a different user program. This speeds and simplifies operation and debugging of the system.

The 110 channels of data sensor voltages are scanned by one program every five minutes when the control system time clock is on, and every 30 minutes when the control system time clock is off. This interval can be changed by computer software. These voltage values are then converted to engineering units; stored in core for short-term use and on magnetic tape for long-term storage.

To monitor event-sensed (on/off) signals, the Hewlett-Packard 6940 Multiprogrammer is programmed through the software to generate an interrupt to the computer whenever the status of one of its on/off inputs changes. This interrupt schedules a program which inputs the data from the 48 event-sense channels and resets the event-sense interrupt mode. Therefore, on/off device status changes may be instantaneously sensed without continuous scanning. Using the event sense input data, an array is updated which represents the status of the on/off devices. Since whether or not many of the real time performance calculations should be performed depends on various specific combinations of these on/off device statuses, another array is then updated which represents on/off (to be or not to be calculated) statuses for such of the 93 calculations shown in Table 5-4.

Following each scan of data sensor voltages, a program run performs the calculations indicated in Table 5-5 for the five (or 30) minute interval just completed. It uses

Table 5-4

PERFORMANCE CALCULATIONS MADE IN REAL TIME

No.	
1	Incident Solar Energy – Collector Array No. 1
2	Incident Solar Energy – Collector Array No. 2
3	Collected Solar Energy – Collector Array No. 1
4	Collected Solar Energy – Collector Array No. 2
5	Collected Solar Energy – Total Collector Array
6	Present Efficiency – Collector Array No. 1
7	Present Efficiency – Collector Array No. 2
8	Present Efficiency – Total Collector Array
9	Efficiency for day so far – Collector Array No. 1
10	Efficiency for day so far – Collector Array No. 2
11	Efficiency for day so far – Total Collector Array
12	Calculated maximum energy collection – Array No. 1
13	Calculated collector loss – Array No. 1
14	Change in heat storage – Array No. 1
15	Calculated efficiency – Array No. 1
16	Energy supplied by boiler
17	Energy consumed by operation of one chiller from solar
18	Energy consumed by operation of one chiller from boiler
19	Energy consumed by all operations of chillers
20	Cold water energy from chillers using solar
21	Cold water energy from chillers using boiler
22	Cold water energy from chillers – total
23	Energy dissipated by chiller cooling tower

Table 5-4 (Cont.)

No.	
24	Chiller C.O.P.
25	Energy input to heat exchanger from hot tank
26	Energy input to hot tank from boiler
27	Energy input to hot tank from solar during low solar mode
28	Energy to hot fan coils – from solar
29	Energy to hot fan coils – from boiler
30	Energy to hot fan coils – from solar heated chiller firing water
31	Energy to hot fan coils – from hot tank
32	Energy to hot fan coils – total
33	Energy to cold fan coils – from cold tank
34	Energy to cold fan coils – tank bypass, chillers run by solar
35	Energy to cold fan coils – tank bypass, chillers run by boiler
36	Energy to cold fan coils – total
37	Hot tank energy level
38	Energy used to heat hot tank make-up water
39	Energy lost to boil off from hot tank
40	Energy consumed heating domestic hot water – from boiler
41	Energy consumed heating domestic hot water – from solar
42	Energy consumed heating domestic hot water – total
43	Heating energy supplied to zone 1
44	Heating energy supplied to zone 2
45	Heating energy supplied to zone 3
46	Heating energy supplied to zone 4
47	Heating energy supplied to zone 5a
48	Heating energy supplied to zone 5b
49	Heating energy supplied to zone 5c
50	Heating energy supplied to zone 6
51	Heating energy supplied to zone 7
52	Heating energy supplied to zone 8
53	Heating energy supplied to zone 9
54	Heating energy supplied to zone 10

Table 5-4 (Cont.)

No.	
55	Cooling energy supplied to zone 1
56	Cooling energy supplied to zone 2
57	Cooling energy supplied to zone 3
58	Cooling energy supplied to zone 4
59	Cooling energy supplied to zone 5
60	Cooling energy supplied to zone 6
61	Cooling energy supplied to zone 7
62	Cooling energy supplied to zone 8
63	Cooling energy supplied to zone 9
64	Cooling energy supplied to zone 10
65	Cooling energy supplied by economizer to zone 1
66	Cooling energy supplied by economizer to zone 2
67	Cooling energy supplied by economizer to zone 3
68	Cooling energy supplied by economizer to zone 4
69	Cooling energy supplied by economizer to zone 5
70	Cooling energy supplied by economizer to zone 6
71	Cooling energy supplied by economizer to zone 7
72	Cooling energy supplied by economizer to zone 8
73	Cooling energy supplied by economizer to zone 9
74	Cooling energy supplied by economizer to zone 10
75-79	Not used
80	Energy consumed in operation of two chillers – from solar
81	Energy consumed in operation of two chillers – from boiler
82	Energy input to hot tank during dump
83	Calculated maximum energy collection – Array No. 2
84	Calculated collector loss – Array No. 2
85	Change in heat storage – Array No. 2
86	Calculated collector efficiency – Array No. 2

Table 5-4 (Cont.)

No.	
87	Total incident solar energy – Array No. 1
88	Total incident solar energy – Array No. 2
89	Total incident solar energy – Total collector array
90	Energy input to hot tank during bleed
91	Energy input to heat exchanger from solar during low solar mode
92	Energy input to heat exchanger from boiler
93	Energy input to heat exchanger from dump and bleed
94	Energy output of heat exchange to building of energy in tank
95	Not used
96	Total heating energy delivered to zones
97	Total cooling energy delivered to zones
98	Total cooling energy delivered by the economizer to zones
99	Energy used to preheat collectors

Table 5-5

DAILY PERFORMANCE CALCULATIONS

No.	
1	Total energy input to the building – solar plus boiler
2	Total energy input to the hot reservoir from all sources
3	Total energy input to the primary side from all sources
4	Total energy output through the primary side of the heat exchanger
5	Total energy input to the primary side from boiler energy
6	Total energy input to the primary side of the heat exchanger from solar energy
7	Energy output through secondary side from boiler energy
8	Energy output through secondary side from solar energy
9	Energy output through primary side from boiler energy
10	Energy output through primary side from solar energy
11	Energy delivered to the HFC[(a)] from the hot reservoir that was boiler originated
12	Energy delivered to the HFC from the hot reservoir that was solar originated
13	Energy delivered to the CFC[(b)] from the cold reservoir that was boiler originated
14	Energy delivered to the CFC from the cold reservoir that was solar originated
15	Daily cold reservoir energy change
16	Daily hot reservoir energy change
17	Daily energy loss from hot reservoir
18	Daily energy loss through insulation from hot reservoir
19	Cold storage reservoir daily efficiency
20	Hot storage reservoir daily efficiency
21	Total building load
22	Heating load of building
23	Cooling load of building
24	Percent of heating load carried by solar
25	Percent of heating load carried by boiler

(a) HFC – hot surface in air handlers
(b) CFC – cold surface in air handlers

Table 5-5 (Cont.)

No.	
26	Percent of cooling load carried by solar
27	Percent of cooling load carried by boiler
28	Percent of cooling load carried by economizer
29	Percent of DHW load carried by solar
30	Percent of DHW load carried by boiler
31	Percent of total load carried by solar and economizer
	Percent distributions of solar energy collected to:
32	Heat exchangers
33	HFC
34	HFC (bleed)
35	Chillers
36	DHW
	Percent distributions of boiler energy produced to:
37	Heat exchanger
38	HFC
39	Chillers
40	DHW
	Percent distributions of hot reservoir energy to:
41	HFC
42	DHW
43	Total heating energy used by the zones
44	Total cooling energy from CFC used by zones
45	Energy for cooling provided by economizer
46	Total DHW load carried from hot reservoir calculated explicitly (will include line losses)
47	Daily energy loss from cold reservoir

the data sensor voltage conversions and a set of previously entered energy system constants, including air and water flows measured during balancing of the system. Magnitudes of flows during the scan interval are determined by noting the length of time during the interval that pump and valve statuses are "on." On/off statuses for performance calculations are used in the same way to establish an array of time lengths for flows relating to specific calculations. These arrays of time lengths are multiprogrammer and analog/digital converted for program input. Using the data gathered or calculated, the performance calculations are made, stored in core and on magnetic tape, and accumulated to the totals for the day to make daily energy balances at midnight.

At midnight, performance calculations totals for the day are made and used to perform the calculations of daily energy use and collection. These include daily energy balances for the energy system, building, and reservoirs. The calculation results are stored in core for use the next day and on magnetic tape for long-term storage.

The data system has collected or the quantities of data it has calculated can be displayed on the CRT and/or printed on the thermal printer. This information is readily available for most all solar system operations. In unattended operation, current data on building operation are displayed for public information. These displays correlate with wall charts located next to the DAS enclosure which provide further information on the energy system.

Data stored on magnetic tape are tagged with date and time information to aid in later use. The magnetic tape for each week will be taken to the University of Santa Clara where it will be transferred to hard copy storage using the high-speed printer available there. The University computer system to be used is comprised of Hewlett-Packard software and hardware, ensuring compatibility with the Community Recreation Center DAS computer system. At the University, the information collected will be used to make compilations of weekly, monthly, and seasonal data.

A representative hardcopy printout produced by the University of Santa Clara from system data for July 21, 1977 is shown in the following computer printouts.

SANTA CLARA COMMUNITY CENTER SOLAR HEATING AND COOLING PROJECT

DAILY TOTALS FOR DAY NUMBER 202

NOTE: ALL QUANTITIES, UNLESS NOTED OTHERWISE, ARE GIVEN IN TERMS OF MILLIONS OF BTUS.

* * * * ENVIRONMENTAL FACTORS * * * *

AVG. AMBIENT TEMP. 68.3 DEGREES F. HIGH .0 DEGREES F. LOW .0 DEGEES F

AVG.WIND SPEED 4.8 M.P.H., HIGH .0 M.P.H., AVG. WIND SPEED DURING COLLECTOR OPERATION .0 M.P.H.

DAILY INSOLATION 2522.4 BTU/DAY SQ.FT., HIGH .0 BTU/HR.SQ.FT.

* * * * COLLECTOR ARRAY CALCULATIONS * * * *

	INCIDENT SOLAR	INCIDENT DURING OPERATION	ENERGY COLLECTED	EFFICIENCY DURING OPERATION	EFFICIENCY OVER DAY	FR(TA)	FRUL	TP-TA/QI AVG.
ARRAY #1	10.66	9.67	2.91	30.05	27.27	.0000E+00	.000E+00	.6848E+00
ARRAY #2	7.21	6.55	1.86	28.45	25.82	.0000E+00	.000E+00	.6841E+00
TOTAL	17.87	16.22	4.49	27.71	25.15	.0000E+00	.000E+00	.6845E+00

* * * * BOILER CALCULATIONS * * * *

GAS USE OF BOILER AS RECORDED BY METER 3825.0 CU.FT. HEAT VALUE OF GAS USED 4.02 MILLION BTUS

ESTIMATED OUTPUT OF BOILER 2.81 MILLION BTUS, BASED ON 70% BOILER EFFICIENCY

* * * * HOT RESERVOIR CALCULATIONS * * * *

ENERGY OUT	.09	ENERGY CHANGE	-.10
ENERGY IN		LOSS	
BOILER	.01	MAKE UP WATER	.0000 (. GALS.)
SOLAR	.14	BOIL OFF	.0000
SOLAR BLEED	.00	INSULATION	.3438
SOLAR DUMP	.19		
		TOTAL	.3438
TOTAL	.33		
PREHEAT TO COLLECTORS	.00	EFFICIENCY	.00

* * * * ABSORBTION CHILLERS CALCULATIONS * * *

ENERGY DIRECTED TO CHILLERS		COLD WATER ENERGY FROM CHILLERS	
SOLAR	4.59	SOLAR	2.32
BOILER	2.67	BOILER	1.23
TOTAL	7.26	TOTAL	3.56

C.O.P. OF CHILLERS		COOLING TOWER ENERGY DISSIPATED	10.84
SOLAR	.506		
BOILER	.462		
OVERALL	.490		

* * * * HOT FAN COILS, DOMESTIC HOT WATER, COLD FAN COILS, AND COLD RESERVOIR ENERGY CALCULATIONS * * * *

ENERGY DIRECTED TO HFC		ENERGY DIRECTED TO DHW	
SOLAR	.03	SOLAR	.1833
BOILER	.16	BOILER	.0055
HOT RESERVOIR	.01	HOT RESERVOIR	.0453
CHILLER BLEED	.02		
		TOTAL	.2340
TOTAL	.21		

HOT WATER USE 112. GALLONS

COLD WATER ENERGY DIRECTED TO CFC		COLD RESERVOIR	
RESERVOIR	4.13	ENERGY CHANGE	-.7028
BYPASS-SOLAR	.00	LOSS	.1233
BYPASS-BOILER	.00		
TOTAL	4.14		

(ABOVE EXPRESSED IN TERMS OF COLD WATER ENERGY)

* * * * AIR SIDE CALCULATIONS * * * *

AVG. BUILDING INTERIOR TEMP. 72.79 DEGREES F

ENERGY USED BY ZONES (EXPRESSED IN THOUSANDS OF BTUS)

ZONE	1	2	3	4	5A	5B	5C	6	7	8	9	10
HEATING	49.0	.4	86.3	61.3	16.2	14.0	15.4	35.8	16.5	7.5	3.9	.0
COOLING	.5	14.3	.0	16.4	437.9	.0	.0	151.2	45.7	.0	580.0	1013.9
ECONOMIZER	.0	6.0	57.7	47.1	45.8	.0	.0	76.4	.6	3.2	2.5	6.4

TOTAL HEATING ENERGY DELIVERED BY ZONES	.31
TOTAL COOLING ENERGY DELIVERED BY ZONES	2.26
TOTAL ECONOMIZER COOLING ENERGY DELIVERED	.25

*** * * * ENERGY SAVINGS * * * ***

	HFC	COOLING	DHW
FOSSIL ENERGY SAVED	.08	-3.78	.33
ELECTRIC ENERGY SAVED	-.01	.51	-.04
ELECTRIC ENERGY SAVED (IN KWH)	-3.08	148.61	-11.54

*** * * * DISTRIBUTIONS OF ENERGY * * * ***

PERCENT OF THERMAL ENERGY REQUIREMENT SUPPLIED BY	HEATING	COOLING	FOR DHW	TOTAL
BOILER	75.75	36.75	2.34	36.75
SOLAR	24.25	63.25	97.66	63.25

DISTRIBUTION OF SOLAR ENERGY

	HOT RES.	HFC	HFC-BLEED	CHL	DHW	SUM
PERCENT TO	8.13	.60	.40	102.17	4.08	115.38

DISTRIBUTION OF BOILER ENERGY

	HOT RES.	HFC	CHL	DHW	SUM
PERCENT TO	.22	5.67	94.89	.19	100.98

DISTRIBUTION OF HOT RESERVOIR ENERGY

	HFC	DHW	PREHEAT	SUM
PERCENT TO	13.24	58.36	.00	71.60

*** * * * TOTAL ENERGY LOADS * * * ***

SUPPLIED HEATING LOAD	.2[illegible]	DELIVERED HEATING LOAD	.31
COOLING LOAD	4.14	COOLING LOAD	2.51
DHW LOAD	.2[illegible]	DHW LOAD	.23
TOTAL	4.58	TOTAL	3.05

SOLAR ENERGY UTILIZED BY LOAD	4.88	
BOILER ENERGY UTILIZED BY LOAD	2.83	
OPERATING ELECTRICAL ENERGY	1.72	503.62 KWH
TOTAL ENERGY CONSUMED	10.61	
TOTAL ELECTRICAL ENERGY SAVED	.46	133.99 KWH
TOTAL FOSSIL FUEL ENERGY SAVED	-3.38	-3214.6 CU.FT.
SOLAR FRACTION OF BUILDING LOAD	.600	(BY ERDA METHOD)
SYSTEM PERFORMANCE FACTOR	.470	(THIS FACTOR IS THE RATIO OF THE TOTAL ENERGY DELIVERED TO THE BUILDING TO THE TOTAL EQUIVALENT FOSSIL FUEL ENERGY EXPENDED. THIS TAKES INTO ACCOUNT THE FOSSIL FUEL USED TO GENERATE ELECTRICAL ENERGY USED.)

Section 6
SOLAR SYSTEM COSTS
by
W. E. SHANNON

As described in the Introduction, the City of Santa Clara had planned for the addition of the Community Recreation Center in their Central Park; construction funds for that facility were provided in the City's budgeting. Table 6-1 is a cost estimate for constructing that facility without the solar system. The contract for construction of the Community Recreation Center without the solar system was awarded in April 1974. Construction was essentially complete, and the facility was occupied before actual installation of the solar system was begun (Table 1-4).

Table 6-1

COMMUNITY RECREATION CENTER ESTIMATED CONSTRUCTION COSTS

	(K)
Building, Structure, and Finishing	670
Parking and Drainage	104
Mechanical	108
Plumbing	35
Electrical	75
Fire Sprinklers	18
	1,010

6.1 INITIAL GRANT AWARD

In November 1974, when the National Science Foundation accepted the City's proposal to install solar heating and cooling on the Community Recreation Center, the total program proposed was more extensive than just the design and hardware installation aspects of the solar system. The multiyear effort was divided into two major program phases. Phase I was devoted principally to the design, specification, procurement, and installation of the solar system. Phase II was devoted to obtaining solar system performance data and to the creation of various reports pertaining to solar heating and cooling, with emphasis on public utility utilization of solar energy. Table 6-2 presents the major cost elements of the original Grant for both program phases. In this table, the Phase I total authorization of $404,200 was divided into broad categories – one for contractual (professional) services associated principally with the design and specification of the solar system. The balance of the funding under the heading identified as Improvements dealt with the acquisition and installation of the solar-peculiar hardware which at that time (Nov 1974) was estimated to cost $246,850.

In Table 6-2, under Phase I (Improvements), the principal categories of hardware costs are grouped into six areas, and these same groupings will be the basis for the following review and analysis of final project costs.

6.2 PROJECT COST ANALYSIS

In November of 1974, estimated costs for solar hardware ($246,850) were based on the presumption that the installed system would be characterized by:

- 6500 square feet of roof-mounted, fixed flat-plate collectors
- Three 25-ton absorption chillers
- Hot storage of 10,000 gallons
- Cold storage of 20,000 gallons
- Solar system connected to the building mechanical system (Ref. Section 2)

During the initial planning and structuring of the project for the Community Recreation Center, Lockheed had suggested to the City and in turn to the National Science Foundation that it not undertake in any of its facilities the fabrication or assembly of hardware for the system. It was believed that if Lockheed – with its extensive technological

Table 6-2

ALLOCATION OF FUNDS

	Phase I	Phase II	Total
Contractual Services			
Architect	$ 20,000	$ 0	$ 20,000
University of Santa Clara	6,600	20,800	27,400
Lockheed	101,000	53,000	155,000
Oversight Committee	5,000	10,450	15,450
Utility Consultants	3,000	12,500	15,500
Legal Consultants	8,000	0	8,000
Science Advisor	12,750	4,250	17,000
	$157,350	$101,000	$258,350
Improvements			
Solar Collectors	$ 80,600	$ 0	$ 80,600
Piping	42,000	0	42,000
Storage Tanks	33,000	0	33,000
Absorption Chillers	26,310	0	26,310
Controls	32,000	0	32,000
Instrumentation	32,940	0	32,940
	$246,850	$ 0	$246,850
Total	$404,200	$101,000	$505,200

NSF PTP 74-23517, Nov 1974

resources – produced any of the hardware, it might imply that only highly sophisticated organizations could undertake the design and installation of solar heating and cooling systems.

The desirability of exposing this project to as many commercial and industrial organizations as possible was recognized as a start in creating a solar energy intrastructure.

Concurrently, the project effort would seek visibility and involvement with appropriate construction trades and crafts.

The City of Santa Clara has a fully structured utility organization, and one of the goals of the project was to determine the extent to which a utility could participate in solar energy system applications, including actual installations by the utility. Accordingly, to control costs, responsibility for acquiring major components was divided between the City for procurement and site installation and the architect who, in turn, implemented the City's decisions through the general contractor, as summarized in Table 6-3.

Table 6-3

SANTA CLARA SOLAR PROJECT

	Item	Procurement Responsibility
1.	Solar Collectors and Hardware	City
2.	Plumbing and Electrical – Hardware and Labor	Architect/General Contractor
3.	Chillers	Architect/General Contractor
4.	Controls	City
5.	Storage	City
6.	Data Acquisition System	City

The appendices to this report present the principal engineering specifications that were prepared as part of the Lockheed effort to design and specify the system. These documents were used:

a. By the City Utility Department as the basis for procurement and site installation.

b. By the Architect/Mechanical Engineering in preparing drawings and specifications for the several change order packages to the general contractor already working on the construction of the building.

The National Science Foundation Grant for Phase I was awarded to the City in November of 1974. In January of 1975, Lockheed concluded its negotiations with the City, receiving a fixed-price completion-type professional services contract for the design of the system and the preparation of supporting engineering drawings and specifications. In mid-1975 the Lockheed work had progressed to the point of selecting a final concept for system mechanization with the elected approach featuring major changes from the initial design. Now, the system was characterized by:

- 7,085 square feet of roof-mounted fixed flat-plate collectors
- Two 25-ton absorption chillers
- Hot storage – 10,000 gallons
- Cold storage – 50,000 gallons (with effective stratification)
- Three major modes of system operation – no, low, and high solar

Contractors and material suppliers submitted cost estimates based on system design progress and on a more definitive requirement for piping, plumbing, and the control system.

The team working on this project – The City, architect, mechanical engineer, and Lockheed – at this point recognized that, even with the City assuming a significant [illegible] procurement and construction, the estimates initially prepared for the project had been projected far below costs. Thus, a new cost summary was prepared with the final system design as the basis for estimate. Also recognized in this estimate was the impact of project delays, the tendency to underestimate the installed costs of pumps, plumbing, etc., and the fact that the solar system would be installed totally out of phase with building construction. Reflecting cost rises in materials and labor, the total project cost for the Phase I activity was revised upward to:

Estimated total project cost (Mid 1975)	$436,221
November 1974 Estimate	246,850
Increase	$189,371

In July of 1975, a change proposal was prepared by the City and submitted to ERDA. As a result of this submission, ERDA agreed to underwrite an additional $136,621 of increased costs, with the balance to be provided by the City.

The revised July 1975 total estimated project costs were broken down into major categories as follows:

Category	Cost
Solar Collectors	$125,820
Plumbing, Piping and Electrical	134,668
Storage	76,000
Absorption Chillers	25,000
Controls	37,600
Data Acquisition System	37,133
	$436,221

Phase I of this program was completed in the spring of 1977; Table 6-4 compares actual expenditures to previous estimates. As shown, final project costs came in at approximately $76,000 above the July 1975 revised cost estimate. While some hardware categories were procured and installed at costs below the July 1975 projections, the overage is primarily attributable to plumbing and piping costs and the requirements for racks to support the collectors on the roof of the multipurpose room (the racks cost as much as the collectors they supported). Further visibility into actual costs in the major categories including a breakdown between materials and labor is presented in Table 6-5.

The actual cost of $509,884 for the completion of Phase I covers labor and materials only. To this amount, add the attendant and necessary professional services delivered primarily by Lockheed and the architect in the following amounts:

Lockheed	$90,000
Architect	$56,441 (including his mechanical and structural engineer)

Table 6-4

COST COMPARISON, COMMUNITY RECREATION CENTER
SOLAR HEATING AND COOLING

Category	Original Grant	July 1975 Estimate	Actual Cost
001 – Solar Collectors	$ 86,600	$125,820	$109,051
002 – Plumbing, Piping, Electrical	42,000	134,668	202,634
003 – Storage	33,000	76,000	57,359
004 – Absorption Chillers	26,310	25,000	24,762
005 – Controls	32,000	37,600	25,566
006 – Data Acquisition System	32,940	37,133	37,827
007 – Building Modifications	–	–	52,685
Totals	$246,850	$436,221	$509,884

Thus, the Phase I total project cost is $656,325 – shared by ERDA ($564,371) and the City ($91,954). Recalling the basic building construction cost estimates (Table 6-1), these costs are approximately 50% of the initial Community Recreation Center construction program costs. As a basis for comparison, note that in conventional commercial construction practice, costs for installed mechanical systems generally range from 20 to 25% of total project costs, with solar systems hardware costs generally additive to mechanical system costs. In addition, many of the costs incurred were necessary to support the demonstration and research aspects of the project and would not be incurred on a non-demonstration solar heating and cooling system.

Contrary to some popular notions, costs for solar collectors (in this case, an array of 436 modules with an aperture of 7085 square feet) was not the major cost element; it was only 20% of the final installed system cost.

The foregoing data represent the total financial incumbrance to complete Phase I of the program; however, many of the major participants in this effort contributed their own time in excess of individual funded support. The exploration and reporting of these cost elements is beyond the scope of this report.

Table 6-5

COMMUNITY RECREATION CENTER, SOLAR HEATING ACTUAL COST SUMMARY BY SUPPLIER AND HARDWARE CATEGORY

Supplier \ Category	1 Collectors	2 Piping and Electrical	3 Storage	4 Chillers	5 Controls	6 Data System and Instrumentation	7 Building Modifications
CITY OF SANTA CLARA							
• City-Purchased Material	102,030	11,788	42,588		1,550	20,875	600
• City-Rented Equipment		41	5,846				
• City Labor*	7,020	5,091	8,923			151	1,099
CONTROLS SUPPLIER							
• Hardware					14,716	7,100	
• Labor*					9,299	3,445	
GENERAL CONTRACTOR							
• Change Order No. 2 (Corten Roof)							
• Purchased Material							11,159
• Labor*							6,445
• Change Order No. 3 (Mech. Room, Pumps and Electrical)							
• Purchased Material		65,824		20,860		726	
• Labor*		48,782		3,901		1,155	
• Change Order No. 4 (Piping and Insolation, Collector Supports)							
• Purchased Material		24,267				1,712	9,475
• Labor*		46,838				2,662	23,904
Subtotals:							
Material	64,974	101,922	48,435	20,860	16,266	30,413	21,235
Labor*	7,020	100,711	8,923	3,901	9,299	7,413	31,450
TOTAL	109,050	202,633	57,358	24,762	25,565	37,827	52,685

*"Labor" includes all burdens and profit.

At this time (September 1977), the total program has been restructured and extended with revised project costs for Phases I and II of $957,375. Of this amount, ERDA is funding $671,321, and the City is funding $286,054.

Appendix A
PRELIMINARY COLLECTOR DESIGN SPECIFICATION

FLAT PLATE SOLAR COLLECTOR
CITY OF SANTA CLARA COMMUNITY CENTER

These specifications are for the type of flat plate solar collector to be used with the Solar-powered Heating/Cooling system for the Santa Clara Community Recreation Center, 967 Kiely Boulevard, Santa Clara, California.

1.0 UNIT REQUIREMENTS

1.1 Unit Line

1.1.1 Outside total dimensions are W 25.5" x L 102" x H 7".

1.2 Unit Structure

1.2.1 Unit is a vented enclosed metal box with structural provisions for thermal expansion of all components including roof attachments.

1.2.2 Unit aperture dimensions are W 22" x L 96".

1.2.3 Cover glasses and copper absorber plate are to be thermally insulated from metal enclosure.

1.2.4 Units are to be water tight except for vent hole.

1.2.5 Top edges of metal enclosure will have a dark brown or black color. Top edge shall not develop rust or other scale that may deposit on the adjacent glazing.

1.2.6 Units are to withstand wind loads up to 50 mph.

1.2.7 Provisions will be made in the unit box design so that both cover plates are removable for in situ replacement.

1.3 Cover Glass

1.3.1 Two tempered glass plates shall be used, each measuring W 24" x L 98" x H 1/8".

1.3.2 The spacing between cover glasses is to be nominally 1". The spacing between the inner cover glass and the absorber plate is to be nominally 1". Lockheed will determine exact values.

1.3.3 Daylight transmission through two cover glasses shall be $\geq$ 75%.

1.3.4 Top cover glass is to be patterned to minimize specular reflection and installed with the smoothest side up for ease in cleaning.

1.3.5 Cover glass sealing material to be used cannot cause optical degradating deposits to form on the cover plate and absorber plate selective coating. The sealing material shall also be thermally insulating.

1.4 Absorber Plate

1.4.1 Nominal system static pressure is 20 psig at 220°F, 10% propylene glycol in water. The absorber plate is to be all copper with dimensions W 22" x L 96".

1.4.2 Pressure drop across each plate shall be nominally 0.4 psi at a uniform flow rate among risers totaling 0.3 gpm per plate.

1.4.3 Absorber plate is to be designed for a minimum of 17 equally spaced risers with an equivalent diameter of 0.15".

1.4.4 The design intent is that the temperature extreme between any two risers on the absorber plate is $\leq$ 2°F when the average plate temperature is 210°F.

1.4.5 All absorber plate fittings should be flexible; brazed, not soldered, with no material degradation up to 450°F.

1.4.6 Headers are to be designed for a maximum pressure drop of 1/25 of the pressure drop across the risers to insure uniform flow in all risers.

1.4.7 Absorber plate surface is to have a selective coating with the following properties $\alpha \geq 0.97$, $\alpha / \varepsilon \geq 3.8$.

1.5 Insulation

1.5.1 Insulation backing is fiberglass batt type with an R factor equal to fifteen (15).

1.5.2 The insulation material is to retain all insulation characteristics after repeated temperature cycling up to 450°F. (e.g., JM 1000 series). There shall be no condensible off-gas products.

1.6 Edge Retaining System

1.6.1 The edge retainer will not have any metal to glass contact with the top cover plate.

1.7 Desiccant

1.7.1 A thermally regenerative type desiccant is to be used. The enclosure shall be vented to the outside air through the desiccant, which should be readily accessible for ease of replacement when necessary.

1.8 Plumbing Connectors

1.8.1 Plumbing connectors are to be flexible connectors to headers of highly reliable material.

1.9 Unit Quantity and Spares

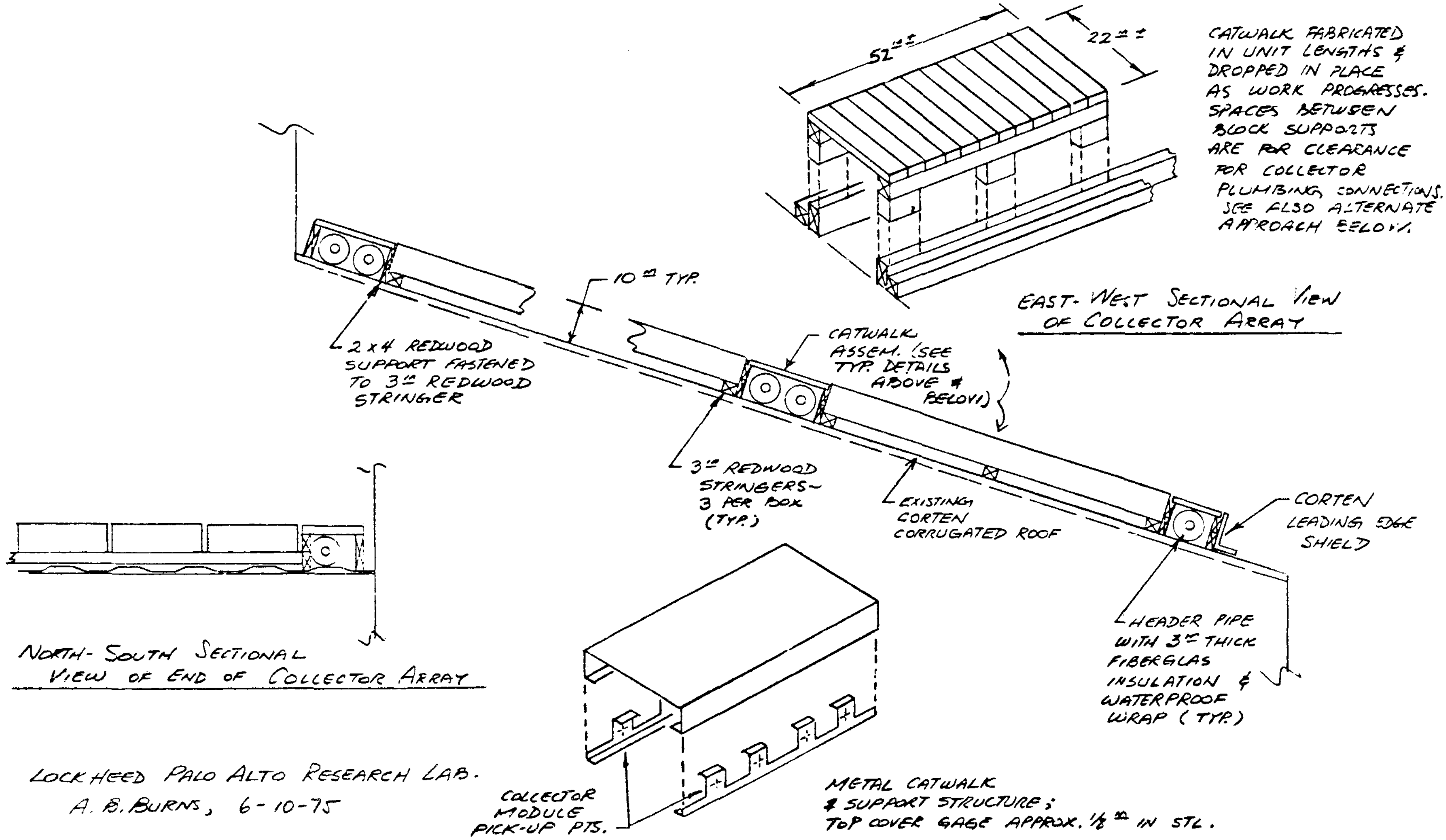
1.9.1 There shall be total quantity of 440 units plus 12 cover plates of each type.

1.10 Delivery

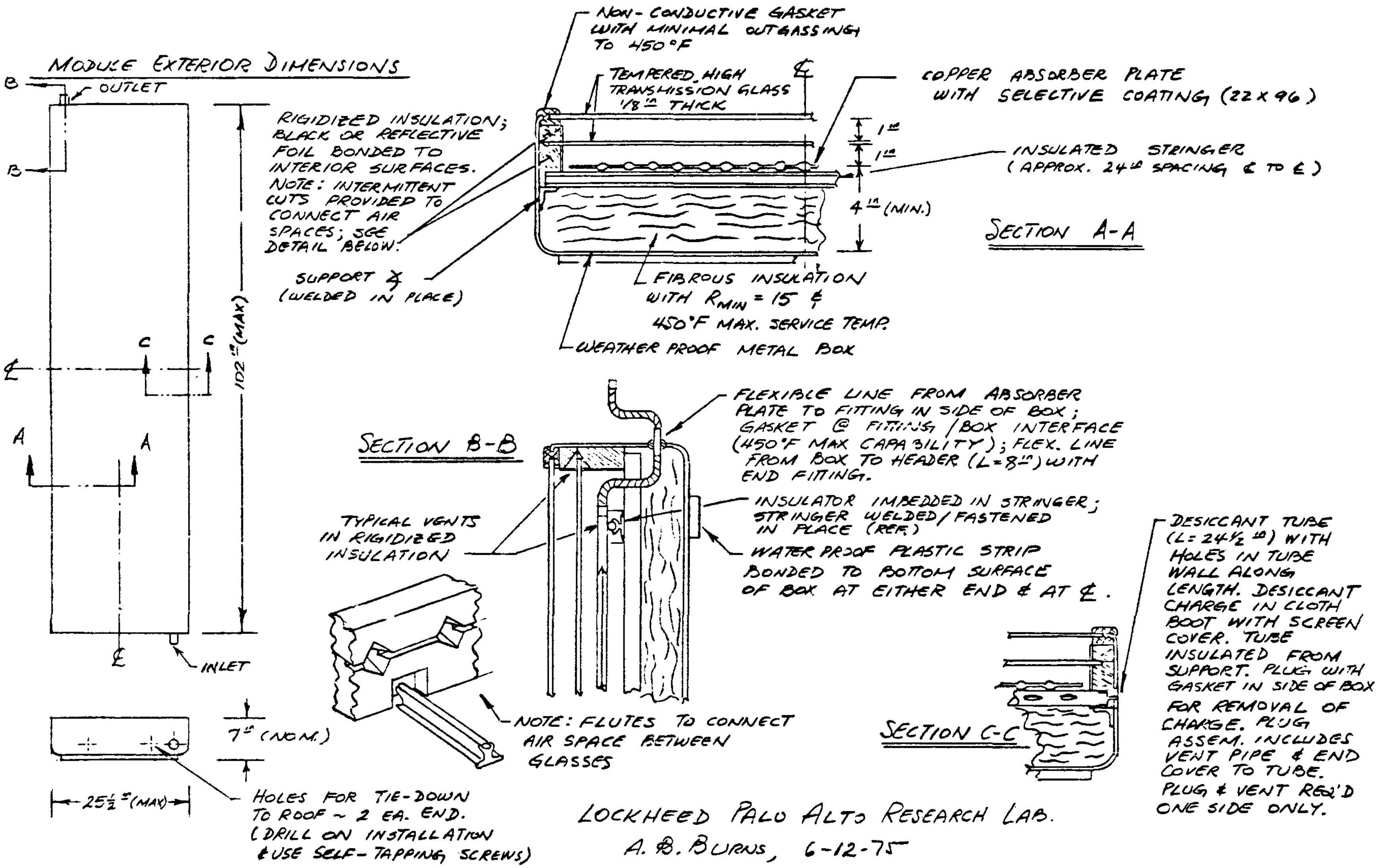
1.10.1 Delivery of units will be FOB Santa Clara Community Center. 967 Kiely Boulevard, Santa Clara, California.

SANTA CLARA COMMUNITY CENTER SOLAR COLLECTOR ~ SLOPING ROOF PORTION

TYPICAL DETAILS FOR HEADER COVERS & CATWALKS



COLLECTOR MODULE - TYPICAL DETAILS



Appendix B

CONTROL SYSTEM ENGINEERING SPECIFICATION

TITLE:	CONTROLS SYSTEM	Prepared by: S. R. Leacock Approved by: [signature]
PROGRAM:	SOLAR HEATING AND COOLING FOR CITY OF SANTA CLARA COMMUNITY RECREATION CENTER	ES No.: SCP 03:01 Date: 23 May 1975

These engineering specifications are for the control and sensing hardware to be installed with the Solar Heating/Cooling System in the new Community Recreation Center at 969 Kiely Blvd., City of Santa Clara. The system objective is to maximize utilization of solar energy to meet building energy demands.

1.0 Installation

1.1 The control system shall be installed under the cognizance of control manufacturer's representative.

1.2 A temperature control panel shall be furnished by the temperature controls contractor with all equipment prewired to numbered terminal strips.

2.0 System Description and Operation

2.1 General

The building is divided into twelve zones that are served by conventional hot and cold fan coil units. The hot or cold water for these units is supplied by solar energy and/or by the auxiliary boiler upon demand from the zone controls. Reservoirs are used to store energy for building demands.

Provisions are made so that the system can meet building load demands if the reservoirs are not available for energy usage. The piping diagrams illustrating the arrangement are included in this specification as **Annex A. These** diagrams identify pumps, control valves, and temperature and data sensors with symbols referred to in this specification. The cold reservoir shall be maintained below (min spec) an upper operating temperature via the gas boiler and chillers. There are optional provisions for the gas fired boiler to min spec the hot reservoir. These specified temperature conditions are respectively:

- When the Hot Reservoir temperature (T_8) $<115^oF$, the gas boiler shall raise the reservoir temperature to 115^oF.

- When the Cold Reservoir temperature (T_{10}) $>55^{o}F$, the gas boiler shall (via chillers) lower the reservoir temperature to $55^{o}F$.

When driven by solar energy, the energy storage ranges for these reservoirs are:

Hot Reservoir between ambient ($115^{o}F$ optional) and $212^{o}F$.
Cold Reservoir between $44^{o}F$ and $55^{o}F$.

The Cold Reservoir has first priority on solar energy. If solar flux is inadequate to fire absorption cycle chiller units, or if their chilled water input temperature from the reservoir is below $44^{o}F$ (T_{11}), all solar energy collected is transferred to the hot storage reservoir via heat exchanger (HX_1).

The chiller units shall have a three minute minimum time delay before their pumps are turned off. This operation is to minimize "short cycling" the chiller units whenever there are intermittent solar generated conditions (e.g. clouds).

The instrument setpoints contained in this specification (e.g. $44^{o}F$, 140 gpm) are nominal design values and are subject to final adjustment when optimizing the performance of the working system. The sensing and control hardware devices shall have inherent nominal setting flexibility to allow for these optimum performance changes. Control and sensing hardware shall implement reservoir operations as follows:

2.1.1 Hot Reservoir

1. Reservoir temperatures shall be sensed at the bottom of the tank.
2. When there is an energy transfer through the heat exchanger to the Hot Reservoir, water shall be taken from, and returned, to, the bottom of the reservoir (V_8 in A→AB position). In the NO SOLAR MODE, (see para. 3.0) water flow shall be taken from the top of the reservoir and returned to the bottom (V_8 in B→AB position).
3. Sensors T_3 and T_7 shall cycle pump P_2 so that energy is exchanged via HX_1 only when the collector exit water temperature or boiler water temperature is greater than the reservoir water temperature.

The operating temperature differential shall be determined by the optimum energy transfer in accordance with the efficiency of the heat exchanger HX_1.

Provisions shall be made for the control hardware to optionally reverse heat exchange (Hot Reservoir to Collectors) by manual selection, S_9, in the No Sun and Low Sun modes only. ($H_{RES} \geq 140^{o}F$)

4. If the reservoir requires a min spec by the boiler, valve V_2 shall be in the B→AB position and pumps P_2, P_9 and P_{10} shall be activated for heat exchanging through HX_1.

2.1.2 Cold Reservoir

1. Reservoir temperatures shall be sensed at the top of the tank.
2. Cold water generated by chillers is introduced at the bottom of the tank. Intake from the reservoir to the chiller(s) shall be from the top of the tank.
3. Return water from the Fan Coil units shall be stored at the top of the tank. Reservoir water to the Fan Coil units shall be from the bottom of the tank.
4. To min spec the Cold Reservoir by the gas boiler (via chillers) the control positions are:

   V_4 in AB→A position
   V_5 in AB→A position
   V_6 in A→AB position
   Pumps P_4, P_6, P_7, P_8 and P_9 - On

2.2 Automatic System Start

A variable time clock device starts the operation of the Fan Coil units. Starting time is automatically varied depending on wind velocity and outdoor ambient temperatures. The time clock shall always start the system before scheduled building occupancy. The system may be programmed for different daily times of occupancy for each of the seven days of the week. A 12 hour bypass timer provides for "off schedule" operation. Manually activated signal sources for system operation shall be provided at the terminal control panel to override manual functions as required.

2.2.1 Sensor Systems

Existing zone sensing devices shall be replaced with resistance temperature device (RTD) sensor systems for control of existing zone hot and chilled water control valves and modulating mixed air damper motors. Signals shall also be suitable for data acquisition system input.

2.2.2 Economizer

Electronic RTD type room sensing elements (T_{19}) modulate hot water valve, mixed air damper system, and chilled water valve in sequence to maintain space temperature. The width of sequence band (^{o}F) is adjustable. If additional cooling is required, the control hardware shall activate the cooling system (via reservoir or chillers). The fresh air damper shall remain open until T_{18} overrides the economizer operation and the damper is closed in accordance with Engineering Memorandum #SPC-04:01 titled, "Performance Analysis Objectives, Techniques and Instrumentation" (A. B. Burns) paragraph "Daily Energy Supplied to Each Building Zone". All setting and adjustment hardware for the zone controllers will be located within the temperature control panel.

There are twelve (12) RTD type room sensing elements (T_{19}) and ten(10) economizer damper control elements (T_{18}).

2.2.3 System Mode Control Signals

The pyranometer shall determine which system mode of operation is to be activated. The adjustable time delay relay hardware shall verify the pyranometer output mode control signal by re-reading the signal after a fixed time period (3-5 minutes) before initializing a different system mode of operation. This operation is to ensure that control system does not respond to pyranometer spurious output voltage transients.

Sensing and control hardware shall respond to and implement solar system operations for each of the three modes. Each mode is related to the quantity of sun flux measured (in millivolts) by the pyranometer (Pyr). The P_{yr} output is proportional to the flux measured.

If there is a pyranometer output signal malfunction, the NO SOLAR ENERGY and LOW SOLAR ENERGY modes shall be activated by a backup signal source from collector water temperature sensors T_1 and T_2. Collector exit water temperature sensor T_4 shall be used as a backup signal to activate the HIGH SOLAR ENERGY MODE.

2.3 Back-Up Mode of System Operation

If the building load requirements cannot be met with stored reservoir energy because the reservoirs are inoperative, the following back-up mode operations shall prevail:

2.3.1 Heating

When the building heating requirements cannot be met by the hot reservoir, and there is no solar energy, the gas fired boiler shall be activated, pumps P_3 and P_9 turned on, and hot water supplied to the Fan Coil units, directly from the boiler. Valve V_3 shall provide mixing capability to maintain an input Fan Coil hot water temperature of 105°F. Manual override switch S_4, isolates the reservoir in this mode.

2.3.2 Cooling

Either solar energy or the gas-fired boiler shall supply the energy required via the chillers to meet building load requirements. The control and sensing hardware shall activate the boiler, when needed, and control hardware positions will be:

V_1 in A→AB position for boiler, B→AB for solar

V_2 in AB position

V_4 in AB→B position

V_5 in AB→B position

V_6 in B→AB position

P_4, P_5, P_6, (P_7), P_8, P_9 - On

Note: Valves V_4, V_5, V_6 are left in these positions when the system is "Off" in order to maintain a pressurized closed system utilizing city water pressure.

The boiler output water temperature shall be set to a constant 220°F to meet chiller firing water requirements. Hot water may be provided simultaneously to the Hot Fan Coil units in this mode, either from solar or boiler.

The boiler is allowed to fire under its own controls. The chiller units and associated equipment operate under their own controls. Then, automatically the boiler and chiller units are turned off, when the building load requirements are met. A control switch (S_6) shall be provided that allows the manual selection of one or both Chiller units to be energized for this operation. Manual override switch S_5 isolates the reservoir in this mode.

2.4 Domestic Hot Water Heating

Domestic hot water shall be generated, via HX_2, in the boiler loop. A self contained temperature sensor located in HX_2 shall switch valve V_7 to the B→AB position (bypass) when the domestic water temperature →120°F. Temperature sensor T_{20} shall activate the boiler when the domestic hot water temp. $< 120°F$.

2.5 Interlocks

The boiler operation shall be interlocked so the boiler cannot min spec the cold reservoir when valve V_1 is in the B→AB position.

3.0 System Modes of Operation

The following discussion is organized according to the three solar system modes of operation:

- No Solar Energy
  Energy required to min spec reservoirs and/or meet building loads supplied by boiler.
- Low Solar Energy
  Available Solar energy is stored in the hot reservoir, and used to meet building heating and domestic hot water loads. Cooling and min spec of cold reservoir supplied by boiler via chiller.
- High Solar Energy
  Cooling, min spec of cold reservoir, heating and domestic hot water provided by solar energy.

3.1 Mode #1 Operation (No Solar P_{yr} $\leq$1.5 MV, T_1 and T_2 $\leq 140^{o}F$)

3.1.1 If either reservoir is not within min spec temperatures, the cold reservoir and optionally the hot reservoir shall be brought into spec under the conditions of paragraphs 2.1.1 and 2.1.2. Building heating and cooling requirements shall be serviced simultaneously.

3.1.2 If the cold reservoir is within min spec, system component operations to meet building cooling (only) loads are:

Control Positions

V_1 in A→AB position

V_2 in B→AB position Heat exchanger open to boiler.

V_3 Modulating under control of T_9 set to $105^{o}F$.

V_4 in AB→A position Store return water at top of reservoir.

V_5 in AB→B position Closed to reservoir to provide pressure to suction side of P_4.

V_6 in A→AB position Water flow from bottom of reservoir to Fan Coils Units.

P_5 - On, All other pumps - Off.

3.1.3 If the hot reservoir is within min spec, system component operations to meet building heating (only) loads are:

Control Positions

V_1 in same position

V_2 in B→AB position Flow from HX_1 through boiler, HX_2 to P_9.

V_3 Modulating under control of T_9 set to $105^{o}F$.

V_4 in AB→B position

V_5 in same position

V_6 in B→AB position

V_8 in B→AB position

P_2, P_3, P_9 and P_{10} - On; All other pumps off.

If both heating and cooling are required simultaneously, refer to paragraph 3.1.2 and start P_2, P_3, P_9 and P_{10}.

3.1.4 If either the hot or cold reservoir is out of service, the system shall operate under the conditions of paragraphs 2.3.1 and 2.3.2.

3.2 Mode II Operation (Low Solar: P_{yr} $1.5 < S < 4.4$ MV, T_1 and T_2 $140^{\circ}F < T < 190^{\circ}F$).

3.2.1 Chiller firing water supplied by boiler in this mode. If the cold reservoir is not within min spec, it shall be brought into min spec under the conditions of paragraph 2.1.2. Building cooling requirements shall be serviced simultaneously. With the cold reservoir within min spec, the operation of system components to meet building loads are:

Control Positions

V_1 in A→AB position flow from collectors through HX_1 loop.

V_2 positioned as required.

V_3 - Modulating under control of T_9 set to $105^{\circ}F$.

V_4 in AB→A position as required.

V_5 in AB→A position as required.

V_6 in A→AB position as required.

V_8 in A→AB position

P_1 - On, pump 140 gpm flow through collector/HX_1 loop.

P_2 - On, pump 140 gpm flow through hot reservoir via HX_1 loop per paragraph 2.1.1.

P_3 - On as required

P_4, P_5, P_6, P_7, P_8 - On as required.

P_9 - On as required

P_{10} - Off.

NOTE: When the boiler min specs the cold reservoir valve V_1 must be in the A→AB position.

3.3.2 If the cold reservoir is out of service, the system shall operate under the conditions of paragraph 2.3.2. Automatic operation of system with the hot reservoir out of service is prohibited during this mode of operation. The hot reservoir prevents possible activation of safety valves (and subsequent system down time due to loss of pressure) by acting as a sump for excess solar energy. Auxiliary flow-through valves shall be provided for this condition.

3.3 Mode III Operation (High Solar P_{yr} ≥4.4 MV, T_4 ≥195°F)

3.3.1 If either the hot or cold reservoir is not within min spec, the boiler shall not be activated to min spec either reservoir per paragraphs 2.1.1 and 2.1.2. The operation of system components to meet building loads are:

Control Positions

V_1 in B→AB position flow collector/chiller loop.

V_2 positioned as required.

V_3 Modulating under control of T_9, set to 105°F.

V_4 in AB→A position. Fan Coil return to Cold reservoir.

V_5 in AB→A position.

V_6 in A→AB position Reservoir to Fan Coil units.

V_8 in A→AB position

P_1 - On, pump 140 gpm flow Collector/Chiller loop.

P_{2A} - On P_2 Off if temp sensor T_{15} reads ≥210°F, if T_{15} reads <210°F, P_{2A} turned off, P_2 turned on.

P_3 - On, as required.

P_4, P_5, P_6, P_7, P_8 On, as required.

P_9 - On, as required, to supply building heating load and domestic hot water.

P_{10} - On, in "Bleed-Off" mode only. (See last paragraph of this section)

When the collector exit water temperature is ≥210°F (T_{14}), and the cold reservoir temperature (T_{11}) is ≥44°F, pumps P_6 and P_8 are activated and one chiller is energized and allowed to operate on its own controls. When the collector exit water temperature reaches 220°F (T_6), energize the second chiller, start pump P_7. As the solar flux diminishes, the second chiller shall be deenergized when the collector ΔT (T_5-T_{13}) ≤10°F. Chiller operation shall always be deenergized when the collector exit water temperature ≤195°F (T_4). Valve V_1 is then switched to the A→AB position allowing full collector flow through HX_1 and heat exchange is hot reservoir per paragraph 3.1.1. The cooling tower is energized when either chiller unit is in operation. The cooling tower fan is cycled, to maintain condensing temperature (T_{12}), as a function of the temperature of the tower input water.

A collector water temperature "bleed-off mode" shall be provided and shall operate as follows: If T_{16} exceeds 230°F, open valve V_2 to B→AB, start P_{2A}, P_{10}, P_9 and heat exchange via HX_1, to Hot Reservoir.

3.3.2 If the cold reservoir is out of service, the system shall operate under the conditions of paragraph 2.3.2. Automatic operation of system with the hot reservoir out of service is prohibited during this mode of operation. The hot reservoir prevents possible activation of safety valves (and subsequent system down time due to loss of pressure) by acting as a sump for excess solar energy.

4.0 Automatic System Safety Operations

4.1 Solar Array High Temperature Protection (Dump Mode)

If the temperature of collector exit water ≥240°F, as sensed by T_{17}, valve V_1 is switched to the A→AB position to pass 140 gpm through HX_1. The heat exchange to the Hot Reservoir is per paragraph 2.1.1. When collector exit water temperature <240°F, switch V_1 to the B→AB position (Chiller loop).

4.2 Loss of System Pressure

Pressure switch PS_1, located in the expansion tank, shall on a loss of system pressure (17 psi ± 2%), turn electrical power off. Nominal solar operating system pressure is 20 psi ± 2%.

5.0 Temperature Control Panel and Functions

Temperature control panel will be furnished with all panel equipment either flush-mounted in face or mounted within and prewired to numbered terminal strips. Face-mounted equipment shall be identified with engraved bakelite nameplates; internally mounted equipment with Dymo tape. NOTE: All valves shall have identifying labels as to their numerical designation and valve positions.

5.1 Face-Mounted equipment shall be as follows:

5.1.1 Indicating Pilot Lights:

1) Fan Coil Units
2) All pumps
3) All valves (in the A→AB position)
4) System pressure loss.
5) Boiler on
6) Chiller #1 and Chiller #2
7) Solar status - No Solar -- Low Solar -- High Solar.

5.1.2 Override Switches

S_1 P_1 - On, Auto

S_2 Boiler - On, Auto

S_3 P_2 - On, Auto

S_4 Hot reservoir - Auto, Bypass, Min Spec

S_5 Cold reservoir - Auto, Bypass

S_6 Chiller #1, #2 - On, Auto - Alternator switch.

S_7 P_{2A} - On, Auto

S_8 Mode Control Switch - Auto, Mode #1, Mode #2, Mode #3.

S_9 Reverse Heat Exchange-On, Auto

5.2 All bridges, amplifiers, relays, transformers, and etc. shall be mounted internally and prewired to numbered terminal strips. Settings and adjustments within the Temperature Control panel shall be:

a. All zone temperature set points.

b. Pyranometer set point and selector switches

c. 12-hour bypass timer

d. Setpoint for any point being controlled by an RTD sensor system.

5.3 Provide terminal strip within panel which gives access to all Platinum Resistance Thermometers (PRT) and sensor inputs for data acquisition system.

5.4 Provide 20 VDC voltage power supply for control panel pilot lights and data monitoring/acquisition signals.

5.5 Provide relay contact points for On/Off indication for all Fan Coil units, pumps, both chillers, and the boiler.

6.0 RTD Sensors

Furnish and install PRT's for all points shown on drawing Control Schematics M7. PRT shall be 100 ohms 70°F.

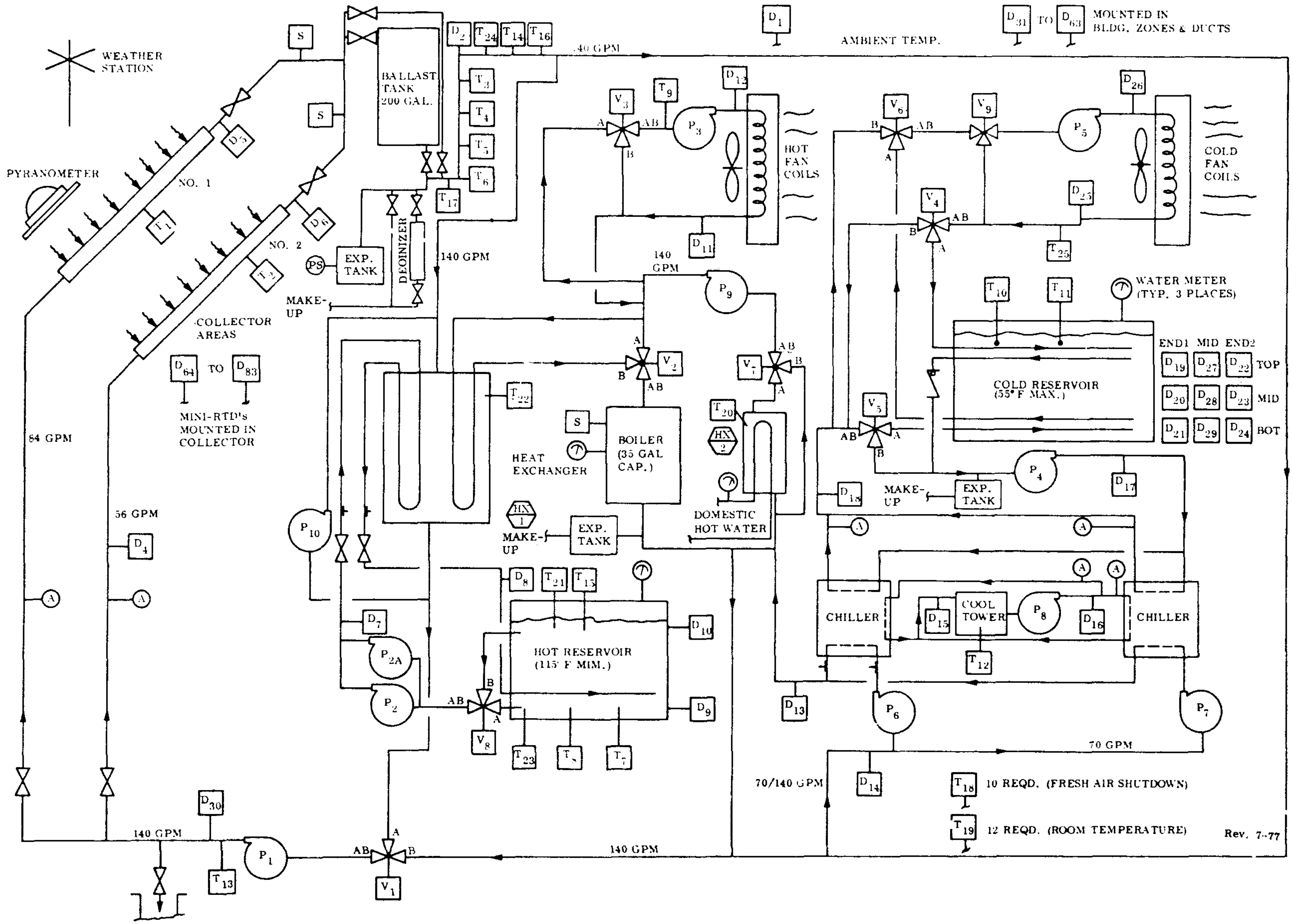
Furnish twenty (20) mini PRT's with same operating characteristics.

7.0 O&M Instructions

Furnish to owner 3 sets of Operating and Maintenance Instructions, including "as-built" drawings.

8.0 Guarantee

Equipment furnished shall be guaranteed for a period of one year after the date of acceptance.


WEATHER STATION
PYRANOMETER
NO. 1
NO. 2
COLLECTOR AREAS
D_{64} TO D_{83}
MINI-RTD's MOUNTED IN COLLECTOR
84 GPM
56 GPM
140 GPM
BALLAST TANK 200 GAL.
EXP. TANK
DEOINIZER
MAKE-UP
140 GPM
AMBIENT TEMP.
D_{31} TO D_{63} MOUNTED IN BLDG. ZONES & DUCTS
HOT FAN COILS
COLD FAN COILS
140 GPM
HEAT EXCHANGER
BOILER (35 GAL CAP.)
DOMESTIC HOT WATER
WATER METER (TYP. 3 PLACES)
COLD RESERVOIR (55°F MAX.)
END1 MID END2
TOP
MID
BOT
HOT RESERVOIR (115°F MIM.)
CHILLER
COOL TOWER
CHILLER
70 GPM
70/140 GPM
140 GPM
T_{18} 10 REQD. (FRESH AIR SHUTDOWN)
T_{19} 12 REQD. (ROOM TEMPERATURE)
Rev. 7-77

Appendix C

DATA ACQUISITION SYSTEM (DAS) SPECIFICATION

TITLE: DATA ACQUISITION SYSTEM (DAS) SPECIFICATION	Prepared by: S. R. Leacock Approved by: [signature]
PROGRAM: SOLAR HEATING/COOLING FOR CITY OF SANTA CLARA COMMUNITY RECREATION CENTER	ES No.: SCP 05:01 Date: 20 June 1975

These specifications are for Data Acquisition System (DAS) to be used with the Solar Heating/Cooling System in the Santa Clara Community Recreation Center.

1.0 INSTALLATION

1.1 The DAS shall be installed by the manufacturer.

2.0 SYSTEM DESCRIPTION AND OPERATION

2.1 General

The DAS shall have the capability to measure a minimum of one hundred and fifty (150) data points and configure the time tagged retrieved data in a format that is compatible with existing post data analyses software programs. Provisions shall be made at the Santa Clara Community Recreation Center for the DAS to be installed in a visable, controlled access location.

The DAS shall be resident on-site (Santa Clara) for a period not less than one (1) year.

2.2 Signal Interface

2.2.1 The DAS shall interface to the solar heating/cooling system via the Temperature Control Panel (TCP) terminal strips. The data signals types and quantities are as follows:

A. Platinum Resistance Thermometers (PRT) Temperature sensors (83) measure temperature in millivolts.

B. Pyranometer (1) measure BTU's/hr in milliamps.

C. Water meter (2) measure gal/min with DC pulses.

D. Wind direction (1) in degrees, and velocity (1) in mph in millivolts.

E. Pumps (11) measure on-time in DC volts.

F. Valves (8) measure position in DC volts.

G. Fan Coil Unit (1) measure on-time in DC volts. (Solar system timeclock activates fan coil units)

H. Absorption Chillers (2) measure on time in DC volts.

I. Gas fired boiler (1) measure on time in DC volts

J. Pressure-Switch (1) measure activation in DC volts.

K. Zone temperature (12) and thermostat set points (12) measured in millivolts.

L. Solar Status (No-Low-High) measured in DC volts (3).

All of the above signals will receive the required signal conditioning to be compatible for reading with a high speed analog to digital subsystem (A/D).

2.2.2 A special subsystem will be designed containing bridge and amplifier circuits for accurate measurement. This subsystem shall be resident in the DAS and shall interface to the TCP via shielded pair wires (approx. seventy-five feet in length).

2.3 Data Monitoring and Retrieval

2.3.1 The DAS shall have the capability to monitor any one point or all data points at programmed selected intervals. Any quantity of data points up through 150, can be programmed to have the data retrieved and stored for any of the selected intervals. The minimum time interval for monitoring and retrieving all 150 data points is one second.

2.3.2 The DAS shall be capable of time-tagging all selected retrieved data to the nearest second. Time base shall be in real-time, time-of-day increments.

2.4 Data Formats

2.4.1 The DAS shall have capability to format all retrieved data under program control and output this data on magnetic tape, paper tape and hard copy printout. Format of data outputs are programmable.

2.5 Software

2.5.1 The DAS shall have high level language program capability with a FORTRAN II compiler, symbolic editor and a software I/O system to be used with the Analog to Digital subsystem. There shall be utility software programs for measurement and control functions, Test and Diagnostic routines and I/O calls for standard peripheral devices.

2.6 DAS Subsystem

2.6.1 The DAS shall be comprised of the following hardware subsystems.

2.6.1.1 Processor

A. Minimum of 8192-16 bit words of core memory - Expandable to 32K.

B. Priority interrupt system.

C. Power fail interrupt.

D. Memory protect.

2.6.1.2 Punched Tape Reader/Punch -
Reader 500 Char/sec
Punch 75 Char/sec.

2.6.1.3 Magnetic Tape Subsystem
9-track, 800 tape, 45 ips and
2400 foot reels.

2.6.1.4 Real-Time Clock
Real-Time Clock in unit measurements of days, hours, minutes and seconds.

2.6.1.5 Terminal Printer Subsystem -
30 Char/sec with keyboard printer 75 Char/line.

2.6.1.6 A/D subsystem (12 bits). 5 each-Solid state low level multiplexer (16 differential input channels, 8 ranges, ± 10 MV to ± 800 MV) and cables. 3-each High level multiplexer (16 differential/32 single-ended inputs ± 20.24V fs) and cables.

2.6.1.7 Operator Terminal
The DAS shall have one terminal interface to the system that contains the following:

- Multi-Task Keyboard
- Full editing capability
- Information display
- Data entry
- Self test

2.7 Self-Test

2.7.1 The DAS shall have a self test capability with fault isolation techniques to the subsystem level.

2.8 Maintainability

2.8.1 The DAS design shall be designed for maximum reliability and performance with minimal maintenance.

A. Interchangeable subsystem components.

B. Standard parts.

C. Limited number of adjustments.

D. Minimal time required of corrective and preventative maintenance periods.

2.9 Security

The DAS shall provide means for preventing unauthorized personnel from having access to software programs via the processor and/or terminal input interface.

Appendix D

INSTRUMENTATION HARDWARE SPECIFICATION

TITLE: Instrumentation Hardware	Prepared by: S. R. Leacock and A. B. Burns Approved by:
PROGRAM: Solar Heating and Cooling for the City of Santa Clara Community Recreation Center	ES No.: SCP - 04:02 Date: 20 May 1975

The instrumentation hardware shall meet the following specifications as to function and type. All instrumentation hardware shall provide signals compatible for continuous data monitoring operations. All signals shall be wired to a centralized point in the Mechanical Equipment Room (MER). All signals shall be measurable in units of either volts, amperes, ohms, or monitored by contact closures. In case of duplication with control hardware necessary to conform with the requirements of Engineering Specification SCP-03:01 "Control System", the latter shall take precedence. For a discussion of the use of instrumentation hardware, see EM:SCP-04:01, "Performance Analysis Objectives, Techniques and Instrumentation." The specifications are listed as to the following instrumentation device:

1. Zone Thermostats
2. Platinum Resistance Temperature Sensors (PRT's)
3. Pyranometer
4. Weather Station
5. Gas Meter
6. Water Meter
7. ON/OFF Indicators
8. Mini-RTD's
9. Miscellaneous

1.0 ZONE THERMOSTATS

1.1 A zone thermostat shall be installed in each of the twelve temperature zones located within the Community Center (see architect's plans). The zone thermostats shall be configured so that their individual temperature settings can respond only to a manual set at the control panel in the MER.

1.2 Zone thermostats shall be calibrated so that signal conditioning provides a specific measurement in volts per degree Farenheit. Signal conditioning shall be to 0.1% accuracy. The temperature for each zone shall be capable of read-out for data monitoring operations. Means for recording the zone thermostat set points shall also be provided.

1.3 Recommended type is Barber Coleman, Model No. TS 8111 or equivalent.

1.4 The controls hardware contractor shall purchase these items and provide installation.

2.0 PRT'S

2.1 PRT's shall be installed in various locations within the solar heating and cooling system as shown in Appendix A or listed in Appendix B. Total number of PRT's supplied by Instrumentation hardware shall be 63 (D_1 through D_{63}).

2.2 PRT's shall have 0.1% stability over their designated temperature range.

2.3 Recommended type is Hy-Cal Model 4135-B-100-C-2-8-3-36-E-A-F19 or equivalent.

2.4 The controls hardware contractor shall purchase these items and provide installation.

3.0 PYRANOMETER

3.1 A pyranometer shall be installed to measure the sun's intensity. Provisions shall be made in installation so that the pyranometer can be relocated.

3.2 The pyranometer shall be calibrated so that signal conditioning provides a specific measurement in millivolts per $BTU\text{-}ft^2$ of intensity with 1% accuracy.

3.3 Recommended type is Eppley Laboratory, Inc., Precision Spectral Pyranometer Model (PSP) with signal amplifier, or equivalent.

3.4 The City of Santa Clara will purchase this item from the manufacturer and the controls hardware contractor shall provide the required installation.

4.0 WEATHER STATION

4.1 A Weather Station shall be installed to measure wind velocity and wind direction. (Note: Ambient temperature measurement is included in the PRT's cited under para. 2.1 above).

Weather Station parameters shall be calibrated so that signal conditioning provides a specific measurement in millivolts per:

I. velocity in miles per hour (MPH), II. direction in azimuth degrees referenced to magnetic North. All readings shall have 1% accuracy.

4.3 Recommended type is Weather-Master W-101-P-HF/360, Skyvane I Wind System, or equivalent.

4.4 The City of Santa Clara will purchase this item from the manufacturer and the controls hardware contractor shall provide the required installation.

5.0 GAS METER

5.1 A gas meter shall be installed on the auxiliary boiler's gas line.

5.2 Conventional type with manual readout is satisfactory.

5.3 The gas meter shall be supplied and installed by PG&E.

6.0 WATER METER

6.1 Water meters shall be installed in the hot and cold reservoirs for refill evaluation and in the domestic hot water supply line. Only the meter in the cold reservoir may have a conventional manual readout.

6.2 Retransmitting water meters shall be calibrated so that signal conditioning provides a specific measurement in millivolts per cubic foot of water with 5% accuracy.

6.3 Recommended type of retransmitting water meter is Neptune type S meter with Model 157 gallon register and Model 31 impulse switch, or equivalent.

6.4 The water meters shall be supplied and installed by the City of Santa Clara; signal wiring shall be supplied by the controls hardware contractor.

7.0 ON/OFF INDICATORS

7.1 Contact closures shall be installed on all eleven (11) pump motors for the indication of the duration of on-time (see Appendix A).

7.2 An ON/OFF indicator for one air-handler shall be installed as a signal of system "ON" and "OFF".

7.3 An ON/OFF indicator for the boiler shall be installed (this may be accomplished by monitoring the solenoid valve on the boiler).

7.4 Position indicators shall be installed for all motor-driven control valves (see Appendix A).

7.5 ON/OFF indicators shall be zero ohms when closed and maximum switch closure time of five hundred (500)microseconds. ON/OFF indicators shall be of high quality and shall not provide ambiguous readings because of contact bounce.

7.6 No recommended type.

7.7 The controls hardware contractor shall purchase these items and provide installation.

8.0 MINI-RTD'S

8.1 A maximum of 20 mini-RTD's shall be provided in order to measure heat intensity on collector panels (D_{64} through D_{83}). Cable shall be installed from the terminal board to the roof. An additional 100 ft. of cable for each device shall be allowed, coiled and stored on the roof pending later hookup of devices.

8.2 Mini-RTD's shall have the same accuracy requirements as PRT's in para. 2.0.

8.3 Recommended type is Hy-Cal Model 4135-B-100-18-2-8-3-36-E-A-FA, or equivalent.

8.4 The controls hardware contractor shall purchase these items and deliver them to the City of Santa Clara.

9.0 MISCELLANEOUS

9.1 Instrumentation Cabling

9.1.1 Conduit shall be installed from the roof to the MER suitable for a minimum of seventy-five (75) shielded twisted pair wires for additional instrumentation devices.

9.1.2 The general contractor shall purchase and install this item.

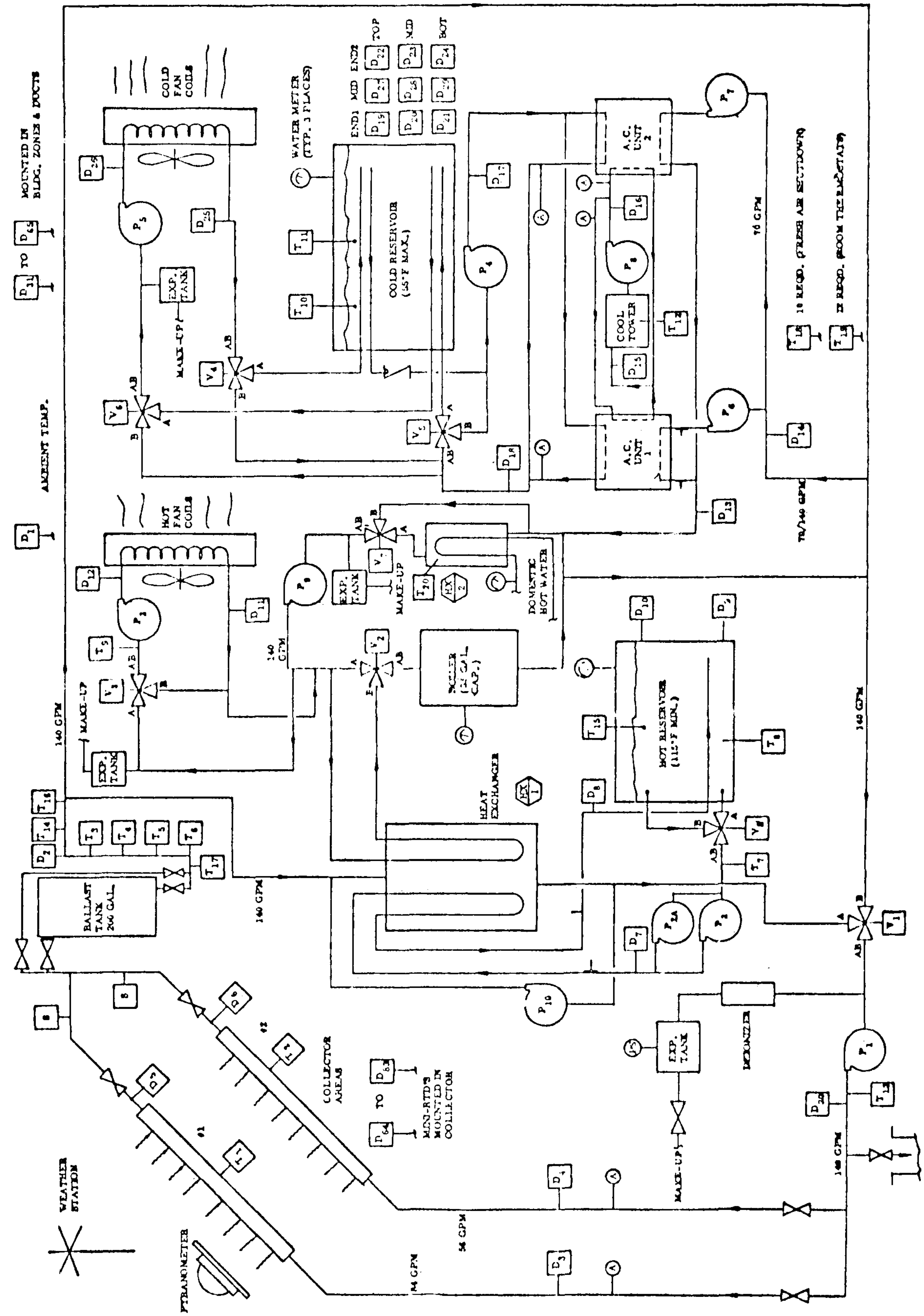
9.2 Bridge Network

9.2.1 The PRT's shall be wired to bridge networks having an accuracy of $0.01\%/^{\circ}F$ over the temperature span of the network.

9.2.2 Recommended type is Hy-Cal Model ESD-9025-C-85B, or equivalent.

9.2.3 These items shall be purchased and installed by the City of Santa Clara.

APPENDIX A


COLD FAN COILS
HOT FAN COILS
COLD RESERVOIR (55°F MAX.)
HOT RESERVOIR (115°F MIN.)
BALLAST TANK 200 GAL
HEAT EXCHANGER
COOL TOWER
DOMESTIC HOT WATER
COLLECTOR AREAS
WEATHER STATION
PYRANOMETER
AMBIENT TEMP.
MOUNTED IN BLDG. ZONES & DUCTS
WATER METER (TYP. 3 PLACES)
140 GPM
76 GPM
56 GPM
84 GPM

APPENDIX B

Locations and Identity Numbers for PRT's In Building Zones and Ducts(1)

ZONE	SUPPLY DUCT		RETURN DUCT
	Upstream from Coils #	Downstream from Coils #	#
1	31	42	54
2	32	43	55
3	33	44	56
4	34	45	57
5a	35 & 41(2)	46	58
5b	↓	47	↓
5c	↓	48	↓
6	36	49	59
7	37	50	60
8	38	51	61
9	39	52	62
10	40	53	63

Notes

(1) See also Fig. 1

(2) Zone 5 is the only zone that may call for reheat while cooling is being supplied; PRT #41 measures temperature downstream from cold coil and upstream from all three hot coils.

(3) Zone temperatures are measured from T_{19} control devices; zone set points are considered fixed, but changes in the set points are registered as signals in the data acquisition system.

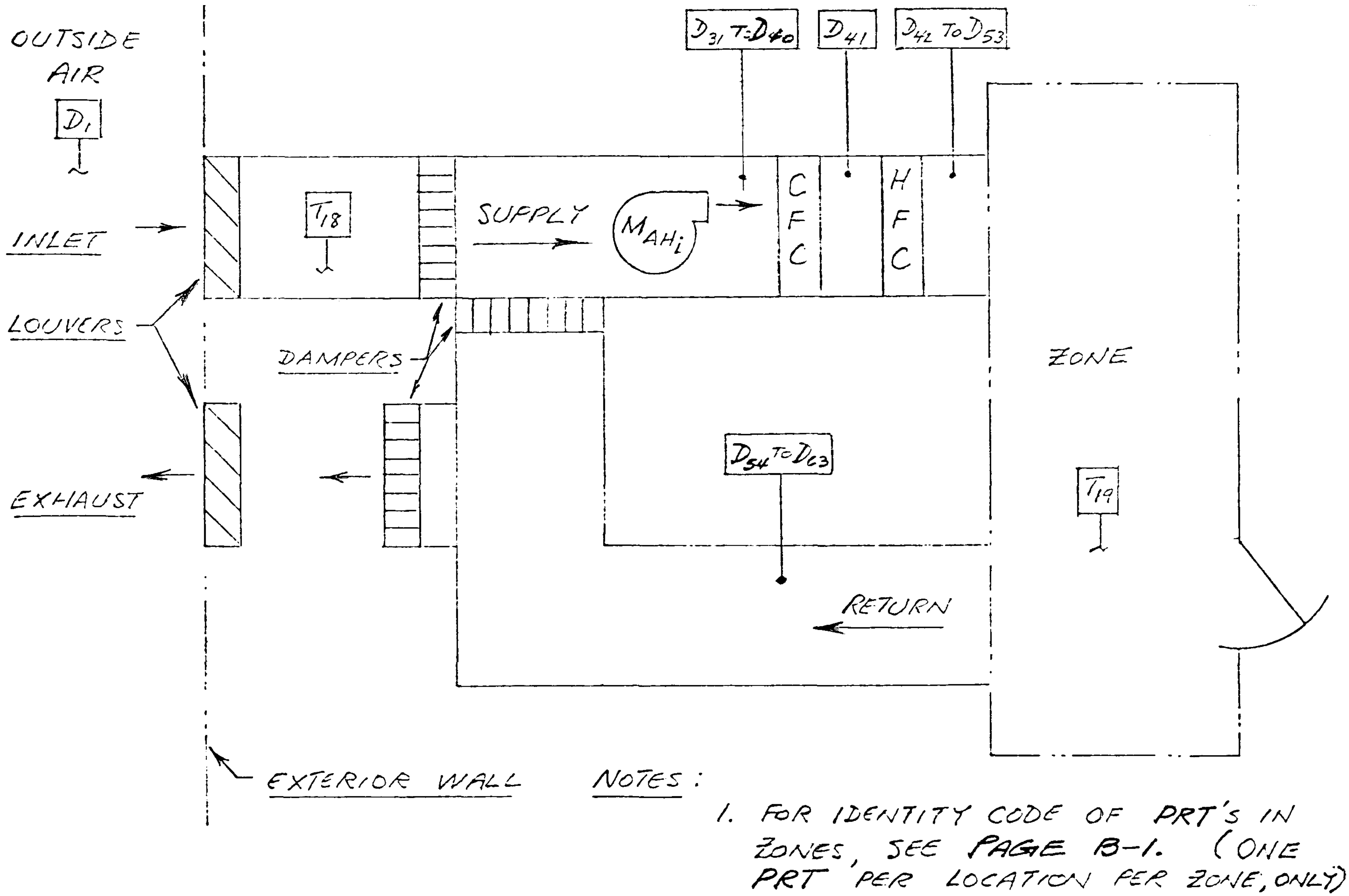


Fig. 1 Typical Zone Duct Arrangement With Instrumentation

Appendix E

PERFORMANCE ANALYSIS OBJECTIVES, TECHNIQUES, AND INSTRUMENTATION ENGINEERING MEMORANDUM

TITLE: Performance Analysis Objectives, Techniques and Instrumentation	Prepared by: A. B. Burns ABB Approved by:
PROGRAM: Solar Heating and Cooling for the City of Santa Clara Community Recreation Center	EM NO.: SCP-04:01 Date: 1 July 1975

1. Purpose

The purpose of this memorandum is to define the quantities that must be measured in order to analyze the solar-powered heating and cooling system for the Santa Clara Community Recreation Center, and to show how these quantities will be used to meet the objectives of the performance analysis task.

2. Data Analysis Objectives

As a result of data analysis, the following items are to be evaluated:

- Local solar insolation and weather data vs. time
- Overall collector efficiency
- Building heating and cooling loads and internal zone distribution
- Portion of heating and cooling loads carried by solar
- Portion of heating and cooling loads carried by auxiliary boiler
- Portion of cooling load carried by economizer
- Volume of gas consumed
- Absorption chiller efficiency
- Energy rejected via hot reservoir
- Hot storage reservoir efficiency
- Cold storage reservoir efficiency
- Energy load for service hot water

3. Nomenclature

Most of the nomenclature used throughout this document is listed below:

Symbol	Definition	Units
A	Total absorber plate area in collector	ft^2
C	Natural gas conversion factor	BTU/ft^3
c	Specific heat of collector materials	BTU/lb^oF

Symbol	Definition	Units
COP	Coefficient of Performance	
D	Temperature (Data)	^oF
E	Energy	BTU
F	Liquid flow defined by flow meter measurements	GPM
G	Gas usage read manually from meter	ft^3
H	Heat capacity	$\frac{BTU}{lb^oF}$ or $\frac{BTU}{ft^3F}$
J	Heat stored in the collector	$\frac{BTU}{ft^2hr}$
L	Load	%
M	Air flow derived from air handler characteristics	CFM
N	Number of time intervals	
P	Liquid flow derived from pump characteristics	GPM
Q	Energy per unit time	$\frac{BTU}{min\text{-}hr\text{-}day}$
S	Pyranometer reading	$\frac{BTU}{ft^2\text{-}hr}$
T	Temperature (Control, or other than Data)	^oF
t	Time	min.
V	Volume	gals.
W	Weight of collector per unit area	$\frac{lb}{ft^2}$
ϵ	Efficiency	

Subscripts

1,2,3, ... Locations as shown on piping diagram (appended)

A	Ambient	I	Inlet
AH	Air Handler	IN	Input
AVG	Average	L	Daily Loss
B	Boiler	LL	Line Losses
BO	Boil-Off	MU	Make-Up
By-Pass	Cold reservoir by-pass	P	Preliminary
C	Cool	PHC	Collector Preheat
CFC	Cold Fan Coils	R	Return
CHL	Chiller	RES	Reservoir
CR	Cold Reservoir	S	Solar, Supply

CT	Cooling Tower
CW	Chilled Water
DAY	Daily
DHW	Domestic Hot Water
E	Economizer
f	final
H	Heat
HE	Heat Exchanger
HEP	Heat Exchanger Primary Side
HES	Heat Exchanger Secondary Side
HFC	Hot Fan Coils
HR	Hot Reservoir
HRI	Hot Reservoir Insulation
HW	Hot Water
SBLD	Bleed Mode Solar Energy
TF	Tank Status at End of Period
TI	Tank Status at Start of Period
TOT	Total
u	useful
w	Make-up-Water

Conversions

$1\ ft^3 = 7.48$ gal (water)

1 gal = 8.34 lbs. (water)

1 gpm = 500.4 lbs/hr (water)

Constants

$$H_{water} = 1\ \frac{BTU}{lb^oF}$$

$$H_{air} = 0.0130\ \frac{BTU}{ft^{3\,o}F} \quad \text{(constant volume)}$$

$$H_{air} = 0.0181\ \frac{BTU}{ft^{3\,o}F} \quad \text{(constant pressure)}$$

4. General Approach

Equipment in the heating and cooling system that is characterized by constant performance is utilized in this analysis for data input in place of duplicate instrumentation. Such equipment includes pumps operating under essentially constant flow and constant electrical load conditions, and a boiler and a heat exchanger with performance that has been previously established by the manufacturer. Where feasible, a manual check of performance, particularly pumps, should be performed prior to initiation of data acquisition and analysis.

Certain pumps feed multiple lines. During installation these lines will be regulated to the desired flow using balancing cocks and annubar flow-measuring devices (that are not equipped with transmitting signal devices). These measurements also become part of the system data initialization.

This approach results in fewer instrumentation devices and simplification of the data acquisition process as well. Pumps, boiler and primary control valves will register at the data acquisition terminal only in terms of "on-off" or "position A→AB". It will not be necessary to register all equipment "on-off"; the air-handlers, for example, are always on when the system clock is set to "on" and therefore a single indicator from among these sources is sufficient for all.

In general, the performance of the solar-powered heating and cooling system will be calculated on a daily basis at the building site using the computer in the data acquisition system. Further performance calculations involving weekly, monthly, seasonal or yearly performance are to be performed off-site at the University of Santa Clara.

Daily operations will consist of data acquisition at specified constant time intervals that may vary with the function being monitored, and a running cumulation of the data throughout the day. Most time intervals will be small enough, on the order of five minutes or less, that the data values can be considered constant over the duration of the time interval. Some performance calculations will be required at each time interval; in many cases, performance will be calculated daily based on the cumulative data for the day.

The equations in this memorandum contain symbols and subscripts relating to equipment that can be located on the piping diagram included herein as Appendix A. Examples include pump (P_i) and temperature sensing devices (D_i). Identifying names for these and other components are presented in Appendix C. This memorandum is based upon the control system defined in Ref. 1.

5. Collector Efficiency (Preliminary)

Collector efficiencies over a unit time interval and cumulative time intervals are required for each collector area and the collector area as a whole. Let:

S = incident solar flux measured by the pyranometer (BTU/Ft^2HR)

H = heat capacity of water ($1 \frac{BTU}{lb^oF}$)

F_1, F_2 = water flow (gpm) in collector areas 1 & 2

A_1, A_2 = area (ft^2) of collector areas 1 & 2

Δt = time intervals (min.)

n = number of intervals

D = temperature (^oF)

For a unit time interval, the incident solar energy is:

$$Q_{S1} = S(A_1)\frac{\Delta t}{60} \text{ .... collector area \#1 .... (1)}$$

$$Q_{S2} = S(A_2)\frac{\Delta t}{60} \text{ .... collector area \#2 .... (2)}$$

and the useful solar energy is:

$$Q_{U1} = 8.34\ (D_5-D_3)\ F_1\ (H)\ \Delta t \text{ .... collector area \#1 .... (3)}$$

$$Q_{U2} = 8.34\ (D_6-D_4)\ F_2\ (H)\ \Delta t \text{ .... collector area \#2 .... (4)}$$

Useful solar energy over the entire collector for a unit time interval is the sum of Q_{U1} and Q_{U2}, but an alternate form is:

$$Q_{U_{1+2}} = 8.34(D_2-D_{30})\ P_1\ (H)\ \Delta t \text{ .... total collector .... (5)}$$

Efficiency over a unit time interval is:

$$\varepsilon_{1p} = \frac{Q_{U1}}{Q_{S1}} \text{ .... collector area \#1 .... (6)}$$

$$\varepsilon_{2p} = \frac{Q_{U2}}{Q_{S2}} \text{ .... collector area \#2 .... (7)}$$

$$\varepsilon_{(1+2)p} = \frac{Q_{U_{1+2}}}{Q_{S_1}+Q_{S_2}} \text{ .... total collector .... (8)}$$

Efficiency over a number of time intervals may be expressed (typically) as:

$$\varepsilon_{1p} = \frac{\Sigma Q_{U1}}{\Sigma Q_{S1}} \quad \text{.... (9)}$$

where the limits of the summation are defined by the real time clock and other conditions defined by the user. For example, a daily summation will be required, and it may be desirable to perform a summation representing "low sun" and "high sun" as defined by pyranometer output signals of specified levels.

Print-out of the values calculated above should be accompanied by the input and other related data to permit easy evaluation. These include S, D_5, D_6, (D_5-D_3), (D_6-D_4), Δt, n, real time and ambient temperature (D_1).

Note that the temperature sensors D_2 through D_6 and D_{30} will be located in the mechanical equipment room and thus the Q_U quantities will include line losses. The quantities F_1 and F_2 are constant flows (established with Annubar devices) that are anticipated to be 84 and 56 gpm for collector areas 1 and 2, respectively.

6. Collector Efficiency (Final)

The foregoing calculations for collector efficiency are intended for the check-out phase of the program when simple, approximate solutions satisfy requirements. However, more detailed calculations should also be made which, for example, take into account the heat storage capacity of the collector. This effect causes asymmetry in collector temperatures about solar noon, with attendant variations in collector efficiency.

The equations presented here have been suggested by Ward (Ref. 2) and may also be found in Ref. 3. For collector area #1, let efficiency be expressed as:

$$\varepsilon_{1f} = \varepsilon_{1o} - U\left(\frac{D_5-D_1}{S}\right) \text{ .... (10)}$$

Where:

ε_{1f} = collector efficiency

ε_{1o} = maximum possible collector efficiency

U = function of heat transfer coefficients of collector materials, $BTU/(hr)(ft^2)(^oF)$

and other quantities are as previously defined. The heat stored in the collector per unit of time is:

$$J = cW \cdot \frac{\Delta D_5}{\Delta t} \cdot 60 \quad .... \quad (11)$$

Where:

c = specific heat of collector materials, $BTU/(lb)(^oF)$

W = weight of the collector per unit area, lb/ft^2

ΔD_5 = change in temperature D_5 during time interval Δt (in minutes).

Then, knowing that:

$$\varepsilon_{1f} Q_{S1} = Q_{U_1} + JA_1 \frac{\Delta t}{60} \quad .... \quad (12)$$

the above equations may be combined in the form:

$$\frac{Q_{U1}}{A_1(\frac{\Delta t}{60})} = \varepsilon_{1o} S - U\,(D_5 - D_1) - cW \cdot \frac{\Delta D_5}{\Delta t} \cdot 60 \quad .... \quad (13)$$

The above equation has three unknowns: ε_{1o}, U and cW. By writing the equation for three separate time intervals, Δt, three equations are obtained that can be solved simultaneously for the three unknowns. Subsequently, ε_{1f} may be solved from Equation 10. The three unknown quantities should be constants for all practical purposes.

Similar equations may be written for collector area #2, or for the total collector area, by using the appropriate subscripts and temperature sensors. Results obtained from these equations will include line losses in the array plus other effects, such as disproportionate flow distributions. Individual collector modules may be instrumented to eliminate these effects if desired.

7. Daily Useful Energy Delivered by Collector

The summation of Q_{U1} and Q_{U2} calculations, or, alternately, the sum of the $Q_{U_{1+2}}$ calculations, gives the daily useful energy delivered by the the collector:

$$Q_{U_{TOT}} = [\Sigma Q_{U1} + \Sigma Q_{U2}]_{day} = [\Sigma Q_{U_{1+2}}]_{day} \cdots (14)$$

8. Daily Energy Supplied by Boiler

$$Q_{B_{TOT}} = \varepsilon_B \cdot G \cdot C \quad .... \quad (15)$$

Where G is the number of cubic feet of gas consumed per day and C is the conversion to BTU's. The boiler efficiency ε_B is used here in place of additional instrumentation on the assumption that the boiler efficiency has been defined by the manufacturer. The boiler supplies energy to four separate functions as required:

- fire chiller units
- optionally spec hot reservoir
- supply hot fan coils
- service domestic hot water tube bundle

9. Daily Total Energy Input to System

$$Q_{IN_{TOT}} = Q_{U_{TOT}} + Q_{B_{TOT}} \quad .... \quad (16)$$

10. Daily Energy Consumed in the Chiller Firing Water

Over a unit time interval, the energy consumed in the chiller firing water is:

$$Q_{CHL} = 8.34\,(D_{14}-D_{13})\,F_3\,(H)\,\Delta t \quad .... \quad (17)$$

Where F_3 is 70 gpm if either pump P_6 or P_7 is on, or 140 gpm if both pumps are on. The total daily energy supplied to the chillers is then:

$$Q_{CHL_{TOT}} = [\Sigma Q_{CHL}]_{day;\ P_6, P_7 \rightarrow On} \quad .... \quad (18)$$

Whenever valve V_1 is in the B→AB position, the firing water is being supplied from solar energy. The daily cumulation of this energy is:

$$Q_{CHLS_{TOT}} = [\Sigma Q_{CHL}]_{day;\ V_1 \text{ in } B \rightarrow AB} \quad .... \quad (19)$$

Therefore, the firing water supplied by boiler is:

$$Q_{CHLB_{TOT}} = Q_{CHL_{TOT}} - Q_{CHLS_{TOT}} \quad .... \quad (20)$$

11. Daily Energy From Chiller Cold Water

The cold water energy produced by the chillers over a unit time interval is:

$$Q_{CW} = 8.34\ (D_{17}-D_{18})\ P_4\ (H)\ \Delta t \quad .... \quad (21)$$

and the total daily chilled water energy is:

$$Q_{CW_{TOT}} = [\Sigma Q_{CW}]_{day;\ P_4 \rightarrow On} \quad .... \quad (22)$$

Whenever valve V_1 is in the B→AB position, the cold water is being produced from solar energy. The daily cumulation of this energy is:

$$Q_{CWS_{TOT}} = [\Sigma Q_{CW}]_{day;\ V_1 \text{ in } B \rightarrow AB} \quad .... \quad (23)$$

and the daily cumulation of cold water produced from boiler energy is:

$$Q_{CWB_{TOT}} = Q_{CW_{TOT}} - Q_{CWS_{TOT}} \quad .... \quad (24)$$

12. Daily Energy Dissipated by Cooling Tower

For a unit time interval, the energy dissipated by the cooling tower is:

$$Q_{CT} = 8.34\ (D_{15}-D_{16})\ P_8\ (H)\ \Delta t \quad .... \quad (25)$$

and the total daily energy dissipation is:

$$Q_{CT_{TOT}} = [\Sigma Q_{CT}]_{day};\ P_8 \rightarrow On \quad \ldots. \quad (26)$$

13. Chiller Daily Energy Balance

$$Q_{CHL_{TOT}} + Q_{CW_{TOT}} \Bigg| \; Q_{CT_{TOT}} \quad \ldots. \quad (27)$$

This equation serves as a check because all quantities have been determined previously.

14. Chiller Daily Efficiency

The daily chiller coefficient of performance is:

$$C.O.P. = \frac{Q_{CW_{TOT}}}{Q_{CHL_{TOT}}} \quad \ldots. \quad (28)$$

This coefficient represents both units. Instrumentation is not provided to evaluate the C.O.P. for each unit individually unless only one unit is in operation during a given time period.

15. Daily Energy Through Heat Exchanger

Instrumentation is provided on the heat exchanger secondary (hot reservoir) side that can be used to measure energy through the heat exchanger over a unit period of time:

$$Q_{HE} = 8.34\ (D_8 - D_7)\ F_4\ (H)\ \Delta t \quad \ldots. \quad (29)$$

Where F_4 is the gpm rate from pump P_2, except in the dump mode when it becomes the gpm rate from pump P_{2A}. The energy exchange may be either to or from the reservoir. Thus the total daily energy from the heat exchanger to the hot reservoir is:

$$Q_{HES_{TOT_{IN}}} = [\Sigma Q_{HE}]_{day};\ D_8 - D_7 \text{ positive, } P_2 \text{ or } P_{2A} \rightarrow On \quad \ldots. \quad (30)$$

and the total daily energy to the heat exchanger from the reservoir is:

$$Q_{HES_{TOT_{OUT}}} = [\Sigma Q_{HE}]_{day};\ D_8 - D_7 \text{ negative, } P_2 \text{ On} \quad \cdots\cdots \quad (31)$$

For succeeding calculations, it is necessary to know the daily energies on the primary side of the heat exchanger. These are:

$$Q_{HEP_{TOT_{IN}}} = [\Sigma\ (\frac{Q_{HE}}{\varepsilon_{HE_{IN-A}}}) + \Sigma(\frac{Q_{HE}}{\varepsilon_{HE_{IN-B}}})]_{day};\ D_8 - D_7 \text{ positive} \quad \cdots\cdots \quad (32)$$

$$Q_{HEP_{TOT_{OUT}}} = [\Sigma(Q_{HE} \cdot \varepsilon_{HE_{OUT}})]_{day};\ D_8 - D_7 \text{ negative} \quad \cdots\cdots \quad (33)$$

The heat exchanger efficiency is expected to vary with operating temperature and probably also with exchange into or out of the reservoir. Therefore, Q_{HE} must be processed for each time interval to satisfy the above equations using the appropriate efficiency. It is assumed that heat exchanger efficiency versus temperature and exchange direction will be defined by the manufacturer. However, efficiencies for the various possible exchanges may be experimentally checked as described below.

The heat exchanger for this system consists of primary and secondary tube bundles inside a shell. Three exchange sequences are possible; two exchange into the reservoir and the third exchanges out of the reservoir. A fourth exchange sequence is also optionally available; this will be discussed in paragraph 16.

- IN-A: Collector to shell to primary tube bundle to hot reservoir. Condition: V_1 in A→AB, P_{10} Off.
- IN-B: Boiler loop to secondary tube bundle to shell to primary tube bundle to hot reservoir. (Input energy is either solar or boiler). Condition: P_{10} On, V_1 in B→AB.
- OUT: Hot reservoir to primary tube bundle to shell to secondary tube bundle to hot fan coils. (Reverse of IN-B). Condition: P_{10} On, V_1 in A→AB.

The heat exchanger efficiency for the IN-A exchange sequence may be checked while the system is in the "low solar" or "dump" mode over a given time interval:

$$\varepsilon_{HE_{IN-A}} = \left[\frac{Q_{HE}}{Q_{U1+2}}\right]_{V_2 \text{ in A}\to\text{AB},\ D_8-D_7 \text{ positive}} \quad \ldots\ (34)$$

Heat exchanger efficiency in the OUT exchange sequence may be checked while the system is in the "no solar" mode:

$$\varepsilon_{HE_{OUT}} = \left[\frac{Q_{HFC}}{Q_{HE}}\right]_{V_7 \text{ in B}\to\text{AB, Boiler Off, } P_2,\ P_3, P_9, P_{10} \text{ (only) on}} \quad \ldots\ (35)$$

The time period covered by this latter calculation should be several unit time intervals to allow for time lag effects between the hot reservoir and the hot fan coils. The quantity Q_{HFC} is discussed in paragraph 17.

Heat exchanger efficiency in the IN-B exchange sequence should equal that in the OUT exchange sequence. However, when checking efficiency for both the IN-A and OUT exchange sequences, a range of temperatures should be examined. In the IN-A exchange sequence, this is accomplished by checking during both the "low solar" and "dump" modes. For the OUT exchange sequence, two checks should be made: when the hot reservoir temperature is at min. spec. and when it is approaching boiling.

The energy to the secondary side of the heat exchanger due to the boiler is:

$$Q_{HESB_{IN}} = [\Sigma Q_{HE}]_{\text{day},\ D_8-D_7 \text{ positive},\ V_1 \text{ in B}\to\text{AB},\ P_{10}\ \&\ \text{boiler On.}} \quad \ldots\ (36)$$

and that due to Solar energy is:

$$Q_{HESS_{IN}} = Q_{HESTOT_{IN}} - Q_{HESB_{IN}} \quad \ldots\ (37)$$

Likewise, on the primary side of the heat exchanger:

$$Q_{HEP_{B_{IN}}} = [\Sigma(\frac{Q_{HE}}{\varepsilon_{HE_{IN-B}}})]_{day,\ D_8-D_7\ positive,\ V_1\ in\ B\rightarrow AB,\ P_{10}\ \&\ boiler\ On} \quad \ldots.(38)$$

$$Q_{HEP_{S_{IN}}} = Q_{HEP_{TOT_{IN}}} - Q_{HEP_{B_{IN}}} \quad \ldots.\ (39)$$

For exchanges out of the reservoir, it will be assumed that all of the boiler energy passed through the heat exchanger to the reservoir on a daily basis is extracted from the reservoir after being reduced appropriately for reservoir losses. Thus:

$$Q_{HES_{B_{OUT}}} = Q_{HES_{B_{IN}}} \cdot \varepsilon_{HR} \quad \ldots.\ (40)$$

and

$$Q_{HES_{S_{OUT}}} = Q_{HES_{TOT_{OUT}}} - Q_{HES_{B_{OUT}}} \quad \ldots.\ (41)$$

The quantity ε_{HR} is discussed in paragraph 22.

On the primary side of the heat exchanger:

$$Q_{HEP_{B_{OUT}}} = [\Sigma(Q_{HE} \cdot \varepsilon_{HE_{OUT}})]_{day,\ D_8-D_7\ negative,\ V_1\ in\ A\rightarrow AB,\ P_{10}\ On.} \quad \ldots.\ (42)$$

$$Q_{HEP_{S_{OUT}}} = Q_{HEP_{TOT_{OUT}}} - Q_{HEP_{B_{OUT}}} \quad \ldots.\ (43)$$

It should be noted that the option to use the boiler to supply energy to the hot reservoir via the heat exchanger may not be exercised once the solar-powered system is in operation. In this event, accounting of energy by type will not be necessary. The data processing system, however, should be capable of providing energy accountability if the option is selected.

16. Preheating the Collector Array

Optionally, the collector array may be preheated with energy from the hot reservoir. The intent of this option is to advance the time at which water hot enough to operate the chiller units is available in the summer time, and therefore extend the total time that the chillers operate each day. During this period of the year, the hot reservoir energy is abundant and expendible.

The preheat energy over a unit period of time is:

$$Q_{PHC} = 8.34\ (D_7 - D_8)\ P_2\ (H)\ \Delta t \quad \ldots. \quad (44)$$

and the total daily energy expended per day is:

$$Q_{PHC_{TOT}} = [\Sigma Q_{PHC}]_{day};\ \text{manual control} \quad \ldots. \quad (45)$$

17. Daily Energy Directed to Hot Fan Coils

Energy delivered to the hot fan coils over a unit time interval is:

$$Q_{HFC} = 8.34\ (D_{12} - D_{11})\ P_3\ (H)\ \Delta t \quad \ldots. \quad (46)$$

and the total daily energy delivered is:

$$Q_{HFC_{TOT}} = [\Sigma Q_{HFC}]_{day};\ P_3 \rightarrow \text{On} \quad \ldots. \quad (47)$$

There are four sources of this energy: solar, boiler, hot reservoir, and bleed-off from the solar-heated chiller firing water.

The daily energy supplied directly from solar (in the low solar mode) is:

$$Q_{HFC_{S_{TOT}}} = [\Sigma Q_{HFC}]_{day};\ V_1 \text{ in A}\rightarrow\text{AB, boiler} \rightarrow \text{Off} \quad \ldots. \quad (48)$$

The daily energy supplied directly from the boiler is:

$$Q_{HFC_{B_{TOT}}} = [\Sigma Q_{HFC}]_{day};\ \text{boiler},\ P_3 \rightarrow \text{On} \quad \ldots. \quad (49)$$

and the daily energy supplied from the solar-heated chiller firing water is:

$$Q_{HFC_{SBLD_{TOT}}} = [\Sigma Q_{HFC}]_{day};\ V_1 \text{ in } B \rightarrow AB,\ P_6 \text{ and/or } P_7 \rightarrow \text{On} \quad \ldots. \quad (50)$$

The energy supplied from the hot reservoir is then:

$$Q_{HFC_{RES_{TOT}}} = Q_{HFC_{TOT}} - Q_{HFC_{S_{TOT}}} - Q_{HFC_{B_{TOT}}} - Q_{HFC_{SBLD_{TOT}}} \quad \ldots. \quad (51)$$

It is assumed that the division of energy from the hot reservoir between boiler and solar is the same as that previously calculated for heat exchange out of the reservoir:

$$Q_{HFC_{RES_{B_{TOT}}}} = \left[\frac{Q_{HES_{B_{OUT}}}}{Q_{HES_{TOT_{OUT}}}}\right] Q_{HFC_{RES_{OUT}}} \quad \ldots. \quad (52)$$

Therefore:

$$Q_{HFC_{RES_{S_{TOT}}}} = Q_{HFC_{RES_{TOT}}} - Q_{HFC_{RES_{B_{TOT}}}} \quad \ldots. \quad (53)$$

Note that line losses are not included in the above calculations. The temperature sensors D_{11} and D_{12} are located in the mechanical equipment room; therefore, the quantity $Q_{HFC_{TOT}}$ includes line losses from the sensors to the fan coils and return.

18. Daily Energy Directed to Cold Fan Coils

Energy delivered to the cold fan coils over a unit time interval is:

$$Q_{CFC} = 8.34\ (D_{25}-D_{26})\ P_5\ (H)\ \Delta t \quad \ldots. \quad (54)$$

Energy is generally obtained from the cold reservoir, but a by-pass mode is available wherein the fan coils are fed directly from the chillers.

Thus:

$$Q_{CFC_{TOT}} = [Q_{CFC_{RES_{TOT}}} + Q_{CFC_{BY\text{-}PASS_{TOT}}}]_{day};\ P_5 \rightarrow \text{On} \quad \cdots\cdot \quad (55)$$

Where

$$Q_{CFC_{RES_{TOT}}} = [\Sigma\ Q_{CFC}]_{day};\ V_4,\ V_6 \text{ in } A\rightarrow AB \quad \cdots\cdot \quad (56)$$

and:

$$Q_{CFC_{BY\text{-}PASS_{TOT}}} = [\Sigma\ Q_{CFC}]_{day};\ V_4,\ V_6 \text{ in } B\rightarrow AB \quad \cdots\cdot \quad (57)$$

It is assumed that the proportions of solar and boiler-originated energy from the cold reservoir to the fan coils are identical to those previously calculated for the supply of energy from the chillers to the cold reservoir:

$$Q_{CFC_{RES_{B_{TOT}}}} = \left(\frac{Q_{CHL_{B_{TOT}}}}{Q_{CHL_{TOT}}}\right) Q_{CFC_{RES_{TOT}}} \quad \cdots\cdot \quad (58)$$

and

$$Q_{CFC_{RES_{S_{TOT}}}} = Q_{CFC_{RES_{TOT}}} - Q_{CFC_{RES_{B_{TOT}}}} \quad \cdots\cdot \quad (59)$$

Energy through the by-pass is divided as follows:

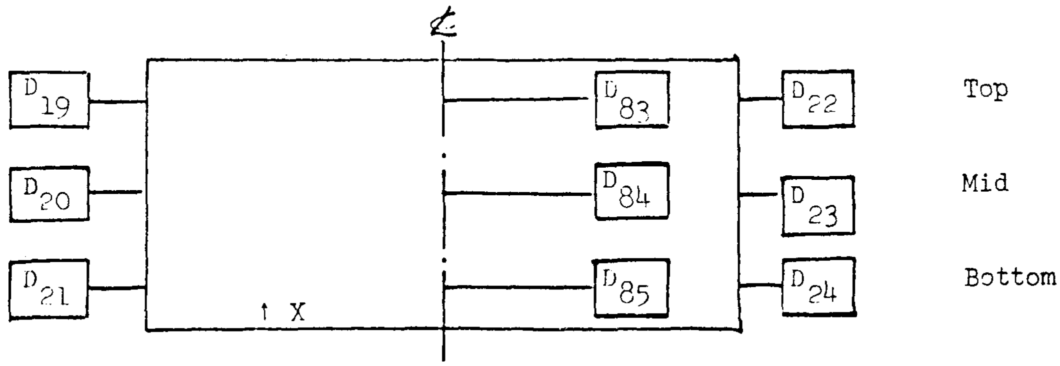
$$Q_{CFC_{BY\text{-}PASS_{S_{TOT}}}} = [\Sigma\ Q_{CFC}]_{day};\ V_1, V_4, V_6 \text{ in } B\rightarrow AB \quad \cdots\cdot \quad (60)$$

$$Q_{CFC_{BY\text{-}PASS_{B_{TOT}}}} = Q_{CFC_{BY\text{-}PASS_{TOT}}} - Q_{CFC_{BY\text{-}PASS_{S_{TOT}}}} \quad \cdots\cdot \quad (61)$$

19. Daily Cold Reservoir Energy Balance

Reservoir temperature readings are taken each day at the same time. Readings from the previous day (TI) are compared with the current readings (TF) and an energy balance is performed.

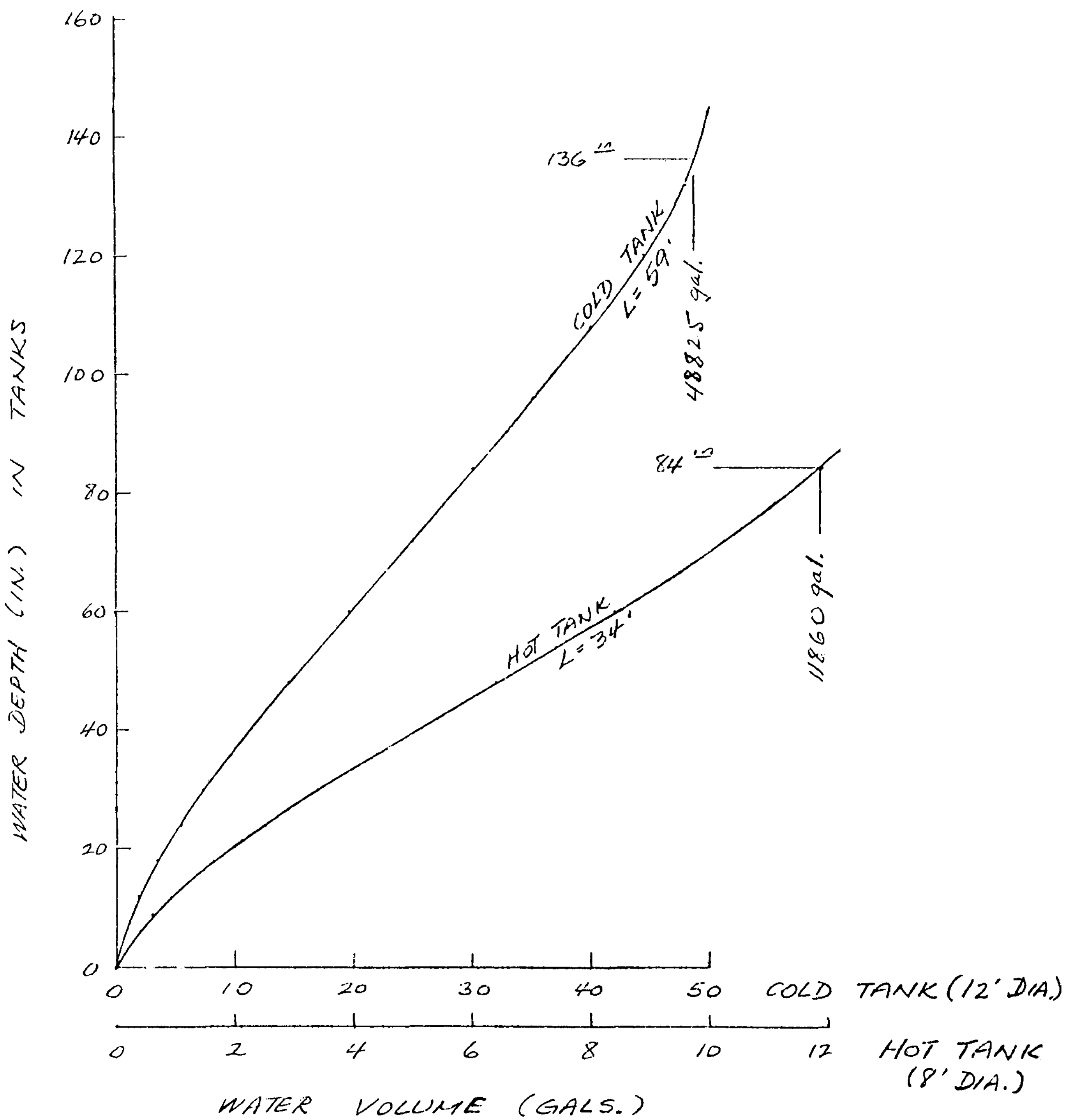
There are 9 temperature sensors in the reservoir, 3 at either end and 3 at mid-length:



At present, the exact position of these sensors has not been established, and in fact it is likely that position will be based upon an initial survey of reservoir temperatures. The procedure for determining the energy in the reservoir is also dependent upon the results of the initial survey, since this will show the distribution of temperatures vertically and horizontally in the reservoir.

An example situation is as follows: Assume that the reservoir is stratified in the vertical direction only and the three temperature sensors D_{19}, D_{20} and D_{21} are located at the top of the water level, the midpoint of the water (volume-wise), and the bottom of the reservoir. Let the water in the reservoir be divided into four layers above D_{20} and four layers below D_{20} in order to account for the nonlinearity of water volume with depth as shown in Fig. 1. (Note that the water level has

FIG. 1: VOLUME OF WATER IN A HORIZONTALLY MOUNTED CYLINDRICAL TANK AS A FUNCTION OF DEPTH (FLAT END BULKHEADS)



been specified to be eight inches below the top of the reservoir and that the position of D_{20} is 68 inches above the bottom of the reservoir.) Let the temperature distribution vertically in the reservoir be as shown in Fig. 2.

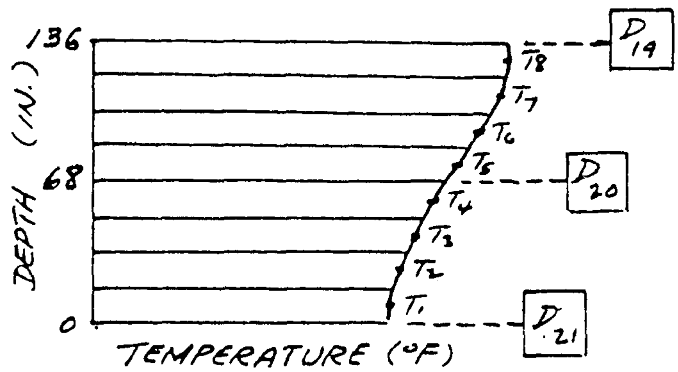


Fig. 2 Vertical Thermal Profile of Cold Reservoir

Then the energy in the reservoir is:

$$E_i = 8.34\ H\ [3250\ T_1 + 5750\ T_2 + 7000\ T_3 + 7250\ T_4 + 7500\ T_5 + 7000\ T_6 + 6750\ T_7 + 4325\ T_8] \quad \ldots. \ (62)$$

This expression may be used to calculate E_{TI} and E_{TF}, and the daily reservoir energy change is:

$$Q_{CR} = E_{TF} - E_{TI} \quad \ldots. \ (63)$$

The reservoir daily energy balance is:

$$Q_{CR} = Q_{CW_{TOT}} - Q_{CFC_{RES_{TOT}}} - Q_{L_{CR}} \quad \ldots. \ (64)$$

Where:

$Q_{CW_{TOT}}$ = daily input of chilled water from Chillers

$Q_{CFC_{RES_{TOT}}}$ = daily output of chilled water to cold fan coils

$Q_{L_{CR}}$ = daily loss

Note that refill effects are neglected, and that the daily loss is principally through the cold reservoir insulation.

20. Daily Hot Reservoir Energy Balance

The hot reservoir energy balance is performed in the same manner as above, and the same reservations apply regarding an initial temperature survey. There are only two temperature sensors, D_{10} and D_9, nominally at the top and at the bottom, respectively, of the reservoir. Again, an example situation is presented, based on a seven-layer model of the water volume, and an idealized temperature distribution vertically in the tank similar to that shown in Fig. 2. Note in this case that the water level is 12 inches below the top of the reservoir (see Fig. 1). Under these conditions, the energy in the reservoir is:

$$E_i = 8.34\ H\ [920\ T_1 + 1580\ T_2 + 1880\ T_3 + 2010\ T_4 + 2010\ T_5 + 1880\ T_6 + 1580\ T_7] \quad \ldots. \quad (65)$$

where T_1 is the average temperature of the bottom water layer in the reservoir, and the succeeding layers are consecutively numbered. E_{TF} and E_{TI} may be calculated from this equation. The daily reservoir energy change is:

$$Q_{HR} = E_{TF} - E_{TI} \quad \ldots. \quad (66)$$

The reservoir daily energy balance is:

$$Q_{HR} = Q_{HES_{TOT_{IN}}} - Q_{HES_{TOT_{OUT}}} - Q_{L_{HR}} \quad \ldots. \quad (67)$$

where

$Q_{HES_{TOT_{IN}}}$ = daily input of hot water

$Q_{HES_{TOT_{OUT}}}$ = =daily output of hot water to hot fan coils, domestic hot water and/or to preheat collector array.

$Q_{L_{HR}}$ = daily loss

The quantity $Q_{L_{HR}}$ includes refill effects and boil-off as well as losses through the reservoir insulation. $Q_{L_{HR}}$ does not include line losses because the temperature sensors whose output is used in calculating $Q_{HES_{TOT_{IN}}}$ and $Q_{HES_{TOT_{OUT}}}$ are located in the hot water pump pit adjacent to the hot reservoir.

The various components of the daily loss may be quantitized and the results used to determine the overall status of the reservoir. Energy lost with the introduction of relatively low-temperature make-up or refill water from domestic water supply over a given time interval is:

$$Q_{MU} = 8.34\ V_W\ (T_{HR} - T_W)\ H \qquad \ldots\ (68)$$

where V_W is the quantity of make-up water in gallons as measured by the transmitting water meter, T_W is the temperature of the domestic water supplied, and T_{HR} is the temperature of the hot reservoir. The quantity T_W is not measured by the instrumentation, and a representative value obtained from sample measurements must be used. Likewise, the quantity T_{HR} is not measured directly, but is an average reservoir temperature based on the readings of temperature sensors D_9 and D_{10}. Taking into consideration that T_{HR} may vary throughout the day, the total daily energy loss is:

$$Q_{MU_{TOT}} = [\Sigma\ Q_{MU}]_{day} \qquad \ldots\ (69)$$

If it is assumed that the refill water replaces volumetric losses due to steam (boil-off), the energy loss via the steam over a given time interval is:

$$Q_{BO} = [8.34\ V_W\ H_V]_{D_{10} \geq 212^\circ F} \qquad .... \quad (70)$$

where H_V is the heat of vaporization of water at normal boiling temperature/pressure (970 BTU/lb).

The daily energy loss through the reservoir insulation, therefore, is:

$$Q_{HRI} = Q_{L_{HR}} - Q_{MU_{TOT}} - Q_{BO} \qquad .... \quad (71)$$

It is possible, of course, that refill water registers on the transmitting water meter when there is no boil-off; i.e., $D_{10} < 212^\circ F$. This indicates a leak in the reservoir with resultant loss of reservoir insulation effectiveness. Consequently, it is important to monitor the refill water meter signal and temperature sensor D_{10} in order to determine overall reservoir status as well as reservoir energy balance.

21. Cold Storage Reservoir Daily Efficiency

This quantity reflects the daily losses in the reservoir:

$$\varepsilon_{CR} = \frac{Q_{CR} - Q_{L_{CR}}}{Q_{CR}} \qquad .... \quad (72)$$

22. Hot Storage Reservoir Daily Efficiency

$$\varepsilon_{HR} = \frac{Q_{HR} - Q_{L_{HR}}}{Q_{HR}} \qquad .... \quad (73)$$

23. Daily Energy for Domestic Hot Water

Domestic hot water for the building is supplied from a heat exchanger in the mechanical equipment room. The domestic lines are hooked to the tube bundle, while the shell is connected to the boiler and solar collector loop. Valve V_7 is a temperature-controlled device that causes the exchanger shell to be by-passed when the domestic hot water temperature exceeds $120^\circ F$. The domestic hot water piping contains a circulating pump that insures instant hot water at all taps upon demand.

The energy supplied to the shell of the heat exchanger is solar in origin except when:

1. The system time clock is off:
2. The hot reservoir and/or the cold reservoir is out-of-spec and the boiler is on to supply building demand.
3. The boiler is bringing the cold reservoir into min spec, or optionally, the hot reservoir into min spec.

Additionally, if the option to use the boiler to min spec the hot reservoir is elected, the energy from the hot reservoir is partially boiler originated. It will be assumed, however, that the condition of energy source is simply boiler on or boiler off at the time of domestic hot water demand. Then, the energy required to supply domestic hot water over a unit period of time is:

$$Q_{DHW} = [8.34\ V_{DHW}(120-T_W)H]/\varepsilon_{HE2} \quad \ldots. \quad (74)$$

where V_{DHW} is the quantity of domestic water in gallons supplied to the system, as measured by a transmitting water meter, and T_W is the temperature of the domestic water. The quantity T_W is not measured by the instrumentation, and a representative value obtained from Pete's Plug readings must be used. The quantity ε_{HE2} is the efficiency of the heat exchanger. This may be obtained from the manufacturer, or determined experimentally from Pete's Plug readings during the check-out phase of the system.

The daily energy consumed by heating domestic hot water is:

$$Q_{DHW_{TOT}} = Q_{DHW_B} + Q_{DHW_S} \quad \ldots. \quad (75)$$

where

$$Q_{DHW_B} = [\Sigma\ Q_{DHW} + \Sigma\ Q_{LL}]_{Boiler\ On} \quad \ldots. \quad (76)$$

$$Q_{DHW_S} = [\Sigma\ Q_{DHW} + \Sigma\ Q_{LL}]_{Boiler\ Off} \quad \ldots. \quad (77)$$

The quantity Q_{LL} in these equations represents constant line losses due to the circulating feature of the domestic hot water system. In terms of the energy supplied to the heat exchanger shell, this quantity is:

$$Q_{LL} = 8.34\ (T_S - T_R)\ F_5\ (H)\ \Delta t \quad .... \quad (78)$$

where T_S, the supply temperature, and T_R, the return temperature, are measured with Pete's Plug devices during the check-out phase in periods when there is no domestic hot water demand. The quantity F_5 is the flow rate of the circulating pump in gpm.

24. Daily Energy Supplied to Each Building Zone

There are twelve zones in the building and each zone has a room air temperature sensor. (T_{19}). In addition, a thermostat control for each zone is located in the mechanical equipment room (T_{set}). Warm or cold air is supplied to each zone by passing air from an air handler (M_{AH}) over hot or cold fan coils mounted in a duct. The air handlers deliver constant volumes of air per unit time (cfm) and are always on whenever the system time clock is on. The coils are equipped with by-passes such that hot or cold water passes through the coils only upon demand from the thermostat. Note that in the nomenclature of this memorandum, the designation "T" refers to a control temperature sensor while the designation "D" refers to a data temperature sensor. All twelve room thermostats carry the designation T_{19}; likewise, there are ten fresh air shutdown sensors carrying the designation T_{18}. All data temperature sensors are individually numbered.

While the system is normally closed, i.e., the same air is recirculated through the zone via a return air duct to the air handler, an economizer is provided to assist in cooling the zone by bringing in outside air whenever conditions permit. Schematically, the economizer operation relates to the system operation in the following manner:

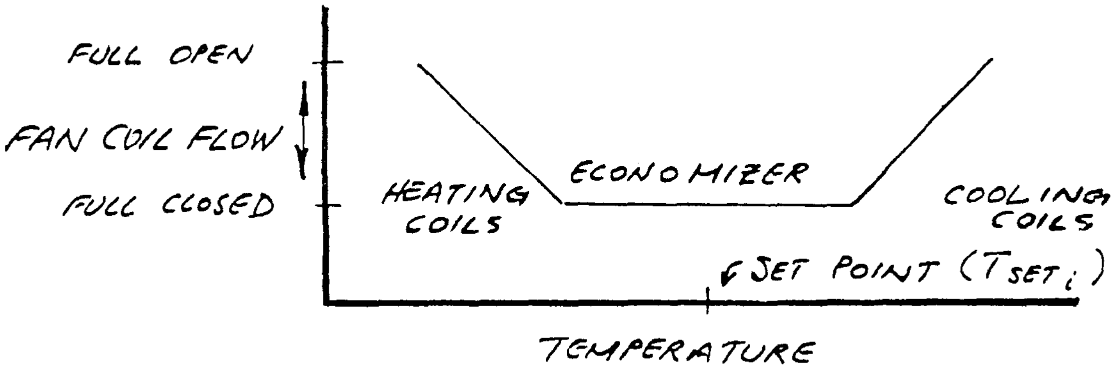


Fig. 3: Economizer Use Diagram

With the exception of Zone 5, heating and cooling are never provided simultaneously, and the economizer is never used for heating on the assumption that outside air is too cold when heating is required by the zone. However, cool outside air brought in by the economizer may be mixed with cold air derived from the cold fan coils as long as the outside ambient temperature D_1 is below T_{set} by some prescribed amount K.

A typical zone duct arrangement showing the location of temperature sensors is presented in Fig. 4. The closed-loop system is straight-forward but the economizer operation requires some explanation. When using the economizer, the return air damper is closed and the fresh air damper is open. These dampers exist in the building. A third damper is to be added and located in the return air duct to balance positive pressures that would otherwise exist in the zone. This damper exhausts air to the attic area of the building, from whence it exhausts out of the building through a louver. Note that there are no return air duct fans in the building. These were not considered necessary in the original building design, and cost of retrofitting return air duct fans was not considered feasible for the present program. The three dampers are connected together by a linkage and operated from a single motor. The relative positions of the dampers are to be regulated upon installation of the third

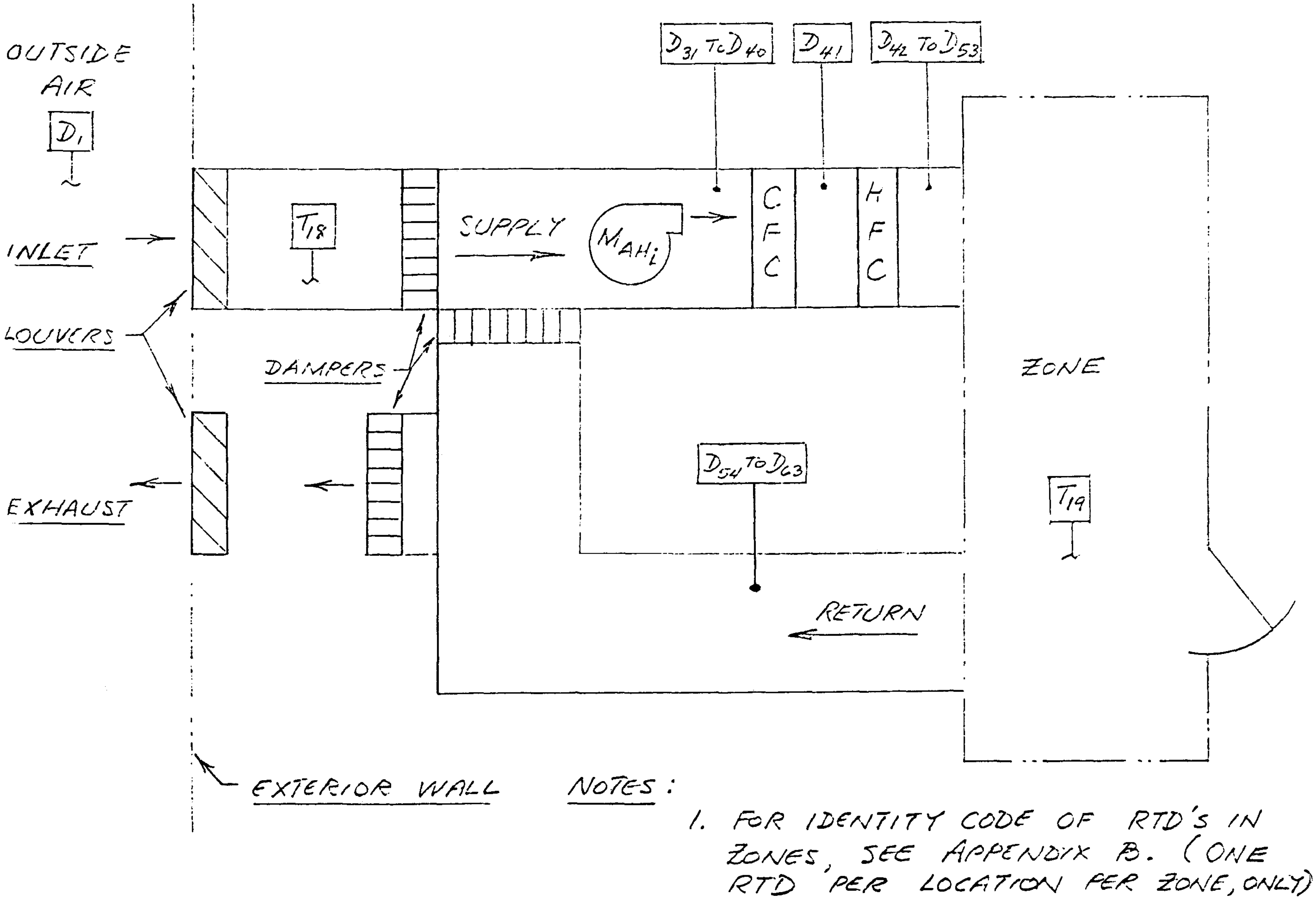


Fig. 4 Typical Zone Duct Arrangement With Instrumentation

damper noted above to balance the flow of air. Inasmuch as the resistance to air flow is much greater in the return duct than it is in the inlet duct, due to relative lengths, it is expected that the inlet damper will only be "cracked" when the return air damper is full open in the mixed air operation mode.

In order to determine an energy balance in each zone, RTD's will be installed in the ducts for each zone as shown in Fig. 4. Refer to Appendix B for a breakdown of sensors by numerical designation for each zone.

Note that there are 10 sensors in the return air duct and in front of the cold fan coils, but 12 sensors in back of the hot fan coils to account for the fact that one duct network (in Zone 5) has three hot fan coils. Each hot fan coil in this arrangement serves its own zone, but the same cold fan coil serves all three zones.

Let us assume for an example that Zone 1 is served by duct sensors D_{31}, D_{42} and D_{54}.

The heating energy supplied to the zone during a unit interval of time (min.) is:

$$Q_{1H} = M_{AH_1} (D_{42} - D_{31}) H_{air} \cdot \Delta t \quad \ldots. \quad (79)$$

and the heating energy supplied daily is:

$$Q_{1H_{TOT}} = [\Sigma Q_{1H}]_{day,\ P_3 \rightarrow On,\ T_{set_1} > T_{19}} \quad \ldots. \quad (80)$$

Note that pump P_3 will not be on unless there is a demand for building heating to be supplied by the hot fan coils.

The zone set points (T_{set_i}) do not register numerically in the data acquisition system. Instead, a signal is sent to the data acquisition system whenever the zone set point has been changed. This system has been utilized to save costs, and with the opinion that the zone set points will not be changed often if at all once the heating and cooling system has been checked out and adjusted. Thus, the zone set point will be read into the data system computer as a constant that is subject to manual adjustment as required by the change signal.

Similar equations may be used to determine cooling energy supplied to the zone from the cold fan coils:

$$Q_{1_C} = M_{AH_1} (D_{31} - D_{42}) H_{air} \cdot \Delta t \quad .... \quad (81)$$

and

$$Q_{1_{C_{TOT}}} = [\Sigma Q_{1_C}]_{day,\ P_5 \rightarrow On,\ T_{set_1} < T_{19}} \quad .... \quad (82)$$

If these quantities are summed throughout the building, they should equate to energies previously calculated except for line losses:

$$[\Sigma Q_{i_{H_{TOT}}}]_{i=Zone\ 1}^{i=Zone\ 10} \Big| Q_{HFC_{TOT}} \quad .... \quad (83)$$

$$[\Sigma Q_{i_{C_{TOT}}}]_{i=Zone\ 1}^{i=Zone\ 10} \Big| Q_{CFC_{TOT}} \quad .... \quad (84)$$

The cooling energy supplied by the economizer during a unit interval of time (min.) is:

$$Q_{1_E} = M_{AH_1} (D_{54} - D_{31}) H_{air} \cdot \Delta t \quad .... \quad (85)$$

and the energy supplied daily is:

$$Q_{1_{E_{TOT}}} = [\Sigma Q_{1E}]_{day,\ (D_1+K) < T_{19},\ T_{set_1} < T_{19}} \quad .... \quad (86)$$

where K is a constant to account for time delays and/or blending with return air. This equation satisfies the condition where the economizer is supplying cooling energy exclusively, and where cold air supplied by the economizer is mixed with cold air derived from the cold fan coils. The two situations can be distinguished if desired by noting that P_5 is off in the former case but On in the latter case. Note that similar equations and logic could be applied to the use of the economizer to heat the building should this option be elected at some time in the future.

Total cooling energy provided throughout the building by economizer is:

$$\left[\Sigma\, Q_{i_{E_{TOT}}}\right]_{i=\text{Zone } 1}^{i=\text{Zone } 10} = Q_{E_{TOT}} \quad \ldots\ldots \quad (87)$$

Equations representing energy supplied to the other eleven zones in the building will not be presented in this memorandum because of their similarity to those shown. However, the equations will be required in order to perform the building summaries that have been indicated.

25. Total Building Load

The total building load may be expressed as the sum of previously calculated quantities:

$$Q_{BLDG_{TOT}} = Q_{HEAT_{TOT}} + Q_{COOL_{TOT}} \quad \ldots\ldots \quad (88)$$

where

$$Q_{HEAT_{TOT}} = Q_{HFC_{TOT}} \quad \ldots\ldots \quad (89)$$

$$Q_{COOL_{TOT}} = Q_{CFC_{TOT}} + Q_{E_{TOT}} \quad \ldots\ldots \quad (90)$$

26. Portion of the Heating Load Carried by Solar

Expressed as a percent, this is:

$$L_{H_S} = \frac{\left(Q_{HFC_{S_{TOT}}} + Q_{HFC_{RES_{S_{TOT}}}} + Q_{HFC_{SBLD_{TOT}}}\right)}{Q_{HFC_{TOT}}}\, 100 \quad \ldots\ldots \quad (91)$$

Note that the Q quantities must be summed daily so that percentages may be calculated daily, monthly and yearly. This is also true for the following calculations.

27. Portion of the Heating Load Carried by Boiler

Expressed as a percent, this is:

$$L_{H_B} = 100 - L_{H_S} \quad .... \quad (92)$$

28. Portion of the Cooling Load Carried by Solar

$$L_{C_S} = \frac{\left(Q_{CFC_{RES_{S_{TOT}}}} + Q_{CFC_{BY\text{-}PASS_{S_{TOT}}}}\right)}{Q_{COOL_{TOT}}} 100 \quad .... \quad (93)$$

29. Portion of the Cooling Load Carried by Boiler

$$L_{C_S} = \frac{\left(Q_{CFC_{RES_{B_{TOT}}}} + Q_{CFC_{BY\text{-}PASS_{B_{TOT}}}}\right)}{Q_{COOL_{TOT}}} 100 \quad .... \quad (94)$$

30. Portion of the Cooling Load Carried by Economizer

$$L_{C_E} = 100 - L_{C_S} - L_{C_B} = \frac{Q_{E_{TOT}}}{Q_{COOL_{TOT}}} 100 \quad .... \quad (95)$$

31. Portion of the Domestic Hot Water Load Carried by Solar

$$L_{DHW_S} = \frac{Q_{DHW_S}}{Q_{DHW_{TOT}}} 100 \quad .... \quad (96)$$

32. Portion of the Domestic Hot Water Load Carried by Boiler

$$L_{DHW_B} = 100 - L_{DHW_S} \quad .... \quad (97)$$

33. Portion of the Total Load Carried by Solar and Economizer (Including Domestic Hot Water)

$$L_{TOT_{S\&E}} = \frac{L_{H_S}(Q_{HFC_{TOT}}) + L_{C_S}(Q_{COOL_{TOT}}) + 100(Q_{E_{TOT}} + Q_{DHW_S})}{Q_{BLDG_{TOT}} + Q_{DHW_{TOT}}} \quad \ldots . \quad (98)$$

34. Daily Distribution of Solar Energy

The solar energy collected during the day is divided among the following usages:

$$Q_{U_{TOT}} \Big| \; Q_{HEP_{S_{IN}}} + Q_{HFC_{S_{TOT}}} + Q_{HFC_{SBLD_{TOT}}} + Q_{CHL_{S_{TOT}}} + Q_{DHW_S} \quad \ldots . \quad (99)$$

All quantities have been calculated previously; differences between the left and right sides of the equation represent line losses.

35. Daily Distribution of Boiler Energy

In a like manner:

$$Q_{B_{TOT}} \Big| \; Q_{HEP_{B_{TOT}}} + Q_{HFC_{B_{TOT}}} + Q_{CHL_{B_{TOT}}} + Q_{DHW_B} \quad \ldots . \quad (100)$$

Equations 99 and 100 may be used to determine the proportional division of energy by type to the various system functions.

36. Daily Distribution of Hot Reservoir Energy

Energy transferred out of the hot reservoir may be used to meet building heating demand, domestic hot water demand, and/or collector preheat requirements:

$$Q_{HES_{TOT_{OUT}}} = \frac{Q_{HFC_{RES_{TOT}}}}{\varepsilon_{HE_{OUT}}} + Q_{DHW_{RES}} + Q_{PHC} \quad \ldots . \quad (101)$$

The quantity $Q_{DHW_{RES}}$, which has not been previously calculated, may be found from the above equation.

37. List of Instruments Required

The following instruments are required in order to sense the quantities needed by the equations in this memorandum. All instruments have transmitting capabilities back to the data terminal for automatic recording. RTD's measuring ambient and fluid temperatures (exclusive of the collector arrays) are located on the piping diagram attached to this memorandum as Appendix A. A schedule for the PRT's measuring air temperatures in the various building zones and ducts is given in Appendix B. Locations of PRT's that are planned for the collector arrays have not been established at the present time.

Instrument	Data Points
o Ambient Temp. PRT (D_1)	1
o Piping PRT's (D_2-D_{30})	29
o Duct PRT's (D_{31}-D_{63})	33
o Collector Mini - PRT's (D_{64}-D_{83})	20
o Zone Thermostats (T_{19})	12
o Zone Set Point Voltage Signals	12
o Pyranometer	1
o Solar Status (No-Low-High)	3
o Wind Velocity & Direction	2
o Water Meters (Hot Res. & Domestic Hot Water)	2
o On-Off Indicators	
o Pumps	11
o Valves	8
o Boiler	1
o Chillers	2
o Pressure Switch	1
o Fan Coil (Indicative of System "On")	1
	Total* 139.

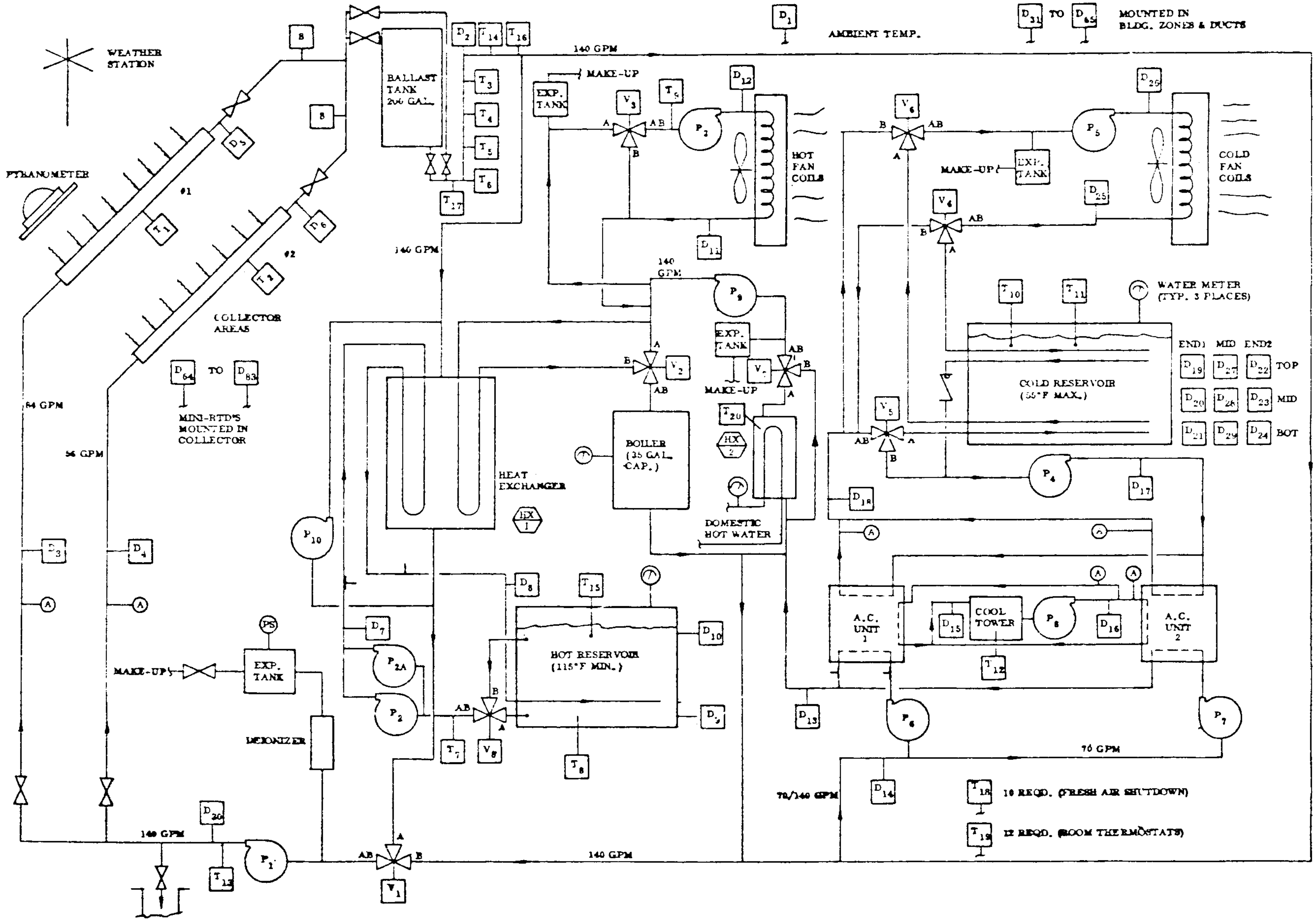
* Planned data channels available : 150

38. References

1. Lockheed Palo Alto Research Laboratory Engineering Specification ES-SCP-03:01, "Controls System" by S. R. Leacock, 22 May 1975.

2. Attachment to letter from Prof. John C. Ward, Colorado State University to Mr. R. Mortenson, City of Santa Clara, May 1, 1975, entitled, "Determination of Solar Collector Efficiency".

3. "Method of Testing for Rating Solar Collectors Based on Thermal Performance," by James E. Hill and Tamami Kusuda, NBSIR 74-635, Dec. 1974. (Prepared by the National Bureau of Standards for the National Science Foundation).


WEATHER STATION
PYRANOMETER
BALLAST TANK 200 GAL.
COLLECTOR AREAS
MINI-RTD'S MOUNTED IN COLLECTOR
64 GPM
56 GPM
140 GPM
MAKE-UP
EXP. TANK
DEIONIZER
HEAT EXCHANGER
BOILER (35 GAL. CAP.)
DOMESTIC HOT WATER
HOT RESERVOIR (115°F MIN.)
HOT FAN COILS
COLD FAN COILS
AMBIENT TEMP.
MOUNTED IN BLDG. ZONES & DUCTS
WATER METER (TYP. 3 PLACES)
COLD RESERVOIR (55°F MAX.)
END1 MID END2
TOP
MID
BOT
A.C. UNIT 1
A.C. UNIT 2
COOL TOWER
70 GPM
70/140 GPM
10 REQD. (FRESH AIR SHUTDOWN)
12 REQD. (ROOM THERMOSTATS)

APPENDIX B

Locations and Identity Numbers for PRT's In Building Zones and Ducts(1)

ZONE	SUPPLY DUCT		RETURN DUCT
	Upstream from Coils #	Downstream from Coils #	#
1	31	42	54
2	32	43	55
3	33	44	56
4	34	45	57
5a	35 & 41(2)	46	58
5b	↓	47	↓
5c	↓	48	↓
6	36	49	59
7	37	50	60
8	38	51	61
9	39	52	62
10	40	53	63

Notes

(1) See also Fig. 4

(2) Zone 5 is the only zone that may call for reheat while cooling is being supplied; PRT #41 measures temperature downstream from cold coil and upstream from all three hot coils.

(3) Zone temperatures are measured from T_{19} control devices; zone set points are considered fixed, but changes in the set points are registered as signals in the data acquisition system.

APPENDIX C

Identifying Names for Principal System Components

Control Valves	Identifier
V_1	High Solar Valve
V_2	Heat Exchange Valve
V_3	Hot Fan Coils (HFC) Blending Valve
V_4, V_5, V_6	Cold Reservoir By-Pass Valves
V_7	Domestic Hot Water By-Pass Valve
V_8	Hot Reservoir Intake Selector Valve

Pumps

P_1	Primary Pump
P_2, P_{2A}	Hot Reservoir Pump, Dump Mode Stand-By
P_3	Hot Fan Coils Pump
P_4	Cold Reservoir Pump
P_5	Cold Fan Coils Pump
P_6	Chiller Pump (#1 unit)
P_7	Chiller Pump (#2 unit)
P_8	Cooling Tower Pump
P_9	Boiler Loop Pump
P_{10}	Heat Exchanger Circulation Pump

Regulated Flows

F_1	Flow in Collector Array #1
F_2	Flow in Collector Array #2
F_3	Firing Water Flow in Chiller Loop
F_4	Flow on Hot Reservoir Side of Heat Exchanger
F_5	Flow Rate of Circulating Pump in Domestic Hot Water Supply.

Appendix F

CHECKOUT PLAN ENGINEERING MEMORANDUM

TITLE: Check-out Plan	Prepared by: A. B. Burns *ab* Approved by: ____________
PROGRAM: Solar Heating and Cooling for The City of Santa Clara Community Recreation Center	EM No. SCP-04:03 Date: 5 January 1976

1. Purpose

This memorandum defines and schedules the necessary tests to be performed on the system hardware prior to initiating system operations.

2. Organization

Activities are divided into two work packages (W/P's). Tasks involving the data acquisition system (DAS) are grouped into W/P I, while tasks dealing with the total system are organized into W/P II.

3. W/P I: Data Acquisition Check-Out Plan

The tasks that comprise W/P I include: 1) test loading of software and check-out of equipment at Hewlett-Packard prior to delivery to the site, 2) installation and hook-up of equipment at the site, 3) calibration of data sensors, 4) final software adjustments, and 5) perform trial runs. These tasks are detailed below as Tasks 1-5:

Task 1: DAS Check-Out at H/P

1.1 Assemble equipment and interconnect in DAS configuration.

1.2 Load software and determine compatibility.

1.3 Modify or extend software to meet program objectives as required.

1.4 Conduct trial DAS runs with mocked-up data input; modify printed output format as required.

Task 2: DAS Installation at Site

2.1 Install H/P equipment in enclosure at building site and interconnect.

2.2 Connect H/P equipment to resistance bridge system and to direct-read sensors.

2.3 Connect resistance bridge system to data temperature sensors.

2.4 Prepare plan for installation of temperature sensors in the collector array.

2.5 Install the temperature sensors in the collector array.

Task 3: Calibration

3.1 Prepare plan for calibration of all data sensors listed on page 32 of Reference 1.

3.2 Assemble necessary testing equipment to perform calibration checks.

3.3 Calibrate all data sensors listed on page 32 of Reference 1.

3.4 Conduct calibrations of DAS equipment within DAS enclosure as required.

Task 4: Final Software Adjustments

4.1 Using inputs from Task 6, or assuming values for these inputs if unavailable, obtain sample computer outputs and modify or correct as required.

4.2 Review output on the CRT for visual public display and modify or correct to promote clarity and understanding.

4.3 Determine fault- isolation and failure analysis techniques to aid in discerning whether malfunctions are in the data acquisition equipment or the sensors.

4.4 Define data acquisition forms and schedules for recording manual read items such as the boiler gas meter and the cold tank water meter.

Task 5: Perform Trial Runs

5.1 Using assumed values for imput as required, conduct trial data acquisition runs as a final DAS check-out.

4. W/P II: Total System Check-Out Plan

The primary objectives of this phase of the work are to: 1) determine those constant quantities in the system that are required to perform the building energy balance, 2) check the equipment installed by others for conformance with drawings and specifications, 3) perform system operational trials, and 4) provide training and documentation as required. These objectives are to be accomplished in Tasks 6-9:

Task 6: Define System Constants

6.1 Prepare a plan to accomplish this task, and assemble necessary test equipment to accomplish the task objectives.

6.2 Measure flows in all twelve pumps in the system, including the domestic hot water circulating pump.

6.3 Measure electric power usage of all pumps with watt-hour meters.

6.4 Define boiler efficiency.

6.5 Define efficiencies of two heat exchangers in system. (Note: Efficiency may vary with temperature; efficiency of HX-1 must be determined for each of three possible heat-exchange sequences.)

6.6 Determine actual prophylene glycol concentration in collector loop.

6.7 Measure storage tank water levels and recalculate storage volumes.

6.8 Check locations of storage tank sensors.

6.9 Determine temperature of make-up water.

6.10 Determine line loss in domestic hot water loop due to circulating feature.

6.11 Calibrate fresh air dampers.

6.12 Define all zone set points.

6.13 Determine value of K appearing in Equation 86 of Reference 1.

6.14 Check CFM rates for all system air handlers.

6.15 Determine temperature distributions vertically in hot and cold tanks.

Task 7: Check Equipment Conformance

7.1 Prepare a plan to accomplish this task, and assemble test equipment necessary to meet the task objectives.

7.2 Check system hardware components for physical conformance with design drawings and specifications. Examples: correct insulation thicknesses, correct pipe sizes, correct piping installation, etc.

7.3 Check system flow distributions at all points on the drawings where annubar devices are specified.

7.4 Calibrate all control sensors to appropriate data sensor.

7.5 Check the boiler temperature setting.

7.6 Check the cooling tower for on-off temperatures.

7.7 Check the two chillers for temperature and flow rate settings for firing water, chilled water and condensing water.

7.8 Check the safety valves, vacuum breakers and bleed valves on the roof.

Task 8: Perform System Operational Trials

8.1 Prepare a plan outlining the scope of these trials, taking into account safety precautions in the event of malfunctions.

8.2 Operate the system in the three basic operational modes: no solar, low solar and high solar. Concurrently, obtain data output from the DAS.

8.3 Operate the system for all manual, override or back-up options, including reverse heat exchange to the collector array.

8.4 Verify the system interlocks on the boiler and time clock.

8.5 Verify the automatic system safety operations.

8.6 On the basis of the performance of the system during these trials, determine the desirability of resetting the nominal design values established for the control sensors. In the event that any sensors are reset, these sensors must be rechecked and the system operated in the mode affected by the reset.

Task 9: Training and Documentation

9.1 Provide support to the City in the training of City personnel to operate the system.

9.2 Prepare a report for the operation and maintenance of the system.

9.3 Document the check-out activities as they were carried out for permanent program records.

5. References

1. LPARL Energy Programs Engineering Memorandum, "Performance Analysis Objectives, Techniques and Instrumentation," EM-SCP-04:01, by A. B. Burns, 1 July 1975.

Appendix G
SOLAR SYSTEM SIMULATION (SOLARDYN)

The Lockheed Solar Energy System Dynamic Simulation Program (SOLARDYN) provides a computer modeling capability for complex solar energy systems. The development of SOLARDYN is an outgrowth of solar energy system simulations by Lockheed, using other simulation programs. Some component subroutines from the Transient Simulation (TRNSYS) Program of the University of Wisconsin have been incorporated in the program. The program user can define the physical solar energy system, select control logic parameters, designate program structure options, and simulate the operation of the solar system over a specified period of time.

As the complexity of simulated solar energy systems increased, it was found that growing combinations of TRNSYS control module components could be replaced by single FORTRAN logic statements. From this point on, a new control logic program was developed using TRNSYS component subroutines where applicable. The structure of the TRNSYS component subroutines, which function independently and are entered and exited only through a common array, makes them adaptable for use with other control logic routines.

SOLARDYN consists of a main program, a principal simulation routine, and a number of component and specialized function subroutines. The main program is used to handle input data, control the general sequence of operations, and accumulate and output summary data. The simulation subroutine is the core of SOLARDYN, containing the solar energy system control logic and some of the more compact component elements. The component subroutines are utilized through the simulation subroutine.

The component elements present in SOLARDYN include a solar processor, solar collectors, storage tanks, auxiliary heater, chiller, building load model, and economizer. The collector output is routed to one of the storage tanks on a priority basis.

The use of auxiliary heat is applied in a similar manner. Heating, cooling, or economizer cooling operate on the building load model in disjointed regions. The building load model is permitted to float between these regions. Beyond the solar processor, the entire system and control logic are interactive, simulating the dynamic condition of a complex solar energy system.

The body of input data consists of five groups of information:

- System design parameters
- Initial conditions within the system
- Control logic (decision) parameters
- Program structure options
- Meteorological data

With the exception of the meteorological data, any one of the input parameters can be changed individually. Meteorological data are used in one-day blocks, the maximum length of the simulation being determined by the body of meteorological data used. The control logic parameters consist of temperature limits and gradients which provide test conditions throughout the system. The program structure options permit the user to select or exclude particular system functions.

The sequence of operation is designed to provide simulation and summary output data at selected intervals, and cumulative data at the conclusion of a simulation period. The user can modify any part of the body of input data and continue running simulations. Termination of program operation is the final user option in SOLARDYN.

A general arrangement of the program is shown in Fig. G-1. The subroutines Solar Processor, Solar Collector, and Stratified Tank are from TRNSYS.

In developing a simulation model for a solar energy system, the functional requirements fall naturally into three groups – basic system requirements, efficient operating conditions, and control logic. The structure of the SOLARDYN program encompasses these requirements.

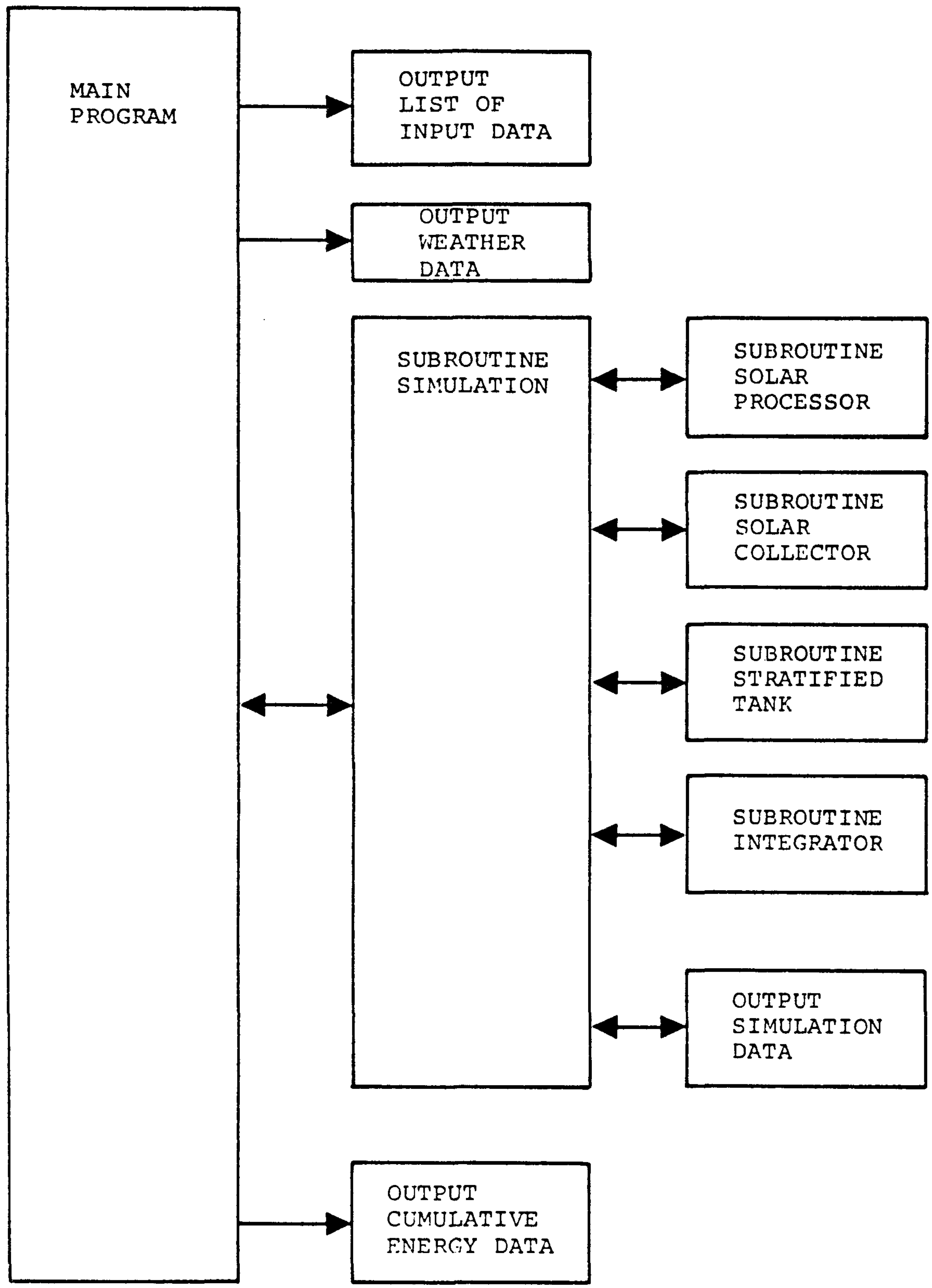


Fig. G-1 General Arrangement of the Solar System Dynamic Simulation Program with the Subroutine and Output Data Flow.

The basic system requirements of a total solar energy system are:

- Hot water
- Heating
- Cooling
- Economizer cooling
- Energy storage
- Auxiliary heating

Within the simulation program, efficient system operating conditions are simulated through provisions for operating the system within the limits of each component element and for selective choices of operating modes. These conditions are satisfied in SOLARDYN through the following features:

- Variable operating limits
- Selective energy storage criteria
- Priority energy transfer
- Protective flow and venting
- Selectable operating options such as partial function lockout and variable operating modes within component elements

The control logic in SOLARDYN performs its functions with the following features:

- Automatic response to maintain all elements in the system within prescribed operating limits
- Priority response
- Dynamic interaction of the total system
- Automatic selection of the correct operating conditions to achieve dynamic stability of the system

SOLARDYN has been developed as a tool for use by persons primarily interested in the investigation of solar energy systems. Expertise in the field of solar energy systems is essential for the effective use of SOLARDYN; however, there is no concomitant imposition upon the user to become an expert in computer systems. The degree of programming sophistication has been kept at a level which can be understood without extraordinary programming expertise or computer operations experience.

Using climatic and solar insolation data from the South Bay Profile Tape, Figs. G-2 through G-7 present a typical SOLARDYN printout for the Community Recreation Center, simulating operation of the system on a July day.

SANTA CLARA COMMUNITY CENTER — SOLAR HEATING AND COOLING

INPUT DATA	UNITS	DESCRIPTION	STATEMENT NAMES	
5.00		PRINTOUT START TIME	REVELY	
7.00		BUILDING OCCUPANCY START TIME	TSTART	
22.00		BUILDING OCCUPANCY STOP TIME	TSTOP	
24.00		PRINTOUT STOP TIME	TAPS	
.02	HOURS	SIMULATION TIME INCREMENT	DELT	
1.00	HOURS	PRINT-OUT TIME INCREMENT	TYPOUT	
.0010		INTEGRATION CONVERGENCE TEST	EI	
1.00		PROCESSOR MODE	PAR(16,1)	IOPT
37.33	DEGREES	LATITUDE	PAR(16,3)	ALAT
18.00	DEGREES	SLOPE	PAR(16,4)	SLOPE
.00	DEGREES	ORIENTATION ANGLE	PAR(16,5)	AZMTH
4870.00	KJ/M2 HR	SOLAR CONSTANT	PAR(16,6)	SC
.00		GROUND REFLECTANCE (USED ONLY IN MODES 3 AND 4)	PAR(16,7)	RHO
1.00		COLLECTOR MODE	PAR(1,1)	MODE
594.10	SQ METERS	AREA	PAR(1,2)	A
.97		F-PRIME (COLLECTOR EFFICIENCY FACTOR)	PAR(1,3)	FP
4.19	KJ/KG DEG C	CPF	PAR(1,4)	CPF
.95		ALPHA (COLLECTOR PLATE ABSORBTANCE)	PAR(1,5)	ALF
10.30		UL (COLLECTOR LOSS COEFF)	PAR(1,6)	UL
.80		TAU (TRANSMITTANCE OF THE COVERS)	PAR(1,7)	TAU
1.89	CU METERS	COOLING HOT TANK VOLUME (SMALL HOT TANK)	PAR(4,1)	VOL
1.51	METERS	HOT TANK HEIGHT	PAR(4,2)	HIGH
4.19	KJ/KG DEG C	HOT TANK CPF	PAR(4,3)	CPF
1000.00	KG/M3	HOT TANK FLUID DENSITY	PAR(4,4)	RHOF
2.50	KJ/M2DEGCHR	LOSS COEFF BETWEEN HOT TANK AND ENVIRONMENT	PAR(4,5)	U
15.56	DEG C	GROUND TEMP	PAR(4,6)	TGRND
949554.00	KJ/HR	AUXILIARY HEATER RATE	QDAUX	
96.11	DEG C	INITIAL TEMP OF COOLING HOT TANK	T(1)	
37.85	CU METERS	HEATING HOT TANK VOLUME (LARGE HOT TANK)	PAR(6,1)	VOL
4.00	METERS	HOT TANK HEIGHT	PAR(6,2)	HIGH
4.19	KJ/KG DEG C	HOT TANK CPF	PAR(6,3)	CPF
1000.00	KG/M3	HOT TANK FLUID DENSITY	PAR(6,4)	RHOF
2.50	KJ/M2DEGCHR	LOSS COEFF BETWEEN HOT TANK AND ENVIRONMENT	PAR(6,5)	U
15.56	DEG C	GROUND TEMP	PAR(6,6)	TGRND
65.56	DEC G	INITIAL TEMP OF HEATING HOT TANK	T(2)	
3.00		NUMBER OF COLD TANK LAYERS	LAYER	
80.27	CU METERS	COLD TANK VOLUME	PAR(5,1)	VOL
3.66	METERS	COLD TANK HEIGHT	PAR(5,2)	HIGH
4.19	KJ/KG DEG C	COLD TANK CPF	PAR(5,3)	CPF
1000.00	KG/M3	COLD TANK FLUID DENSITY	PAR(5,4)	RHOF
2.50	KJ/M2DEGCHR	LOSS COEFF BETWEEN COLD TANK AND ENVIRONMENT	PAR(5,5)	U
15.56	DEG C	GROUND TEMP	PAR(5,6)	TGRND
10.00	DEG C	INITIAL TEMP OF COLD TANK TOP LAYER	TC(1)	
7.22	DEG C	INITIAL TEMP OF COLD TANK MID LAYER	TC(2)	
4.44	DEG C	INITIAL TEMP OF COLD TANK BOTTOM LAYER	TC(3)	
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 1 (COOLING HOT TANK - COLLECTOR LOOP	PAR(2,1)	MDOT1
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 2 (COOLING HOT TANK - COOLER LOOP	PAR(2,2)	MDOT2

Fig. G-2 SOLARDYN Printout, Page 1

31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 3 (COLD TANK - COOLER LOOP	PAR(2,3)	MDOT3
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 4 (COLD TANK - BLDG LOOP	PAR(2,4)	MDOT4
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 5 (COOLING HOT TANK - AUX HEATER	PAR(2,5)	MDOT5
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 6 (HEATING HOT TANK - BLDG LOOP	PAR(2,6)	MDOT6
31777.00	KG/HR	MASS FLOW RATE THROUGH PUMP NO. 7 (HEATING HOT TANK - COLLECTOR LOOP)	PAR(2,7)	MDOT7
6.70	DEG C	COLD TANK CONDITION FOR STARTING AUXILIARY HEATER	COOLIM	
23.00	DEG C	TEMP TO START CYCLING COLD TANK WATER THROUGH BLDG HEAT EXCHANGER	THSTAT	
98.50	DEG C	HOT TANK INITIAL TEMP - TEST FOR STARTING AUXILIARY HEATER	SIMMER	
8.89	DEG C	TEMP TO START CYCLING COLD TANK WATER THROUGH COOLER	WARMUP	
105.00	DEG C	CHILLER HOT TANK CONDITION TO SWITCH COLLECTOR FLOW TO HEATING HOT TANK	HOTSW	
20.00	DEG C	TEMP TO TURN ON HEAT IN BLDG	COMFRT	
48.89	DEG C	LOW TEMP LIMIT IN HEATING HOT TANK (CONDITION TO SWITCH COLLECTOR FLOW	WARMLO	
47.78	DEG C	TEMP TO TURN ON AUX HEATER FOR HEATING HOT TANK	TEPID	
15.56	DEG C	SET TEMP TO WHICH ECONOMIZER MAY PULL BLDG TEMP (IF ITEM(13) SELECTED)	CHILL	
12.78	DEG C	AMBIENT TEMP AT WHICH ECONOMIZER WILL FUNCTION	ECTEMP	
97.00	DEG C	TEMP TO START CYCLING HOT TANK WATER THROUGH COOLER	HOTLIM	
98.00	DEG C	HOT TANK VENTING TEMP	VENT	
7.22	DEG C	TEMP DROP IN HOT TANK SIDE OF COOLER	TDELP2	
4.69	DEG C	TEMP DROP IN COLD TANK SIDE OF COOLER	TDELP3	
8.33	DEG C	TEMP RISE IN BLDG HEAT EXCHANGER	TDELP4	
8.33	DEG C	TEMP DROP IN BLDG HEAT EXCHANGER	TDELP6	
15000.00	KJ/DEG C	HEAT CAPACITY BUILDING AIR	CH	
.010000		SOLAR EXCESS COEFF	TR	
2.044247	KJ/M2DEGCHR	ROOF U-FACTOR	URROOF	
2.044247	KJ/M2DEGCHR	FLOOR U-FACTOR	URFLR	
4.088493	KJ/M2DEGCHR	WALL AVERAGE U-FACTOR	URWALL	
2508.30	SQ METERS	BLDG ROOF AREA	AROOF	
2508.30	SQ METERS	BLDG FLOOR AREA	AFLR	
1393.50	SQ METERS	BLDG WALL AREA	AWALL	
285000.00	KJ/HR	RATE OF HEAT GENERATION IN BLDG (PEOPLE + LIGHTS)	QDINTL	

Fig. G-3 SOLARDYN Printout, Page 2

7-16-71

TIME	H	TA	WV
.00	.00	15.60	2.10
1.00	.00	16.10	.00
2.00	.00	15.00	1.00
3.00	.00	15.60	.00
4.00	.00	15.60	.00
5.00	25.10	16.10	2.10
6.00	175.80	16.10	1.00
7.00	477.30	17.19	2.10
8.00	1582.50	19.39	1.00
9.00	2486.80	18.89	3.10
10.00	2863.60	19.39	2.10
11.00	3089.60	22.19	3.10
12.00	3114.80	22.19	3.10
13.00	2939.00	22.80	5.10
14.00	2587.30	23.30	4.10
15.00	2110.00	23.30	4.10
16.00	1507.10	23.30	4.10
17.00	879.10	20.60	4.10
18.00	301.30	19.39	4.10
19.00	25.10	17.80	3.10
20.00	.00	17.19	2.10
21.00	.00	16.10	2.10
22.00	.00	16.10	2.10
23.00	.00	16.10	2.60
24.00	.00	15.60	2.60

Fig. G-4 SOLARDYN Printout, Page 3

SANTA CLARA COMMUNITY CENTER SOLAR HEATING AND COOLING

P1 ON WHEN Q OUT OF COLLECTOR IS POSITIVE - P7 OVERRIDES IF CONDITIONS ARE MET
P2 AND P3 ON WHEN SMALL HOT TANK .GE. 97.00 AND TOP LAYER OF COLD TANK .GE. 8.89
P4 ON WHEN BLDG TEMP .GT. 23.00 AND BLDG TEMP .GT. BOTTOM LAYER OF COLD TANK
AUX HEATER ON WHEN SMALL HOT TANK .LT. 98.50 AND BOTTOM LAYER OF COLD TANK .GT. 6.70
P6 ON WHEN (BLDG TEMP .LT. 20.00 OR P6 ON) AND BLDG TEMP .LT. LARGE HOT TANK
AUX HEATER ON WHEN LARGE HOT TANK .LT. 47.78 AND P6 ON . WITHIN BLDG OCCUPANCY PERIOD
P7 ON WHEN Q OUT OF COLLECTOR IS POSITIVE AND EITHER SMALL HOT TANK .GT. 105.00 .OR. (P6 ON AND LARGE HOT TANK .LT. 48.89)
ECONOMIZER WILL FUNCTION IF AMBIENT TEMP IS .LT. 12.78 BUILDING CAN BE PULLED DOWN TO 15.56 IF ITEM(13) SELECTED

DATE 7-15-71

TIME	H KJ/M2HR	H TILT KJ/M2HR	AMB TEMP DEG C	WIND VEL M/SEC	COLLECTOR T-IN DEG C	COLLECTOR T-OUT DEG C	CHILLER HOT TANK T(1) DEG C	HEATING HOT TANK T(2) DEG C	COLD TANK TC(1) DEG C	COLD TANK TC(2) DEG C	COLD TANK TC(3) DEG C	BLDG HEAT EXCH T-IN DEG C	BLDG HEAT EXCH TOUT DEG C	BLDG TEMP DEG C
5.00	25.10	.00	16.10	2.10	95.03	.00	95.03	65.31	10.02	7.24	4.49	.00	.00	15.83
6.00	175.80	95.95	16.10	1.00	94.82	.00	94.82	65.26	10.03	7.24	4.50	.00	.00	16.13
7.00	477.30	402.03	17.19	2.10	94.61	.00	94.60	65.07	10.03	7.25	4.51	.00	.00	17.29
8.00	1582.50	1497.12	19.39	1.00	96.73	98.18	97.21	63.90	10.26	7.72	5.30	.00	.00	22.76
9.00	2486.80	2475.63	18.89	3.10	97.82	102.34	96.91	63.86	9.57	7.70	6.26	.00	.00	22.62
10.00	2863.60	2925.33	19.39	2.10	105.82	111.47	103.39	64.00	8.92	7.46	6.38	.00	.00	22.10
11.00	3089.60	3196.45	22.19	3.10	102.77	109.54	102.62	65.92	8.85	7.45	6.44	.00	.00	22.47
12.00	3114.80	3234.95	22.19	3.10	105.45	112.23	105.45	68.11	8.98	7.56	6.58	6.52	14.85	21.81
13.00	2939.00	3040.66	22.80	5.10	103.13	109.41	102.81	69.90	8.93	7.55	6.56	.00	.00	21.44
14.00	2587.30	2643.10	23.30	4.10	101.71	106.79	103.41	70.89	8.85	7.51	6.52	.00	.00	22.64
15.00	2110.00	2100.57	23.30	4.10	100.26	103.66	98.97	71.06	9.01	7.60	6.62	6.60	14.93	20.62
16.00	1507.10	1425.84	23.30	4.10	95.43	96.87	98.31	71.01	9.13	7.69	6.72	6.66	14.99	21.69
17.00	879.10	740.61	20.60	4.10	96.48	.00	98.87	70.95	9.17	7.73	6.76	6.70	15.03	21.64
18.00	301.30	164.71	19.39	4.10	95.60	.00	95.60	70.90	9.05	7.67	6.68	.00	.00	22.95
19.00	25.10	.00	17.80	3.10	97.25	.00	97.21	70.84	9.08	7.69	6.71	.00	.00	21.99
20.00	.00	.00	17.19	2.10	96.50	.00	96.49	70.79	9.04	7.67	6.68	.00	.00	22.65
21.00	.00	.00	16.10	2.10	95.80	.00	95.80	70.73	9.05	7.67	6.68	.00	.00	22.36
22.00	.00	.00	16.10	2.10	95.17	.00	95.17	70.68	9.06	7.68	6.69	.00	.00	22.94
23.00	.00	.00	16.10	2.60	94.96	.00	94.95	70.62	9.07	7.68	6.70	.00	.00	18.43
24.00	.00	.00	15.60	2.60	94.74	.00	94.74	70.57	9.08	7.69	6.71	.00	.00	16.70

Fig. G-5 SOLARDYN Printout, Page 4

SANTA CLARA COMMUNITY CENTER SOLAR HEATING AND COOLING

DATE 7-15-71

TIME	QU (SOLAR) KJ	Q OUT OF CHILLER HOT TANK KJ	Q OUT OF HEATING HOT TANK KJ	Q FROM AUX HEATER KJ	Q OUT OF COLD TANK KJ	Q THROUGH BLDG HTG COILS KJ	Q THROUGH BLDG CLG COILS KJ	ENERGY IN CHILLER HOT TANK KJ	ENERGY IN HEATING HOT TANK KJ	ENERGY IN COLD TANK KJ
5.00	0.	0.	0.	0.	0.	0.	0.	753768.	10359208.	2439101.
6.00	0.	0.	0.	0.	0.	0.	0.	752080.	10351408.	2441251.
7.00	0.	0.	11091.	0.	0.	0.	0.	750396.	10321426.	2443401.
8.00	39700.	19226.	199638.	0.	12489.	0.	177456.	771104.	10136356.	2610461.
9.00	438658.	413363.	199638.	0.	268514.	0.	465323.	768683.	10128764.	2638534.
10.00	1135585.	1028596.	199638.	0.	668162.	0.	776370.	820130.	10151188.	2551460.
11.00	1361309.	1547698.	199638.	0.	1005365.	0.	1109100.	813966.	10455852.	2549032.
12.00	2861601.	2076413.	199638.	0.	1348813.	0.	1475103.	836418.	10804657.	2590958.
13.00	3730852.	2662806.	199638.	0.	1729727.	0.	1863288.	815498.	11087905.	2582926.
14.00	4481463.	3249199.	199638.	0.	2110642.	0.	2218200.	820281.	11244889.	2565202.
15.00	5044373.	3797140.	199638.	0.	2466578.	0.	2606385.	785077.	11272691.	2604329.
16.00	5371916.	4268177.	199638.	123442.	2772559.	0.	2939115.	779800.	11263991.	2639329.
17.00	5423653.	4729601.	199638.	541245.	3072295.	0.	3249663.	784250.	11255291.	2652129.
18.00	5423653.	5152573.	199638.	949551.	3347053.	0.	3504756.	758348.	11246591.	2623362.
19.00	5423653.	5508254.	199638.	1319876.	3578099.	0.	3748758.	771154.	11237941.	2632062.
20.00	5423653.	5844709.	199638.	1652218.	3796657.	0.	3948396.	765428.	11229291.	2621378.
21.00	5423653.	6152325.	199638.	1956074.	3996481.	0.	4148034.	759932.	11220641.	2623183.
22.00	5423653.	6421489.	199638.	2221948.	4171327.	0.	4325490.	754923.	11211991.	2627785.
23.00	5423653.	6421489.	199638.	2221948.	4171327.	0.	4325490.	753232.	11203341.	2629785.
24.00	5423653.	6421489.	199638.	2221948.	4171327.	0.	4325490.	751545.	11194700.	2631785.

Fig. G-6 SOLARDYN Printout, Page 5

TOTALS FOR 7-15-71

QU TO CHILLER HOT TANK KJ	CHILLER OUTPUT FROM SOLAR .65*QU-CHT	QU TO HEATING HOT TANK KJ	QU (SOLAR) TOTAL KJ	QAUX TO CHILLER HOT TANK KJ	QAUX TO HEATING HOT TANK KJ	Q FROM AUX HTR TOTAL KJ
4230722.	2749969.	1192931.	5423653.	2221948.	0.	2221948.

Q OUT OF CHILLER HOT TANK KJ	Q TO ENV FROM CHT KJ	Q AUT OF HEATING HOT TANK KJ	Q TO ENV FROM HHT KJ	Q DUMP FROM HHT KJ	Q OUT OF COLD TANK KJ	Q TO ENV FROM COLD TANK KJ	Q THROUGH BLDG HTG COILS KJ	Q THROUGH BLDG CLG COILS KJ	Q THROUGH ECON KJ	NET Q THROUGH BLDG COILS KJ
6421489.	41874.	199638.	196326.	0.	4171327.	-49849.	0.	4325490.	0.	-4325490.

Fig. G-7 SOLARDYN Printout, Page 6

Appendix H

LOCKHEED SOLAR COLLECTOR COMPUTER PROGRAM* (SOLAR)

The SOLAR Computer Program is used to perform analytical studies of flat plate solar collectors. The program accepts input data of air, water inlet, and backside of insulation temperatures, the collector orientation and its physical properties and dimensions, the transfer fluid flow conditions, relevant optical properties, solar insolation, and wind speed. The output consists of component temperatures, a detailed heat map of the collector elements, and the collector efficiency. The program calculates collector performance considering as many as five cover plates, including those which are partially transparent to infrared radiant energy. Designs utilizing honeycomb materials are also analyzed with the honeycomb's effect on both radiation and convection heat losses considered. SOLAR is the only collector computer program currently known to exist which handles such special effects.

A very useful feature of the computer printout is the heat map. From this mapping, the heat flow distribution is clearly defined and displayed to allow the designer to identify those areas to consider for design improvement. The program is flexible so that changes in any collector component can be easily simulated and results quickly obtained. Calculations from the program have been compared with published data. Good agreement was obtained when comparing the results to those published by PPG for their two cover-glass system and to those obtained experimentally on a Mylar honeycomb system at Lockheed.

H.1 MODEL DESCRIPTION

The energy exchange mechanisms considered are as follows:

- Solar radiation energy to collector and covers, considering absorption, reflection, and transmission at all surfaces.

*From SAN/1081 – 76/1; LMSC-D462879; "Development of Plastic Honeycomb Flat-Plate Solar Collectors", Apr 1976

- Long wavelength (infrared) radiation exchanges between the various surfaces and to the sky considering emission, absorption, reflection, and transmission at each surface.
- Convection between the top cover and the environment as a function of the windspeed.
- Natural convection between surfaces, including the degree of convection suppression as a function of honeycomb design.
- Combined conduction and forced convection between the collector and the heat transfer fluid.
- Conduction through the insulation on the back of the collector.

A description of each of the energy exchange mechanisms is given in the following paragraphs.

H.2 SOLAR RADIATION

The solar energy absorbed by the absorber plate and the various transparent covers is based on the work of Stokes. Both the parallel and perpendicular components of solar radiation are used to calculate the reflectivity of each cover as a function of solar incidence angle and material index of refraction from the equation

$$\rho = \frac{(n^2 - 1)^2 (n^2 \cos^2 \theta - \sin^2 \theta \cos 2\theta)}{\left(\sqrt{n^2 - \sin^2 \theta} + \cos \theta\right)^2 \left(\sqrt{n^2 - \sin^2 \theta} + n^2 \cos \theta\right)^2}$$

where

ρ = reflectivity

θ = incident angle

n = index of refraction in solar spectrum

If Brewster's angle, defined as

$$\varphi = \mathrm{TAN}^{-1}(n)$$

where

n = index of refraction

is reached or exceeded, the user is so notified. The transmissivity for a cover is calculated from the electromagnetic theory as $\tau = e^{-k\ell/\cos\theta}$ where θ is the angle of incidence measured from normal, k is the absorption coefficient, and ℓ is the cover thickness. The effective reflectance, transmittance, and absorptance of each cover are calculated considering internal reflections and transmission as follows:

$$R = \rho + \frac{\rho\tau^2(1 - \rho^2)}{(1 - \rho^2\tau^2)}$$

$$T = \tau(1 - \rho)^2/(1 - \rho^2\tau^2)$$

$$A = 1 - T - R$$

where

R = effective cover plate reflectance

T = effective cover plate transmittance

A = effective cover plate absorptance

The results of Stokes are then used to obtain the amount of energy absorbed in each cover and in the absorber plate surface considering all reflections. When honeycomb is used, an effective absorptance of the absorber plate/honeycomb combination is used.

H.3 LONG WAVELENGTH RADIATION EXCHANGE

The amount of energy emitted from one surface which reaches another is determined considering the infrared transmission through covers and all the reflections between the various covers and the absorber. In these calculations the geometric view factor is assumed to be unity since the distance between surfaces is small compared to their overall size. The external radiation is to a "black sky" that is 6°K colder than the air. For a honeycomb covered collector the effective emittance of the absorber plate and honeycomb combination is used.

H.4 CONVECTION BETWEEN TOP COVER AND ENVIRONMENT

The heat transfer coefficient between the top cover exposed to the ambient air is given by McAdams as

$$h = 5.7 + 3.8 \cdot V$$

where h is in W/m^2-K and V is the wind speed in meters/sec.

H.5 CONVECTION BETWEEN SURFACES

If honeycomb is used between surfaces, the Rayleigh number is calculated. It is compared to the critical Rayleigh number, defined from

$$RA_c = \left(a^2 + 3.99^2\right)^3 / a^2$$

where $a = (0.95)(5)\sqrt{\pi}$ (Aspect ratio). If the critical Rayleigh number is not exceeded, convection is suppressed, which gives a Nusselt number of unity. If the critical Rayleigh number is exceeded, the expression used to define the Nusselt number is

$$Nu = 1 + 0.586\, RA^{1/3}\left[1 - \exp\left(- \frac{1.19\left(RA^{1/3} - RA_c^{1/3}\right)}{RA_c^{1/3}}\right)\right]$$

where

Nu = Nusselt number

RA = Rayleigh number

If no honeycomb is used, the equations for Nusselt number given by Tabor are used. For a horizontal surface the Nusselt number is

$$Nu = 0.152 \cdot Gr^{0.281}$$

where

Gr = Grashof number

Similar relations are given for collector tilt angles of 45 deg and 90 deg. Linear extrapolation is used to obtain the Nusselt number for intermediate tilt angles. All of these calculations are done using the temperature-dependent properties of air.

H.6 COMBINED CONDUCTION AND CONVECTION BETWEEN COLLECTOR AND FLUID

The heat transfer coefficients with the flow passages are calculated for either laminar or turbulent flow. For laminar flow the Sieder and Tate equation is used.

$$Nu = 1.86\,(RE \times PR \times D/L)^{0.33}\,(\mu_b/\mu_s)^{0.14}$$

where

RE = Reynolds number
PR = Prandtl number
D = hydraulic diameter

L = tube length

μ = viscosity

For fully developed turbulent flow, the Kays equation is used.

$$Nu = 0.55\ RE^{0.83} \times PR^{0.5}$$

The Nusselt number is modified if the tube is short, based on the results in Kreith.

In the analysis the flow can either be through parallel passages or by a single serpentine path. The conductance for the bond joint between the tubes and absorber plate is also included as one of the input parameters.

The useful heat removed from the absorber considers the existence of a temperature gradient in the direction of flow as well as one between tubes. The temperature distribution between tubes is analyzed using the classical fin equations, assuming a tube and sheet construction for the absorber. The fin efficiency is calculated and combined with the convection coefficient for the tube and the bond conductance to obtain an overall efficiency factor. In considering the effect of the temperature gradient in the direction of flow, an absorber heat removal factor is calculated. All the factors are temperature dependent, and the mean plate temperature defined as

$$T_M = \frac{1}{L} \int_0^L T_y\, dy$$

is used. L is the length in direction of flow (y direction).

H.7 INSULATION LOSS

The conductance from the collector to the surroundings through the insulation is calculated by the user of the program. In so doing, three-dimensional effects and edge losses are considered in the detail the user deems necessary.

H.8 METHOD OF ANALYSIS

The program presently calculates efficiencies and temperatures for steady-state conditions only. Figure H-1 gives a flow diagram of the method of an analysis. After the user completes the input, the cover's single film and effective optical properties, considering reflections, are calculated. Next, the incident solar energy and the absorbed solar energy for each surface are calculated. Then all IR radiant interchange factors are determined considering possible IR transmittance for the covers. All of the above calculations are done only once, whereas the following work is done each iteration using the component temperatures of the previous iteration. First, the convection coefficients and, from these, the convection conductances are calculated using the temperature-dependent properties of air. Next, the radiation terms are linearized to obtain a radiation heat transfer coefficient. Also, the convection coefficient between the fluid and flow passages are calculated. The various collector efficiency factors are calculated considering the two-dimensional absorber plate temperature distribution. The useful energy removed by the fluid is then obtained.

At this point a numerical relaxation method similar to the one in the LMSC Thermal Analyzer program is used to calculate the temperatures of the absorber plate and transparent covers. When all temperatures change less than 0.005°K, steady state is assumed to be reached. If any temperature change between iterations is greater than 0.005°K, the program returns to the location where temperature-dependent properties are calculated and repeats the analysis from that point. When steady state is reached, the system efficiency is calculated, and the output is displayed. Figure H-2 is an example of both the input and output. It is for a design with two transparent covers, and the heat map shows the energy distribution for the system. (The radiation from the second cover to the sky is not given.)

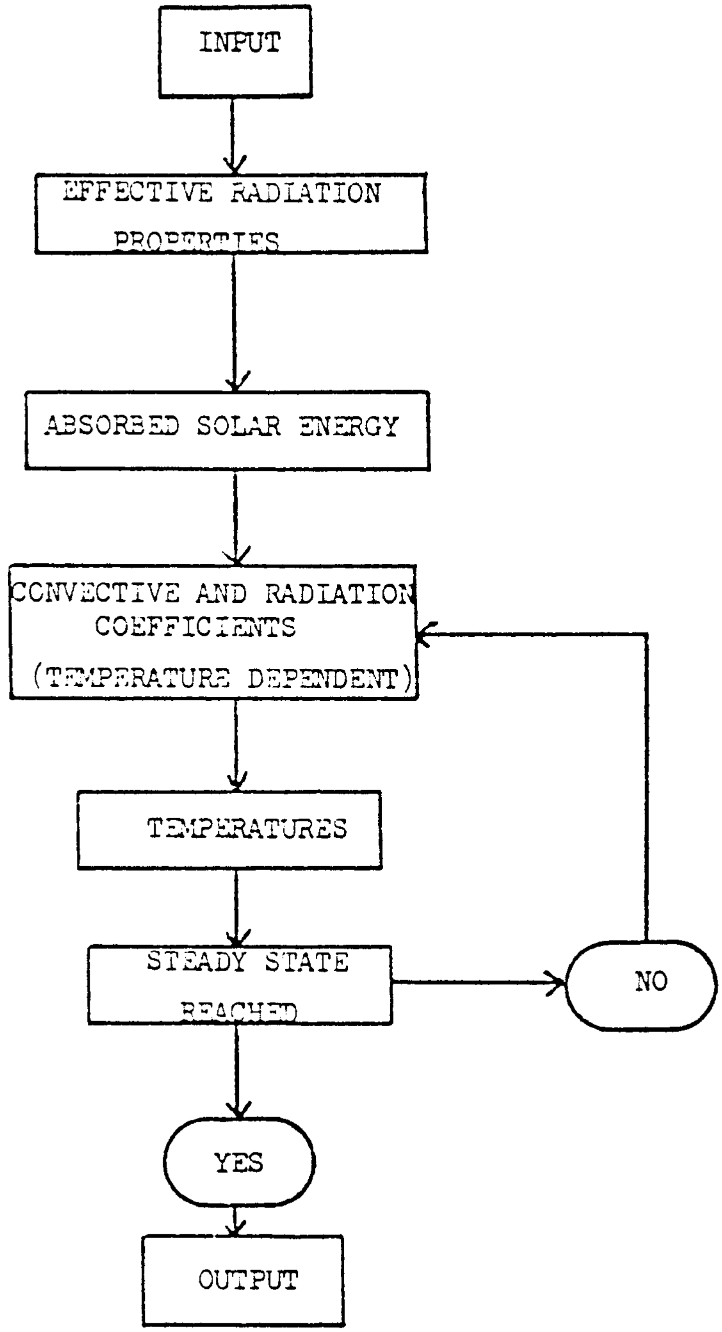


Fig. H-1 Flow Diagram for Solar Computer Program

```
SOLAR COLLECTOR CHARACTERISTICS PROGRAM

TITLE: AMETEK COLL. DN2-18 AT 70 C INLET

  ITEM    TEMP (DEG C)
 AIR         17
 INSULATION 17
 WATER INLET 70
 INIT COLL.   73
 DAILY (DA) OR SINGLE PT(SP) CALC? SP,SOLAR CONSTANT (W/SQ-M)=1008
 TILT ANGLE=50, SUN ANGLE=0, WIND VELOCITY (MPH)=5
 LENGTH (FT)=8, WIDTH (FT)=2.03, NO. OF COVERS=2,NO. OF TUBES=21
 SINGLE PASS? N, TUBE DIA (IN)=.25, COLL. DELTA (IN)=.06
 BOND COND. (W/CM-K)=1000, INSULATION CONDUCTANCE (W/K)=.68
 COLL. CONDUCTIVITY (W/CM-K)=3, FLOW RATE (GPM)=
INTERRUPT
34.6 >CONTINUE
NO. OF TUBES=21, SINGLE PASS? N, TUBE DIA (IN)=.25, COLL. DELTA (IN)=.06
 BOND COND. (W/CM-K)=1000, INSULATION CONDUCTANCE (W/K)=.68
 COLL. CONDUCTIVITY (W/CM-K)=3.44, FLOW RATE (GPM)=.56
 SPEC. HT. (J/G-C)=3.6

C.           C.G. INDEX EXT.  THICK-
G. EMIS REF. GAP  REF.  COEFF NESS
             (CM)      (1/CM)  (CM)
1  .85  .15  2.54  1.55  .0394  .318
2  .85  .15  2.54  1.55  .0394  .318
COLL EMIS.=.3, ABS.=.98, FOR COST ANALYSIS: C1=1, C2=0, C4=0
SEL COATING COLL COST=10,. SEL CTING COLL EFF=5

                              EFFECTIVE            AREA=   1.509 SQ M
          C.G.    ABS. TRANS. ABS. TRANS.
             1    .013  .900  .014  .900
             2    .013  .900  .012  .816
         COLL.    .980        .802

CONVERGE RESULTS AFTER   22 ITERATIONS


    ITEM            TEMP.                    HEAT MAP (WATTS)
                   (DEG C)
                             INCIDENT
    SKY              11.0    SOLAR=1520.8
                            !            ^ RAD=   ^CONV.=         ^ RAD=
    AIR              17.0   !            ^ 103.0  ^ 176.5         ^    .0
                            !            ^        ^               ^
   COVER 1     ----- 25.2-----ABS=  22.0--------------------------^-----
                            !            ^        ^       ^       ^
                            !            ^ RAD=   ^CONV.= ^ RAD=  ^
                            !            ^ 166.4  ^  91.0 ^    .0 ^
   COVER 2     ----- 46.8-----ABS=  17.6------------------^-------^-----
                            !            ^        ^       ^       ^
                            !            ^ RAD=   ^CONV.= ^       ^
                            !            ^ 109.1  ^ 130.6 ^       ^
   COLLECTOR ------- 76.4-----ABS=1219.6--------------------------------
   FLUID INLET-->--- 70.0------------->-FLUID-->--------EXIT TEMP= 77.4
                        !COND           HEAT                          !
                        !THRU           REMOVAL= 938.4                !
                        !INS= 40.4                                    !
   BOUNDARY--------- 17.0---------------------------------------------!

          HT REMOVAL FACTOR=  .943
          EFFICIENCY= .617 FOR COLLECTOR AT  76.4 DEG C ( 169.3 DEG F)
          D TEMP/I=  .056 K-SQ M/W

          COST OF H.C. COLL. COMPARED TO NO H.C. 1 COVER COLL:   .081
```

Fig. H-2 Example of Typical Results From Solar Computer Program

Appendix I
LOCKHEED SOLAR COLLECTOR TEST FACILITY

I.1 ABSTRACT

The Lockheed Solar Collector Test Facility was constructed in 1974 for the purpose of providing a modern test complex for evaluation of solar collector materials and designs. The facility is located at the Lockheed Research Laboratory in Palo Alto, California, and is operated by the Thermal Sciences Laboratory of R. E. Rolling, Manager. Equipment is available for testing individual flat-plate collector panels or modular units of two or more panels, as well as test racks for environmental exposure testing of candidate collector materials. Instrumentation provides continuous data acquisition of ambient temperature, relative humidity, wind velocity and direction, and solar irradiation. The facility meets the requirements established by the National Bureau of Standards for evaluation testing of solar collectors.

I.2 INTRODUCTION

In order that solar energy may be utilized on a large scale for the heating and cooling of buildings, it is imperative that low cost, low maintenance, and high efficiency solar collectors adaptable to mass production be developed within the next few years. To meet this goal, it is necessary that both analytical and experimental tools be developed to design and evaluate collector concepts. In an effort to meaningfully participate and contribute to the national needs associated with solar energy, Lockheed Missiles & Space Company, Inc., has developed computer programs for component and system analysis and has established a test facility for performance evaluation of solar collectors. This appendix describes the solar collector test complex located at the Lockheed Palo Alto Research Laboratory.

I.3 TEST FACILITY DESCRIPTION

The test facility was constructed and instrumented for evaluation of all types of solar collector materials and designs. The facility has the capability for testing individual flat collector panels or modular units of two or more panels. In addition, test racks are available for environmental exposure testing of candidate collector materials. Design and construction of the collector test facility was accomplished such that testing can be done in accordance with published standard procedures for solar collector evaluation.

The test facility, which covers an area of 7,200 ft^2, is located adjacent to Bldg. 209 at the Lockheed Palo Alto Research Laboratory. This location provides the required utilities and affords easy access for installation and maintenance. In addition, sufficient solar exposure is available for unobstructed year-round testing as determined by transit measurements and sun angle calculations. A plot plan of the site and orientation of the collector test racks within the facility are shown in Fig. I-1.

The facility contains a local weather station with the following instrumentation: precision pyranometers for measurement of direct, scattered, and total incident solar irradiation, wind sensors for measurement of air velocity and direction, and sensors to measure ambient temperature and relative humidity. These parameters are continuously recorded to provide test data as well as archive data for future use.

The facility currently provides sufficient flexibility to evaluate individual test model collectors from 1 ft^2 size to multi-panel systems up to 108 ft^2 total collector area. Individual performance parameters that can be measured include inlet and outlet working fluid temperature, fluid flow-rate, and transparent cover and absorber panel temperature distributions. A data acquisition system records data on punched paper tape at regular intervals and displays individual values in real-time on both a digital meter and on printed tape. This serves as the link between test activities and computerized data reduction. A number of strip chart recorders are employed to provide continuous monitoring of key parameters.

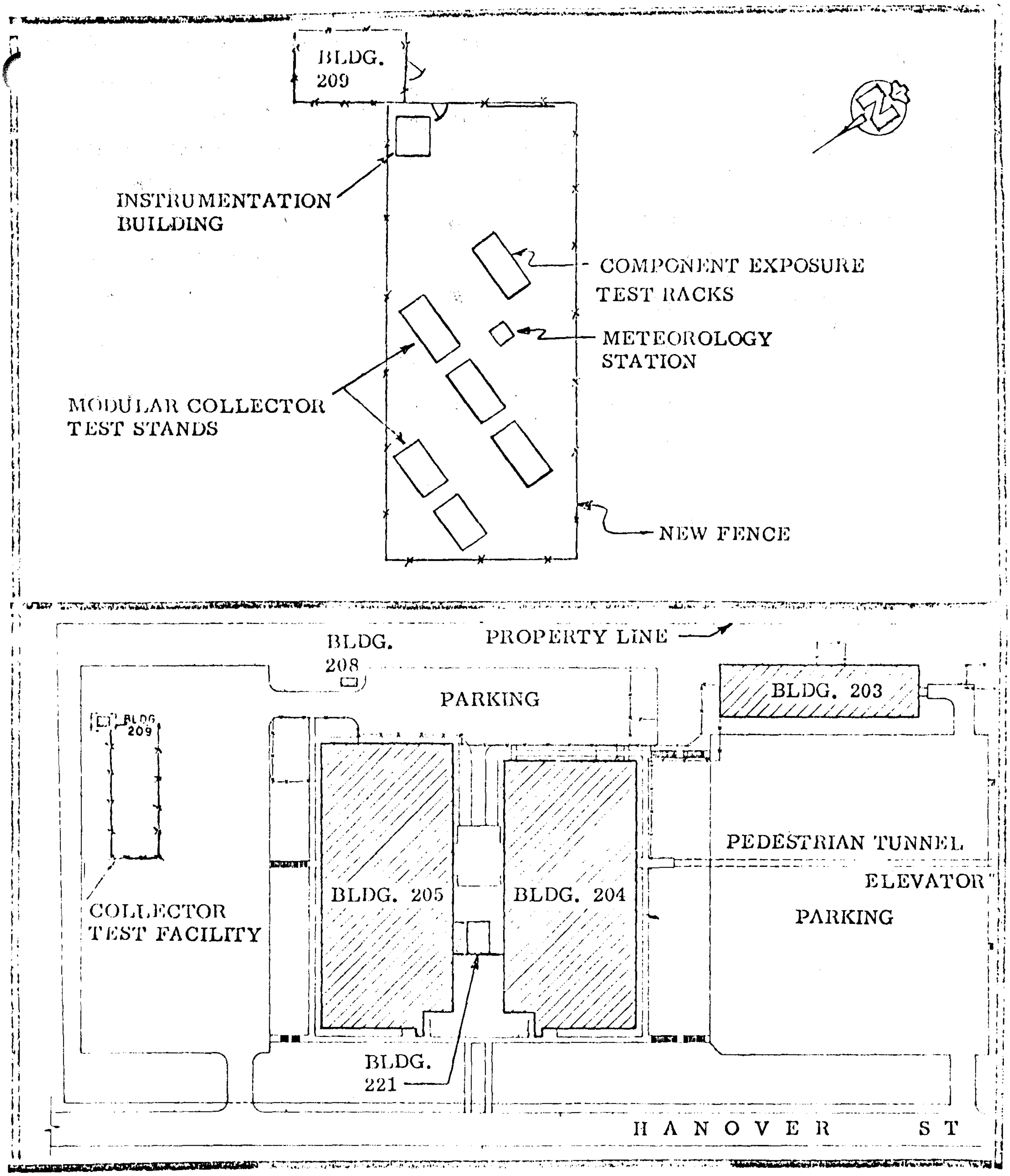


Fig. I-1 Solar Collector Test Facility

A schematic of the individual collector panel test layout is shown in Fig. I-2. Positive displacement pumps with 1 percent constant flow characteristics are used to supply heat transfer fluid for each test collector. Flow meters are used to monitor and confirm the flow rate. Pressure drops across test collectors are measured with manometers. A temperature-controlled reservoir is utilized to maintain constant input liquid temperature during a test run. A heat exchanger is connected between the collector outlet and the storage tank to transfer the excess energy when operating at low inlet temperatures. Miscellaneous manual and automatic valves and accumulators are utilized as required to complete the plumbing layout.

The facility (Fig. I-3) has the capability for testing up to twenty individual collector panels.

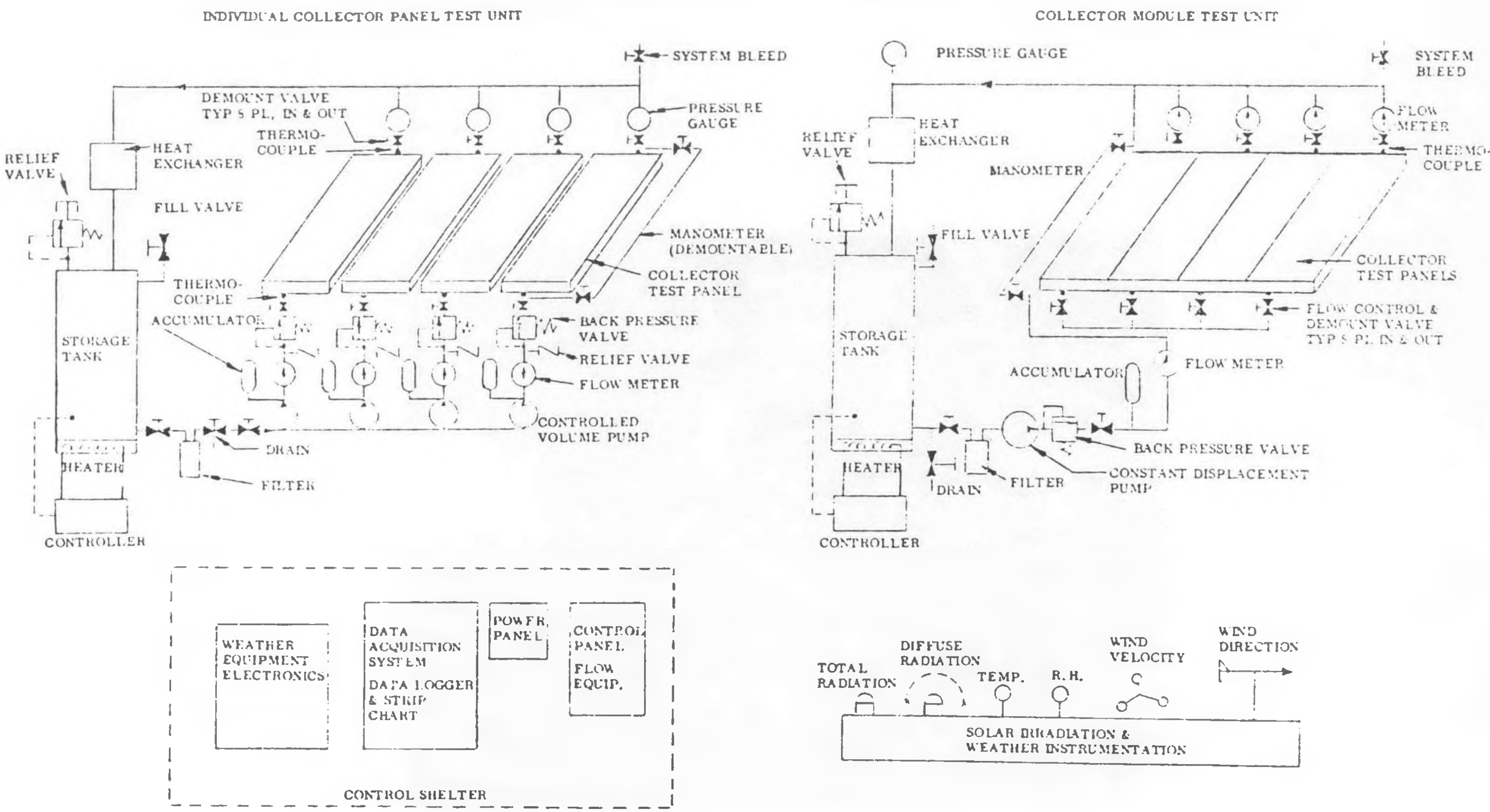


Fig. I-2 LMSC Solar Collector Test Facility Schematic

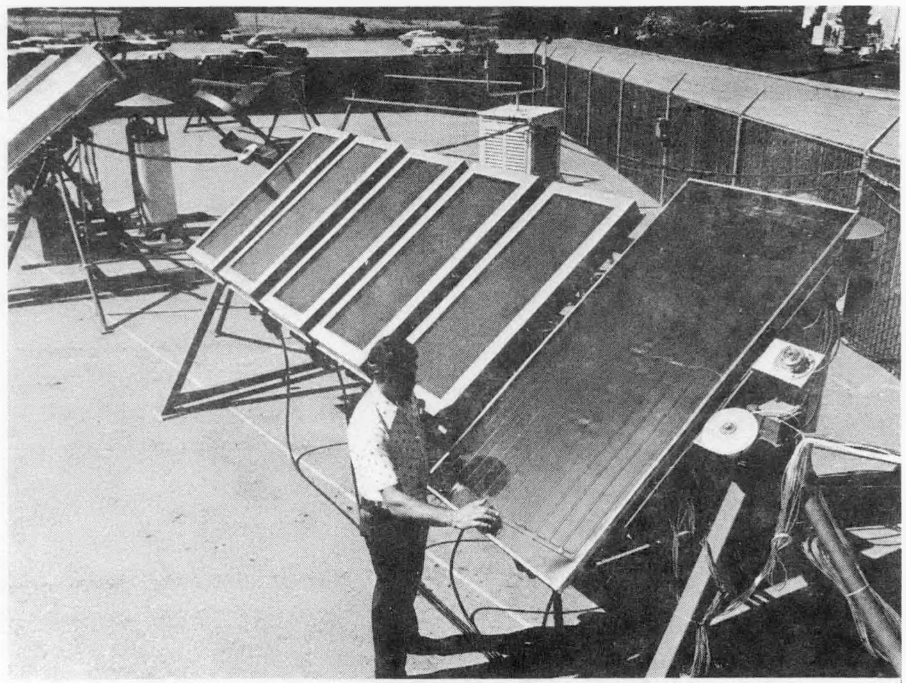


Fig. I-3 Lockheed Solar Collector Test Facility

Appendix J

COLLECTOR AND STORAGE CONSIDERATIONS FOR SOLAR-DRIVEN COOLING SYSTEM

The Lockheed-designed storage system for solar-driven cooling of the Santa Clara Community Recreation Center uses flat-plate collectors, two 25-ton Arkla Model WF300 absorption chillers, 50,000 gallons of cold storage, and 10,000 gallons of hot storage. In designing this system, the challenge was to achieve direct solar-driven cooling during the hot summers common to the Santa Clara Valley.

J.1 ENERGY STORAGE PROBLEMS

How would one decide whether to store cold or hot water; what are some of the considerations: Basically, it is a question of volume and cost. To store hot water, one is looking at a minimum chiller input temperature of 200°F and a maximum storage temperature of about 220°F because the collector efficiency decreases rapidly at higher temperatures. This implies a large volume of water because one only has 20 degrees times the heat capacity to store heat in and so a lot of volume is needed to make up for that. The hot water storage system would have to be pressurized, and that is very expensive. With the cold storage approach, the cold water from the chiller is stored in a cold tank. The tank temperature is near the normal ground temperature which solves the insulation problem. The tank does not have to be pressurized. Therefore, cold storage is the less expensive approach.

The hot storage tank for heating the building is a different matter. This can be a relatively small tank because it can run from 110°F up to 212°F and has a big temperature range in which to store the energy. A lot of energy can be stored in a small tank at atmospheric pressure for heating of the building.

It is imperative to achieve stratification in the cold tank. The chiller minimum output temperature is about 40°F. The fan/coil units for cooling will not work on water that is any hotter than about 55°F. This implies a maximum of 15 degrees temperature range within which to work. The chiller unit takes in water and then puts it out 10 degrees colder. But, if the tank is stirred up in the process of taking water out and putting it back in, the average tank temperature may be about 47°F. The chiller will try to put out water colder than 40°F and will shut off. Therefore, one has to layer the water in such a way as to be able to draw warmer water off the top of the tank and deposit the cold water on the bottom. If 50 degree water comes off of the top of the tank and the chiller puts it back on the bottom at 40°F, then all is well. This particular mode of operating the cold storage tank involves only the chiller. There are two other major operational modes to consider. If the fan/coil units in the building are operating and the chillers are not on, cold water is drawn from the bottom of the storage reservoir and warmer water is returned to the top. Under certain conditions, this mode can lead to instability and convective stirring; this can occur if the water returning to the top of the tank from the fan/coils is not as warm as the top layer of water already present in the tank. The third operational mode occurs when both the fan/coils and chillers are operating simultaneously. In this case, there are localized flows in the tank which cancel so that there is no net flow in the top or bottom layers of the tank. In any case, the fundamental question is, can one achieve the required stratification at all? Can one suppress mixing?

J.2 STRATIFIED COLD STORAGE TANK

A cold storage tank that is stratified will be more efficient. The stratification is generated by depositing the chilled water that results from the water cooling cycle at the bottom of the tank, and the warmer water resulting from the air conditioning cycle at the top of the tank. However, three factors detract from stratification: heat conduction in the tank, advection in the tank, and mixing of various kinds in the tank.

J.2.1 Conduction

Figure J-1 deals with conduction. Starting from the heat conduction equation, one can get a solution in two dimensions in the cross section of the tank. Every cross section is essentially the same. In a circular tank one gets a solution in terms of Bessel functions and exponentials, and at long times these exponentials dominate. The time constant for the exponential is about 80 days. If you had originally linear stratification such as indicated, it would take something on the order of 80 days or so to reduce the stratification by a factor of "e". This type of study plus other calculations resulted in the conclusion that conduction is not an important mechanism in the tank, and this is an important and an interesting fact because as water is put into the tank it will carry its own temperature independently of what gradients there may be in the neighborhood, except perhaps for isolated regions of steep gradients.

J.2.2 Advection

Figure J-2 deals with advection. The tank is always full of water so there is a general mass motion in the tank as new water is added at the top or bottom, and let out at the opposite point. For the air conditioning mode water is taken out of the bottom and put back at the top, so it was modeled in a simple fashion as a source and sink in the cross section of the tank. In the absence of gravity this would give stream lines as indicated in the dashed lines and isotherms (equal temperature lines) such as the solid curves. On the other hand, with gravity and perfect stratification, the isotherms would be horizontal, as shown on the right of Fig. J-2. The question is which one of these two patterns will dominate. In other words is advection going to bother the stratification to any degree? One gets an idea of the relative importance of these effects by looking at the flow time. The characteristic flow time for advection for this general mass motion in the tank is on the order of 4 or 5 hours, which is an average time for some particle to travel across the tank. The characteristic time for stratification is the Brunt-Vaisala period, which is shown in Fig. J-2. It has gravity and density gradients in it, and it is on the order of 2 minutes or so. This means that the general advection in the tank has a long time period compared with the stratification. So stratification seems to dominate advection, and the isotherms should be horizontal.

J.2.3 Mixing

Figure J-3 deals with mixing. One can identify several sources of mixing, such as the process of water deposition in the tank, and the rotational stratified flow discussed before which has internal shear that might generate turbulence. Calculated theoretical vorticity of the stratified flow is maximum at the top and bottom of the tank and decays toward the center. The parameter that measures the relative effect of internal mixi[ng] and stratification is Richardson's number, which contains the stabilizing effects of density gradient on the numerator and shear in the denominator. For very small values of this number, the flow is shear-dominated and there is a lot of mixing; for large values, the turbulence is damped by stable stratification. In atmospheric phenomena, a Richardson's number of about 0.2 is generally accepted as a borderline case; if it is much smaller than 0.2, there is a lot of mixing, if it is much larger, there is very little. Here we deal with Richardson's numbers on the order of decades, or hundreds for that matter, so we conclude that this type of mixing is negligible.

J.3 SUMMARY OF RESULTS

A first-order mathematical modeling of the situation indicates that internal mixing, general mass motion in the tank, and heat conduction are going to be weak, and one should expect the flow to retain its stratification.

The one unknown factor here is mixing due to water deposition, so this theoretical study led to the formulation of an experimental program to try to see what the effect of that mixing would be and to try to optimize the design of manifolds to deposit water in the tank. The simple mathematical model of the flow in the tank corresponds to continuously stratified flow with horizontal isotherms. This model has been computerized, and the output gives temperature distributions as a function of time.

Figure J-4 shows some of the distributions in the form of a computer-generated plot with temperatures as a function of vertical distance in the tank. Suppose that we start with a linear stratification on an air conditioning mode, so that we take water at 40 degrees from the bottom, warm it 10 degrees through the air conditioning fan coil and put it back at the top. Figure J-4 (a) shows successive temperature distributions at equally spaced times, corresponding to about one-half hour. We can see some loss of stratification at the top and bottom, where the lines are more vertical, but generally we maintain the stratification and after the full cycle we recover a linear distribution, with the whole tank now 10 degrees warmer.

Figure J-4(b) shows a similar situation where we have a weaker stratification at the beginning, with the bottom at 40 degrees and the top at 45 degrees. Since the fan coil units generate a 10-degree temperature difference, there is a jump across the interface. Effects of conduction near the jump were included, but this still does not smear it very much. In this case we proceed in the same fashion; at later times we get temperature distributions such as shown, with more or less uniform temperatures above and below a fairly large 5-degree jump at the interface. After a full cycle, we get again a linear distribution (line on fairly large 5-degree jump at the interface. After a full cycle, we get again a linear distribution [line on the right of Fig. J-4(b)].

Figure J-4(c) is a little more confusing, but it does illustrate a potential problem. If there were more than 10 degrees of initial stratification (greater than the temperature difference across the fan coils), then the fan coils would be depositing colder water on top of warm water. This would originate a convective motion, which would probably create some mixing in the tank.

A conclusion of this study is that the stratification will generally be maintained in the tank, but the maximum temperature differences are somewhat dictated by the rest of the equipment such as fan coils and water chillers.

Any temporary or cumulative stratification greater than the temperature differences of the machinery may create unstable inversion layers, which in turn would promote mixing and degradation of the original stratification.

The main problem remaining was the deposition of the water without undue mixing, for the purpose of keeping the tank stratified. The duty of the exhaust manifold is to distribute the flow uniformly along the tank and to do so at low head for greater efficiency of the system. Another requirement is low discharge velocity through orifices to minimize mixing. It is also desirable to have large ports to avoid the maintenance problems that may occur with fine meshes and porous walls. The system was designed with holes of constant diameter spaced according to a formula so that every linear foot of the manifold deposits the same amount of water, to avoid temperature gradients along the tank.

Figure J-5 shows this. The inlet manifold (into the tank) is fairly well understood, but there is not a lot of information on the outlet manifold. The pressure distributions a slightly different because in one case the losses work in one direction and in the other case in the opposite direction with respect to the diffuser effect in the manifold. The pressure distribution versus distance is flatter in the inlet manifold and steeper in the outlet manifold, which means different hole spacings to deposit and withdraw the water uniformly in the tank. We have designed that and now the problem is the jetting and mixing effect in the tank.

Figure J-6 shows a couple of arrangements for the experimental program, where the bottom three feet or so of the tank were simulated, making a motion picture film to show the flow when dye was injected. Having one inlet and one outlet pipe and just drilling holes in the pipe to see what happens, one finds that the jets are fairly powerful, and even though the head was kept as low as possible, wall jets formed and started climbing the walls of the tank, causing recirculation as they reach the free surface. With the partial simulation of the tank we could not tell how far the jets would climp up the walls of the tank. It was hard to dissipate the momentum of the jets.

An inlet pipe with multiple holes and baffles on the side of the tank was also tried, but even there it was found that the flow tends to get around the baffles and still wants to climb the walls. Letting the water out simultaneously through the outlet pipe, which also has holes, does not make any appreciable difference because the reach of the suction is not very great. This test was done with and without stratification and it does not make much difference.

The latest results obtained indicate that the problem can be licked, and that it is possible to deposit the water in smooth layers. The film just shows some of the pitfalls, and that it takes a bit of doing to design the plumbing. Use of a semi-cylindrical trough over the jets works very well.

In summary, a very simple mathematical model has been generated that gives temperature distributions in time, and indicates that the tank will be stratified, but that one must take some care to design the distribution manifold.

$$\frac{\partial T}{\partial t} - \kappa \nabla^2 T = 0$$

$$T(r, \theta, t) = \Delta T \sum_{n=1}^{\infty} C_n e^{-\lambda_n t} J_1(a_n r/R) \cos \theta + T_o ,$$

WHERE

$$J_1'(a_n) = 0 \qquad n = 1, 2, \ldots$$

$$\lambda_n = a_n^2 \kappa / R^2 , \qquad C_n = \left[(a_n^2 - 1) J_1(a_n) \right]^{-1} .$$

TIME CONSTANT, $1/\lambda_1 = 80.6$ DAYS.

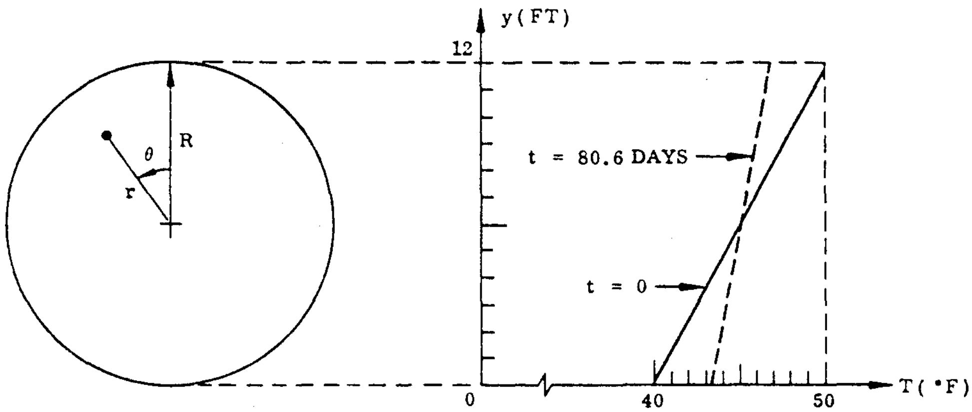
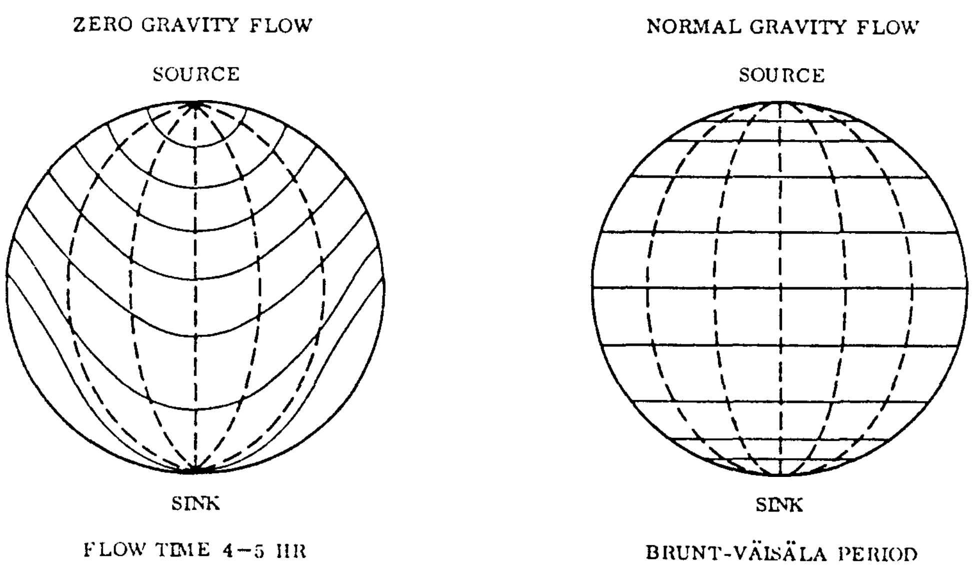


Fig. J-1 Heat Conduction in a Cylindrical Water Storage Tank With Linear Temperature Stratification



BRUNT-VÄISÄLA PERIOD
FOR 10° LINEAR STRATIFICATION

$$t_{BV} = 2\pi \left(-\frac{g}{\rho} \frac{d\rho}{dy} \right)^{-1/2}$$

$$\approx 2.2 \text{ MIN}$$

Fig. J-2 Advection in the Storage Tank With and Without Gravity Effects

TWO SOURCES OF TURBULENT MIXING:

- WATER DEPOSITION
- ROTATIONAL STRATIFIED FLOW

SHEAR IN THE STRATIFIED FLOW

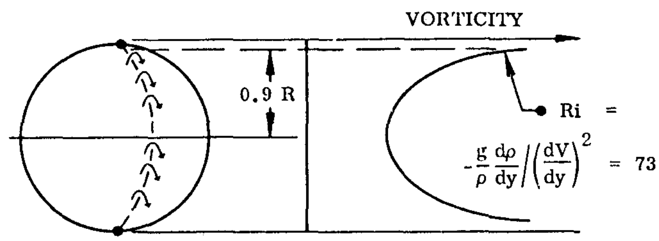


Fig. J-3 Mixing in the Storage Tank

INITIAL LINEAR STRATIFICATION OF 10° F MATCHES THE TEMPERATURE INCREASE THROUGH THE FAN COILS

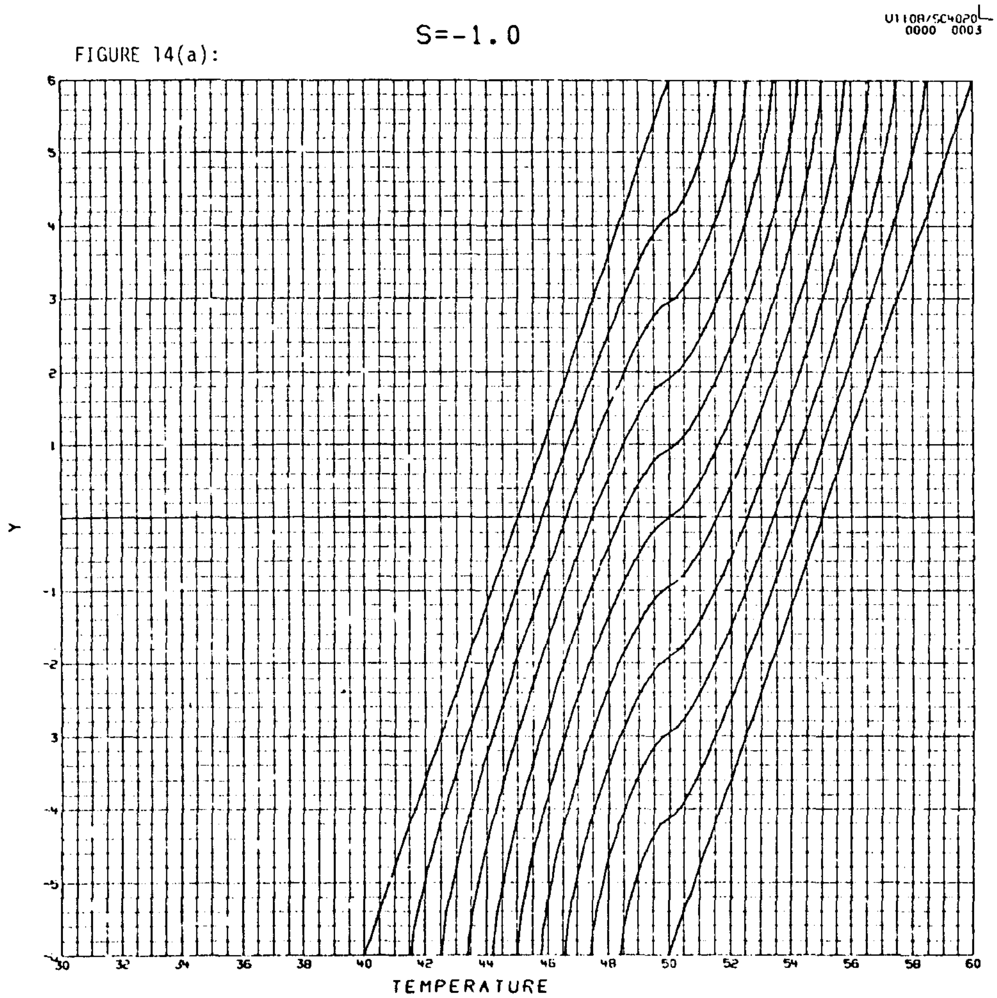


Fig J-4 Mathematical Modeling of TemperatureDistributions in the Cold Water Storage Tank During the Airconditioning (Fan Coil) Cycle

INITIAL LINEAR STRATIFICATION OF 5° F IS LESS THAN THE TEMPERATURE INCREASE THROUGH THE FAN COILS

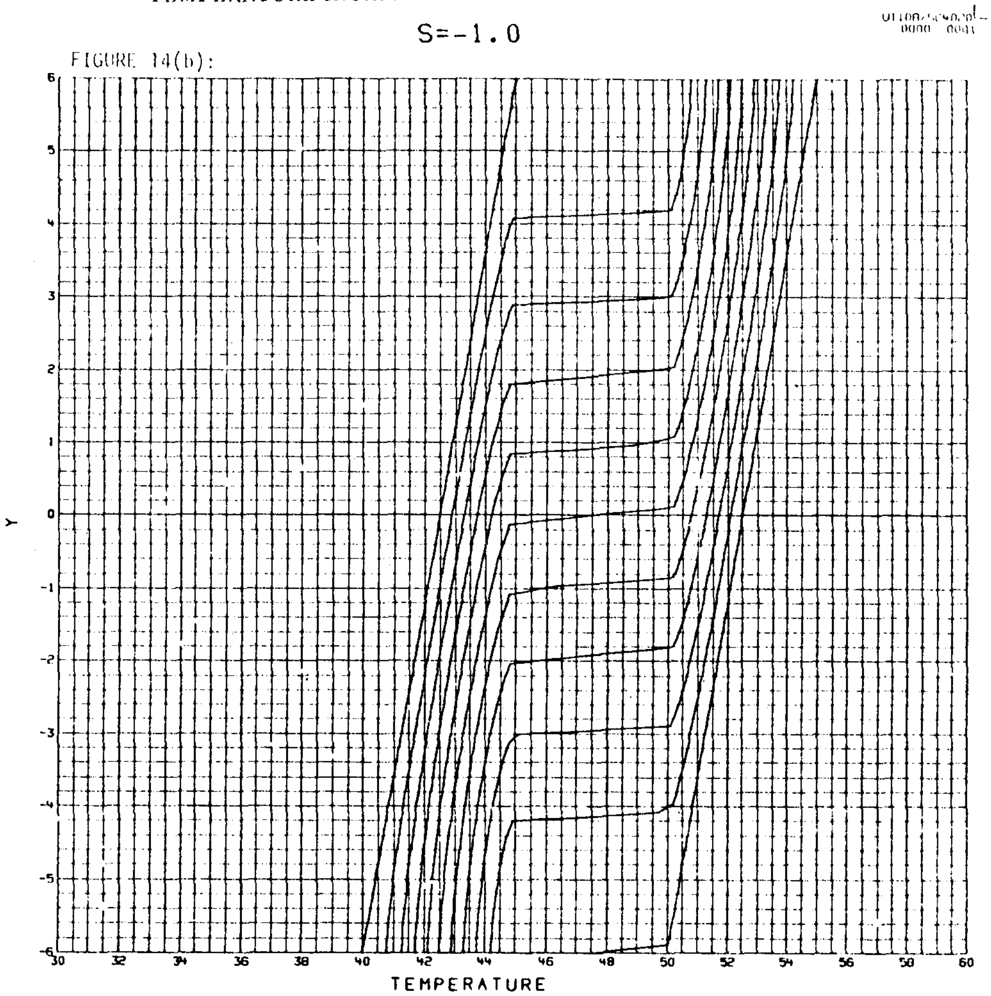


Fig. J-4 (Cont.)

INITIAL LINEAR STRATIFICATION OF 15° F IS MORE THAN THE TEMPERATURE INCREASE THROUGH THE FANCOILS

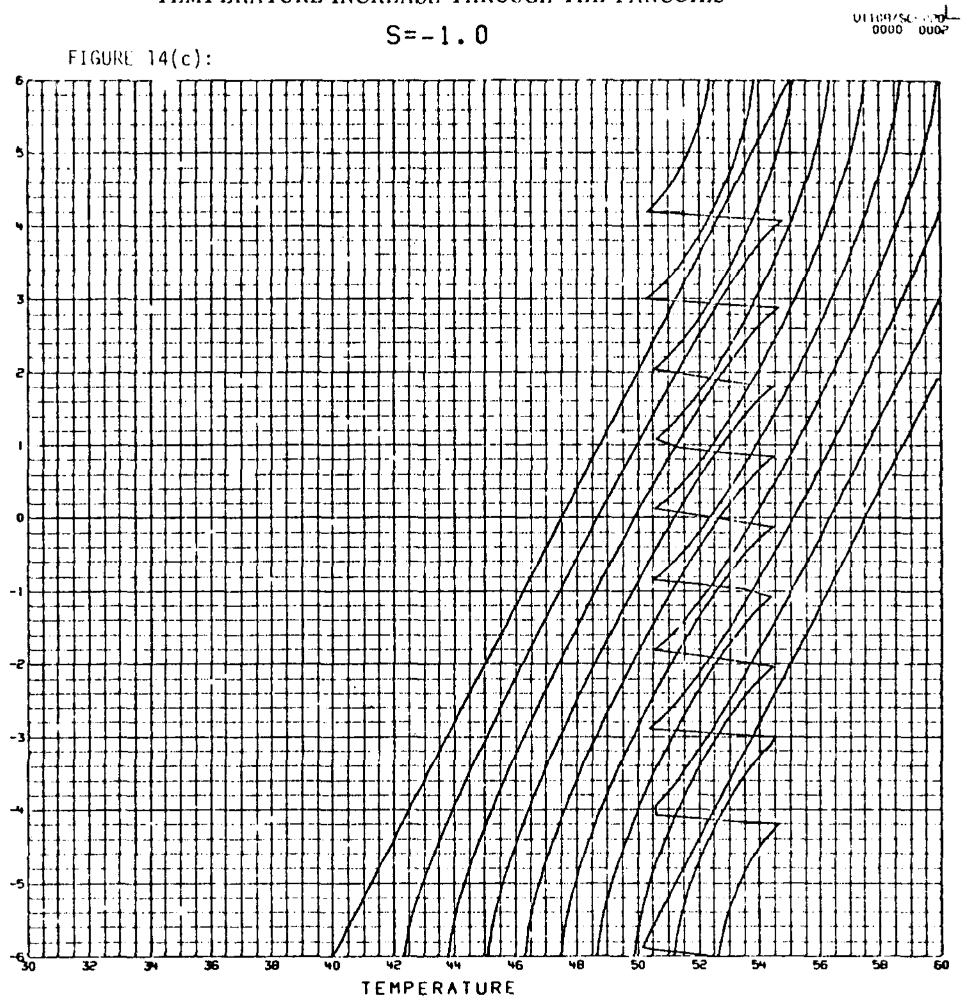


Fig. J-4 (Cont.)

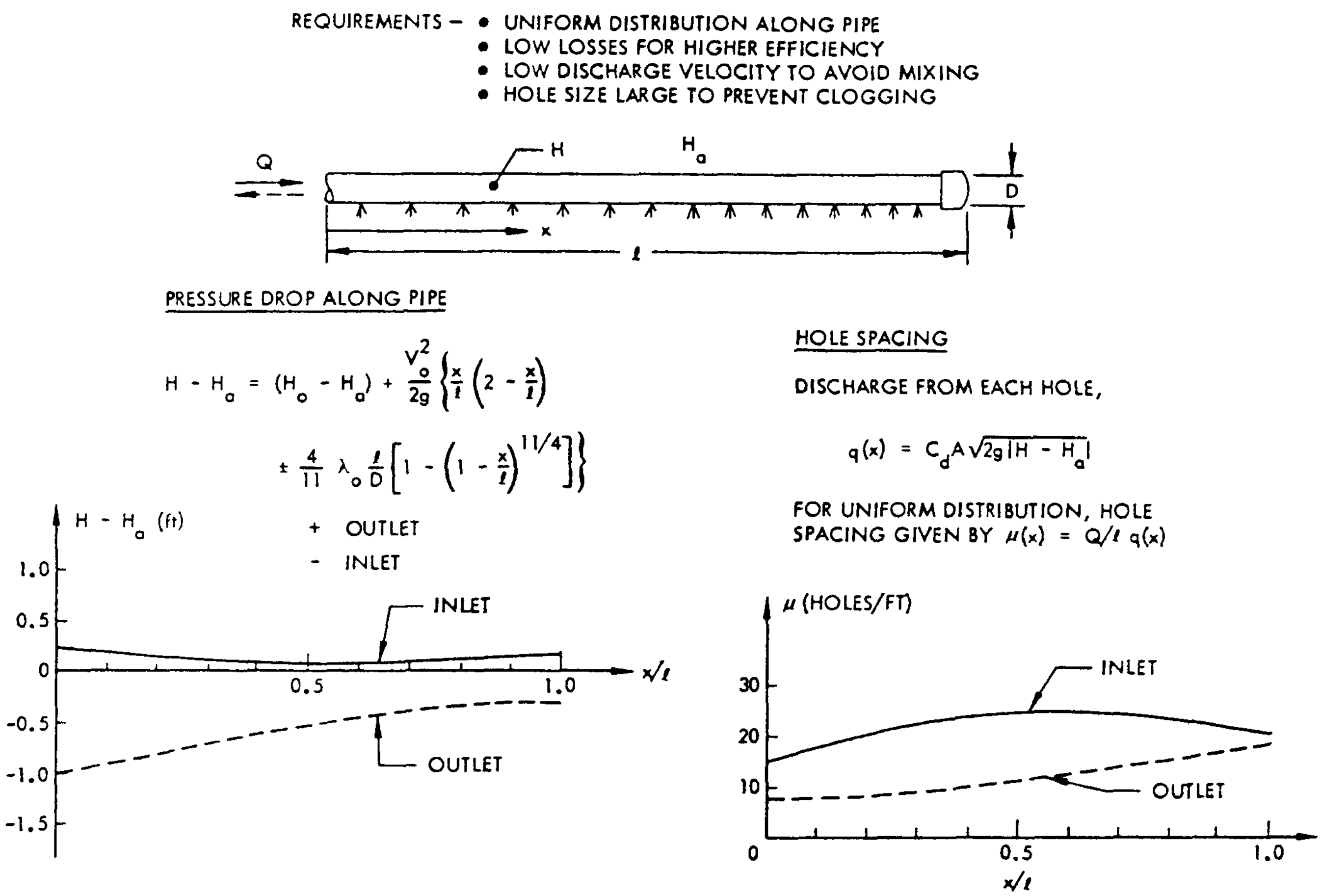


Fig. J-5 Design of Inlet and Outlet Manifolds – Variable Hole Spacing

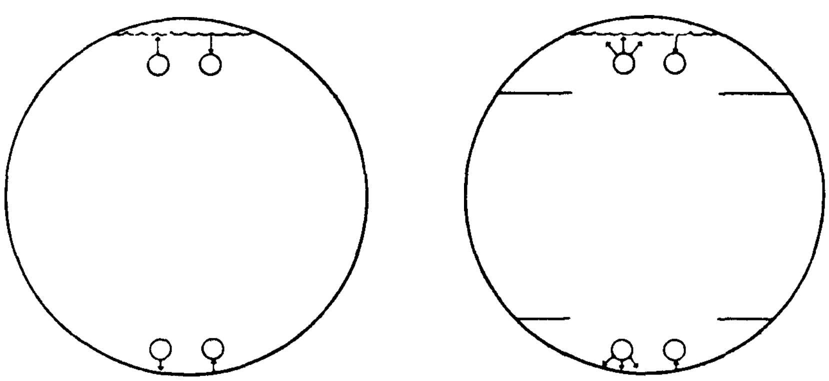


Fig. J-6 Arrangement of Inlet and Outlet Pipes

Appendix K
HOT RESERVOIR INSULATION THICKNESS FOR MINIMUM COST

A solar heating and refrigerating system contains, among other things, a flat-plate solar collection of area, A, and a hot water tank with insulation of thickness, L. If the insulation thickness is increased the collector area can be decreased. The cost of the system can be minimized by adjusting A and L to optimum values.

Let the solar energy collected per day be

$$E_c = K_E A t_s \tag{1}$$

where K_E is the solar collector constant in Btu/hr-ft^2 and t_s is the hours per day that the sun shines. Let the heat loss from the hot water tank be

$$E_L = U \Delta T A_T t_R / L \tag{2}$$

where U is the thermal conductivity of the insulation in Btu/hr-ft° F, ΔT is the temperature drop across the insulation in °F, A_T is the surface area of the tank in ft^2, and t_R is the hours per day during which one has a Δt.

The cost of the collector is

$$C_c = K_c A \tag{3}$$

where K_c is a constant in \$/ft^2, and the cost of the insulation is

$$C_L = K_L A_T L \tag{4}$$

where K_L is the cost of insulation in \$/ft^3.

The total cost of collector and insulation is

$$C_T = K_c A + K_L A_T L \tag{5}$$

This is an extremum when

$$\frac{dC_T}{dL} = K_c \frac{dA}{dL} + K_L A_T = 0 \tag{6}$$

We require that the insulation thickness and the collector area be adjusted in such a way that the daily average energy in the tank remain constant. That is,

$$dE_T = dE_c - dE_L = 0 \tag{7}$$

Using Eqs. (1) and (2) in Eq. (7) we get

$$\frac{dA}{dL} = - \frac{U \Delta T A_T t_R}{L^2 K_E t_s} \tag{8}$$

Substituting Eq. (8) in Eq. (6) yields the insulation thickness for minimum cost.

$$L_{min} = \sqrt{\frac{U \Delta T K_c t_R}{K_E K_L t_s}} \tag{9}$$

Integration of Eq. (6) using the value of dA/dL given by Eq. (8) yields the cost as a function of insulation thickness.

$$C_T = K_L A_T L + \frac{U \Delta T A_T t_R K_c}{K_E t_s L} + \text{constant} \tag{10}$$

This is the cost subject to the condition of Eq. (7), i.e., that any increase of heat flow into the tank due to increase of collector area is exactly compensated by an increase of heat flow out of the tank due to a decrease of insulator thickness. This equation has a minimum at L_{min} given by Eq. (9).

L_{min} is independent of collector area and tank size. These are determined by requirements of the total system. L_{min} can be set as soon as one has settled on the values of the quantities in Eq. (9). Then the collector area can be calculated from all the requirements of the system including the heat leak from the hot tank. The heat leak from the tank is given by substituting L_{min} in Eq. (2).

$$E_L \left(\frac{\text{Btu}}{\text{day}}\right) = \sqrt{\frac{U \Delta T K_E K_L t_s t_R}{K_c}}\; A_T \qquad (11)$$

This is the heat leak for insulation thickness of minimum system cost.

The constant of integration in Eq. (10) is proportional to the energy, E_s, needed by the system above that lost from the hot tank. Equation (1) becomes

$$E_c = K_E A t_s = E_L + E_s \qquad (1')$$

The collector area is calculated from Eqs. (1') and (2).

$$A = \frac{1}{K_E t_s}\left[E_s + \frac{U \Delta T A_T t_R}{L}\right] \qquad (12)$$

The cost is found by substituting Eq. (12) in Eq. (5).

$$C_T = \underset{\text{(a)}}{K_L A_T L} + \underset{\text{(b)}}{\frac{U \Delta T A_T t_R K_c}{K_E t_s L}} + \underset{\text{(c)}}{\frac{K_c}{K_E t_s} E_s} \qquad (10')$$

The terms are

(a) Cost of insulation

(b) Cost of collector needed to supply hot tank heat loss

(c) Cost of collector needed to supply heat for rest of system

When $L = L_{min}$ is put into Eq. (10') it becomes

$$C_T = \overset{(a)}{A_T K_L L_{min}} + \overset{(b)}{A_T K_L L_{min}} + \overset{(c)}{\frac{K_c E_s}{K_E t_s}} \qquad (10'')$$

The cost of insulation is equal to the cost of the extra collector needed to supply the hot tank losses.

A graph of Eq. (10') is shown in Fig. K-1. The various quantities of interest are indicated. This cost curve cannot be used for very small L because series heat impedances such as that of the tank wall have not been taken into account. It cannot be used for very large L since then one-dimensional heat flow, as assumed in Eq. (2), no longer occurs.

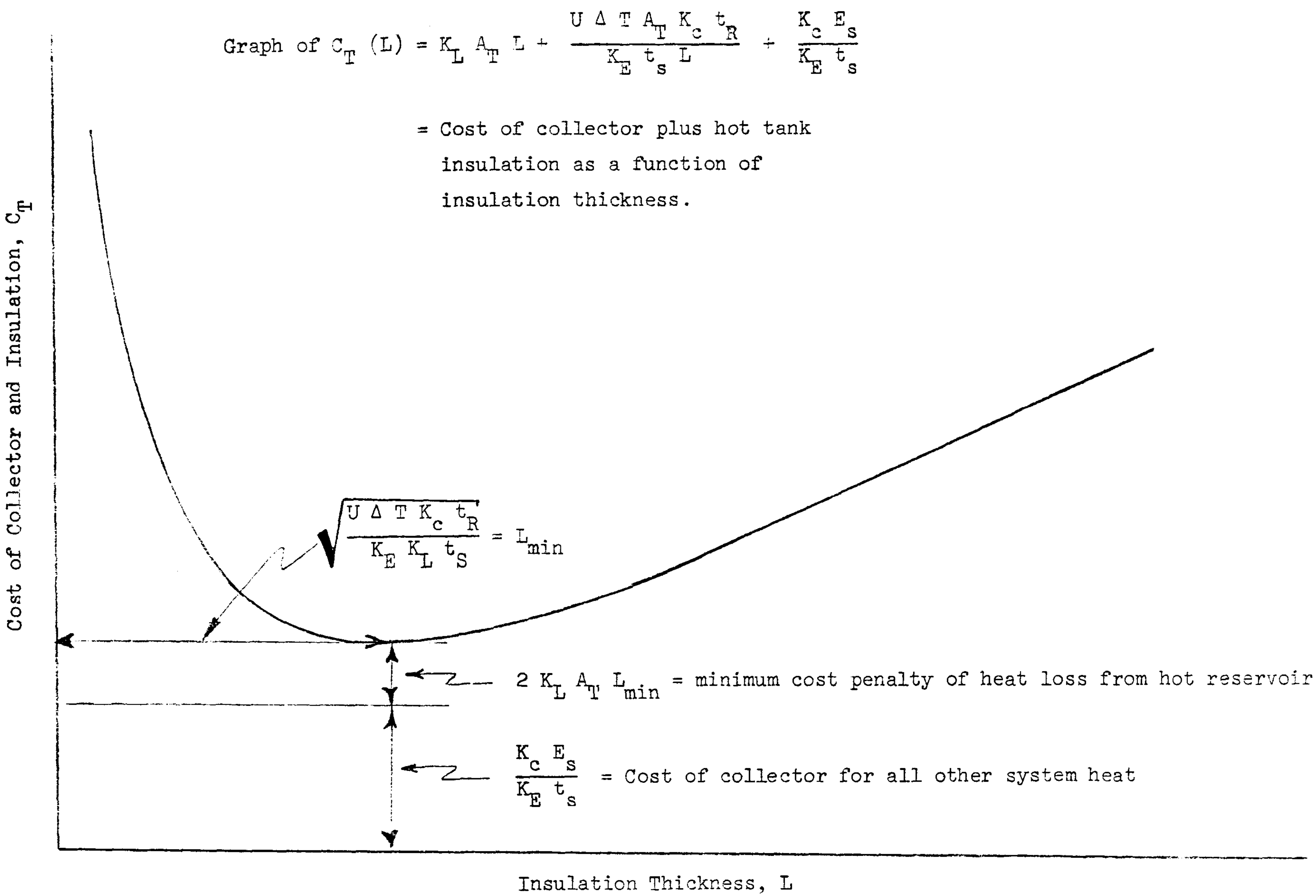


Fig. K-1 Insulation Thickness vs. Cost

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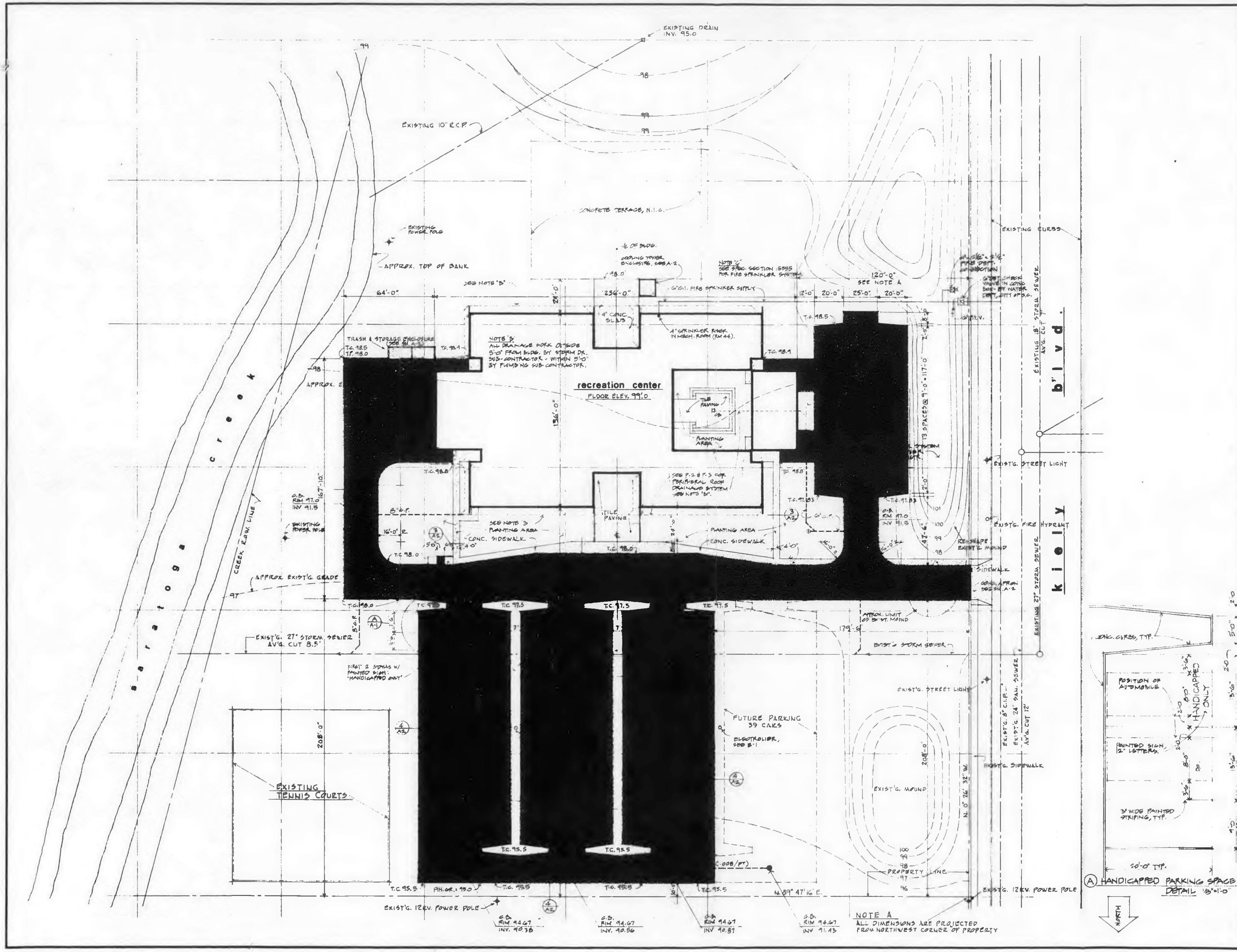


santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

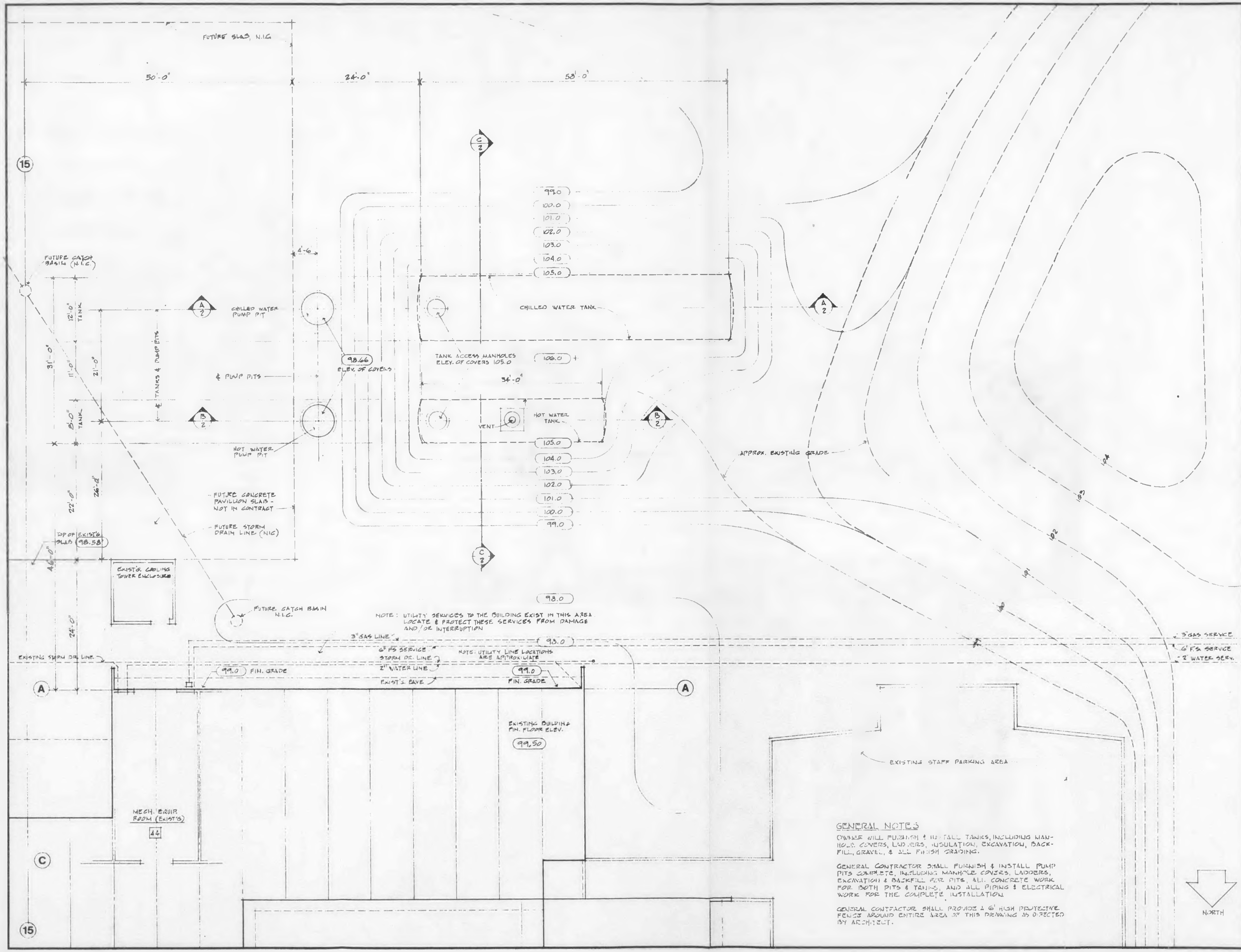
C-5399

site plan

SCALE 1" = 30'-0"

PROJECT	7319
DATE	3-5-74

L-1



santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

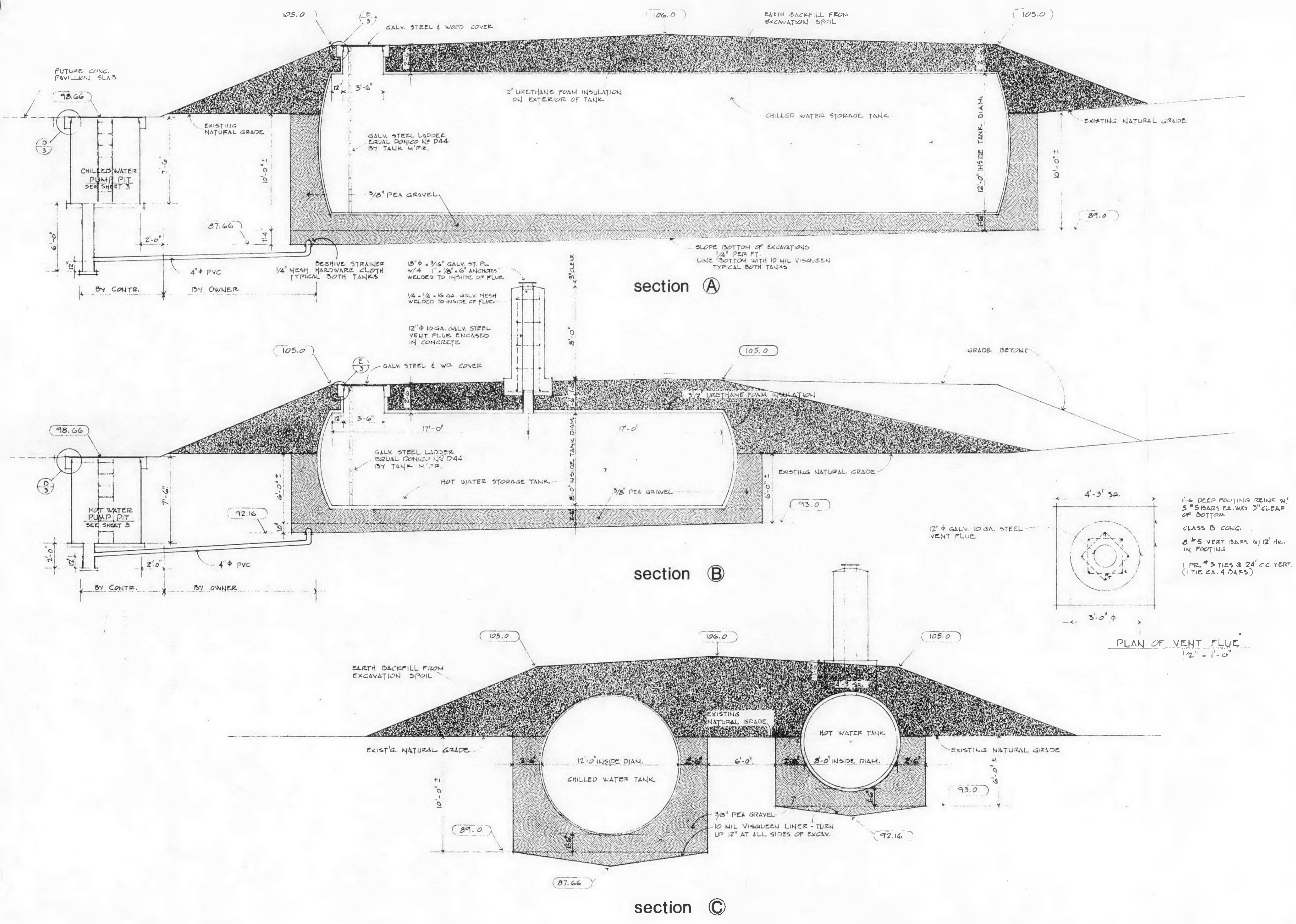
C-5399

partial site plan

1/8" = 1'0" scale 5 0 5 10 15 20 feet

PROJECT	7319
DATE	6-12-75

L-2



santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

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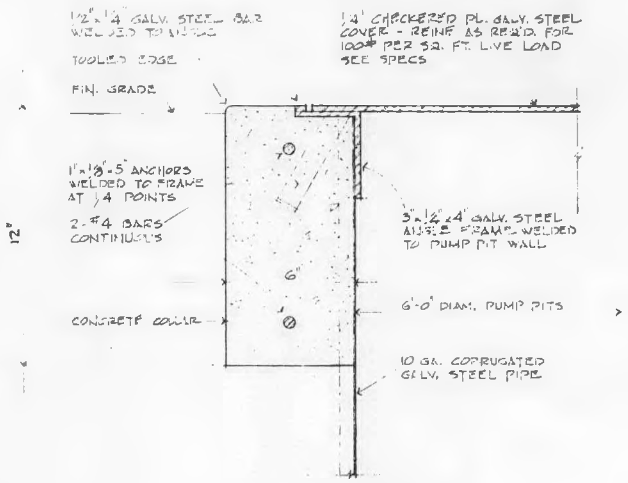
1/4" = 1'0" scale feet

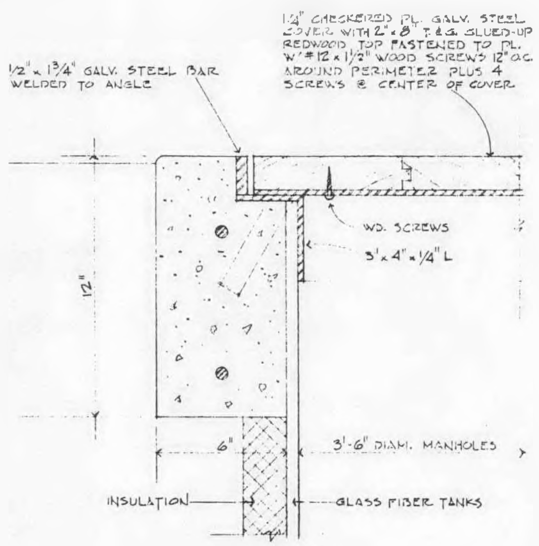
PROJECT 7319

DATE 6-12-75

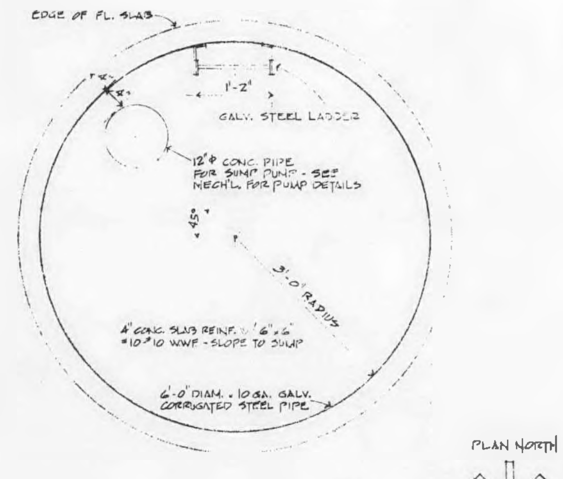
L-3



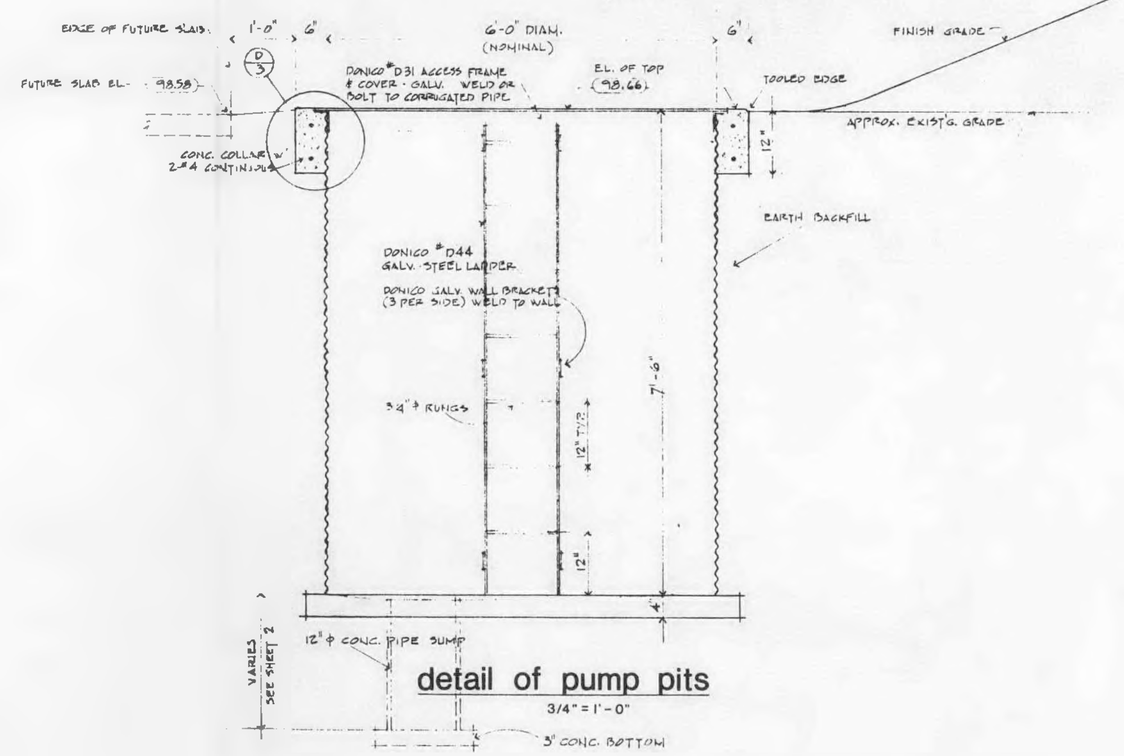
detail Ⓓ
pump pit covers
3" = 1'-0"



detail Ⓔ
tank manholes
SIMILAR TO DETAIL D ABOVE EXCEPT FOR CHANGES SHOWN



plan



detail of pump pits
3/4" = 1'-0"

santa clara community recreation center

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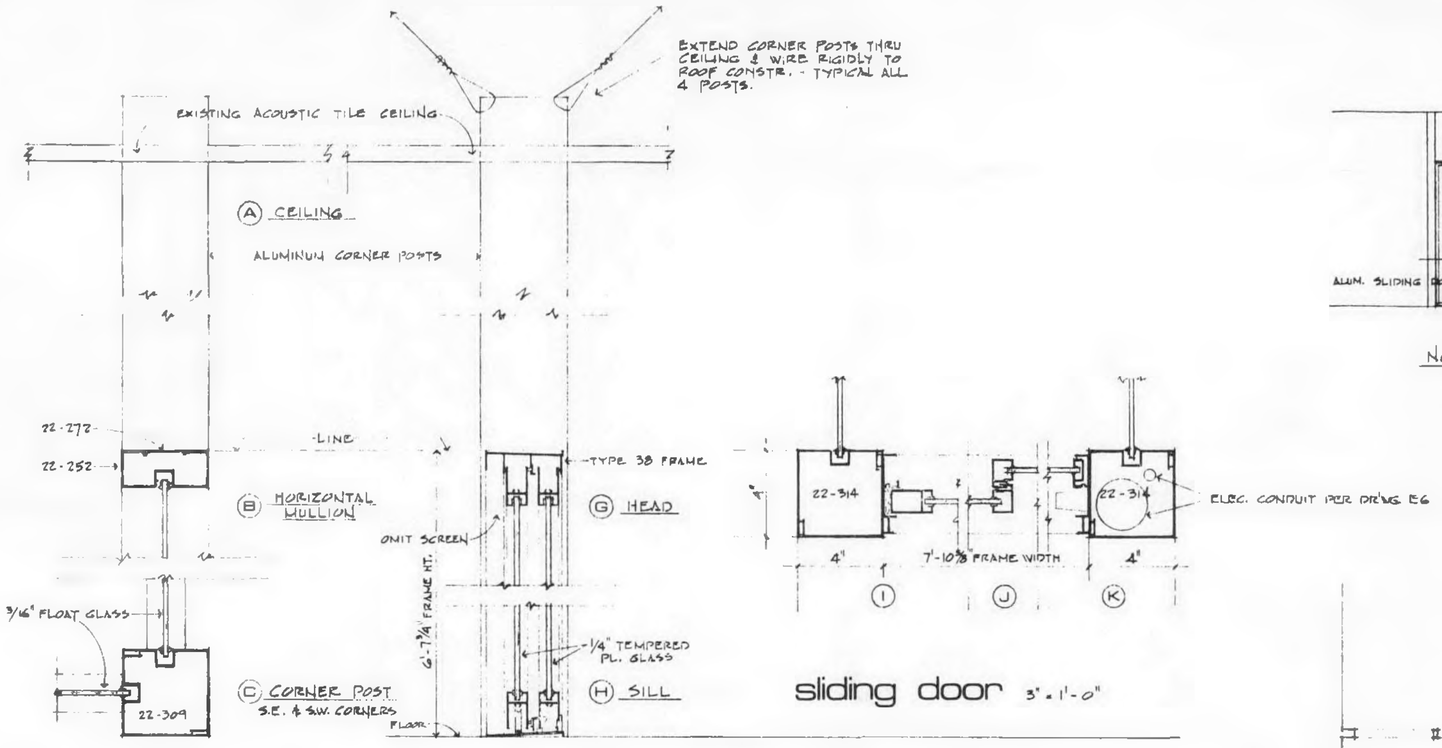
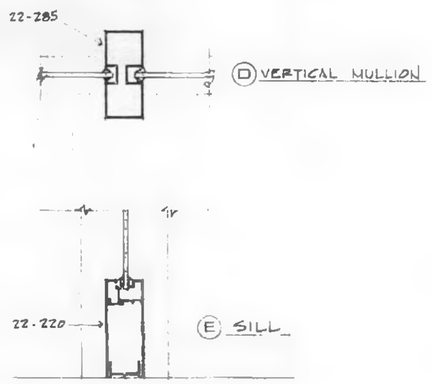
DATE 6-12-73

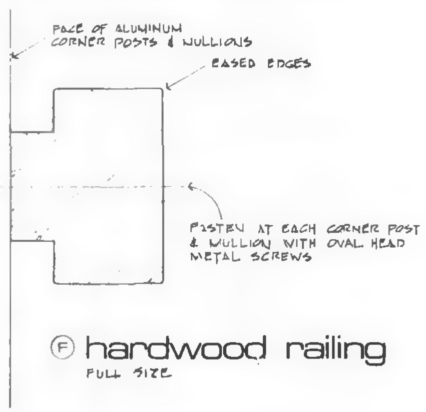
L-4



sliding door 3" = 1'-0"



aluminum frame details 3" = 1'-0"



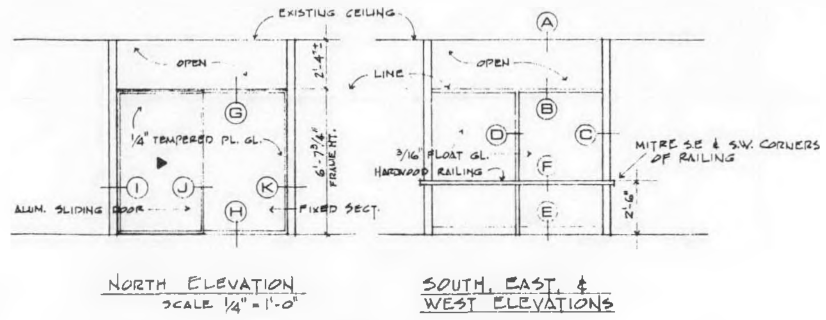
(F) hardwood railing
FULL SIZE

GENERAL NOTES:

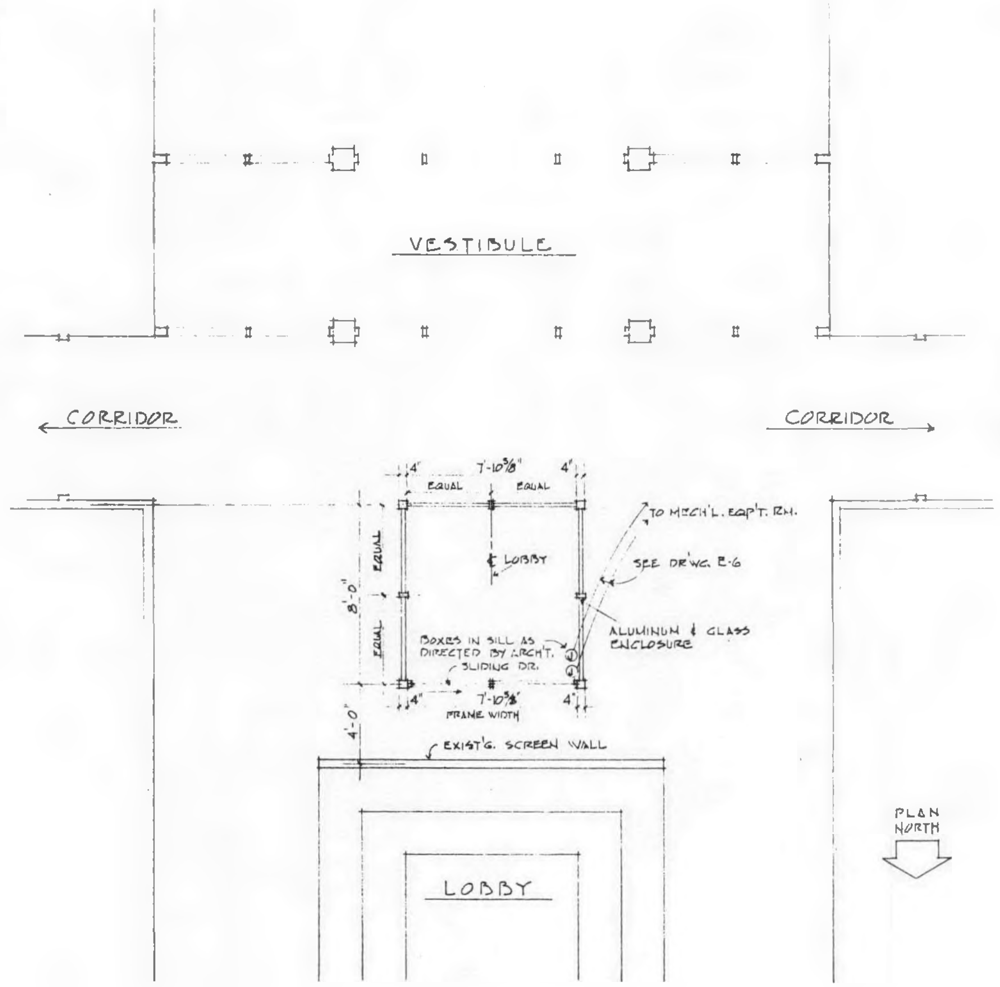
ENCLOSURE FRAME & SLIDING DOOR TO BE MEDIUM BRONZE ANODIZED ALUMINUM. FRAMES EQUAL TO ARCADIA SERIES 22-250 1 3/4" x 4" FRAMING SYSTEM. ANCHOR SOLIDLY TO FLOOR & TO ROOF CONSTRUCTION.

SLIDING DOOR EQUAL TO ARCADIA SERIES 550 WITH 3 3/8 WIDE TYPE 38 FRAME. PROVIDE EXTERIOR CYLINDER LOCK. OMIT SCREEN.

HARDWOOD RAILING TO HAVE 1 COAT STAIN, 1 COAT SHELLAC, 1 COAT GLOSS VARNISH, 1 COAT SATIN VARNISH.



elevations 1/4" = 1'-0"



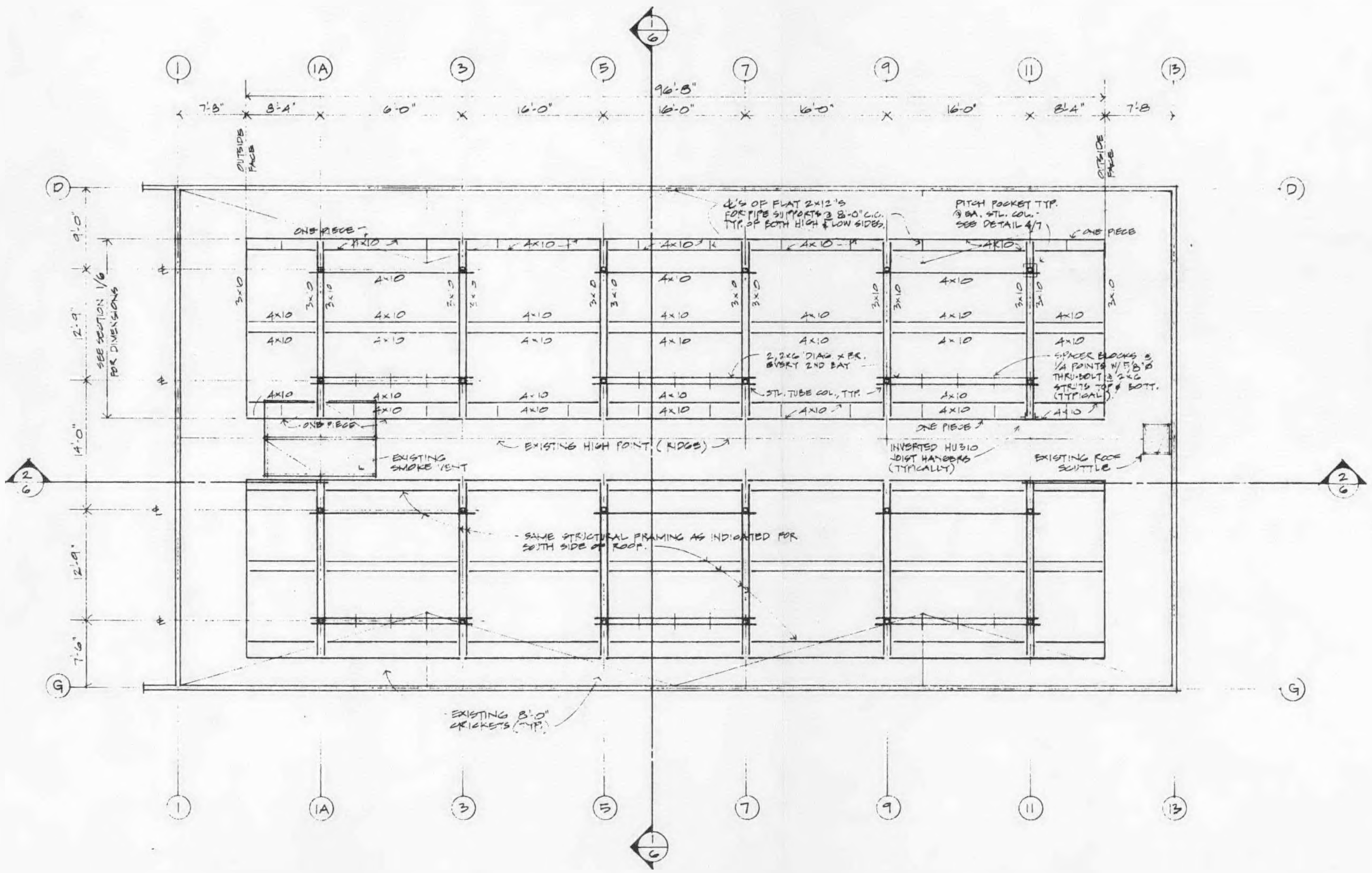
floor plan
1/4" = 1'-0"

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT
MEMBER OF THE AMERICAN INSTITUTE OF ARCHITECTS
SANTA CLARA, CALIFORNIA
David C. Thimgan
C-5399

ENCLOSURE FOR MONITORING EQUIPMENT

PROJECT 7319	L-5
DATE 6-12-75	



UPPER ROOF PLAN 1/8" = 1'0"

north

santa clara community recreation center

DAVID C. THIMGAN, MA, ARCHITECT

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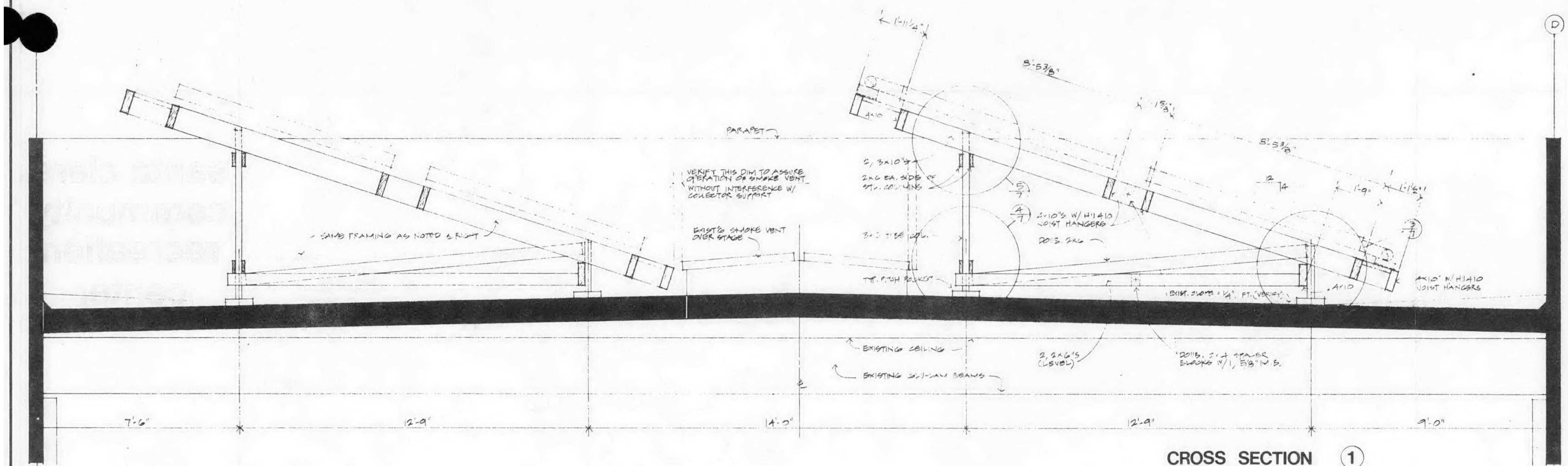
roof plan (partial)

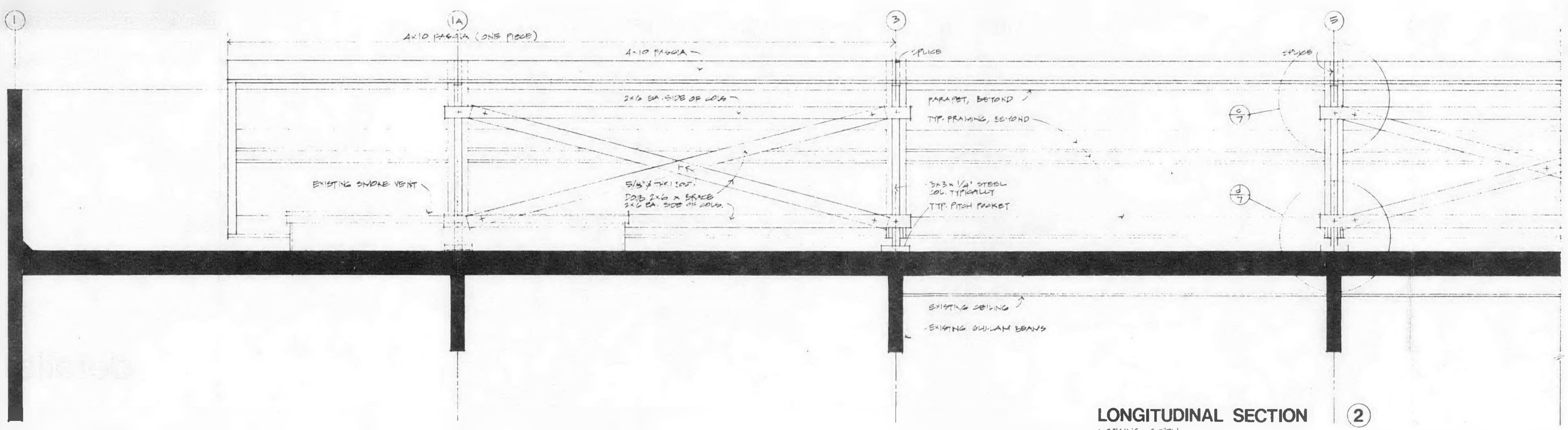
PROJECT 7319

DATE 12-17-75

L-6



CROSS SECTION (1)
LOOKING EAST



LONGITUDINAL SECTION (2)
LOOKING SOUTH

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sections

1/2" = 1'0"

PROJECT 7319
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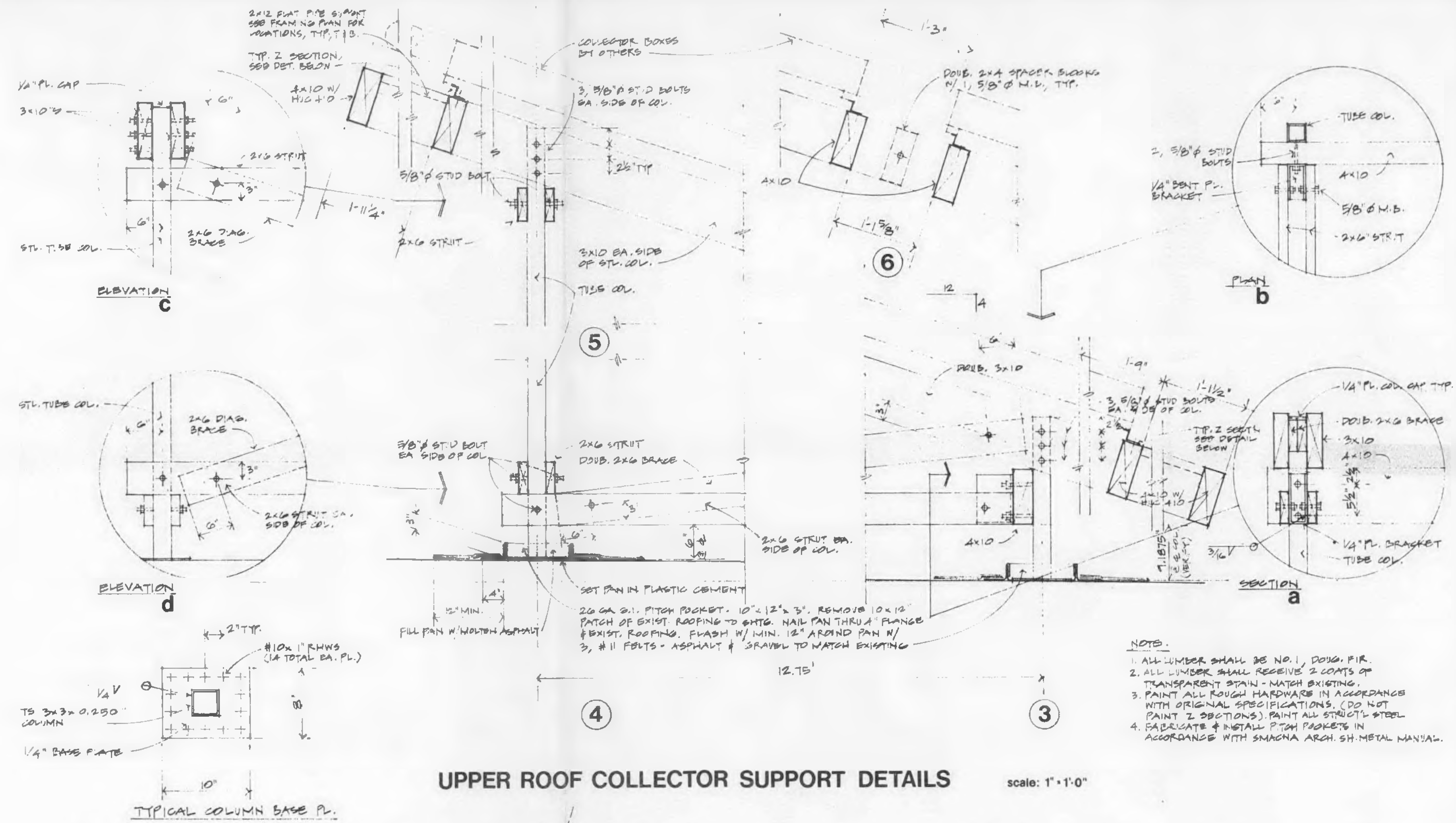
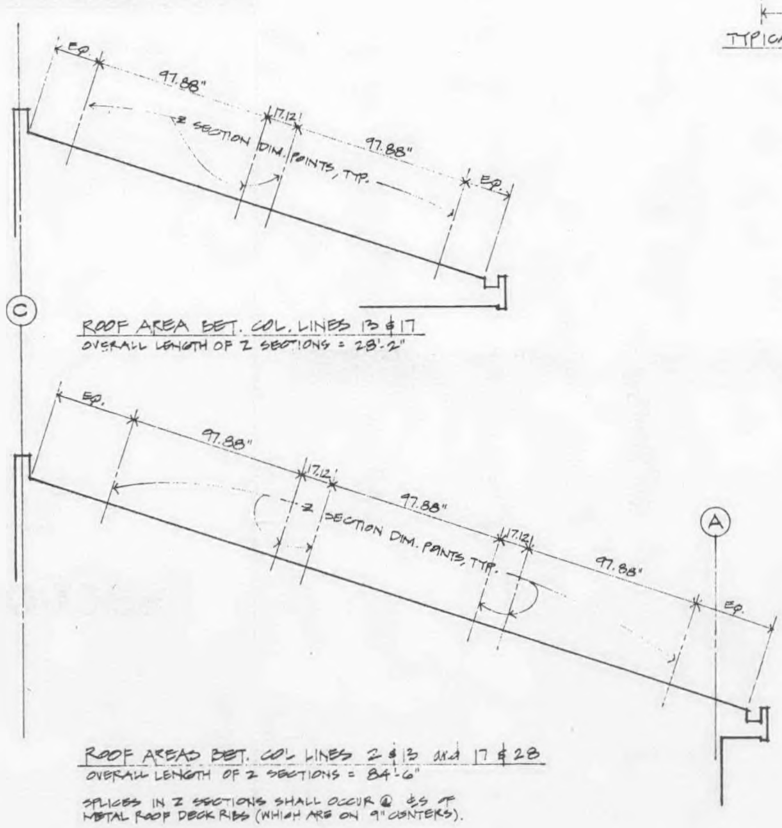
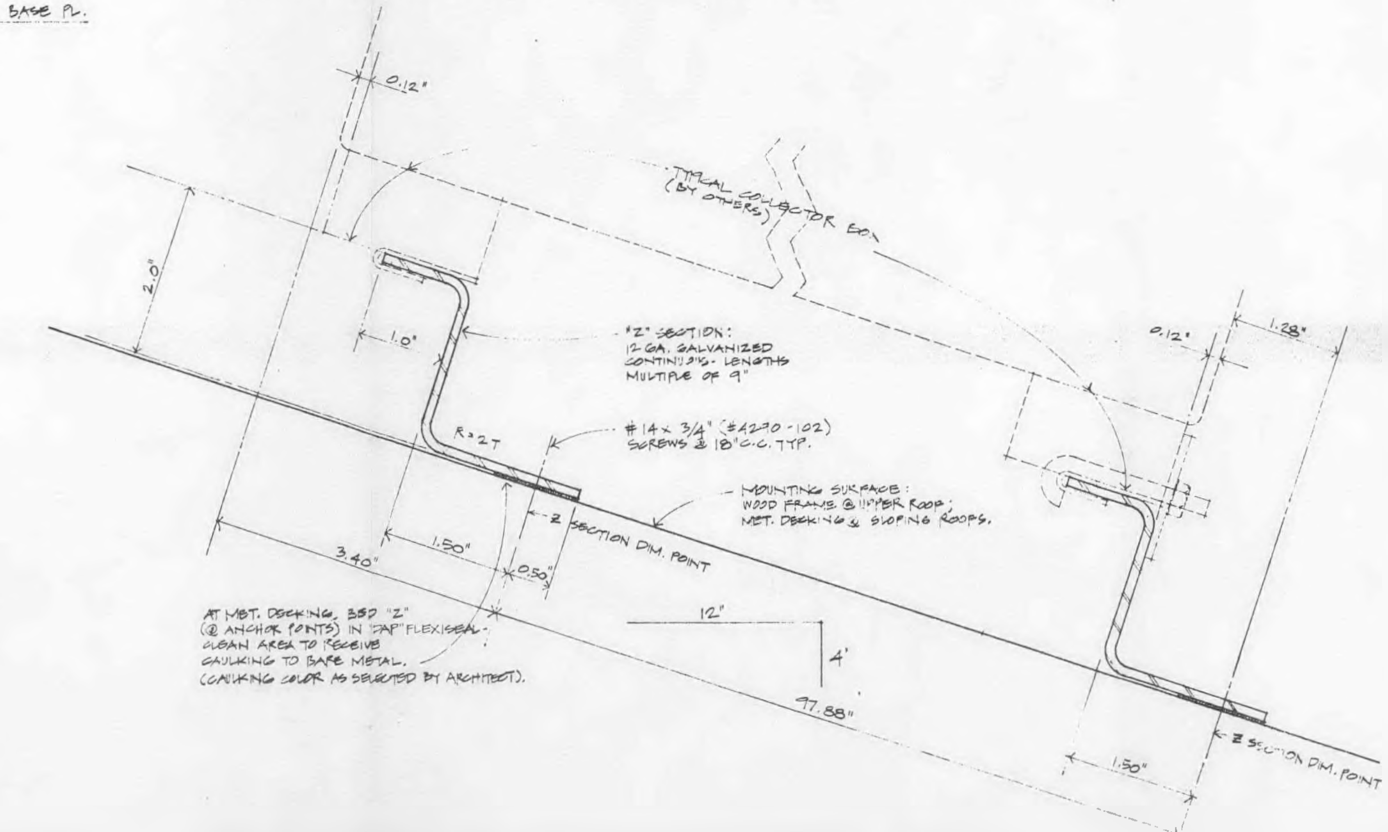


UPPER ROOF COLLECTOR SUPPORT DETAILS

scale: 1" = 1'-0"



① Z SECTION LAYOUT DIAGRAMS



② Z SECTION · COLLECTOR BOX MOUNTING DETAILS

scale: full size

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details

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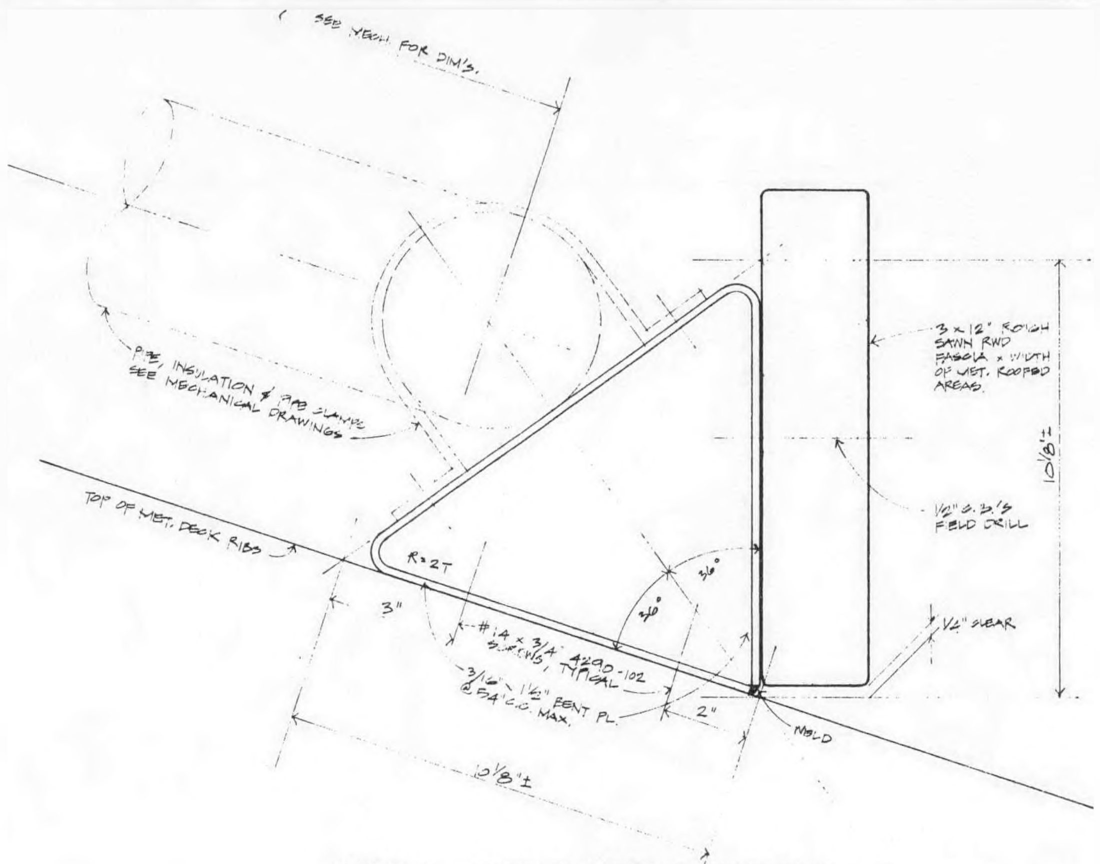
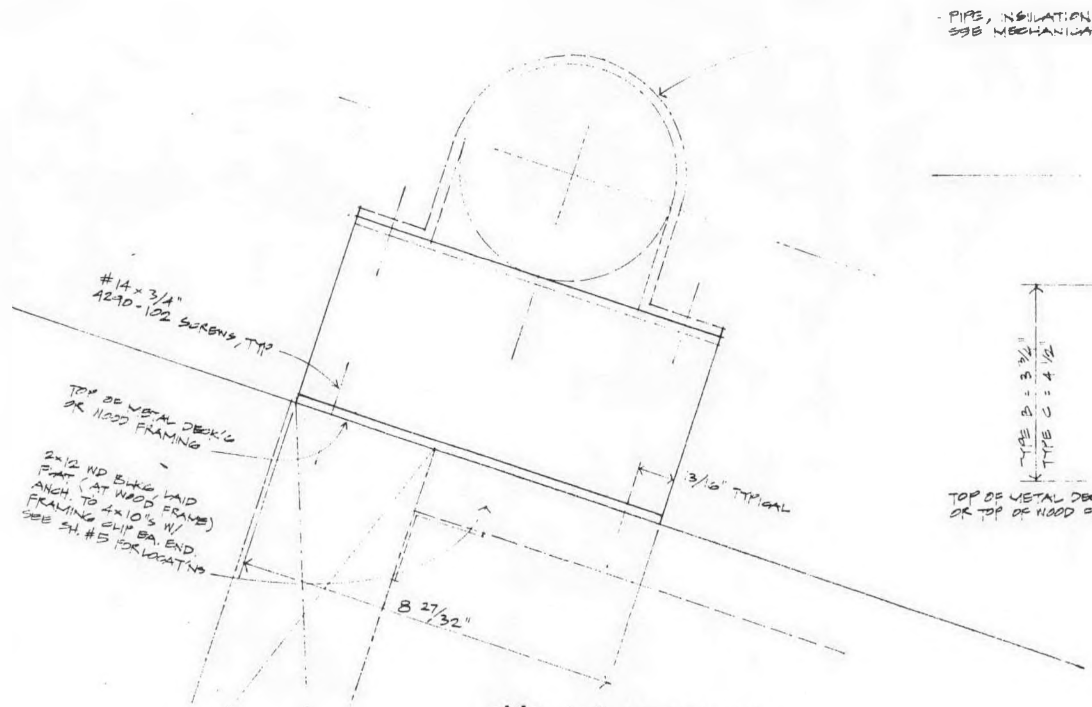


TYPE A · PIPE & FASCIA SUPPORT

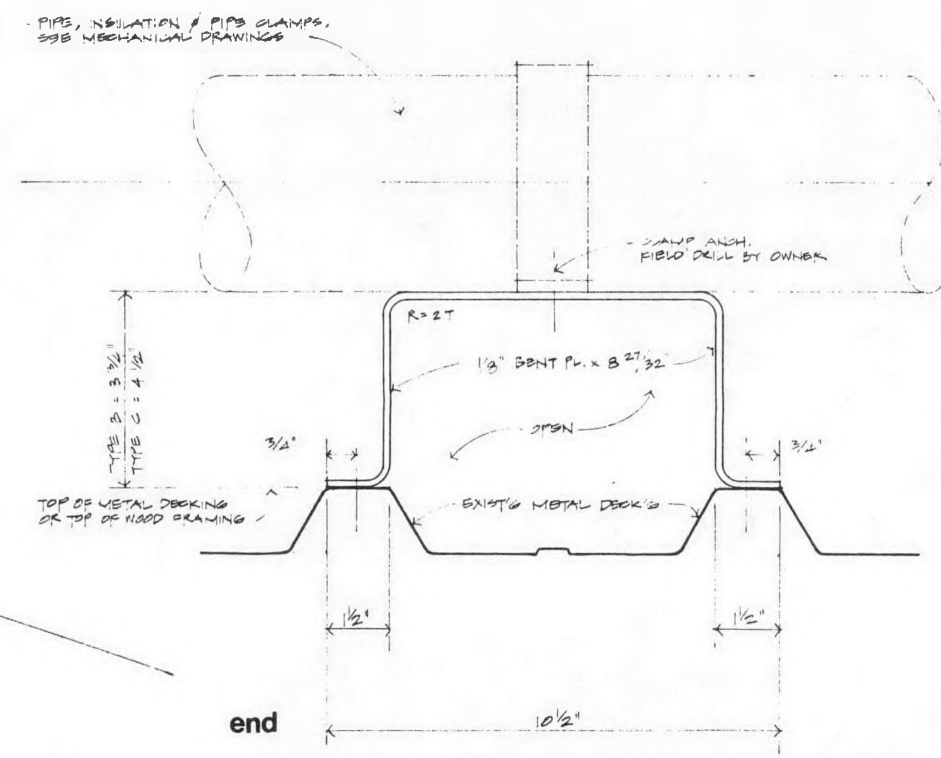
GENERAL NOTES

1. ALL PIPE & FASCIA SUPPORTS SHOWN HEREON SHALL BE FABRICATED & PAINTED UNDER THIS CONTRACT AND SUPPLIED TO THE OWNER AT THE JOB-SITE FOR HIS INSTALLATION OF THESE ITEMS.
2. ALL PIPE & FASCIA SUPPORTS SHALL BE PAINTED IN ACCORDANCE WITH THE ORIGINAL SPECIFICATIONS UNDER THIS CONTRACT. COLOR(S) SHALL BE AS SELECTED BY ARCHITECT. REDWOOD FASCIA & EXPOSED, WOODEN COLLECTOR SUPPORTS AT FLAT ROOF PORTION SHALL RECEIVE 2 COATS OF TRANSPARENT STAIN IN ACCORDANCE WITH THE ORIGINAL SPECIFICATIONS. COLOR(S) AS SELECTED BY ARCHITECT.
3. ALL MISCELLANEOUS METAL ACCESSORIES (PIPE & FASCIA SUPPORTS & ANCHORS SHOWN ON MECH. DRWGS.) TO BE INSTALLED OVER METAL ROOFING SHALL BE INSTALLED BY THE OWNER IN THE FOLLOWING MANNER:
   A) AREA TO RECEIVE ITEM SHALL BE CLEANED TO BARE METAL (BY A METHOD APPROVED BY ARCHITECT).
   B) BED ITEM IN FILL WITH "DAP FLEXISEAL" AND INSTALL ITEM AS DETAILED. COLOR(S) OF CAULKING MATERIAL SHALL BE AS SELECTED BY ARCHITECT.
4. ALL "Z" SECTIONS SHOWN HEREON SHALL BE FURNISHED & INSTALLED UNDER THIS CONTRACT IN THE SAME MANNER AS DESCRIBED IN ITEM 3 ABOVE. (NOTE: "Z's" ARE REQUIRED ON ALL METAL ROOFS AND ON WOODEN COLLECTOR SUPPORTS ABOVE AUDITORIUM). SEE DRWG. #7 FOR "Z" LOCATIONS & DETAILS. ALL "Z" SECTIONS ARE NOTED AS GALVANIZED AND SHALL RECEIVE NO PAINT FINISH.
5. LOCATION OF PIPE & FASCIA SUPPORTS (INSTALLED BY OWNER).

   TYPE A. - TO BE INSTALLED AT "LOW" SIDE OF METAL ROOFED AREAS AND LOCATED IN ACCORD WITH DIMENSIONS SHOWN ON THE MECH. DRAWINGS.
   TYPE B. - 10 1/2" x 8 27/32" x 3 3/4" HIGH TO BE INSTALLED AT "LOW" SIDES OF WOODEN COLLECTOR SUPPORTS.
   TYPE C. - 10 1/2" x 8 27/32" x 4 1/2" HIGH TO BE INSTALLED AT "HIGH" SIDES OF BOTH METAL-ROOFED AREAS AND WOODEN COLLECTOR SUPPORTS.



side (HIGH SIDE SHOWN, LOW SIDE SAME BUT REVERSED).



end

TYPES B & C · PIPE SUPPORTS

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DAVID C. THIMGAN, AIA, ARCHITECT

C-5399

details

1/2 FULL SIZE

PROJECT 7319

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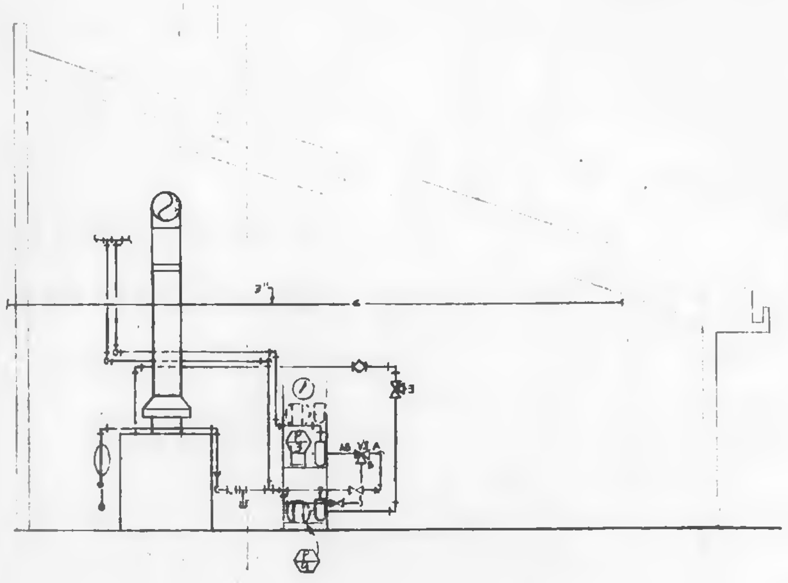
NOTES:

1. PROVIDE PUMP RACK FOR THREE PUMPS. LEAVE TOP RACK VACANT FOR FUTURE PUMP.



MECHANICAL ROOM SECTION (A / M-4)

SCALE: 1/4" = 1'-0"

NOTES:

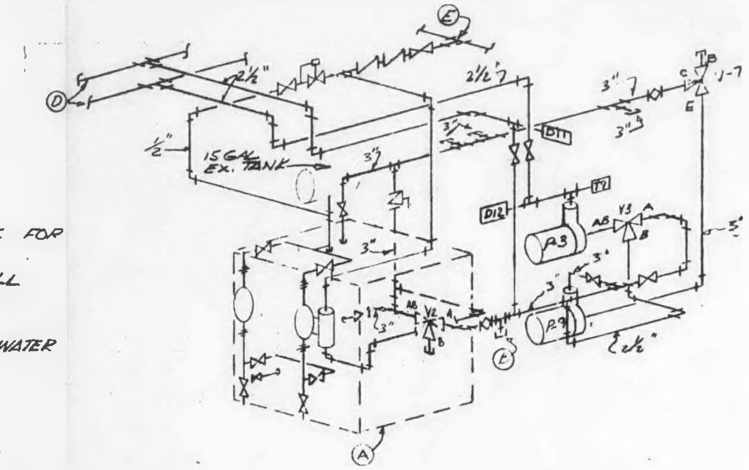
(A) EXISTING BOILER

(B) TYPICAL CAPPED TEE FOR FUTURE CONN.

(C) THERMOMETER WELL

(D) EXISTING HWS & HWR

(E) CONN. TO EXIST. DOM. WATER

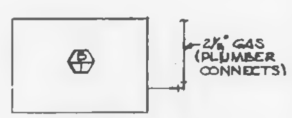


MECHANICAL ROOM BOILER-HEATING CONNECTIONS (C / M-4)

NO SCALE

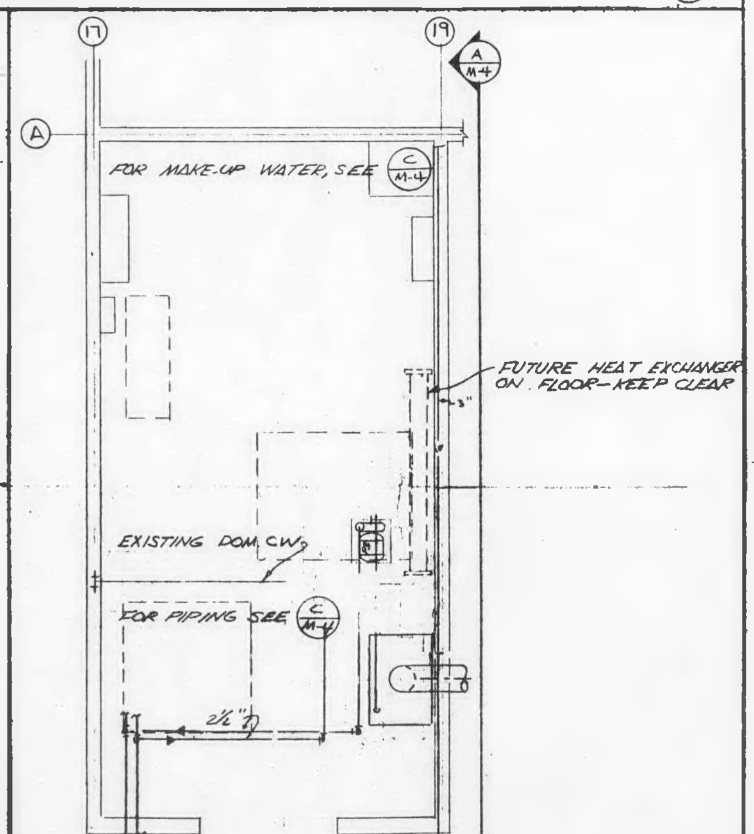
PUMP SCHEDULE

TAG	MAKE	MODEL	SIZE	IMP.	GPM	HEAD	CONSTRUCTION	SEAL	HP	RPM	VOLT	Ø	APPLICATION	REMARKS
P-3	B&G	1531	2½ A	6¼"	94	37.1'	BRONZE FITTED	MECH	2	1725	480	3	HW CIRC	
P-9	B&G	1531	2½ A	6"	140	27.4	" "	"	2	"	"	"	BOILER	



PIPING CONNECTIONS (B / M-4)

NO SCALE



MECHANICAL ROOM FLOOR PLAN

SCALE: 1/4" = 1'-0"

santa clara community recreation center

david c. thimgan, architect

MECHANICAL LAYOUT FOR SOLAR ENERGY SYSTEM

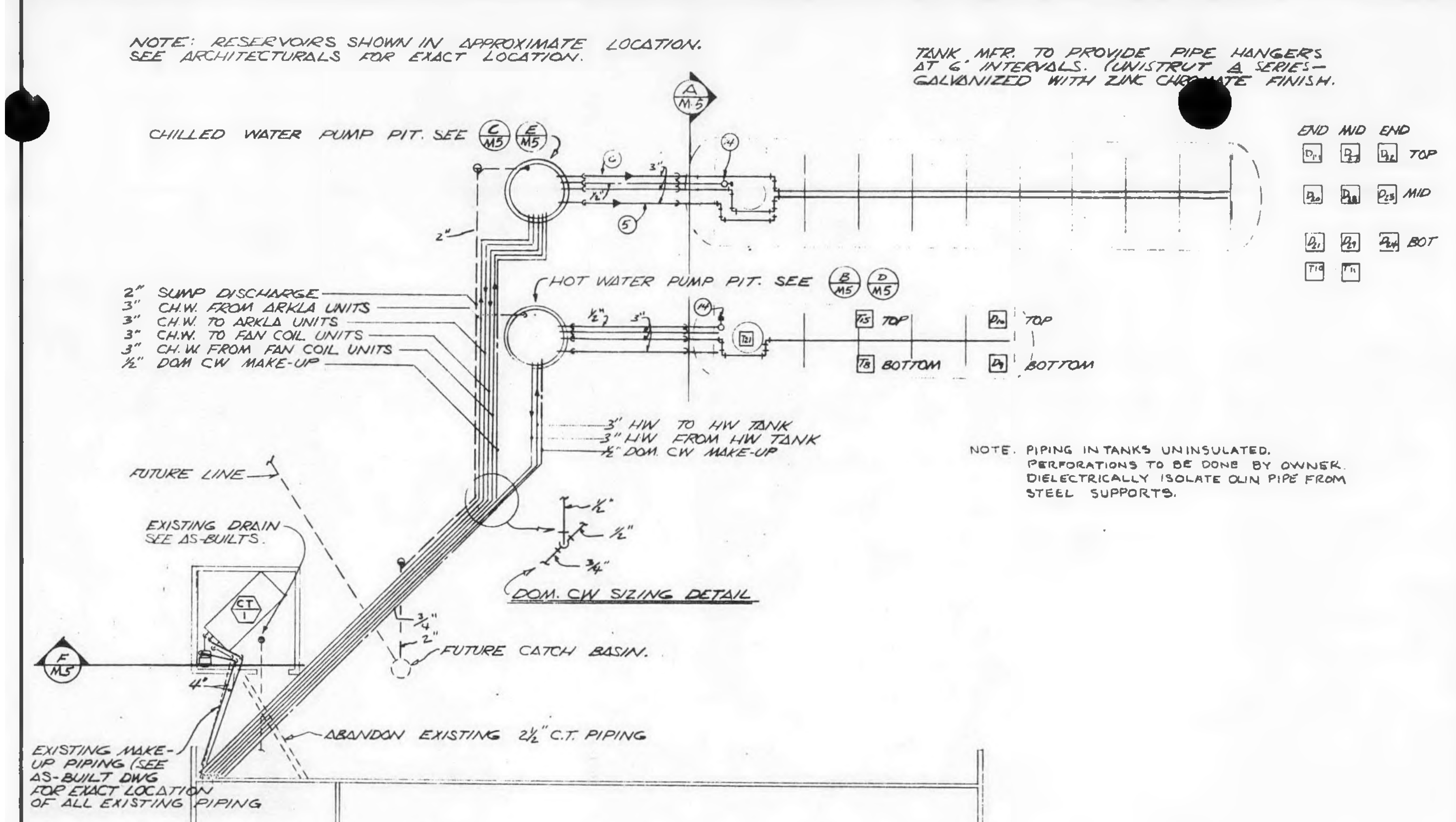
P.R. McCOY & ASSOCIATES
MECHANICAL & ELECTRICAL ENGINEERS
597 STOCKTON AVENUE
SAN JOSE, CA 95126

REVISED 12 JUN 75 GRW
REVISED 17 MAY 75 GRW

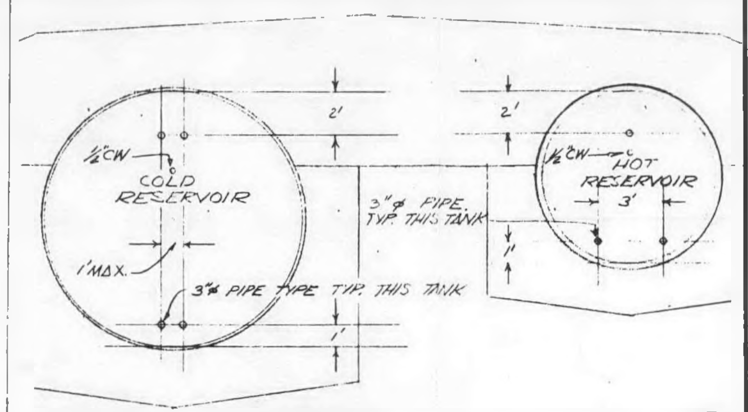
7319

2-24-75

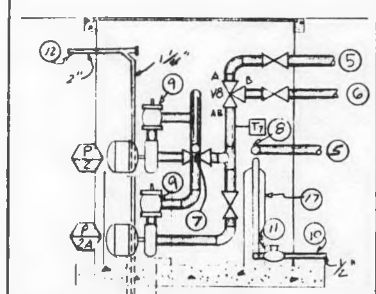
L-10



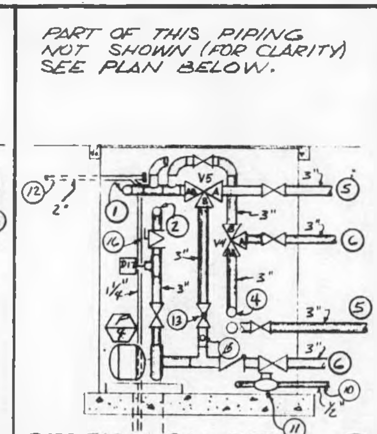
PARTIAL SITE PLAN
SCALE: ⅛" = 1'-0"



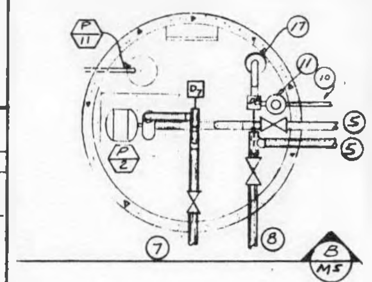
TANKS SECTION
SCALE: ⅛ = 1'-0"



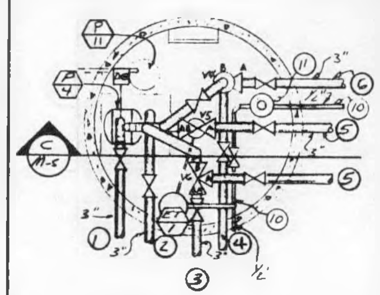
SECTION HW PIT
SCALE: ⅜" = 1'-0"



SECTION CW PIT
SCALE: ⅜" = 1'-0"



HW PUMP PIT
SCALE: ⅜" = 1'-0"



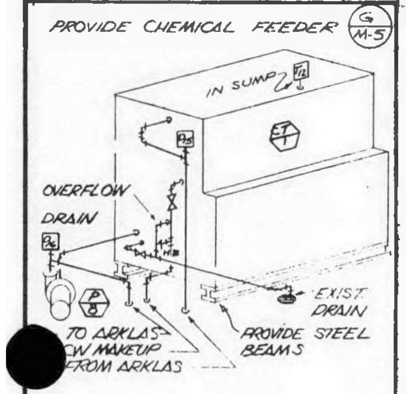
CW PUMP PIT
SCALE: ⅜" = 1'-0"

HEAT EXCHANGER SCHEDULE

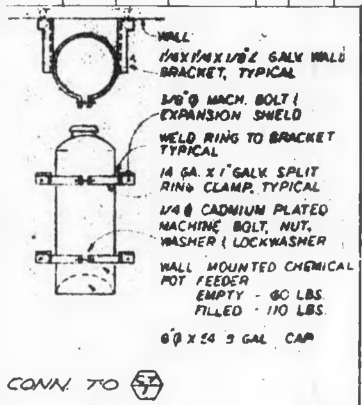
TAG	MAKE	MODEL	DIAM.	PASS	TUBE SIDE #1		TUBE SIDE #2		SHELL		REMARKS
					GPM	PD	GPM	PD	GPM	PD	
HX-1	B&G	WU-149-25-2	14"⌀	2	140	1.7'	140	1.7'	140	17.0'	W/FLOOR STAND
HX-2	B&G	WU-47-42	4"⌀	4	5	1.5	NA	NA	15	7'	W/WALL HANGER

COOLING TOWER SCHEDULE

TAG	MAKE	MODEL	GPM	ON	OFF	WB	HP	VOLTS	⌀	HZ	WEIGHT	REMARKS
CT-1	BAC	VNT 70B	180	96.4°	80°	67	7½	480	3	60	2580	W/SUMP SWITCH CONTROLLING TOWER FAN. SET AT 75°F



COOLING TOWER
NO SCALE



CHEMICAL FEEDER MTG
No Scale

NOTES:

1. CH.W FROM AC-1 & AC-2
2. CH.W TO AC-1 & AC-2
3. CH.W TO FAN COIL UNITS.
4. CH.W FROM FAN COIL UNITS.
5. TO BOTTOM OF RESERVOIR
6. TO TOP OF RESERVOIR
7. TO HX-1
8. FROM HX-1
9. TRIPL-DUTY VALVE
10. ½" DOM. CW MAKE-UP
11. INSTALL WATER METER (PROVIDED BY CITY).
12. SUMP PUMP DISCHARGE (2").
13. COMBINATION BAL COCK & SOV.
14. FLOAT VALVE MAINTAINS TANK LEVEL.
15. TO FILLTROL ET/1 W/SOLENOID VALVE
16. B&G CKT SETTER
17. DE-IONIZER-AMSCO-AH-24-11 HANG ON WALL.

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

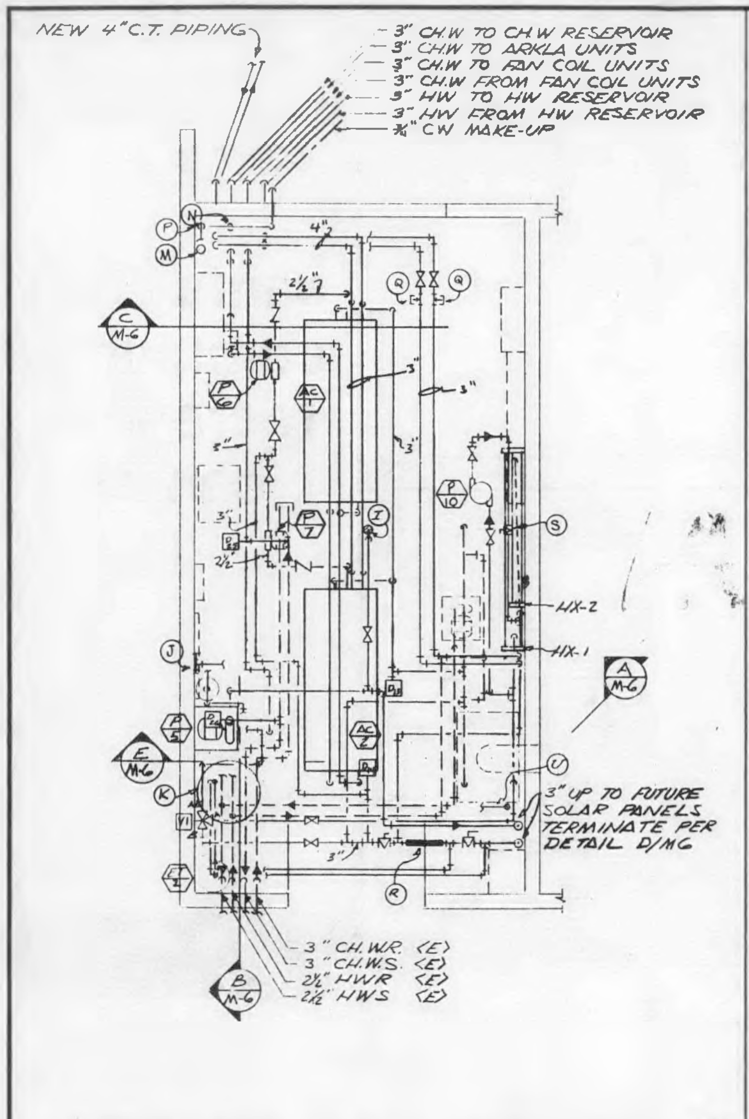
C-5399

SITE PLAN, DETAILS, AND SCHEDULE

P.R. McCOY & ASSOCIATES
MECHANICAL AND ELECTRICAL ENGINEERS
597 STOCKTON AVE
SAN JOSE, CA 95126

PROJECT 7319
DATE 6-12-75

L-11

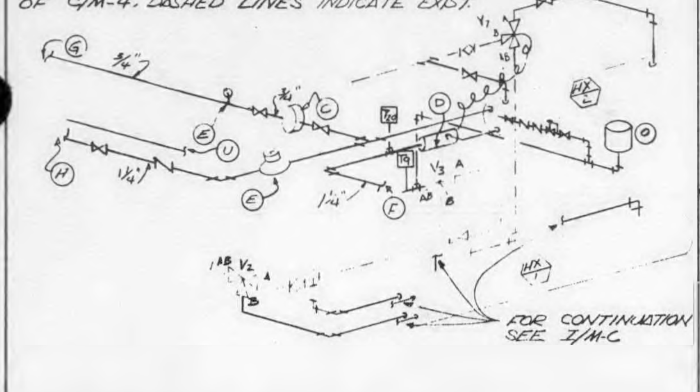


MECHANICAL ROOM FLOOR PLAN (I/M6)
SCALE: ¼"=1'-0"

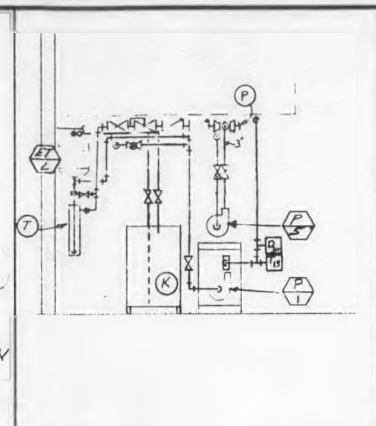
NOTES

- (A) DASHED LINES INDICATE EXISTING EQUIPMENT AND PIPING.
- (B) B&G TRIP-L-DUTY VALVE
- (C) EXISTING CIRC PUMP
- (D) 2½"⌀ × 40" PIPE SECTION FOR BULB INSERTION. SEE G/M-6
- (E) WATER METER FURN. BY OWNER, WIRED BY CONTROL CONTR.
- (F) 1¼" TO DOM. HW SYSTEM
- (G) ¾" RETURN FROM DOM HW SYSTEM
- (H) CONNECT TO EXISTING DOM. CW SYSTEM.
- (I) ADD FUNNEL TO DRAIN. RUN SYSTEM DRAIN TO IT.
- (J) EXISTING DOM. COLD WATER
- (K) 3'⌀ BY 4' HIGH 200 GAL TANK. PROVIDE PHENOLIC COATING, ACCESS HOLE, MANUAL AIR RELIEF AT TOP AND HOSE BIBB AT BOTTOM. STRAP TO WALL WITH 1/16 × 2 STRAP. PLACE 10" BELOW TOP. MOUNT W/ LEGS ON FLOOR. COVER WITH 4" FIBERGLASS, CANVAS, AND ARABOL.
- (M) EXISTING 4" STORM LEADER
- (N) EXISTING 2½" DOM. COLD WATER
- (O) ROL-AIR-TROL
- (P) CONNECT TO EXISTING DOM. WATER.
- (Q) FIRE DEPT. CONNECTIONS.
- (R) 10"⌀ PIPE WITH T6 T5 T4 T3 T2 T1 T4 T1 INSERTED. SEE H/M-6 PROVIDE TWO EXTRA.
- (S) B&G CIRCUIT SETTER
- (T) AMSCO REFILLABLE DE-IONIZER. MODEL AH-24-11 MOUNT ON WALL.
- (U) ¾" DOM. CW TO FUTURE ROOF HOSE BIBB. STUB-OUT AS INDICATED IN DETAIL D/M-6.
- (V) TO DOM. CW (¾") SEE A/M-6 (U) & D/M-6
- (W) THIS NOTE APPLIES TO ALL SHEETS: PROVIDE PETES PLUGS AT INLET AND OUTLET OF EACH PIECE OF EQUIPMENT.

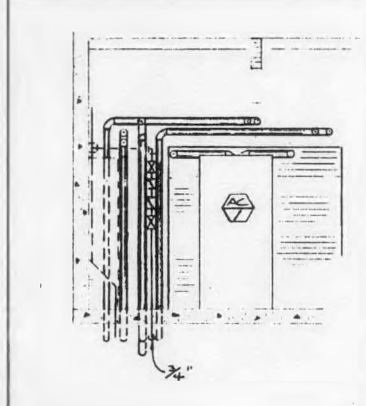
NOTE: THIS IS A PARTIAL REPRODUCTION OF C/M-4. DASHED LINES INDICATE EXIST.



ISOMETRIC HX-1 & HX-2 (A/M-6)
NO SCALE

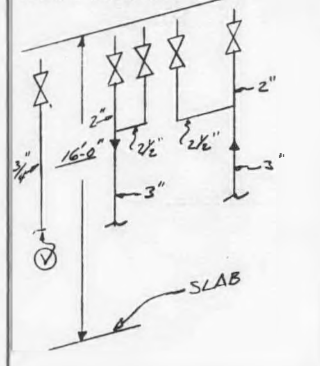


SECTION (B/M-6)
SCALE: ¼"=1'-0"

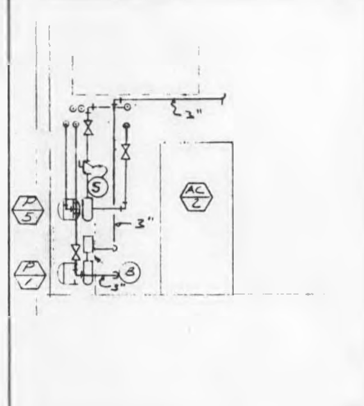


SECTION (C/M6)
SCALE: ¼"=1'-0"

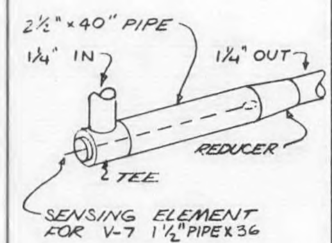
SEE FLOOR PLAN
VERIFY LOCATION



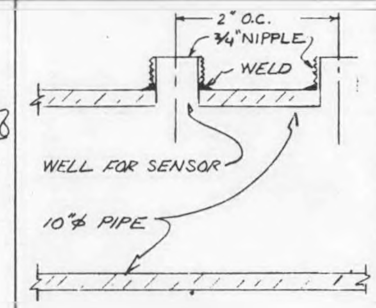
PIPE TERMINATION (D/M6)
NO SCALE



SECTION (E/M6)
SCALE: ¼"=1'-0"

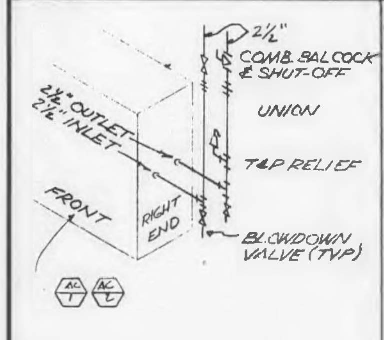


SENSOR WELL (G/M-6)
NO SCALE

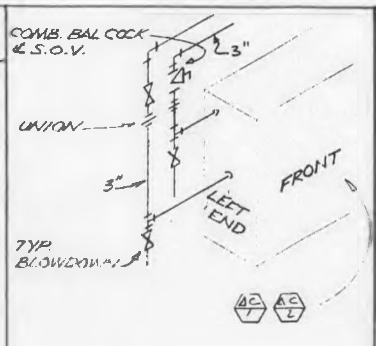


PROVIDE NIPPLES FOR 10 TEMP SENSORS AT 2" O.C. TWO ARE FOR FUTURE USE. CAP THESE TWO.

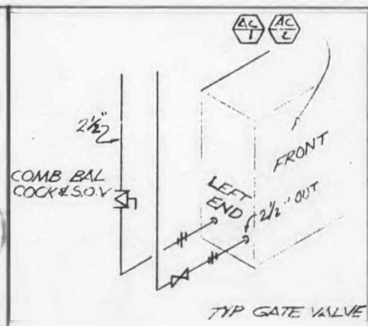
SENSOR WELL (H/M-6)
NO SCALE



CHILLED WATER PIPING (F/M6)
NO SCALE



CONDENSER PIPING (G/M6)
NO SCALE



FIRING WATER PIPING (H/M6)
NO SCALE

PUMP SCHEDULE

TAG	MAKE	MODEL	SIZE	IMP	GPM	HEAD	CONSTRUCTION	SEAL	HP	RPM	VOLTS	⌀	APPLICATION	REMARKS
P1	B&G	1531	2½A	7"	140	45	BRONZE FITTED	MECH.	3	1750	480	3	COLLECTOR LOOP	ET-2 ACCEPTS 45 GAL
P2	B&G	1531	2½A	7"	140	47	BRONZE FITTED	MECH.	3	1750	480	3	HOT RESERVOIR	
P2A	B&G	1531	2BB	8	160	61	BRONZE FITTED	MECH.	5	1750	480	3	HOT RESERVOIR	
P3	EXISTING PUMP - SEE M-4												HOT FAN COILS	
P4	B&G	1531	2"BB	8⅝	150	75'	BRONZE FITTED	MECH.	5	1750	480	3	COLD RESERVOIR	FILL-TROL 110
P5	B&G	1531	2"BB	9⅛	148	88'	BRONZE FITTED	MECH.	7½	1750	480	3	COLD FAN COILS	
P6	B&G	60	2"A	5⅜	70	30'	BRONZE FITTED	MECH.	1½	1750	480	3	FIRING LOOP	
P7	B&G	60	2"A	5⅜	70	30'	BRONZE FITTED	MECH.	1½	1750	480	3	FIRING LOOP	
P8	B&G	1531	2½"B	7½	180	52'	BRONZE FITTED	MECH.	5	1750	480	3	COOLING TOWER	
P9	EXISTING PUMP - SEE M-4												BOILER LOOP	
P10	B&G	80	3×3×7	6⅛"	140	27'	BRONZE FITTED	MECH	2	1750	480	3	HX-1 CIRCULATOR	
P11	LITTLE GIANT	9CBA	—	—	8	20'	BRONZE	STD.	2/5	STD.	120	1	SUMP PUMPS	

ABSORPTION UNIT SCHEDULE

TAG	MAKE	MODEL	CHILLER					CONDENSER				FIRING WATER				VOLTS	⌀	WT
			TONS	GPM	EW	LW	ΔP	GPM	EW	LW	ΔP	GPM	EW	LW	ΔP			
AC-1	ARKLA	WF300	25	75	48°	40°	9.8	90	80°	96.4°	23	70	200°		9.2	115	1	3405
AC-2	"	"	"	"	"	"	"	"	"	"	"	"	"		"	"	"	"

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

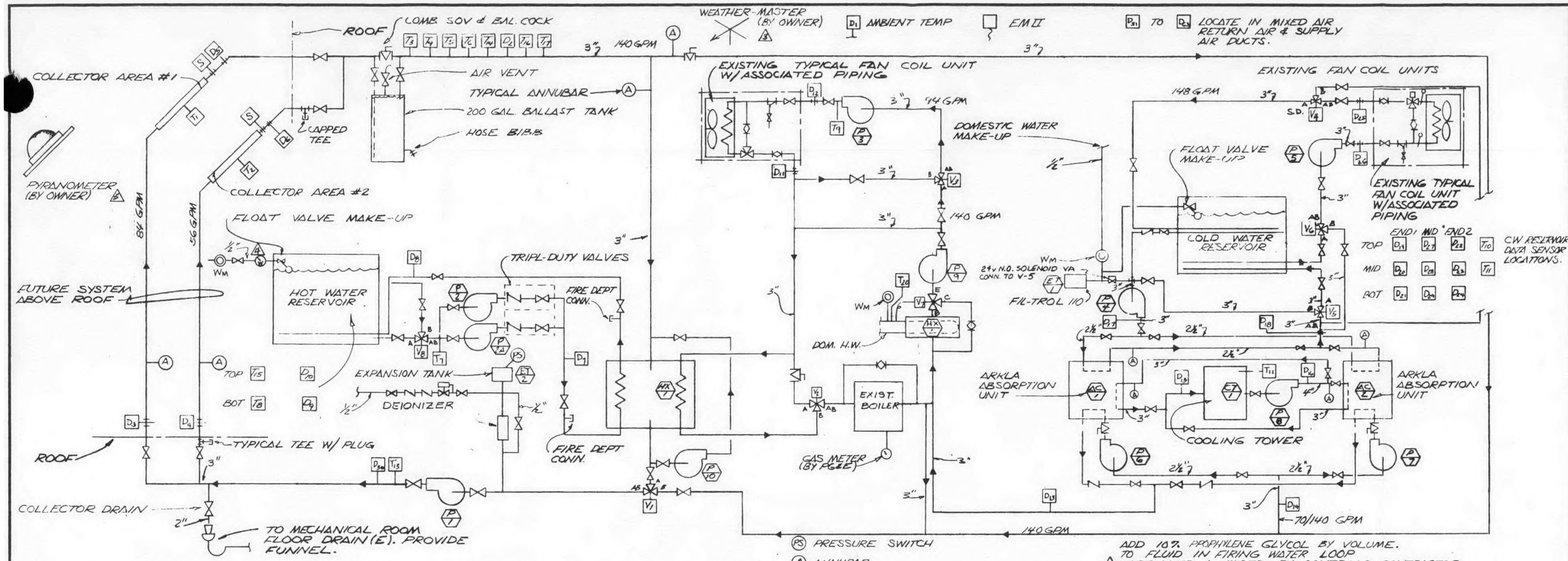
C-5399

FLOOR PLAN, DETAILS AND SCHEDULES

P.R. McCOY & ASSOCIATES
MECHANICAL AND ELECTRICAL ENGINEERS
597 STOCKTON AVE
SAN JOSE, CA 95126

PROJECT 7319
DATE 6-12-75

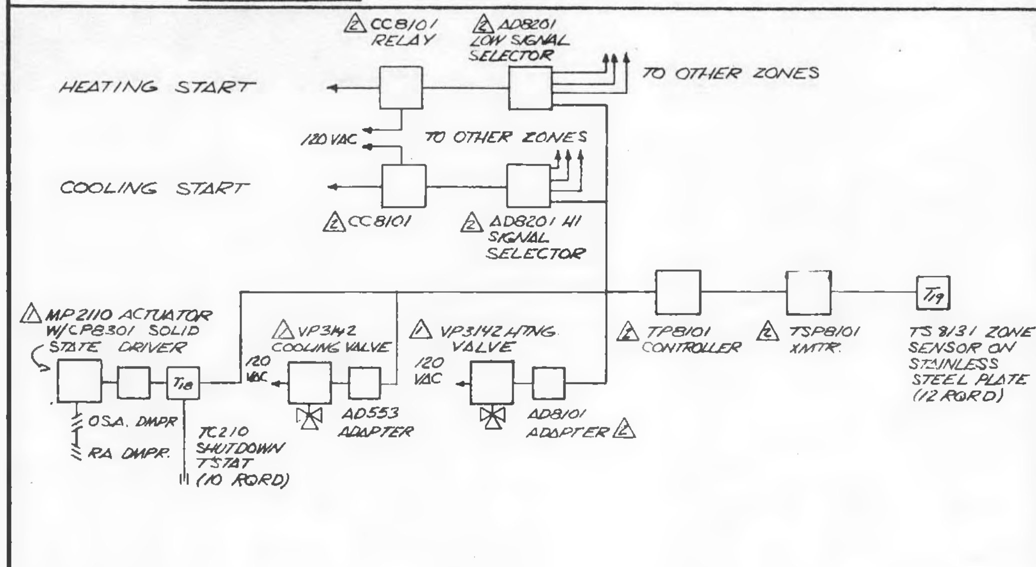
L-12



SOLAR HEATING AND COOLING PIPING SCHEMATIC
NO SCALE

(PS) PRESSURE SWITCH
(A) ANNUBAR
D_{64} D_{83} SUPPLIED BY CONTROLS CONTRACTOR

ADD 10% PROPHYLENE GLYCOL BY VOLUME. TO FLUID IN FIRING WATER LOOP
3 INSTALLED & WIRED BY CONTROLS CONTRACTOR
4 INSTALLED BY PLUMBING CONTRACTOR. WIRED BY CONTROLS CONTRACTOR.

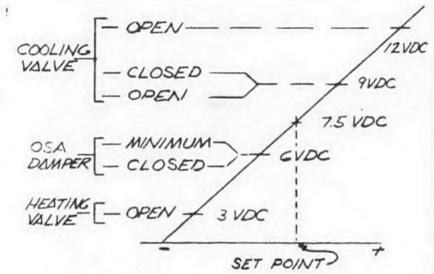


NOTES:

1 INDICATES EXISTING EQUIPMENT

2 INDICATES ITEMS IN TEMP CONTROL PANEL.

INSTALL P.W.C. TYPE 123, 75 PAIR CABLE FROM TEMP CONTROL PNL TO COLLECTOR AREA.



SYSTEM SIGNALS

FAN COIL SYSTEM CONTROL
NO SCALE

CONTROL SCHEDULE

T	THERMOSTAT OR CONTROL RTD
D	RTD INDICATING
T_1	TC204 THERMOSTAT 100°–180°
T_2	TC204 THERMOSTAT 100°–180°
T_3	TS8201 RTD IMMERSION
T_4	TC205 THERMOSTAT 150°–230°
T_5	TS8201 RTD IMMERSION
T_6	TC205 THERMOSTAT 150°-230°
T_7	TS8201 RTD IMMERSION
T_8	TS8201 RTD IN SPECIAL 3/8" COPPER WELL; ADJUST LENGTH TO SUIT TANK REQUIREMENT
T_9	TP307 BULB MICROTHERM 50°–130°
T_{10}	TS8201 RTD IN SPECIAL 3/8" COPPER WELL; ADJUST LENGTH TO SUIT TANK REQUIREMENT
T_{11}	TS8201 RTD IMMERSION
T_{12}	TC203 THERMOSTAT 50°–130°
T_{13}	TS8201 RTD IMMERSION
T_{14}	TC205 THERMOSTAT 150°–230°
T_{15}	TS8201 RTD IN SPECIAL 3/8" COPPER WELL; ADJUST LENGTH TO SUIT TANK REQUIREMENT
T_{16}	TC223 THERMOSTAT 190°–350°
T_{17}	TC223 THERMOSTAT 190°–350°
T_{18}	TC210 THERMOSTAT 30°–110°
T_{19}	TS8201 RTD ON STAINLESS-STEEL PLATE.
T_{20}	TC204 THERMOSTAT 100°–180°
D_1 THRU D_{63}	TS5923 RTD 1000 OHM AT 70°F COPPER. NOTE: D_9, D_{10}, D_{19} THRU D_{24} AND D_{27} THRU D_{29} IN SPECIAL 3/8" COPPER WELL; ADJUST LENGTH TO SUIT TANK REQUIREMENT.
D_{64} THRU D_{83}	TS5923X MINI RTD 1000 OHM AT 70°F COPPER.
PS-1	PF126 PRESSURE SWITCH
PYRANOMETER–	EPPLEY PSP W/ B-C MODEL 521A-40381-810-0-00 DIGITAL SET-POINT CONTROLLER. BY OTHERS
W_m	WATER METER RETRANSMITTING TYPE. (BY OTHERS).
W_s	WEATHER STN., WEATHER MEASURE CORPORATION, MODEL W101-P-HF/360 W/101MA, MAST ADAPTOR,
CONT.	WT801 HF/360 TRANSLATOR AND 200' 7 CONDUCTOR CABLING. BY OTHERS.
GAS METER–	BY OTHERS
EMII	ENERGY MANAGER, VERTREX CORPORATION, MODEL EMII
V_1 THRU V_6	VP-3044-106
V_7	ROBERTSHAW RT1010, 3" DOM. H.W. REGULATOR
V_8	VP3044-106

SPECIFICATIONS

ANNUBARS TO BE OF MATERIAL COMPATIBLE WITH PIPING. INSTALL IN STRICT ACCORDANCE WITH ANNUBAR BULLETIN E100-9/74; TABLE ON P. 14

HOT WATER PIPING – OLIN TUBING AND FITTINGS. DIELECTRICALLY ISOLATE DISSIMILAR MATERIALS. INSULATE PIPE & FITTINGS TO AN R VALUE GREATER THAN OR EQUAL TO 13 WITH VAPOR BARRIER. UNDERGROUND PIPING SHALL HAVE A PLASTIC OR FIBERGLASS OUTER JACKET SEALED WATER-TIGHT.

BALLAST TANK AND SENSING PIPE SECTIONS SHALL BE STEEL.

COOLING TOWER PIPING SCHEDULE 40 PVC. SOCKET WELD FITTINGS.

CHILLED WATER PIPING – SCHEDULE 80 PVC. SOCKET WELD FITTINGS. INSULATE ALL PIPE AND FITTINGS INSIDE MECHANICAL ROOM, UNDERGROUND AND TO TANK TO AN R VALUE GREATER THAN OR EQUAL TO 4 WITH VAPOR BARRIER. UNDERGROUND PIPING SHALL HAVE A PLASTIC OR FIBERGLASS OUTER JACKET SEALED WATER-TIGHT.

ALL EXPOSED PIPING, EQUIPMENT & VALVES DESIGNED IN THIS FIELD ORDER SHALL BE IDENTIFIED IN ACCORDANCE WITH SECTION 15000 (PAGE 3) OF THE ORIGINAL SPECIFICATIONS.

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

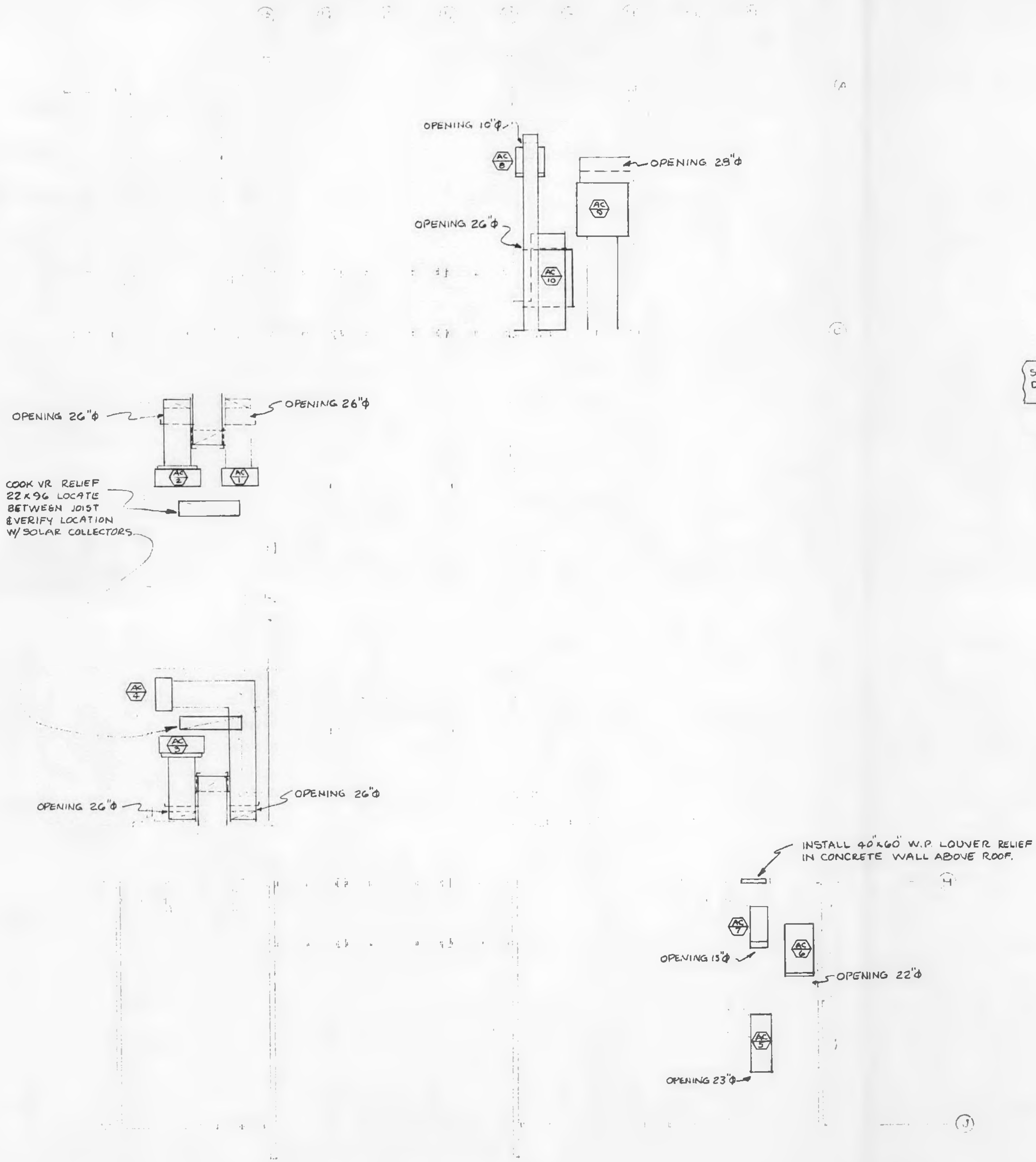
C-5399

PIPING SCHEMATIC

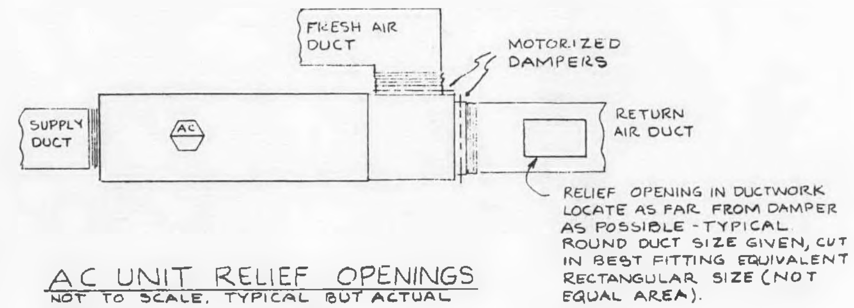
P.R. McCOY & ASSOCIATES
MECHANICAL AND ELECTRICAL ENGINEERS
597 STOCKTON AVE
SAN JOSE, CA 95126

PROJECT 7319
DATE 6-12-75

L-13



PARTIAL FLOOR PLAN
SCALE: 1/8" = 1'-0"



AC UNIT RELIEF OPENINGS
NOT TO SCALE. TYPICAL BUT ACTUAL DAMPER LOCATIONS VARY

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

C-5399

P.R. McCOY & ASSOCIATES
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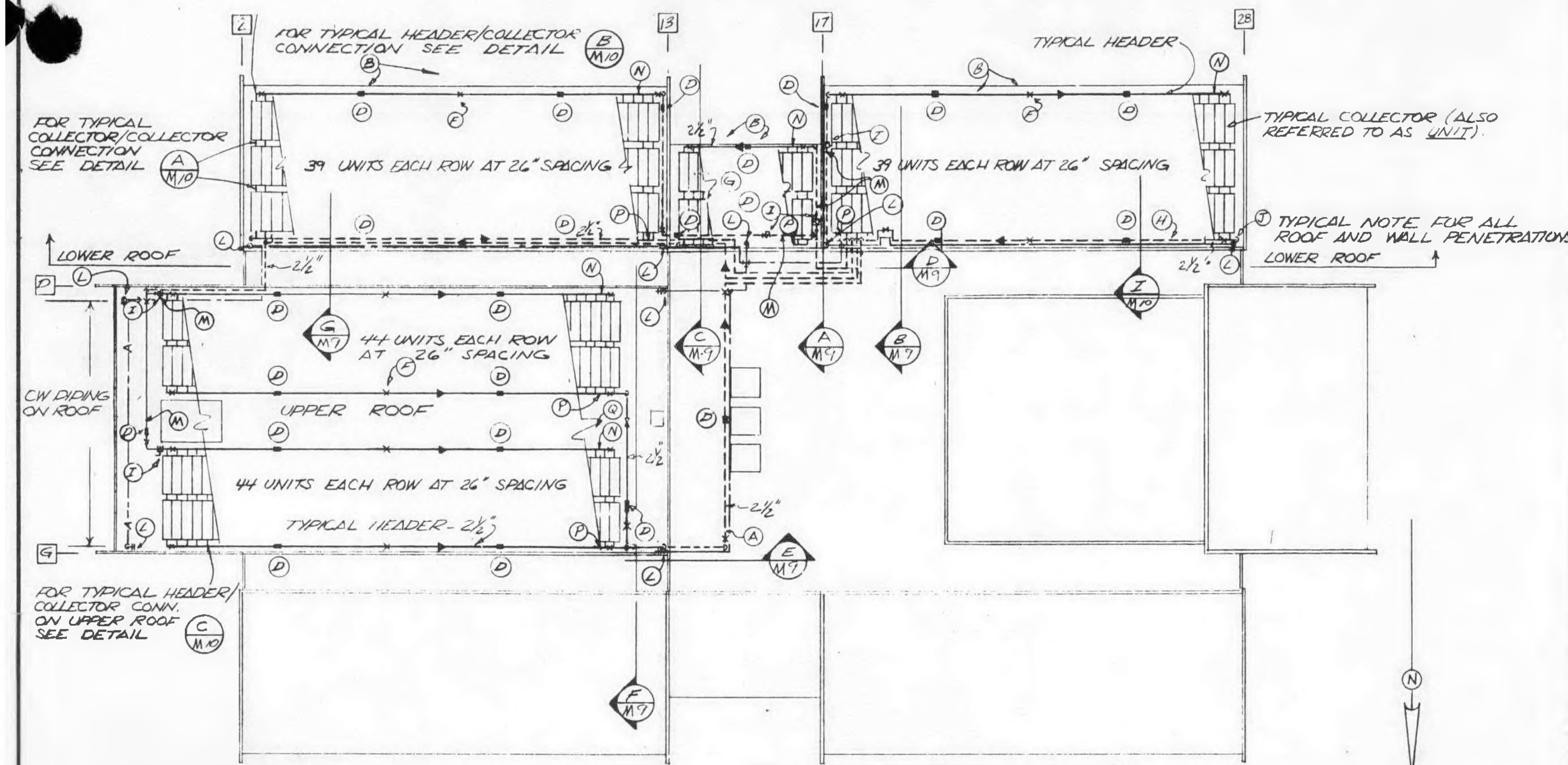
SAN JOSE, CA 95126

RELIEF OPENINGS

PROJECT 7317
DATE 6-12-75

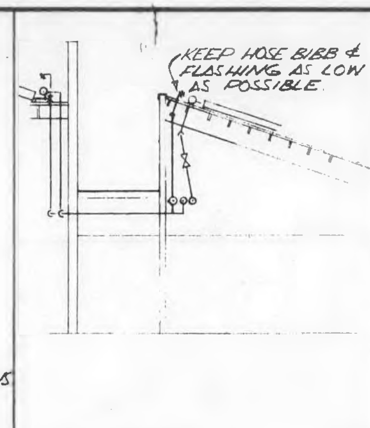
L-14

NOTE! CITY TO FURNISH AND INSTALL ALL COLLECTORS, PIPING, AND CONNECTIONS ABOVE THE ROOF EXCEPT THE FOLLOWING: A) HOSE BIBBS AND RELATED PIPING. B) ALL ROOF PENETRATIONS, FLASHINGS, AND ELBOWS AT TOP OF PENETRATIONS. C) SPECIAL SHEET METAL COVER SHOWN IN DETAIL H/M9 D) ALL INSULATION (INCLUDING FINISH & PAINTING).
CONTRACTOR TO FURNISH AND INSTALL WORK SHOWN ON DRAWINGS BUT NOT INCLUDED IN CITY'S WORK.

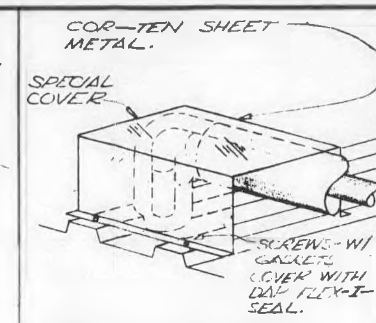


ALL HOT WATER PIPING TO BE 2½".
ALL HOSE BIBB PIPING TO BE ¾"

ROOF PLAN– PIPING LAYOUT
SCALE: 1/16"=1'-0"



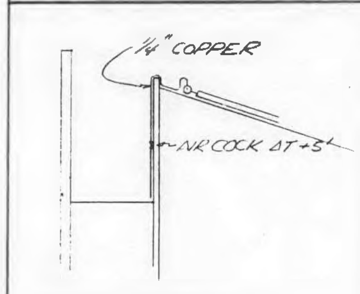
SECTION (G/M9)
SCALE: 1/8"=1'-0"



SPECIAL COVER TO BE PROVIDED IN PHASE TWO.

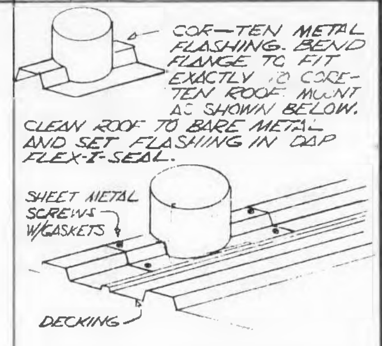
SHOWN ON COR-TEN ROOF, BUT PROVIDE ON ALL ROOFS.

ROOF PENETRATION (H/M9)
NO SCALE



UPPER ROOF VENTING SIMILAR. PROVIDE AT ALL HIGH POINTS. FASTEN TUBING TO WALL WITH TUBE STRAP. RUN TIGHT TO ROOFING AND WALL.

REMOTE AIR VENT (I/M9)
SCALE: 1/8"=1'-0"



FLASHING TO BE SIZED TO ALLOW PASSAGE OF 5"φ INSULATION.

DECKING PENETRATION (J/M9)
NO SCALE

GENERAL NOTES

Ⓐ DASHED LINE INDICATES TUBING BELOW ROOF (TYPICAL).

Ⓑ TYPICAL HEADER ANCHORS AND EXPANSION JOINT SHOWN ON LOWER (SUPPLY) MANIFOLD. UPPER (RETURN) MANIFOLD (NOT SHOWN) TO BE THE SAME. FURNISH TO OWNER.

Ⓓ TYPICAL EXPANSION JOINT WITH TWO TUBE ALIGNMENT GUIDES ON EACH SIDE. PLACE TUBE GUIDES NO MORE THAN 4 TUBE DIAM. FROM EXP. JOINT AND NOT MORE THAN 14 TUBE DIAM. FROM FIRST GUIDE. ADDITIONAL TUBE ALIGNMENT GUIDES TO BE PLACED AT 30' INTERVALS. TUBE SUPPORTS TO BE 10' APPART UNLESS NOTED OTHERWISE. HEADER EXPANSION JOINTS TO BE LOCATED AT CENTER OF TWO ANCHORS. EXPANSION JOINT TO BE THE FOLLOWING (SEE H/M-10 ALSO): FLEXONICS HB-250-FFS EXPANSION COMPENSATOR.

Ⓕ TYPICAL ANCHOR. SEE DETAIL E/M-10. HEADER ANCHORS TO BE LOCATED AT ENDS AND AT EXACT CENTER OF HEADER.

Ⓖ 13 COLLECTOR UNITS EACH ROW AT 26" SPACING

Ⓗ WHERE EXPOSED TO ROOM BELOW, RUN AS HIGH AS POSSIBLE. CONFIRM LOCATION WITH ARCHITECT. SEE I/M-10.

Ⓘ B&G CIRCUIT SETTER (TYPICAL) CB-2½ LOCATE WHERE ACCESSIBLE.

Ⓙ ALL ROOF AND WALL PENETRATIONS TO BE LOCATED IN FIELD BY ARCHITECT.

Ⓚ IN ALL INSTANCES WHERE INSULATION COMES IN CONTACT WITH TUBING SUPPORTS, PROVIDE 26 GAUGE SHEET METAL SADDLE BETWEEN SUPPORT AND INSULATION. LENGTH = 3" BEYOND POINT OF CONTACT EA. SIDE.

Ⓛ HOSE BIBB ON ROOF-ALL CW PIPING TO BIBBS IS ¾" ALL CW PIPING-UNDER ROOF-EXCEPT AS NOTED. BIBB TO BE NIBCO 763 AS CLOSE AS POSSIBLE TO FLASHING.

Ⓜ ANNUBAR- TO BE COMPATIBLE WITH PIPING. INSTALL IN STRICT ACCORDANCE WITH ANNUBAR BULLETIN E100/9-74. TYPE 735 FOR 2½" COPPER TUBE. CONFIRM TUBE TYPE.

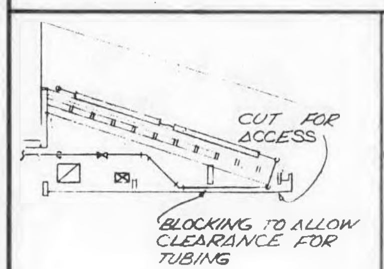
Ⓝ McDONNELL SAFETY RELIEF VALVE NO. 230-¾"-30 303,000 BTU/HR OPENS AT 44.7 PSIA (30 PSIG) 275°F. INLET & OUTLET = ¾". PIPE PER DETAIL F-M10.

Ⓞ INSULATION ON HOT WATER PIPING BENEATH ROOF SHALL HAVE R=13 AT 225°F OR, OPTIONALLY, 4" THICKNESS FIBERGLASS OR EQUIVALENT. EXPOSED PIPING IN TEEN ROOM TO HAVE VIKING ISO-CYANURATE INSULATION.

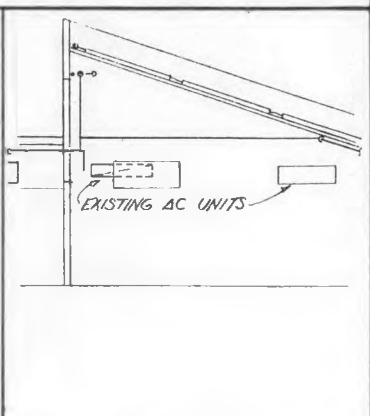
Ⓟ CHAS. M. BAILEY #8 VACUUM BREAKER 2" SIZE. SET AT 14 PSI MUST BE ALL BRONZE. NOTE THAT MANUAL AIR VENTS ARE REQUIRED AT THIS POINT ALSO (HIGH POINTS). SEE DETAIL I/M-9 FOR VENTING.

Ⓠ LOCATION OF PYRANOMETER AND WEATHER STATION. THIS EQUIPMENT SUPPLIED AND INSTALLED UNDER OTHER DIVISION. COLOR(S) BY ARCHITECT.

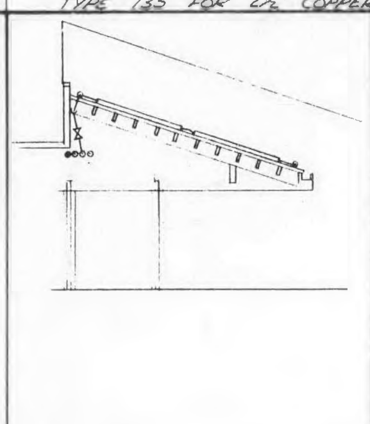
Ⓡ ALL INSULATION EXPOSED TO WEATHER TO BE PAINTED WITH SILICONE-BASED PAINT. ALSO PAINT EXPOSED INSULATION IN TEEN ROOM. CO-ORDINATE INSTALLATION OF INSULATION WITH OWNER.



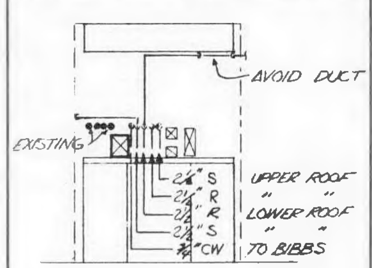
SECTION (A/M9)
SCALE: 1/8"=1'-0"



SECTION (B/M9)
SCALE: 1/8"=1'-0"

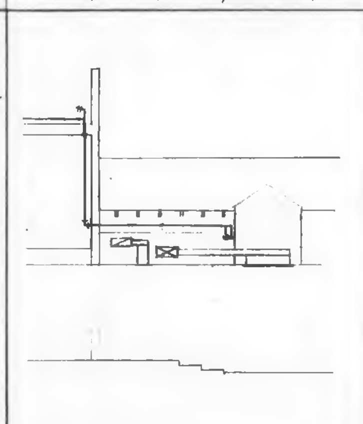


SECTION (C/M9)
SCALE: 1/8"=1'-0"

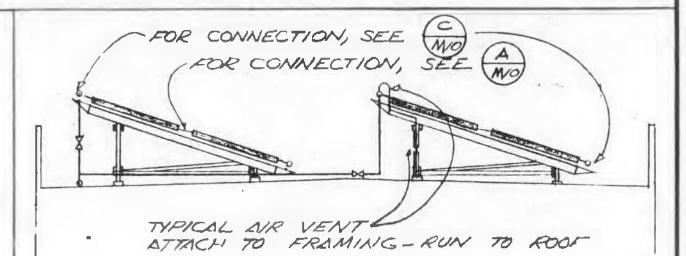


CONNECT FOUR TUBES ABOVE TO EXISTING CORRESPONDING TUBING IN MECHANICAL ROOM; LABEL AS "UPPER ROOF" AND "LOWER ROOF" WITH STENCIL OR TAG.

SECTION (D/M9)
SCALE: 1/8"=1'-0"



SECTION (E/M9)
SCALE: 1/8"=1'-0"



SECTION-UPPER ROOF (F/M9)
SCALE: 1/8"=1'-0"

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

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COLLECTOR PIPING LAYOUT

P. R. McCOY & ASSOCIATES
MECHANICAL AND ELECTRICAL ENGINEERS
597 STOCKTON AVENUE
SAN JOSE, CA 95126

PROJECT 7391
DATE 17 DEC 75

L-15

Ⓐ HADBAR 80-062 SILICONE RUBBER HOSE REINFORCED WITH BRAIDED KEVLAR ID=5/8" OR EQUIVALENT. USE TWO SPRING CLAMPS AT EACH JOINT.

Ⓑ COLLECTOR INLET AND OUTLET (FURNISHED WITH COLLECTOR).

Ⓒ #110 PETE'S PLUG WITH 1/4" NPT THD.

Ⓓ MUELLER W-4006 TEE 1/2 × 1/2 × 1/2 OR EQUIVALENT

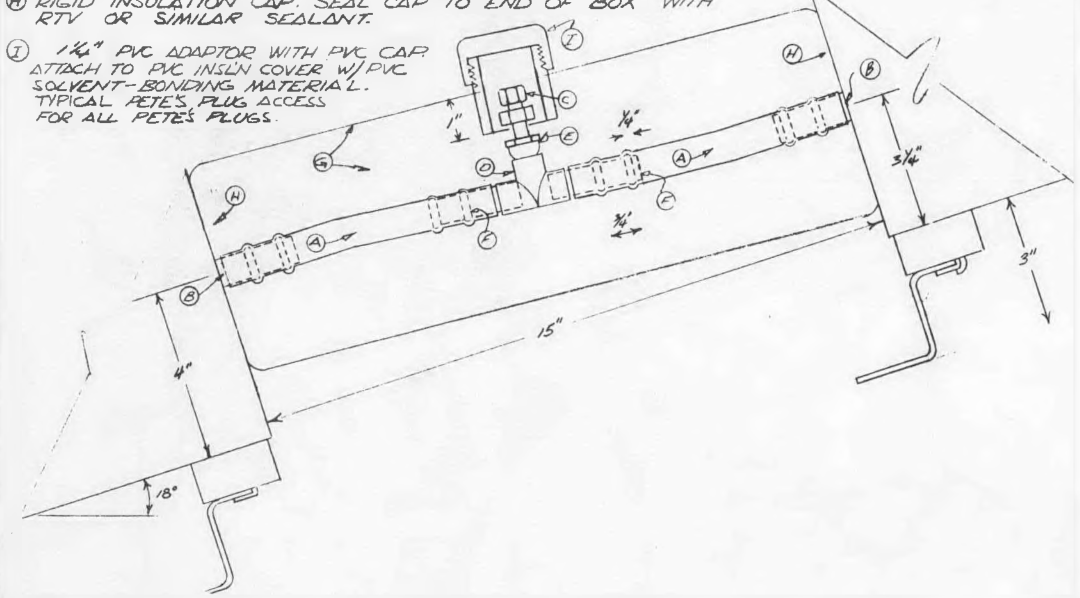
Ⓔ MUELLER W-1233 ADAPTER 1/2 × 1/4 OR EQUIVALENT

Ⓕ 1/2" TYPE M COPPER TUBE (OD= 0.625, L= 2 1/4) WITH TWO BEADS PER MS 33660. FERRULES SILVER SOLDERED OK AS ALTERNATE.

Ⓖ 1 3/16 VIKING ISO-CYANURATE FOAM RIGID INSULATION WITH WEATHERPROOF COVER AND FIBERGLASS LINING. HOLLOW OUT FOR PETE'S PLUG.

Ⓗ RIGID INSULATION CAP. SEAL CAP TO END OF BOX WITH RTV OR SIMILAR SEALANT.

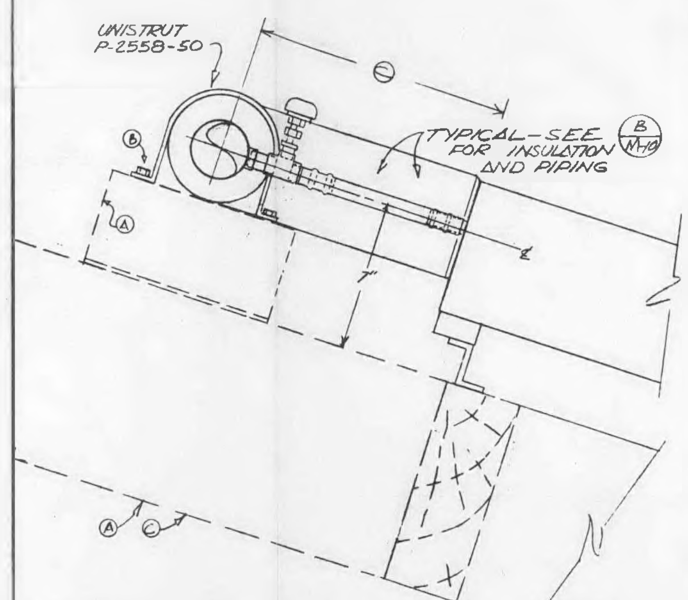
Ⓘ 1 1/4" PVC ADAPTOR WITH PVC CAP. ATTACH TO PVC INSUL COVER W/ PVC SOLVENT-BONDING MATERIAL. TYPICAL PETE'S PLUG ACCESS FOR ALL PETE'S PLUGS.



BOX TO BOX CONNECTION—UPPER & LOWER ROOFS (A / M-10)
SCALE: 1" = 2"

HIGH POINT OF COLLECTORS SHOWN. BOTTOM TO BE THE SAME—BUT REVERSED. CONNECTIONS OF TWO COLLECTORS TO BE SAME AS A/M-10. DIMENSION Ⓒ OF LOWER HEADER TO BE CONSTANT 12".
NOTE: Ⓐ BELOW INDICATES WORK OF OTHER DIVISION. (SHOWN DASHED).

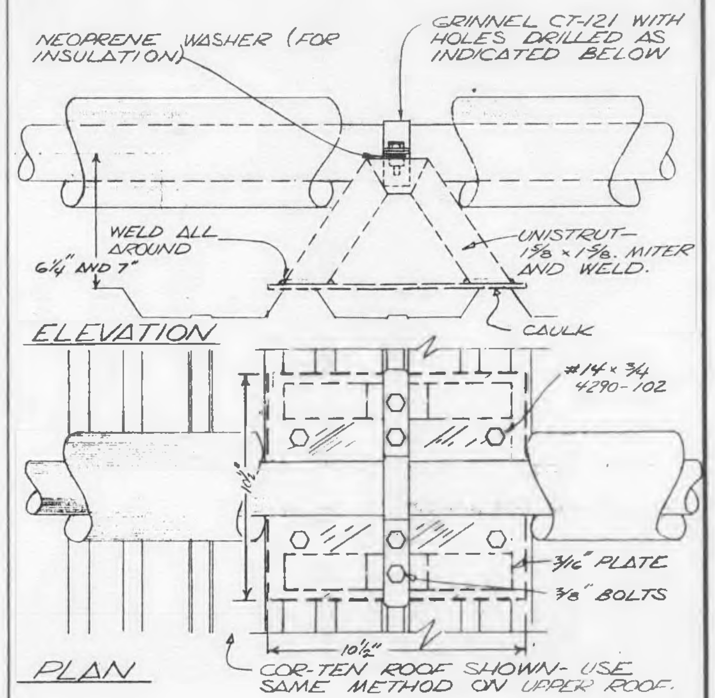
Ⓑ HOLES TO BE DRILLED BY OWNER.



DIMENSION Ⓒ VARIES FROM 12" TO 17" AS THE SUPPORT IS SLID UP BRACKET Ⓒ TO PROVIDE SLOPE UP IN DIRECTION OF FLOW.

HEADER CONNECTION—UPPER ROOF (C / M-10)
SCALE: 1" = 4"

SUPPORT (SHOWN DASHED) BY OTHER DIVISION OF WORK.



WHERE 3/16" PLATE CONTACTS COR-TEN ROOF CLEAN COR-TEN AND PLATE TO BARE METAL AND APPLY DAP FLEX-I-SEAL TO BOTH SURFACES.

TUBING ANCHOR (E / M-10)
SCALE: 1" = 4"

Ⓐ 1 3/16 VIKING ISO-CYANURATE FOAM RIGID INSULATION WITH WEATHERPROOF COVER.

Ⓑ MANIFOLD HEADER WITH INTEGRAL NIPPLES. 2 1/2" TYPE M COPPER OR BETTER WITH (ID= 0.625, L= 3/8 MIN.) ON 26" CENTERS.

Ⓒ #110 PETE'S PLUG WITH 1/4" NPT THD.

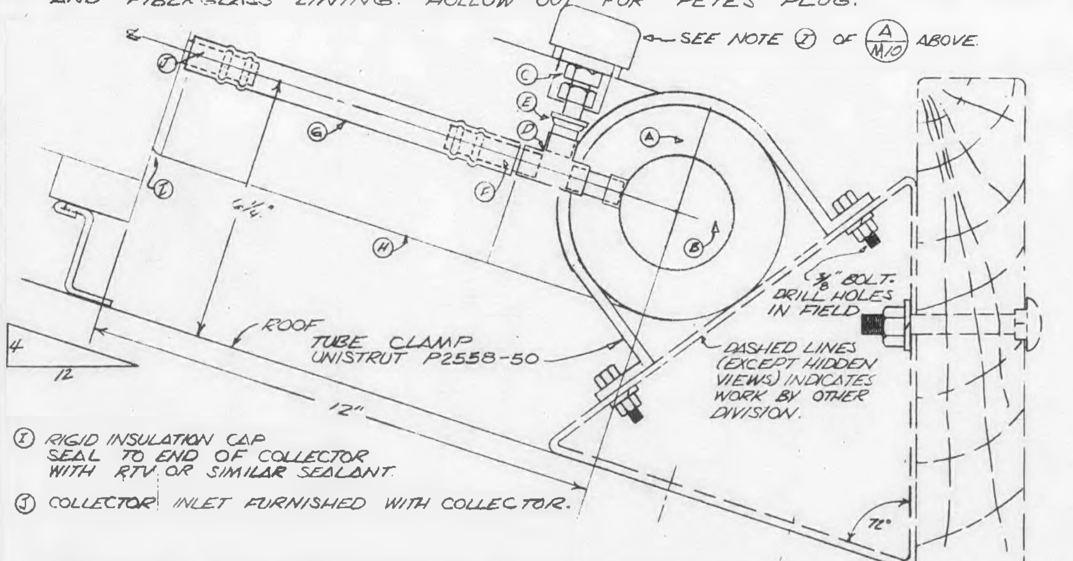
Ⓓ MUELLER W 4006 TEE 1/2 × 1/2 × 1/2 OR EQUIVALENT.

Ⓔ MUELLER W 1233 ADAPTER 1/2 × 1/4 OR EQUIVALENT.

Ⓕ 1/2" TYPE M COPPER TUBE (OD- 0.625, L= 2 3/4) WITH TWO BEADS PER MS 33660. FERRULES SILVER-SOLDERED OK AS ALTERNATE.

Ⓖ HADBAR 80-062 SILICONE RUBBER HOSE REINFORCED WITH BRAIDED KEVLAR (ID= 5/8) OR EQUIVALENT. USE TWO SPRING CLAMPS AT EACH JOINT.

Ⓗ 1 3/16 VIKING ISO-CYANURATE FOAM RIGID INSULATION WITH WEATHER-PROOF COVER AND FIBERGLASS LINING. HOLLOW OUT FOR PETE'S PLUG.

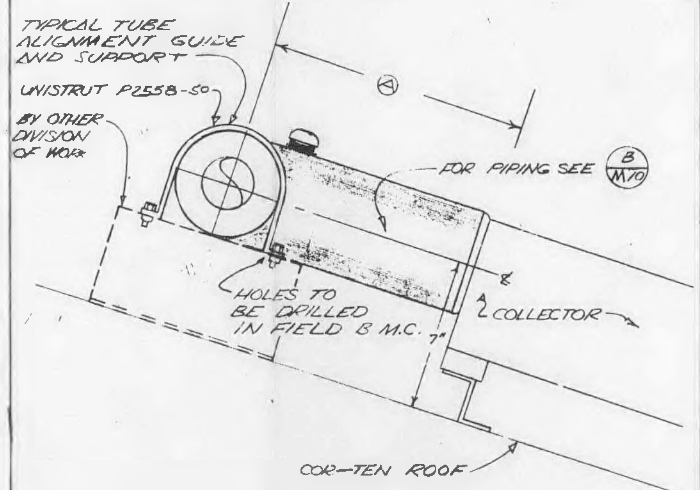


Ⓘ RIGID INSULATION CAP SEAL TO END OF COLLECTOR WITH RTV OR SIMILAR SEALANT.

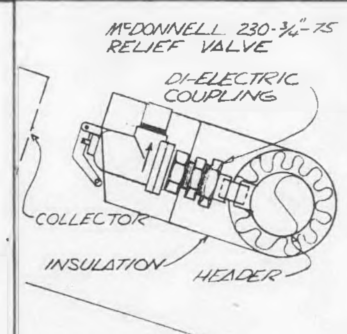
Ⓙ COLLECTOR INLET FURNISHED WITH COLLECTOR.

HEADER CONNECTION DETAIL—LOWER ROOF (B / M-10)
SCALE: 1" = 2"

DIMENSION Ⓐ BELOW VARIES FROM 12" TO 17" AS THE SUPPORT IS SLID UP THE ROOF. THIS PROVIDES SLOPE UP IN DIRECTION OF FLOW.

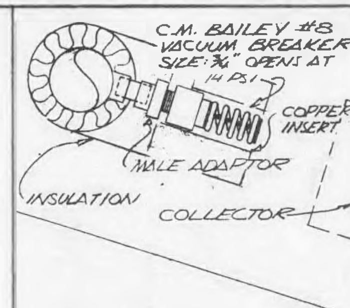


HEADER CONNECTION—LOWER ROOF (D / M-10)
SCALE: 1" = 4"



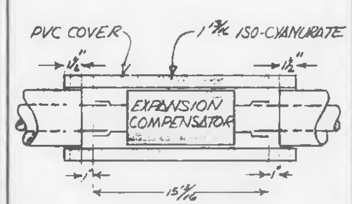
WRAP FIBERGLASS AROUND RELIEF VALVE BUT DO NOT INTERFERE WITH OPERATION. COVER WITH PVC.

RELIEF VALVE (F / M-10)
SCALE: 1" = 4"

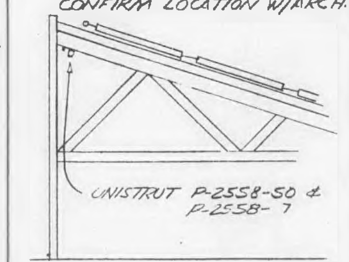


WRAP FIBERGLASS AROUND VACUUM BREAKER AND COVER WITH PVC. PROVIDE COPPER INSERT TO PREVENT INTERFERENCE WITH MECHANISM.

VACUUM BREAKER (G / M-10)
SCALE: 1" = 4"



EXPANSION JNT INSULN. (H / M-10)
SCALE: 1" = 8"



SECTION (I / M-10)
SCALE: 1/8" = 1'-0"

santa clara community recreation center

DAVID C. THIMGAN, AIA, ARCHITECT

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COLLECTOR PIPING DETAILS

597 STOCKTON AVENUE
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L-16