DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-161238

SOLAR ENERGY SYSTEM INSTALLED AT MOUNT RUSHMORE NATIONAL VISITOR CENTER IN KEYSTONE, SOUTH DAKOTA

Prepared from documents furnished by

South Dakota School of Mines and Technology
Rapid City, South Dakota 57701

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For the U. S. Department of Energy

(NASA-CR-161238) SOLAR ENERGY SYSTEM INSTALLED AT MOUNT RUSHMORE NATIONAL VISITOR CENTER IN KEYSTONE, SOUTH DAKOTA Final Report (South Dakota School of Mines and Technology) 42 p HC A03/MF A01 CSCL 10A G3/44

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U.S. Department of Energy

Solar Energy

FINAL REPORT OUTLINE

Table of Contents

1 . Narrative Description of solar energy system and building

INTRODUCTION

This project is a solar retrofit project of Mount Rushmore National Memorial Visitor Center at Keystone, SD, where over two million tourists visit each year. The Visitor Center has a total space of approximately 6,000 sq. ft. The solar system is designed to furnish approximately 45% of heating for the total facility, and approximately 53% partial cooling of the 2,000 sq. ft. observatory room. There are a total of 112 panels of Lennox liquid circulated collectors, each 3 ft by 6 ft in dimension, with a gross surface of approximately 2,000 sq. ft. Collector panels are mounted in 5½ rows on the roof of the Visitor Center owned by National Park Service of the Department of Interior. The building was designed by the Spitznagel Partners, Inc. The project consists of four team members with South Dakota School of Mines and Technology as program manager; the Spitznagel Partners, Inc. as construction manager and designer; Honeywell as a collector supplier; and the Mount Rushmore National Memorial as the owner.

DESIGN PHILOSOPHY

The first design decision was to install collectors which used liquid rather than air as the heat transfer fluid. There were three factors which indicated that this was the best choice: (1) A liquid medium would integrate easily with the existing system by simply installing a heating coil in the furnace air duct. The liquid could be circulated directly from the collectors to the heating coil for optimum transfer without additional blowers. (2) There is a need for extra air-conditioning in the observatory room which could be met by solar activated lithium bromide absorption refrigeration units. Air collectors do not produce high enough temperatures to activate these units. (3) The limited space to mount the collector array required collectors with high efficiency and air collectors are generally less efficient than liquid collectors.

Some of the more important design decisions were determined according to the following conditions: (1) The collector area (active area of 1720 sq. ft.) is the maximum which can be fit on the roof and allow enough spacing to avoid shading (5% of total in December). This is also based on the actual total fuel consumed in FY 1975 or 8,721 gallons of No. 2 oil, assuming a heating value of 140,000 BTU per gallon and a furnace efficiency of 50% due to the age of the furnace and an altitude of about one mile, the total annual heating load of about 6.1×10^8 BTU's is determined. (2) The three 3-ton Arkla units are the maximum number which can be operated with the given collectors. (3) The 3,000 gal. storage tank is a compromise between performance and available space. (4) The solar heat coil, effectiveness = 0.538, is the largest reasonable coil which can fit into the existing furnace duct. (5) The angle at which the collectors are placed is a combination of the orientation of the roof, a 45° angle relative to the roof for ease of construction, and a need for solar collection both in winter and summer. The optimum angle for this particular application was not determined, but other simple models show that the performance is probably only 2% less at this angle than at the optimum of about 55° in winter. The angles used here favor the air conditioning application. (6) The control system is designed to use solar heating or cooling first and then the current conventional system as backup. It will be possible to air condition and solar heat during the same day, even though this feature is not in the computer model for simplification.

Solar energy system calculations were based on climatological data for Rapid City supplied by the National Oceanic and Atmospheric Administration (NOAA). The climatological conditions at Mount Rushmore (25 miles southwest and 2,000 feet higher than Rapid City) are expected to be more favorable due to the altitude and lack of pollution in the air, making these calculations conservative.

TRNSYS system developed by the University of Wisconsin modified by South Dakota School of Mines and Technology was used to simulate the solar system. The climatological data for 1971-74 was used for the simulation model. The TRNSYS program used here should enable the user to write a workable transient simulation program with a minimal knowledge of computers. TRNSYS has built-in checks to spot obvious errors such as calling for an input from a non-existent unit, failure to specify initial conditions, etc. Other errors such as improper conversion of units, crossing the temperature with the flow rate, etc. can be very difficult to spot. In this case the user must know enough about the system to realize that the answers are nonsense, even though the computer processes the numbers without printing an error message. If the program fails to produce answers which converge within the specified tolerances in the specified number of iterations, the user has recourse to decreasing the time step, raising the tolerances or number of iterations, or sticking the control units after fewer calls in one time step. When these fail to produce convergence, then it is essential to have familiarity with FORTRAN and general knowledge of iterative techniques to trace and correct the difficulty.

The flow rate is calculated on the basis of .3 gpm per collector panel specified by the supplier.

The 3,000 gallon storage tank to provide reasonable heat storage for heating and reasonable period of continuous cooling is housed above the ground with three 3-ton Arkla units, heat exchanger, pumps, and all controls in a building connected to the Visitor Center on the east side. This selection gives ease in installation of piping, storage tank and other equipment. The length of piping is minimized.

OPERATION OF THE SYSTEM

The whole system was completed in September of 1977. First the system was tested with pure water in the solar collector loop for about a week, and the system seemed to function properly and was then charged with ethelene glycol for continuous operation. The presence of air bubbles in the system was a constant problem. The pressure build-up due to the air bubbles was alleviated by frequent venting on the top of the roof. The system pressure could be in excess of 70 psig. The air venting could be as frequent as once a week.

The winter of 1977 in South Dakota was one of the severest ones experienced. The National Park Service was quite happy with the saving of many gallons of oil. The system apparently functioned well in solar heating. No major problems were detected except that the main system pump was always running for all modes of operation. Nobody knew exactly how well the system was functioning until the early part of May of 1978 when IBM contracted Site Data Acquisition System (SDAS) to begin to produce some computer printouts. Quite a few anomalies were picked up by the SDAS such as the main system pump was running all the time; the sequence of operations was different from what was originally planned; solar and auxiliary heating have the same control setting; energy from storage is not always being taken to meet the heating load, etc.

The Arkla cooling units were started after mid-July of 1978. The cooling system was never utilized to its full capacity due to the fact that the control of the system was not completely under control. Adjustments and corrections are still being made by the Honeywell people. In general, most major anomalies have been corrected. It is expected the system will operate properly both heating and cooling in seasons to come.

SUCCESSFUL COMPONENTS OR PROCESSES

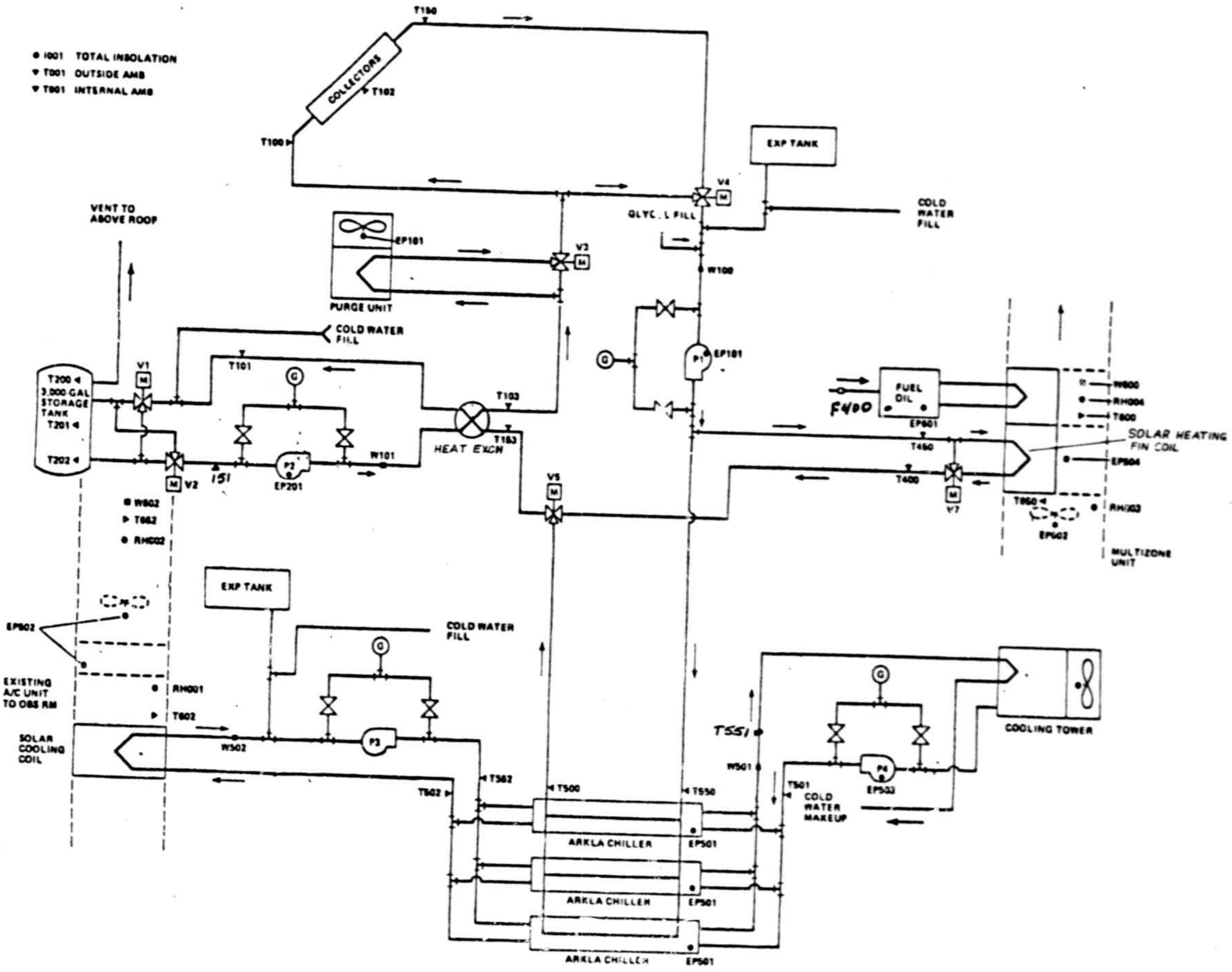
Aesthetically the Park Service people were worried that the presence of solar energy heating project might distract from the main attraction. Since the installation of the collector panels, the visitors apparently are not aware of the presence of collector panels on the roof of the building. This seems to satisfy the Park Service. Comments from people who have seen the collector panels are good. Aesthetically, they blend in very naturally with the building.

2. Acceptance Test Data

a. ACCEPTANCE TEST PLAN

The basic philosophy of the acceptance test plan will be simply to insure that the entire system functions as designed. The acceptance test will be primarily based on the results provided by the government's Site Data Acquisition System and its on-site monitor. Results of a minimum of one week of continuous operation are required for the acceptance test.

Referring to the attached diagram, a total of 44 sensors as shown are installed to the whole system. 8 sensors with a prefix of EP are for the measurements of electrical power consumed by pumps; 6 sensors with a prefix of W for the measurements of pump flowrate of liquid; 24 sensors with a prefix of T are for temperature measurements; and 6 remaining sensors are: 4 with a prefix of RH for the measurements of humidity, 1 with a prefix of F for the measurements of fuel oil flowrate, and 1 with a number of 1001 for the measurement of the total solar insolation. Results of the Site Data Acquisition System are obtained from the 44 sensors as shown in the attached diagram.



MOUNT RUSHMORE SYSTEM SCHEMATIC (10/4/78)

FIGURE 1

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On a component basis, the items to be tested will be all pumps, motors, heat exchanger, coils, fans, cooling tower, solar collectors. valves, controls and sensors, and ARKLA cooling units. A general visual and physical inspection of all items including leakage and insulation free from any defect will be conducted. Tolerances for various items are to meet within ± 10% of the designed performance, for most of the items, as specified in the attached designed equipment schedule.

The controls will be tested according to the attached sequence of operations.

GENERAL

Space heating and cooling is controlled by the existing space thermostats. First stage heating is provided by solar heated water directly from the collectors or from the storage tank to the solar heating coil located in the existing multizone unit. Second and third stage heating are accomplished by firing the existing burner which is sequenced through two firing stages. First stage cooling is provided by the Arkla absorption units. Second stage cooling is accomplished by sequencing the existing multi-zone unit and direct expansion unit.

FIRST STAGE HEATING FROM COLLECTOR

On a call for heat from the space thermostats and by the discharge air temperature THD, valve V7 is modulated to control the hot deck temperature. Pump P1 is enabled to run and valve V4 is positioned A to AB if the collector plate temperature (TPH) is greater than 125°F (adjustable). A time delay will delay pump P1 shut down to prevent short cycling.

FIRST STAGE HEATING FROM STORAGE

Heating from storage is accomplished whenever energy is not available from the collectors, heating demand occurs and energy is available from storage. On a call for heat, valve V7 and V5 are in the heating positions.

Valve V4 is B to AB. Pump P2 and P1 are enabled to run if the storage tank temperature TSD is greater than 100°F (adjustable). Valves V1 and V2 are positioned B to AB respectively.

SECOND AND THIRD STAGE HEATING

If first stage heating cannot be satisfied from the collectors or storage as sensed by discharge air sensor THD and the space thermostat, then the existing burner will be sequenced through it's two firing stages.

FIRST STAGE COOLING FROM COLLECTORS

First stage cooling is provided by the Arkla Absorption units A1 through A3. On a call for cooling, valve V5 is positioned A to AB and valve V7 is positioned B to AB. If solar heat is available from the collectors, which is sensed by collector plate sensor TPH, then pump P1, P3 and P4 are enabled to run. Plate temperature TPH must be greater than 180°F (adjustable) for cooling by the absorption units. A time delay will delay Pump P1 shut down to prevent short cycling. A fan aquastat in the cooling tower will cycle the cooling tower fan to hold sump temperature to 85°F (adjustable).

SECOND STAGE COOLING

Second stage cooling is accomplished sequencing the existing multi-zone unit and direct expansion units. When second stage cooling is called, the multi-zone unit will be activated. If the discharge air temperature TCD is greater than 60°F (adjustable) and second stage cooling is on, the direct expansion unit will then operate.

STORAGE TANK CHARGING

Storage tank charging is accomplished only when there is energy available from the collectors (TPH or TPC - set), and TF in is greater than TSC by 20°F (adjustable). Valve V1 and V2 are positioned A to AB respectively and pumps P1 and P2 are enabled to run.

PURGE UNIT

The purge or heat rejection unit is activated by positioning valve V3 B to AB whenever TF out is greater than 200°F (adjustable). The fan is under the control of the fan aquastat which cycles the fan on if the discharge temperature is greater than 205°F.

EQUIPMENT SCHEDULE

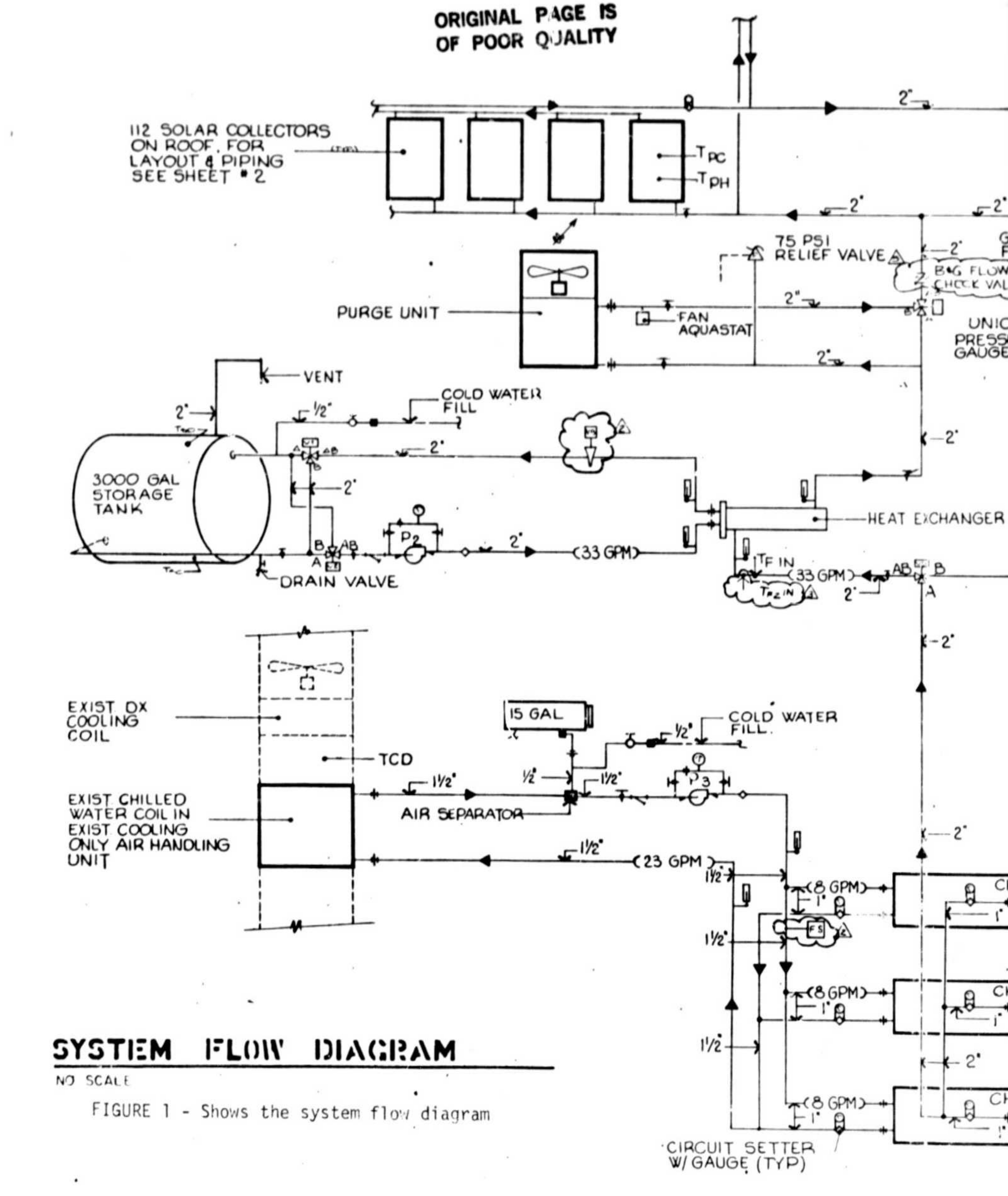
System Pump	-	B & G Model PD-35, 33 GPM at 21 H_2O, $\frac{1}{2}$ HP. 208V-60-3 Spare set of seals.
Storage pump	-	B & G Series $1\frac{1}{2}$, 33 GPM at 5.5' H_2O, 1/6 HP. 115V-60-1 Spare set of seals.
Chilled water pump	-	B & G Series HD3, 23 GPM at 17.5' H_2O, 1/3 HP, 115V-60-1 Spare set of seals.
Condenser Water pump	-	B & G Series 1522 AB-5", 36 GPM at 23' H_2O, 1/2 HP, 120V-60-1. Spare set of seals.
Heat Exchanger	-	B & G Shell & Tube Heat Exchanger #QWU-88-44 Shell side, 33 GPM, 50% Glycol, 122°EWT, 107°LWT, 6' H_2O P.D. - Tube side, 33 GPM, 90°EWT, 103°LWT, 1.5' H_2O P.D., Heat transmitted at rate of 200 MBH.
Cooling Tower	-	Marley Model 46-17, 1/3 HP, 115V-60-1.
Cooling Coil	-	MacQuay Model LHD-108, 1 HP, 208V-60-3, 3800 CFM. 33 GPM, 200°EWT, 180°LWT, 4.7' H_2O Water P.D., 0.7" H_2O A.P.D., 100% EAT, 175°LAT, 326 MBH, Coil #5WH 1204C.
Solar Collector	-	(112 thus) Honeywell/Lennox #LSC18, .3 GPM/collector. 1.9' H_2O Water P.D., Total Sq. ft. of collectors = 2016 sq. ft.
Chiller	-	(3 thus), Arkla/Solaire 36 (WF-36), Data for each-cooling capacity 36,000 BHUH, Hot water input requirement 50,000 BTUH at 210°F, Heat rejection requirement 86,000 BTUH. 115 volt 250 Watts electrical.
Storage Tank	-	3000 gal. capacity, 7" x 10.5' loop, 7 Gauge steel tank.
Expansion Tank	-	B & G 15 gal, 13" x 34 1/2" long, slight glass. AFT-9 Tank fitting, Drain cock.
Pressure Relief	-	located near purge unit, set at approximately 100 PSI.

b. Acceptance test results including corrective action taken for nonconformance. Acceptance test was based on the Instrumented Solar Site Status report dated 9-25-78 put out by IBM. (A copy of the report is attached.) The anomalies and actions involving the grantee are summarized in the following table.

System	Anomaly	Action	Activity	Remarks
S/I	Main system pump runs continuously (1/78)	Control adjustment is needed and has been requested from Honeywell. The problem is due to the way hot deck temperature was set. Damper needs to be readjusted as well as the hot deck temperature so that Valve V7 will cycle to open and close.	Grantee	
S/I	Solar energy simultaneously goes to load and storage. Does not agree with control definition (2/78)	Control definition has been changed and drawing has been corrected. Storage is not used for cooling	Grantee	
S	Solar & auxiliary heating (fuel oil) have same control setting. Disagrees with control definition (2/78)	Damper cam should be readjusted to start solar heating prior to auxiliary heating. We have requested Honeywell controls to make due adjustment.	Grantee	
S	Solar energy not being taken from storage to meet heating load (2/78)	See above	IBM/Grantee	
S	Single plate temperature control sensor may cause over heating.		Grantee	It was okayed to delete this.

S/I	Pump P-2 is running even when pump P-1 is off. Does not agree with control definition (6/78)		Grantee/ IBM	It was okayed to delete this.
S	Purge unit should come on when TF out is 220°F. T103 indicates purge unit is coming on at 175° to 180°F (6/78)	Has been corrected to 200°F (V3)	Grantee	Purge unit rarely ran.
S	Collector loop becomes active at 8:30 AM - runs until 8:30 PM. System losing energy from 4:00 PM - 8:30 PM.		Grantee	It was okayed to delete this.

3. Complete set of as-built drawings with wire and piping schematics.



SYSTEM FLOW DIAGRAM

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FIGURE 1 - Shows the system flow diagram

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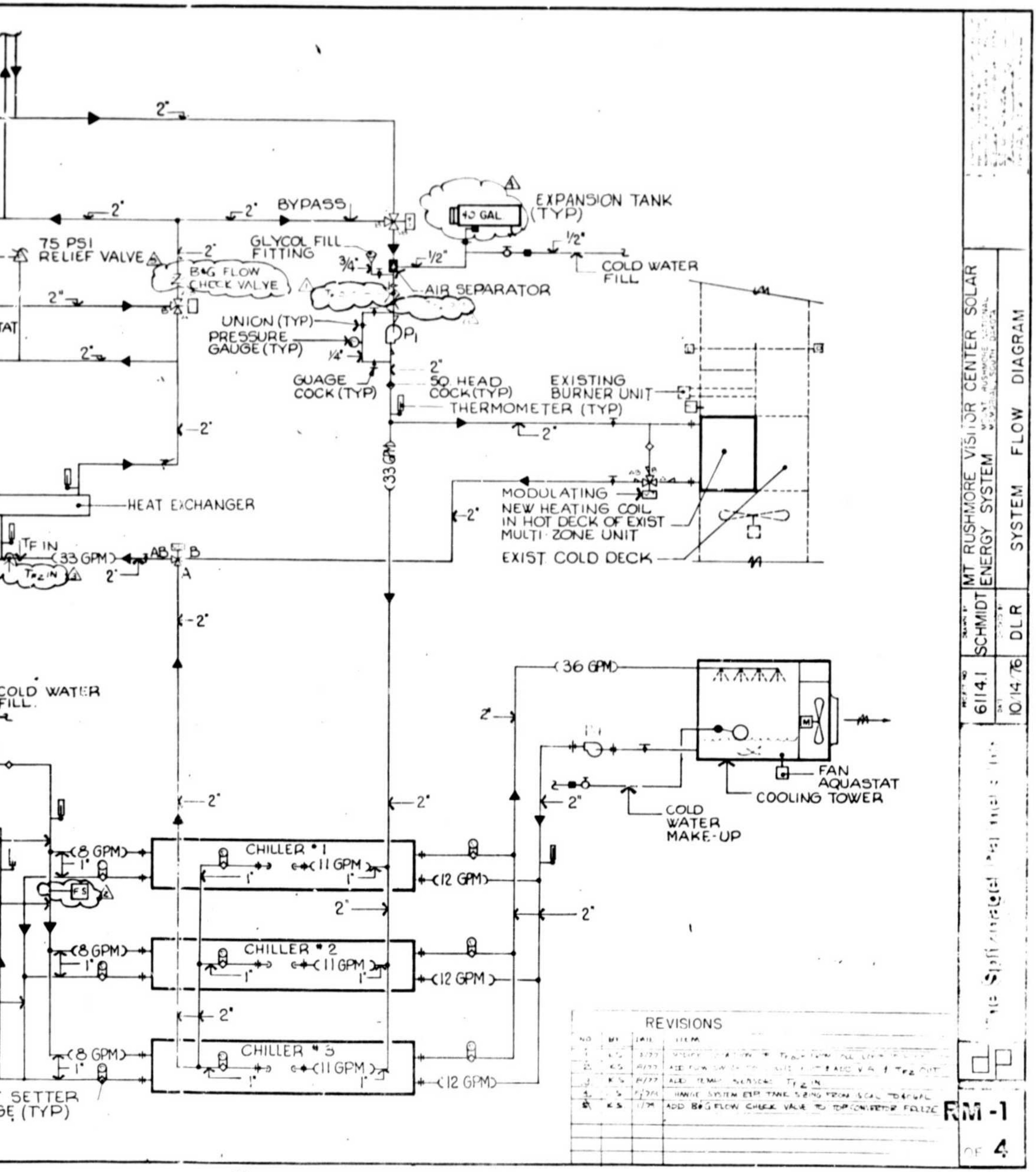

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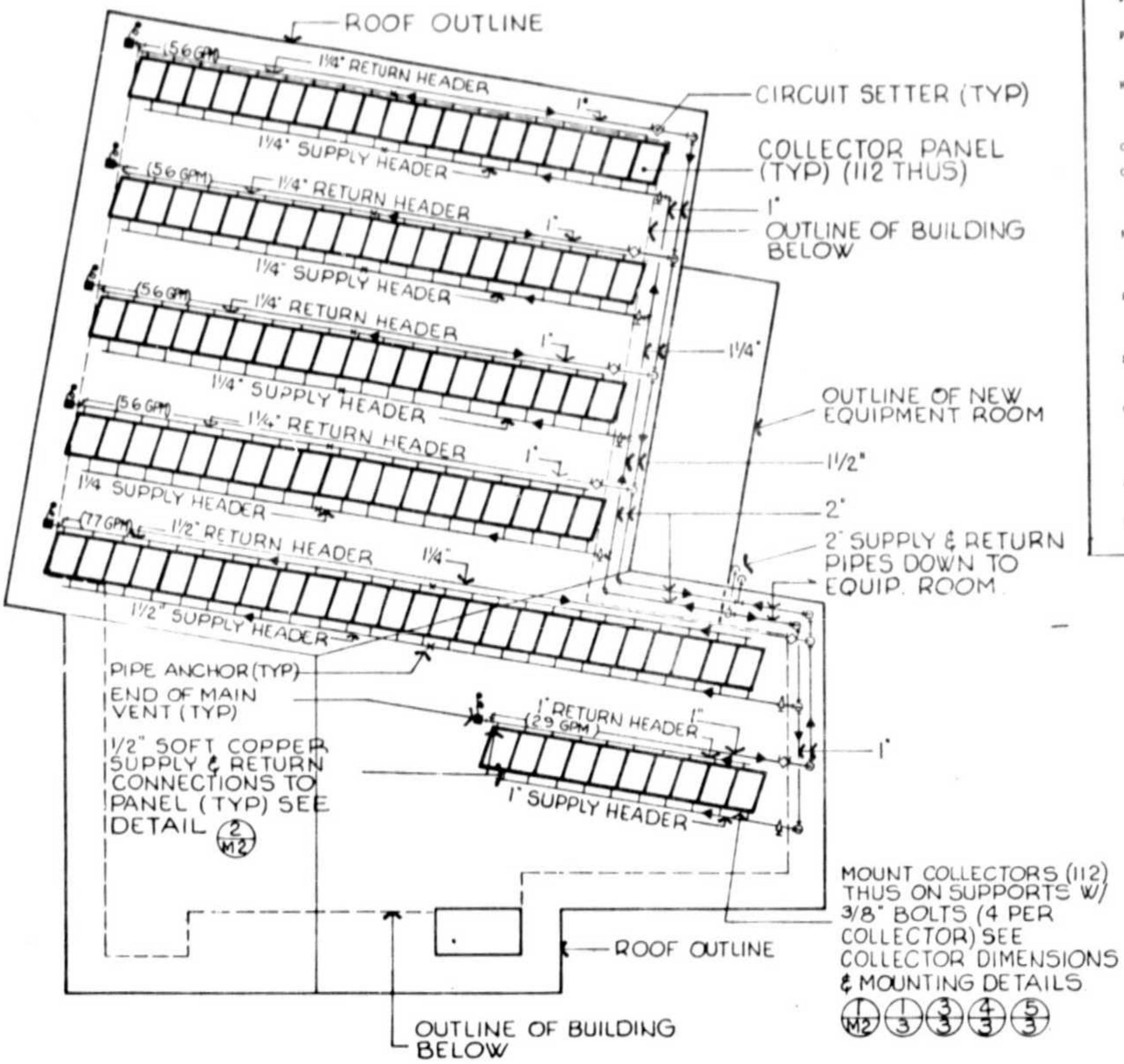

ROOF PLAN - COLLECTOR LAYOUT

SCALE: 1/8" = 1'-0"

· FIGURE 2 - Shows roof plan-collector layout with equipment schedule and sequence of operation

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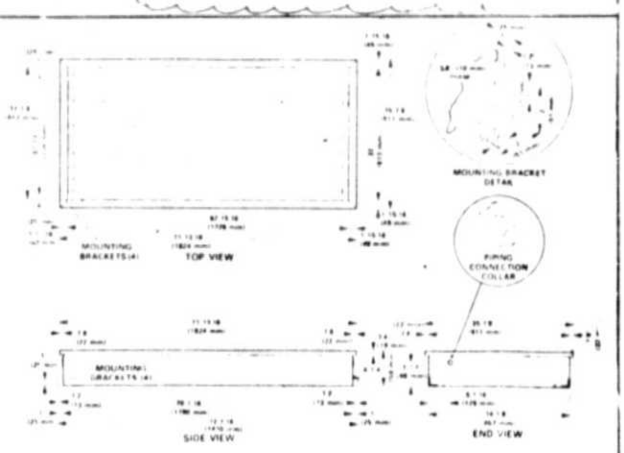
DIMENSIONS
DETAILS

EQUIPMENT SCHEDULE

P-1	System Pump - B & G Model ~~HD-2A~~/ 33 GPM at 5' H_2O. 2 HP, 208V-60-3φ. Spare set of seals.
P-2	Storage Pump - B & G Series 1 1/2, 33 GPM at 5.5' H_2O. 1/6 HP, 115V-60-1φ. Spare set of seals.
P-3	Chilled Water Pump - B & G Series HD3, 23 GPM at 17.5' H_2O, 1/3 HP, 115V-60-1φ. Spare set of seals.
P-4	Condenser Water Pump - B & G Series 1522-B 1¼AAB 36 GPM at 23' H_2O, 1/2 HP, 120V-60-1. Spare set of seals.
HEAT EXCHANGER	B & G Shell & Tube Heat Exchanger #QWU-8P-44 Shell side, 33 GPM, 50%Glycol, 122°EWT, 107°LWT, 6' H_2O P.D. - Tube side, 33 GPM, 90° EWT, 103° LWT, 1.5' H_2O P.D., Heat transmitted at rate of 200 MBH.
COOLING TOWER	Marley Model 46-17, 1/3 HP, 115V-60-1.
COOLING COIL	McQuay #5HH 1005, 10 Fins/inch, 5 Rows, 36" wide by 30" high, 23 GPM, 45° EWT, 55° LWT, 80° DB/67° WB EAT, 55° DB LAT, 533 FPM F.V., 3.5' H_2O Water P.D., & 1.2" H_2O A.P.D. 4000 cfm
HEATING COIL	McQuay #5WH 1403, 14 Fins/inch, 3 Rows, 51" wide by 24" high, 130° EWT, 115° LWT, 33 GPM, 225 MBH, 73° EAT, 108° LAT, 706 FPM F.V., 5.3' H_2O Water P.D., & .5" H_2O A.P.D., 6000 CFM.
PURGE UNIT	McQuay Model LSL-108, 1 HP, 208V-60-3, 3800 CFM. 33 GPM, 200° EWT, 180° LWT, 4.7' H_2O Water P.D., 0.7" H_2O A.P.D., 100° EAT, 175° LAT, 326 MBH. Coil #5WH 1204C.
SOLAR COLLECTOR	(112 thus) Honeywell/Lennox #LSC18, 0.3 GPM/Collector, 1.0' H_2O Water P.D., Total SQ. FT. of Collectors = 2016 SQ. FT.
CHILLERS A1, A2, & A3	(3 thus), Arkla/Solaire 36 (WF-36), Data for each - Cooling Capacity 36,000 BTUH, Hot water input requirement 50,000 BTUH at 210° F, Heat rejection requirement 86,000 BTUH. 115 Volt 250 watts electrical.
STORAGE TANK	3000 Gal capacity, 7'φ x 10.5' Long, 7 Gauge steel tank.
EXPANSION TANKS	B & G 15GAL. & B&G 40 GAL w/ Sight glass, B&G Tank fitting. Drain cock.



1 COLLECTOR DIMENSIONS
NO SCALE

2 COLLECTOR CONNECTIONS
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SEQUENCE OF OPERATIONS

General

Space heating and cooling is controlled by the existing space thermostats. First stage heating is provided by solar heated water directly from the collectors or from the storage tank to the solar heating coil located in the existing muit -zone unit. Second and third stage heating are accomplished by the existing fuel fired burner. First stage cooling is provided by three solar water fired absorption water chillers. Second stage cooling is provided by activating the cooling on the multizone unit. A third stage of cooling is provided by the existing vapor compression unit.

First Stage Heating from Collectors

On a call for heat from the space thermostats and by the discharge air temperature THD, valve V7 is modulated to control the hot deck temperature. Pump P1 is enabled to run and valve V4 is positioned A to AB if the collector plate temperature (TPH) is greater than 100° F (adjustable). A time delay will delay pump P1 shut down to prevent short cycling.

First Stage Heating from Storage

Heating from storage is accomplished whenever energy is not available from the collectors, heating demand occurs and energy is available from storage. On a call for heat, valve V7 and V5 are in the heating positions. Valve V4 is B to AB. Pump P2 and P1 are enabled to run if the storage tank temperature TSD is greater than 100° F (adjustable). Valves V1 and V2 are positioned B to AB respectively.

Second and Third Stage Heating

If first stage heating cannot be satisfied from the collectors or storage as sensed by discharge air sensor THD and the space thermostat, then the existing burner will be sequenced through it's two firing stages.

First Stage Cooling from Collectors

First stage cooling is provided by the Arkla Absorption units A1 through A3. On a call for cooling, valve V5 is positioned A to AB and valve V7 is positioned B to AB. If solar heat is available from the collectors, which is sensed by collector plate sensor TPH, then pump P1, P3 and P4 are enabled to run. Fluid temperature TF must be greater than 180° (adjustable) for cooling by the absorption units. A time delay will delay Pump P1 shut down to prevent short cycling. A fan aquastat in the cooling tower will cycle the cooling tower fan to hold sump temperature to 85° F (adjustable). *

First Stage Cooling from Storage

Cooling from storage is accomplished whenever energy from the collectors is not available, a cooling demand occurs and the storage tank temperature TSD is greater than 180° F (adjustable). On a call for cooling, valves V7 and V5 are in the cooling positions. Valve V4 has been positioned to bypass the collectors (TPH - set). Pumps P1 and P2 are then enabled to run and the absorption units function as previously described.

Second Stage Cooling

Second stage cooling is accomplished sequencing the existing multi-zone unit and direct expansion units. When second stage cooling is called, the multi-zone unit will be activated. If the discharge air temperature TCD is greater than 60° F (adjustable) and second stage cooling is on, the direct expansion unit will then operate.

Storage Tank Charging No Cooling

Storage tank charging is accomplished only when there is energy available from the collectors (TPH or TPC - set), there is no demand for cooling and TFin is greater than TSC by 20° F (adjustable). Valve V1 and V2 are positioned A to AB respectively and pumps P1 and P2 are enabled to run. Valve V8 shall be energized and open when P2 is energized.

Purge Unit

The purge or heat rejection unit is activated by positioning valve V3 B to AB whenever TF out is greater than 220° F (adjustable). The fan is under the control of the fan aquastat which cycles the fan on if the discarge temperature is greater than 210° F.

* Add to First Stage Cooling: Flow switch FS in the chilled water circuit shall prevent V5 from positioning A to AB, and allowing hot water to flow through the chillers unless P3 is running and flow is sensed.

Storage Tank Charging When Cooling:

Storage Pump P2 shall be enabled to run when the system is in the cooling mode only when TF2out is greater than 190° F (adjustable) and all of the criteria under Storage Tank Charging (no cooling) are met.

REVISIONS

NO	BY	DATE	DESCRIPTION
1	[illegible]	[illegible]	[illegible] CONTROL SYSTEM
2	CS	8/78	CHANGE P1 TO LARGER PUMP
3	CS	8/78	CHANGE EXP. TANK SIZES.

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM	MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA
ROOF PLAN & SCHEDULES	
PROJECT NO 6114.1	DRAWN BY SCHMIDT
DATE 10/14/76	CHECKED BY D.L.R.

The Spitznagel Partners Inc.

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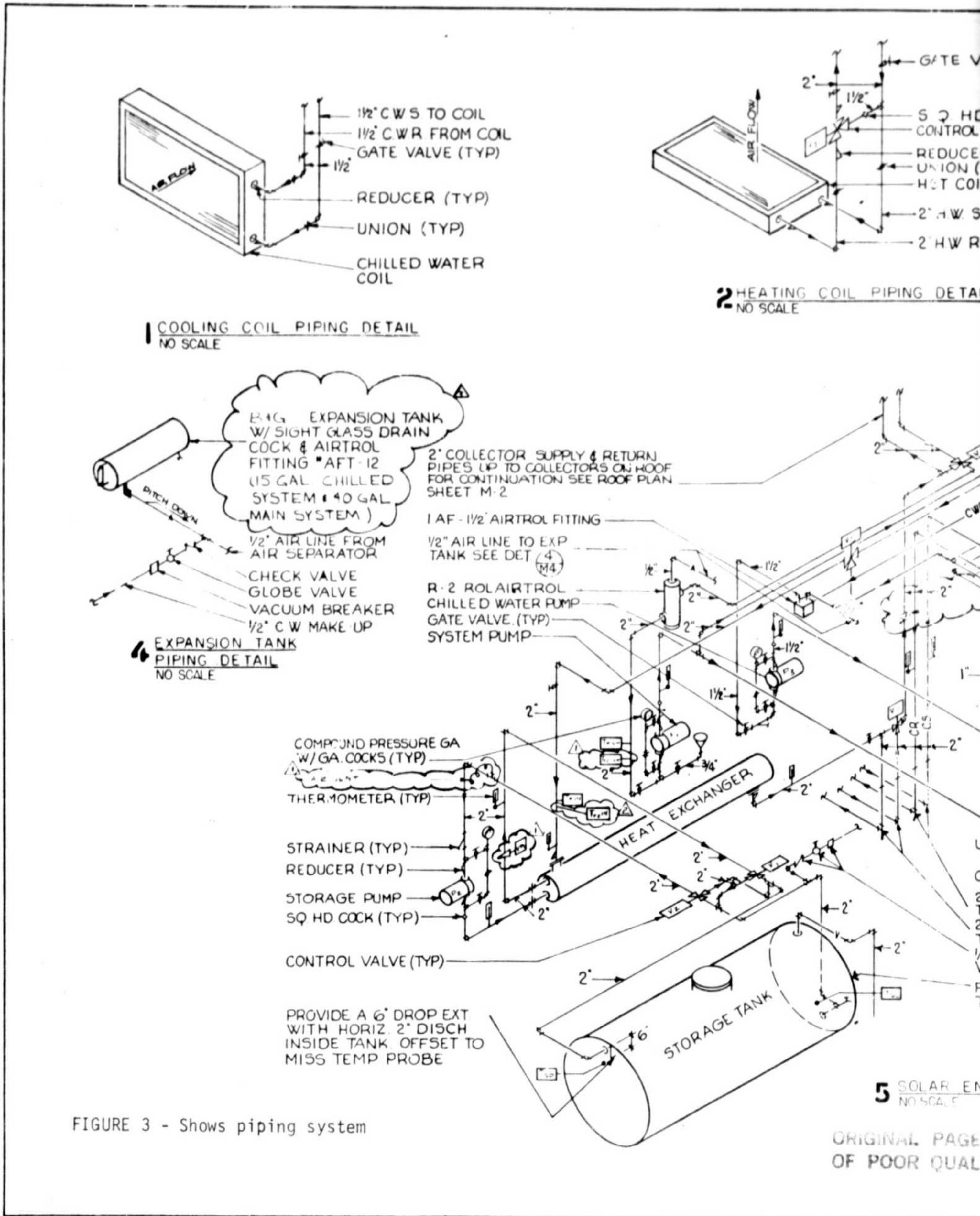
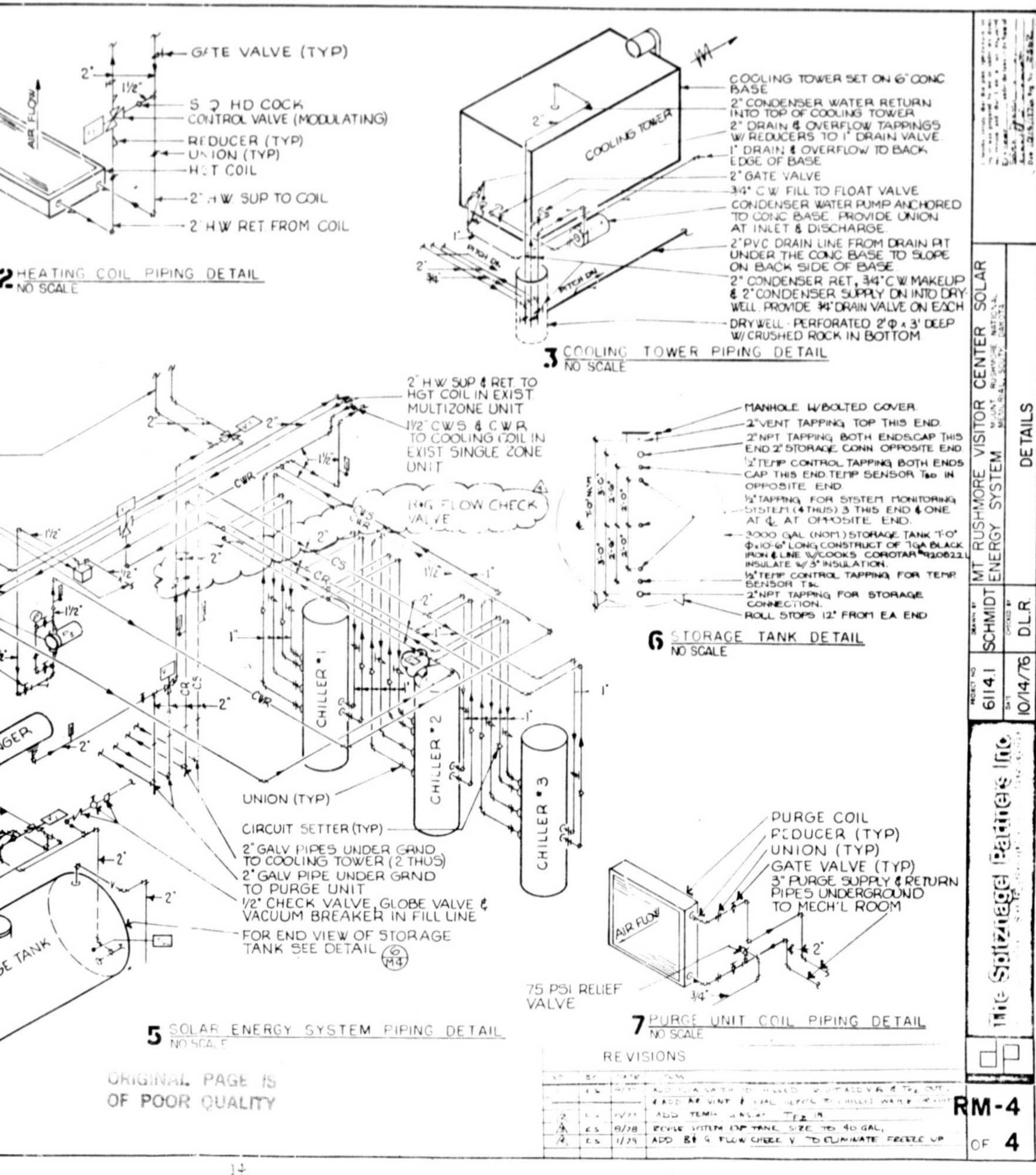


FIGURE 3 - Shows piping system



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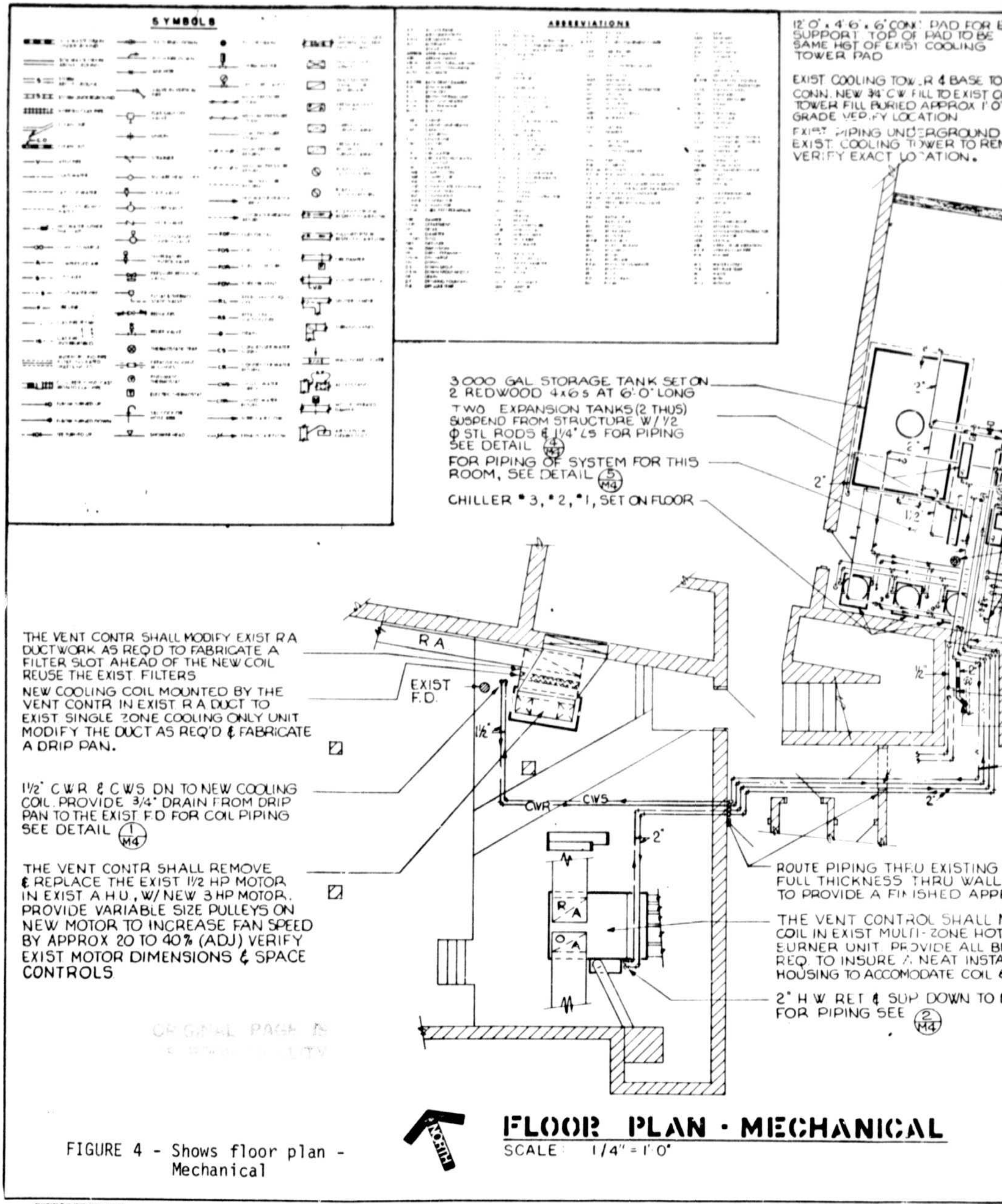
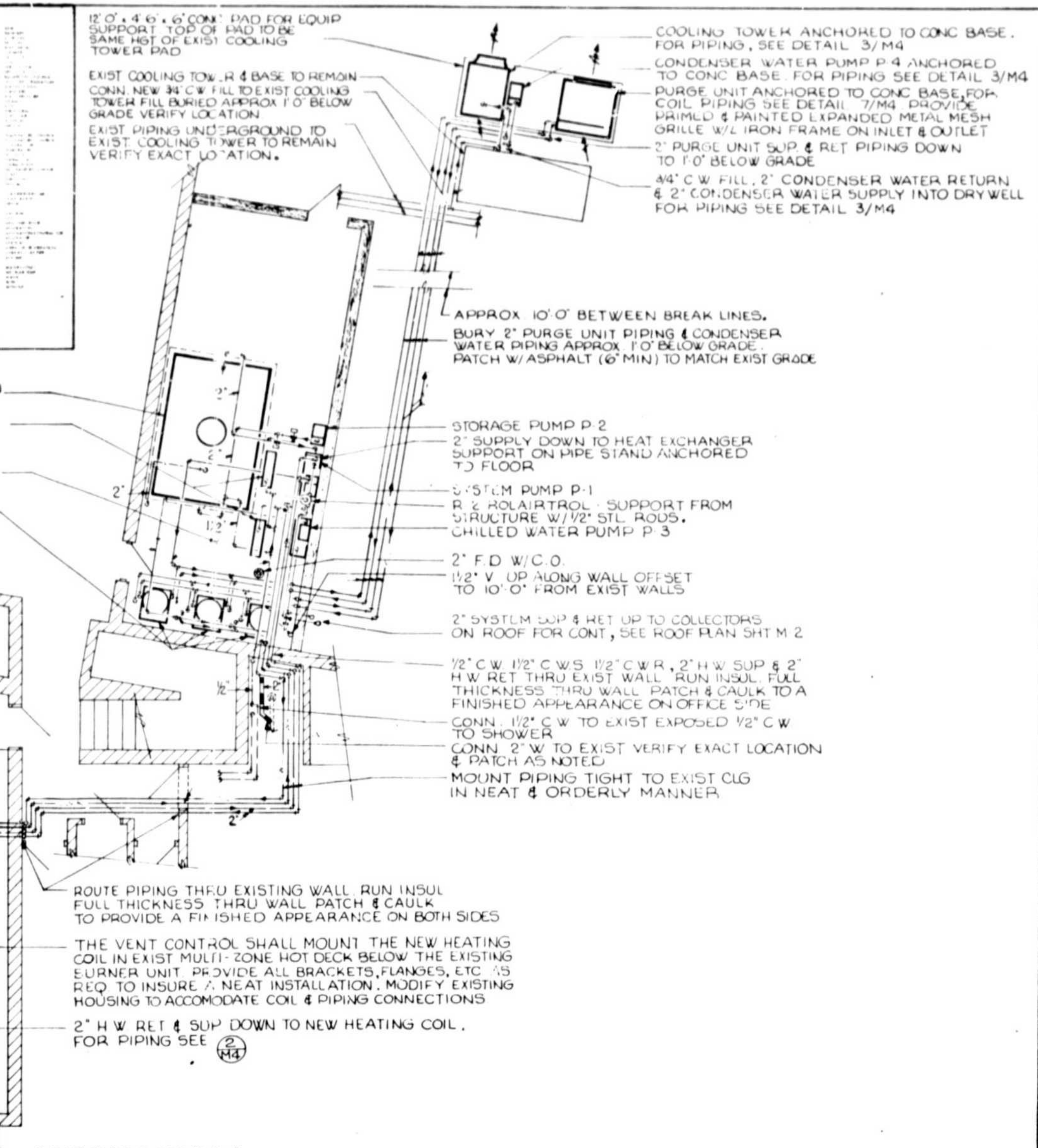


FIGURE 4 - Shows floor plan - Mechanical



1 · MECHANICAL

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM
MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA

FLOOR PLAN — MECHANICAL

PROJECT NO	DRAWN BY	CHECKED BY	DATE
61141	SCHMIDT	D.L.R.	10/14/76

The Spitznagel Partners Inc.

M-3
OF 4

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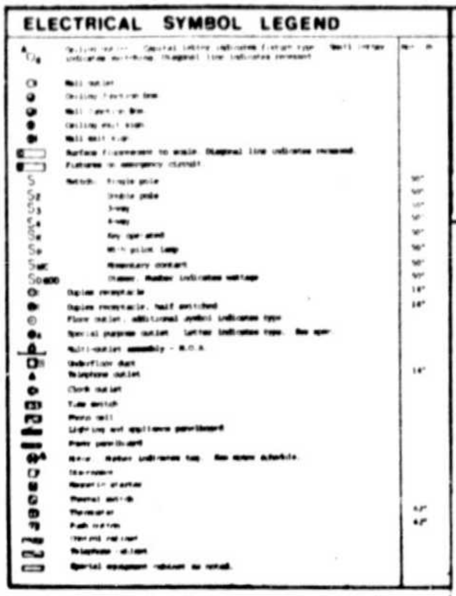
No.	Description	Location		HP or Watt	Volts	Phase	Remarks
1	System Pump P-1	Equip.	3'	2	208	3	ON SAME FEEDER AS MOT #6
2	Storage Pump P-2	Equip.	3'	1/6	120	1	
3	Chilled Water Pump P-3	Equip.	3'	1/3	120	1	*
4	Condenser Water Pump P-4	Ext.	1'	[illegible]2	120	1	
5	Cooling Tower	Ext.	1'	1/3	120	1	*
6	Purge Unit	Ext.	1'	1	208	3	ON SAME FEEDER AS MOT #1
7	Chiller A1, A2, & A3	Equip.	Flr.	250 WEA	120	1	*
8	Blast Unit Heater	Equip.	+8'	5000W	208	3	
9	Existing AHU	Exist		3HP	208	3	Remove 1-1/2 HP and connect 3HP

* GROUP THE FEEDERS EC7 7 4 6 FOR PURPOSE OF METERING

PANELBOARD SCHEDULE

Panel Ident	Type	Mounting	Bus Rating Amps	Volts	Ø	W	Main Lugs Size	Loc	Branches Total	Size	Remarks
EC7	QO	Surface	125	208	3	4	#6	Top	11 2	20/1 20/3	Main Lugs only



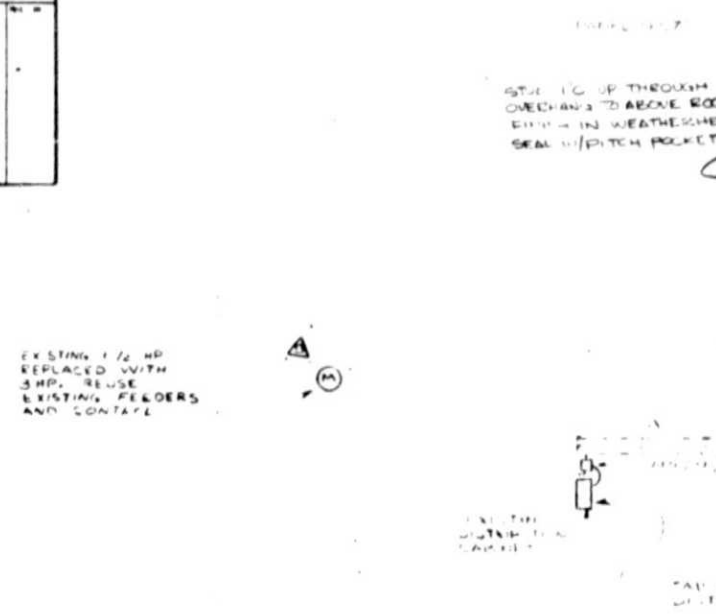


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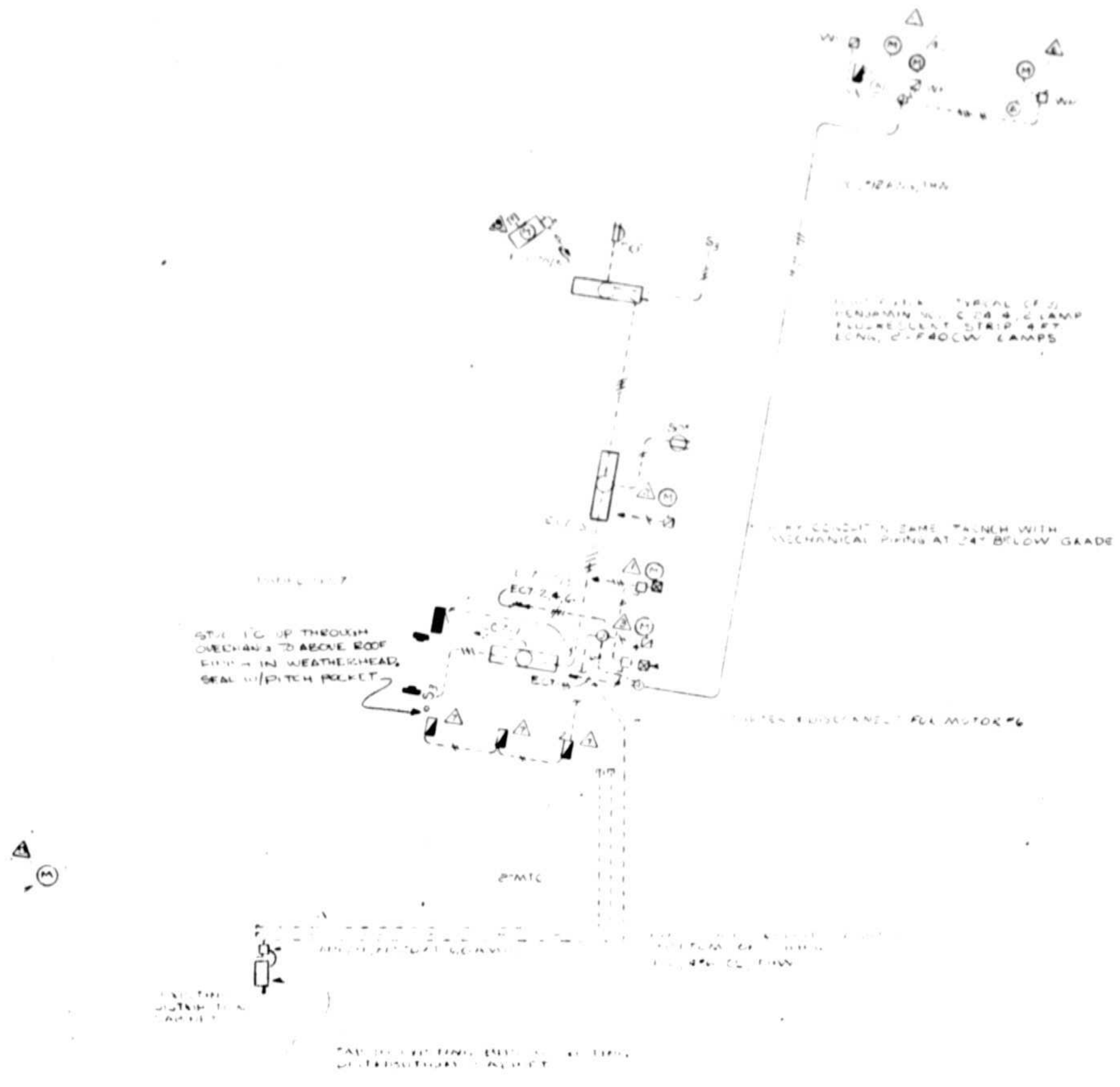
FIGURE 5 - Shows floor plan-Electrical

FLOOR PLAN - EL

SCALE: 1/4" = 1'-0"

FOLDOUT FRAME



FLOOR PLAN - ELECTRICAL

SCALE: 1/4" = 1'-0"

REVISIONS

NO	BY	DATE	ITEM
△		4/78	CHG P. HP. FROM ½ HP TO 2 HP

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA

FLOOR PLAN — ELECTRICAL & DETAILS

PROJECT NO	DRAWN BY
6114.1	R.W.G.
DATE	CHECKED BY
10/14/76	D.L.R.

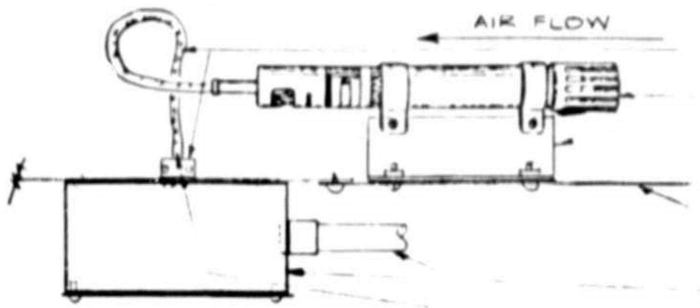
The Spitznagel Partners Inc.

E - 1
OF 1

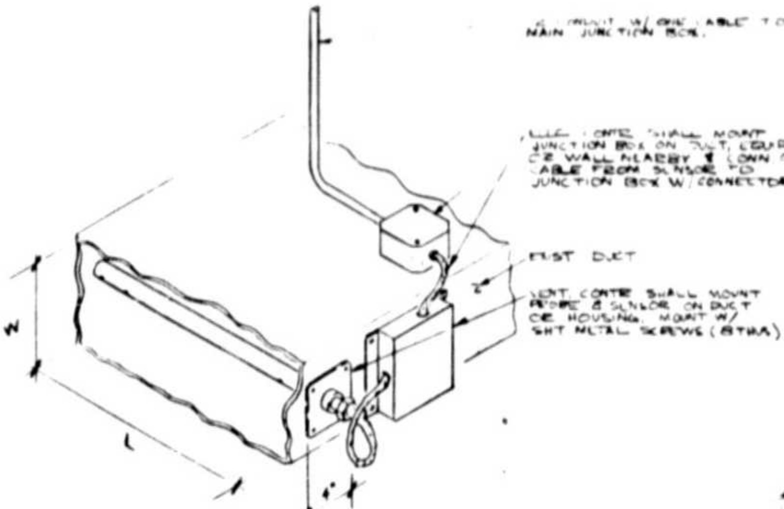
FOLDOUT FRAME 2

DUCT SENSORS

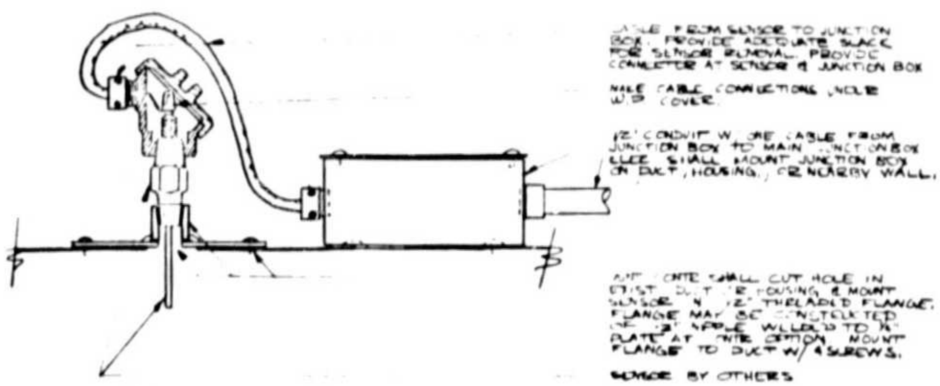
Desc.	Name	Range Min.	Range Max.	Duct Size L" x W"	Sensor Type
T602	A/C to Observation Room Inlet Type	50°F	100°F	—	A
TD602	A/C to Observation Room Differential	0°F	50°F	—	A
T600	Multizone Cooling Outlet	30°F	80°F	—	A
TD600	Multizone Cooling and Heating Coils Differential Inlet Temp.	0°F	50°F	—	A
W602	A/C Air Flow to Observation Room	1000 FPM	2000 FPM	18" 30"	B
W600	M.I. Unit Total Airflow	0 FPM	1000 FPM		B
RH001	Inlet Relative Humidity of Observation Room A/C Unit	0%	100%	—	C
RH002	Outlet Relative Humidity of Observation Room A/C Unit	0%	100%		C
RH003	Inlet Relative Humidity of M.I. A/C Unit	0%	100%	—	C
RH004	Outlet Relative Humidity of M.I. A/C Unit	0%	100%		C



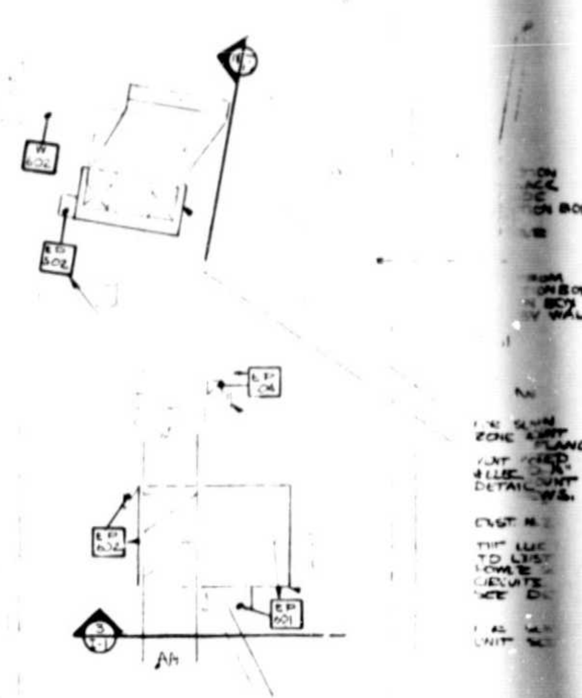
(C) HUMIDITY SENSOR



(B) AIR FLOW SENSOR



(A) AIR TEMPERATURE SENSOR



DUCT SENSORS (A) (B) (C)

FIGURE 6 - Shows floor plan-Instrumentation

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NORTH

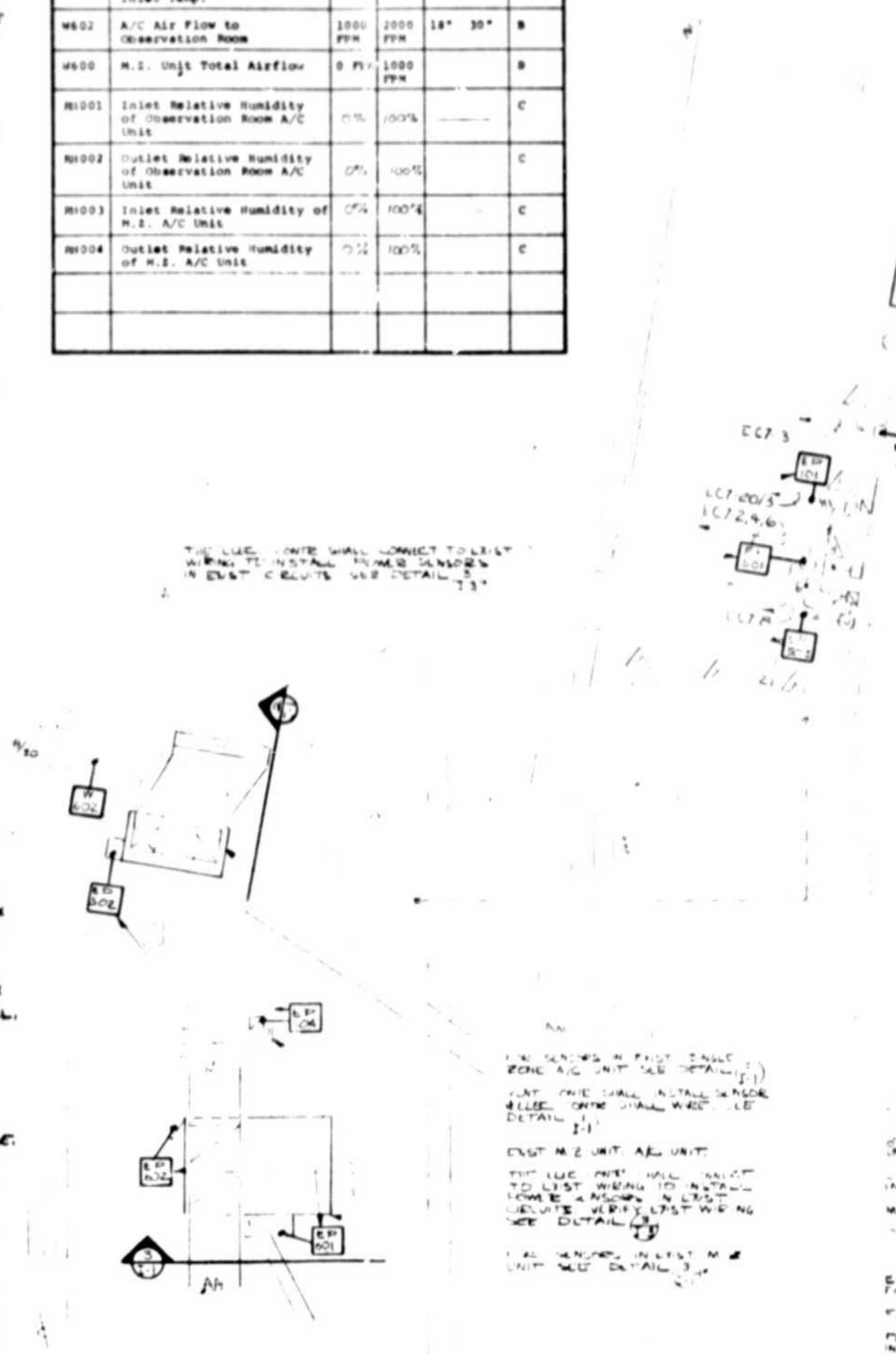
FLOOR PLAN INSTRUMENTA

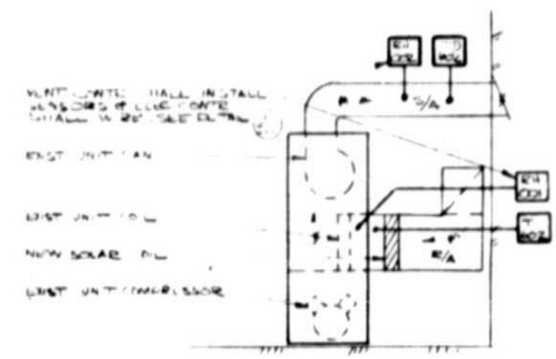
SCALE 1/4" = 1'-0"

FOLDOUT FRAME /

DUCT SENSORS

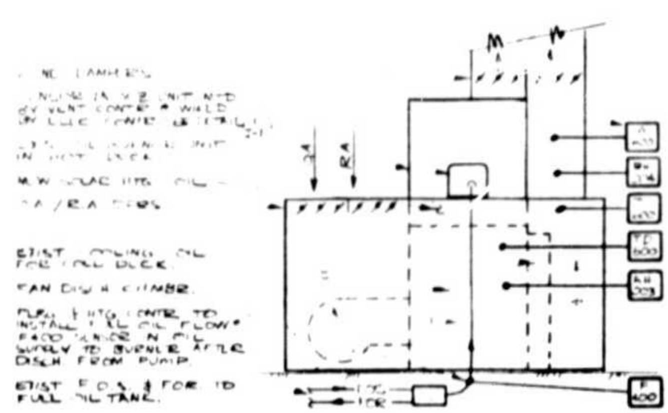
Desc.	Name	Range Min.	Range Max.	Duct Size L" x W"	Sensor Type
T602	A/C to Observation Room Inlet Type	50°F	100°F		A
TD602	A/C to Observation Room Differential	0°F	50°F	—	A
T600	Multizone Cooling Outlet	30°F	80°F	—	A
TD600	Multizone Cooling and Heating Coils Differential Inlet Temp.	0°F	50°F	—	A
W602	A/C Air Flow to Observation Room	1000 FPM	2000 FPM	18" 30"	B
W600	M.Z. Unit Total Airflow	0 FPM	1000 FPM		B
RH001	Inlet Relative Humidity of Observation Room A/C Unit	0%	100%	—	C
RH002	Outlet Relative Humidity of Observation Room A/C Unit	0%	100%		C
RH003	Inlet Relative Humidity of M.Z. A/C Unit	0%	100%	—	C
RH004	Outlet Relative Humidity of M.Z. A/C Unit	0%	100%		C





2 SECTION - EXIST. SINGLE ZONE A/C UNIT

NO SCALE



SECTION - EXIST. MULTIZONE UNIT

NO SCALE

FLOOR PLAN - INSTRUMENTATION

SCALE: 1/4" = 1'-0"

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM

SCHMIDT

6114 3

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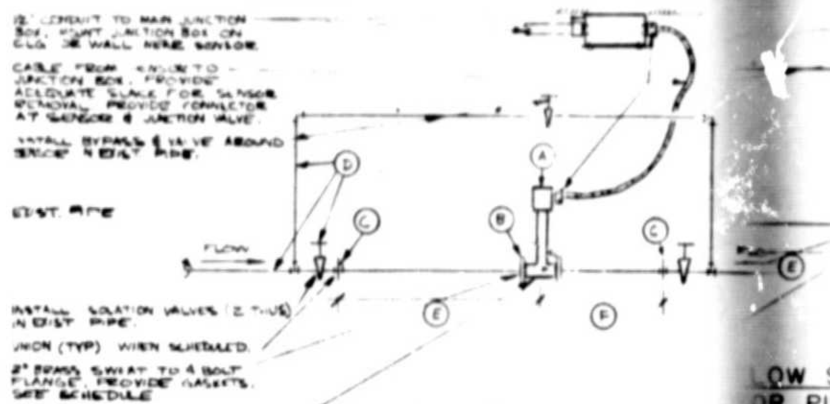
OF

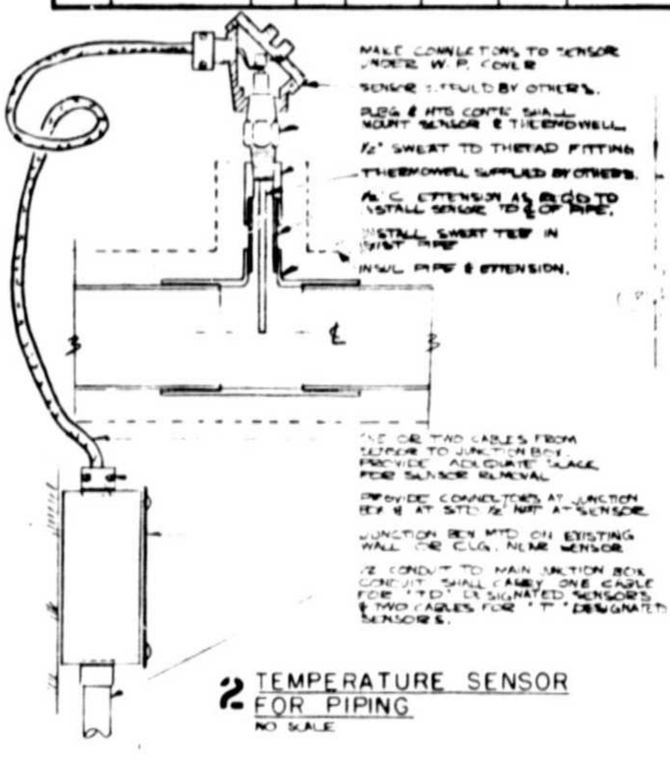
TEMPERATURE SENSORS FOR PIPING

Desc.	Name	Range (°F) Min.	Range (°F) Max.	Pipe	Pipe Size (Inches)	Sensor Size	
T100	Collector Array Inlet Temp.	30	220	Copper	2"	1/2"	
TD100	Collector Array Differential Temp.	0	50	Copper	2"	1/2"	
T101	Storage Tank Inlet Temp.	50	200	Copper	2"	1/2"	
TD101	Storage Tank Differential Temp. (+)	0	100	Copper	2"	1/2"	
T200	Storage Tank Upper Temp.	50	200	1/2" Tank Fitting	-	1/2"	
T201	Storage Tank Center Temp.	50	200	1/2" Tank Fitting	-	1/2"	
T202	Storage Tank Lower Temp.	50	200	1/2" Tank Fitting	-	1/2"	
T400	Heating Coil Outlet Temp.	50	250	Copper	2"	1/2"	
TD400	Heating Coil Differencital Temp.	0	50	Copper	2"	1/2"	
T500	Arkla Generator Outlet Temp.	150	250	Copper	2"	1/2"	
TD500	Arkla Generator Differential Temp.	0	50	Copper	2"	1/2"	
T501	Arkla Condenser Inlet Temp.	30	100	Copper	2"	1/2"	
TD501	Arkla Condenser Water Differential Temp.	0	50	Copper	2"	1/2"	
T502	Arkla Chilled Water Outlet	30	80	Copper	1-1/2"	1/2"	
TD502	Arkla Chilled Water Differential Temp.	0	30	Copper	1-1/2"	1/2"	
T103	Collector/Heat Exchanger Outlet Temperature	30	250	Copper	2"	1/2"	
TD103	Collector/Heat Exchanger Differential Temperature	0	150	Copper	2"	1/2"	



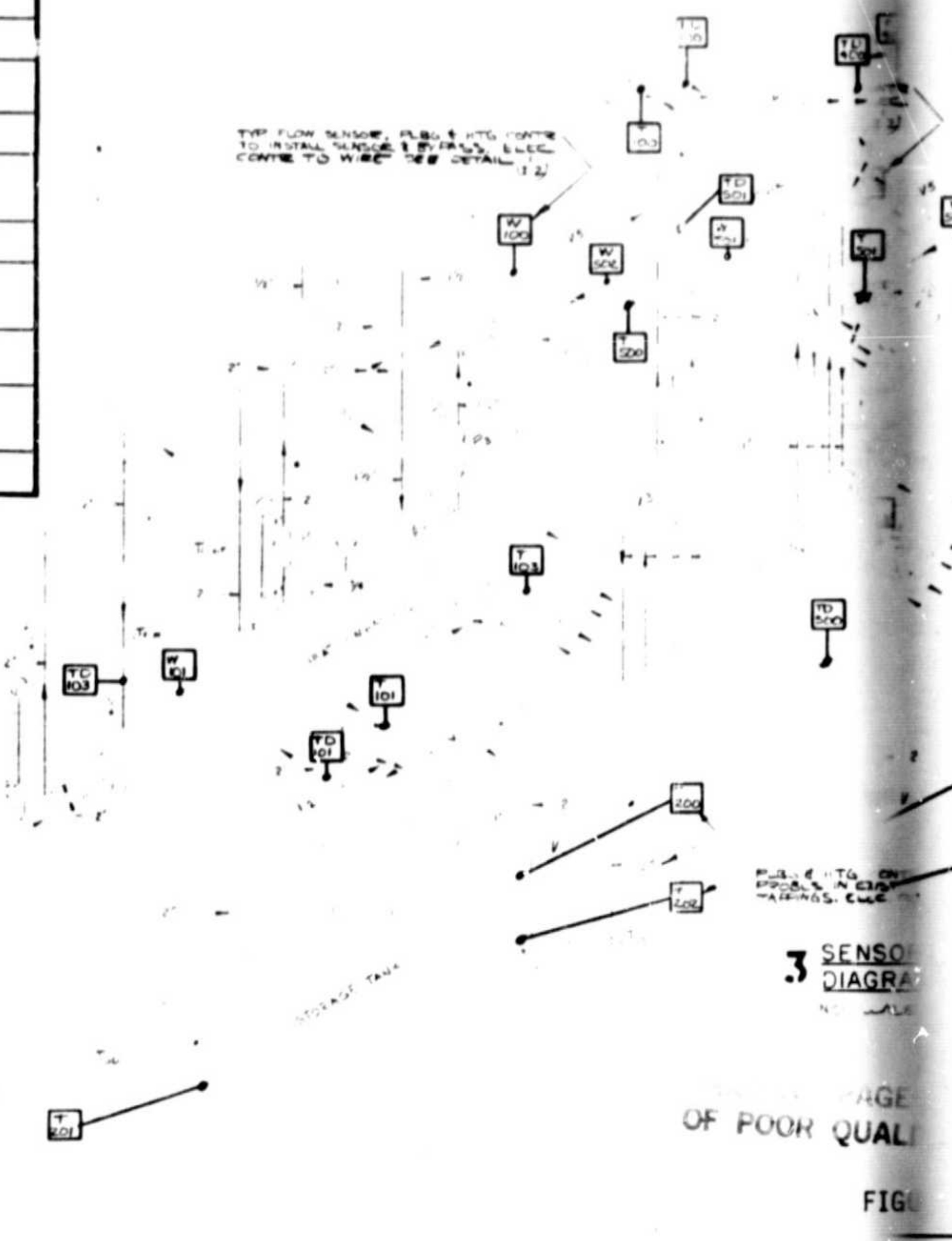
1 FLOW SENSOR FOR PIPING

NO SCALE



2 TEMPERATURE SENSOR FOR PIPING

NO SCALE

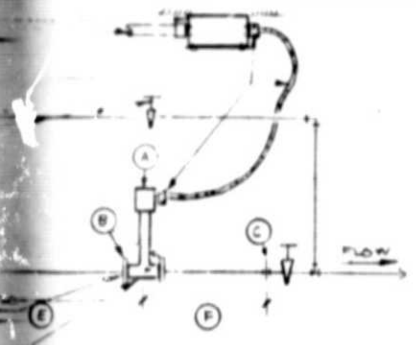


3 SENSOR DIAGRA...

OF POOR QUALI...

FIG...

FOLDOUT FRAME 1



LOW SENSOR
OR PIPING

FLOW SENSORS FOR PIPING											
Desc.	Name	Range (GPM) Min.	Design.	Max.	Pipe Type	Flow Meter Type & Size A	B	C	D	E (Min.)	F (Min.)
W100	Collector Array Flow Rate	20	33	50	Copper	2" Flanged	2-2" Sweat Flanges W/4-4"x5/8" Bolts	Not Required	2"	20"	10"
W101	Storage Tank Supply Flow Rate	20	33	50	Copper	2" Flanged	2-2" Sweat Flanges W/4-4"x5/8" Bolts	Not Required	[illegible]	20"	10"
W501	Arkla Condensing Water Flow Rate	20	36	50	Copper	2" Flanged	2-2" Sweat Flanges W/4-4"x5/8" Bolts	Not Required	2"	20"	10"
W502	Chilled Water Flow Rate	15	23	35	Copper	1-1/2" Threaded	2-1-1/2" Sweat to Threaded Nipples	1-1/2" Union	1-1/2"	15"	8"
F400	Fuel Flow to Multizone Heating Unit	0 - 5 G.P.H.			Copper	1/2" Threaded	2-1/2" Sweat to Threaded Nipples	1/2" Union	1/2"	6"	4"

GENERAL NOTES

1) [illegible] PROVIDE FOR THE INSTALLATION OF A DATA ACQUISITION SYSTEM FOR THE MOUNT RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM. THE ADDITION OF THESE ITEMS DOES NOT & SHALL NOT AFFECT THE ORIGINAL SYSTEM'S OPERATION.

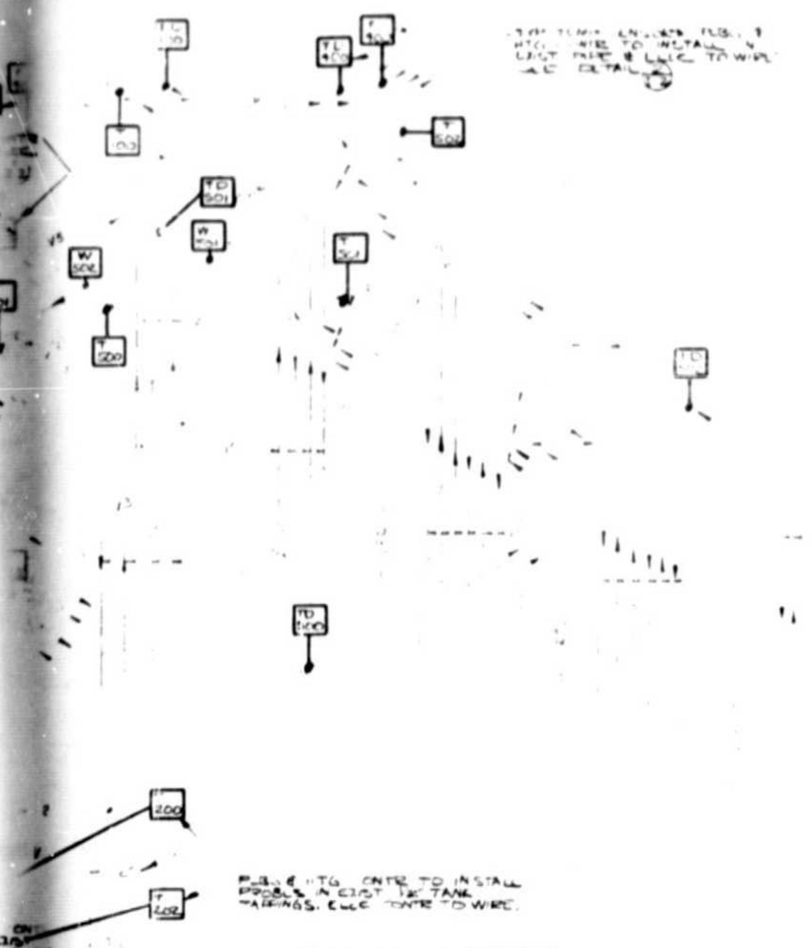
2) PRODUCTS & MATERIALS USED FOR THE INSTALLATION OF THIS INSTRUMENTATION SHALL BE THE SAME AS & OR COMPATIBLE W/ THOSE USED IN THE ORIGINAL SYSTEM & IN THAT SPECIFICATION MANUAL.

3) ALL WORK [illegible] SHALL BE DONE IN A NEAT & [illegible] WAY TO OBTAIN A QUALITY PRODUCT.

4) PORTIONS OF THE WORK HEREIN APPLY TO THE PLUMBING & HEATING CONTRACTOR, THE VENTILATION CONTRACTOR, & THE ELECTRICAL CONTRACTOR. EACH SHALL DO THE WORK SO NOTED [illegible] TO HIM.

5) WHERE IN THE ELECTRICAL CONTRACTOR'S NOTES [illegible] SHALL MEAN [illegible] SHIELDED UL APPROVED. [illegible] SHALL BE [illegible] 7718 [illegible], ALPHA 2424 OR EQUAL & APPROVED.

6) WHERE [illegible] IS NOTED HEREIN, SAME SHALL MEAN E.R.D.A. ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION. E.R.D.A. SHALL PROVIDE A COMPLETE WIRING DIAGRAM INDICATING SENSOR WIRING CONNECTIONS & MAIN JUNCTION BOX WIRING CONNECTIONS.



3 SENSOR LOCATION DIAGRAM

NO SCALE

OF POOR QUALITY

FIGURE 7 - Shows flow sensors for piping

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM

MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA

INSTRUMENTATION

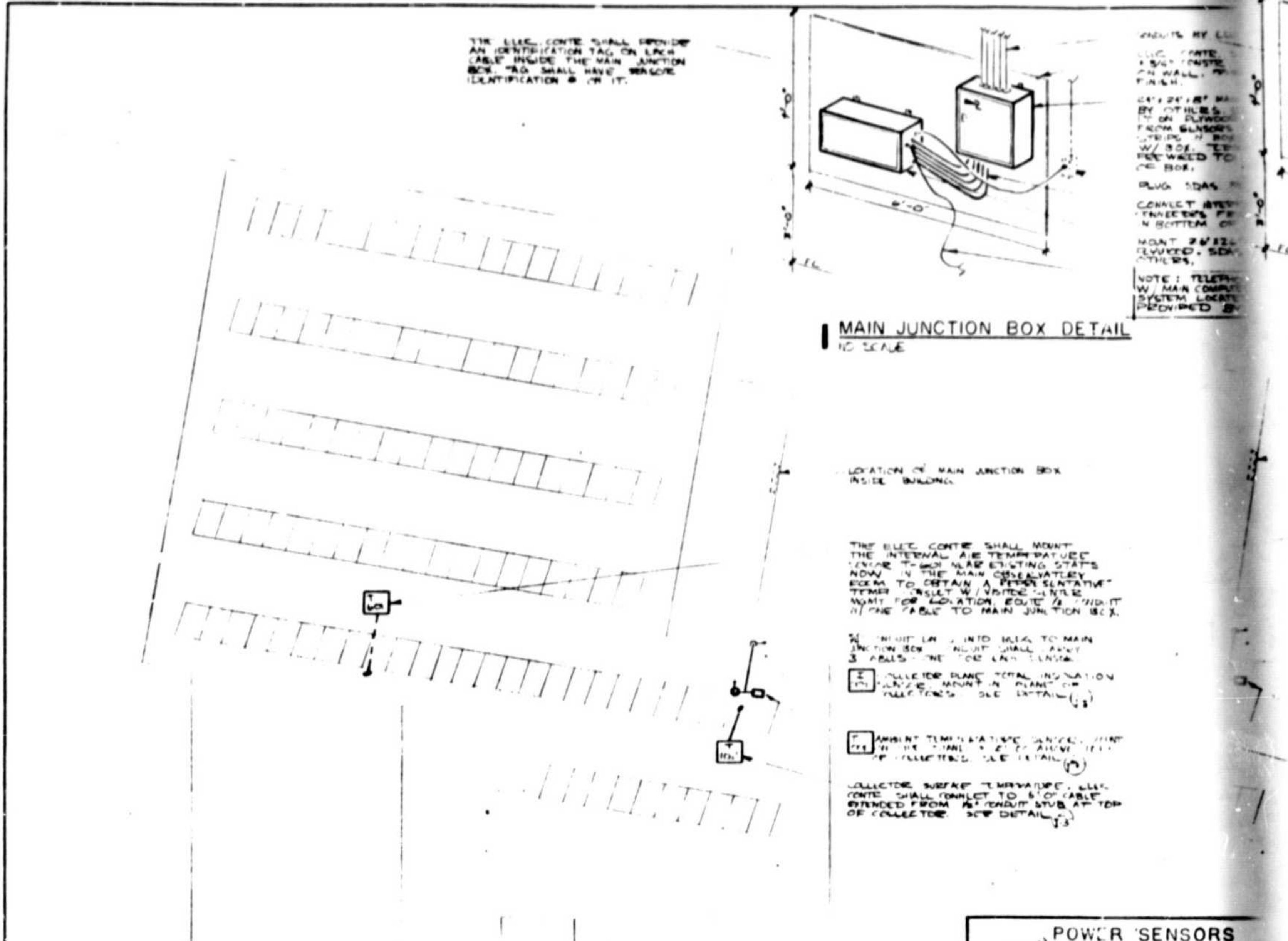
DRAWN BY SCHMIDT | CHECKED BY D.L.R.

PROJECT NO 6114.3 | DATE 1/28/77

The Spitznagel Partners Inc.

I-2 OF 3

2 FOLDOUT FRAME



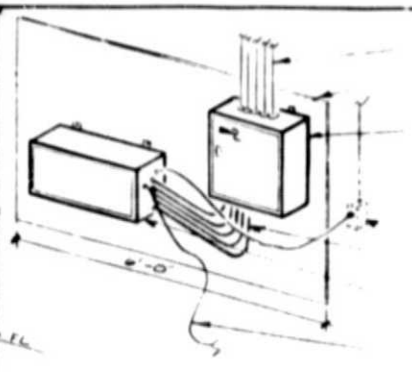
ROOF PLAN - INSTRUMENTATION

SCALE: 1/8" = 1'-0"

FIGURE 8 - Shows roof plan-instrumentation

POWER SENSORS				
Desc.	Name	Phase	Volts	Amps
CP101	Collector Pump & Purge Unit Fan Power P-1	3 3	208 208	
CP201	Storage Pump Power P-2	1	115	
CP503	Cooling Tower Pump Power P-[illegible]	1	115	
CP501	Solar Space Cooling Operating Energy which includes:			
	Cooling Tower Fan Power	1	115	
	Three Arkla Units Operating Power	1	115	
	Chilled Water Pump Power P-[illegible]	1	115	
CP502	Observation A/C Room [illegible] Blower A/C Unit & Air Blower Power	3 3	208 208	45
CP504	Multizone A/C Unit Power	3	208	70
CP601	Multizone Heating Unit Power (Fuel Oil Pump & Burner)	1	120	
CP602	Multizone Cooling & Heating Air Blower Power	3	208	

FOLDOUT FRAME



CONDUITS BY ELEC CONTR FROM SENSORS.

ELEC CONTR SHALL FURNISH A 4'-0" x 4'-0" x 3/4" CONSTR GRADE PLYWOOD & MOUNT ON WALL. PRIME & PAINT W/ WHITE GLOSS FINISH.

24" x 24" x 8" MAIN JUNCTION BOX PROVIDED BY OTHERS. ELEC CONTR SHALL MOUNT IT ON PLYWOOD & MAKE FINAL CONNECTIONS FROM SENSORS TO NUMBERED TERMINAL STRIPS IN BOX. WIRING DIAGRAM SUPPLIED W/ BOX. TERMINAL STRIPS ARE PREWIRED TO CONNECTORS IN BOTTOM OF BOX.

PLUG SDAS POWER INTO EXIST OUTLET.

CONNECT INTERFACE CABLES W/ PREWIRED CONNECTORS FROM S.D.A.S. INTO CONNECTORS IN BOTTOM OF MAIN JUNCTION BOX.

MOUNT 26" x 26" x 12" SDAS MODULE ON PLYWOOD. SDAS MODULE SUPPLIED BY OTHERS.

NOTE: TELEPHONIC CONNECTION & LINE W/ MAIN COMPUTER DATA PROCESSING SYSTEM LOCATED ELSEWHERE IS PROVIDED BY OTHERS.

1 MAIN JUNCTION BOX DETAIL
NO SCALE

LOCATION OF MAIN JUNCTION BOX INSIDE BUILDING.

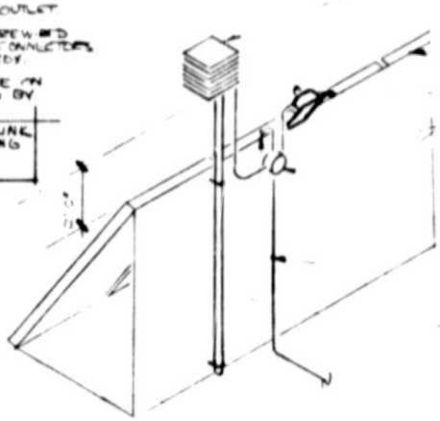
THE ELEC CONTR SHALL MOUNT THE INTERNAL AIR TEMPERATURE SENSOR T-600 NEAR EXISTING STATS NOW IN THE MAIN OBSERVATION ROOM TO OBTAIN A PROPER SENSOR TEMP. CONSULT W/ VISITOR CENTER MGMT FOR LOCATION. ROUTE IN CONDUIT W/ ONE CABLE TO MAIN JUNCTION BOX.

3/4" CONDUIT LINES INTO BLDG TO MAIN JUNCTION BOX. CONDUIT SHALL CARRY 3 CABLES ONE FOR EACH SENSOR.

COLLECTOR PLANE TOTAL INSOLATION SENSOR. MOUNT IN PLANE OF COLLECTORS. SEE DETAIL.

AMBIENT TEMPERATURE SENSOR. MOUNT IN THE SHADE ABOVE TOP OF COLLECTORS. SEE DETAIL.

COLLECTOR SURFACE TEMPERATURE. ELEC CONTR SHALL CONNECT TO 6' OF CABLE EXTENDED FROM 3/4" CONDUIT STUB AT TOP OF COLLECTOR. SEE DETAIL.



AMBIENT TEMPERATURE SENSOR BY OTHERS. ELEC CONTR SHALL MOUNT ABOVE ON 1/2" SCHEDULE 40 GALV PIPE. PIPE SHALL BE ANCHORED SECURELY TO COLLECTOR SUPPORT. ELEC CONTR SHALL ROUTE THE CABLE IN 3/4" CONDUIT TO W.P. JUNCTION BOX.

COLLECTOR ON ROOF (TYP.)

INSOLATION SENSOR BY OTHERS. ELEC CONTR SHALL MOUNT SENSOR ON A PLATE STEEL SUPPORT. SUPPORT SHALL BE BOLTED INTO PLACE SO THAT THE SENSOR IS IN THE SAME PLANE AS THE COLLECTOR SURFACE & NOT SHADOWED BY ANY EQUIPMENT OR SUPPORTS. ELEC CONTR SHALL ROUTE THE CABLE IN 3/4" CONDUIT TO W.P. JUNCTION BOX.

W.P. JUNCTION BOX ANCHORED SECURELY TO COLLECTOR SUPPORT.

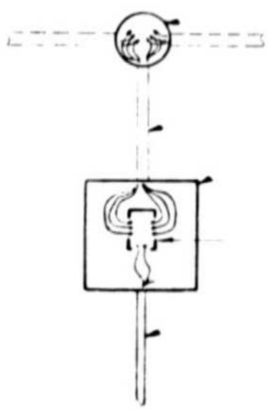
3/4" CONDUIT W/ 3 CABLES TO MAIN JUNCTION BOX IN BLDG. ANCHOR CONDUIT SECURELY.

COLLECTOR SURFACE TEMP SENSOR & 5'-0" PIGTAIL BY OTHERS. ROUTE PIGTAIL IN CONDUIT TO W.P. JUNCTION BOX.

2 ROOF INSTRUMENTATION
NO SCALE

Desc.	Name	Phase	Volts	Amps	Power	Sensor Model No.
CP101	Collector Pump & Purge Unit Fan Power P-1	3 3	208 208		1/2 HP 1 HP	PC5-5
CP201	Storage Pump Power P-2	1	115		1/6 HP	PC5-1
CP303	Cooling Tower Pump Power P-	1	115		1/2 HP	PC5-10
CP501	Solar Space Cooling Operating Energy which includes:					PC5-19
	Cooling Tower Fan Power	1	115		1/3 HP	
	Three Arkla Units Operating Power	1	115		250 Watts/unit	
	Chilled Water Pump Power P-3	1	115		1/3 HP	
CP502	Observation A/C Room Blower A/C Unit & Air Blower Power	3 3	208 208	45	9360 Watts 3 HP	PC5-51
CP504	Multizone A/C Unit Power	3	208	70	15 HP	PC5-53
CP601	Multizone Heating Unit Power (Fuel Oil Pump & Burner)	1	120		1/4 HP	PC5-1
CP602	Multizone Cooling & Heating Air Blower Power	3	208		3 HP	PC5-14

POWER SENSORS



EXIST JUNCTION BOX OR NEW JUNCTION BOX IN EXIST CIRCUIT. ELEC CONTR SHALL INTERCEPT POWER WIRES & ROUTE SAME SIZE WIRES THRU NEW CONDUIT TO POWER SENSOR.

CONDUIT SIZE PER NEC.

NEMA 1 ENCLOSURE BY ELEC CONTR. MOUNT ENCLOSURE ON WALL OR CLG NEAR JUNCTION BOX. MOUNT POWER SENSOR INSIDE BOX & MAKE ELEC CONNECTIONS REQD.

POWER SENSOR SUPPLIED BY OTHERS.

3/4" CONDUIT W/ ONE CABLE TO MAIN JUNCTION BOX.

3 POWER SENSORS FOR WIRING
NO SCALE

NORTH

MT. RUSHMORE VISITOR CENTER SOLAR ENERGY SYSTEM
MOUNT RUSHMORE NATIONAL

PROJECT NO 6114.3

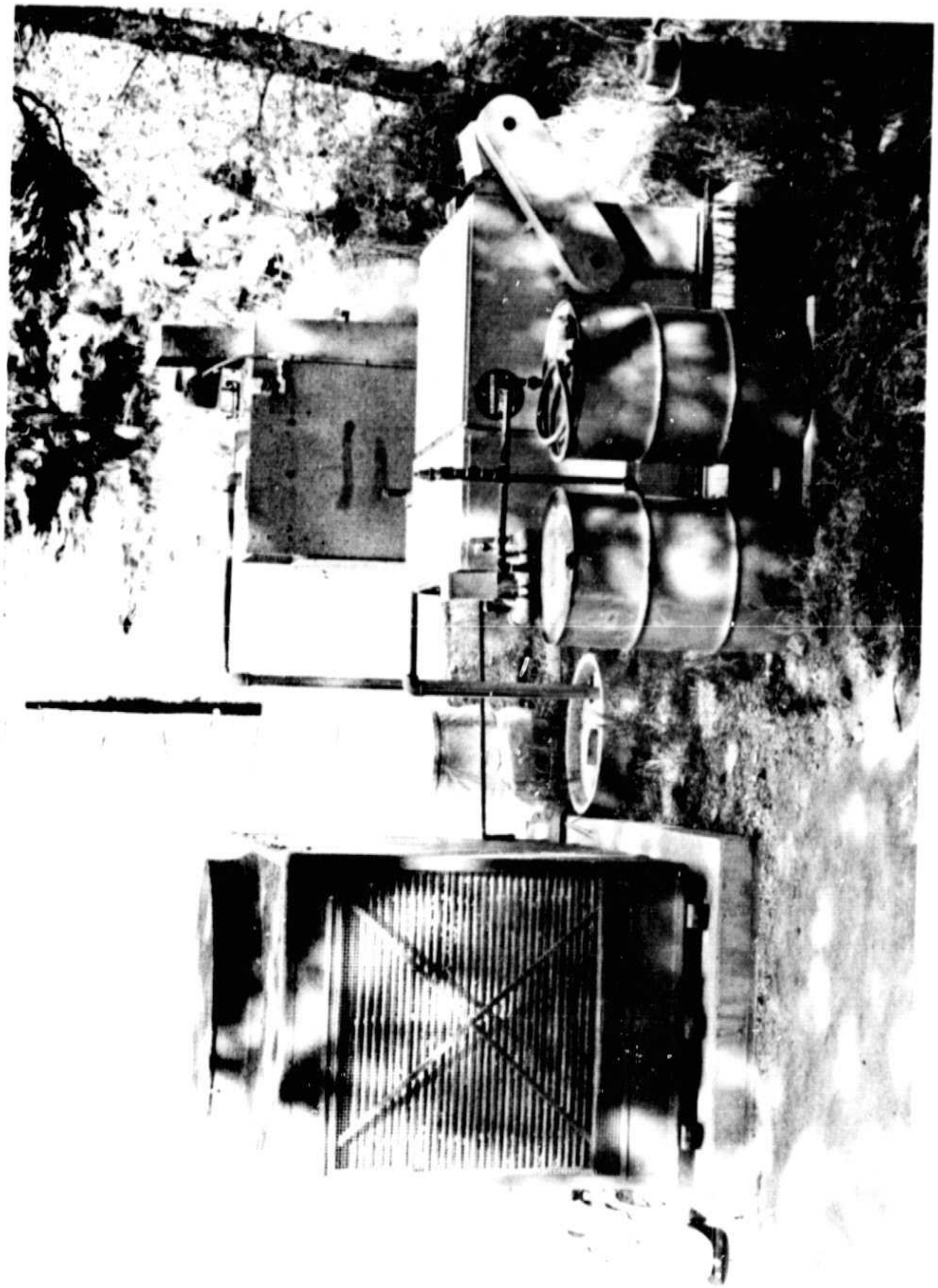
SCHMIDT

FOLDOUT FRAME 2

4. Operation and Maintenance Manual

Due to the fact that the O & MM is too bulky to make a part of this report for many reproductions, three complete copies of this manual are available at the following locations. One is located at the site of Mount Rushmore Visitor's Center; one as contractor's file at MSFC: and one in the office of Dr. C. W. Chiang, Mechanical Engineering Department, South Dakota School of Mines and Technology, Rapid City, SD 57701.

5. Pictures of final installation.



PURGE UNIT AND EXISTING COOLING TOWER

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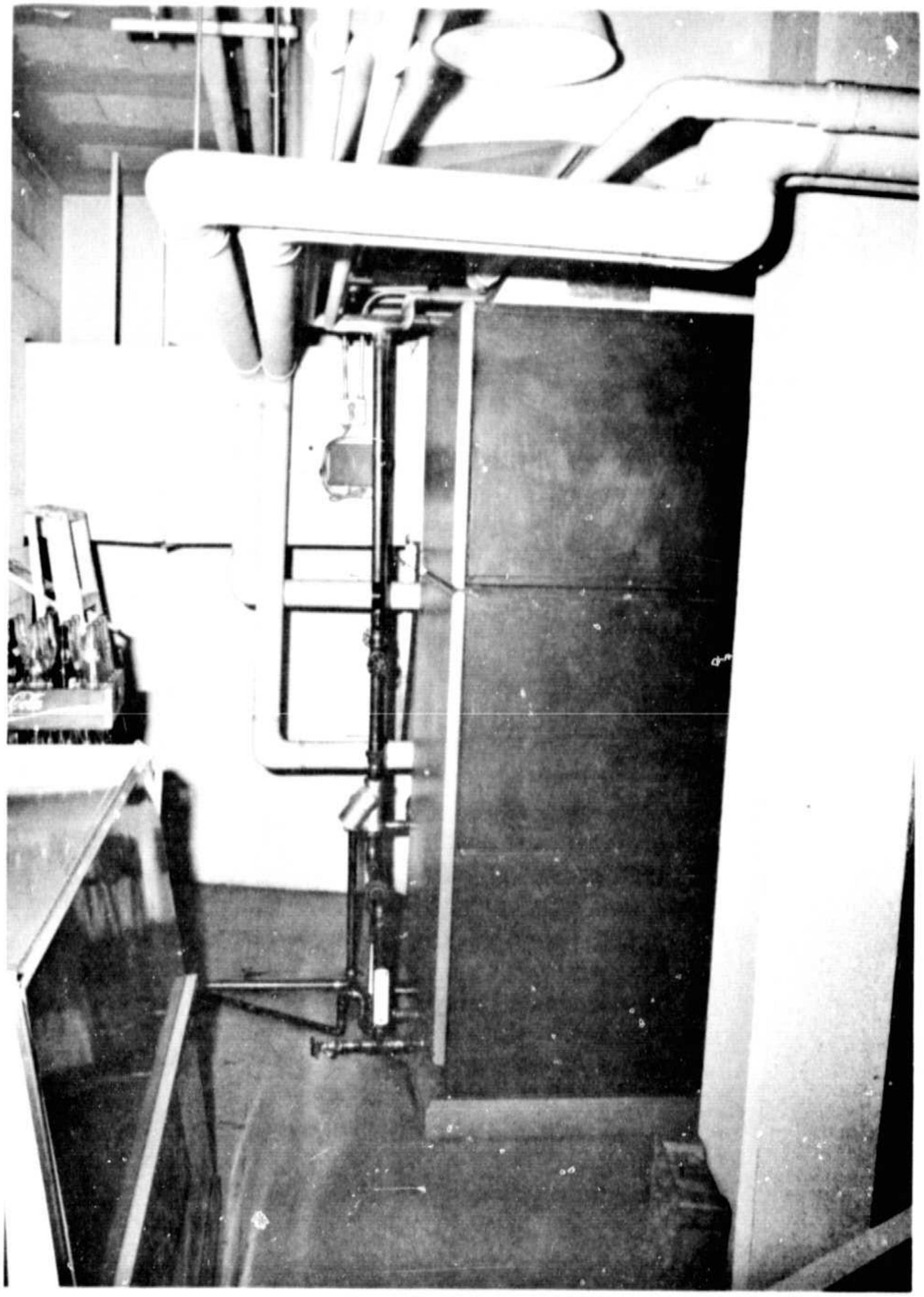
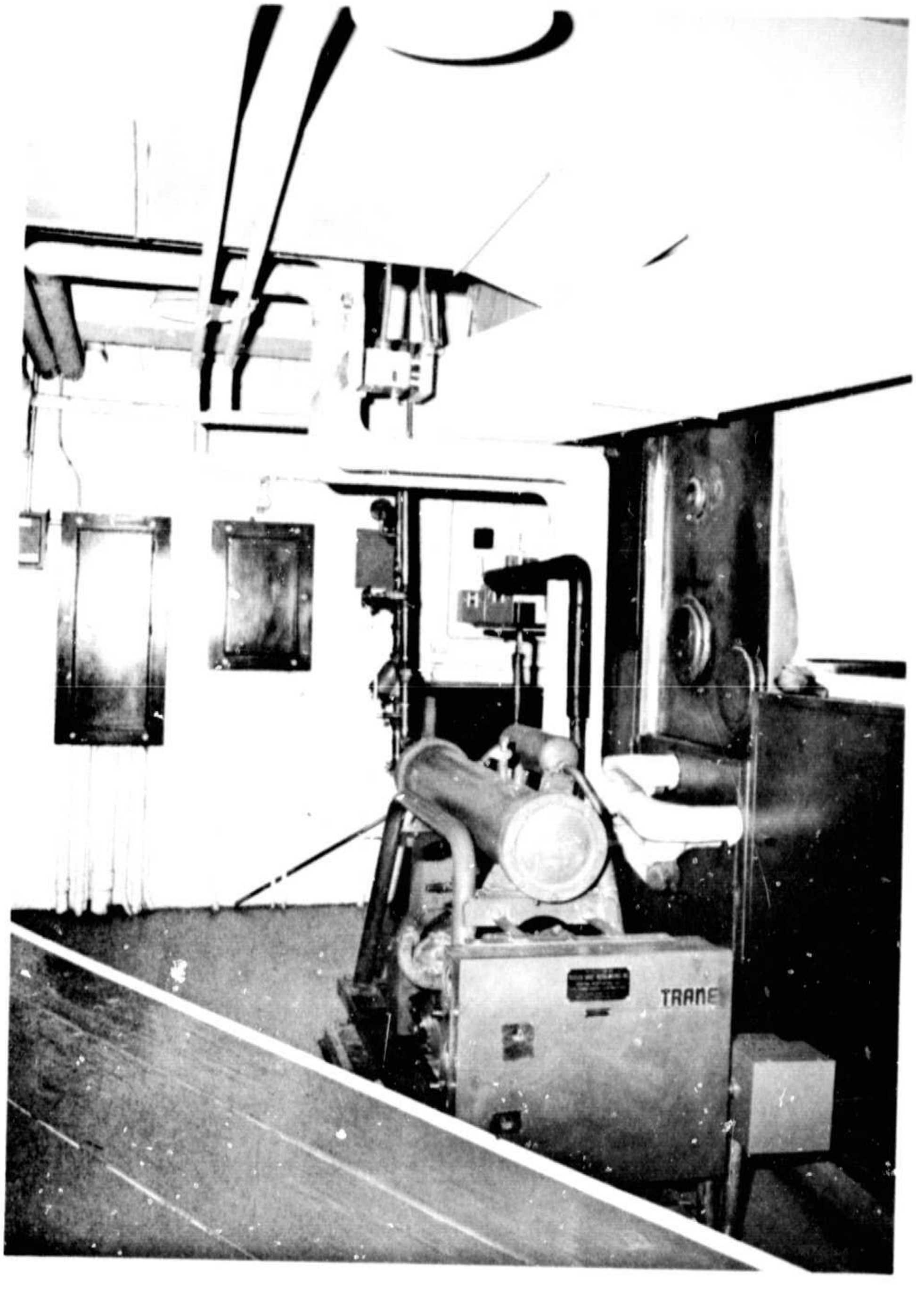
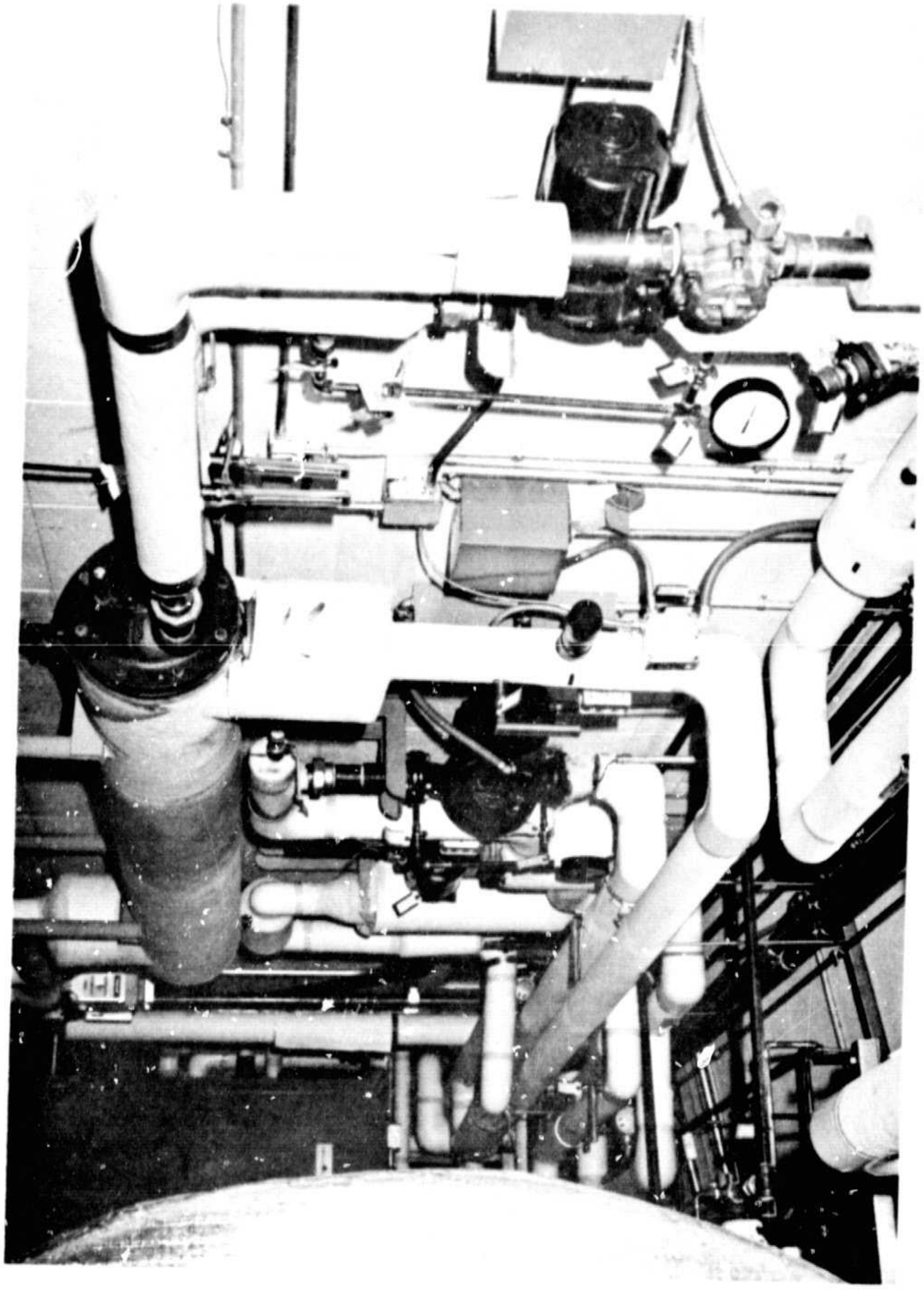


COOLING COIL AND PIPING TO EXISTING AIR HANDLING UNIT



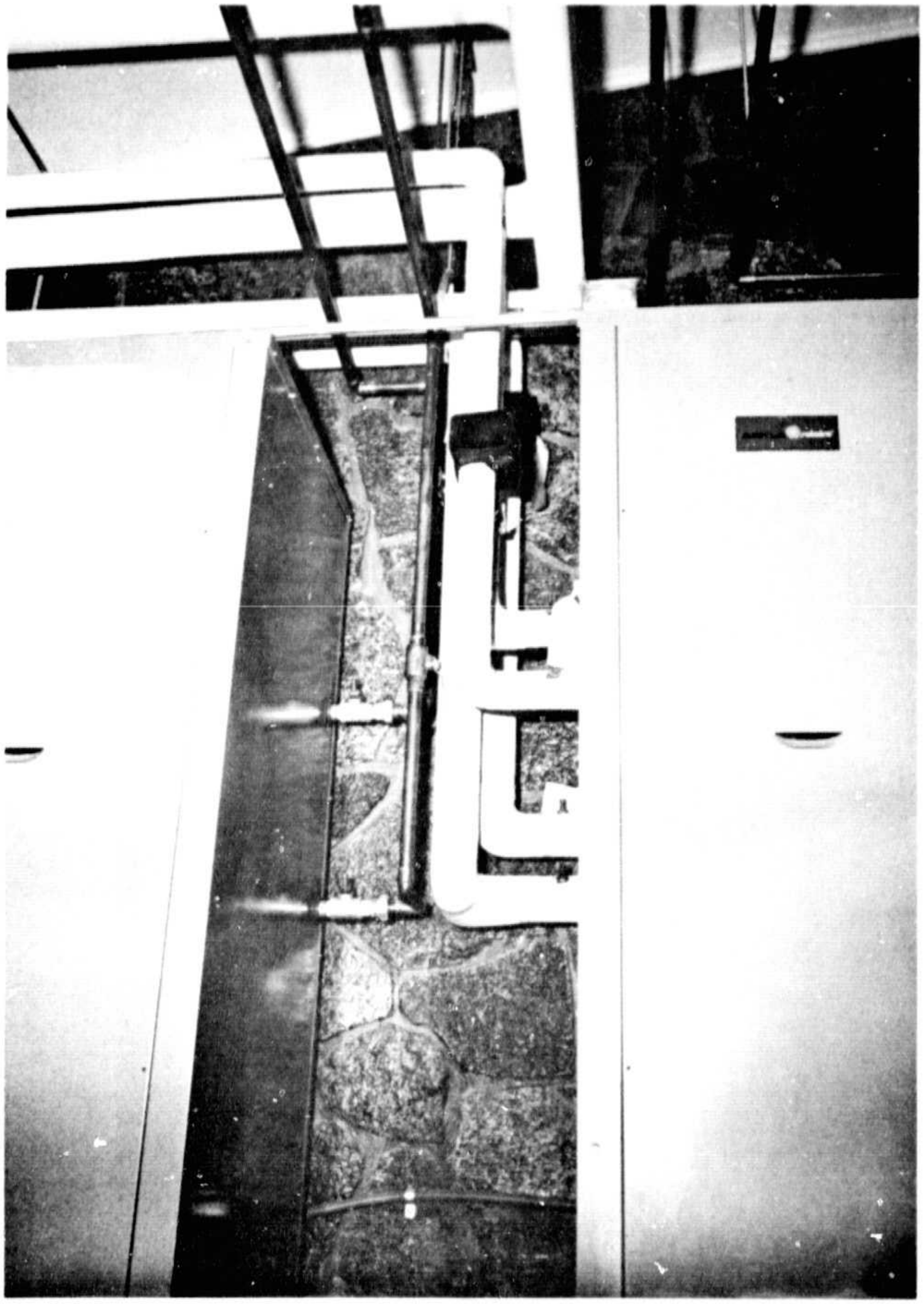
HEATING COIL WITH PIPING IN VALVE LEADING
TO EXISTING FURNACE



HEAT EXCHANGERS, PUMPS AND PIPING AT THE RIGHT
PART OF STORAGE TANK AT THE LEFT

ROOM ADDITION HOUSING

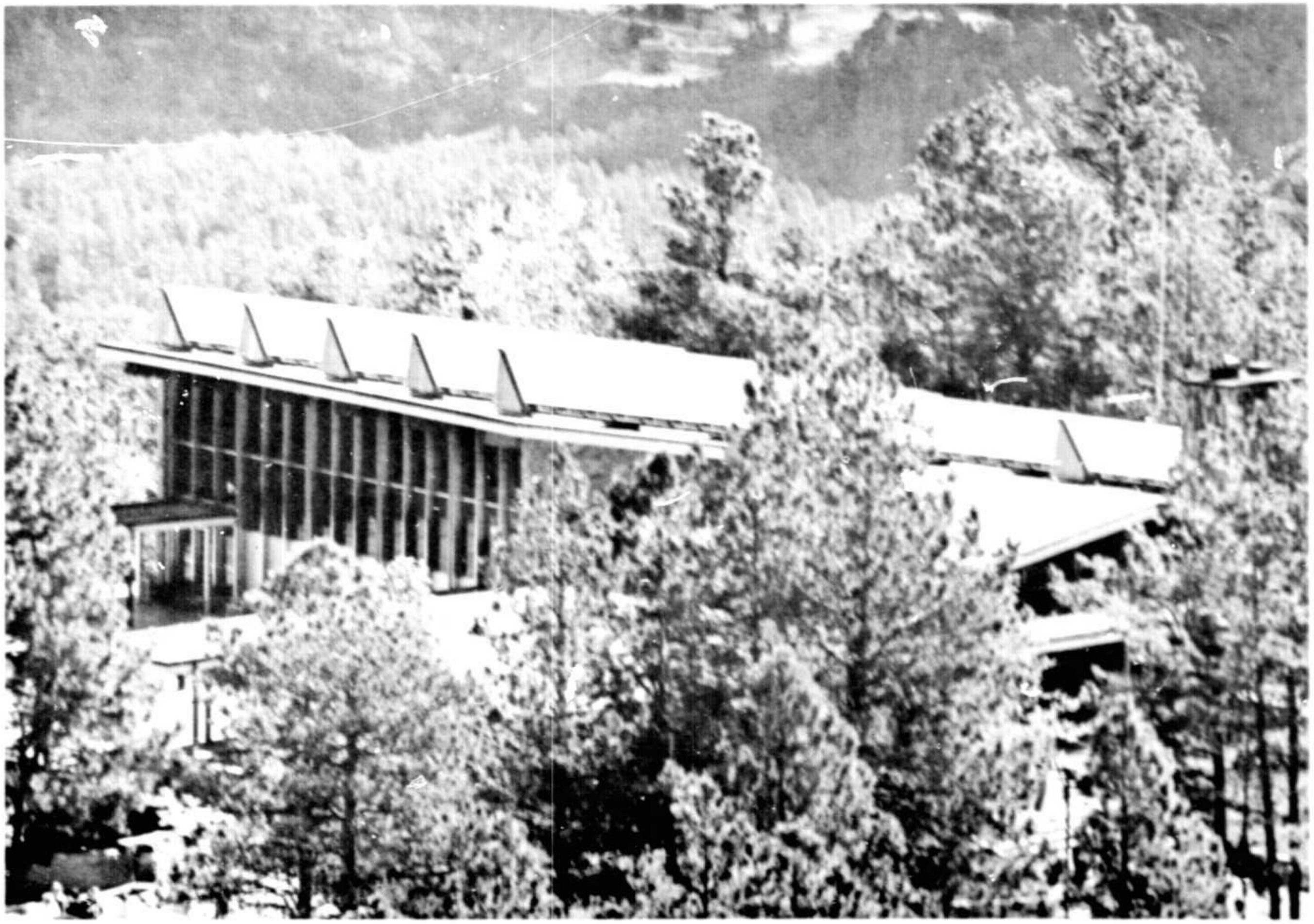
STORAGE TANK AND MECHANICAL SYSTEMS



TWO OF THE THREE ARKLA UNITS WITH PIPING

COLLECTORS WITH PIPING ON THE ROOF

COLLECTORS ON THE ROOF
SIDE VIEW



View of Complete Collector Arrays on the roof of Mount Rushmore Memorial Visitor Center

6. Predicted System Performance Data

Heating load calculations indicate a maximum heating load of 400,000 Btu/hr for severe winter, as shown by Table B. 3-1. The total fuel consumed in FY 1975 was 8721 gallons of No. 2 oil. Assuming a heating value of 140,000 Btu/gal and a furnace efficiency of 50 percent due to the age of the furnace and an altitude of about one mile, the total conventional heat supplied was about 6.1×10^8 Btu.

Load calculations of the observatory room indicate a cooling load of 15-ton refrigeration needed as shown by Table B. 3-2. Solar energy system calculations were based on climatological data of Rapid City supplied by the National Oceanic and Atmospheric Administration (NOAA). The climatological conditions at Mount Rushmore (25 miles southwest and 2000 feet higher than Rapid City) are more favorable due to the altitude and lack of pollution in the air, making these calculations conservative.

The calculations are based on 2000 ft^2 of Honeywell LSC-18-1 double-glazed collectors tilting at a slope of 45.7 deg and facing 18.8 deg west of south. These angles are the result of mounting the collectors at 45 deg with respect to the roof, which has a slope of 9.3 deg facing 28 deg south of east. The collectors have a transmissivity absorptivity product of 0.84 and a heat loss coefficient of 0.68 Btu/hr-ft^2-°F. The fluid flow rate is taken to be 40 gpm. The heat demand of the building, based on the actual heating data, was taken to be 2900 $(70-T_{amb})$ Btu/hr. The heat available from the solar system was taken to be 500 $(T_{st}-90)_x$ + 500 $(T_{st}-T_{amb})$. (T_{st} = storage temperature, T_{amb} = outside temperature.) This assumes a heating coil design which allows 200,000 Btu/hr heating with 130°F water and no heating at 90°F and pre-heat coil for 10 percent ventilation. The heat capacity of storage was taken to be 32,000 Btu/°F. The solar insolation was calculat-

Table B. 3-1. Heating Load Calculation

Room Name	Dimension ft x ft	Infiltration ft	Glass ft^2	Wall ft^2	Roof ft^2	Floor ft^2	Btu/hr	Factor	Subtotal Btu/hr
102 Elect. vault	8x12			64		96	1990 192		2182
103 Storage	12x12	20	30	96		144	1260 1560 2980 290		6090
104 Work Room	20x38	60	110	460		760	3780 5720 14260 1520	10%	27,800
107 Work Room	25x14	52	64	413		350	3280 3330 12800 700		20,110
108 Women toilet room	13x5			54		65	1675 130		1805
110 Men toilet room	13x5			54		65	1675 130		1805
201 Men toilet room	28x12	44		468	366	366	2770 14500 4020 740	10%	24,230
202 Observatory	57x35	70	1360	550		2000	4400 70700 17000 22000	15%	135,800
203 Office	20x20	40	70	430	400		2520 3640 13300 4400	10%	26,440
204 office	13x14	40	53	90	182		2520 2760 2790 2000		10,070

Table B. 3-1. Heating Load Calculation (Concluded)

Room Name	Dimension ft x ft	Infiltration ft	Glass ft^2	Wall ft^2	Roof ft^2	Floor ft^2	Btu/hr	Factor	Subtotal Btu/hr
205 office	17x15	20	53	135	255		1260 2760 4190 2805		11,015
208 office	13x11	40	56	136	143		2520 2910 4230 1570		11,230
210 office	12x12	20	32	112	144		1260 1660 2470 1585		7975
211 office	12x16	40	48	204	192		2520 3400 6330 2100		14,360
212 audio control	4x7			48	28		1485 3080		4565
213 lobby	36x44	154	470	550	1660	1660	9700 24400 17050 18300 3350		72,800
214 women toilet room	28x12	44		468	366	366	2770 14500 4020 740		22,030
215 janitor closet	5x5			45	25	25	1345 275 50		1670
							Total		401,977

Table B. 3-2. Cooling Load Calculation

Room 202 observatory:

Design conditions

Outside temp - 95°F, inside temp - 80°F, difference - 15°F

Outside walls: (sq ft)

Side	Glass	Net wall
North	150	450
West	1200	

Cooling load: BTU/HR

Items	Sensible	Latent	Remarks
Sensible heat gain thru glass			
150 sq. ft. x 23 Btu/ft^2/hr	3,450		
(22-3.5) x 54 x 140	140,000		3.5 ft approx. shading solar heat gain approx 140 Btu/ft^2/hr 4:00 pm July 21
Transmission gain			
Walls 450 sq ft x .20 (factor) x 15 (ΔT)	1,350		
Roof 2000 x .80 x 15	24,000		
Internal heat gain: People & lights			
People: No. 40 x Sensible factor 200	8,000		
People: No. 40 x Latent factor 250		10,000	
Lights: 5000 watts x 3.4	17,000		
Total	149,800	10,000	

Ventilation or infiltration

450 CFM x 1.08 x 35 = 17,000 Sensible

450 CFM x 1.08 x $\frac{35}{3}$ = 5,700 Latent

Total load = 149800 + 10,000 + 17,000 + 5,700 = 182,500 Btu/hr

or $\frac{182,500}{12,000} \approx 15$ tons ed by multiplying a typical direct sunlight reading in Rapid City of 290 Btu/hr-ft^2 by a geometrical factor and also multiplied by the percentage sunlight for the particular day. The geometrical factor was the scalar product of the normal to the collector surface with the sun's rays expressed as a function of tilt of the earth's axis, local latitude, slope of the roof, orientation of the building, slope of the collector with respect to the roof, day of the year and time of day. The geometric factor also includes the shading effect of adjacent collectors.

The model was run using the climatological data for 1971-1974. The results shown in Table B.3-3 are for a typical day using the average high and low temperatures for that month and assuming 100 percent sunshine. This total is multiplied by the average percentage sunshine for the month. This method of approximation was checked by detailed hour-by-hour calculation using February 1973, when the storage temperature dropped to nearly 80°F every night, and October 1973, when the storage temperature rose to around 160°F. In both cases the results were very close to the approximation; for February it was 3 percent low; for October the difference was less than 1 percent.

The percentage heating carried by the solar system is expected to be at least 53 percent since the atmospheric conditions at Mount Rushmore are more favorable than in Rapid City. Based on the current market price of $0.39 per gallon for No. 2 fuel oil, the savings amounts to about $1,710 of the $3,226 worth of fuel consumed in FY 1975.

Solar cooling calculations are based on 165,000 Btu/hr of heat delivered to the cooling units at 210°F from the collectors. The limiting conditions of ambient temperature, percentage sunshine and time of day under which the above criteria could be met were determined. The climatological

Table B. 3-3. Heating/Cooling Solar Contribution

Heating Based on 1971-74 climatological data for Rapid City								Cooling based on 1971 data			
Month	Percent Sunshine	T_{ave} °F	T_{max} °F	T_{min} °F	Q_{need} 10^6 Btu	Q_{solar} 10^6 Btu	Monthly total 10^6 Btu	Cooling Hrs	Cooling °days	Solar Cooling Hrs	Solar Cooling °days
Jan	54.8	20.9	32.7	9.0	3.44	0.99	29.7				
Feb	63.0	27.0	38.9	15.1	3.01	1.33	39.8				
March	63.5	33.5	48.4	23.6	2.56	1.51	45.1				
April	52.0	44.9	57.2	32.5	1.77	1.18	35.3				
May	58.0	54.1	67.2	41.0	1.12	>1.12	33.6				
June	61.8	65.6	78.8	52.4	0.30	>0.30	9.0				
July	68.5	70.4	85.2	55.6				294	81	56	25
Aug	75.3	71.3	86.4	56.1				441	142	104	62
Sept	66.2	57.9	72.4	43.4	0.85	>0.85	25.5	567	284	112	98
Oct	65.2	48.2	61.7	34.8	1.53	1.46	43.8	186	43	62	40
Nov	55.3	33.6	44.6	22.5	2.54	1.07	32.1				
Dec	60.3	24.1	35.6	12.5	3.21	0.99	29.7				
Total	62.2						323.6	1488	550	334	225

Heating contribution $= \frac{3.24\times10^8}{6.1\times10^8} = 53$ percent

Cooling contribution $= \frac{225}{550} = 41$ percent data of 1971 were then examined to determine the number of hours that the limiting conditions were exceeded when there was also a demand for cooling in the observatory. This is recorded in Table B. 3-3 as the number of solar hours of cooling. The total number of hours of cooling demand and the number of cooling degree days are also in that table.

The number of degree days when the solar absorption units were operating was found. The percentage of solar cooling was then figured by the ratio of solar degree days to cooling degree days.

$$\text{Percent solar} = \frac{\text{Solar degree days}}{\text{Cooling degree days}} \times 100$$

The savings from solar cooling can be approximated by assuming 334 hours of operation replacing a nine-ton conventional-type chiller with a coefficient of performance of 2.5. The savings is about 4230 kW-hr. At an estimated 3¢ per kW-hr, the saving amounts to about $127.00 per year.

7. Major problems encountered and resolutions thereto

One of the major problems is the air bubbles in the system. As explained in the operation of the system, constant venting with frequencies as much as once a week to prevent a buildup of temperatures and pressures was necessary. The main pump was originally designed at the flow rate of 30 gpm. It was felt that the higher flow rate could solve the problem of pressure buildup or air bubbles problem. A larger pump was installed with the flow rate of approximately 48 gpm. This seemed to solve the air bubble problem. The frequency of air venting has drastically reduced.

Another problem encountered was one transformer was struck by lightening on August 14, 1978. Because of this, the main pump had lost the electric power supply so that the stagnant ethylene glycol solution in the collector loop was overheated and turned into steam. It took more than two weeks to repair the transformer, recharge the system and get it back into operation. This situation rarely happens.

The third major problem encountered was the thermosiphoning. On the last day of 1978, the ambient temperature was extremely low and the cold antifreeze back-flowed into the main heat exchanger through a three way valve V4. Apparently there was a slight leakage through the three way valve V4 even though the three way valve was in a completely shut off position. The cold antifreeze back-flowed into the jacket of the main heat exchanger and froze the water inside the tube bundle. As a result, the cover plate of the main heat exchanger cracked about 5 to 6 inches; there were two cracked lines of about 3/4" in two tubes; and antifreeze began to leak out. The system was drained, the cracks on the tube bundle were brazed, and the cover plate was replaced. The whole system was down for about one month. A check valve was installed in the pipeline to prevent any future back-flow of antifreeze into the main heat exchanger.

The last major problem is the control adjustment. In particular, the cam of all three way valves needs fine readjustment such that the sequence of operations will follow closely.

8. <u>Lessons learned and recommendations</u>

From the major problem of frequent air venting encountered in the operation of the system, the biggest cause may be the wrong locations of the inlet and outlet tubings to each solar panel. The roof on which the collector banks are mounted is sloping towards the east, such that each collector bank axis is tilting toward the east. The outlet tubings are on the lower end of each panel, thus any vapor lock or air bubbles may stay in the upper header tube of each panel and can never escape. This was a negligence on the part of collector supplier in shipping panels which were not according to shop drawings. A lesson learned here was that a close check of the panels before installation could have avoided the frequent air venting problems.

The second lesson learned from this project is that positive stop valves should be used instead of leaky three way valves. With positive stop valves the problem of thermosiphoning of cold antifreeze into the main heat exchanger could have been avoided.

The third lesson learned is that some of the sensor locations should have been at different places to ensure more meaningful results. For example, the inlet and outlet water temperature sensors to collectors were placed too close to the three way valve, V4. When the water is not circulating in the collectors, the two sensors do not represent the true readings due to heat conduction from piping.

The fourth lesson learned is that the current control system is too complex. A slight mal-adjustment of the three way valve cam can easily cause malfunction of the operation sequence. A simpler control system is needed for the whole system such that any trouble-shooting will be much easier.

The last lesson learned from this project is a definite need of an on-site-monitor (OSM). During the last few months of operation, Mr. Val Fogle of Marshall Space Flight Center, NASA, Huntsville, Al (project monitor) helped install (on short loan basis) an on-site-monitoring system to the system. Through the OSM system, instant monitoring of various temperatures, flow rates, power requirement for various pumps and fans help understand and adjust the control sequence. Thus it enables us to know whether the system is in the right mode of operation.

9. The project manager, Dr. C. W. Chiang, of the South Dakota School of Mines has verified the following:

   a. The solar system was installed per the enclosed as-built drawing.

   b. The solar system met the acceptance test plan provisions.

   c. The solar system met the interim performance criteria (NBSIR-1187) requirements.