



Design Description of the Schuchuli Village Photovoltaic Power System

Anthony F. Ratajczak, Richard W. Vasicek,
and Richard DeLombard
National Aeronautics and Space Administration
Lewis Research Center

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U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Division of Solar Thermal Energy Systems

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ACRONYMS AND ABBREVIATIONS

DAT-3	automatic data recorder
DOD	depth-of-discharge
DOE	Department of Energy
DSB	Domestic Services Building
EEB	Electrical Equipment Building
EWS	electronic weather station
I/C	instrumentation and control
LeRC	Lewis Research Center
NASA	National Aeronautics and Space Administration
PCCIA	power collection, control and instrument assembly
PTUA	Papago Tribal Utility Authority
PV	photovoltaic
SOC	state-of-charge
T&A	Tests and Applications Project

SUMMARY

This report describes the engineering design of a stand-alone photovoltaic (PV) power system for the village of Schuchuli (Gunsight), Arizona, on the Papago Indian Reservation. This experimental solar power system project was funded by the Department of Energy and implemented by the National Aeronautics and Space Administration, Lewis Research Center, together with the United States Department of Health and Human Services, Public Health Service, Indian Health Service, Office of Research and Development, Office of Environmental Health, and the Papago Tribe of Arizona. The purpose of this experiment was to demonstrate that a stand-alone photovoltaic power system could provide dependable power for basic human needs in a remote village environment.

The power system was designed as a limited energy, all 120-V(d.c.) system to which loads cannot be arbitrarily added. The system consists of a 3.5-kW (peak) PV array, 2380 ampere-hours of battery storage, an Electrical Equipment Building, a 120-V(d.c.) electrical distribution network, and equipment and automatic controls to provide control power for pumping water into an existing water system; operating 15 refrigerators, a clothes washing machine, and a sewing machine in the Domestic Services Building; and lights for each of the homes and communal buildings. In addition, a solar hot water heater was provided to supply hot water for the washing machine and communal laundry. The system employs automatic control systems which provide voltage control by limiting the number of PV strings supplying power during system operation and battery charging, and load management for operating high priority loads at the expense of low priority loads as the main battery becomes depleted.

The engineering design of this system is presented in this report and includes loads profiles and loads descriptions; an explanation of the PV array and battery sizing methodology; descriptions of the mechanical designs; electrical designs and descriptions of the array, battery, controls, instrumentation and distribution system; and a discussion of safety features. The system was dedicated and began operation on December 16, 1978. The operational history and data are not contained in this report.

INTRODUCTION

The Department of Energy (DOE) is pursuing a National Photovoltaic Program aimed at developing cost effective photovoltaic (PV) power systems capable of providing a significant amount of the Nation's energy requirements with solar energy by the year 2000. In 1978, this program was divided into several projects, one of which is the Stand-Alone Applications Project which is being managed for DOE by the National Aeronautics and Space Administration Lewis Research Center (NASA LeRC).

The Stand-Alone Applications Project is intended to introduce PV power systems by several means to a wide range of potential users with near-term applications to accelerate their entry into the commercial market. Applications which indicate near-term cost effectiveness, technical feasibility, solar cell promotional value, and/or substantial use multiplication are considered for appropriate support. Based on these objectives, a photovoltaic power system for the village of Schuchuli (Gunsight), Arizona, on the Papago Indian Reservation was selected for implementation.

Participating in this joint experiment are: NASA Lewis Research Center; the United States Department of Health and Human Services, Public Health Service (PHS), Indian Health Service, Office of Research and Development, Office of Environmental Health; and the Papago Tribe of Arizona (PTA).

The Village of Schuchuli, with a population of approximately 96 people, is located in the far western part of the Papago Indian Reservation about 120 miles west of Tucson, Arizona, on State Highway 86 (see map, Figure 1). At the time the system design was developed, the village had 15 homes*--some "traditional" and some modern ranch style--a church, feast house, miscellaneous small structures and sheds, a large corral, and a water supply system. Prior to the installation of the PV power system, the village had no electrical service. The nearest available Papago Tribal Utility Authority utility line was approximately 17 miles from the village. The village water supply system consisted of two wells, one drilled (new well) and the other dug (old well, equipped with a gasoline powered pump used as standby); a positive displacement pump at the new well powered by a 7-hp. single cylinder, manual start diesel engine; 4- and 2-in. water distribution lines; and a 11,000-gallon-capacity steel water storage tank. This system served the villagers and their livestock. (See photograph of village, Figure 2.).

The new village PV power system is a limited energy, all 120-V(d.c.) system to which loads cannot be arbitrarily added. This stand-alone

*Three homes have since been added.

utility system consists of a 3.5-kW (peak) PV array, electrical storage batteries, an Electrical Equipment Building (EEB), a 120-V(d.c.) electrical distribution network, and equipment and automatic controls to provide central power for: pumping water for the existing water system; operating 15 refrigerators, a clothes washing machine, and a sewing machine in the Domestic Services Building (DSB); a solar hot water heater for the laundry; and lights in each of the homes and communal buildings (see block diagram of system, Figure 3 and Site and Location Plan, Appendix A, Drawing No. CF 56376). The selection of the specific appliances and services was made jointly among the participants and included inputs from the villagers. This system employs an automatic control system which provides voltage control and load management for operating high priority loads (refrigerator/freezers) at the expense of low priority loads (washing and sewing machines) as the main battery charge becomes depleted. Operation of the low priority loads is resumed as the main battery becomes recharged. The control system also provides voltage control during operation and battery charging by limiting the number of PV strings supplying power to the system. (Manufacturer equipment is listed in Appendix B.)

In general, NASA LeRC provided the PV power system, pump motor, appliances, solar hot water heater, and light fixtures together with construction management, system checkout, and instruction for operating personnel. The PHS provided for the mechanical hook-up of the motor to the pump, pump fence, and sanitary drainage for the EEB and DSB. The PTA provided the DSB (except electrical wiring) and interior electrical wiring of village homes, feast house, and church. Construction was done by the Papago Construction Company. The pole line power distribution system was provided and installed by the Papago Tribal Utility Authority. The installed cost of this system is approximately \$330,000.

The experimental phase of the project is scheduled for a 3-year period (approximately January 1979 to January 1982) following the installation and checkout of the system. During this period, the operation, maintenance, troubleshooting, and repairs will be shared by the PTA, PHS, and NASA LeRC. Daily, weekly, and monthly records of data and inspections are taken and analyzed. NASA LeRC performs site inspections at least twice a year. At the conclusion of the 3-year experimental period, the disposal of government property will be made based on negotiations with the PTA.

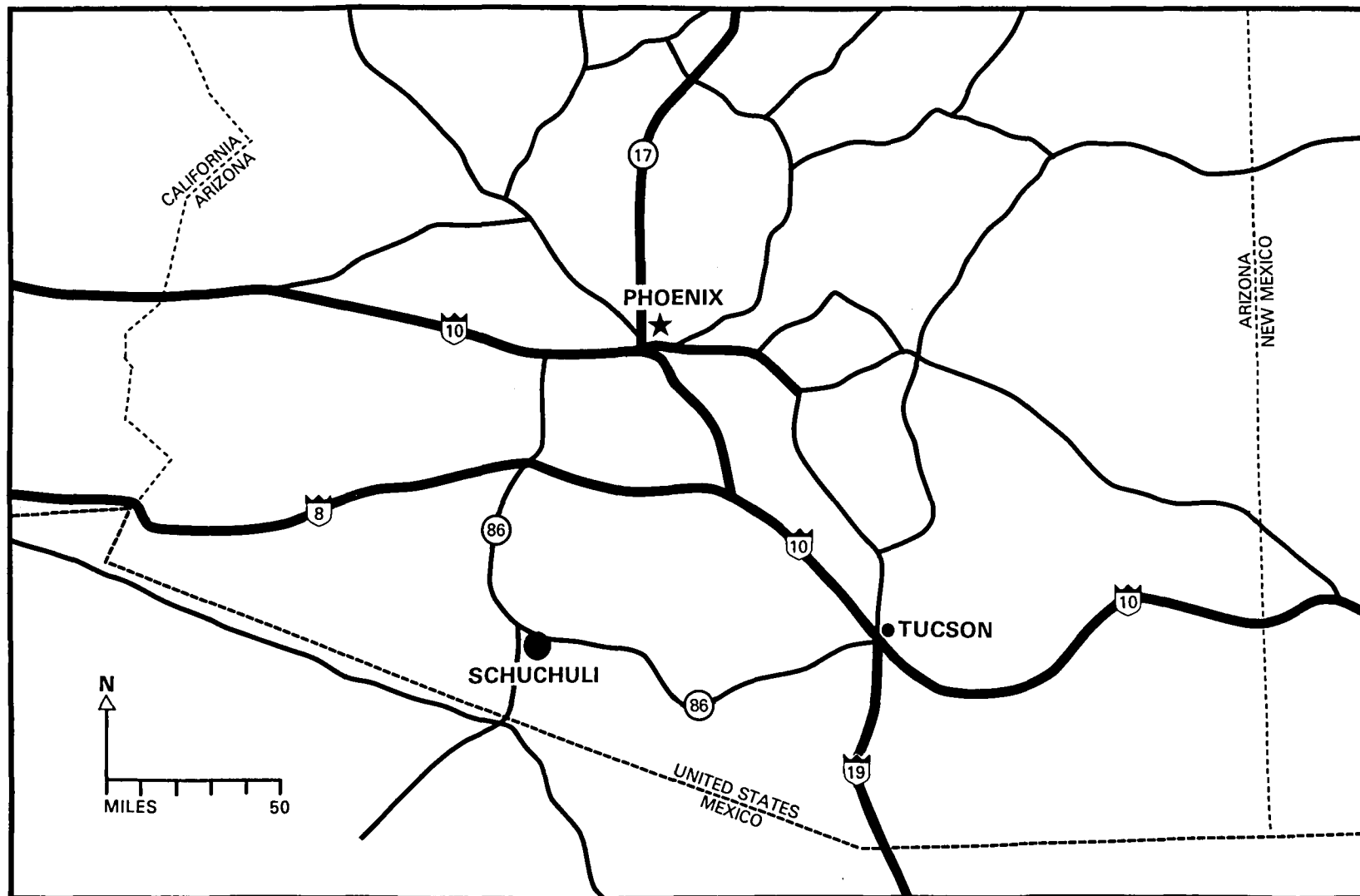
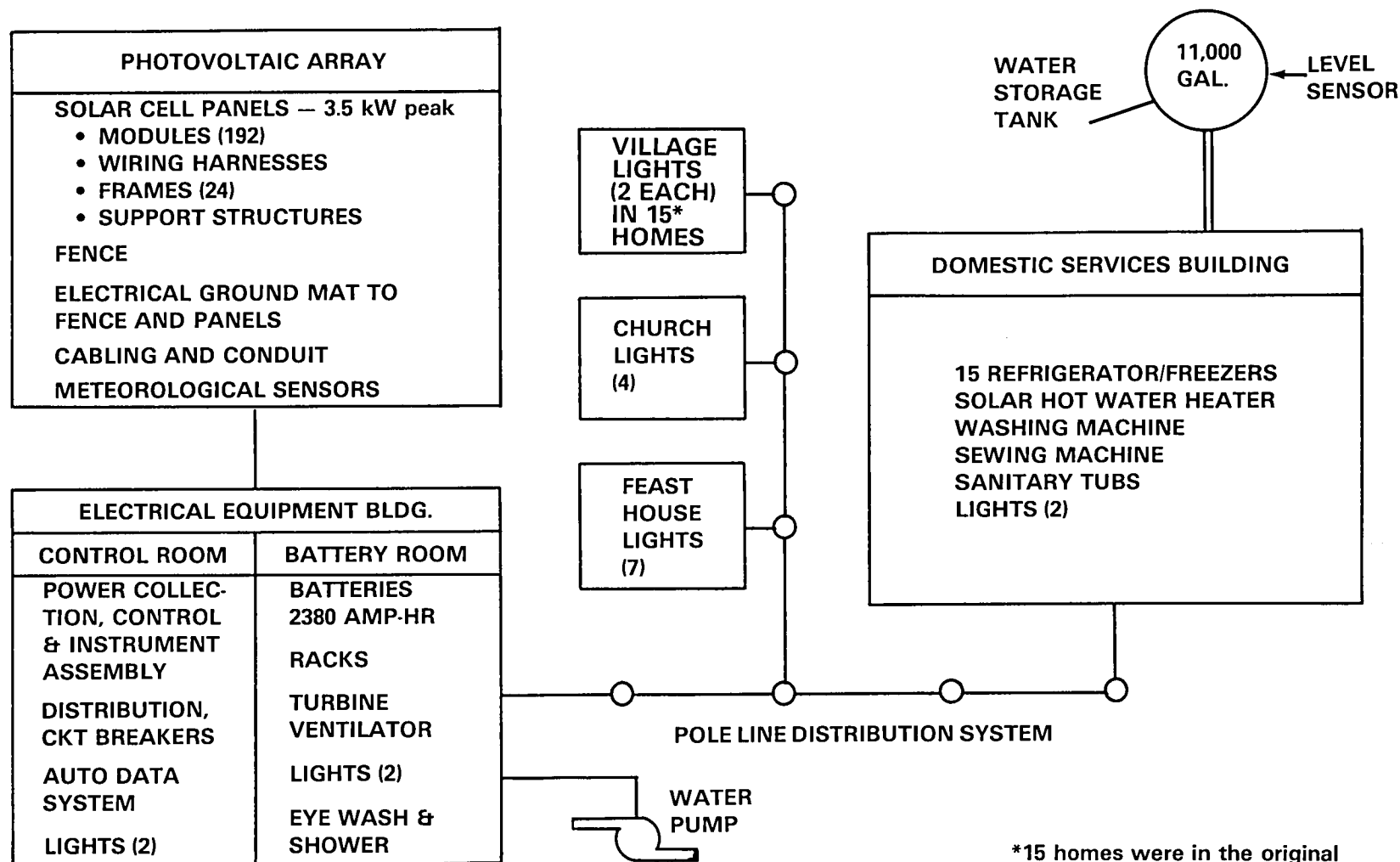


Figure 1. Location of Project



Figure 2. Schuchuli Village (looking southeasterly)



*15 homes were in the original system design and construction. Subsequently, 3 additional homes were included in the system.

Figure 3. Block Diagram of Schuchuli Village Power System

SYSTEM DESCRIPTION

The photovoltaic power system is a small, limited energy, self-contained, all 120-V(d.c.) electrical utility system which consists of a 24-panel PV array, commercially available lead-calcium storage batteries, instrumentation and controls housed in an Electrical Equipment Building (EEB), 120-V(d.c.) electrical distribution network and the various motors, lights, instruments, and controls that constitute the electrical loads. The system provides the electrical power and automatic controls for the existing village water supply system; fluorescent lights in the village buildings and homes; and 15 refrigerators (one for each family in the village), a washing machine, and a sewing machine in the Domestic Services Building (DSB). A solar thermal hot water heater is located on the roof of the DSB and supplies hot water for the laundry. The freeze protection heater in this unit is powered from the PV system. The sensors and PV array for a self-contained electronic weather station (EWS) are located within the fenced array area with its battery and recording equipment located in the EEB.

The 3.5-kW (peak) PV array consists of three rows of eight panels each mounted to steel frames and uprights set in concrete piers enclosed within a 100- by 76-ft area secured by an individual type chain link fence (Figure 4). Each PV panel contains eight Solarex 9200 J modules connected in series to form a nominal 120-V string. The panels have three tilt angle positions and are changed four times a year to 48°, 35°, 11°, and 35° from the horizontal to seasonally maximize the array output. The rows are stepped in elevation on the uprights to reduce the spacing between rows while eliminating low sun angle shadowing. The array panels and supporting structure are designed for 100-mph winds.

The electrical storage system is installed in a vented room in the EEB and consists of the 120-V main battery and the 12-V instrumentation and control (I/C) battery. The 120-V main battery consists of 52 cells rated at 2380 ampere-hours and four "pilot" cells (Figures 5 and 6) which are used in conjunction with the load management system discussed in detail in a following paragraph. Together, the pilot cells represent approximately 50, 10, 10, and 10 percent capacity increments of the main battery. The first or "50 percent" pilot cell is rated at 1055 ampere-hours and the other three or "10 percent" pilot cells are rated at 310 ampere-hours each. During normal charging battery operation, i.e., when all pilot cells are fully charged, the four pilot cells are connected in parallel and together constitute the 53rd cell of the main battery (Figure 7). The 12-V I/C battery consists of 6 cells rated at 1055 ampere-hours each and is kept charged from the main battery through a d.c./d.c. converter.

The instrument and control system provides for the sequential disconnecting of individual PV array strings during battery charging, for sequential

load shedding during progressive battery depletion, and for the automatic operation of the water pump. Figure 8 is an overall view of the instrument and control panel. The Power Collection, Control, and Instrumentation Assembly (PCCIA) collects all power from the array and the main battery. It contains most of the controls for the array string switching, load management, and safety system. It also contains most of the instrumentation. Specifically, it contains the drum programmer; 17 ammeters, 2 of which are meter relays; 17 ampere-hour meters; 8 volt meters, 5 of which are meter relays; 8 run-time meters; blocking diodes for each array string; fuse disconnects for each array string; control relays; and a d.c./d.c. converter. It also contains a switchable panel meter to read and display temperatures for one main battery cell, one array panel, a refrigerator compartment, and the pump motor. The meter relay is a combination of an analog meter and low power relays which are used to actuate power relays for various system control functions. The analog indicator on the meter has the same function as a needle on a standard meter, showing the voltage of the circuit. The meter also contains two adjustable set point needles. When the analog needle moves past an upper or lower set point, the internal relay contacts are transferred. It should be noted that the instrument panel contains instrumentation for complete input-output measurements to facilitate a full understanding and analysis of this experimental system. If this system were to be replicated as a strictly operational system, most, if not all, of these instruments might be omitted.

Data from the I/C system are taken in two ways: (1) by daily observation of meters recorded by hand on prepared data sheets (Figure 9) and (2) automatic recording at hourly intervals by the DAT-3 (Figure 10). The parameters read by the DAT-3 are shown in Figure 11. The cassette tapes and the data sheets are sent to NASA LeRC for data reduction.

System voltage regulation and battery charge control are accomplished by PV array string switching. Each of the 24 series strings in the array is connected to the main bus through a solid-state relay. A controller senses system voltage and commands a programmable drum relay to disconnect sequentially (open circuit) individual series strings to keep the system voltage at or below the maximum battery charge voltage ($V_{HI} = 130 \text{ V}$) and to reconnect these strings sequentially when the system voltage falls to a predetermined lower level ($V_{LO} = 125 \text{ V}$).

Because of uncertainties regarding actual power usage, a load management system was included in the design to protect the battery from excessive discharge and to maintain service to critical loads at the expense of less critical loads. This load management system uses the indication of main battery depth-of-discharge (DOD) levels to trigger sequential load shedding. Main battery depth-of-discharge is determined by sensing end-of-discharge voltage (1.95 V) of each of the four pilot cells which, during discharge, are individually connected in series with the main battery cells starting with the No. 1 or "50 percent" pilot cell. When the No. 1 or 50 percent pilot cell becomes discharged, the washing and sewing machines are disconnected, the 50 percent pilot cell is disconnected, and the No. 2 pilot cell is connected in series with the main battery. If the main battery is further discharged, the sequence continues such that at approximately 60 percent DOD, the No.

2 pilot cell reaches its discharge voltage and the village lights are disconnected (except in the DSB and EEB) and the third pilot cell connected; at approximately 70 percent DOD, the water pump and the third pilot cell are disconnected and the fourth pilot cell connected; and at approximately 80 percent DOD, the refrigerators are disconnected. The lights in the DSB and the 300-W freeze protection heater in the Solarhart water heater are disconnected with the refrigerators. During recharge, the pilot cells and the associated loads are reconnected in the reverse sequence. "Full discharge" operation and subsequent time standing so discharged will affect the lifetime of the pilot cells but provide the desired protection for the other 52 cells of the main battery. As previously described, during normal charging operation (i.e., when the main battery and the pilot cells are fully charged), all four pilot cells are connected in parallel and together act as an additional series cell. Pilot cell sequencing and load shedding are accomplished by the programmable drum relay. It should be noted that the lights in the EEB are not included in the load shedding sequence.

System over- and under-voltage protection is also provided as a backup to the system voltage control and load management controls. If the system voltage exceeds a maximum allowable value (135 V), the entire PV array is disconnected. If the system voltage drops below 95 V, all loads are disconnected. Alarm lights and an audible alarm are provided to indicate these conditions. Also, a manual emergency switch disconnects array, batteries, and loads.

The basic water supply system was in place and functional using a 7-hp, single cylinder, diesel engine to power the pump (Table 1). Control was accomplished by observation of the supply tank level target; when the water level was low, an appropriate amount of diesel fuel was put into the engine tank, and the diesel engine started to power the pump. Experience with the system established the amount of fuel to be used so that the fuel was expended and the engine stopped when the tank level was restored. The new system replaced the diesel engine with a 2-hp, 120-V(d.c.) permanent magnet motor and automatic controls employing water level sensors at the storage tank (Figure 12).

The pump motor operation is controlled automatically by water level sensors in the water storage tank and a PV array current sensor. During normal operation, the pump motor operates only in the daytime (i.e., when the array is generating power) and starts the pumping when the tank level is approximately 1.5 ft below "full." As long as the pump load has not been shed, a low level sensor starts the pump when tank water level falls below half the tank capacity regardless of array output. Whenever the motor is started in the automatic mode, the pump motor will operate until the water level is restored to the full level in the tank, or the battery becomes discharged beyond 70 percent DOD and sheds the pump load as described above. The pump area is protected by a commercial grade chain link fence. The fence gate to the area is kept locked as a safety measure as the automatic starting of the pump could cause severe injury. A manual on-off switch is located at the pump to provide additional protection for personnel doing maintenance work.

There are 15 individual refrigerator/freezers located in the DSB. Originally, the design was for one large refrigerator and one large freezer to be located in the DSB; therefore, the control system load management, Drum Programmer, etc., were designed for local control in the DSB. Well after the design was completed and parts of the control system developed, the villagers, through the village chairman, indicated their desire for the individual units. To stay with the existing control system design of load management, it was agreed that these units would remain in the DSB to be under one control. The refrigerator/freezer units were custom made for this project by Magna Kold, Inc., a commercial supplier of custom-built, high efficiency refrigerator units for marine and other special applications. These 15 refrigerator/freezers (R/F) are installed in a locker-like arrangement of five cabinets. Each cabinet operates from a single compressor and contains three 4-ft³ R/F compartments (Figure 13). These units have COLD-PLATE* evaporators that use a phase change gel, special 3-in. polyurethane foam insulation around all sides, special door gaskets, and locking door latches. The five compressors are located under a protective shed-like cover on the outside of the north wall of the DSB (Figure 14). The White Zigzag sewing machine and the Maytag wringer washing machine are located in the DSB.

The PV system provides power for two 20-W fluorescent lights in each of the village homes and the DSB, 7 in the feast house, and 4 each in the church and EEB.

A Solahart Model 80 GE Solar Hotwater System is located on the roof of the DSB. This unit has a storage capacity of 80 gallons, works on the thermal siphon principle which eliminates the need for circulation pumps and operates at a normal pressure of 50 psi. It contains a 300-W resistance heater in the "cold" end of the collector to prevent water freeze-up in cold weather (Figure 15). The electric heater is thermostatically controlled to "on" at 36°F and "off" above 43°F.

The Climatronics EWS is self-contained and does not derive its power for sensing or recording data from the main or I/C power circuits. The EWS is equipped with a small photovoltaic module and a rechargeable battery which permits unattended operation. The EWS sensors and photovoltaic module are located within the fenced array area while the rechargeable battery and strip chart recorder are located in the EEB. The chart paper is replaced every 30 days and sent to NASA LeRC for data reduction.

In summary, the PV system provides power to four load circuits: the village water pump; lights in the homes, church, feast house, and EEB; the DSB which contains the refrigerators, a sewing machine, a washing machine, solar water heater freeze protection heater, and lights; and the instrumentation and controls.

*Patent Pending.



Figure 4. Array Field — 24 Panels

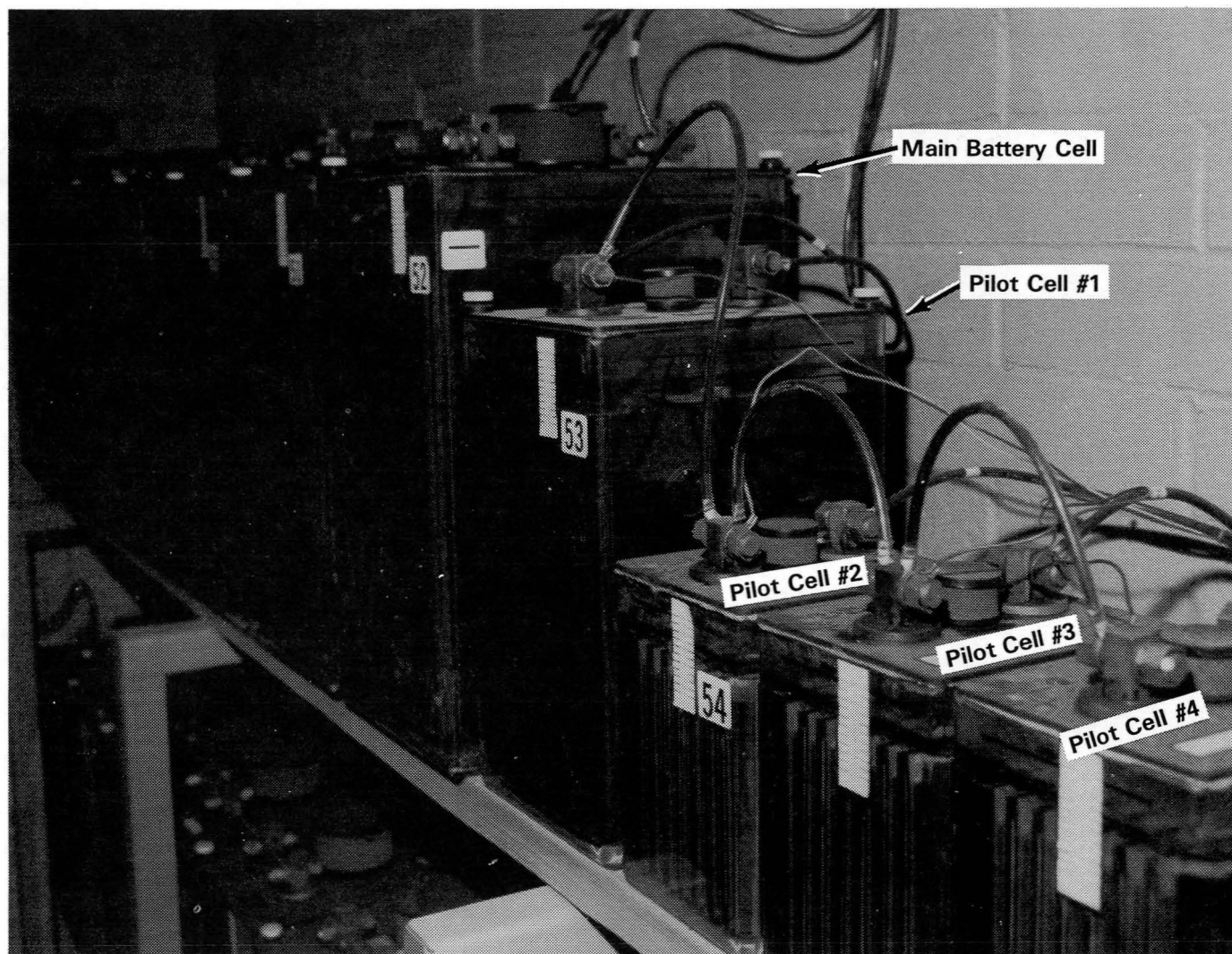


Figure 5. Main and Pilot Cell Batteries



Figure 6. EEB Battery Room

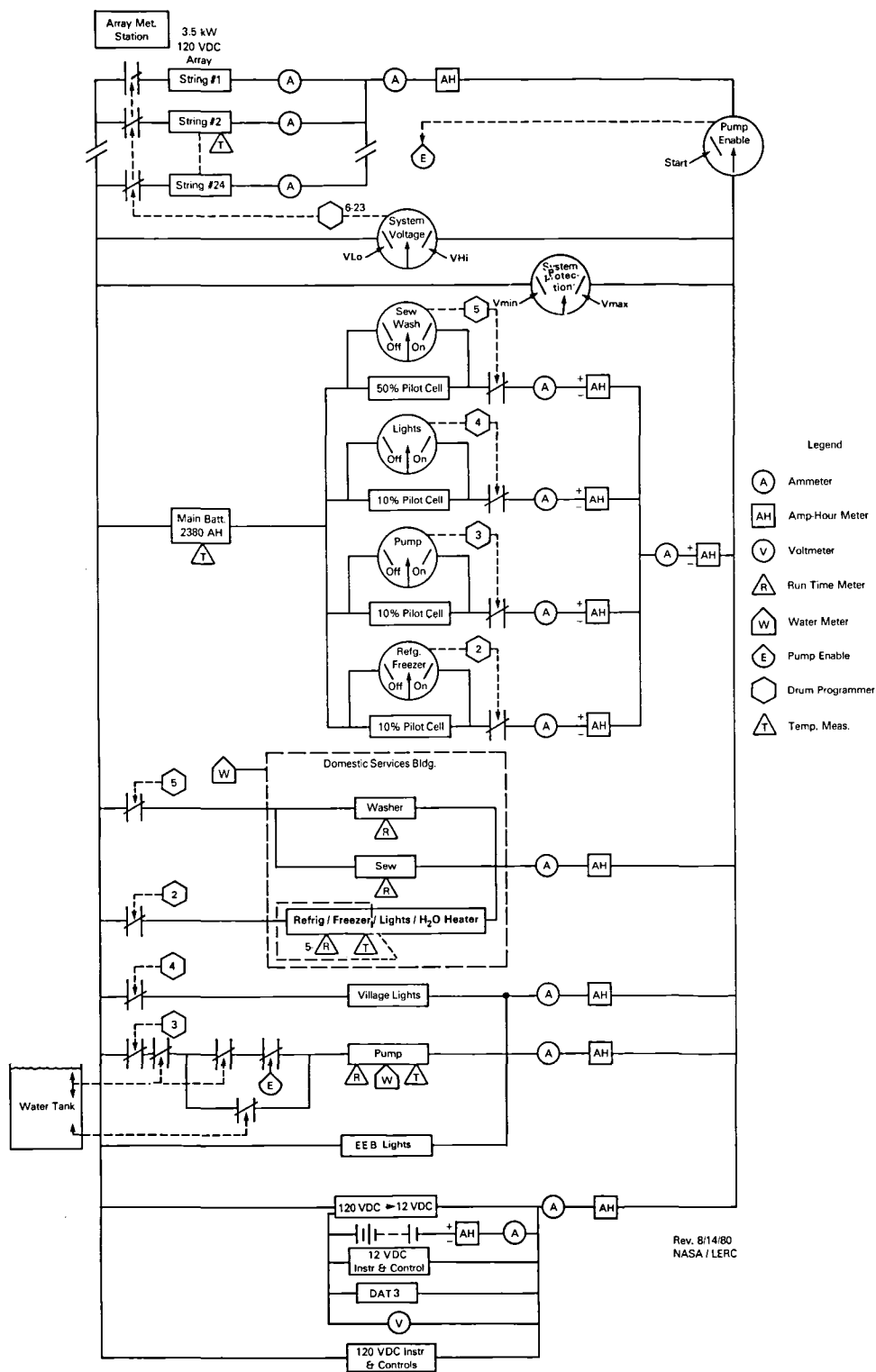


Figure 7. Schuchuli Village Power System Electrical Block Diagram

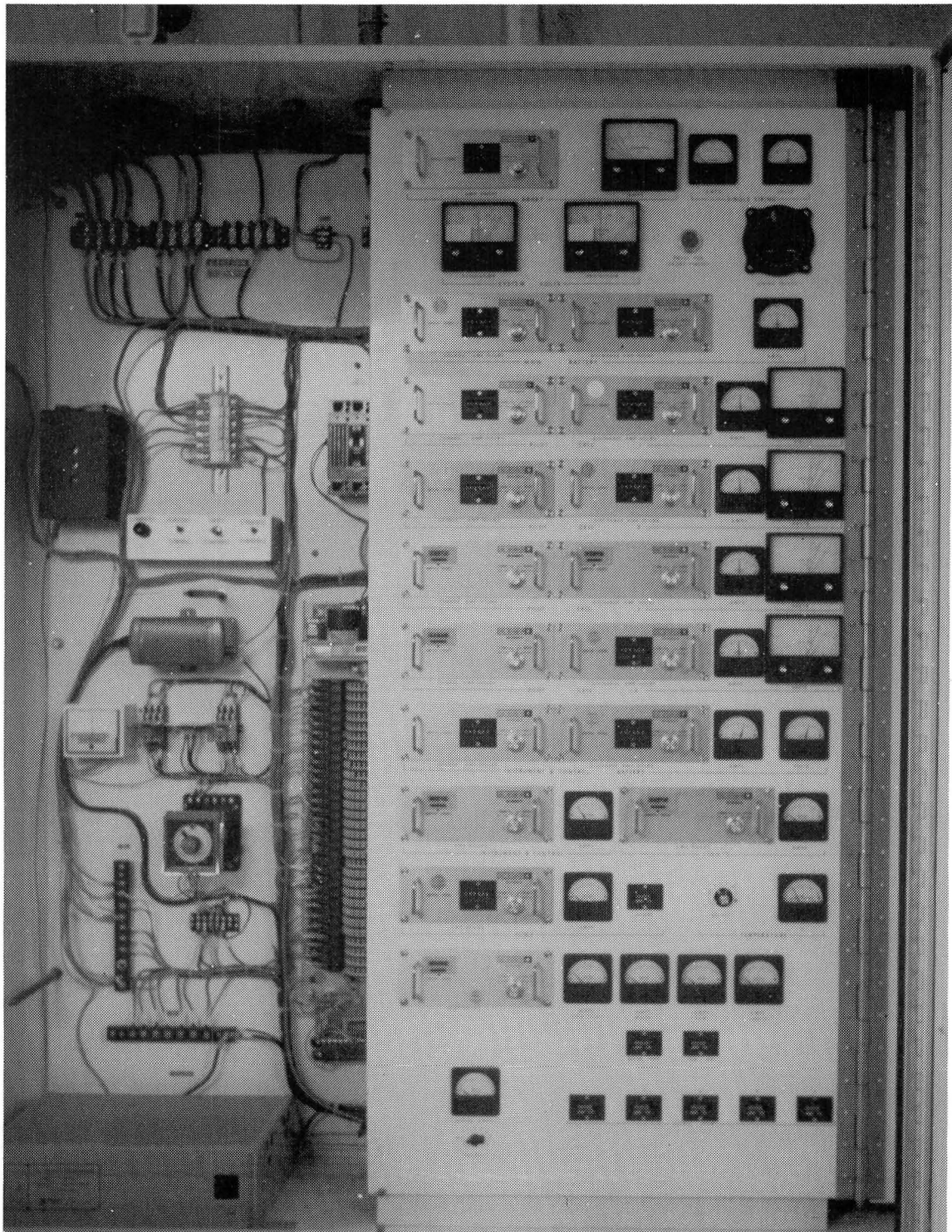


Figure 8. Power Collection, Control and Instrument Assembly Front View

SCHUCHULI DAILY DATA SHEET

ROW								
1	amp-hours		amps		NAME		DATE	
	ARRAY							
2	regulation		protection		AM			
	SYSTEM VOLTS				PM			
			TIME				CLOUD COVER	
3	charge amp-hours		discharge amp-hours		amps			
			MAIN BATTERY					
4	charge amp-hours		discharge amp-hours		amps		volts	
			PILOT CELL 1					
5	charge amp-hours		discharge amp-hours		amps		volts	
			PILOT CELL 2					
6	charge amp-hours		discharge amp-hours		amps		volts	
			PILOT CELL 3					
7	charge amp-hours		discharge amp-hours		amps		volts	
			PILOT CELL 4					
8	charge amp-hours		discharge amp-hours		amps		volts	
			INSTRUMENT & CONTROL BATTERY					
9	amp-hours		amps		amp-hours		amps	
	INSTRUMENT/CONTROL				LIGHTS			
10	amp-hours		amps		hours		TEMPERATURE	
			PUMP					
11	amp-hours		amps		amps		amps	
	DSB TOTAL				WASHER		SEW	
12					hours		hours	
	T		3		WASH HRS		SEW HRS	
13	1		4		1		2	
	2		5		3		4	
	REFRIG-AMPS				REFRIG-HOURS		5	

Figure 9. Prepared Data Sheet

- Inside Panel of PCCIA:

amps	
Converter Output	Drum Programmer

- Village Water Pump: _____ Gallons
- DSB Water Meter: _____ Gallons

Figure 9. Prepared Data Sheet (continued)



Figure 10. DAT-3 Auto Data Retrieval

SCHUCHULI DAT-3 DATA PATTERN

2/4/80

Output Word Number	Input Channel Number	Input Word Number	Input Conv. Number	Data Type	Function	Conversion* Factor	Eng. Unit Conversion (Range)
1	1	00	40	Ins.	Array Current	80	0-50 amp
2	1	00	40	Ave.	Array Current (Ave)	80	0-50 amp
3	17	20	60	Ins.	System Voltage	20	0-200 volts
4	17	20	60	Max.	System Voltage (Max)	20	0-200 volts
5	17	20	60	Min.	System Voltage (Min)	20	0-200 volts
6	2	01	41	Ins.	Main Battery Current	80	-50 - +50 amps
7	2	01	41	Ave.	Main Battery Current (Ave)	80	-50 - +50 amps
8	2	01	41	Max.	Main Battery Current (Max)	80	-50 - +50 amps
9	2	01	41	Min.	Main Battery Current (Min)	80	-50 - +50 amps
10	3	02	02	Ave.	Pilot Cell (Bat) #1 Current	80	-50 - +50 amps
11	4	03	03	Ave.	Pilot Cell (Bat) #2 Current	80	-50 - +50 amps
12	5	04	04	Ave.	Pilot Cell (Bat) #3 Current	80	-50 - +50 amps
13	6	05	05	Ave.	Pilot Cell (Bat) #4 Current	80	-50 - +50 amps
14	18	21	21	Ins.	Pilot Cell Voltage	1000	0-4 volts
15	19	22	22	Ins.	Instr. Battery Voltage	200	0-20 volts
16	7	06	46	Ins.	Instr. Load Current	400	0-10 amps
17	7	06	46	Ave.	Instr. Load Current (Ave)	400	0-10 amps
18	8	07	07	Ave.	Instr. Battery (Ave)	160	-25 - +25 amps
19	9	10	50	Ins.	Pump Motor Current	160	0-25 amps
20	9	10	50	Ave.	Pump Motor Current (Ave)	160	0-25 amps
21	10	11	51	Ins.	Lights Bus Current	400	0-10 amps
22	10	11	51	Ave.	Lights Bus Current (Ave)	400	0-10 amps
23	10	11	51	Max.	Lights Bus Current (Max)	400	0-10 amps
24	11	12	52	Ins.	D.S.B. Bus Current	160	0-25 amps
25	11	12	52	Ave.	D.S.B. Bus Current (Ave)	160	0-25 amps
26	11	12	52	Max.	D.S.B. Bus Current (Max)	160	0-25 amps
27	20	23	63	Ins.	Insolation	9.3	0-430 mw/cm2
28	20	23	63	Ave.	Insolation (Ave)	9.3	0-430 mw/cm2
29	12	13	13	Ins.	Panel Temperature	20	0-200 Deg F
30	21	24	24	Ins.	Air Temperature	20(+20)	+20 - +120 Deg F
31	22	25	65	Ins.	Wind Speed	20	0-200 MPH
32	22	25	65	Max.	Wind Speed (Max)	20	0-200 MPH
33	23	26	26	Ins.	Wind Direction	3.7037	0-1080 Deg
34	13	14	14	Ins.	Battery Temperature	20	0-200 Deg F
35	14	15	15	Ins.	Pump Temp.	20	0-200 Deg F
36	15	16	16	Ins.	Ref. Temp	20	0-200 Deg F
37	16	17	17	Ins.	Freezer Temp.	20	0-200 Deg F
38	24	27	27	Ins.	Step Switch Position	82.46(+1)	1-50 Step
39	25	28	28	Ins.	String #1 Current	2000	0-2 amps
↓	↓	↓	↓	↓	↓	↓	↓
62	48	3F	3F	Ins.	String #24 Current	2000	0-2 amps

* For Engineering Units: Divide counts by Conversion Factor and add quantity in () if there is one.

Note; This listing in DATPAT.SCHUCHUL of SEDAT3.

Figure 11. Sample of Data

Table 1. Existing Water Supply System

Population:	Approximately 96	
Number of Service Connections:	19	
Water Supply:	Drilled well (a dug well is used as a standby)	
	Diameter:	8 inches
	Depth:	243 feet
	Static Water Level:	48 feet
	Well Capacity:	29 gpm
	Pumping Level:	125 feet
Pumping Equipment:	Jensen Jack	Model 125 DC
	Cylinder:	1.75 inches diameter
	Pumping Capacity:	18.7 gpm
	Drop Pipe:	3 inches diameter
	Total Dynamic Head:	175 feet
	Power Required:	2 hp (pump manufacturer's recommendation)
		Note: 7 hp single cylinder diesel engine previously used.
Water Storage:	11,000 gallon capacity steel storage tank	
	- approximately 8 feet diameter	
	- approximately 30 feet high	

U.S. Public Health Service 1977

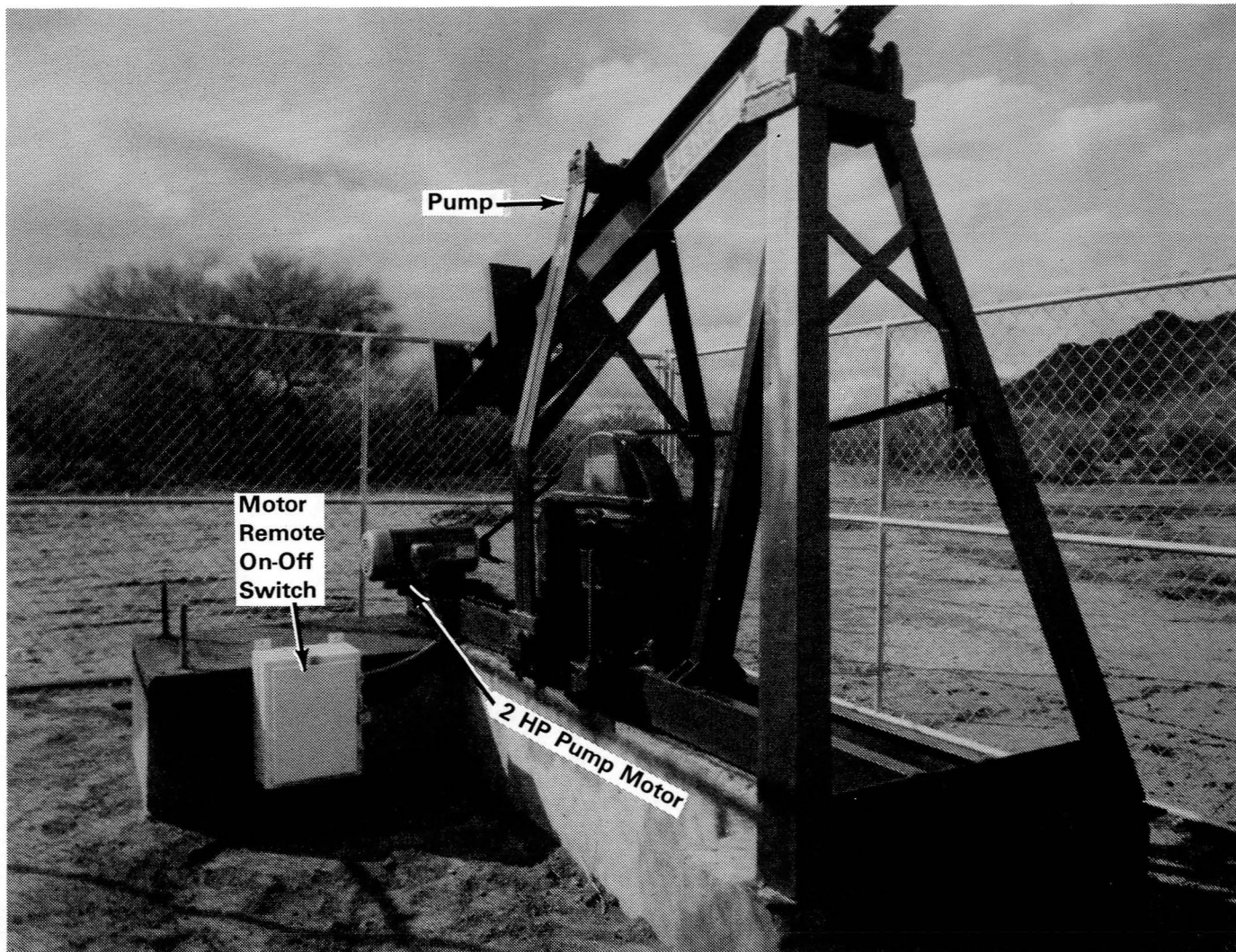


Figure 12. Water Pump

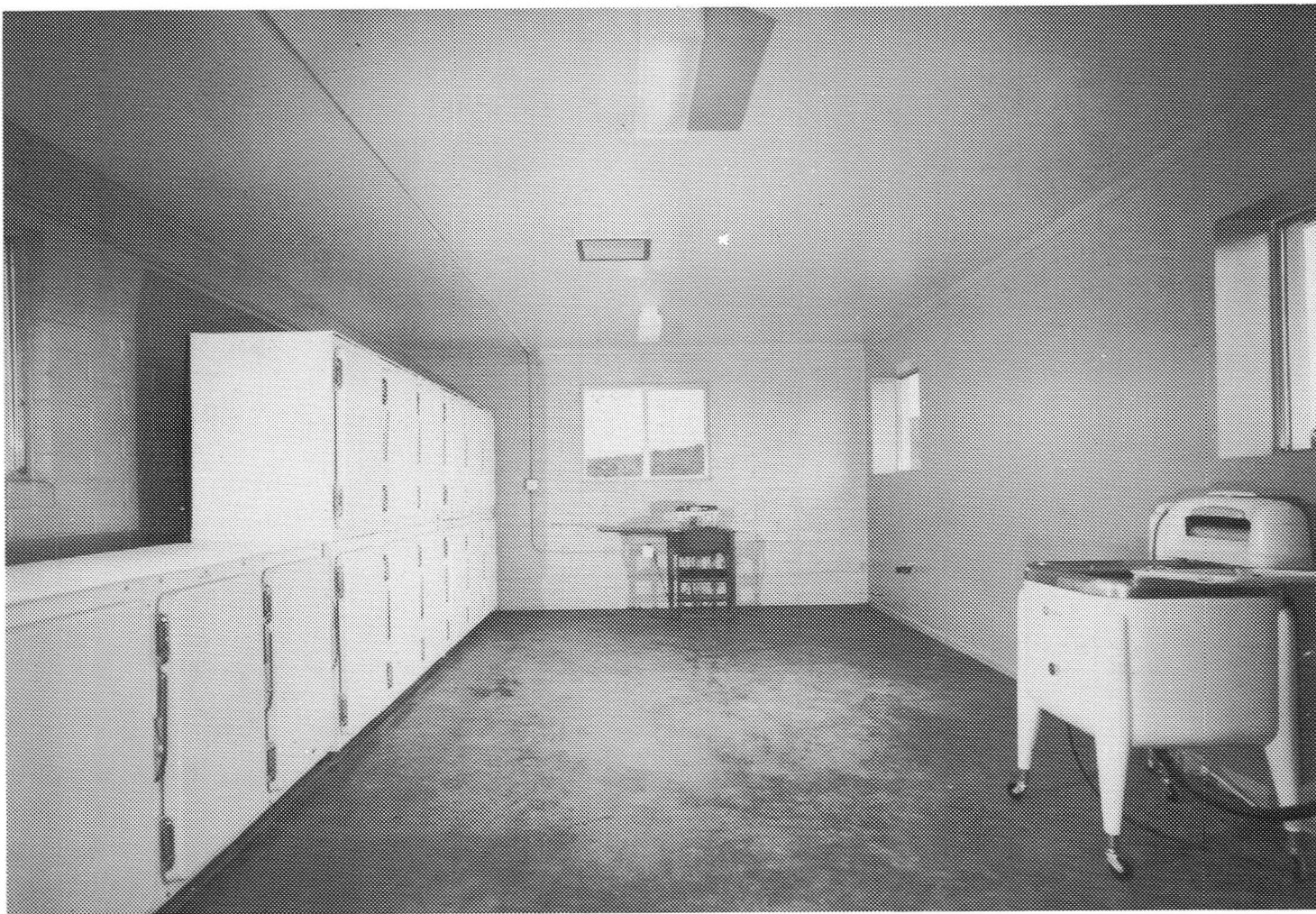


Figure 13. Refrigerator/Freezer Units Located in the DSB

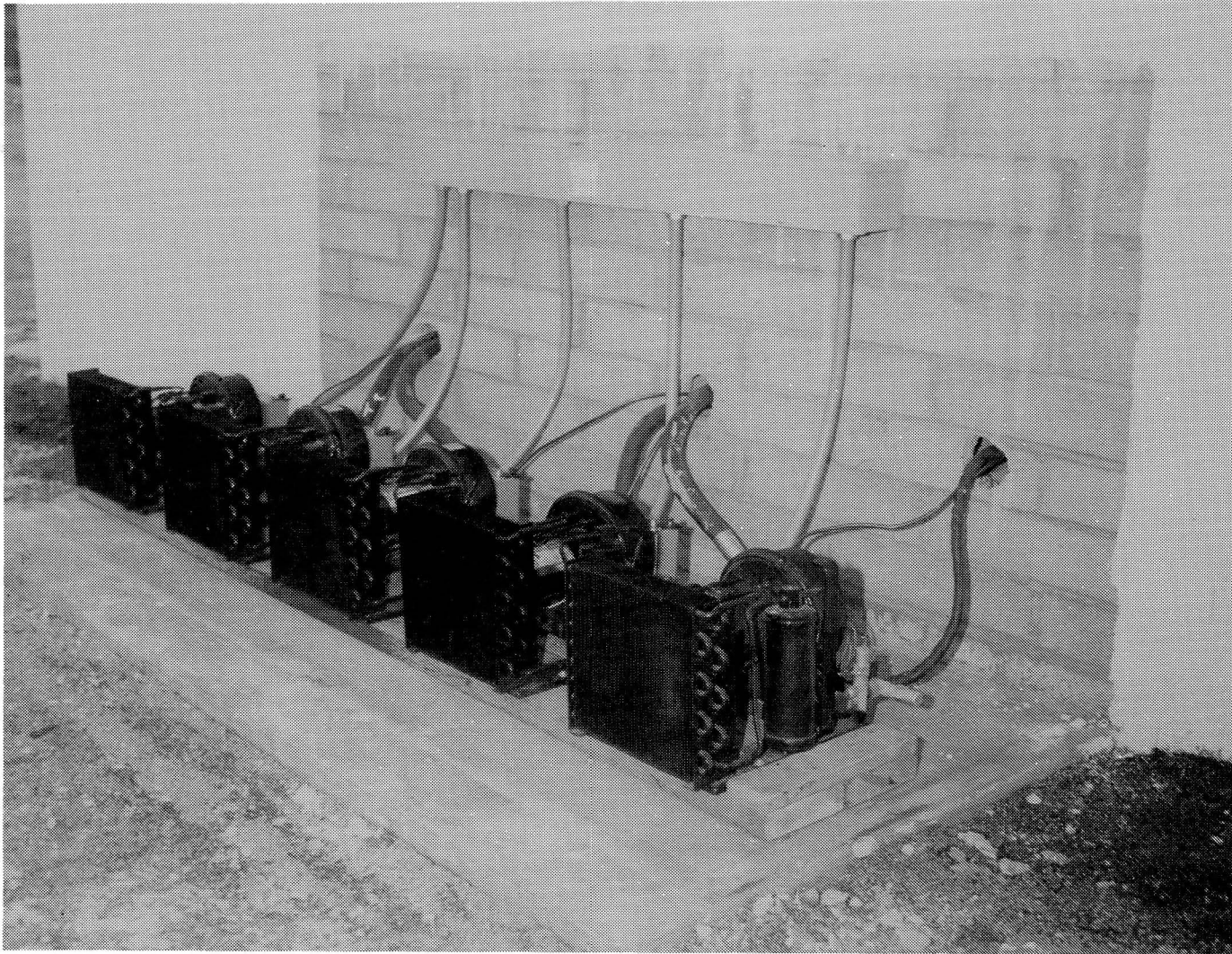


Figure 14. Refrigerator/Freezer Compressors

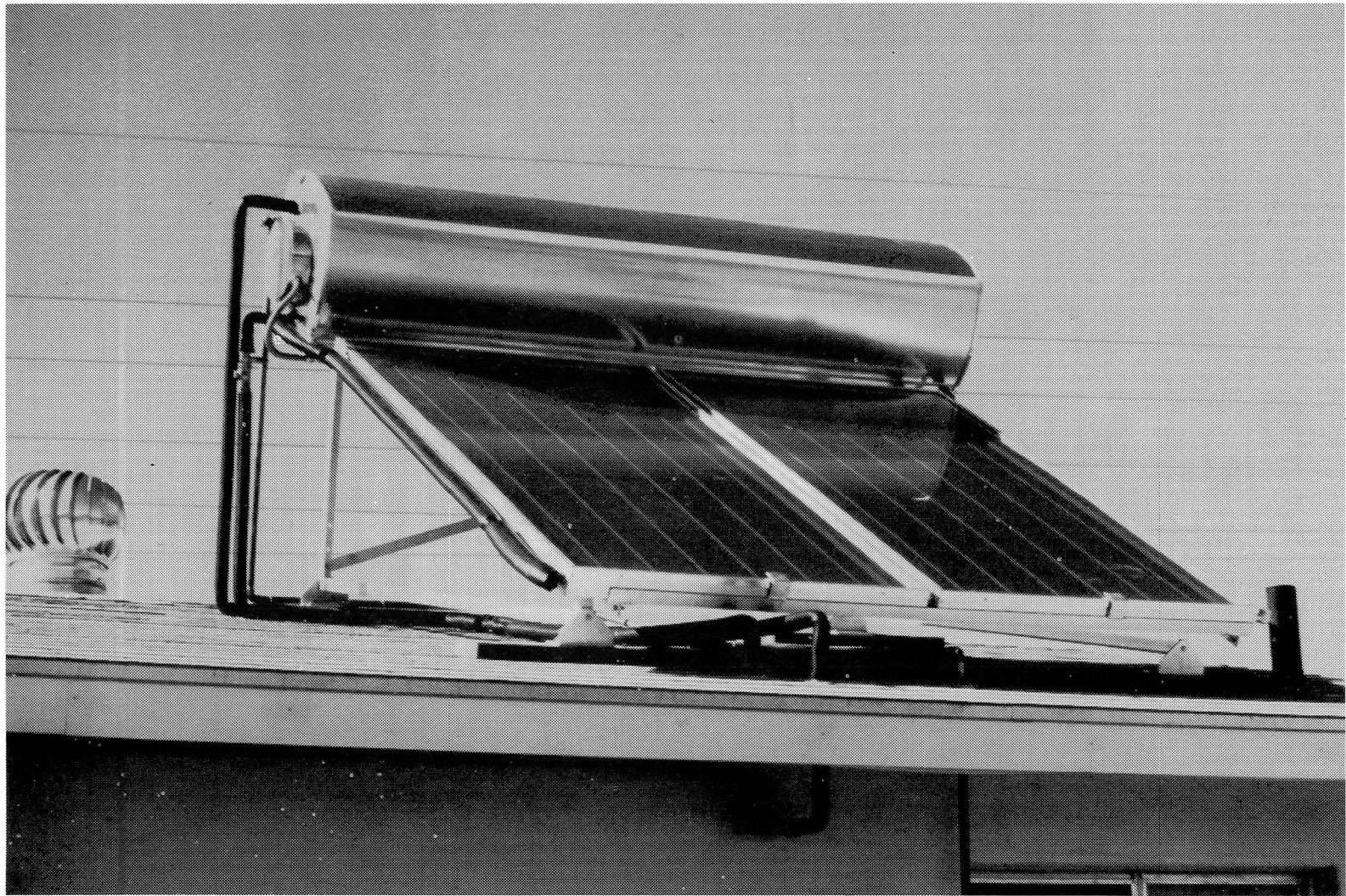


Figure 15. Solahart Solar Water Heater System

SYSTEM DESIGN

LOAD AND LOAD PROFILES

General

As previously stated, the PV system provides power to four load circuits: the village water pump; lights in the homes, church, feast house, and EEB; the DSB which contains the refrigerators, a sewing machine, a washing machine, solar thermal water heater freeze protection heater, and lights; and the instrumentation and controls. All loads are 120 V(d.c.) except for the instrumentation and some controls which are 12 V(d.c.). These loads were jointly selected by the participating organizations including the villagers themselves. The selection of specific loads was strongly influenced by the desire to maximize the energy efficiency of the loads and the cost benefits, i.e., high efficiency d.c. motors, high lumen efficiency lights, extra thermal insulation on refrigerator/freezers, low power consumption of instrumentation and controls. Throughout, safety of operation and ease of maintenance were foremost in mind. Early operating experience prompted the village women to request heated water for the laundry and a solar thermal hot water unit was obtained and installed on the roof of the DSB. Also, three additional homes were wired for lights following initial operation of the system. These changes were minor and have had little or no effect on the overall system operation.

Water Pump

The Public Health Service provided the estimated village water consumption data (exclusive of the washing machine) and NASA LeRC estimated the water use for the washing machine (Table 2). Based on a projected growth in population to 112 and an estimated 1.5 washer loads per person per week with an estimated 40 gallons of water used per load, the resulting projected use is approximately 960 gallons per day. This means that the machine would average two loads per hour over the 12-hour day, 8:00 a.m. to 8:00 p.m. Table 2 also lists the load estimates for the water pump motor based on the 2-hp motor at full pumping rate drawing approximately 15.5 amperes.

Village Lights

The PV system provides power for two 20-W fluorescent lights in each of the village homes and the DSB, 7 in the feast house, and 4 each in the church and EEB. The lights in the feast house, church, EEB, and DSB are for occasional usage and were not included in the design load profile. The house lighting profile for the original 15 homes is shown in Table 3 and was estimated by NASA LeRC based on information from PHS and the village chairman. Each 20-W lamp operates from a special Bodine Co. "Tran-Bal" inverter-ballast which inverts the 120 V(d.c.) to 120 V(a.c.)/23 kHz. Inverter-ballast current requirements were forecast by the manufacturer as

0.241 amperes. Each light uses a standard 120 V(a.c.) fluorescent lamp and a standard light fixture substituting the inverter ballast for the standard ballast. The home lighting schedule of Table 3 was based on 0.241 amperes per light, 2 lights per home, 15 homes and a use factor of 80 percent. Thus the lighting load current during periods when lights were assumed to be in use was estimated to be $(0.241 \times 2 \times 15 \times 0.80) = 5.78$ amperes.

Washing Machine Motor

The washing machine is located in the DSB and is a Maytag wringer model with an Applied Motors 120 V(d.c.), permanent magnet, 1/4-hp motor drawing approximately 2.59 amperes when operating at full load. Washing machine use was scheduled on the basis of 1.5 washer loads per person per week for a projected population of 112 meaning the machine would average two loads per hour for 12 hours each day. Thus, the washing machine motor was estimated to draw an average of 31.08 ampere-hours per day.

Solar Hot Water Heater

This unit was not part of the original design but was added to the system in June 1979 to provide hot water to the DSB in response to the women's reluctance to use cold water in the washing machine. It is a Solahart Model 80 GE Solar Hotwater System, located on the roof of the DSB. It contains a 300-W resistance heater in the "cold" end of the collector to prevent water freeze-up in cold weather. There is no other electric heating of the water. This electric load was not included in the original design load profiles but was considered within the capabilities of the PV system when the water heater was added to the system based largely on less than planned use of the washing machine.

Sewing Machine

The sewing machine is also located in the DSB and is a White Zigzag Model with a 1/8-hp universal motor drawing approximately 1.1 amperes at 120 V(d.c.). It was assumed that the sewing machine would be used an average of 3 hours per day, 5 days per week, with the motor running approximately 70 percent of the time. Thus, the sewing was estimated to use an average of 2.3 ampere-hours per day.

Refrigerators

The 15 refrigerator/freezers are installed in a locker-like arrangement of five cabinets, each cabinet operating from a single compressor. The five compressors, located under a protective cover on the outside of the north wall of the DSB, are driven by 1/4-hp P.M. d.c. motors drawing 1.45 amperes each. Table 4 indicates the estimate of the power consumption for these refrigerators on this basis.

Instruments and Controls

The instrument and controls load includes all of the 12-V(d.c.) instruments and controls and the 120-V(d.c.) controls with the exception of the Climatronics EWS which is independent of the PV power system. Power flow is governed and regulated and voltage and currents are measured in the Power Collection, Controls, and Instrument Assembly (PCCIA) located in the EEB (Figure 8, and Figures 16 through 20). The starter controls for the 2-hp pump motor are located in the EEB (Figure 21). Some load shedding controls and current measuring shunts are in the DSB control panel (Figure 22). A DAT-3 auto data recorder is located in the EEB. As previously stated, the I/C battery furnishes 12-V(d.c.) power to the PCCIA panel in the EEB, the control panel in the DSB, and the DAT-3 in the EEB. The I/C battery consists of six C&D KCPSA-15 cells rated at 1055 AH each and is kept charged from the main battery through a d.c./d.c. converter.

The estimated I/C current requirements are shown in Table 5.

Combined Load Profile

Combining all of the above described loads for each hour, day, and month produced the detailed loads profile which was used to simulate the system operation and determine PV array size (kW_{pk}) and battery capacity. Samples of combined load profiles are shown for typical days in Table 6.

Table 2. Water Pump Load Profile

Month	Village Water Consumption (Excluding Washing Machine) Gal / Day	Washing Machine Water Consumption Gal / Day	Total Gallons Per Day	Pump Hours/ Day	Pump Motor Ampere-Hours/ Day *
January	1500	960	2460	2.25	34.9
February	1500	960	2460	2.25	34.9
March	2500	960	3460	3.17	49.1
April	2500	960	3460	3.17	49.1
May	4000	960	4960	4.54	70.4
June	4000	960	4960	4.54	70.4
July	4000	960	4960	4.54	70.4
August	4000	960	4960	4.54	70.4
September	2500	960	3460	3.17	49.1
October	2500	960	3460	3.17	49.1
November	1500	960	2460	2.25	34.9
December	1500	960	2460	2.25	34.9

*Pump motor current assumed to be 15.5 amperes.

Table 3. House Lighting Load Profile

Month	Operating Hours		Total Hours Average Per Day	Ampere-Hours Average Per Day *
	AM	PM		
January	6:00 – 8:30	5:00 – 10:00	7.5	43.4
February	6:00 – 7:30	5:00 – 10:00	6.5	37.6
March	6:00 – 6:30	6:00 – 10:00	4.5	26.0
April	—	7:00 – 10:00	3.0	17.4
May	—	8:00 – 11:00	3.0	17.4
June	—	9:00 – 11:00	2.0	11.6
July	—	9:00 – 11:00	2.0	11.6
August	—	8:00 – 11:00	3.0	17.4
September	6:00 – 6:30	7:00 – 10:00	3.5	20.2
October	6:00 – 7:30	6:00 – 10:00	5.5	31.8
November	6:00 – 7:30	5:00 – 10:00	6.5	37.6
December	6:00 – 8:30	5:00 – 10:00	7.5	43.4

*Based on 0.241 amperes/lamp;
Assumes 80% use factor during operating hours.

Table 4. Refrigerator/Freezer Load Profile

Month	Maximum Temperature (° F)	Average Amperage *	Average Daily Ampere-Hours *
January	69	0.634	15.22
February	74	0.743	17.83
March	81	0.888	21.31
April	88	1.106	26.54
May	96	1.323	31.75
June	103	1.577	37.85
July	108	1.758	42.20
August	107	1.740	41.76
September	103	1.577	37.85
October	92	1.178	28.27
November	79	0.852	20.45
December	71	0.671	16.10

*For 5 compressors.

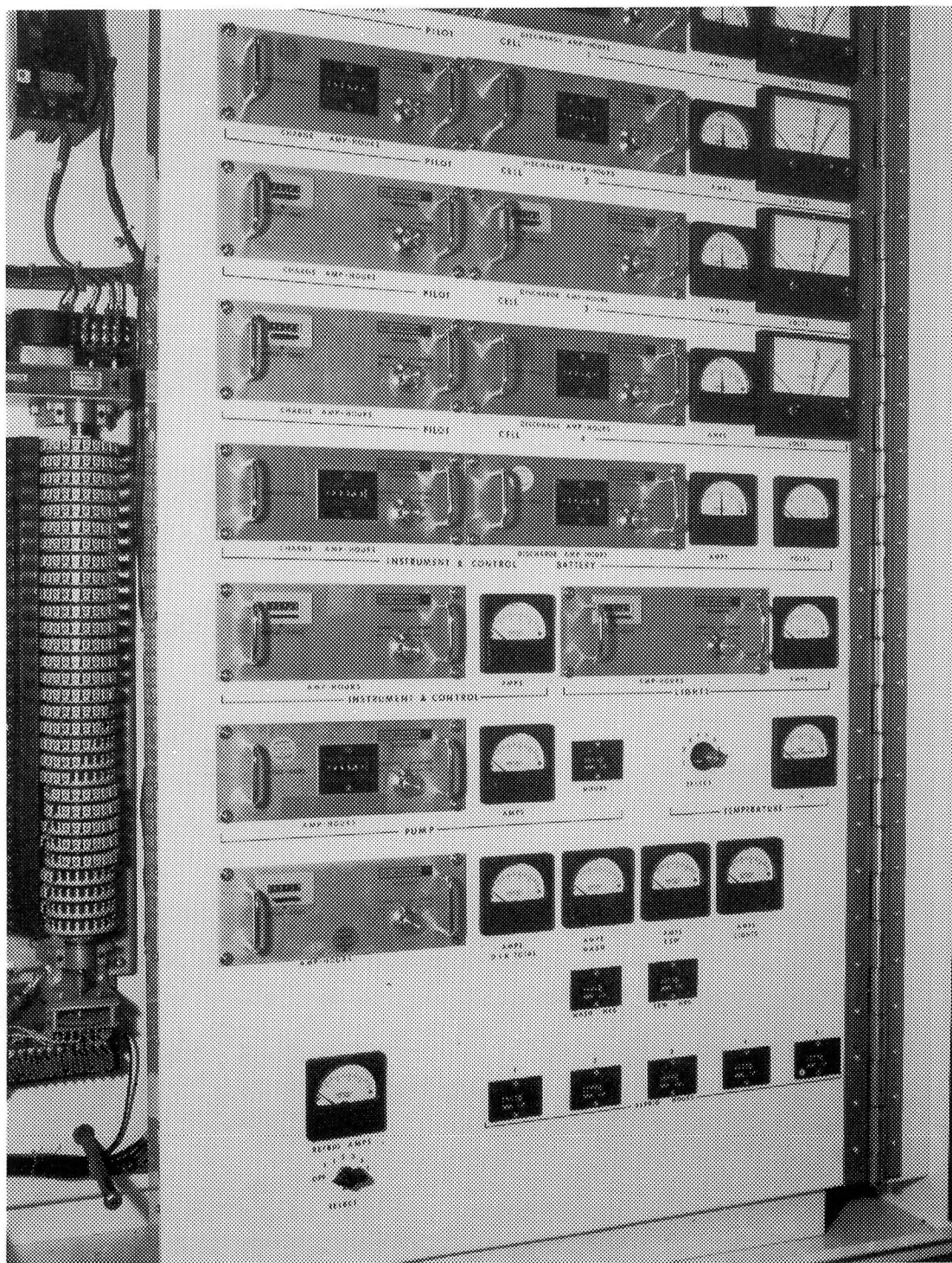


Figure 16. PCCIA Panel Meters

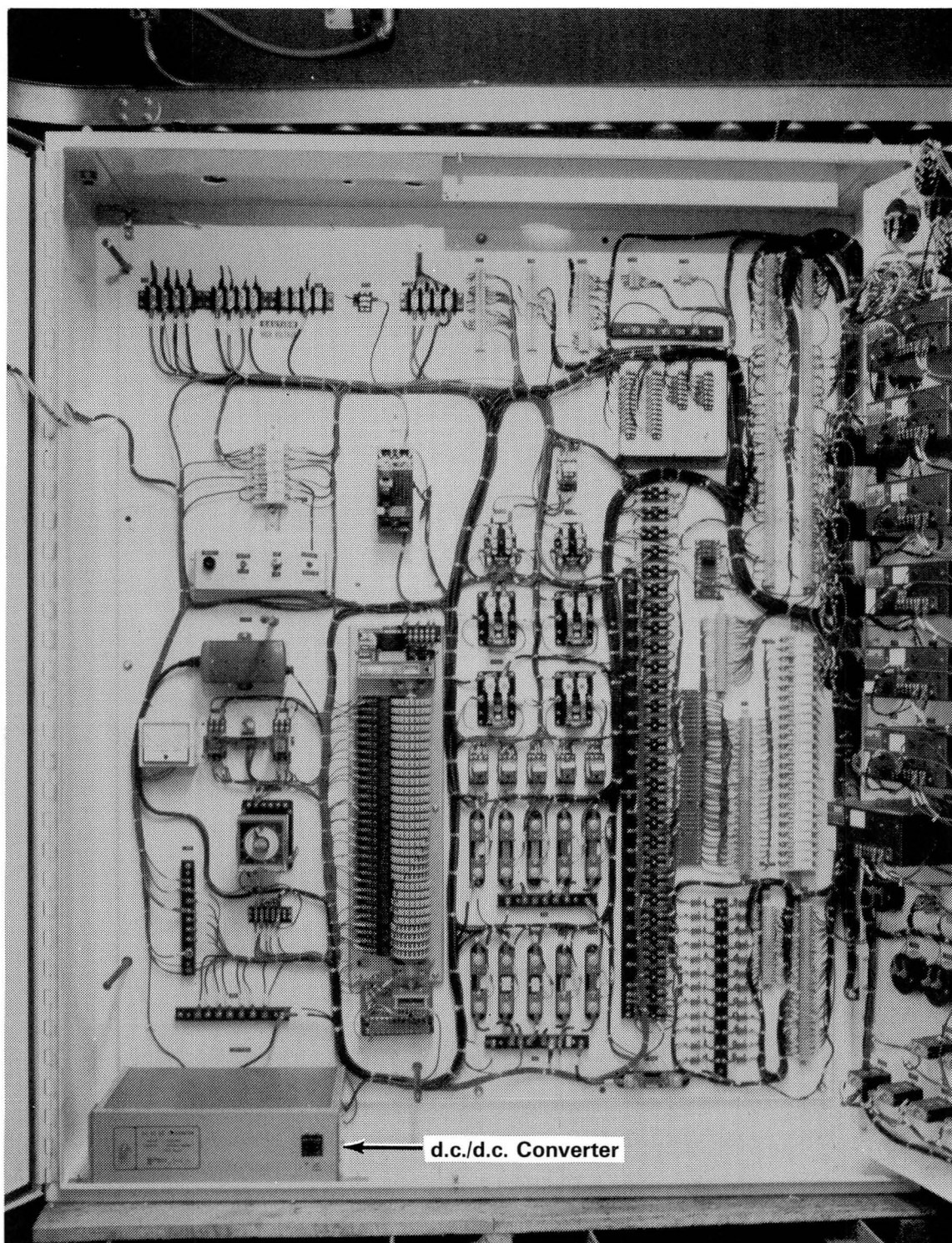


Figure 17. PCCIA Power and Control

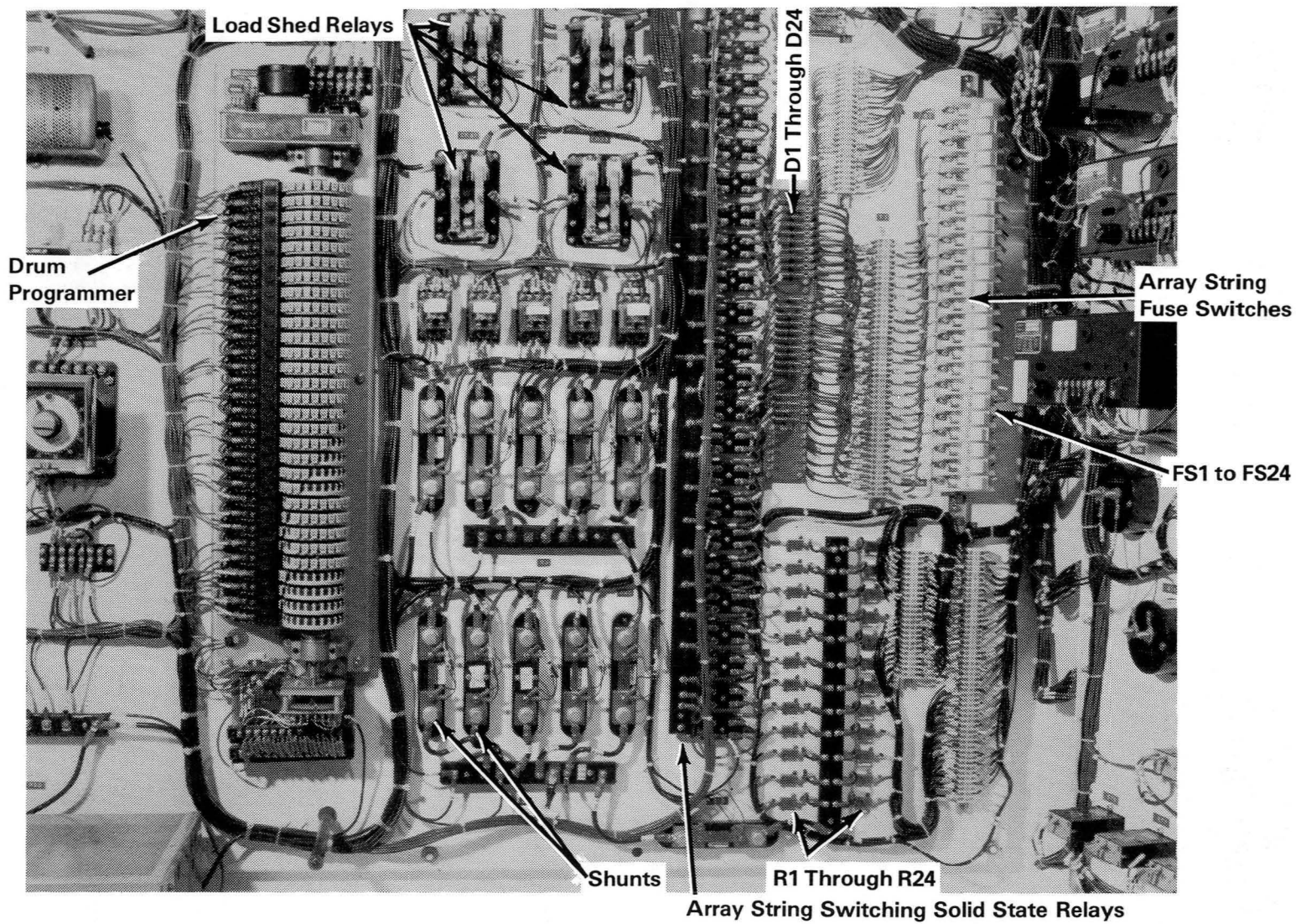


Figure 18. PCCIA

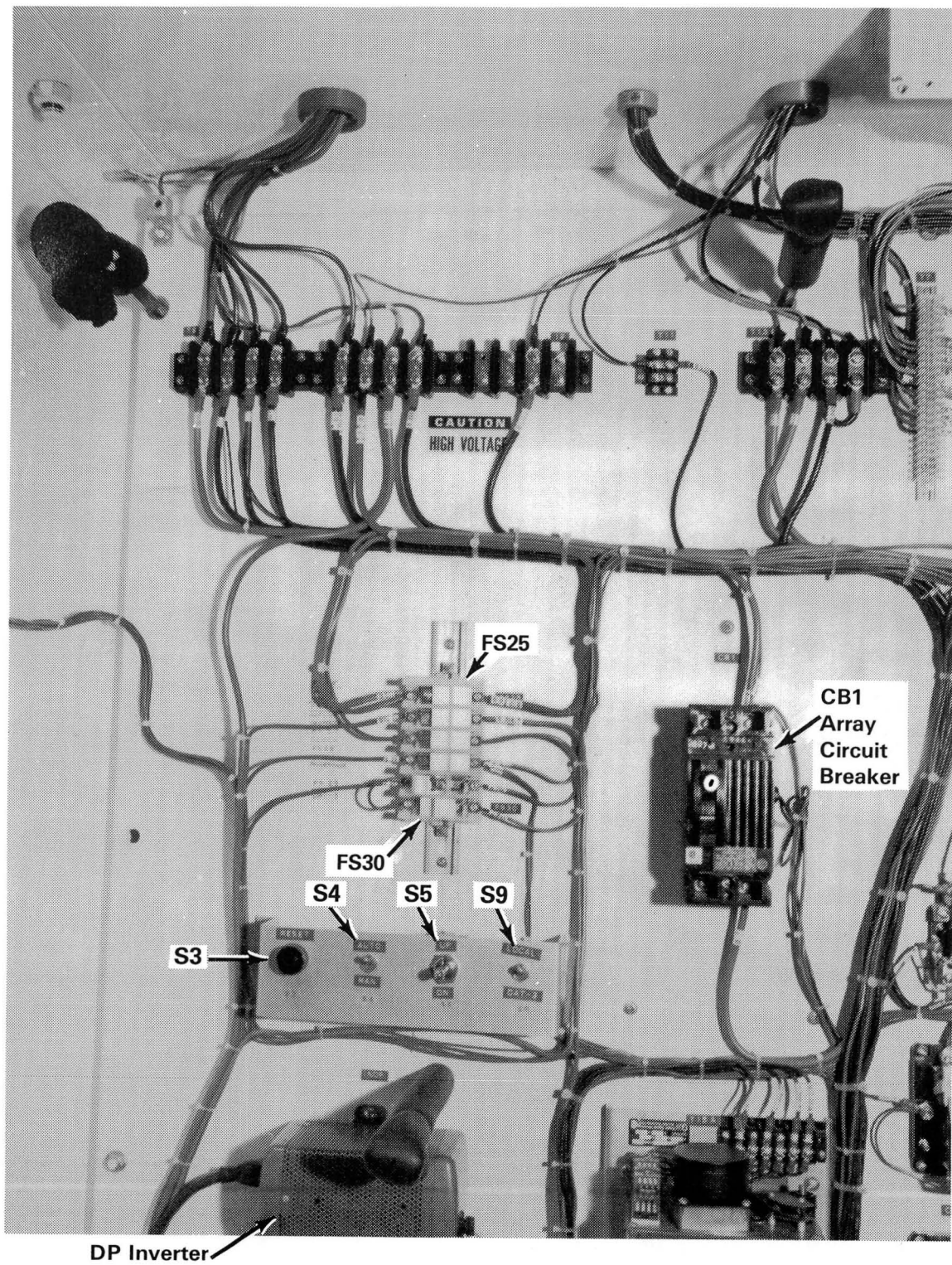


Figure 19. PCCIA

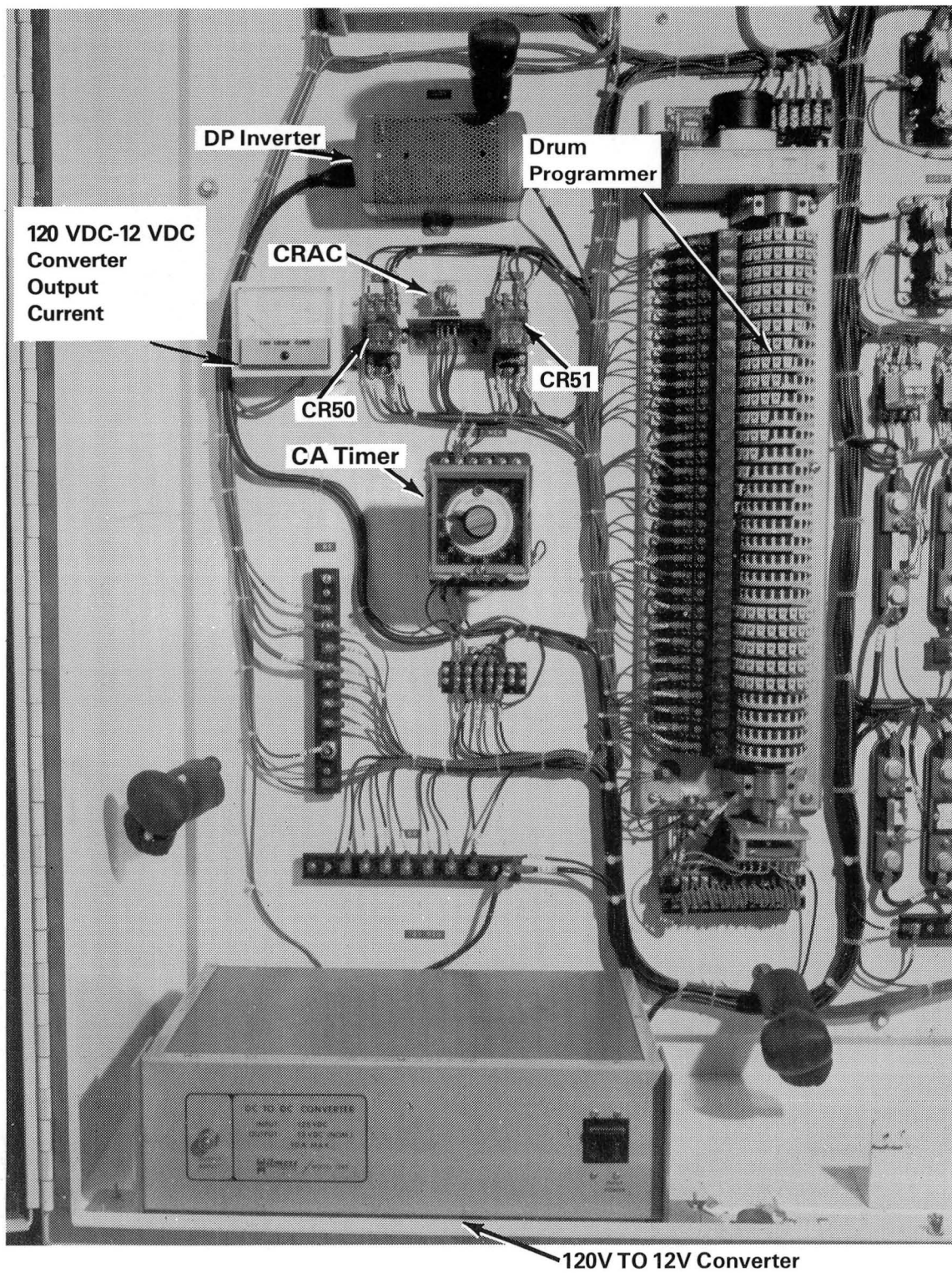


Figure 20. PCCIA

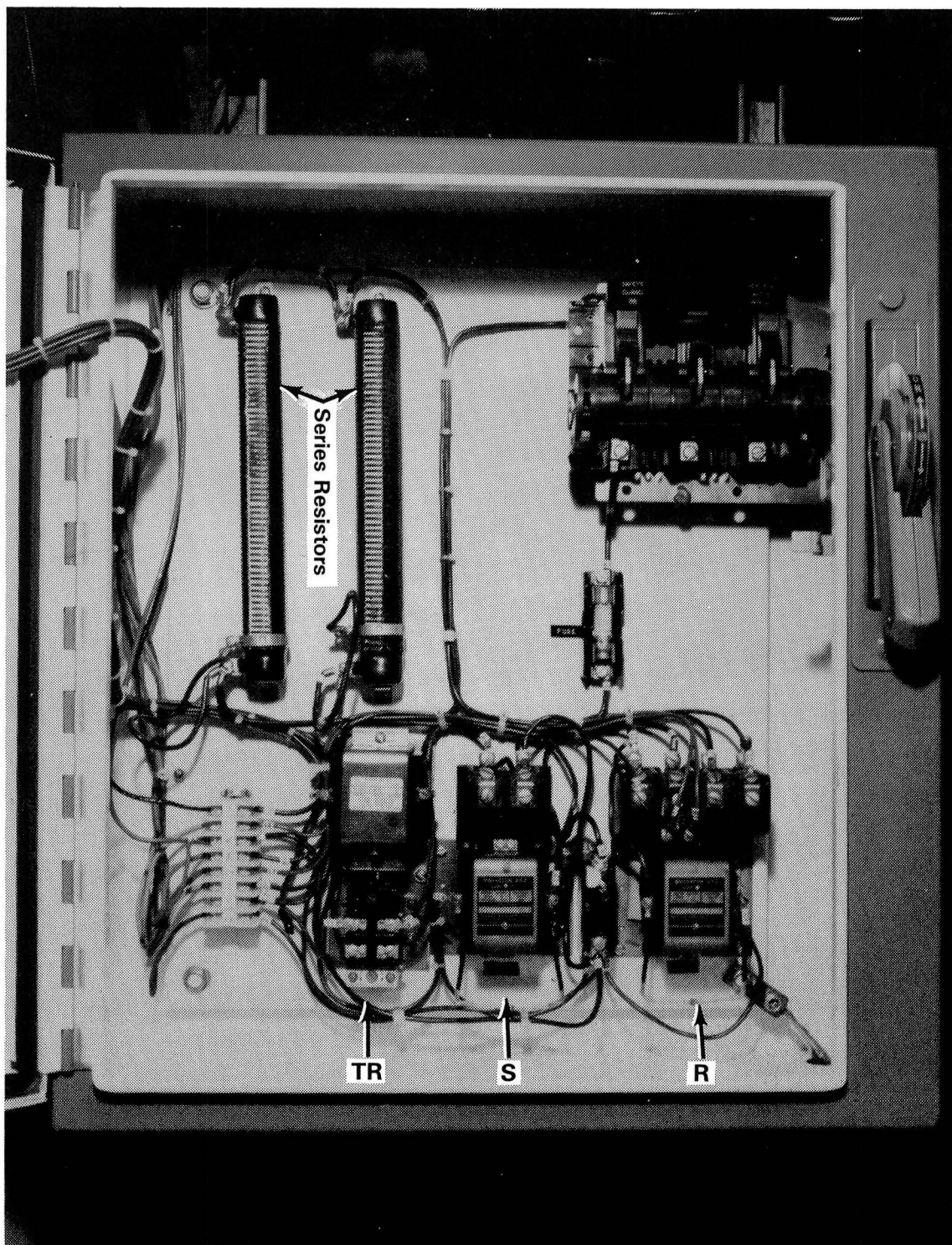


Figure 21. 2 HP Motor Starter Control Panel

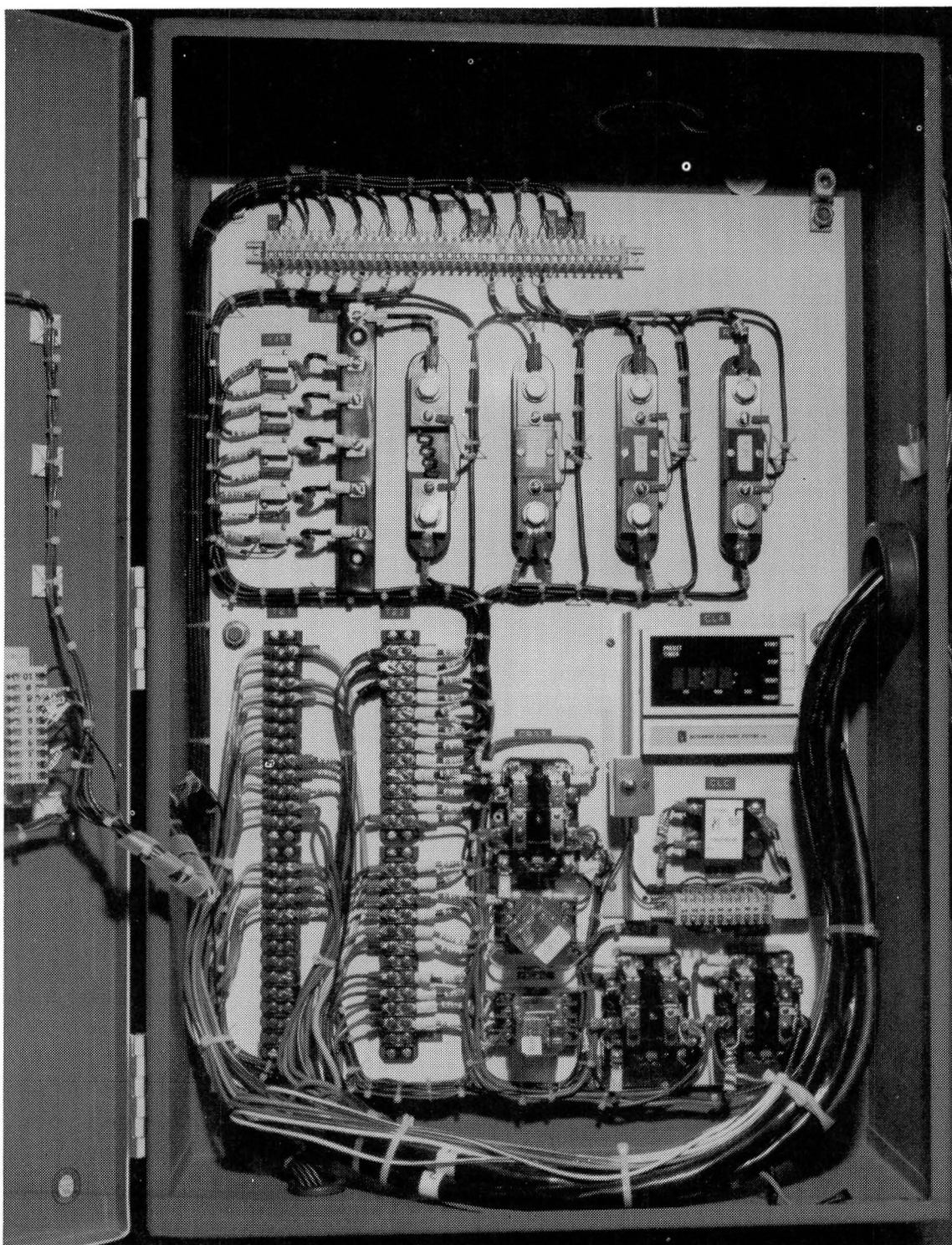


Figure 22. DSB Control Panel

Table 5. Instrument and Controls Load Profile

Month	Average Amperage @ 120V (d.c.)	Average Daily Ampere-Hours
January	0.543	13.04
February	0.530	12.72
March	0.579	13.90
April	0.591	14.19
May	0.645	15.48
June	0.645	15.48
July	0.579	13.90
August	0.579	13.90
September	0.579	13.90
October	0.579	13.90
November	0.562	13.50
December	0.543	13.04

Table 6. Typical Load Profiles, Amperes-Hours/Hour
Mid-September (Mid-March is similar)

Hour	Pump Motor	Lights	Washing Machine	Sewing Machine	Refrigerators (Average Amps)	Instruments and Controls	Amperes Total
1					1.577	0.579	2.156
2					1.577	0.579	2.156
3					1.577	0.579	2.156
4					1.577	0.579	2.156
5					1.577	0.579	2.156
6					1.577	0.579	2.156
7		2.88			1.577	0.579	5.036
8					1.577	0.579	2.156
9			2.59		1.577	0.579	4.746
10			2.59		1.577	0.579	4.746
11	9.05		2.59		1.577	0.579	13.796
12	15.50		2.59		1.577	0.579	20.246
13	15.50		2.59		1.577	0.579	20.246
14	9.05		2.59	0.77	1.577	0.579	14.566
15			2.59	0.77	1.577	0.579	5.516
16			2.59	0.77	1.577	0.579	5.516
17			2.59		1.577	0.579	4.746
18			2.59		1.577	0.579	4.746
19			2.59		1.577	0.579	4.746
20		6.23	2.59		1.577	0.579	10.976
21		5.75			1.577	0.579	7.906
22		5.75			1.577	0.579	7.906
23					1.577	0.579	2.156
24					1.577	0.579	2.156

Table 6. Typical Load Profiles, Amperes-Hours/Hour (continued)

Mid-December

Hour	Pump Motor	Lights	Washing Machine	Sewing Machine	Refrigerators (Average Amps)	Instruments and Controls	Amperes Total
1					0.671	0.543	1.214
2					0.671	0.543	1.214
3					0.671	0.543	1.214
4					0.671	0.543	1.214
5					0.671	0.543	1.214
6					0.671	0.543	1.214
7		5.75			0.671	0.543	6.964
8		5.75			0.671	0.543	6.964
9		3.11	2.59		0.671	0.543	6.914
10			2.59		0.671	0.543	3.804
11	1.95		2.59		0.671	0.543	5.754
12	15.50		2.59		0.671	0.543	19.304
13	15.50		2.59		0.671	0.543	19.304
14	1.95		2.59	0.77	0.671	0.543	6.524
15			2.59	0.77	0.671	0.543	4.574
16			2.59	0.77	0.671	0.543	4.574
17			2.59		0.671	0.543	3.804
18		6.23	2.59		0.671	0.543	10.034
19		6.23	2.59		0.671	0.543	10.034
20		6.23	2.59		0.671	0.543	10.034
21		5.75			0.671	0.543	6.964
22		5.75			0.671	0.543	6.964
23					0.671	0.543	1.214
24					0.671	0.543	1.214

Table 6. Typical Load Profiles, Amperes-Hours/Hour (continued)

Mid-July

Hour	Pump Motor	Lights	Washing Machine	Sewing Machine	Refrigerators (Average Amps)	Instruments and Controls	Amperes Total
1					1.758	0.579	2.337
2					1.758	0.579	2.337
3					1.758	0.579	2.337
4					1.758	0.579	2.337
5					1.758	0.579	2.337
6					1.758	0.579	2.337
7					1.758	0.579	2.337
8					1.758	0.579	2.337
9			2.59		1.758	0.579	4.927
10	4.20		2.59		1.758	0.579	9.127
11	15.50		2.59		1.758	0.579	20.427
12	15.50		2.59		1.758	0.579	20.427
13	15.50		2.59		1.758	0.579	20.427
14	15.50		2.59	0.77	1.758	0.579	21.197
15	4.20		2.59	0.77	1.758	0.579	9.897
16			2.59	0.77	1.758	0.579	5.697
17			2.59		1.758	0.579	4.927
18			2.59		1.758	0.579	4.927
19			2.59		1.758	0.579	4.927
20			2.59		1.758	0.579	4.927
21					1.758	0.579	2.337
22		5.75			1.758	0.579	8.087
23		5.75			1.758	0.579	8.087
24					1.758	0.579	2.337

PHOTOVOLTAIC (PV) ARRAY AND BATTERY SIZING

General

The PV system sizing method used to determine the PV array size (kW_{pk}) and battery capacity of the Schuchuli system was developed by LeRC and consists of four separate steps:

- Identification of load voltage sensitivities and a determination of hourly load profile for 1 day each month;
- A determination of PV cell operating temperature and the required number of series cells in an array string;
- Use of a computerized array output calculation and system simulation program which is used to determine the number of parallel PV cells in the PV array and the battery capacity; and
- Determination of the number of series battery cells required.

Load Profile

A pivotal factor in the continuous annual operation of any PV system is the battery SOC during periods of maximum load and/or minimum insolation. A typical hourly load profile for 1 day for each month thus provides the designer with a realistic basis from which to calculate battery SOC. The details of the Schuchuli load profile, as discussed above, were incorporated in the PV system sizing simulation program which is described below.

Voltage Sensitivities

Two loads imposed voltage limitations on the system design: the pump motor and the fluorescent lights inverter/ballasts. The 2-hp 120-V motor cannot be operated with voltage above 130 V due to speed limitations of the jack pump, and the inverter/ballasts will not start the fluorescent lights with voltage below approximately 105 V.

Number of Series PV Cells

PV cell temperature is an important factor in PV array sizing because it affects the number of series cells required to satisfy system voltage requirements. Because cell maximum power voltage decreases with increasing temperature at the rate of approximately $2.0 \text{ mV}/^{\circ}\text{C}/\text{cell}$ with a concomitant decrease in cell output power, summertime cell temperatures must be considered to avoid serious power output shortfalls during the summer months.

The Schuchuli PV array was designed to operate near maximum power output in summer to provide enough energy to ensure battery recharge prior to the next winter season, to provide a reserve to pump more water in the event of dry periods and consequent need to water stock, and to provide a margin for higher than anticipated refrigerator operation in the hot summer months.

Cell operating temperature can be estimated from the expression:

$$T_{\text{cell}}(^{\circ}\text{C}) = T_{\text{air}}(^{\circ}\text{C}) + 0.3 L$$

where L = insolation in mW/cm^2 .

For Schuchuli, average daytime summer temperatures are at or above 35°C (95°F) (Table 7) and average insolation was assumed to be $80 \text{ mW}/\text{cm}^2$; thus, cell operating temperature was calculated to be approximately 60°C .

Cell maximum power voltage at 60°C is obtained from the expression

$$V_{T2} = V_{T1} - 2.0 \text{ mV}/^{\circ}\text{C}/\text{cell}(T_2 - T_1).$$

For the 42 series cell Solorex Model 9200J module used for this project, maximum power voltage at 28°C is 19.15 volts based on LeRC measurements and is 16.46 volts at 60°C .

The nominal system bus bar voltage for this system was selected as 120 V(d.c.) primarily to minimize distribution line wire size and I^2R losses while at the same time providing for the use of universal motors (sewing machines) and other commercially available equipment. The number of series connected PV modules required to provide a nominal 120 V(d.c.) at the system bus bar was determined as eight from the following considerations:

8 series connected modules at 16.46 V/module	131.68 Volts
Less: Blocking diode drop (@ 1 ampere)	0.80
400 ft of No. 14 wire from array to PCCIA (@1 ampere)	1.01
Series string current measuring resistor (1.0 ohm) @ 1 ampere	1.0
Miscellaneous contacts	0.02
	<hr/> 128.85 volts

Description of Sizing Program

The size of the Schuchuli PV power system, i.e., PV array peak kW and battery capacity, was determined using the LeRC computerized PV

System Sizing Program. The program consists of two parts: a determination of the hourly current output for the selected PV cell at the selected site, and a system simulation that compares hourly PV array output with the hourly load profile to determine a running tabulation of battery SOC.

It should be noted that the LeRC sizing is carried out on an ampere-hour basis. Thus the ampere-hour output of a single module (or a string of series connected modules) is the same as for a single cell. The ensuing discussion, therefore, refers to single cells but should be understood in the context of a string of series connected modules. The final determination of array size in kW_{pk} is therefore the product of the number of series connected modules/string, the number of parallel strings, and the peak power/module. The cell output calculation uses site latitude and site-specific average monthly values of insolation, sky cover, atmospheric precipitable water, and atmospheric turbidity to calculate the direct and diffuse sunlight components. These data are then combined with the characteristics of a single cell (area, efficiency, and maximum power voltage) of the module selected for the application to determine cell output (ampere-hours) for each month and at several different PV array tilt angles. This matrix (see Table 8) is then used to identify the optimum tilt angles to input into the array output calculations in the system simulation program. The number of tilt angle changes per year is based on the amount of additional array output achieved and the availability of personnel to change the tilt angle.

An array degradation factor can be included to account for array output reduction due to dust accumulation, encapsulation darkening, cell mismatch losses, etc. And, in order to introduce random four-day weather cycle variability into the daily cell output profile, the average daily insolation value for each month can be randomly varied within defined limits every fourth day.

The system simulation program combines the hourly array output profile (cell profile times number of parallel strings) for each month with the composite hourly load profile for that month to determine battery DOD on an hourly basis.

Each sizing "run" is for a 16-month period to ensure that the initial condition of a fully charged battery does not mask any annual effects. When using randomized cell output data, the 16-month simulation is run 10 times, each time with differently randomized cell outputs, to identify the worst case DOD.

The output of the simulation program may be in either of two forms: a summary listing of system status at 0600 hours every 30th day from start of simulation (Figure 23) or an hourly listing for every 11th day from start of simulation (Figure 24), or both. Included with the summary listing is the value of maximum DOD in the simulation period and the run day on which it occurs.

Schuchuli Sizing

The insolation and other atmospheric data used for the array output calculation are shown in Table 7. An array degradation factor of 20 percent was used based on LeRC soiling tests and the prevalence of dust from a nearby dirt road in the village. The randomization limits were ± 20 percent, there not being too much variability in day-to-day weather in southwest Arizona.

Table 8 shows the cell (or series string) output as a function of tilt angle and time of year. It was determined that quarterly tilt angle changes would provide significant increase in array output without burdening local operating personnel. The tilt angles selected are: 11° for the summer, 35° for spring and fall, and 48° for winter.

In a normal sizing operation, the designer is free to vary the size of the PV array and battery capacity to achieve his particular technical or economic design goals. The Schuchuli system sizing was somewhat constrained in that the DOE module allocation for the Schuchuli project was 3650 W (based on JPL maximum power rating of 18.6 W/module at 100 mW/cm² and 60°C cell temperature). In the interest of minimizing battery capacity, almost all of the allocation (3571 W) was used as a fixed parameter in the system sizing. The "sizing" thus reduced to calculating the appropriate size battery for a given array.

The battery cell selected for this system is from the 1.300 specific gravity lead-calcium grid lead-acid cells designed and manufactured specifically for PV systems by the C&D Batteries Division of The Eltra Company. These cells have the advantage of low gassing resulting in low water consumption, low self-discharge, constant charge voltage over cell lifetime, large electrolyte capacity, large individual cell capacities which eliminated the need for paralleled cells and attendant charge balancing problems, and a potential cycle life of 1600 80 percent DOD cycles.

The inputs to the system simulation program were the composite load profile shown in Table 6 and an array size of 24 series strings of Solorex 9200J modules tilted seasonally as described above. The sizing goal was to limit battery maximum DOD to 80 percent or less in the worst case situation (vis-a-vis randomization). Load shedding was not included in the system simulation which resulted in a somewhat conservative design approach.

Sizing Results

The results of the system simulation sizing indicated that, for the 3571-W PV array, 1815 ampere-hours of battery capacity are needed to keep maximum DOD to 80 percent or less.

The next larger available C&D cell size was 1925 ampere-hours and cost \$248.00. Due to peculiarities of cell costing, the C&D 2380-ampere-hour cell cost \$257.00. An added cost of \$9.00 (3.6 percent per cell) thus

provided a 455 ampere-hour or 23.6 percent increase in cell capacity. The 2380 ampere-hour cells were therefore selected with the result that calculated maximum DOD was reduced to 61 percent, which also would tend to increase battery life.

Pilot cell capacities selected on the basis of nominal 50, 10, 10, and 10 percent capacity increments of the 2380 ampere-hour cell were 1055 and 310 ampere-hours. The total pilot cell capacity is therefore 1985 ampere-hours, or 83 percent of the capacity of the main cells, and is distributed in 44, 13, 13, and 13 percent increments.

The results of the system simulation sizing for the original design conditions, but with a 2380-ampere-hour battery, are shown in Figure 23. Note that the maximum DOD of 61 percent occurs on run day 460 which corresponds to January 30, based on a simulation start day of Julian day 300 (October 27). Figure 24 is an hourly listing for run days 463 and 474 from this simulation and gives the reader some insight into the hourly status shortly after maximum DOD occurs. A computer projected main battery state-of-charge annual profile is shown in Figure 25.

Number of Series Battery Cells

The number of series battery cells required is determined from such considerations as manufacturer's recommended float voltage and maximum and minimum voltage limitations of the various loads.

Battery manufacturer's recommended float voltage varies with temperature at the rate of $-5 \text{ mV}/^{\circ}\text{C}/\text{cell}$ ($-2.8 \text{ mV}/^{\circ}\text{F}/\text{cell}$), i.e., lower float voltages at higher temperatures. Battery temperatures at Schuchuli were estimated to range from 32°C (90°F) in summer to 4.4°C (40°F) in winter. Corresponding float voltages are 2.42 volts/cell at 32°C (90°F) and 2.56 volts/cell at 4.4°C (40°F).

Instantaneous system voltage for the Schuchuli system is determined by battery state-of-charge and charge or discharge current. As was shown in the system simulation, with the onset of winter and decreasing array output, the battery will gradually discharge until seasonal insolation increases to the extent that average daily array output exceeds the average daily loads. Because the battery would be in a discharged condition during winter, and, therefore, well below maximum float voltage for winter, the summer float voltage became the critical factor in determining the number of series battery cells. Thus, the number of series battery cells needed to satisfy the summertime voltage constraint was:

$$\frac{130 \text{ V (nominal maximum system voltage)}}{2.42 \text{ V/cell (32}^{\circ}\text{C (90}^{\circ}\text{F) float voltage)}} = 53 \text{ cells}$$

System minimum voltage was determined from the discharge voltage at the 500 hour rate and at 80 percent DOD. The manufacturer's recommended value for these conditions was approximately 1.98 V/cell. Thus for 53 series cells, the system minimum voltage would be approximately 105 volts, the approximate minimum required to start the fluorescent lights.

Table 7. Insolation and Weather Data*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambient Temperature °F ¹ Max.	65	70	75	85	90	100	100	100	95	85	75	65
Min.	40	40	45	50	60	65	75	75	70	60	42	40
Ave.	52	55	60	70	75	85	90	90	82	72	60	55
Mean Sky Cover ¹	0.5	0.4	0.4	0.3	0.2	0.2	0.4	0.3	0.2	0.3	0.3	0.4
Daily Insolation ¹ (Langley's)	315	391	540	655	729	699	626	588	570	442	356	305
Precipitable Water ² (cm)	1.09	0.97	0.99	1.25	1.5	1.76	2.8	2.75	2.5	1.7	1.0	1.2
Atmospheric Turbidity ³	0.05	0.05	0.06	0.073	0.073	0.073	0.08	0.085	0.08	0.07	0.065	0.07

*Values shown are daily average values for the month.

¹Climatic Atlas.

²Bulletin of the American Meteorological Society, Feb. 1960.

³Journal of Applied Meteorology, Dec. 1969.

Table 8. PV Cell Output, Tilt Angle vs Time of Year

Cell: SXII

NASA-Lewis Research Center
Cleveland, Ohio

Single String Output; Amp-Hr/Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tilt Angle: 3.5	163	183	273	318	364	339	316	300	283	229	179	157
Tilt Angle: 11	178	198	285	323	362	334	313	302	292	244	196	173
Tilt Angle: 18.5	191	210	293	324	356	324	305	299	297	254	210	186
Tilt Angle: 26	201	218	297	319	343	309	293	292	297	261	221	196
Tilt Angle: 33.5	208	223	296	311	327	290	276	281	293	265	228	203
Tilt Angle: 41	212	225	291	298	305	267	256	266	285	264	232	208
Tilt Angle: 48.5	214	224	283	280	280	240	233	247	272	260	233	210
Tilt Angle: 56	212	219	270	259	251	211	207	224	256	251	231	208

Summary Listing

RUN DAY	HCUR	YEAR DAY	ARRAY (AMPS)	LOAD (AMPS)	DPTH DSCG	SURPLUS	30 DAY SURPLUS

1	6	300	0.0	1.18	0.00	0.0	0.0
31	6	330	0.0	0.85	0.11	0.0	88.8
61	6	360	0.0	0.67	0.27	0.0	0.0
91	6	25	0.0	0.63	0.48	0.0	0.0
121	6	55	0.0	0.74	0.47	0.0	0.0
151	6	85	0.0	0.89	0.11	0.0	0.0
181	6	115	2.7	1.10	0.01	0.0	1291.6
211	6	145	4.7	1.32	0.01	0.0	1959.6
241	6	175	3.5	1.58	0.01	0.0	1218.5
271	6	205	4.7	1.76	0.01	0.0	705.4
301	6	235	2.3	1.74	0.12	0.0	273.1
331	6	265	1.3	1.58	0.02	0.0	465.5
361	6	295	0.0	1.18	0.10	0.0	551.5
391	6	325	0.0	0.85	0.16	0.0	0.0
421	6	355	0.0	0.67	0.30	0.0	0.0
451	6	20	0.0	0.63	0.54	0.0	0.0
481	6	50	0.0	0.74	0.57	0.0	0.0
MAXIMUM DEPTH OF DISCHARGE= 0.61 OCCURED ON RUN DAY # 460							

Figure 23. Summary Listing for Final Sizing

RUN DAY	HCUR	YEAR DAY	ARRAY (AMPS)	LOAD (AMPS)	DPTH DSCG	SURPLUS	30 DAY SURPLUS

463	1	32	0.0	0.74	0.60	0.0	0.0
463	2	32	0.0	0.74	0.60	0.0	0.0
463	3	32	0.0	0.74	0.60	0.0	0.0
463	4	32	0.0	0.74	0.60	0.0	0.0
463	5	32	0.0	0.74	0.60	0.0	0.0
463	6	32	0.0	0.74	0.60	0.0	0.0
463	7	32	1.9	6.50	0.60	0.0	0.0
463	8	32	6.9	3.62	0.60	0.0	0.0
463	9	32	12.5	4.94	0.60	0.0	0.0
463	10	32	17.5	4.94	0.55	0.0	0.0
463	11	32	21.4	6.90	0.55	0.0	0.0
463	12	32	23.6	20.44	0.55	0.0	0.0
463	13	32	23.6	20.44	0.55	0.0	0.0
463	14	32	21.4	7.70	0.58	0.0	0.0
463	15	32	17.5	5.74	0.58	0.0	0.0
463	16	32	12.5	5.74	0.57	0.0	0.0
463	17	32	6.9	3.34	0.57	0.0	0.0
463	18	32	1.9	9.58	0.58	0.0	0.0
463	19	32	0.0	9.58	0.58	0.0	0.0
463	20	32	0.0	9.58	0.58	0.0	0.0
463	21	32	0.0	6.50	0.55	0.0	0.0
463	22	32	0.0	6.50	0.55	0.0	0.0
463	23	32	0.0	0.74	0.55	0.0	0.0
463	24	32	0.0	0.74	0.55	0.0	0.0

474	1	43	0.0	0.74	0.57	0.0	0.0
474	2	43	0.0	0.74	0.57	0.0	0.0
474	3	43	0.0	0.74	0.57	0.0	0.0
474	4	43	0.0	0.74	0.57	0.0	0.0
474	5	43	0.0	0.74	0.57	0.0	0.0
474	6	43	0.0	0.74	0.57	0.0	0.0
474	7	43	1.5	6.50	0.57	0.0	0.0
474	8	43	5.3	3.62	0.57	0.0	0.0
474	9	43	9.7	4.94	0.57	0.0	0.0
474	10	43	13.5	4.94	0.57	0.0	0.0
474	11	43	16.5	6.90	0.56	0.0	0.0
474	12	43	18.2	20.44	0.56	0.0	0.0
474	13	43	18.2	20.44	0.57	0.0	0.0
474	14	43	16.5	7.70	0.56	0.0	0.0
474	15	43	13.5	5.74	0.56	0.0	0.0
474	16	43	9.7	5.74	0.56	0.0	0.0
474	17	43	5.3	3.34	0.56	0.0	0.0
474	18	43	1.5	9.58	0.56	0.0	0.0
474	19	43	0.0	9.58	0.56	0.0	0.0
474	20	43	0.0	9.58	0.57	0.0	0.0
474	21	43	0.0	6.50	0.57	0.0	0.0
474	22	43	0.0	6.50	0.57	0.0	0.0
474	23	43	0.0	0.74	0.57	0.0	0.0
474	24	43	0.0	0.74	0.57	0.0	0.0

Figure 24. Hourly Listing for Run Days 463 and 474

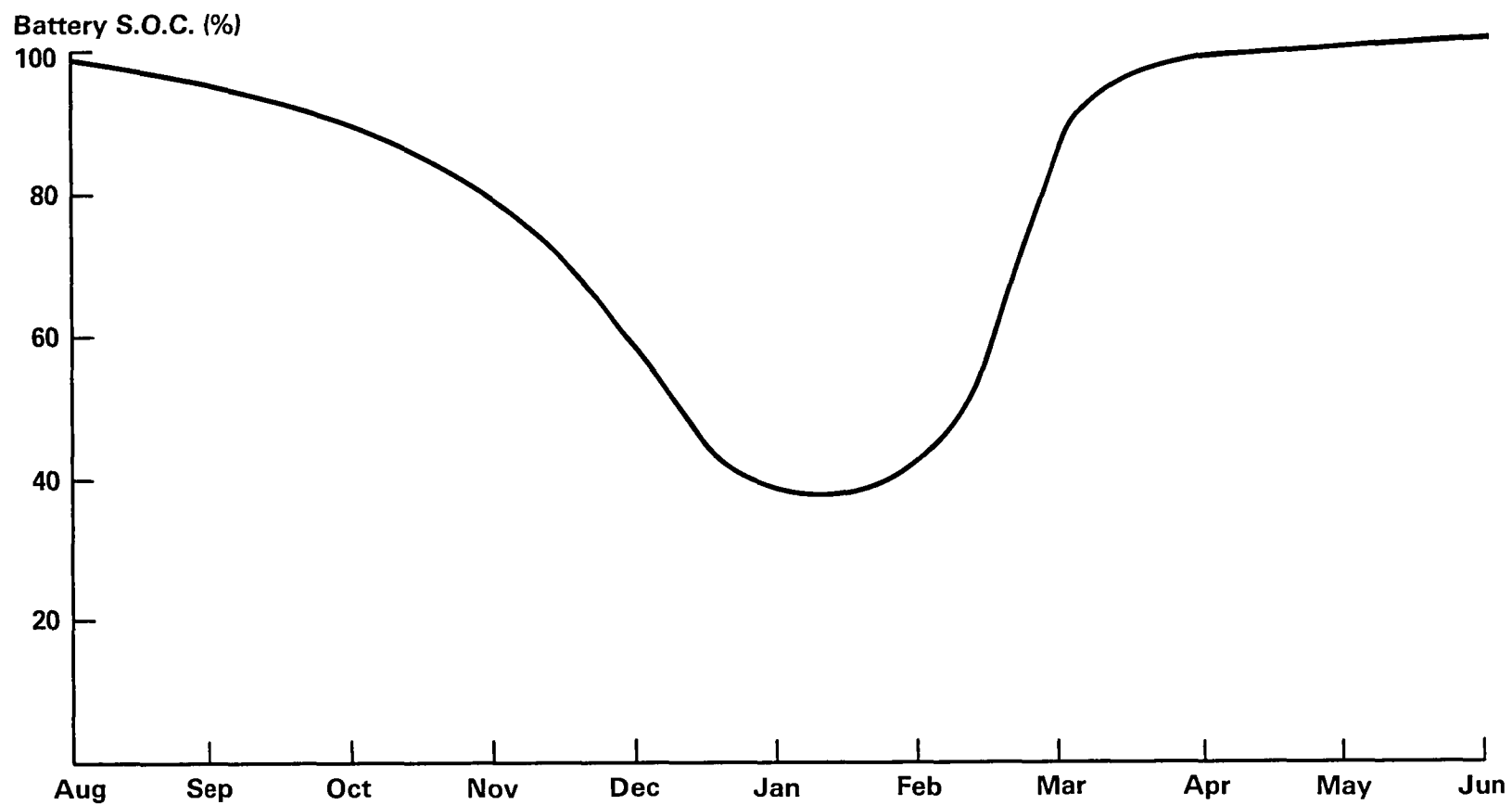


Figure 25. Computer Projected Battery State of Charge Profile

MECHANICAL DESIGNS

Site Layout

The village is about 1/4 mile south of State Route 86 and consists of 18 homes, a church, feast house, miscellaneous sheds, and a large corral. The village site and location plan is shown in Appendix A, Drawing No. CF 56376, which also shows locations of the pumps, the water and electrical distribution systems, the PV array, the EEB, and the DSB.

The EEB and PV array are located near the western edge of the village adjacent to the existing new drilled well. This location provides several advantages. It is reasonably removed and isolated from the normal village activities, thereby minimizing accumulation of dust and dirt on the arrays. It is close to the existing well and pump and thus forms the village utility system area.

The DSB is located in the southeast portion of the village, near the other existing community buildings--the church and feast house. This location was selected by the villagers.

The water distribution system was already in place around the village. The power line and poles were located by the PTUA in the general vicinity of the water line to establish a utility corridor around the village.

Array

The array consists of 24 panels arranged in 3 rows of 8 panels each. The array area is bounded by a 6-ft commercial grade chain link fence, topped with 3 strands of barbed wire. Access to the area is gained through a 12-ft double swing vehicular gate at the southwest corner of the area. The gate is kept locked for security reasons.

The array structure is shown in Appendix A, Drawing No. CF 56378. The panel frames and supporting structure are designed to resist the aerodynamic loads from a 100-mph wind in any of the positions of tilt for the array panels. These structures are made up of pre-formed "superstrut" components with bolted fabrication. The panels and structure were assembled in Cleveland, Ohio, by a NASA LeRC contractor. This design was employed to minimize the on-site fabrication and assembly time and to eliminate the need for specialized work skills at Schuchuli. The design permits manual setting of the panel tilt angle to any of 3 settings; i.e., 11°, 35°, and 48° from the horizontal. As noted on the drawing, the height of the support posts are stepped, south to north, at 3 ft 9 in., 4 ft 3 in., and 4 ft 9 in. to reduce the spacing between rows while eliminating shadowing with low sun angles. The design was kept simple and direct to facilitate ease of construction and maintenance including the quarterly resetting of tilt angle and the possibility of panel replacement.

Buildings

Two buildings were constructed to house elements of the power system: the Electrical Equipment Building and the Domestic Services Building. Both buildings have one story and are of standard block wall and concrete slab floor construction. Both buildings contain insulation in the wall block cores and the ceiling and have turbine ventilators on the roof to aid ventilation.

The EEB architectural plans, elevations, and details are shown in Appendix A, Drawing No. CF 56377. This building contains two rooms, one for electrical equipment and storage and the other for batteries. The electrical equipment room contains the PCCIA, main circuit breaker panel, pump motor starter, DAT-3, EWS recorder and battery, and a storage cabinet. The battery room contains the 120-volt and 12-volt batteries, fused switches, disconnects, and an emergency eyewash and shower.

The DSB, except for electrical wiring, was provided by the PTA and constructed to the same general specifications as the EEB. The building layout is shown in Appendix A, Drawing No. 56379. The DSB contains the 15 refrigerator/freezer units, a washing machine and tubs, a sewing machine, two ceiling lights, a control panel for effecting load management functions, and a circuit breaker panel. A solar thermal hot water heater is located on the roof to supply hot water for the laundry.

ELECTRICAL DESIGNS

General

The electrical system has been described in the section on system description and the individual sections covering the array, battery, and instrumentation and control. The electrical system is shown diagrammatically in Figure 7 and the system drawings and schematics are contained in Appendix A, Drawings No. CF 56379 through CF 56382. The Electrical One Line Diagram (Drawing CF 56380) shows the basic electrical system. Power from the array and battery is distributed to the loads through a 40-ampere main load shunt trip circuit breaker located in Power Panel P1. Five major load buses emanate from P1 and each is protected by a circuit breaker. The load bus to the DSB is protected by two circuit breakers, one in the EEB and the other in the DSB. The circuit breaker in the DSB provides for additional personnel safety in the DSB which is located 1500 feet from the EEB.

Array

The 192 Solarex model 9200J PV modules in the PV array are arranged in 24 panels of 8 modules each. The 8 modules in each panel are connected in series to form a nominal 120-volt string. The details of the panel wire harness are shown on Drawing CF 56380. Power from each panel is routed to a junction box at the end of each row and then cabled underground into the PCCIA in the EEB. Note that there is a disconnect plug in the center of each harness in addition to the disconnect plug which connects the panel to the system cabling. When both plugs are disconnected, the array panel is segmented into four groups of two series connected modules. The maximum open circuit voltage of a panel is thus reduced to less than 50 volts, the commonly accepted minimum lethal d.c. voltage.

The complete circuit for each array panel is shown in lines 1 through 47 of Drawing CF 56381. Except for the panels, all of the other array circuit elements are in the PCCIA. The fuses are included to protect circuitry from lightning-induced surges. The physical orientation of the fuse switch is designed for safety purposes to de-energize the exposed contact when the array strings are removed from the system bus and when CB1 is open. The diodes serve to prevent battery discharge through the strings at night. The relay contacts are the solid-state relays (SSR) used for array string switching in conjunction with system voltage control. The 1.0-ohm resistor in each string is used in conjunction with the panel meter and DAT-3 to monitor individual string currents.

The total array output is carried by the 40-ampere circuit breaker CB1 (lines 51 through 55, Drawing CF 56381). CB1 is a shunt trip circuit breaker and can be actuated in three ways: (1) manually when being used to disconnect the array during maintenance operations in the PCCIA, (2) automatically in conjunction with over-voltage conditions (see controls discussion), and (3) remotely by the system emergency OFF switch (lines 72, and 246, Drawings CF 56381 and CF 56382). The Neon glow lamp (line

53) across CB1 is intended as an operator alarm of a system problem, as is the audible alarm (line 171, Drawing CF 56381).

The array is protected from lightning by an extensive grounding circuit. The frame of each module is connected to a separate ground harness (Drawing CF 56380), which is attached to the array panel frame and support structure. The support structures are in turn connected to a No. 4/0 ground wire buried about 15 inches below grade (Drawing CF 56379). The array field fence and the Climatronics weather station tower are also attached to the ground wire. The fence gives added lightning protection to the array field. There are six 1-in. by 10-ft grounding rods located on the periphery of the ground system. In addition, the ground wire is connected to the well casing which also serves as the ground point for the EEB. All connections to the No. 4/0 ground wire, as well as splices in the wire system, are thermite welds.

Batteries

The main battery consists of the 52 C&D model LCPSA-19 cells rated at 2380 ampere-hours and 4 pilot cells; 1 C&D model KCPSA-15 rated at 1055 ampere-hours, and 3 C&D model DCPSA-15 cells each rated at 310 ampere-hours. The 52 2380 A-H cells are connected in series. The four pilot cells are connected in parallel to form the 53rd cell in the series string. The cells and other associated circuit components are shown in lines 72 through 99 of Drawing CF 57381 and Elevation D of Drawing CF 56379.

The battery is isolated by a circuit breaker and several fused disconnects. Circuit breaker CB13 is a shunt trip circuit breaker which is actuated by the system emergency OFF switch S10B. CB13a and CB13b are used to disconnect the main and I/C batteries, respectively. Fuse switch S7 contains a 40-ampere fuse. Switches S7, S7A, and S7B are designed to sectionalize the battery into four series strings (three 32-volt strings and one 17-volt string) to provide personnel safety during maintenance operations. Switch S7C isolates the pilot cells.

The voltage regulation control meter relay (V1) is connected to the positive battery bus at the battery so as to minimize line drops and their subsequent effect on the battery control. Meter relays V4, V5, V6, and V7 and relay contacts CR27, CR29, CR31, and CR33 are used as part of the load management system and are described below.

The I/C battery consists of six C&D model KCPSA-15 cells rated at 1055 ampere-hours as shown in Elevation D of Drawing CF 56379 and on Line 217 of Drawing CF 56382. This battery is kept charged by a 120-V(d.c.) to 12-V(d.c.) converter and is protected by circuit breakers CB13 and CB11 (lines 217 through 222, Drawing CF 56382). CB13b is one set of contacts of the shunt trip circuit breaker actuated by the emergency OFF switch S10B.

There are two thermistors associated with the batteries. One senses battery room air temperature approximately 5 feet above the floor, and the other is inserted in the electrolyte in one of the main battery 2380-ampere-hour cells located in the top tier of the battery rack.

Controls

An electromechanical system voltage and load management control system was selected for Schuchuli because it can be understood and maintained by technicians familiar with electric utility systems. The control system consists of meter relays that sense system voltage and current parameters and feed control signals to a programmable drum relay, or drum programmer (DP). The DP in turn drives electromechanical and solid-state relays which control system functions. Table 9 lists the major control subsystem elements and their functions.

To understand the control subsystem, the reader must understand the way the DP interfaces with the other control system elements. Figure 26 is a reproduction and elaboration of the Drum Programmer Schedule shown in Drawing CF 56382. Rather than describe in detail each of the various control circuits (most of which are understandable by readers familiar with electromechanical controls), only those aspects or features of the controls which cannot be readily understood from the schematics are described below. For these descriptions, line number references will be to the electrical schematics of Drawings CF 56381 and CF 56382.

1. The meter relay contacts are in the "normal" position when the value of the parameter being sensed is between the high and low limit settings and when 12-volt power is applied to the meter relay.
2. Whenever possible, control relays were designed to function in the unenergized mode so as to conserve energy. However, relays in safety-related circuits operate normally in the energized mode so as to fail safe in the event of loss of power.
3. The control system incorporates an over- and an under-voltage protection feature which protects the system in the event the normal controls fail. Over-voltage protection prevents damage to controls, battery, and loads. Under-voltage protection prevents excessive battery discharge. The over- and under-voltage protection circuits use normally energized relays CR41 and CR42 and meter relay V1a to actuate circuit breakers CB1 and CB2. V1a (Hi) contacts de-energize CR41 which trips CB1, disconnecting the PV array from the main bus. V1a (Lo) contacts de-energize CR42 which trips CB2 and disconnects all 120-volt loads.
4. The DP uses a 120-V, 60-Hz stepping motor and stepping interval timer. The inverter which inverts 12 V(d.c.) to 120 V(a.c.) (Line 310) requires a regulated 12-V input in order to provide a 117- to 120-V(a.c.) output to the stepping motor and the stepping timer (CA timer, line 312). Because the 120-V(d.c.) to 12-V(d.c.) converter outputs 13.6 volts to keep

the I/C battery charged, a 12-V regulator (lines 307 and 308) was required to provide 12 volts to the input of the inverter.

5. Because of the number of switches and relay closures associated with DP stepping, it is possible that before the stepping process is completed, the actuating device (i.e., V1, V4, V5, V6, V7, or A15) may open its contact. This would de-energize stepping motor control relays CR50 or CR51 (lines 290 and 304, and 311 and 312) and remove the 12-V power to the DP in mid-step. Relay CRAC (lines 309 and 311) ensures that power is applied to the DP until the stepping process is completed.

6. Referring to lines 292 and 303, note that V1 (Hi) can drive the DP "up" when the system is operating under pilot cell control. This bypass or override feature is necessary because there are combinations of high battery charge current, moderate to high main battery state-of-charge and moderate to low pilot cell states-of-charge which can result in system (V1) voltages in excess of 130 volts while pilot cell voltage can be less than the V4, V5, V6, or V7 (Hi) settings. This situation is most likely to occur when pilot cell No. 1 is connected to the main battery because, for a given main cell state-of-charge, a discharged or discharging pilot cell may have a substantially lower state-of-charge than the main (2380-ampere-hour) cells. For very high array charging currents, it is thus possible for the 52 main cells to be driven to or above float voltage while the same current charging a more deeply discharged single pilot cell drives it to something less than its float voltage. Under these conditions, system voltage can exceed V1 (Hi) (130 V) and reach the system over-voltage limit ($V1A(Hi) = 138$ volts) and cause CB1 (PV array circuit breaker) to be tripped. By providing the option for V1 (Hi) control when in pilot cell control, system voltages above 130 volts ($V1(Hi)$) can be avoided by progressively switching to the next higher pilot cell until all pilot cells are paralleled, and array string switching can occur.

7. When the DP is in position 1, a special step-up logic and an additional relay (CR 43) is required to prevent the DP from stepping directly from position 1 to position 3 without remaining in position 2. The DP is stepped from position 2 to position 1 by V7 (Lo) N.O. contact (line 295) when the V7 voltage drops below the V7 (Lo) limit. In position 1, the refrigerator/freezer circuit is turned off by CR37 (line 276), and CR43 (line 278) is energized. When the V7 voltage goes above the V7 (Lo) limit and A15 is greater than 6 amperes, the DP is stepped from position 1 to position 2 by the V7 (Lo) N.C. contact, the CR43 N.O. contact (line 302), and the A15 (Hi) contact (line 303). In position 2, CR43 is de-energized, and the refrigerator/freezer circuit is turned on. The DP is stepped from position 2 to position 3 by the V7 (Hi) N.O. contact (line 301), the CR43 N.C. contact (line 301), and the A15 (Hi) contact.

8. The water pump motor controls are shown in two places. The power circuit to the pump motor is shown in lines 100 to 105, and the controls circuits are shown in lines 277 to 286. From a system efficiency and cost standpoint, it is better to store water than to store energy. The pump motor controls are therefore designed to allow normal pump operation

only during daylight hours, or more specifically, only when the PV array is generating more than 3 amperes. The control logic is arranged such that when the array output is ≥ 3 amperes, the pump will come on when the water level in the water storage tank has dropped about 18 inches below the full level. Once turned on, the pump will operate until the tank is full. In the event of heavy water use at night, the pump will come on when the tank is approximately half full and continue to pump until the tank is full.

Referring to lines 275 to 286, there are four elements involved in pump motor operation: adjustable pressure switches (PS1, PS2, and PS3) located near the bottom of the water storage tank that sense various water levels; the high limit contacts of A1 acting through CR39; DP switch 26 acting through CR25; and load management status control acting through DP29 and CR36.

When the water level in the tank drops about 18 inches below the full level, PS2 closes to provide power to the motor starter through relay contacts CR39 and/or CR25. The CR39 contacts are closed when array current exceeds the A1 (Hi) setting of 3 amperes. This restriction is intended to minimize pilot cell discharge when the system is under pilot cell control (DP position 5 or 4) by deferring pump operation until array output reaches a significant portion (3 amperes) of the average pump load (7 amperes). The CR25 contacts, which are closed when the system is in V1 control (i.e., DP positions 6 through 24 and all pilot cells connected in parallel and normally charged), allow pump operation to be independent of array output.

When PS2 closes and either CR39 or CR25 is closed, power is applied to the start (S) relay and to the 3-second timer (TR, line 282) of the 2-step pump motor starter. A 2-step motor starter is used for the 2-hp permanent magnet motor to avoid high starting currents and possible demagnetization. Starting voltage is applied to the motor through (S) contacts in series with a starting resistor (line 102). After 3 seconds, timer contacts TR close applying power to run relay (R) which: (1) de-energizes starter relay (S) which disconnects the starter resistor, (2) applies line voltage to the motor (line 104), and (3) causes (R) to latch itself in through its (R) contacts in series with its coil (line 283) and its RUN (R) contacts in series with PS1 (line 284) which contacts are closed when the water level is below full. When the tank is full, PS1 opens de-energizing (R) which opens the (R) contact in series with the motor (line 104).

PS3 closes when the tank level falls below half full and causes the pump to operate regardless of array output until the tank is full. The pump will not come on at all when the main battery is discharged beyond approximately 70 percent DOD and the system switches to pilot cell No. 4 control (DP position 2 or 1).

The lights L1, L2, L3, and L4 (lines 281, 283, and 285) are located in the PCCIA to indicate the status of the level switches which are located at the water tank which is approximately 1500 ft from the PCCIA. Although the pump normally operates in an automatic mode, it can be

operated manually, regardless of the water level, by means of the Auto/Hand switch (lines 280 and 281). The pump may be stopped at any time by (1) pushing the EMERGENCY STOP push button switch (line 280) or (2) switching the Auto/Hand switch to the OFF position.

9. Terminals T5-83, 84, 87, 88 (lines 305 and 306) are included in the DP for an external controller to control the DP position. This control is enabled by switching S9 from the LOCAL to the DAT-3 positions. This provision was incorporated because the DAT-3 contains microprocessor circuits which could be used to control the system at some later time. To use the DAT-3 for control would, however, require additional programming of the DAT-3 and would also eliminate the separation of the DAT-3 data recovery function from the system control function thus running the risk of losing both control and monitoring capacity should certain parts in the DAT-3 fail.

Instrumentation

The bulk of the instrumentation is for diagnostic purposes for this experimental system and would not be required for the operation of a similar system. The instrumentation consists of 17 ammeters, 17 ampere-hour meters, 8 voltmeters, 8 runtime meters, 2 water meters, a sample temperature sensor at the center of the array, the DAT-3 automatic data recorder, and the self-contained EWS as previously described. Figure 27 illustrates the instrumentation layout, and Table 10 defines their functions and ranges (See Drawings CF 56381 and 56382).

Instrumentation for individual PV array strings consists of a voltmeter V2 (Drawing CF 56381, line 55) to indicate the string voltages and a millivoltmeter MV1 (Drawing CF 56381, line 55) to indicate the string currents. A two-deck, 28-position switch, SS1 in Row 2, is used to select individual array string voltages and currents. A momentary push button switch, S6 in Row 2, is used to check the string short circuit current for the individual strings.

Ampere-hour meters AH3 through AH7 and AH15 are dual ampere-hour meters. One section measures the ampere-hours of charge the battery or cell receives. The other section measures the ampere-hours of discharge supplied by the battery or cell.

A1, A15, V1, V1a, and V4 through V7 are meter relays which have two set points and are used to initiate control action. The normally open (N.O.) and normally closed (N.C.) convention used in Drawings CR 56381 and CF 56382 for the meter relays are reversed compared to the meter relay manufacturer's information. The manufacturer's convention is the position of the relay contacts when the meter relay is de-energized whereas the convention used in the drawings is with the meter relay energized and the meter reading between the two set points.

A thermistor signal conditioner, THC (Drawing CF 56381, line 170) includes bridges and amplifiers that are used to condition the thermistor signals. Temperature measurements include: (1) PV module in the array,

(2) main battery electrolyte, (3) pump motor, (4) a sample refrigerator, (5) a sample freezer, and (6) ambient air in the battery room.

The temperature readout meter in Row 10 of Figure 27 and the refrigerator compressor current meter in Row 13 of Figure 27 each uses six position selector switches for selecting individual parameter readouts.

The I/C system measurements are for voltage (V3), current (A3), and ampere-hours (AH3). The 120-V power for the I/C system is measured by the AH16 ampere-hour meter.

The DAT-3 automatic data recorder monitors the parameters shown in Figure 11. It uses the same sensors as the panel meters; the connections are marked T-5 on the drawings (CF 56381 line 49 and CF 56382 line 305). Measurements are automatically taken every 20 seconds and recorded on cassette tape once an hour on the hour. The average maximum and/or minimum value for the preceding hour and/or the instantaneous value on the hour may be selected for recording by a software program in the DAT-3. The tapes are changed once a week and sent to LeRC for computer reduction of the data. The type data taken at each test point are shown in the column labeled "Data Type" of Figure 11.

Distribution

The distribution system consists of overhead wires carried on wooden poles provided by the PTUA as shown on Drawings CF 56376 and 56379. This system consists of two circuits of two wires each--a two-wire system provides power from the EEB to the DSB (to panel No. 2) and the two-wire village light system loop which serves the homes, church, and feast house including the drops to each building. It should be noted that the I/C cabling to the DSB is carried on the distribution poles. A fifth (topmost) wire on the distribution poles is a grounding wire for lightning protection.

Cabling

The cabling from the array to the EEB is buried underground in galvanized conduit (Drawing CF 56379). All other cabling is carried in galvanized conduit and, where external to the buildings, is underground (i.e., EEB to pump motor).

Table 9. Control System Elements and Their Functions

Element and Location	Function
Drum Programmer DP (lines 290–304)	<ul style="list-style-type: none"> • Part of the Electromechanical Logic System Under Control of Various Meter Relays Which: <ol style="list-style-type: none"> (1) Switches PV Array Strings On and Off for System Voltage Control. (2) Switches Individual Pilot Cells In and Out When in Main Battery Discharge Mode. (3) Disconnects and Reconnects Load Circuits When Load Management Is Being Effected in Response to > 50% DOD of Main Battery Cells.
V1 (Meter-Relay, Line 72) "System Voltage Regulation"	<ul style="list-style-type: none"> • Displays System Voltage Sensed at Main Battery Terminal. • High Limit (130V)—Initiates Array String Disconnect: <ol style="list-style-type: none"> (1) Reduce Array Output (2) Reduce System Voltage • Low Limit (125V)—Initiates Array String Reconnect: <ol style="list-style-type: none"> (1) Increase Array Output (2) Increase System Voltage (3) After All Strings Are Reconnected and V System < 125V, Drives DP to Pilot Cell Control Mode.
V1A (Meter-Relay Line 57) "System Voltage Protection"	<ul style="list-style-type: none"> • Displays System Voltage Sensed at System Bus. • High Limit ($\geq 138V$)—Over Voltage Condition Actuates CBI to Disconnect PV Array • Lo Limit ($\leq 100V$)—Under Voltage Condition Actuates CB2 to Disconnect All 120V Loads.
A1 (Meter-Relay, Line 60) "Array Current"	<ul style="list-style-type: none"> • Display Total Array Current • High Limit (≥ 3 amperes)—Enables Pump Operation When in Pilot Cell Control Mode.
A15 (Meter-Relay, Line 88) "Main Battery Charge/ Discharge Current"	<ul style="list-style-type: none"> • Displays Main Battery Charge and Discharge Current • High Limit (6 amperes)—Restricts DP Switching From a Charged Pilot Cell to a Discharged Pilot Cell During Battery Recovery Sequencing (e.g., From DP Position 4 to 5), Until There Is Sufficient Charge Current to Maintain the

Table 9. Control System Elements and Their Functions (continued)

Element and Location	Function
	<p>Discharged Pilot Cell Voltage Above Its Low Limit Setting (i.e., V4, V5, V6 and V7 (Lo)) so as to Prevent Oscillations Between Charged and Discharged Pilot Cells.</p> <ul style="list-style-type: none"> • Lo Limit (2 amperes)—Restricts DP Switching From V1 Control to Pilot Cell Control (i.e., DP Position 6 to 5) to Periods of Low or No Battery Charge Current to Prevent Control System Oscillation Between DP Positions 6 and 5.
<p>V4 (Meter-Relay, Line 73(CF-1) "Pilot Cell No. 1 Control"</p>	<ul style="list-style-type: none"> • Indicates Terminal Voltage of Pilot Cell No. 1. • Low Limit (1.95V)—During Discharge of Pilot Cell No. 1, Low Limit Indicates End-of-Discharge for Pilot Cell No. 1 (Approximately 50% DOD of Main Battery) and Commands the DP to Step From Position 5 (No. 1 Pilot Cell Control) to Position 4 (No. 2 Pilot Cell Control) and to Disconnect the Washing and Sewing Machine Circuit. • High Limit (2.45V)—During Re-Charge of Pilot Cell No. 1, High Limit Indicates Pilot Cell No. 1 Is Approximately Fully Charged and Commands DP to Step From Position 5 (No. 1 Pilot Cell Control) to Position 6 (V1 Control and All Pilot Cells Connected in Parallel).
<p>V5 (Meter-Relay, Line 78) "Pilot Cell No. 2 Control"</p>	<ul style="list-style-type: none"> • Indicates Terminal Voltage of Pilot Cell No. 2 • Low Limit (1.95V)—Indicates End-of-Discharge for Pilot Cell No. 2 (Approximately 60% DOD of Main Battery) and Commands the DP to Step From Position 4 (No. 2 Pilot Cell Control) to Position 3 (No. 3 Pilot Cell Control) and to Disconnect the Village Lights Circuit. • High Limit (2.45V)—During Re-Charge of Pilot Cell No. 2, High Limit Indicates Pilot Cell No. 2 Is Approximately Fully Charged and Commands DP to Step From Position 4 (No. 2 Pilot Cell Control) to Positions 5 (No. 1 Pilot Cell Control), and to Reconnect the Washing and Sewing Machine Circuit.
<p>V6 (Meter-Relay, Line 84) "Pilot Cell No. 3 Control"</p>	<ul style="list-style-type: none"> • Indicates Terminal Voltage of Pilot Cell No. 3 • Low Limit (1.95V)—Indicates End-of-Discharge

Table 9. Control System Elements and Their Functions (continued)

Element and Location	Function
	<p>for Pilot Cell No. 3 (Approximately 70% DOD of Main Battery) and Commands the DP to Step From Position 3 (No. 3 Pilot Cell Control) to Position 2 (No. 4 Pilot Cell Control) and to Disconnect the Water Pump Motor Circuit.</p> <ul style="list-style-type: none"> • High Limit (2.45V)—During Re-Charge of Pilot Cell No. 3, High Limit Indicates Pilot Cell No. 3 Is Approximately Fully Charged and Commands DP to Step From Position 3 (No. 3 Pilot Cell Control) to Position 4 (No. 2 Pilot Cell Control) and to Reconnect the Village Lights Circuit.
<p>V7 (Meter-Relay, Line 90) “Pilot Cell No. 4 Control”</p>	<ul style="list-style-type: none"> • Indicates Terminal Voltage of Pilot Cell No. 4 • Low Limit (1.95V) <ul style="list-style-type: none"> (1) Indicates End-of-Discharge for Pilot Cell No. 4 (Approximately 80% DOD of Main Battery) and Commands the DP to Step From Position 2 (No. 4 Pilot Cell Control) to Position 1 Maintaining Pilot Cell No. 4 Control But Disconnecting the Refrigerator/Freezer Circuit. (2) Senses Battery Re-Charge (> 1.95V) and Commands DP to Step From Position 1 to Position 2 and Reconnects the Refrigerator/Freezer Circuit. • High Limit (2.45V)—During Re-Charge of Pilot Cell No. 4, High Limit Indicates Pilot Cell No. 4 Is Approximately Fully Charged and Commands DP to Step From Position 2 (No. 4 Pilot Cell Control) to Position 3 (No. 3 Pilot Cell Control) and to Reconnect the Water Pump Motor Circuit.

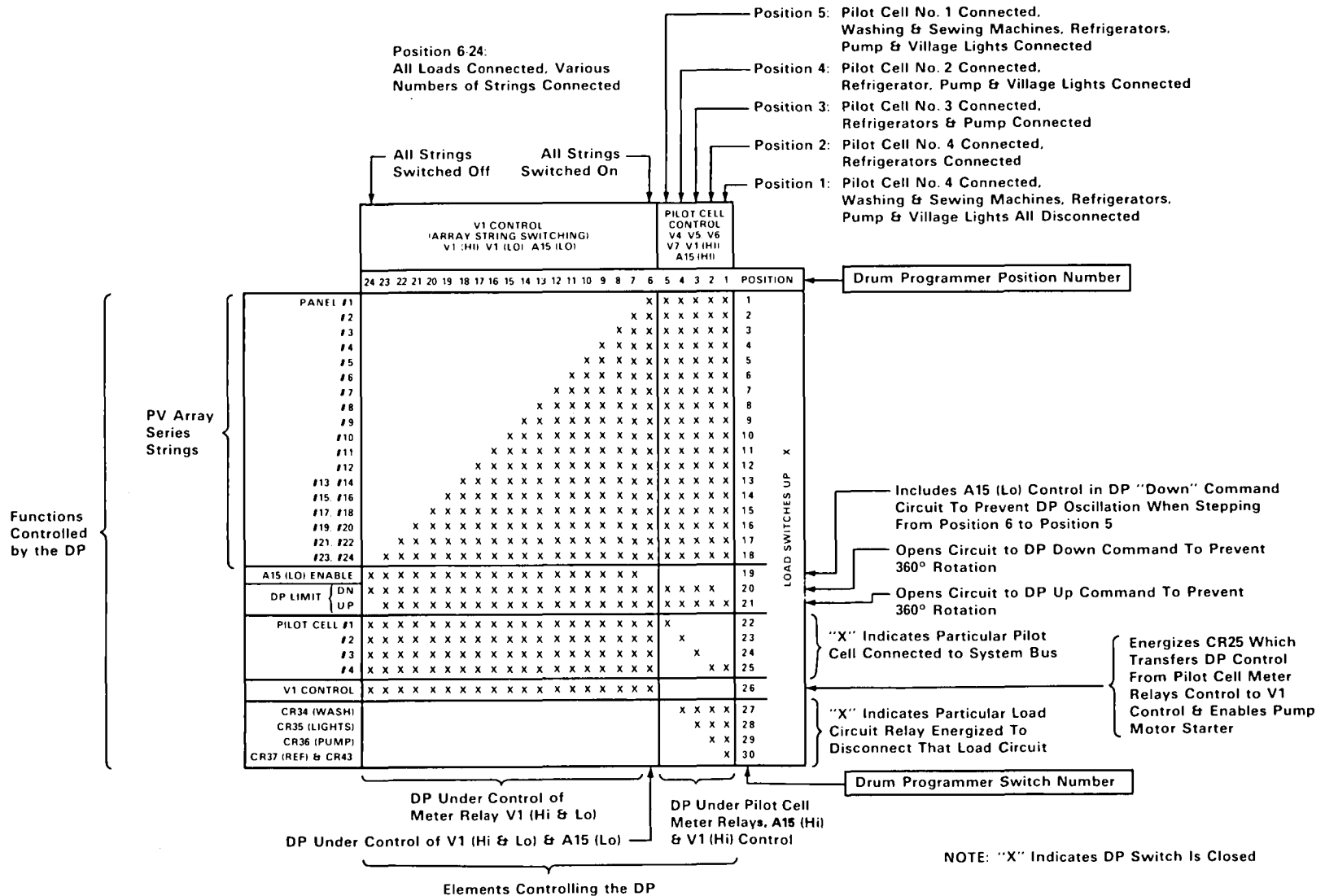


Figure 26. Drum Programmer (DP) Schedule

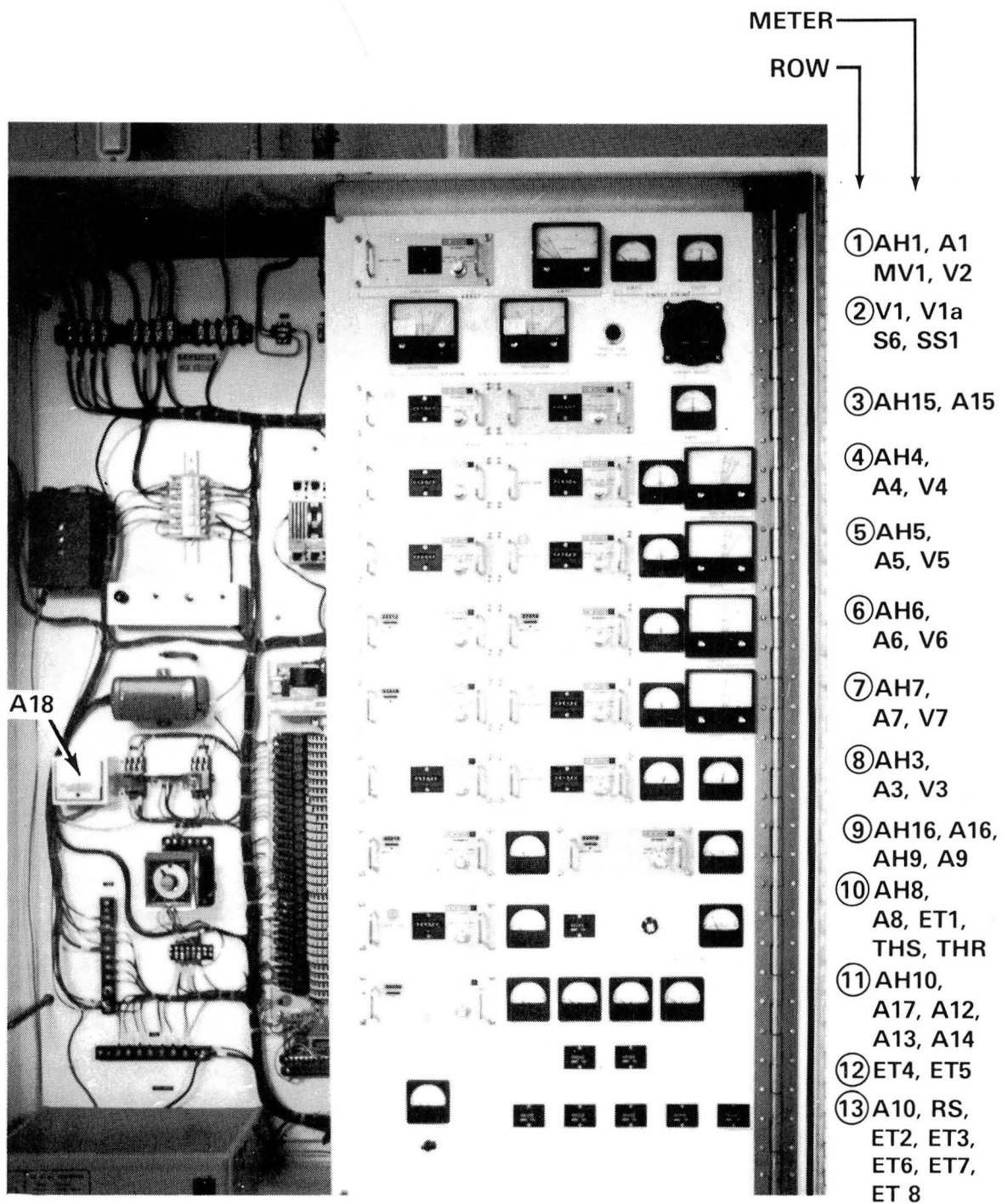


Figure 27. Instrument Panel Layout

Table 10. Panel Meter Instrumentation

LOCATION	SUBJECT	METER TYPE	LABEL	MEANING	METER RANGE
PCCIA Instrument Panel					
Row 1	Array Total	Amp-hours	AH1	Accumulated current from array	0-9999.99 and recycle
	Array Total	Amps	A1	Current from the array	0-50 amps
	Array String	Amps	MV1	Indiv. string current	0-1.5 amps
	Array String	Volts	V2	Indiv. string volts	0-200 volts
Row 2	System volts	Regulation	V1	Controls drum programmer to maintain proper voltage	90-140 volts with limits set at 125 and 130
		Protection	V1a	Automatic shut off if voltage reaches extreme limits	90-140 volts with limits set at 100 and 138
Row 3	Main Battery	Charge Amp-hours	AH15	Accumulated battery charge current	0-9999.99 and recycle
		Discharge Amp-hours	AH15	Discharge current discharged from main battery	0-9999.99 and recycle
		Amps	A15	Current to or from the Main Battery	± 50 amps
Rows 4-7	Pilot Cells	Charge Amp-hours	AH4-7	Pilot Cell accumulated charge current	0-9999.99 and recycle
		Discharge Amp-hours	AH4-7	Pilot Cell accumulated discharge current	0-9999.99 and recycle
		Amps	A4-7	Current to or from Pilot	Pilot Cell #1 ± 50 amps Pilot Cell #2 ± 50 amps Pilot Cell #3 ± 50 amps Pilot Cell #4 ± 50 amps
		Volts	V4-7	Pilot Cell voltage	0-3 volts
Row 8	Instrument and Control (I&C)	Charge Amp-hours	AH3	I&C Battery accumulated charge	0-9999.99 and recycle
		Discharge Amp-hours	AH3	I&C Battery accumulated discharge	0-9999.99 and recycle
		Amps	A3	Current to or from the I&C Battery	± 30 amps
		Volts	V3	Battery voltage	0-20 volts

Table 10. Panel Meter Instrumentation (continued)

LOCATION	SUBJECT	METER TYPE	LABEL	MEANING	METER RANGE
Row 9	Instrument and Control Load	Amp-hours	AH16	Accumulated current used by instruments and controls	0-9999.99 and recycle
		Amps	A16	Current to instruments and controls	0-10 amps
	Lights in the village homes, church, Feast House, EEB	Amp-hours	AH9	Accumulated current used by lights	0-9999.99 and recycle
		Amps	A9	Current to lights	0-10 amps
Row 10	Pump load	Amp-hours	AH8	Accumulated current used by pump	0-9999.99 and recycle
		Amps	A8	Current to pump	0-25 amps
		Run Time (hours)	ET1	Total time pump has run	0-9999.99 and recycle
	Temperature	Rotary selector and temperature readout	THS & THR	Temperature in degrees Fahrenheit:	0-200°F
				<ul style="list-style-type: none"> • Solar module temp. • Refrigerator and freezer for 1 unit • Pump motor • 1 cell of the main battery • Outside air temp. 	
Row 11	Total Loads in DSB	Amp-hours	AH10	Accumulated current used by all loads in the DSB.	0-9999.99 and recycle
		Amps Total	A17	Total DSB current	0-25 amps
	Washing Mach.	Amps	A12	Current to the washing machine	0-5 amps
	Sewing Mach.	Amps	A13	Current to sewing machine	0-1 amps
	Lights	Amps	A14	DSB light current	0-1 amps
Row 12	Washing mach.	Run Time (hours)	ET4	Run time of washing mach.	0-9999.99 and recycle
	Sewing mach.	Run Time	ET5	Run time of sewing mach.	0-9999.99 and recycle
Row 13	Compressor load	Amps & Rotary selector	A10, RS	Individual & total compressor current	0-10 amps

Table 10. Panel Meter Instrumentation (continued)

LOCATION	SUBJECT	METER TYPE	LABEL	MEANING	METER RANGE
	Compressor run time	Run time (hours)	ET2, ET3, ET6, ET7, ET8	Run time of refrigerator	0-9999.99 and recycle
Inside Panel of PCCIA	Converter Output	Amps	A18	Current output of 120V converter	0-15 amps
	Drum/ Programmer/ Position			Number of strings turned on or condition of load shedding	STEP 1 → 24
Water Pump	Water meter	Water (gal)		Amount of water pumped from the well	99999.99
DSB					
Water Storage Tank	Water	Target		Amount of water stored in the tank	Estimate 1/2, 1/4, etc.
		Water (gal)		Amount of water used in the DSB	99999.99

SAFETY

Throughout the design and installation of this system, safety for user, operational and maintenance, and installation personnel was of utmost concern. All areas of access needed for operation or maintenance are locked. Only authorized, properly trained people are allowed into the array field, the water pump area, the EEB, and the panel No. 2 in the DSB. All loads are hard wired to wall switches thus preventing unauthorized access to the 120-V(d.c.) lines. Visual and audio signals are provided to alert the operator to abnormal conditional. The battery room is vented and separate from the control room in the EEB and is provided with an emergency eye flush and shower facility in case of contact with battery acid. The array is located apart from the normal village activitiy areas to reduce the probability of damage to the PV cells as well as to reduce the accumulation of dirt and other airborne material.

An emergency OFF button is also provided in the EEB to disconnect the array and batteries from all loads and controls in the PCCIA. This condition does not automatically reset and must be manually reset to restore power to the system.

Two circuit breakers protect the power supplied to the DSB from the EEB. A circuit breaker, CB8, in the DSB protects the loads and users from fault conditions. A circuit breaker, CB6, in the EEB, protects the transmission lines from the EEB to the DSB.

COMMENTS ON SYSTEM OPERATION

The Schuchuli system has been operating satisfactorily since its dedication in December 1978. Data from system operations are being reduced and analyzed and will be reported separately. There were some minor design changes made after the system became operational, and these have been included in the text. Two of these design changes are worth discussing further. One was to correct a manufacturer shortcoming in the optical motor relays, and the other was to correct a problem in the load management control relay logic.

The problem with the optical meter relays was premature burnout of the meter relay lamp due to higher than design operating voltage. When a motor relay burns out, all contacts in the relay transfer causing various system perturbations depending upon which meter relay is affected. Premature lamp burnout occurred because the meter relays were designed for 12-volt operation, but not for 12-volt battery operation, i.e., voltages up to 14 volts. To obtain the 5 volts necessary to operate the lamp, the manufacturer merely inserted an appropriate dropping resistor. The nominal 12-volt I/C bus normally floats at 13.6-volts thus increasing lamp voltage and substantially reducing lamp life. LeRC engineers subsequently designed and installed lamp voltage regulators in all meter relays which hold lamp voltage at 5 volts independent of source voltage. The manufacturer was alerted to this design problem.

The nature of and fix for the load management control logic problem is described in paragraph 6 on page 58. While the system was under pilot cell control, high system voltage caused CBI to be tripped. Although the alarm light was on (the audio alarm was subsequently installed), the condition went unnoticed until the battery became 60 percent discharged. At about this same time (December 1979), the contacts in the thermostat switch of the freeze protection heater for the solar hot water heater welded closed imposing a 300-watt continuous load on the system. Before the condition was noted, the battery had intermittently reached greater than 70 percent DOD. Although the control logic and heater failure were untimely problems, together they forced the exercise of the load management system which, in all other respects, operated properly.

CONCLUDING REMARKS

The Schuchuli Village Project was designed to show that PV power systems can provide electricity for essential village needs in remote locations. Over 2½ years of operation and a 98.6 percent online record has proved the validity of the concept of village PV power systems and the design of this system. The village has been visited by well over 200 official visitors representing 55 foreign countries. In testimony to the validity of the project, there are now village power systems being designed for villages in several countries.

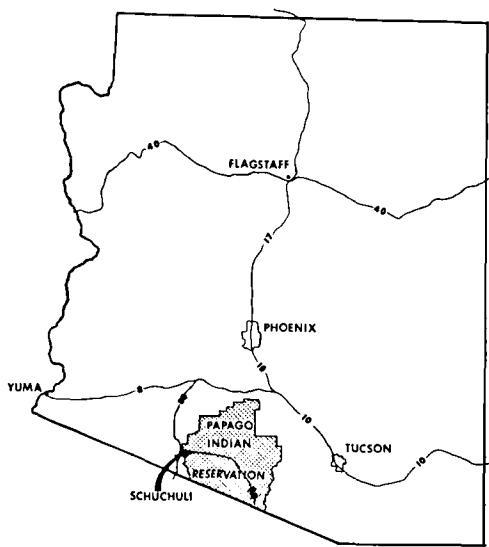
APPENDIX A

DESIGN DRAWINGS

NASA LeRC DRAWING NOS. CF 56375 THROUGH CF 56382

PHOTO VOLTAIC VILLAGE
POWER SYSTEM
SCHUCHULI ARIZONA

D.O.E. - N.A.S.A.
LEWIS RESEARCH CENTER
TESTS AND APPLICATION PROJECT

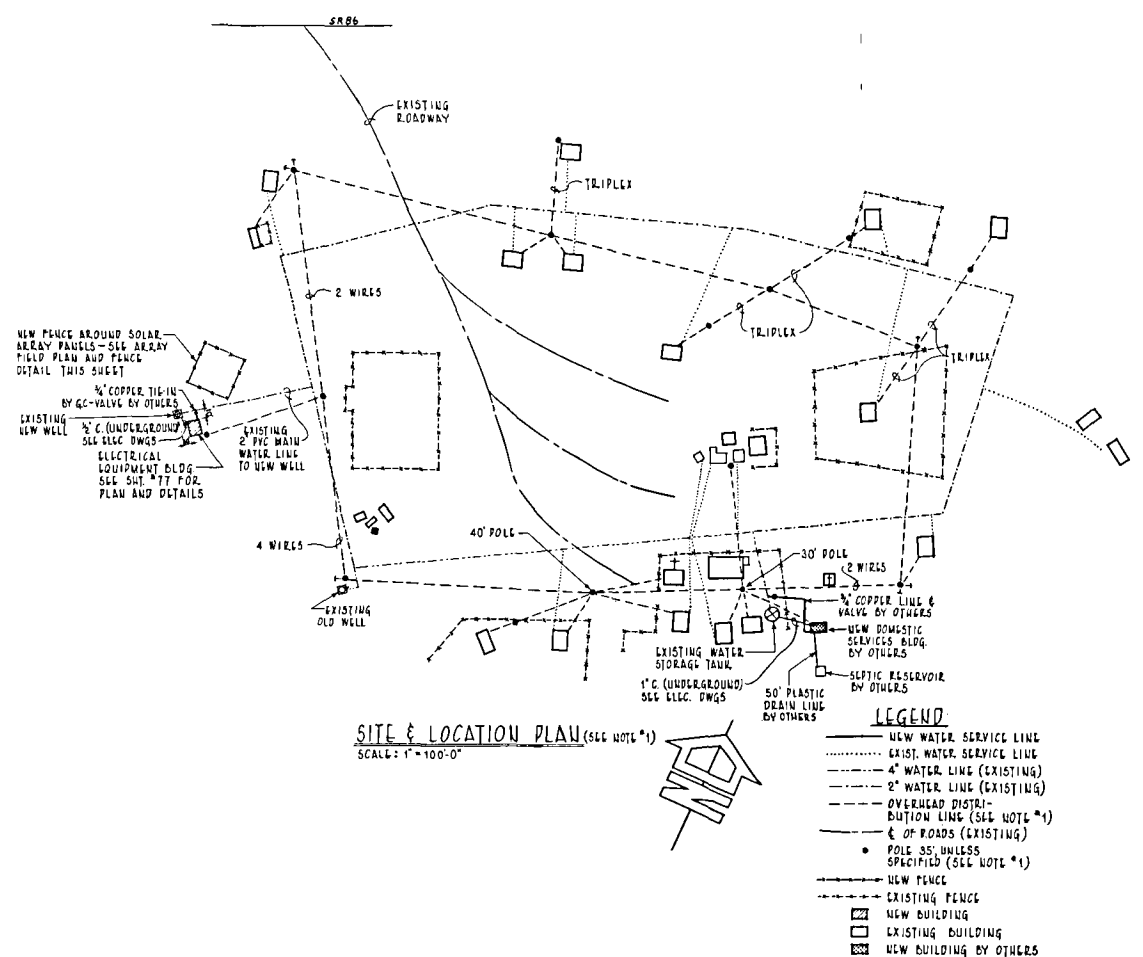
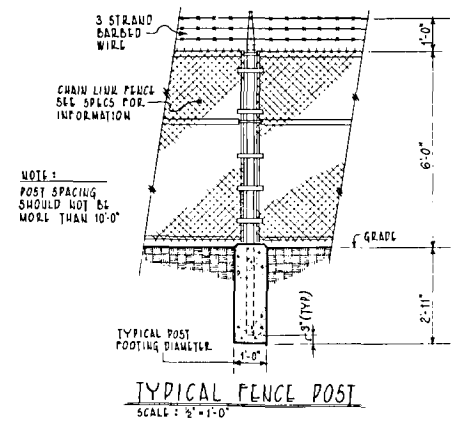
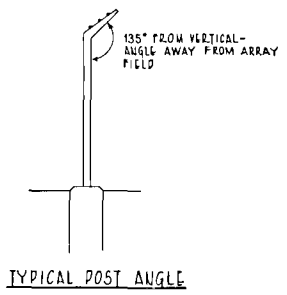
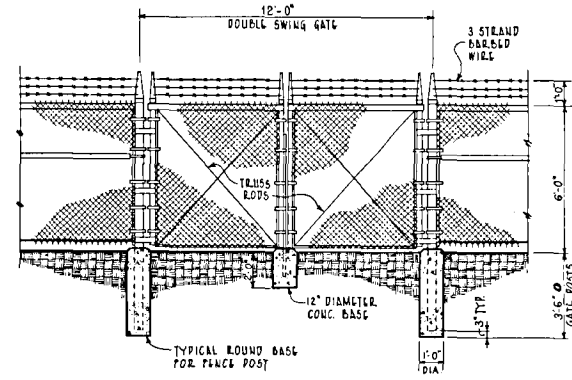
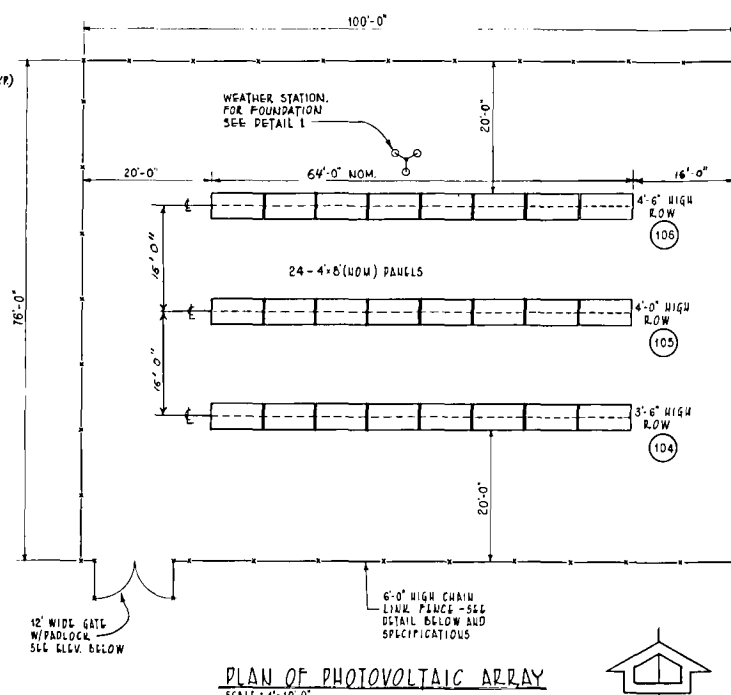
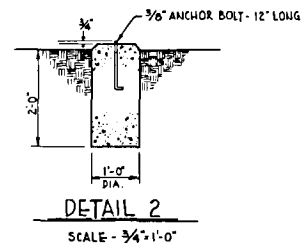
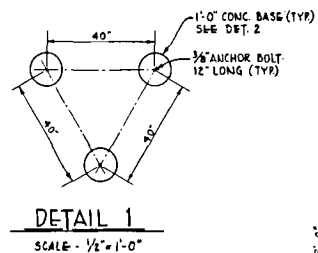


STATE OF ARIZONA
SCALE: 1" = 50 MILES

INDEX OF DRAWINGS

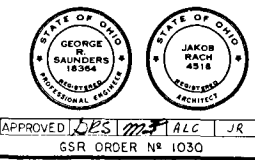
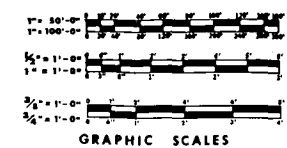
- CF56375 TITLE SHEET
- CF56376 SITE PLAN, ARRAY FIELD PLAN, FENCE DETAILS
- CF56377 ELECTRICAL EQUIPMENT BUILDING—PLAN, ELEVATIONS, AND DETAILS
- CF56378 TYPICAL SOLAR PANEL AND DETAILS
- CF56379 ELECTRICAL PLANS AND DETAILS
- CF56380 ONE LINE DIAGRAM AND ARRAY DETAILS

DESIGN CONTRACTOR	SCALE	REFERENCE	INITIAL	DATE	CHANGE NO.	REVISION	DATE	OK APP.
	UNLESS OTHERWISE SPECIFIED		DR	2-28-78		PHOTO VOLTAIC VILLAGE POWER SYSTEM SCHUCHULI ARIZONA		
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	193. DIM. MAY VARY ±		DR					
	194. DIM. MAY VARY ±		DR					
	195. DIM. MAY VARY ±		DR					
	196. DIM. MAY VARY ±		DR					
	197. DIM. MAY VARY ±		DR					
	198. DIM. MAY VARY ±		DR					
	199. DIM. MAY VARY ±		DR					
	200. DIM. MAY VARY ±		DR					
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	202. DIM. MAY VARY ±		DR					
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	209. DIM. MAY VARY ±		DR					
	210. DIM. MAY VARY ±		DR					
	211. DIM. MAY VARY ±		DR					
	212. DIM. MAY VARY ±		DR					
	213. DIM. MAY VARY ±		DR					
	214. DIM. MAY VARY ±		DR					
	215. DIM. MAY VARY ±		DR					
	216. DIM. MAY VARY ±		DR					
	217. DIM. MAY VARY ±		DR					
	218. DIM. MAY VARY ±		DR					
	219. DIM. MAY VARY ±		DR					
	220. DIM. MAY VARY ±		DR					
	221. DIM. MAY VARY ±		DR					
	222. DIM. MAY VARY ±		DR					
	223. DIM. MAY VARY ±		DR					
	224. DIM. MAY VARY ±		DR				</	



NOTES

1. ELECTRICAL EQUIPMENT BUILDING, SOLAR ARRAY FIELD WIRING, THE OUTSIDE DIRECTORY AND ELECTRICAL WIRING OF THE DOMESTIC SERVICES BUILDING SHALL BE A PART OF THIS CONTRACT. THE FENCE LINE POWER DISTRIBUTION SYSTEM, THE DOMESTIC SERVICES BUILDING AND THE HOUSE WIRING SHALL BE BY OTHERS

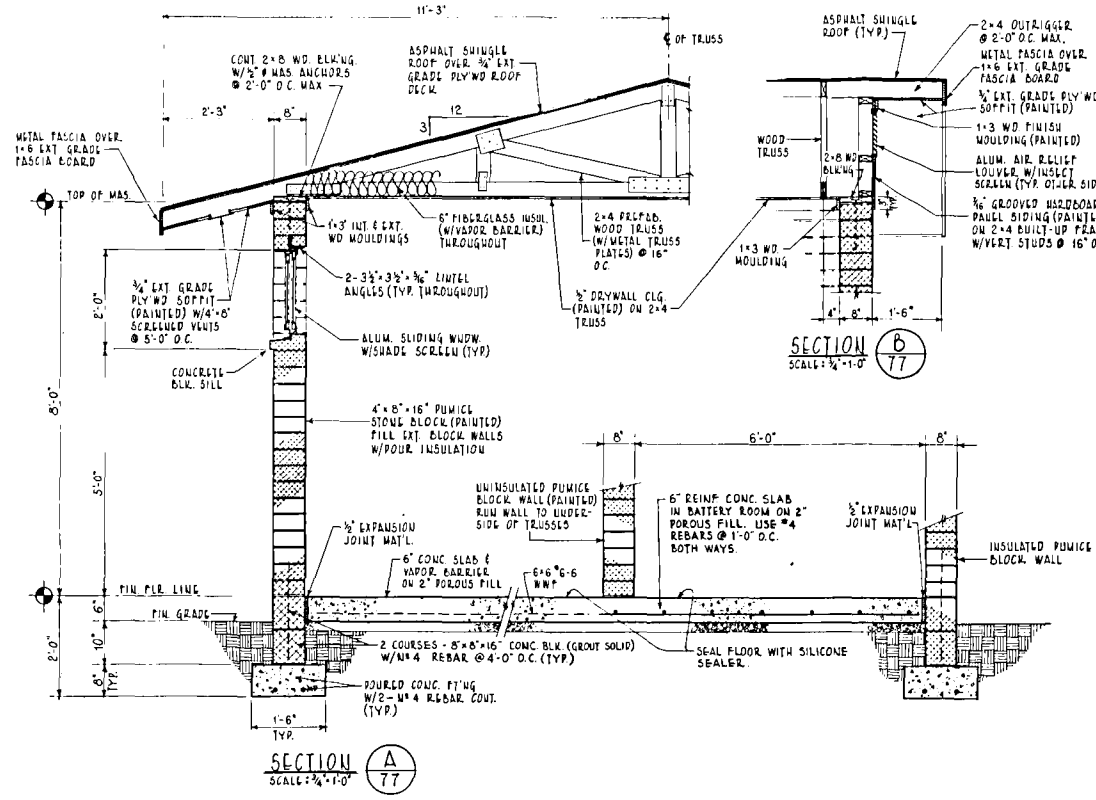
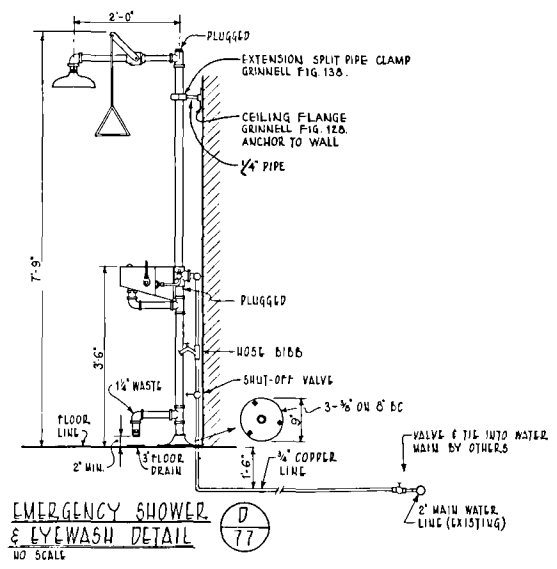
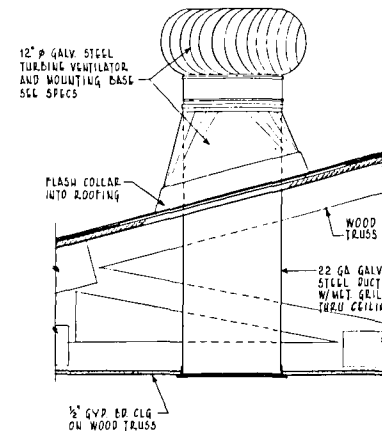
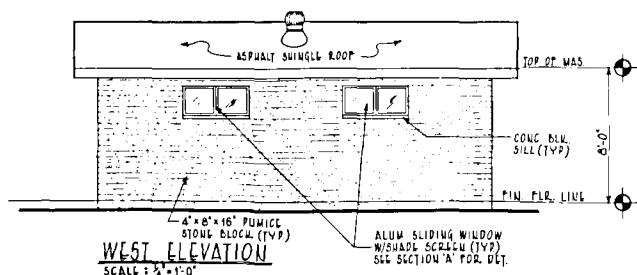
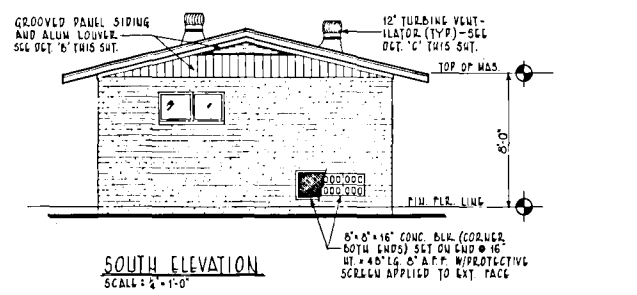
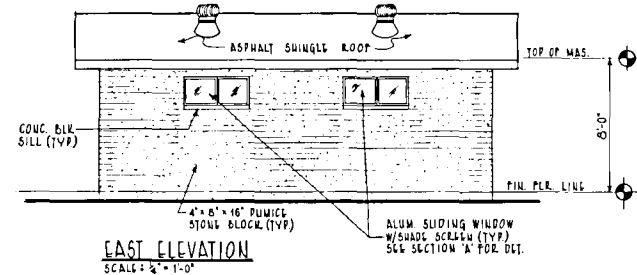
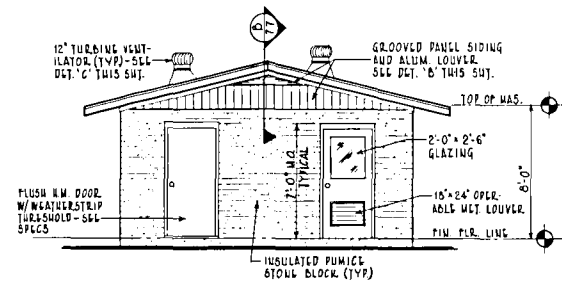
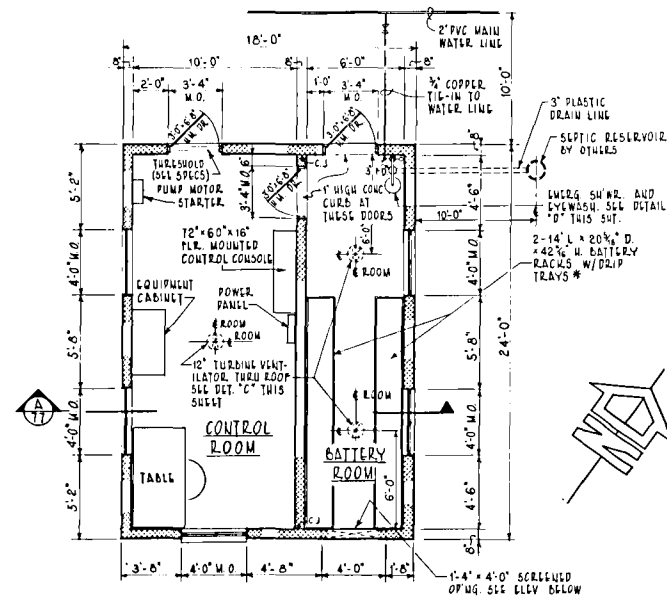


DESIGN CONTRACTOR
Slider
 20025 CENTER HIGHWAY
 HOCKEY RIVER, OHIO 43021

SCALE	REFERENCE	INITIAL	DATE
UNLESS OTHERWISE SPECIFIED		BR.	
2 WIRE MAY VARY		CK.	8-24-78
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	
24 WIRE MAY VARY		ENG.	

REVISION	DATE	BY	CHK
1	8-24-78	ADD 3 PANELS	ADD 3 PANELS
2	8-24-78	ADD 3 PANELS	ADD 3 PANELS
3	8-24-78	ADD 3 PANELS	ADD 3 PANELS
4	8-24-78	ADD 3 PANELS	ADD 3 PANELS
5	8-24-78	ADD 3 PANELS	ADD 3 PANELS
6	8-24-78	ADD 3 PANELS	ADD 3 PANELS
7	8-24-78	ADD 3 PANELS	ADD 3 PANELS
8	8-24-78	ADD 3 PANELS	ADD 3 PANELS
9	8-24-78	ADD 3 PANELS	ADD 3 PANELS
10	8-24-78	ADD 3 PANELS	ADD 3 PANELS




NATIONAL AERONAUTICS AND SPACE
 ADMINISTRATION
 LEWIS RESEARCH CENTER
 CLEVELAND, OHIO

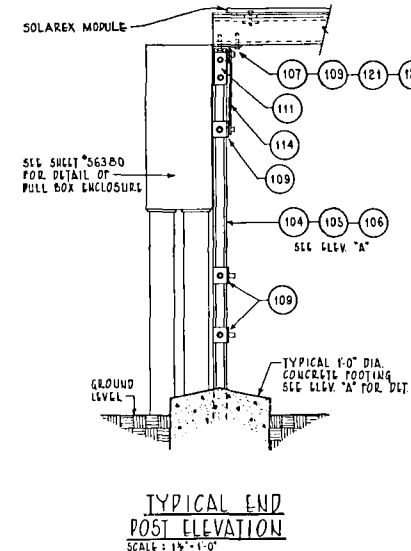
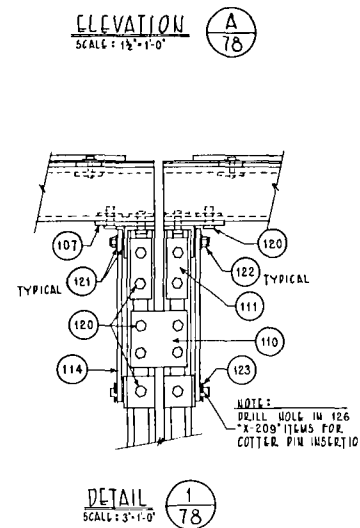
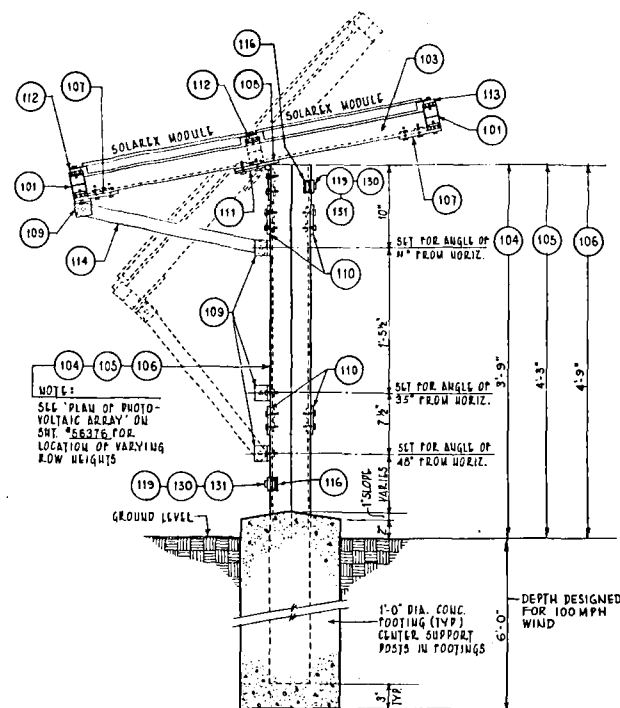
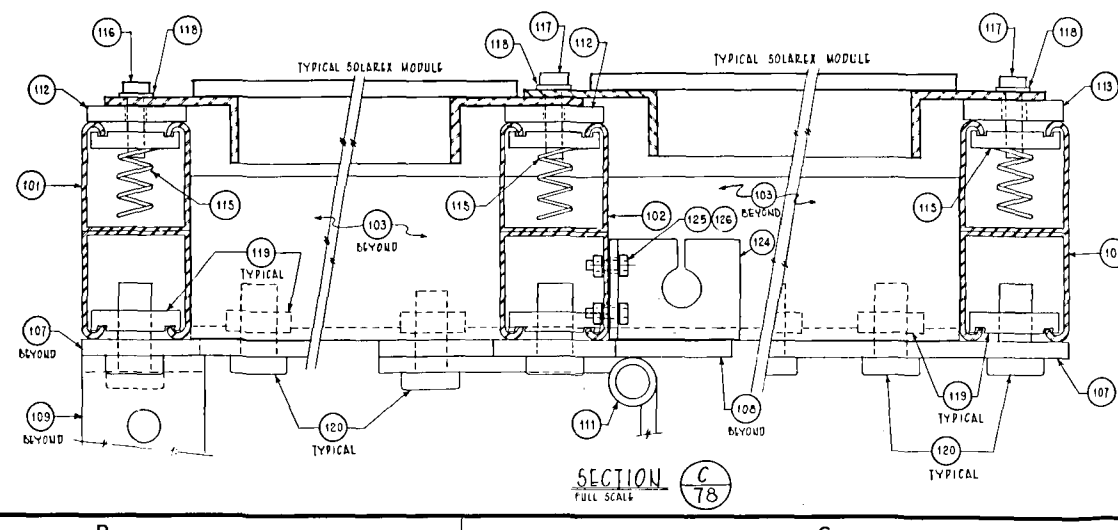
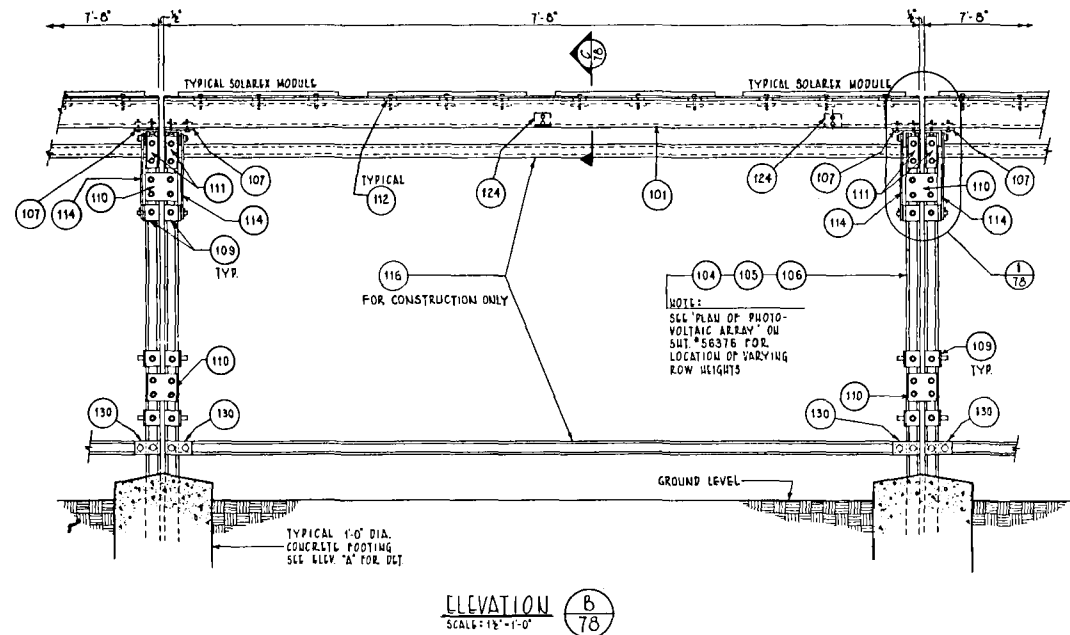
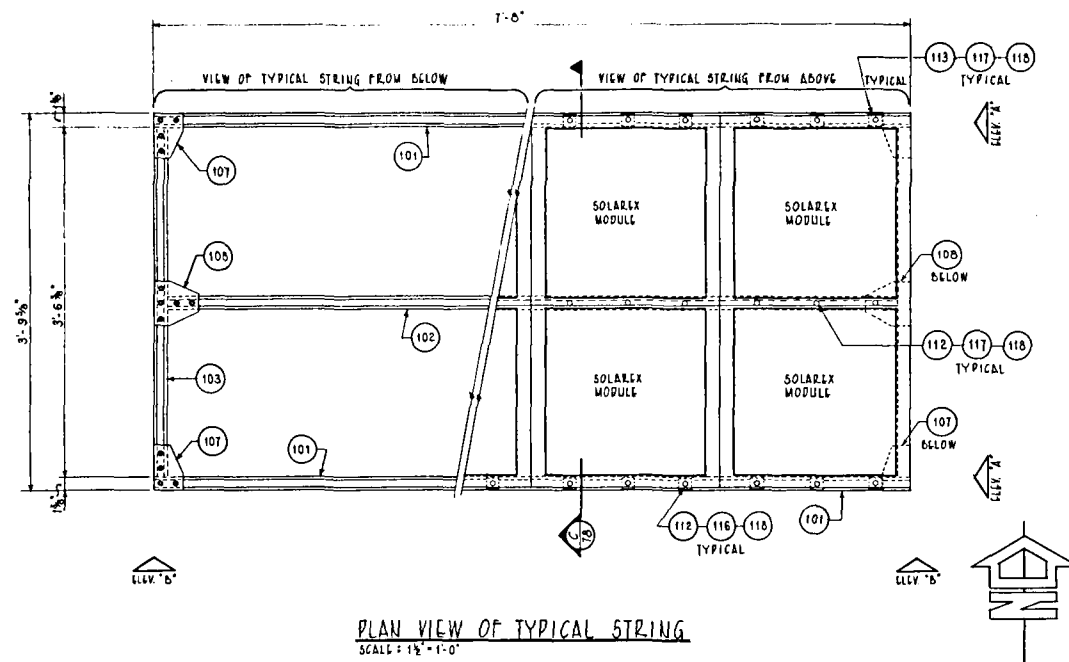


SECTION B
SCALE: 1/4" = 1'-0"



- NOTES**
- * INDICATES GOVERNMENT FURNISHED.
 1. PROVIDE BLOCK REINFORCING FOR HORIZONTAL JOINTS AND ON EACH SIDE OF OPENINGS AND AT CORNERS.
 2. PROVIDE SOLID BLOCK FOR TOP COURSE ON EXTERIOR WALLS.
 3. PROVIDE 5 FOOT BY 5 FOOT BY 4 INCH STOPS OUTSIDE EACH EXTERIOR DOOR. REINFORCE WITH WIRE MESH.
 4. SLOPE GRADE AWAY FROM STRUCTURE.

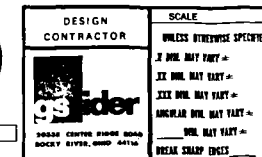
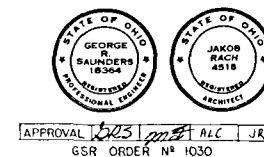
		DESIGN CONTRACTOR	SCALE	REFERENCE	INITIAL	DATE	CHANGE NO.	REVISION	DATE	CHK.	
 GENERAL SERVICES INCORPORATED 100 EAST 9TH AVE. SUITE 400 CLEVELAND, OHIO 44114		UNLESS OTHERWISE SPECIFIED			IN	2-24-72		PHOTO-VOLTAIC VILLAGE POWER SYSTEM SCHUCHMAN ARIZONA			
		1. SEE DET. MAY VARY			1. E						
		2. SEE DET. MAY VARY			2. E						
		3. SEE DET. MAY VARY			3. E						
		4. SEE DET. MAY VARY			4. E						
		5. SEE DET. MAY VARY			5. E						
		6. SEE DET. MAY VARY			6. E			ELECTRICAL EQUIPMENT BUILDING - PLAN, ELEVATIONS, AND DETAILS			
		7. SEE DET. MAY VARY			7. E			NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LEWIS RESEARCH CENTER CLEVELAND, OHIO	ARCHITECTURAL		
		8. SEE DET. MAY VARY			8. E			CF 56377	OFFICIAL DATE		
		9. SEE DET. MAY VARY			9. E						



COMMERCIAL PARTS LIST			
NO.	DESCRIPTION	QUANTITY	REMARKS
101	DOUBLE CHANNEL "SUPERSTRUT" N° A-1202-7'-8" LG	2	48
102	DOUBLE CHANNEL "SUPERSTRUT" N° A-1202-7'-4" LG	1	24
103	SINGLE CHANNEL "SUPERSTRUT" N° A-1200-3'-6" LG	2	48
104	DOUBLE CHANNEL "SUPERSTRUT" N° A-1202-9'-6" LG	2	FOR ROW 104
105	DOUBLE CHANNEL "SUPERSTRUT" N° A-1202-10'-0" LG	2	FOR ROW 105
106	DOUBLE CHANNEL "SUPERSTRUT" N° A-1202-10'-6" LG	2	FOR ROW 106
107	FLAT PLATE FITTING "SUPERSTRUT" N° AB-257	4	96
108	FLAT PLATE FITTING "SUPERSTRUT" N° AB-261	2	48
109	90° ANGLE FITTING "SUPERSTRUT" N° X-209	6	144
110	SPECIAL PLAT PLATE "SUPERSTRUT" N° AB-251	—	72
111	ADJUSTABLE WING CONNECTION "SUPERSTRUT" N° D-209	2	48
112	STANDARD BRACKET "SUPERSTRUT" N° AB-241 (1/2")	24	576
113	FLAT PLATE FITTING "SUPERSTRUT" N° AB-251 (1/2")	12	288
114	1/2" x 1/2" x 24" PLAT STEEL PLATE	2	48
115	REGULAR SPRING WUT "SUPERSTRUT" N° A-100 (1/2")	36	864
116	SINGLE CHANNEL "SUPERSTRUT" N° B-1600 7'-4" LG	2	48
117	HEX HEAD CAP SCREW - 1/2" (20) x 1 1/2"	36	864
118	LOCK WASHER (FOR 1/2" CAP SCREWS)	36	864
119	SPRINGLESS WUT "SUPERSTRUT" N° AC-100 (1/2")	58	1392
120	HEX HEAD CAP SCREW - 1/2" (13) x 1 1/2"	50	1200
121	LOCK WASHER (FOR 1/2" CAP SCREWS)	4	96
122	STANDARD 1/2" HEX WUT	2	48
123	COTTER PIN CHAINED	2	48
124	BRACKET WIRING HARNESS	2	48
125	HEX HEAD CAP SCREW 10-32 x 3/8"	4	96
126	LOCKWUT 10-32	4	96
127	CAUTION LABEL	6	144
128	NAMEPLATE	2	48
129	PANEL IDENTIFICATION PLATE	1	24
130	FLAT PLATE "SUPERSTRUT" N° T106 1/2" x 1 1/2" x 3 1/4"	4	96
131	HEX HEAD CAP SCREW - 1/2" (13) x 3/4"	8	192

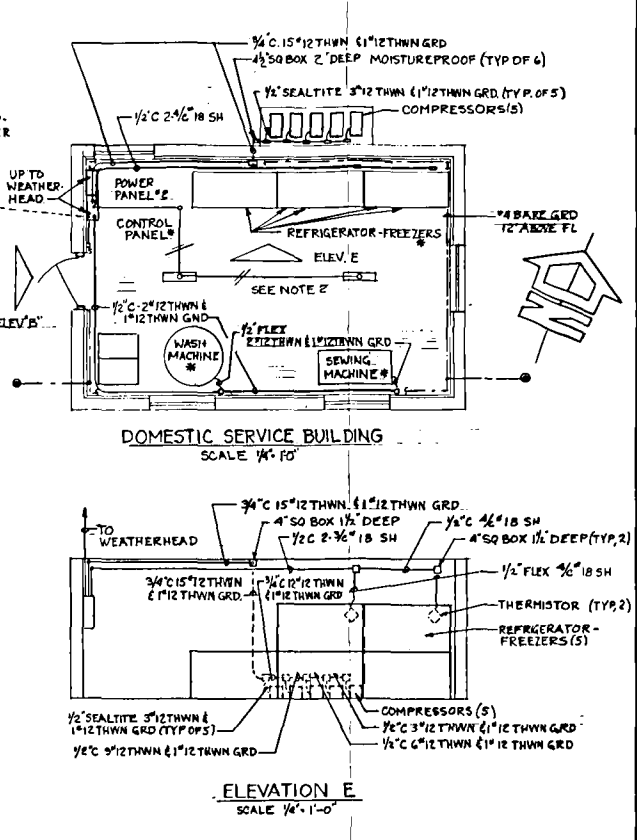
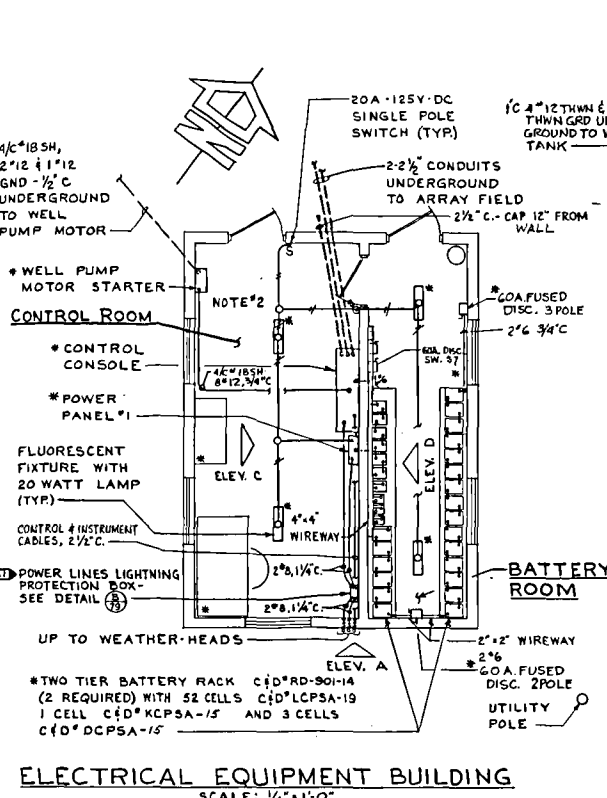
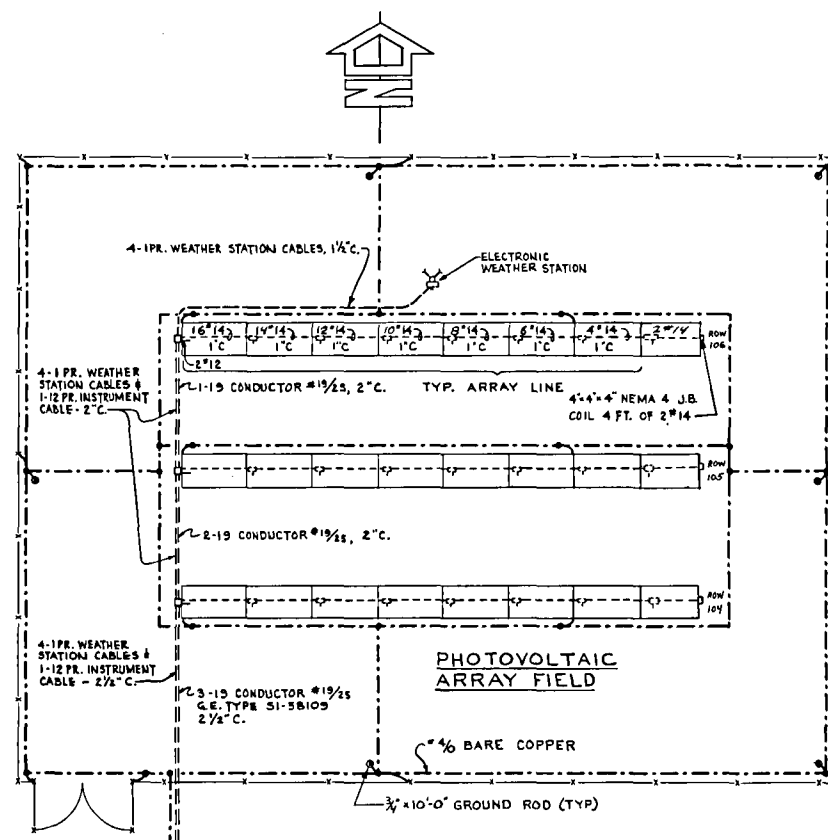
NOTES:

- ALL ITEMS IN "COMMERCIAL PARTS LIST" SHALL BE FURNISHED BY THE GOVERNMENT.
- CONCRETE, EXCAVATION, BACKFILL, INSTALLATION, AND ASSEMBLY SHALL BE UNDER THIS CONTRACT.

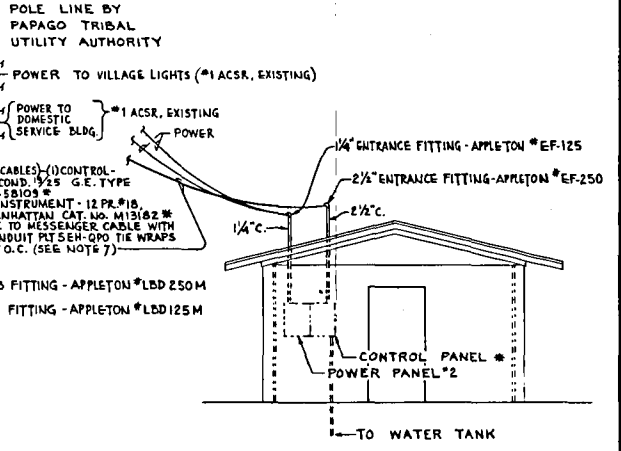
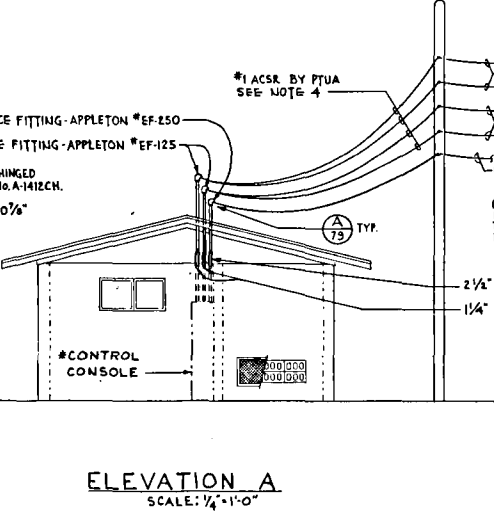
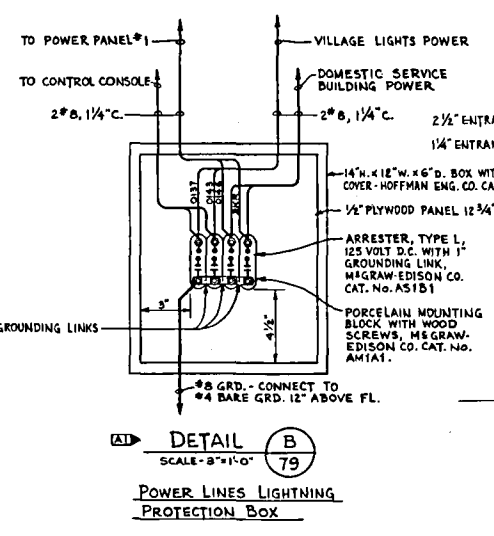
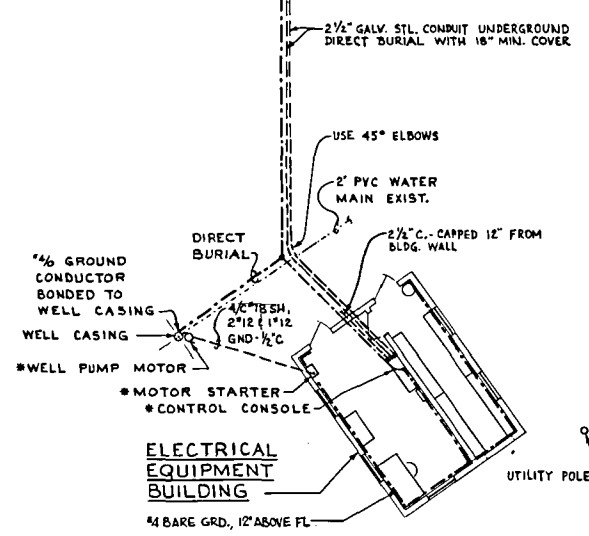


DESIGN CONTRACTOR	SCALE	REFERENCE	INITIAL	DATE
GEORGE B. SAUNDERS 18364	UNLESS OTHERWISE SPECIFIED		DR	7-29-77
	SEE DIM. MAY VARY ±		EC	
	SEE DIM. MAY VARY ±		ENG	
	SEE DIM. MAY VARY ±		FIN	
	SEE DIM. MAY VARY ±		REV	
	SEE DIM. MAY VARY ±		REV	
	SEE DIM. MAY VARY ±		REV	
	SEE DIM. MAY VARY ±		REV	

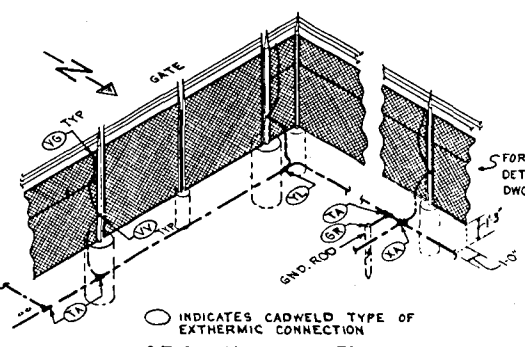
PARTS LIST UPDATE 24-25-77, 8-29-78, RWJ			
CHANGE NO.	REVISION	DATE	CHK. APP.
1	1	7-29-77	
PHOTO-VOLTAIC VILLAGE POWER SYSTEM SCHUCHULI ARIZONA			
TYPICAL SOLAR PANEL AND DETAILS			
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LEWIS RESEARCH CENTER CLEVELAND, OHIO			
STRUCTURAL CF 56378			
OFFICIAL DATE			



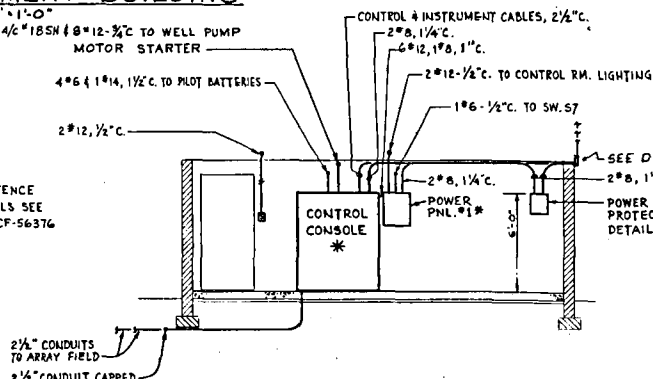
- NOTES:**
1. * INDICATES GOVERNMENT FURNISHED
 2. CONDUIT FOR LIGHTING FIXTURES ABOVE CEILING. ALL OTHER CONDUIT EXPOSED ON THE UNDERSIDE OF THE CEILING
 3. NUMBER OF HASH MARKS (---) INDICATES THE NUMBER OF AWG #12 COPPER WIRES IN THE CONDUIT
 4. CONTRACTOR SHALL PROVIDE #8 AWG TYPE THW THROUGH WEATHERHEADS TO BE SPLICED BY PTUA TO POLE LINE DROPS. CONTROL & INSTRUMENTATION CABLE SHALL BE CONTINUOUS FROM POLE LINE THROUGH WEATHERHEAD TO CONTROL CONSOLE.
 5. BOND ALL ELECTRICAL CABINETS & BATTERY RACKS TO BUILDING GROUND SYSTEM.
 6. TIE NEGATIVE SIDE OF 120 VOLT D.C. TO GROUND AT POWER PANEL #1 ONLY.
 7. CONTROL & INSTRUMENT CABLES WILL BE INSTALLED ON THE POLE LINE BY PTUA.



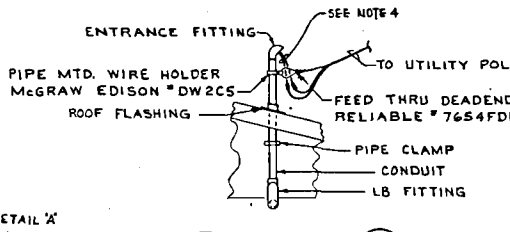
PARTIAL SITE OF PHOTOVOLTAIC ARRAY FIELD & ELECTRICAL EQUIPMENT BUILDING
SCALE: 1/8\"/>



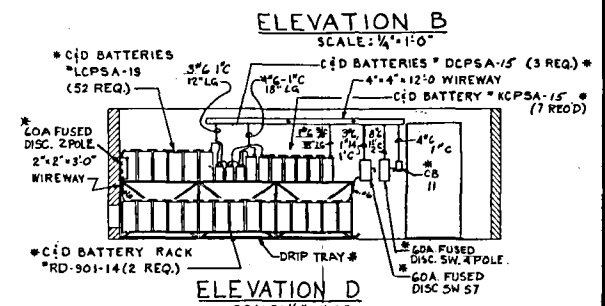
GROUNDING DETAIL
N.T.S.



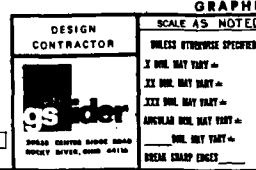
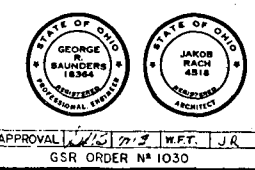
ELEVATION C
SCALE: 1/4\"/>



DETAIL A
SCALE: 1/2\"/>



ELEVATION D
SCALE: 1/4\"/>



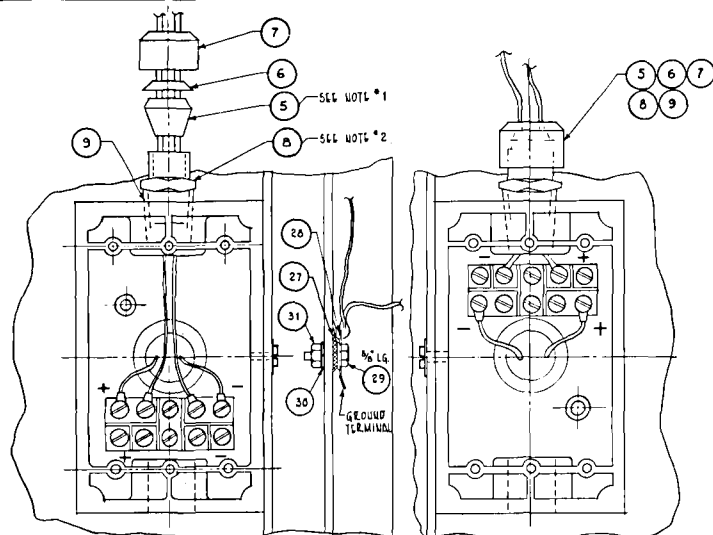
GRAPHIC SCALES			
SCALE AS NOTED	REFERENCE	INITIAL	DATE
UNLESS OTHERWISE SPECIFIED			
1" = 100'			
1" = 200'			
1" = 300'			
1" = 400'			
1" = 500'			
1" = 600'			
1" = 700'			
1" = 800'			
1" = 900'			
1" = 1000'			
1" = 1100'			
1" = 1200'			
1" = 1300'			
1" = 1400'			
1" = 1500'			
1" = 1600'			
1" = 1700'			
1" = 1800'			
1" = 1900'			
1" = 2000'			
1" = 2100'			
1" = 2200'			
1" = 2300'			
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1" = 8100'			
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1" = 8300'			
1" = 8400'			
1" = 8500'			
1" = 8600'			
1" = 8700'			
1" = 8800'			
1" = 8900'			
1" = 9000'			
1" = 9100'			
1" = 9200'			
1" = 9300'			
1" = 9400'			
1" = 9500'			
1" = 9600'			
1" = 9700'			
1" = 9800'			
1" = 9900'			
1" = 10000'			

NO.	REVISION	DATE	BY	CHKD.
1	CHG. ARRAY CONDUIT WIRES	8-25-80	AWV	
2	ADDED 3 PANELS	5-30-80	AWV	
3	ADDED POWER LINES LIGHTNING PROTECTION BOX & DETAIL	11-16-79	AWV	

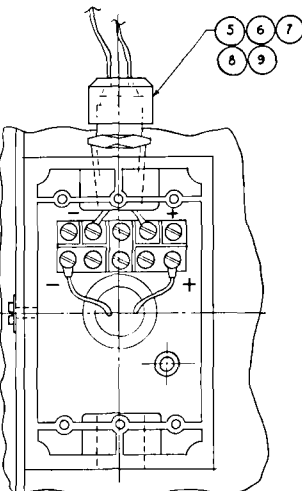
PHOTO-VOLTAIC VILLAGE POWER-SYSTEM SCHUCHULI ARIZONA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LEWIS RESEARCH CENTER CLEVELAND, OHIO

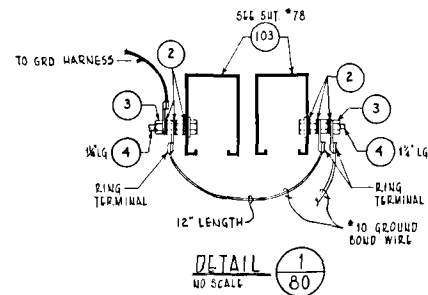
ELECTRICAL
CF 56379
OFFICIAL DATE



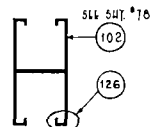
JUNCTION BOX DETAIL FOR
SOLAR MODULES 1, 3, 6, & 8



JUNCTION BOX DETAIL FOR
SOLAR MODULES 2, 4, 5, & 7

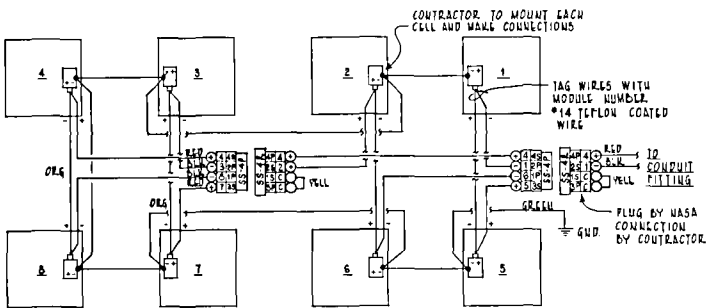


DETAIL 1
NO SCALE



DETAIL 2
NO SCALE

NOTE: THERE WILL BE A MINIMUM OF 10 PER. 8" SECTION

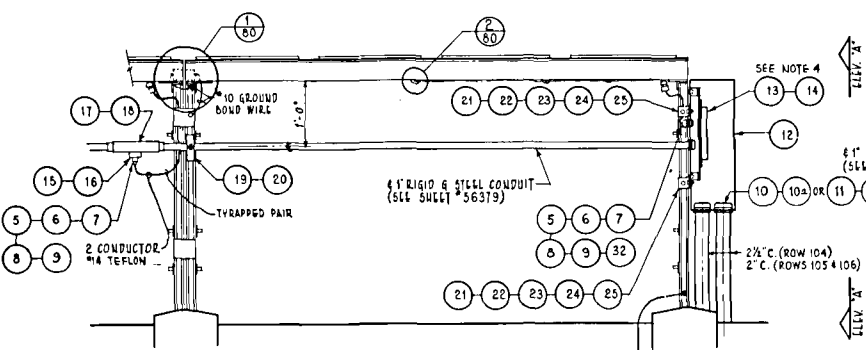


120 VOLT PANEL
WIRING DIAGRAM
(GOVERNMENT FURNISHED)

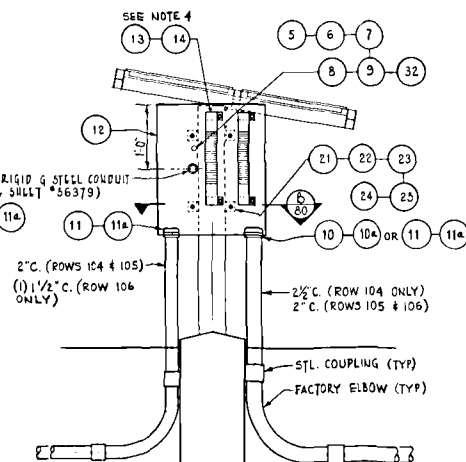
PANEL CHARACTERISTICS			
NOMINAL SYSTEM VOLTAGE	N° OF SERIES STRS	NOM VOLTAGE @ 60° C	VOLTS/SEGMENT PWR PER
120 VDC	1	120 VDC	47 WATT MAX 8 W
* PWR @ 60° C, 16.0 V PER MODULE, 6.100 W/M² CM²			
MODULES: SOLARIX, BLOCK 2			

GROUND HARNESS ASSEMBLY
FOR 120 VOLT PANEL
(GOVERNMENT FURNISHED)

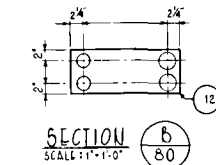
55-42 RECEPTACLE BODY
177 CANNON PART NOS.
120-1806-000
55-47 PLUG BODY
120-1809-000
55-5 CONTACT SOCKET
031-1267-000
55-7 CONTACT PIN
030-2196-000



TYPICAL END PANEL W/TERMINAL BOX
AND CONDUIT RUN
REAR VIEW
SCALE: 1"=1'-0"



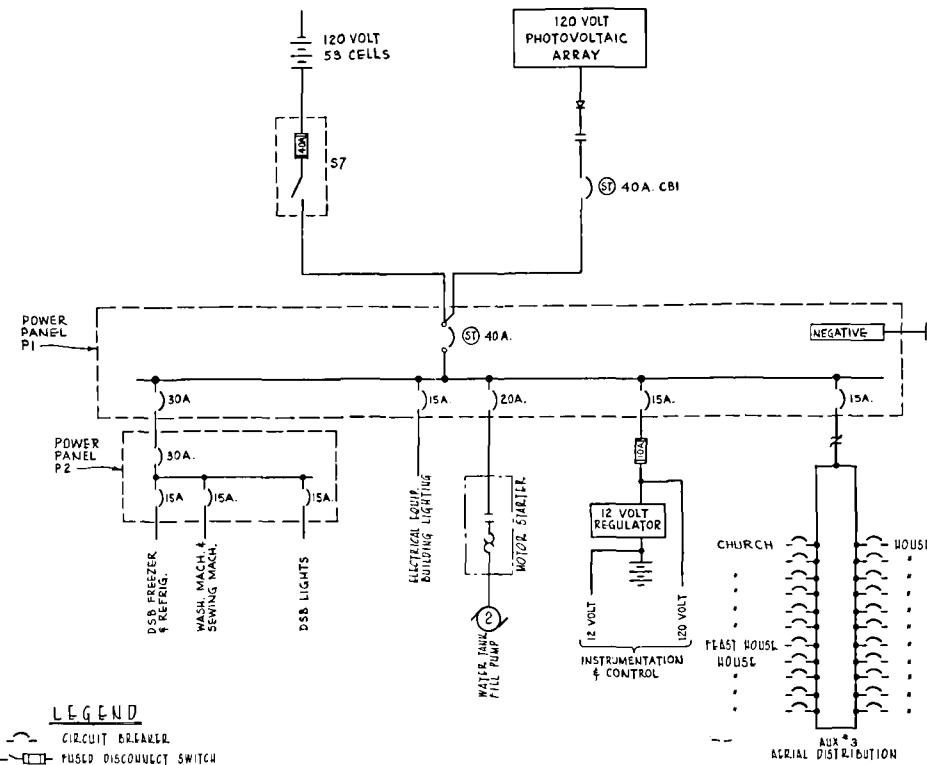
ELEVATION A
SCALE: 1"=1'-0"



SECTION 6
SCALE: 1"=1'-0"

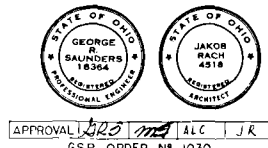
- LEGEND**
- CIRCUIT BREAKER
 - FUSED DISCONNECT SWITCH
 - DISCONNECT SWITCH
 - SHUNT
 - AMMETER
 - AMPERE HOUR METER
 - AMPERE HOUR METER - CHARGE
 - AMPERE HOUR METER - DISCHARGE
 - VOLTMETER

ELECTRICAL ONE LINE DIAGRAM



MATERIAL LIST

ITEM NO	DESCRIPTION	REQ'D
1	FLAT WASHER - 1/2" OD x .20" ID x .03" THICK	189
2	STAR WASHER (FOR N° 10 SCR)	---
3	HEX NUT N° 10-32	---
4	HEX HD CAP SCR - N° 10-32 UNC-2 x 3/8" LQ	---
5	PVDC NATIONAL DB SERIES FORM 1 - BLANK GROMMET (SEE NOTE #1)	189
6	PVDC NATIONAL DB SERIES FORM 1 CO PLATED STEEL CONICAL WASHER - PART N° FX-4-CS	189
7	PVDC NATIONAL DB SERIES FORM 1 COMPRESS-ION NUT PART N° DB-4-B	189
8	PVDC NATIONAL DB SERIES FORM 1 BODY PART N° DB-3-A	189
9	TEFLON TAPE, ANTI-SLIZING, 1/2" WIDE x 3 MIL THICK	189
10	2 1/2" INSULATING BUSHING - ADALTE * PES-10	4
10A	2 1/2" LOCKNUT - APPLETON * BL250	4
11	2" INSULATING BUSHING - ADALTE * PES-B	8
11A	2" LOCKNUT - APPLETON * BL200	16
12	HOFFMAN NEMA 4 ENCLOSURE * A-24H20BLP	3
13	TERMINAL STRAP SUPPORT KIT * A7E 6 STRAP * A-20T	6
14	BUCHANAN FACTORY ASSEMBLED CHANNEL W/UTD TERMINAL BLOCK * 062524	6
15	REDUCER 1 1/2" x 3/4" CROUSE WINDS * RL41	6
16	REDUCER 1" x 3/4" CROUSE WINDS * RL31	12
17	APPLETON MOGUL TYPE "T" CONDUIT FITTING * M125M	6
18	APPLETON MOGUL TYPE "T" CONDUIT FITTING * M100W	12
19	STAND OFF PIPE STRAP - SUPERSTRUT N° 702-A (1/2")	3
20	STAND OFF PIPE STRAP - SUPERSTRUT N° 702-A (1")	18
21	90° ANGLE FITTING - SUPERSTRUT N° A-209	12
22	LOCK WASHER (FOR 1/2" CAP SCREWS)	12
23	STANDARD 1/2" HEX NUT	12
24	HEX HEAD CAP SCREW - 1/2" (13) x 1 1/4"	12
25	SPRINGLESS NUT - SUPERSTRUT N° AC-100 (1/2")	12
26	CABLE TIE THOMAS-BATTIS CAT N° TY-923MX	SEE DET 2
27	INTERNAL STAR WASHER 3/4" O.D.	---
28	FLAT WASHER 1/2" x .030 x .03" THICK	---
29	BOLT 1/4 x 20 x 3/8"	---
30	LOCK WASHER FOR 1/4" BOLT	---
31	NUT 1/4-20	---
32	1/2" CONDUIT LOCKNUT - APPLETON * BL250	3



SCALE	REFERENCE	INITIAL	DATE
1/2" = 1'-0"	---	---	1/20/70
1" = 1'-0"	---	---	---

- NOTES:**
1. BLANK GROMMETS TO BE ALTERED BY DRILLING TWO .075" DIA. THRU HOLES .10" APART LOCATED SYMMETRICALLY ABOUT CENTERLINE.
 2. CARE SHALL BE TAKEN TO PREVENT OVER-TORQUING AND/OR GALLING DURING INSTALLATION OF WATER PROOF BOX CONNECTOR INTO MODULE JUNCTION BOX.
 3. INSTALL PANEL ELECTRICAL HARNESS AND GROUND LEAD ASSEMBLY AS INDICATED.
 4. FASTEN TERMINAL STRAP SUPPORT KITS IN CABINET BEFORE MOUNTING CABINET. BOLT HEAD SHALL BE ON THE OUTSIDE OF CABINET.

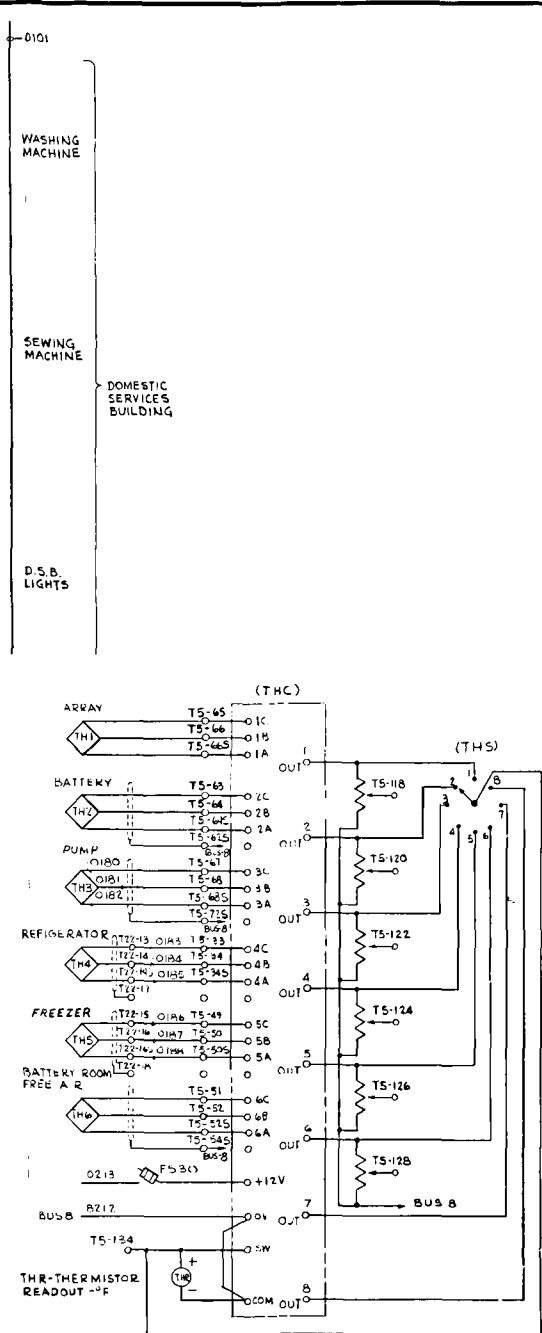
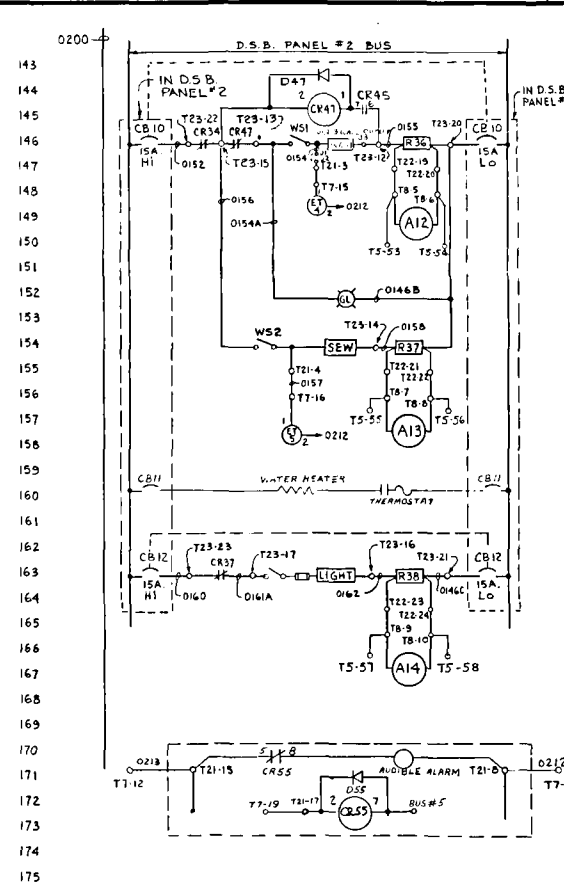
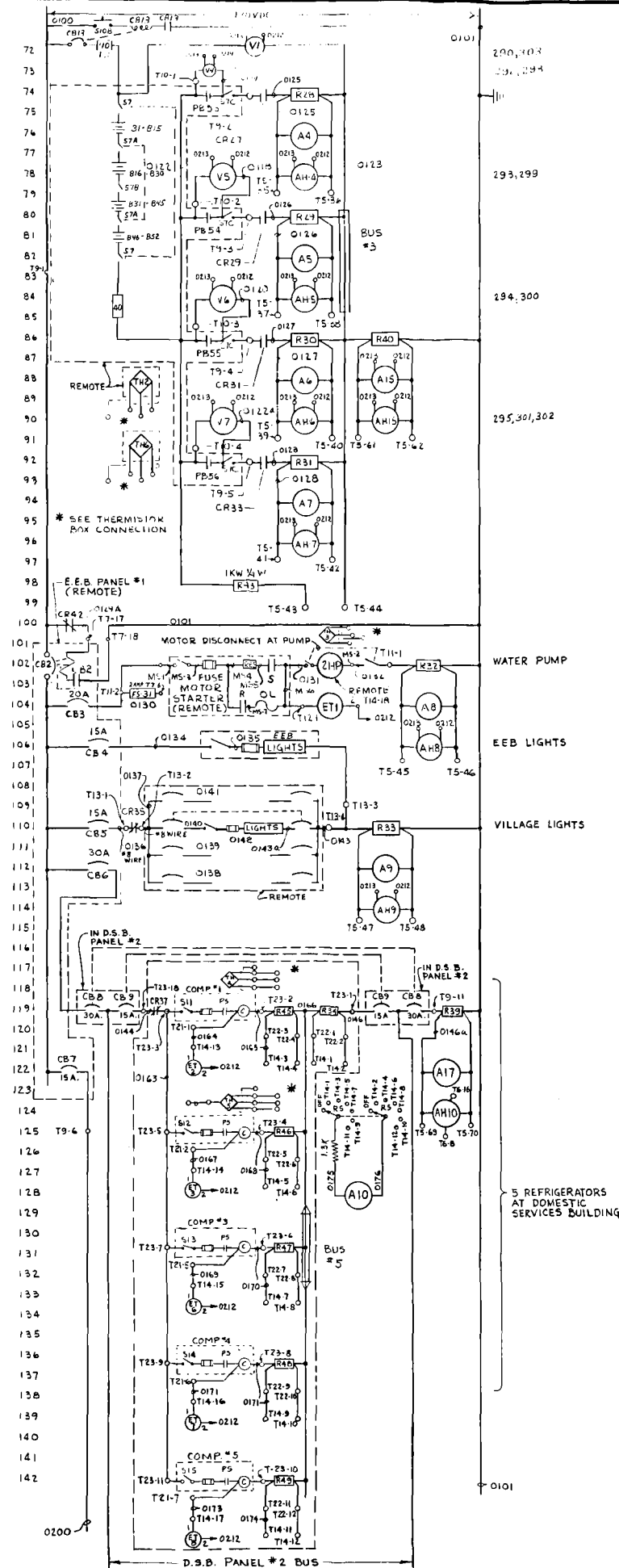
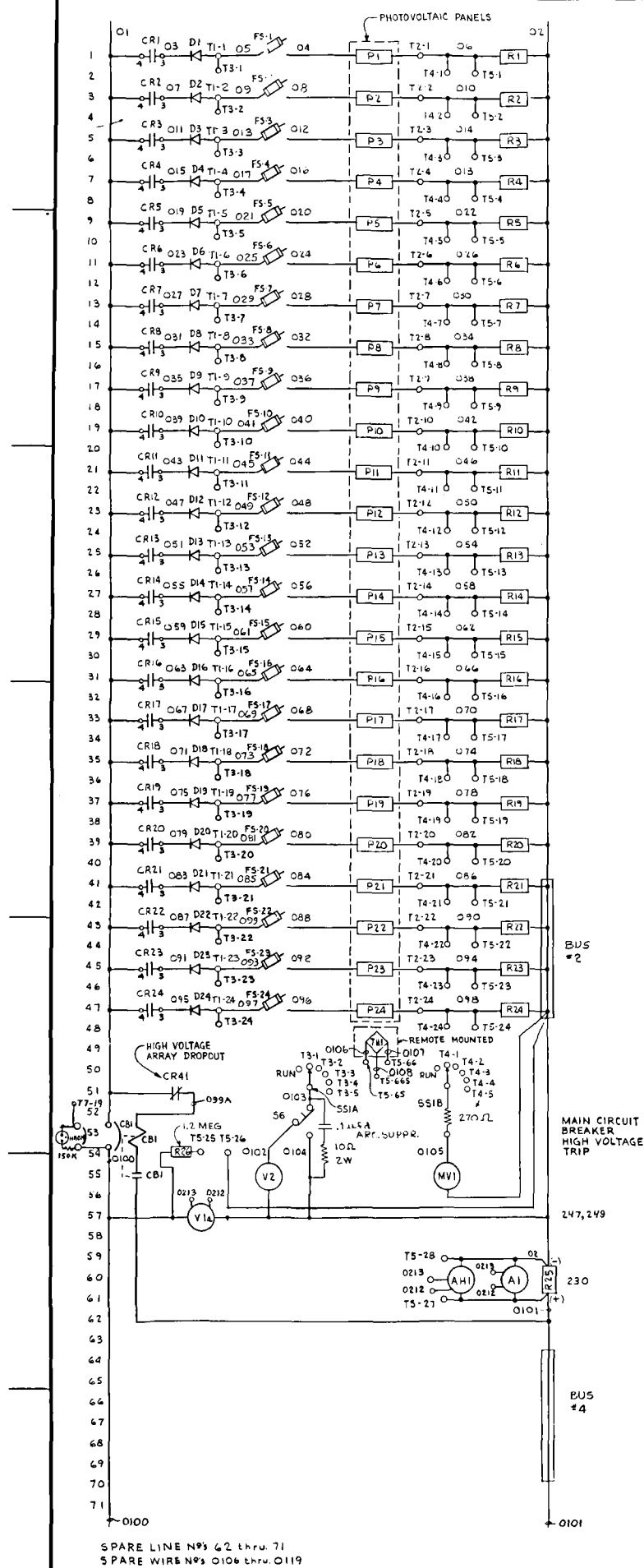
CHANGE NO.	REVISION	DATE	CHK. APP.
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PHOTO-VOLTAIC VILLAGE
POWER SYSTEM
SCHUCHULI, ARIZONA

ONE LINE DIAGRAM AND ARRAY DETAILS

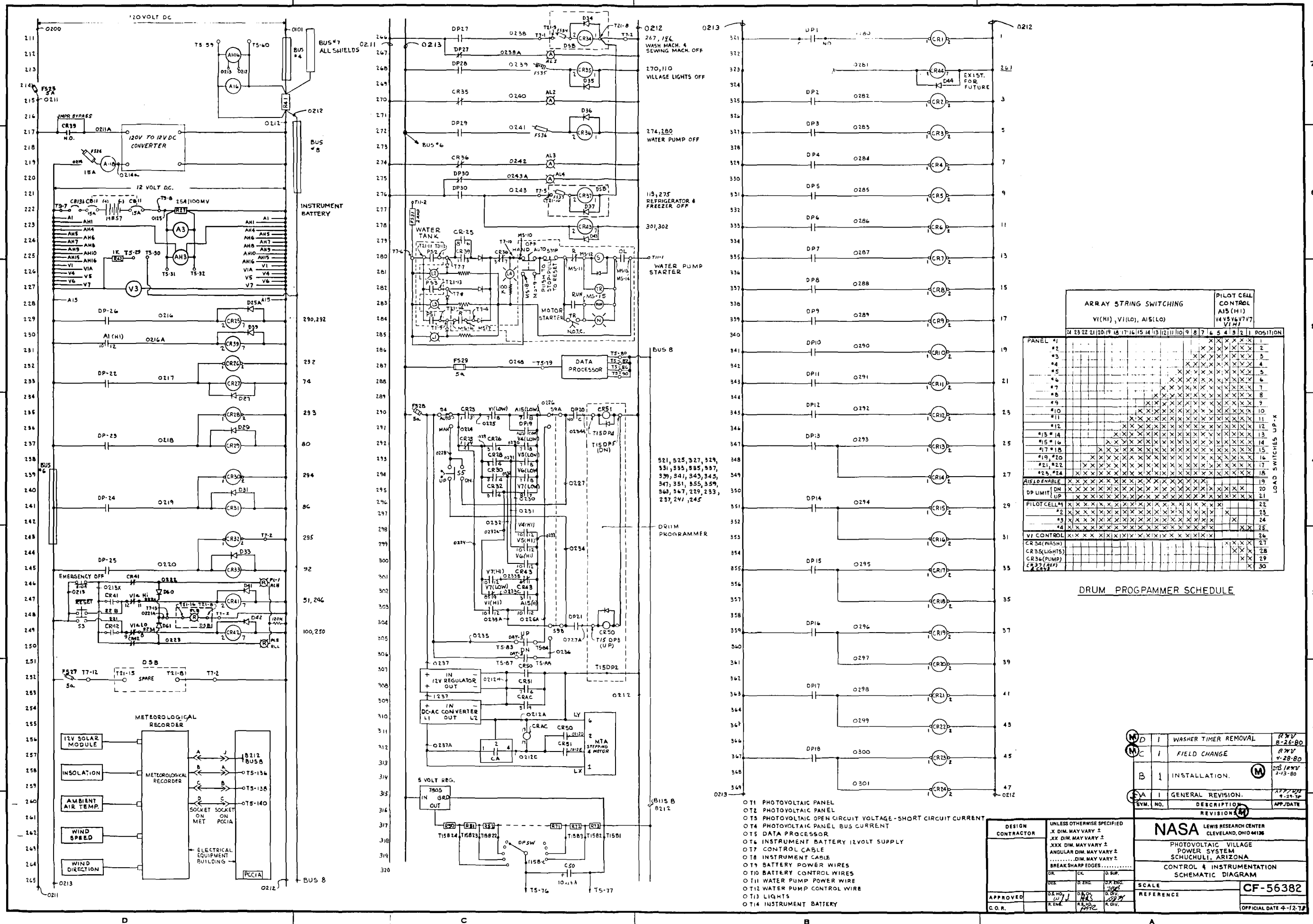
NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO

ELECTRICAL
CF 56380
OFFICIAL DATE



RESISTOR DATA							
NO	OHMS	WATT	SHUNT	NO	OHMS	WATT	SHUNT
1	01	10		26	12	MEG	
2	01	10		27			
3	01	10		28			
4	01	10		29			
5	01	10		30			
6	01	10		31			
7	01	10		32			
8	01	10		33			
9	01	10		34			
10	01	10		35			
11	01	10		36			
12	01	10		37			
13	01	10		38			
14	01	10		39			
15	01	10		40			
16	01	10		41			
17	01	10		42			
18	01	10		43			
19	01	10		44			
20	01	10		45			
21	01	10		46			
22	01	10		47			
23	01	10		48			
24	01	10		49			
25	01	10		50			

DESIGN CONTRACTOR	UNLESS OTHERWISE SPECIFIED X DIM. MAY VARY ± XXX DIM. MAY VARY ± ANGULAR DIM. MAY VARY ± DIM. MAY VARY ± BREAK SHARP EDGES.....	SCALE	REFERENCE
APPROVED	DESIGNER	SCALE	REFERENCE
C.O.R.	REVISION	SCALE	REFERENCE



APPENDIX B

MANUFACTURERS AND EQUIPMENT

(This list of manufacturers and equipment is provided for information purposes only and does not imply endorsement by the NASA-Lewis Research Center or the U.S. Department of Energy.)

Equipment	Model	Vendor
POWER SYSTEMS		
Solar Cell Modules	9200J	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850 Attn: Joseph Lindmayer (202) 948-0202
Array PV Panel and Panel Support Structural Material		Super Strut 802 Eisenhower Drive, North Goshen, IN 46526 (219) 533-0335
Storage Battery Cells (lead-calcium)	LCPSA-19 KCPSA-15 DCPSA-15	C&D Batteries Division Eltra Company 3043 Walton Road Plymouth Meeting, PA 19462 Attn: Mr. Henry Jensen (215) 828-9000
LOADS		
Refrigeration	4.5 ft ³ with compressors	Magna-Kold, Inc. 1790 Monrovia Avenue Costa Mesa, CA 92627 Attn: Mr. Ralph Baker (714) 631-2555
DC Inverter Ballasts for Fluorescent Lights	115RS20BEB2	The Bodine Company 236 Mt. Pleasant Road Colliersville, TN 38017 Attn: Mr. Dick Bodone (901) 853-7211
Sewing Machine (Universal Motor)		White Sewing Machine Co. 11750 Berea Road Cleveland, OH 44111 Attn: Mr. Joseph Arendash (216) 252-3300

Equipment	Model	Vendor
Water Pump	125DC30	Jensen Bros. Manufacturing Company, Inc. 14th and Pacific St. Coffeyville, KS 67337 Attn: Mr. Derrick Morris (316) 251-5700
Washing Machine Wringer Type	E2L without pump	The Maytag Company Newton, IA 50208 (515) 792-7000
120-VDC Permanent Magnet DC Motors		Applied Motors P. O. Box 106 Rockford, IL 61125 Attn: Mr. Kyburz (815) 397-2006
<ul style="list-style-type: none"> ● Washing Machine - 1/4 hp SR 3632-2806-48B ● Water Pump - 2 hp SRF 5556-2804-56BC 		
Motor Starter - 2 hp		Winkle Electric 1900 Hubbard Road Youngstown, OH 44505 Attn: J.A. Hartman (216) 744-5303 (made by Allen Bradley Special DC reduced voltage direct current 2-step combination motor starter per quotation no. 12-178-78)
INSTRUMENTATION & CONTROL		
Electronic Weather Station	100243	Climatronics Corp. 1324 Motor Parkway Hauppauge, NY 11787 Attn: R. Throop Bergh (516) 234-2772
Datalogger	DAT-3	Mars Data Systems 14666 Doolittle Drive San Leandro, Calif. 94577 Attn: Arthur A. Loya (415) 483-7902

Equipment	Model	Vendor
Programmable Drum Relay (PDR) PDR System	JDS 2343	Eagle Signal Division 736 Federal Street Industrial Controls Davenport, Iowa 52803 Attn: Don Morris (319) 326-8105
12V Regulator PDR Subsystem	1340	Wilmore Electronics Co. Post Office Box 1329 Hillsborough, N.C. 27278 Attn: Chris Ely (919) 732-9351
DC to AC Inverter PDR Subsystem 12V DC to 120V AC	TROJAN 50-120	Terado Corp. 1068 Raymond Ave. St. Paul, MN 55108 Attn: Fred Munson (612) 646-2868
AC Timer PDR Subsystem	CA2222S3A60310	Eagle Signal Division 736 Federal St. Industrial Controls Davenport, Iowa 52803 Attn: Don Morris (319) 326-8105
Thermistor Readout System	16508X8	Yellow Springs Instrument Company Box 279 Yellow Springs, Ohio 45387 Attn: Phil Chitty (513) 767-7241
Elapsed Time Indicator	LTH 15.10	Kessler & Ellis Products Dept EM 120 1st Ave. Atlantic, Highlands, N.J. 07716 Attn: Ray Pocza (216) 247-3295
DC Convertor (120V DC to 12V DC) Instrument Battery Regulator	1295	Wilmore Electronics Co. Post Office Box 1329 Hillsborough, NC 27278 Attn: Chris Ely (919) 732-9351

Equipment	Model	Vendor
Ampere Hour Meter	1002	Curtis Instruments 200 Kisco Ave. Mt. Kisco, NY 10549 Attn: Rhoda McDonald (914) 666-2971
Optical Controller Meter Relay	COMPAK I-503K	LFE Corp. 1601 Trapelo Rd. Waltham, Mass. 02154 Attn: Ray Pocza (216) 247-3295

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4. Title and Subtitle DESIGN DESCRIPTION OF THE SCHUCHULI VILLAGE PHOTOVOLTAIC POWER SYSTEM				5. Report Date May 1981	
				6. Performing Organization Code 776-52-41	
7. Author(s) Anthony F. Ratajczak, Richard W. Vasicek, and Richard DeLombard				8. Performing Organization Report No. E-908	
				10. Work Unit No.	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address U.S. Department of Energy Division of Solar Thermal Energy Systems Washington, D.C. 20545				14. Sponsoring Agency Code Report No. DOE/NASA/20485-10	
15. Supplementary Notes Final report. Prepared under Interagency Agreement DE-AI01-79ET20485.					
16. Abstract <p>This report describes the engineering design of a stand-alone photovoltaic (PV) power system for the village of Schuchuli (Gunsight), Arizona, on the Papago Indian Reservation. This experimental solar power system project was funded by the Department of Energy and implemented by the National Aeronautics and Space Administration, Lewis Research Center, together with the United States Department of Health and Human Services, Public Health Service, Indian Health Service, Office of Research and Development, Office of Environmental Health, and the Papago Tribe of Arizona. The purpose of this experiment was to demonstrate that a stand-alone photovoltaic power system could provide dependable power for basic human needs in a remote village environment. The power system was designed as a limited energy, all 120-V (d. c.) system to which loads cannot be arbitrarily added. The system consists of a 3.5-kW (peak) PV array, 2380 ampere-hours of battery storage, an Electrical Equipment Building, a 120-V (d. c.) electrical distribution network, and equipment and automatic controls to provide control power for pumping water into an existing water system; operating 15 refrigerators, a clothes washing machine, and a sewing machine in the Domestic Services Building; and lights for each of the homes and communal buildings. In addition, a solar hot water heater was provided to supply hot water for the washing machine and communal laundry. The system employs automatic control systems which provide voltage control by limiting the number of PV strings supplying power during system operation and battery charging, and load management for operating high priority loads at the expense of low priority loads as the main battery becomes depleted. The engineering design of this system is presented in this report and includes loads profiles and loads descriptions; an explanation of the PV array and battery sizing methodology; descriptions of the mechanical designs; electrical designs and descriptions of the array, battery, controls, instrumentation and distribution system; and a discussion of safety features. The system was dedicated and began operation on December 16, 1978. The operational history and data are not contained in this report.</p>					
17. Key Words (Suggested by Author(s)) Schuchuli Village Photovoltaic Power System			18. Distribution Statement Unclassified - unlimited STAR Category 44 DOE Category UC-63		
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