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REPORT

DOE/NASA CR-161202

DESIGN DATA BROCHURE FOR A PYRAMIDAL OPTICS SOLAR
SYSTEM

Prepared by

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Under Contract NAS8-32250 with

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George C. Marshall Space Flight Center, Alabama 35812

For the Department of Energy

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Solar Energy

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16. ABSTRACT This Design Data Brochure provides information on a Pyramidal Optics Solar System for solar heating and domestic hot water. The system is made up of the collecting, storage, and distribution subsystems. Contained in the brochure are such items as system description, available accessories, installation arrangements, physical data, piping and wiring diagrams, and guide specifications. The final design and results are contained in documents DOE/NASA CR-161546, Solar Energy System Performance Evaluation Seasonal Report for Wormser, Columbia, South Carolina, and Solar Energy System Economic Evaluation Final Report for Wormser, Columbia, South Carolina (CR# to be issued).					
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1.0 Pyramidal Optics System Description

The Pyramidal Optics Solar Energy System (with Dual Source Heat Pump Auxiliary Distribution Package) is a low gain solar concentrator which captures solar energy economically for use in space and domestic hot water heating. The typical installation is made up of three major subsystems:

- The Collecting Subsystem:

This is the "Pyramidal Optics" part of the system made up of a collector-reflector assembly mounted in the attic space as shown in Figure 1.1.

- The Storage Subsystem:

The suggested tank is a plywood tank with an industrial grade, waterproof liner.

- The Distribution Subsystem:

The heat distribution is by a conventional residential forced air ducted network. A package unit contains a water-to-air heat exchanger for direct use of the solar heated water, a dual source heat pump which can operate from the solar heated water or outside air as a heat source, plus backup electric resistance heat strips, Figure 1.2.

Solar Energy Collection:

As shown in Figure 1.1, the flat plate absorbers

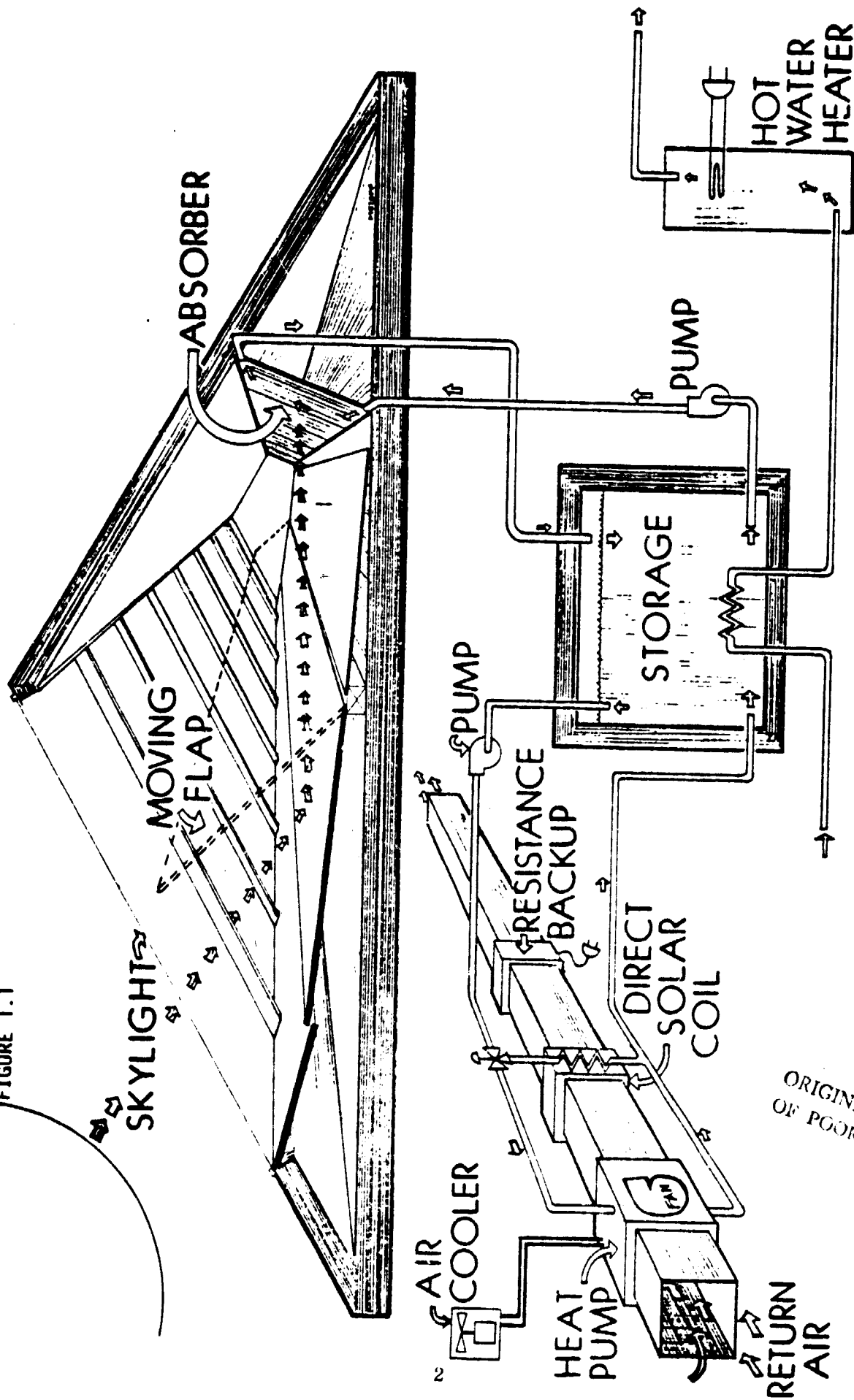
are mounted on the northern edge of an attic space. A window in the south facing roof admits the solar energy to the attic. The interior of the attic space is lined with mirror surfaces which reflect the incoming sunlight on to the absorber surfaces. These reflective surfaces roughly describe a pyramid lying on its side with its base forming the window opening, and the absorber plates lying near its apex or focus. From the shape of these reflective surfaces is derived the name, Pyramidal Optics. The reflective surface lying along the floor of the attic is hinged near the collector and is lifted by winch and cables attached along its window or south edge. This movement is slow, approximately 2 inches per week, and can be controlled by a clock motor regulator. This moving panel compensates for the seasonal altitude movement of the sun, moving from a low position at 10° for the December sun to a high position at 45° for the June sun, Figure 1.3.

The sun rays are focused on the copper absorber panels through which water is circulated to pick up the incident energy. The window glazing on the south slope of the roof is contained in a neoprene zipper gasket for a tight weather seal, Figure 1.4.

The Storage Subsystem:

The heat energy captured at the absorbers is stored in a large water tank, usually in the basement of the dwelling. A number of tank designs will provide adequate capacity and insulation value. Material choices include

FIGURE 1.1

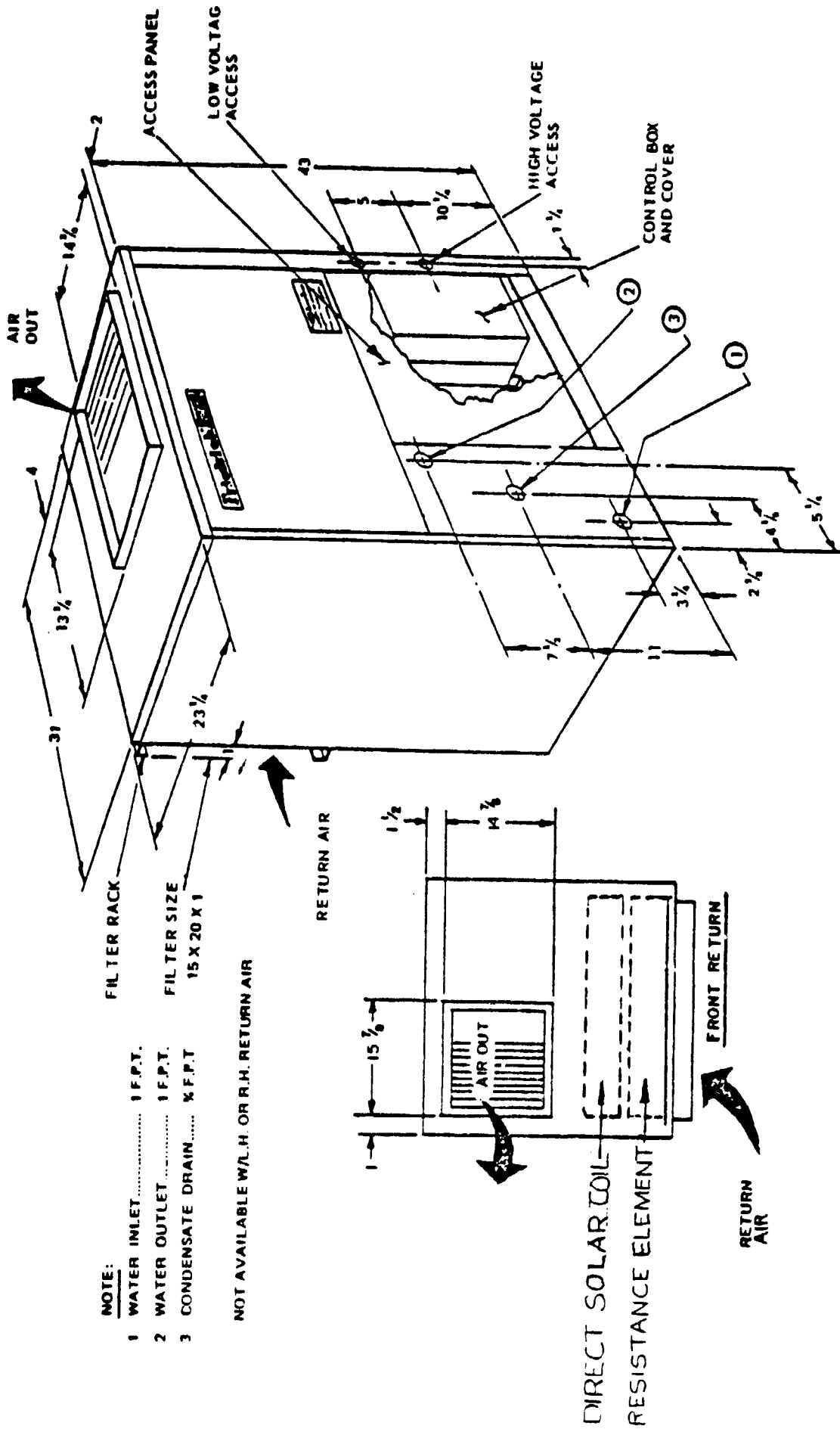


PYRAMIDAL OPTICS SOLAR SYSTEM

U.S. PATENT 3,041,302

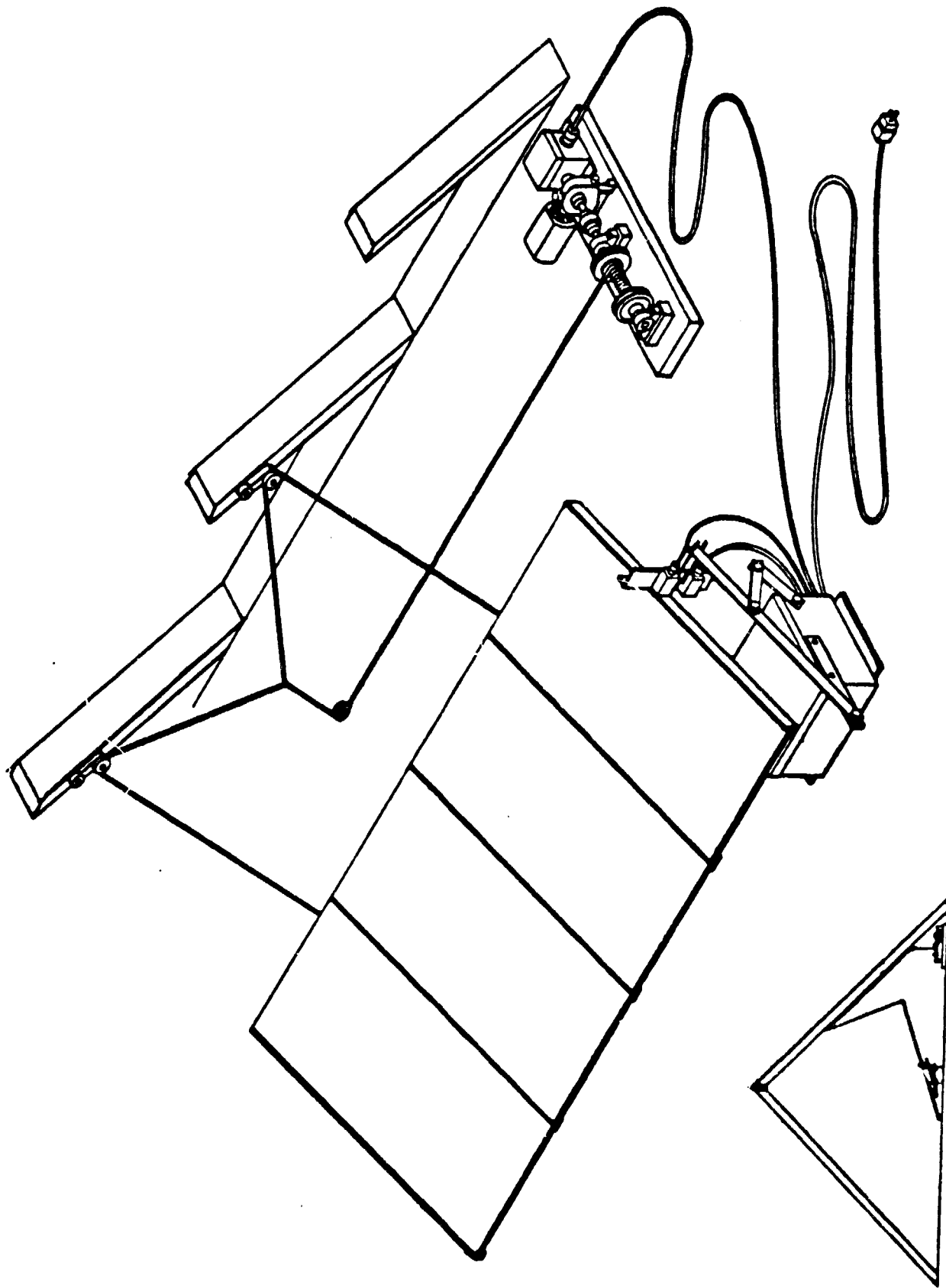
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FIGURE 1.2



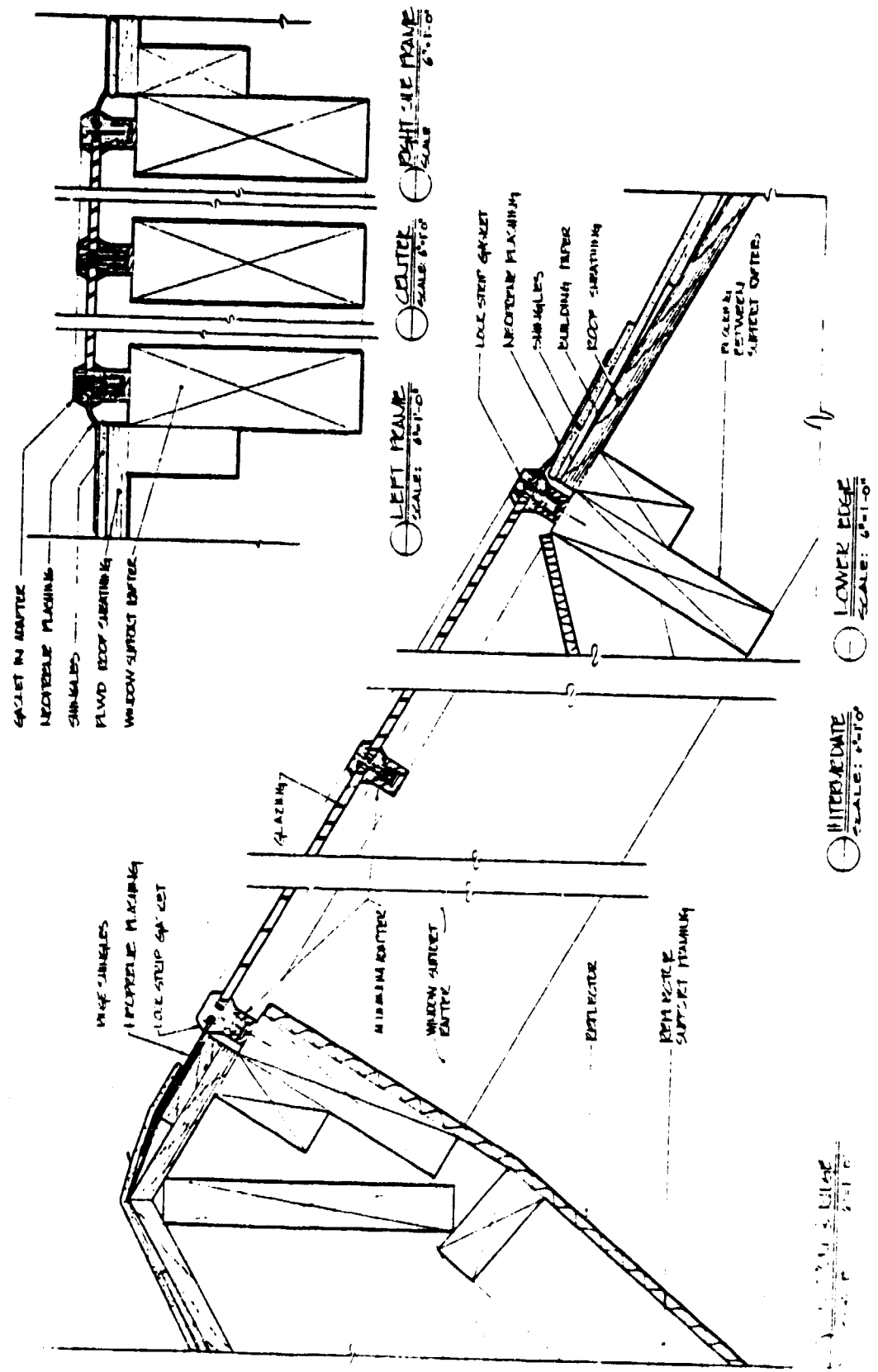
SOLAR AUXILIARY UNIT

FIGURE 1.3



SOLAR ALTITUDE COMPENSATOR

FIGURE 1.4



SOLAR WINDOW GASKET

poured-in-place concrete, precast concrete, plywood, steel, fiberglass reinforced plastic.

Distribution of Heat:

A unique package unit has been developed to provide distribution of space heat, and auxiliary energy when sufficient solar power is not available. Schematically shown in Figure 1.5, this unit is made up of four components:

- A water-to-air heat exchanger "coil" which transfers heat directly from the solar heated water to the air in the duct.
- A combination water and air source heat pump which can use either solar heated water between the temperatures of 40° and 85°F, or outside air between the temperatures of 10° and 55°F. Conventional cooling is provided by the air source portion of the unit.
- A two-stage backup electric resistance heater provides auxiliary heating energy when temperature conditions limit the output of the solar coil or heat pumps.
- An air handler blower to move the heated or cooled air through the ducts. Domestic hot water heating is produced by a heat transfer loop between the hot water tank and the solar storage tank as shown in Figure 1.5. Double separation of potable water from the water in the solar storage tank is

accomplished by the two heat exchangers shown.

System Controls:

A control panel furnished with the system operates the system in the following modes illustrated in the system schematic, Figure 1.5, and the individual modes schematic, Figure 1.6.

Mode 1, Collecting Solar Energy:

When the absorber panel temperature rises 10° above the temperature of the water in the storage tank, pump P1 is turned on and circulates water through the absorbers. This circulation continues until the panel temperature falls to within 3° of the storage temperature.

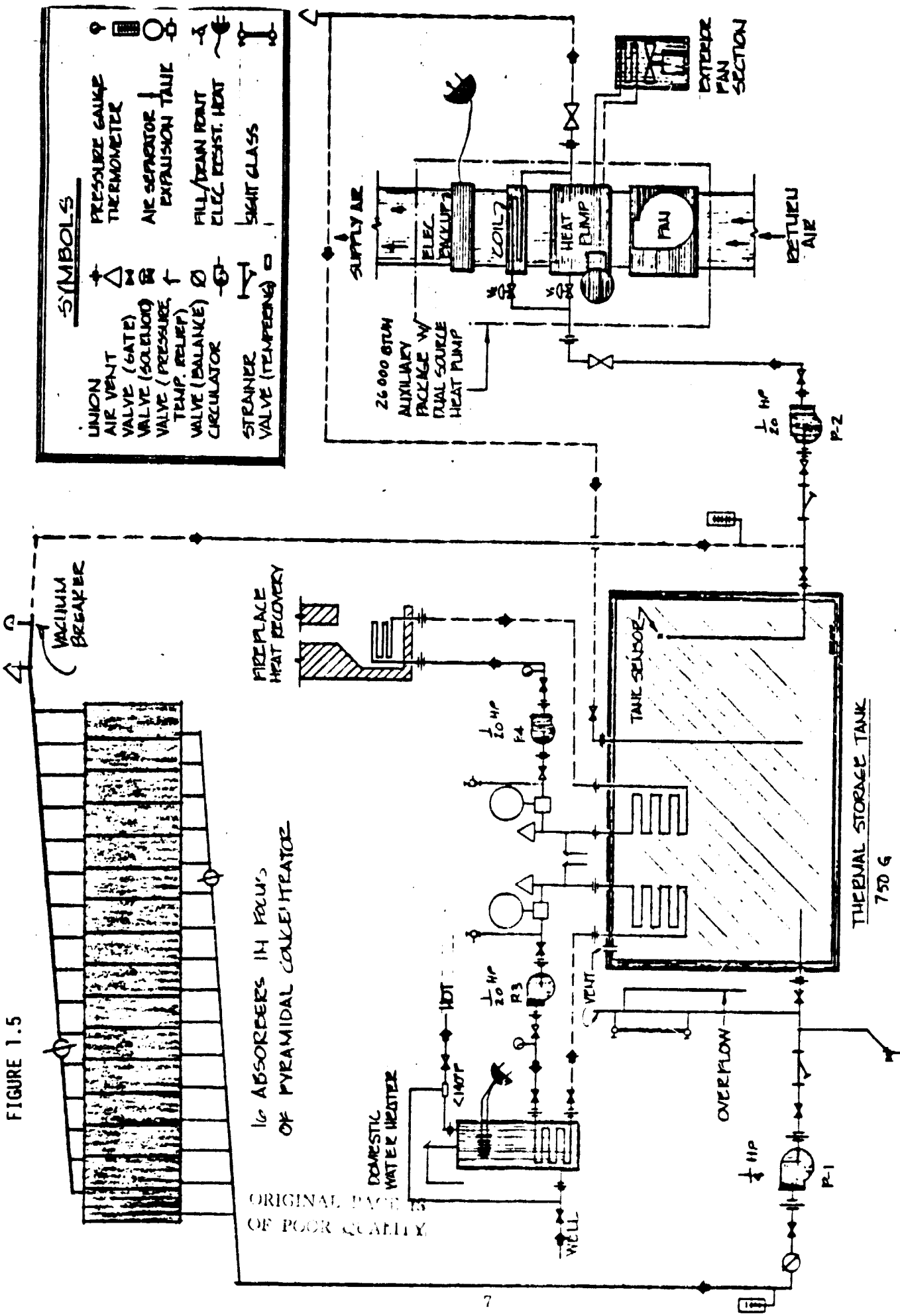
Mode 2, Space Heating Directly from the Tank:

When the tank is above 85°F, pump P2 circulates tank water to the auxiliary unit. Within the auxiliary, water passes through a water-to-air coil in the air stream. The blower is on to move the heated air through the house. In this mode, heating is 100% solar powered.

Mode 3, Space Heating by Water Source Heat Pump:

When the tank temperature is between 40° and 85°F, heat is extracted by the water-to-air heat pump from the warm solar water supplied by pump P2. The blower circulates the heat to the living space.

FIGURE 1.5



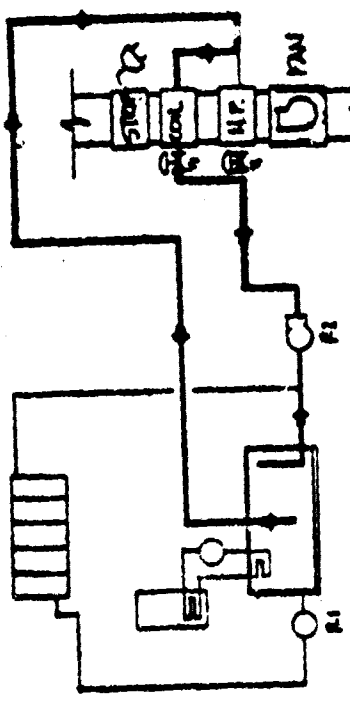
SYMBOLS

UNION	PRESSURE GAUGE
AIR VENT	THERMOMETER
VALVE (GATE)	AIR SEPARATOR
VALVE (SOLENOID)	EXPANSION TANK
VALVE (PRESSURE TEMP. RELIEF)	FILL/DEAN POINT
VALVE (BALANCE)	ELEC. RESIST. HEAT
CIRCULATOR	SIGHT GLASS
STRAINER	
VALVE (TEMPERING)	

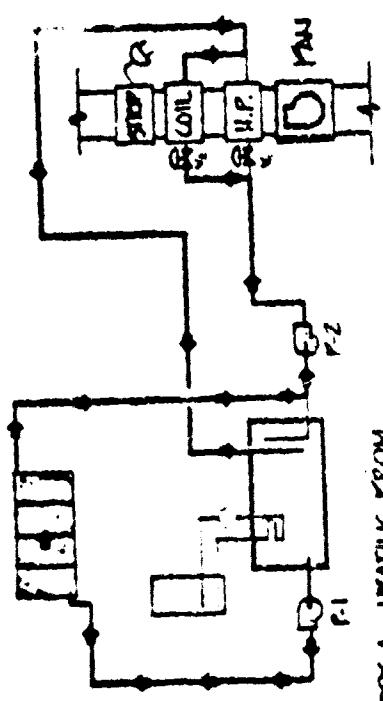
SYSTEM FLOW SCHEMATIC

FIGURE 1.6

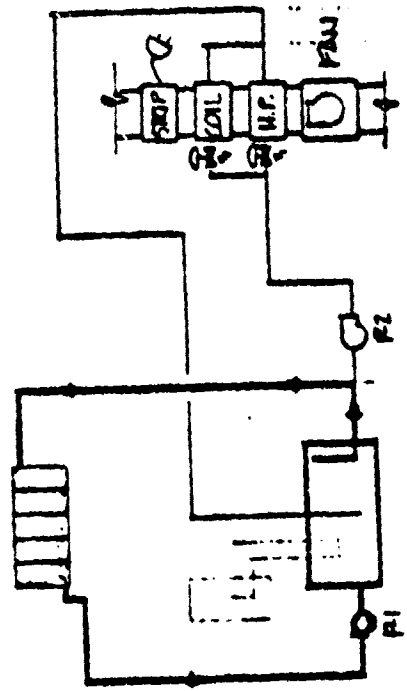
INDIVIDUAL MODES SCHEMATIC



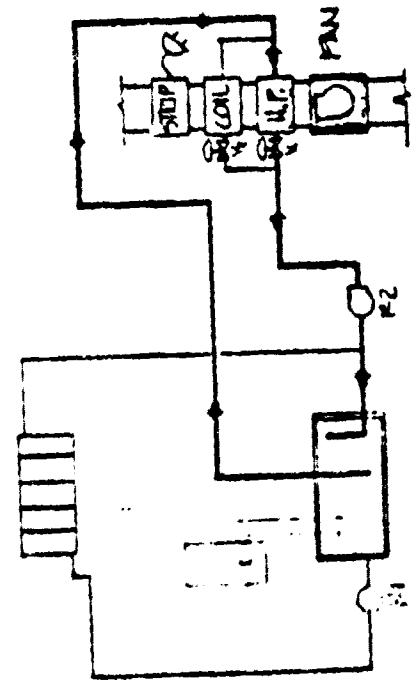
MODE 1: HEATING STORAGE
TO BUILDING (STORAGE ABOVE 85°F)
P1 ON
P2 ON
V1 CLOSED
V2 OPEN



MODE 2: HEATING STORAGE
TO BUILDING (STORAGE 40-81°F)
P1 ON
P2 ON
V1 CLOSED
V2 OPEN



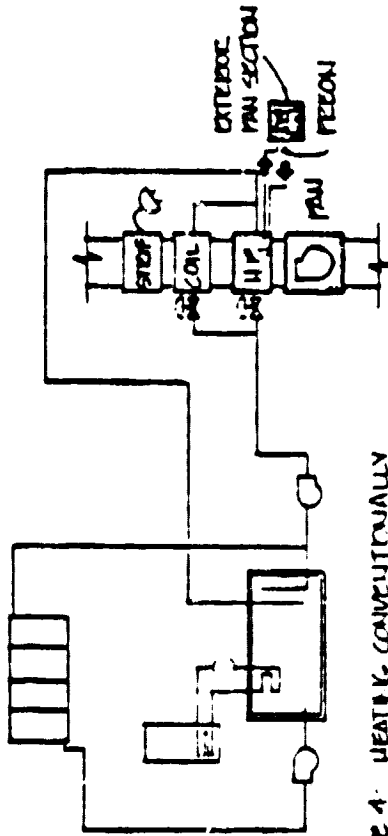
MODE 3: STORING HEAT FROM COLLECTORS
P1 ON
P2 OFF



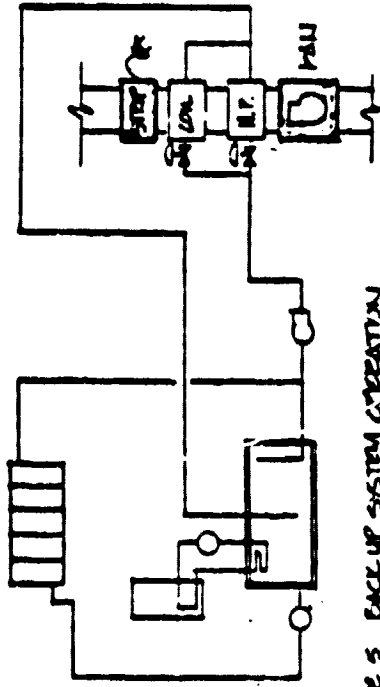
MODE 4: HEATING STORAGE
TO BUILDING (STORAGE 40-81°F)
P1 ON
P2 ON
V1 OPEN
V2 CLOSED

FIGURE 1.6 continued

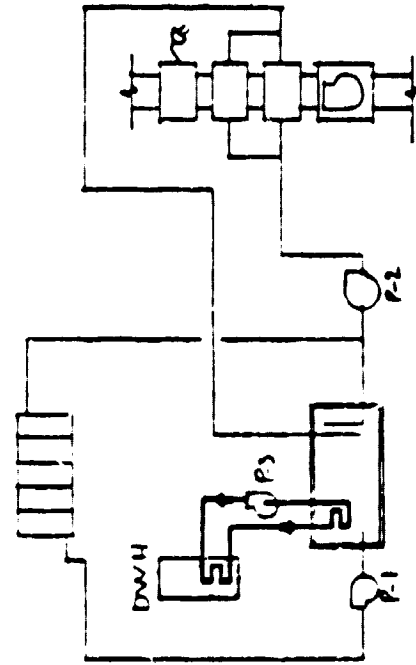
INDIVIDUAL MODE SCHEMATIC



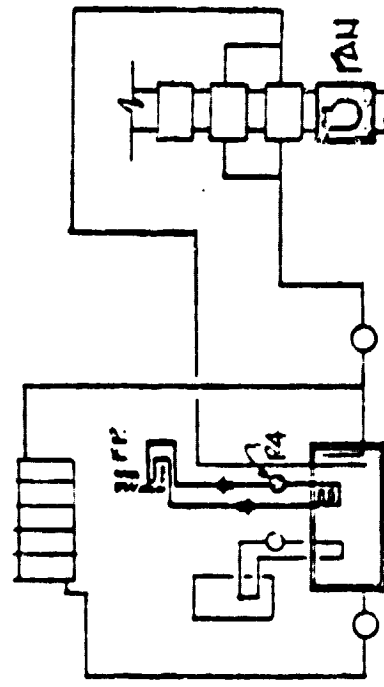
MODE 4: HEATING CONVENTIONALLY
 MODE 6: COOLING CONVENTIONALLY
 FAN ON
 HEAT PUMP OPERATES
 IN AIR-TO-AIR CYCLE



MODE 5: BACK-UP SYSTEM CIRCULATION
 FAN ON
 RESISTANCE HEAT STEPS ON



MODE 7: DOMESTIC WATER HEATING
 P-3 ON



MODE 11: HEAT RECOVERY
 FIRE-PLACE HEAT RECOVERY
 P-4 ON
 CIRCULATION THRU COIL IN GRATE
 WINDOW HEAT RECOVERY
 FAN - ON
 AIR CIRCULATION THRU SLAB
 RETURN AIR

Mode 4, Space Heating by Air Source Heat Pump:

When the tank temperature is below 40°, the air source unit located outside the house permits the heat pump to extract heat from the outside air. The blower circulates this heat to the living space.

Mode 5, Backup Resistance Heating:

The living space is equipped with a two-stage thermostat which will turn on half of the electric resistance backup heating should the space temperature continue to fall below the first heating set point. The second half of the resistance heat comes on if the tank is below 40° and the outside temperature is below 10°. The blower is on whenever the heat strips are on.

10

Mode 6, Cooling by Air Source Heat Pump:

Cooling is provided by the air source heat pump when called for at the thermostat. The blower moves the cooled air through the house.

Mode 7, Domestic Hot Water Heating:

Circulation (by pump P3) between the solar tank heat exchangers and heat exchanger located in the bottom of the DHW tank begins when the temperature difference between the two tanks exceeds 10°F and ceases when the difference is less than 3°F.

System Capacity:

The system is designed to provide 100% of the heating and cooling requirements of the dwelling through a combination of solar input and backup auxiliary. The ratio of solar energy input to auxiliary input varies according to the size of the solar system and could theoretically approach 1.0. However, it has been found that systems providing 60 to 80% solar utilization are generally the most economic. Above 80%, it becomes increasingly difficult to justify solar equipment standing idle during temperate weather.

2.0 Available Accessories

A. Fireplace Heat Recovery

This consists of a water jacket integral to the fireplace grate of the dwelling, illustrated in Figure 2.1. Here water is warmed by a wood fire, then pumped through a closed loop that includes a heat exchanger immersed in the solar storage tank. The warmth of the wood fire is thereby used to recharge the temperature of the solar storage tank. A sensor near the fireplace water jacket detects the temperature of the water. When the temperature exceeds 180°, a relay is closed, which supplies power to the pump. The pump then remains on as long as the temperature of the water heated by the wood fire exceeds 180°F.

The sensor bulb and box must be mounted out of direct heat or flame, but close enough to the fire to accurately measure the temperature of the heated water. The suggested location for the bulb is between the air vent in the loop and the grate. With the sensor higher than the grate, the thermosyphoning that occurs will tend to warm the sensor.

B. Window Heat Recovery

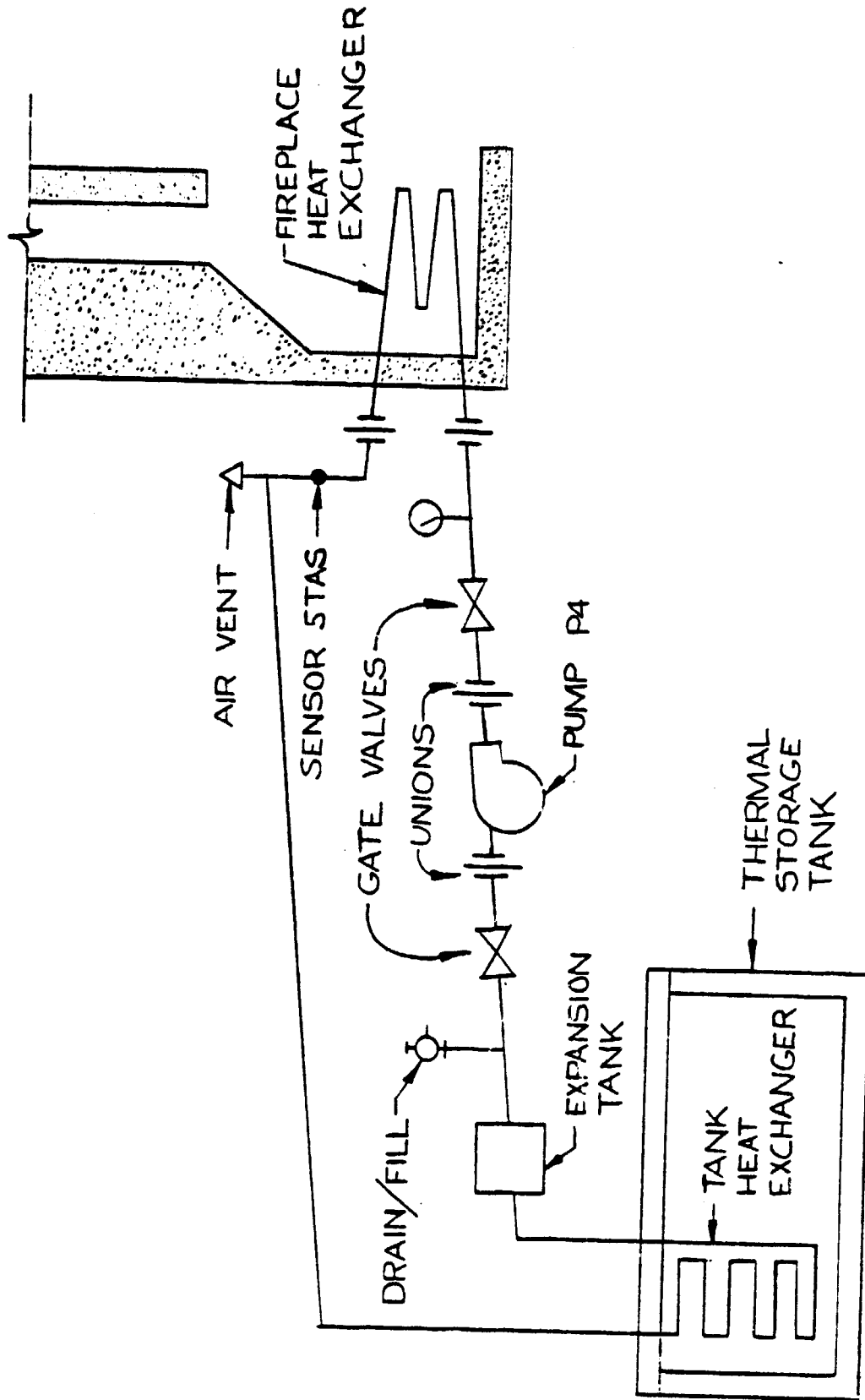
The dwelling interior can be designed to take advantage of heat captured by south facing windows. The glass area functions as a solar collector. Effective use of the energy admitted through this collector requires a method of storage and distribution. If a cathedral ceiling or loft is used in the room with the south facing glass the heated air will rise to the highest spot. A duct located at this high

point connected to a thermostatically operated blower can convey the warm air to other rooms. Storage of this low grade heat can be effective in the thermal mass provided by block, poured concrete, or stone walls of the dwelling. For best use of the potential thermal storage mass of exterior masonry walls, insulation should be applied to the outside surface of such walls.

C. Manual Flap Control

Should automatic movable flap adjustment by the Solar Altitude Compensator not be desired, manual adjustment of the flap can be installed. This consists of a winch connected by cables to the flap, which is operated by a toggle switch placed near the access hatch. To gauge the manual adjustment of the flap, which should be done monthly, a scale is placed on the wall at one end of the flap.

FIGURE 2.1



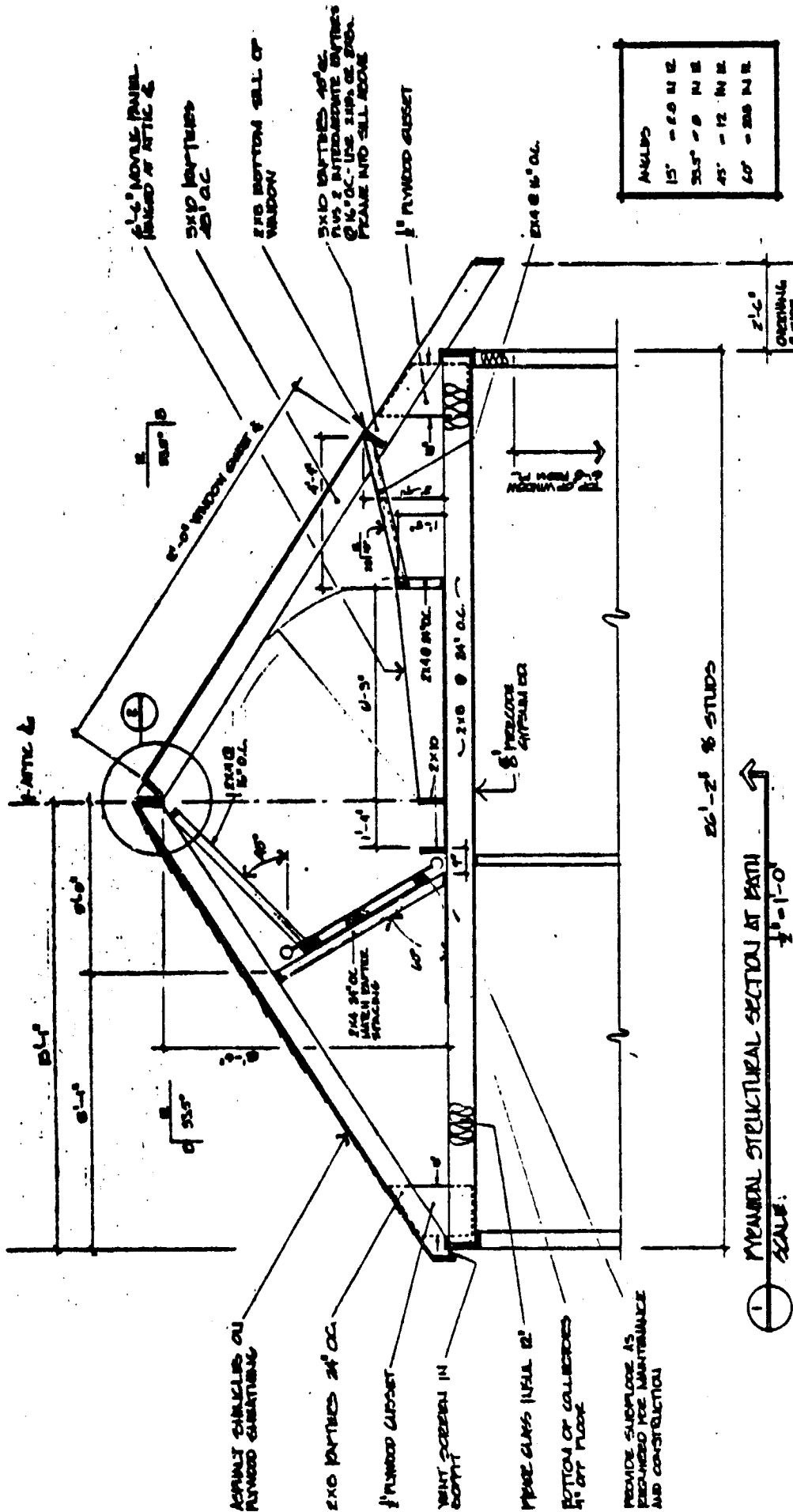
FIREPLACE HEATING SCHEMATIC

3.0 Typical Installation Arrangement

The layout of a typical Pyramidal Optics solar system is shown in a structural section, Figure 3.i. The RollBond absorber can be seen, as well as the fixed and adjustable reflectors. In the examples shown, the solar window has a 12' slant height and the roof pitch is 8 in 12.

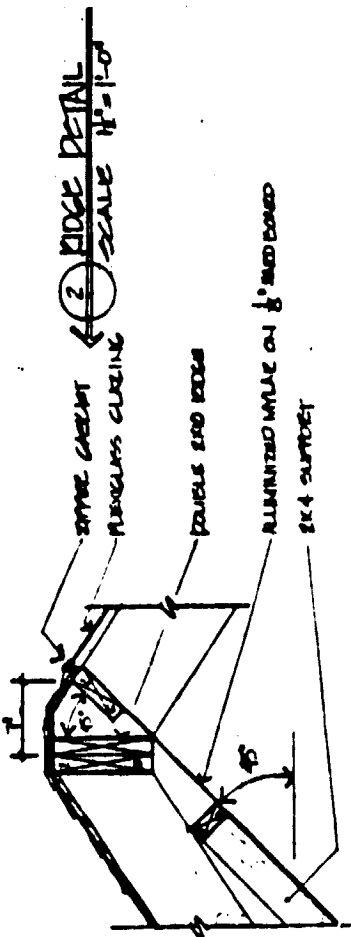
A typical mechanical room plan is shown in Figure 3.2. Included are the storage tank, solar auxiliary unit, domestic hot water tank, and the associated plumbing fittings.

FIGURE C.1



ANGLES	
15°	= 2.0 IN 12
26.5°	= 5 IN 11 1/2
45°	= 12 IN 12
60°	= 20 1/2 IN 12

1 MAIN WALL STRUCTURAL SECTION AT RATH
SCALE: 1/8"=1'-0"



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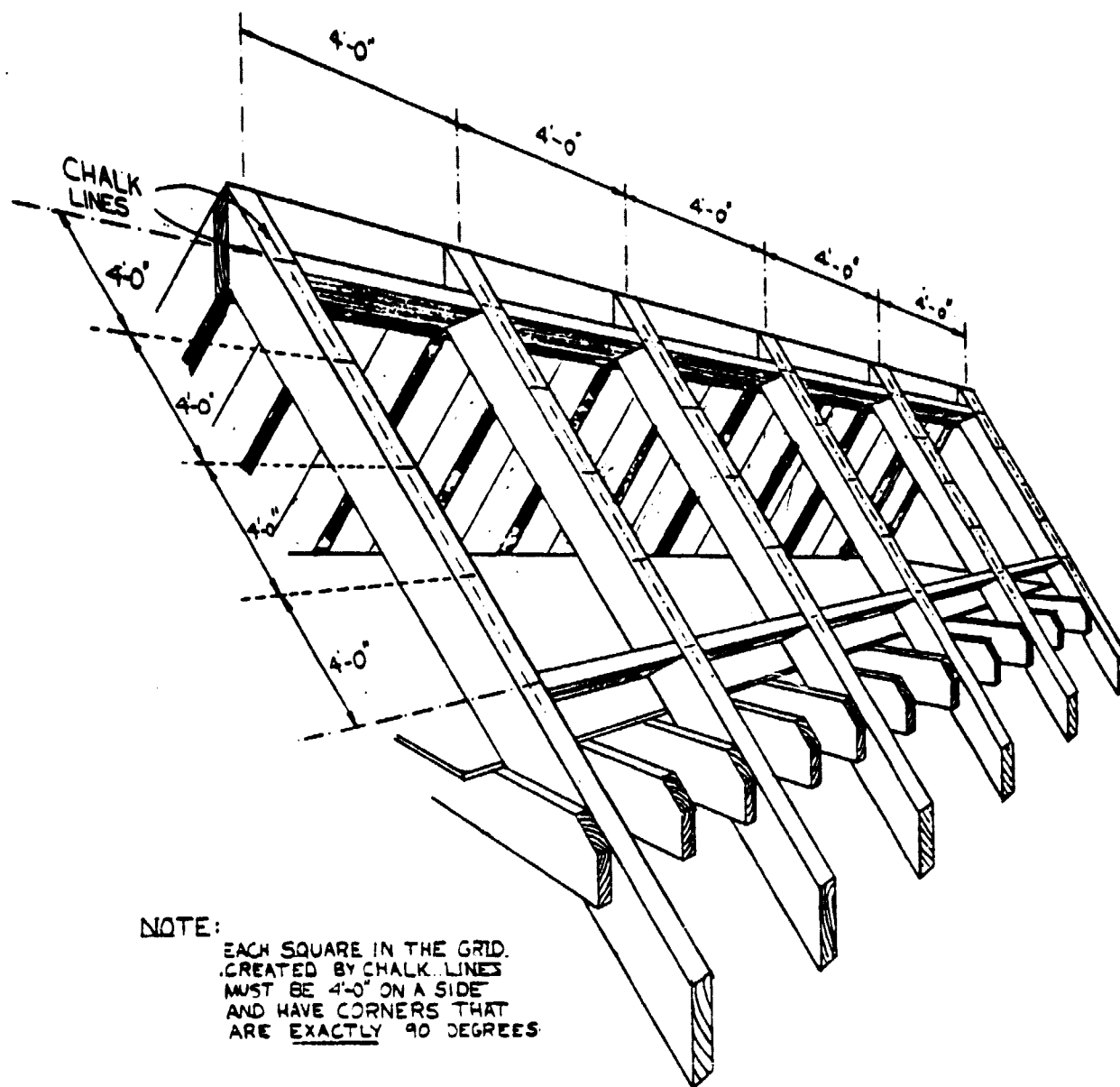
4.0 Unit Dimensions and Installation Instructions

The window is available in 4' x 4' modules with other sizes available upon special request. Typical window heights are 12' or 16' in slant height. The width of the window can be any multiple of 4' with wider windows performing better than narrow ones due to relatively less edge effect. The rafter framing is illustrated in Figure 4.1. The installation of the aluminum channel to which the window gasket is attached is shown in Figure 4.2.

Collectors are 34" wide by 47" high, or for very large jobs, 34" wide by 96" high. The collectors are installed at the focal point in a width chosen which is the nearest multiple of 34 1/8", which is smaller than the width of the window opening. The remaining edge distance is made up by edge reflectors. The collector framing, insulation and attachment is shown in Figure 4.3. The design process by which attic layout is determined is outlined in Chapter 6.

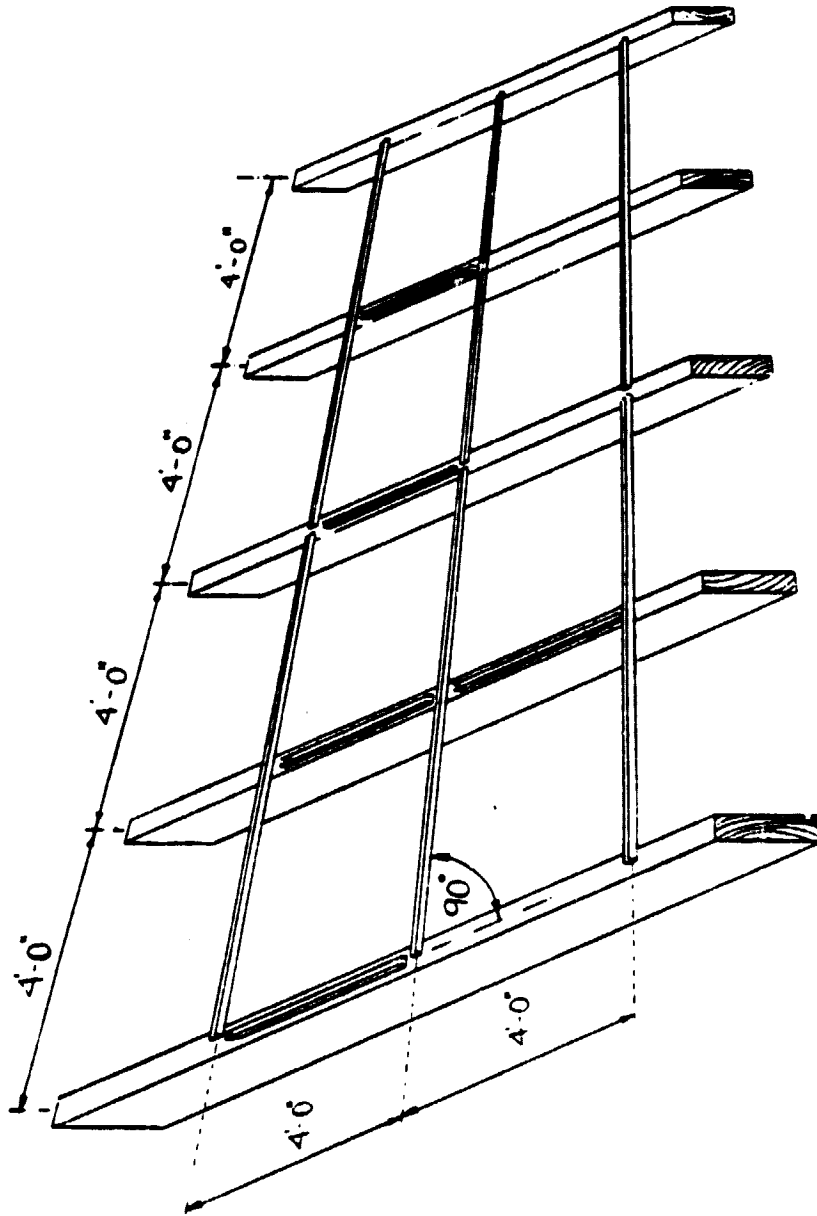
Installation procedures are outlined in detail in the Installation, Operation, and Maintenance Manual for the Pyramidal Optics Solar System. An installation procedure summary is given below in the form of a critical path chart, Figure 4.4.

FIGURE 4.1



NOTE:
EACH SQUARE IN THE GRID.
CREATED BY CHALK LINES
MUST BE 4'-0" ON A SIDE
AND HAVE CORNERS THAT
ARE EXACTLY 90 DEGREES

FIGURE 4.2



SOLAR APERTURE WITH SEVERAL
SQUARES OF CHANNEL IN PLACE

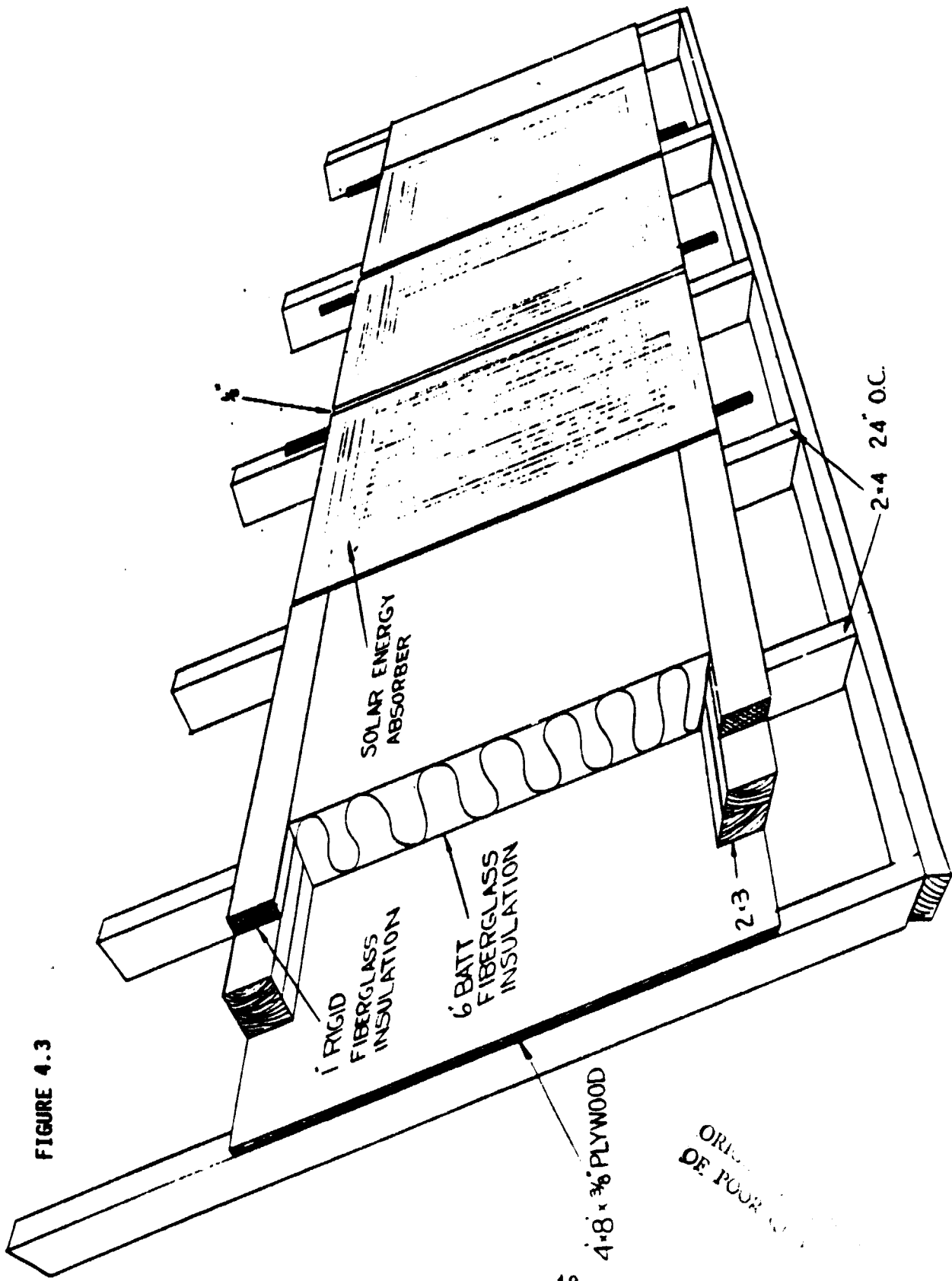


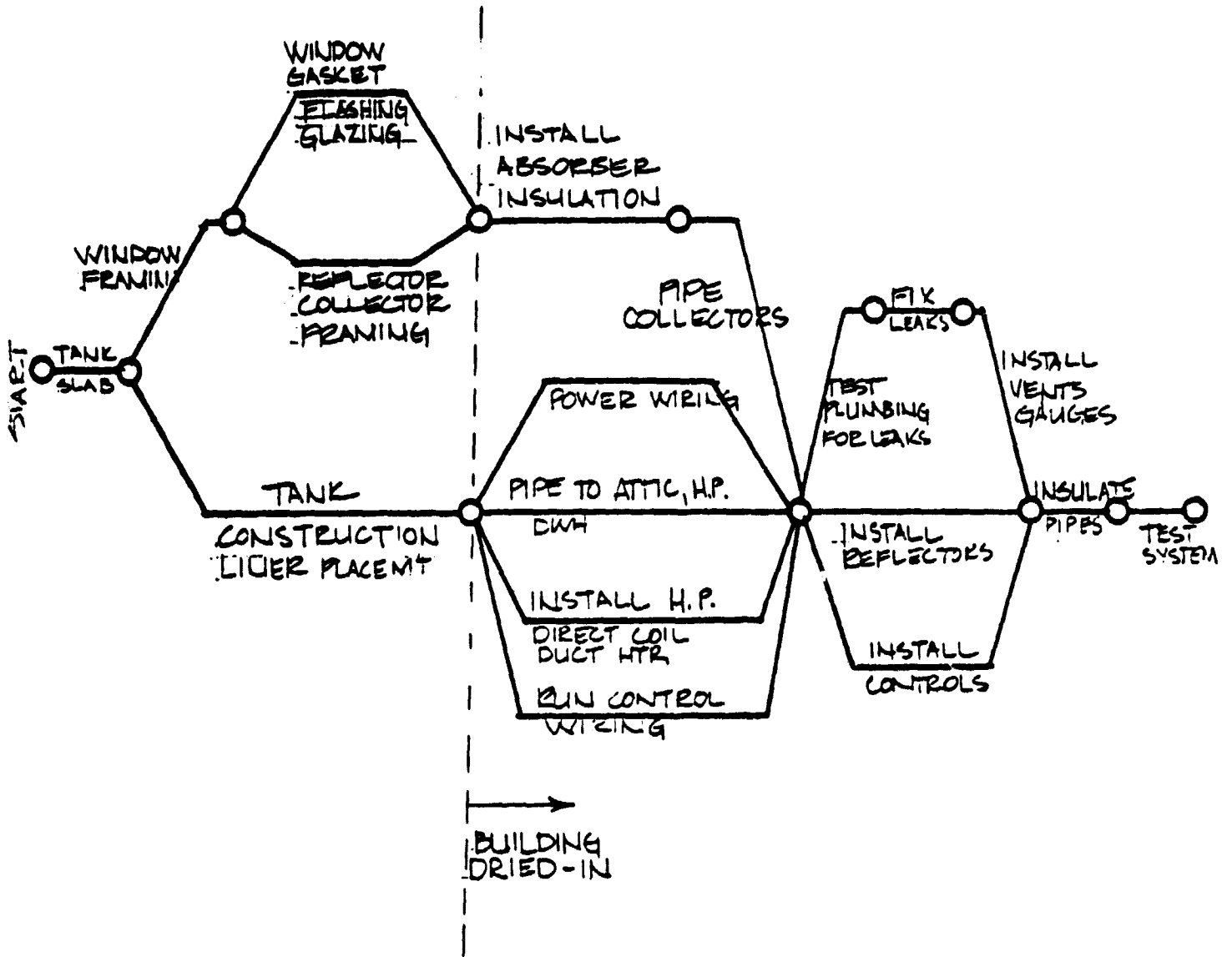
FIGURE 4.3

CUT-AWAY VIEW OF THE ABSORBER PLATE SYSTEM

ORIG. DRAWING
DE. POOR

Sequence of Installation of the Pyramidal Optics Solar System

FIGURE 4.4



On this chart time flows from left to right. Tasks are indicated by lines between nodes (circles).

5.0 Physical Data

<u>Item</u>	<u>Material</u>	<u>Sizes</u>	<u>Item</u>	<u>Material</u>	<u>Sizes</u>
Solar Window Glazing	Acrylic Plastic	4'x4'x1/4"	Pumps	Centrifugal fractional horsepower circulator of stainless steel	1/12, 1/20 h.p.
Glazing Gasket	Neoprene zipper gasket & Aluminum Attachment Chanel	Factory molded to cover entire window opening with corners, tees, and edge flashing	Storage	Waterproofing liner timber container or equal, insulated with 3" or thicker sprayed urethane	as required
Reflec-tors	Aluminized Mylar vinyl sandwich laminated to a 1/8" hard-board substrate	4'x8'x1/8"	Solar Auxiliary Unit	Special dual source heat pump air handler, resistance backup and direct solar water-to-air heat exchanger	10,000, 14,000 18,000, 22,000 27,000, 33,000 42,000, 52,000 62,000 BTUH
Lifting Flap	Reflector sheet in aluminum frame	8'x16'x1"	Controls	Self Contained panel with remote thermostats	24"x24"x6"
Solar Altitude Compensator	Clock controlled winch mechanism	Controls & lifts up to 2 flaps	Hot Water Tank	Hot water tank with 120 gallon integral copper heat exchanger coil	
Collectors	Copper Rollbond with black chrome selective coating	34"x47"x1/4"	Collector Piping	Reverse return 1" copper with balance valves insulated with flexible pipe insulation	

6.0 Sizing Procedure

A solar aperture area of between 20% and 40% of the floor area of the dwelling represents a system size that can supply a significant portion of the heating load of the building. Sizing should be done on the basis of heat losses of the building and an active aperture efficiency of 40%.

Component Arrangement

A typical Pyramidal Optics collection system has a 12' slant height window, a roof with an 8 in 12 pitch, and a 26' attic width measured east to west. The design procedure for the Pyramidal Optics solar system is a flexible process that permits the adaptation of the collection scheme to a wide variety of house styles. Figure 6.1 shows the pertinent attic features.

1. First determine the tilt of the RollBond Collector (surface B). This angle is selected from Table 1.

Table 1:

Your Latitude °N	Collector Angle
25-35	55°
35-45	60°
45-55	65°

2. The lower edge of the collector should be

9" above the floor joists. (This allows room for the slanting of pipes to permit the system to drain down.)

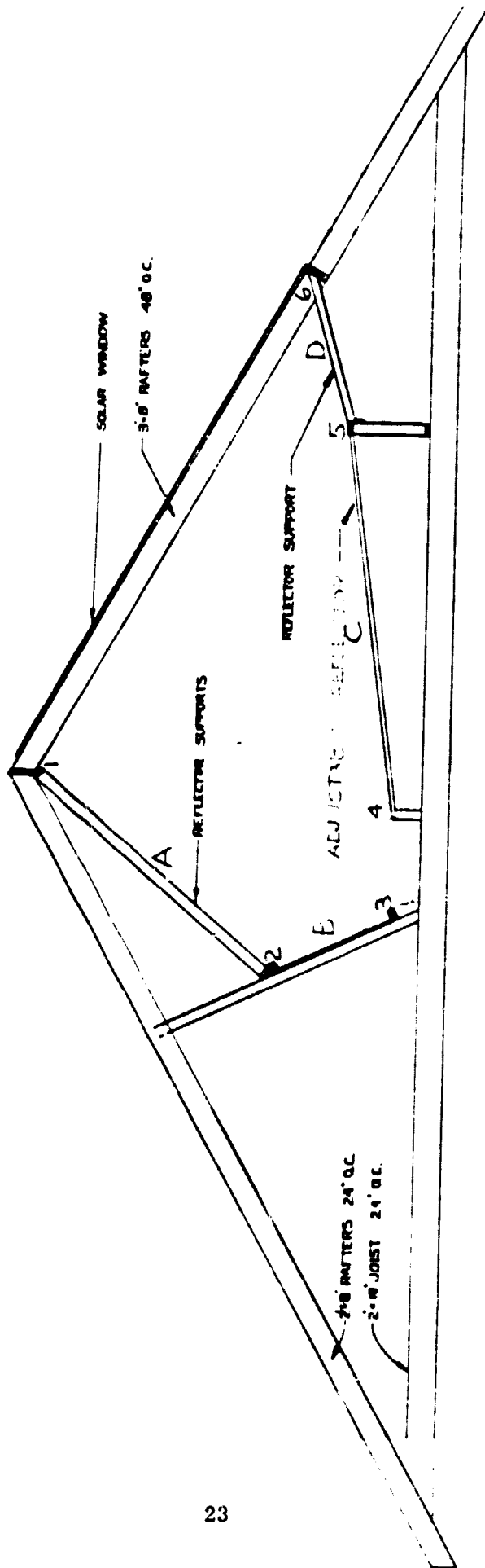
3. The uppermost fixed reflector (surface A) extends from the ridge of the roof (point 1) to the junction with the collector at point 2. The angle of this reflector is set so that the December 21 sun ray which enters the upper edge of the solar window (point 1) will be reflected and strike the lower edge of the collector (point 3).

4. The hinge point of the moving reflector, surface C, should be at the same height as the bottom of the collector. The north-south position of the hinge (point 4) is determined by finding the location that permits the moving reflector (usually 8' long) to have at least 2" clearance when it is perpendicular to the rafters. A walkway of at least 1' in width must be left between the collectors and the hinge point. A reflective board laid over this walkway is removed for access to the collectors. If the 2" clearance cannot be provided using an 8' long moving reflector, the reflector may be shortened.

5. The lowest position of the movable reflector, point 5, is determined by finding the lowest angle that will cause the December 21 noon ray striking the tip of the movable reflector (point 5) to be reflected to the top of the collector (point 2).

6. Fixed reflective surface D is positioned to

FIGURE 6.1



ATTIC STRUCTURAL SUPPORTS

connect point 5 with point 6, the lower edge of the solar window. The optimum angle for this reflector is steeper by 3 or 4° than reflector C, so that the December 21 noon ray striking point 6 is reflected to the top of the collector (point 2).

7.0 Typical Control Schematic

A typical control schematic is given in Figure 7.1. This control arrangement will operate the modes described in Chapter 1.

SYSTEM CONTROLS

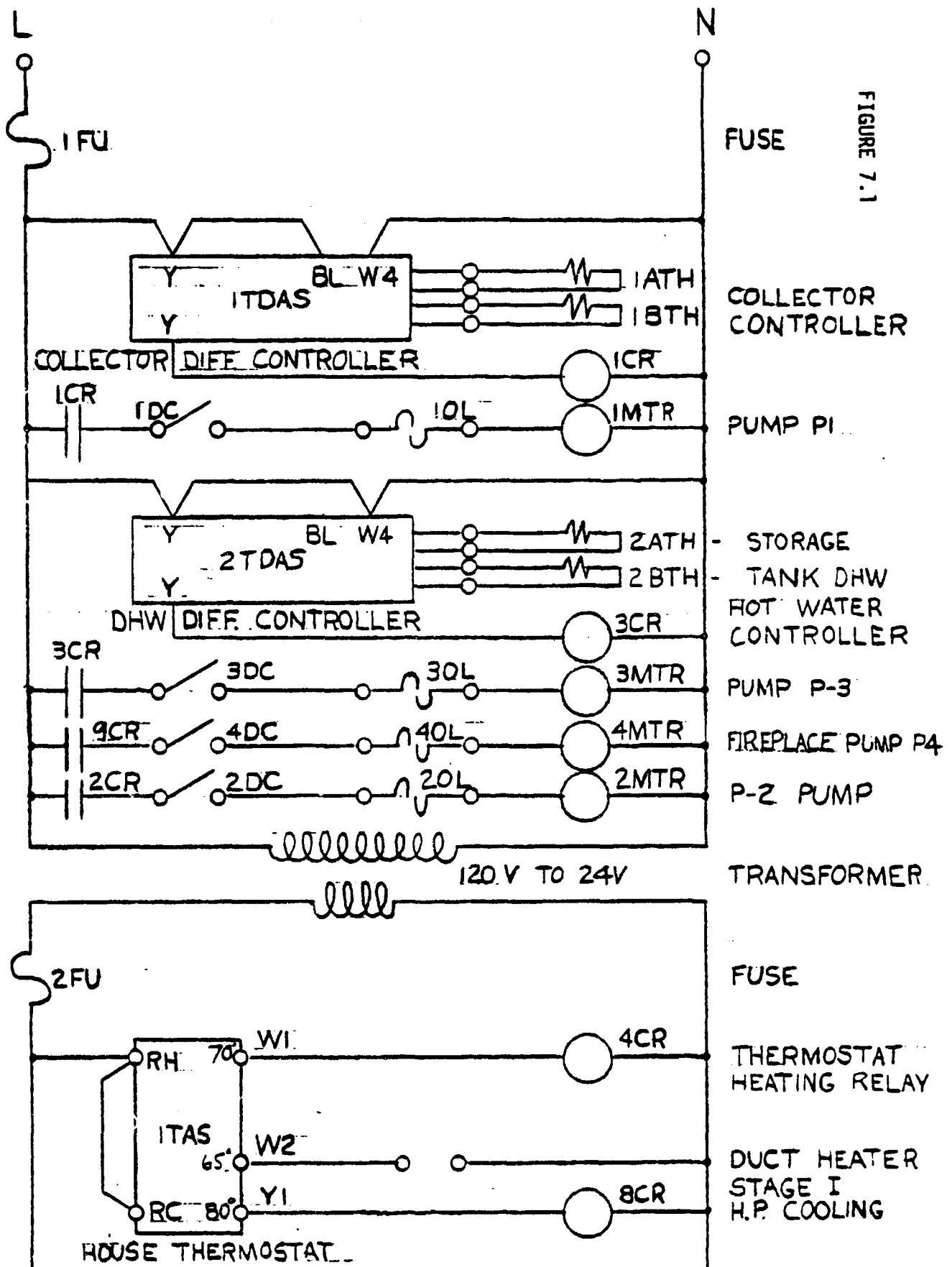


FIGURE 7.1

SYSTEM CONTROLS, CONTINUED

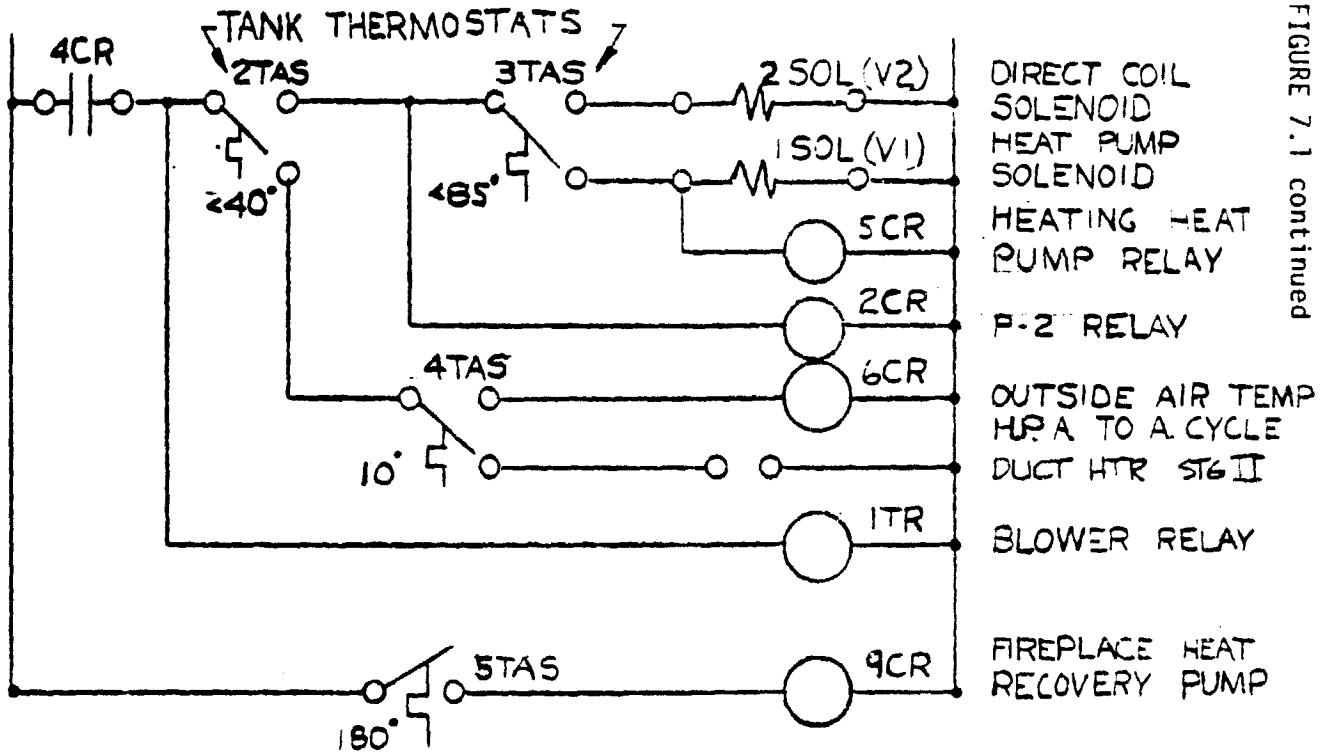
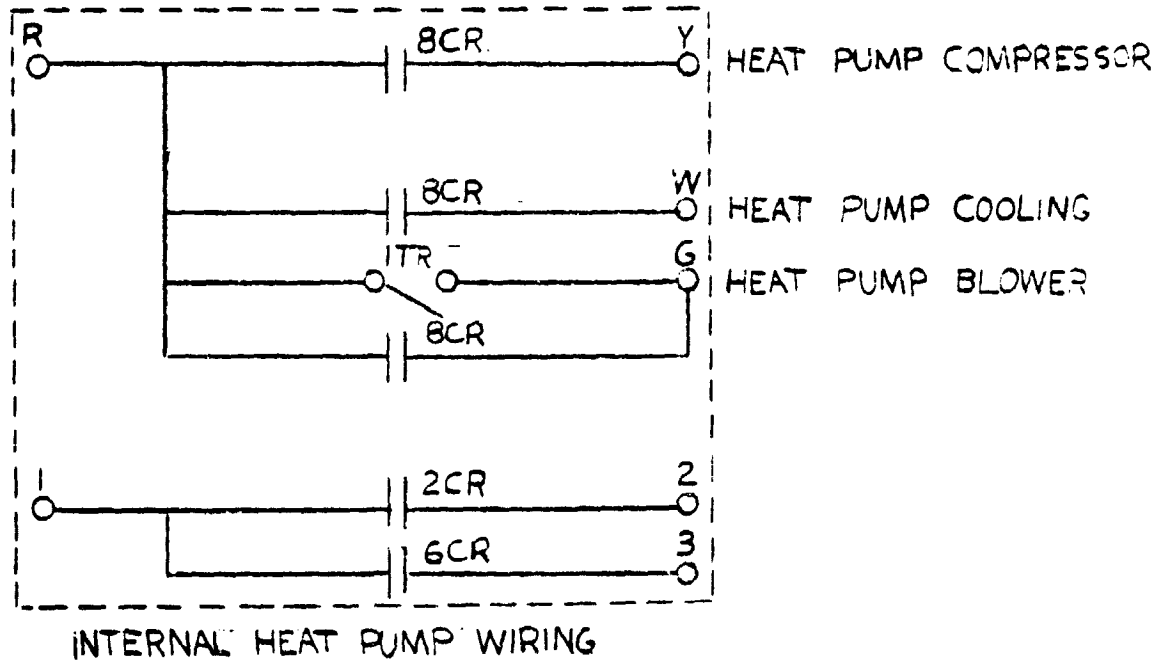


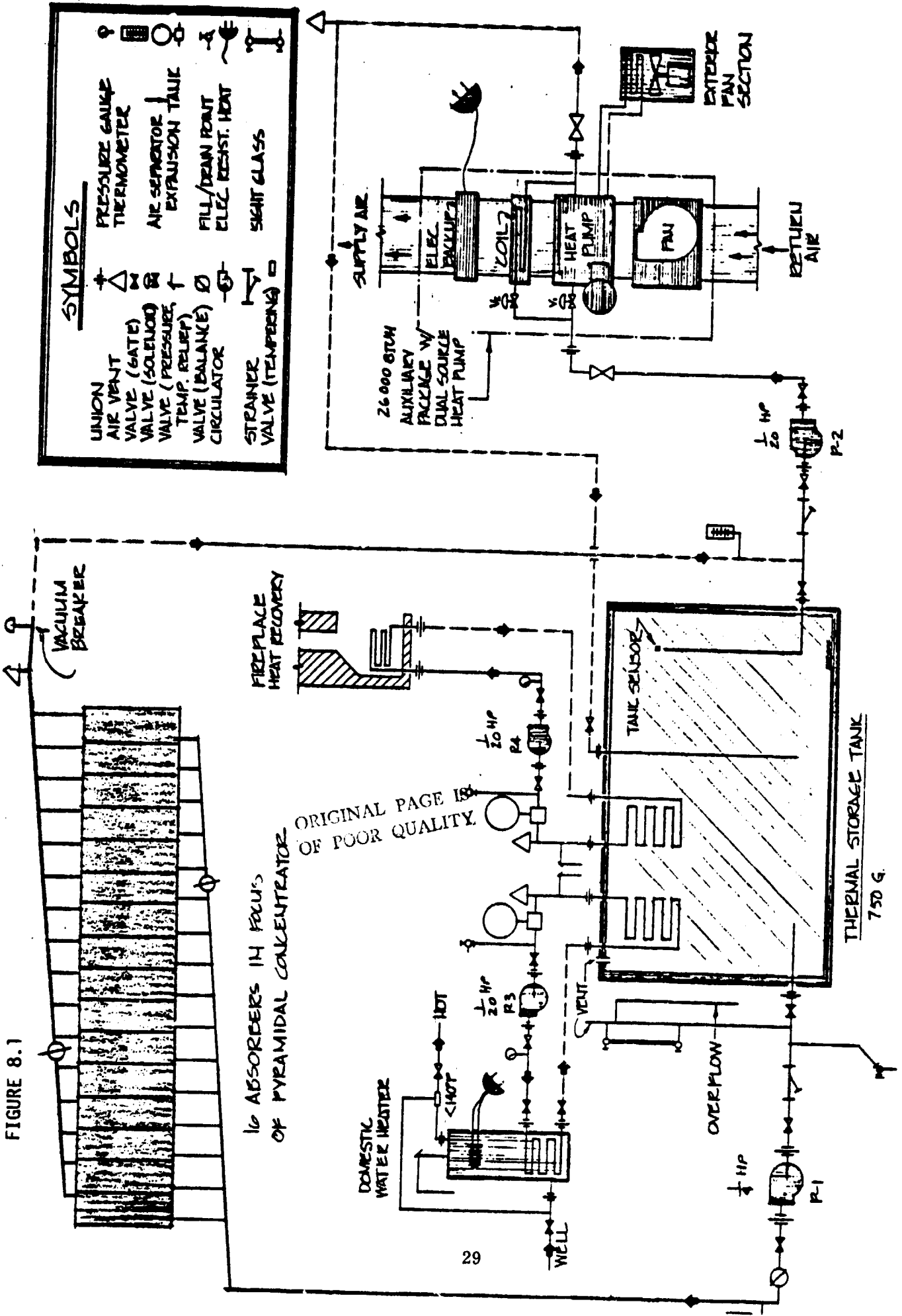
FIGURE 7.1 continued



8.0 Typical Piping Diagram

Figure 8.1 shows a flow schematic for a Pyramidal Optics system sized for a single family residence. The collector loop, optional fireplace heat recovery loop, domestic hot water preheating loop, and solar auxiliary unit piping can be seen together with the associated unions, valves, pumps, and gauges.

FIGURE 8.1



SYSTEM FLOW SCHEMATIC

9.0 Guide Specification

Provide materials, design and supervision to install the Pyramidal Optics solar energy collecting system composed of an attic mounted window, an attic lining of aluminumized mylar on hardboard, a tracking flap which follows solar altitude changes, a solar altitude compensator clock mechanism which controls the motion of the moving flap, a series of black chrome plated copper absorber panels, a system of insulated piping and fittings connecting the systems components, a solar auxiliary unit, including a dual source solar heat exchanger, resistance backup heating elements and air handler.

Provide a thermal storage tank, necessary pumps for fluid circulation, necessary wiring for electrically powered components and a control system for operating the system in the required modes. All items to be installed in a workmanlike manner according to good trade practice.

Piping

- Type "M" hard copper with 95-5 soldered joints and wrought fittings on all solar plumbing.
- Domestic hot and cold water piping shall be Type "L" hard copper with wrought copper fittings and 95-5 soldered joints.
- All plumbing shall be tested for leaks

with 75 psig air pressure for eight hours (vents must be removed).

- Piping shall be run so that the lines can be drained and vented at accessible points.
- Offset branches, expansion compensators, or flexible pipes shall be used to provide for expansion and contraction within the system. Piping shall be adequately supported to prevent undue strain on piping and branches.
- Unions or flanges shall be installed in accessible locations on both sides of all heat exchangers and pumps to permit the easy removal of this equipment.
- Pipes shall be sloped and vented to prevent air pockets anywhere in the plumbing. Where reducers are used, they shall be installed flush side up to prevent formation of air pockets.
- All openings through walls, partitions, ceilings, and floors shall be large enough to allow pipe insulation to be continuous. Prefabricated pipe seals as manufactured by Carlisle Tire and Rubber Corporation shall be used in the solar storage tank to join tank liner to piping.
- Where copper piping connects to equipment or piping of differential materials, dielectric insulating couplings shall be used to inhibit corrosion. These shall be equal to Walter Vallett Co., Detroit, Michigan.

Pipe Insulation

- Insulation, adhesives, tape and facing shall meet

the requirements of NFPA 90A. All interior piping shall be insulated with 3/4" preformed foamed pipe insulation equal to Johns Manville Aerotube. Insulation shall be secured with cement equal to Johns Manville JM 57. Flanges and unions shall be insulated.

- All outdoor piping shall be insulated with 3/4" thick plastic insulation equal to "Ft/Armaflex." It shall be waterproofed with two coats of plastic finish reinforced with glass mesh.

Valves

All valves shall be rated at 125 lbs. Drain valves shall be angle pattern where possible. Relief valves shall be side outlet ASME label.

<u>System</u>	<u>Type</u>	<u>Size</u>	<u>Mfr and No.</u>
Piping	Gate Balancing Cock (BC) Balancing valve (BV)	2" and under 3" and under	Jenkins #1240 Hays #1605
Drains	Angle	1/2"	Taco Monitor 782 Boiler Drain with hose and thread
Flow check		2" and under	B & G Model SA

Tempering Valve:

#526 TACO, external Adjustment 120 to 160°F up to 12 GPM, 3/4" sweat

Water Specialties:

- Air Vents: Collector header, Amtrol #700, 1/4" FPS-Slope from vertical to 45° maximum Heating vents, Amtrol #700 with cap. Vent is to be closed after bleeding to prevent air entering vent after pump shut down.
- Vaccum Relief - Watts 36A
Backflow preventer - Watts 9D or 900
Expansion Compensators - Flexonics HB, 150 psi, sweat fittings
Water level gauge - Ernst Fig. L-150, 24" long
1/2" NPT, Bronze
Strainers - Watts 27, 40 mesh screen
- Thermometers and Pressure Gauges: Pressure and temperature test plugs shall be equal to Model 100, Peterson Equipment Company, Richardson, Texas. Installed thermometers shall be 9" scale, vari-angle pattern, brass separable socket, equal to Marshalltown No. 91302 1/2. Expansion tank assembly shall be equal to #3000 package Amtrol having 1" connections, tank, and air purger, vented at 45 psi.
- Pumps: Centrifugal pumps of 1/12 and 1/20 h.p. as manufactured by Grundfos Pump Corporation shall be used.
- Filters: Filters shall be provided wherever necessary to remove sediment initially in the system or accidentally admitted during maintenance procedures. The filters must be easily accessible for servicing. They should be fiber-glass throw-away type or permanent washable type

- n. th frames.
- Collectors: Collectors shall be type 122 Copper RollBond as manufactured by the Olin Brass Company.
- DHW Tanks: Hot water tanks shall be Aqua Coil, 120 gallon as manufactured by Ford Products Corporation. They shall be wrapped with an additional 3" layer of fiberglass insulation and neatly finished.
- DHW Heat Exchanger: Domestic hot water heat exchanger coil shall contain at least one gallon of water for each 500 gallons in the solar storage tank. Tubing material to be "Turbo-tec" by Spiral Tubing Corporation or equal. Coil shall be immersed in the top portion of the tank and supported with non-ferrous hardware. Ends of the coil shall extend upward through the tank cover and be connected to the DHW loop by unions. Coil shall be pressure tested with air at 75 psig for eight hours.
- Solar Auxiliary Unit: Solar Auxiliary Unit shall be "Climate Master" dual source heat pump manufactured by Friedrich Air Conditioning and Refrigeration. Available outputs are 10, 14, 18, 22, 27, 33, 42, 52, or 62 thousand BTUH. The unit shall contain an insulated cabinet, filters, spring mounted hermetically sealed compressor, reversing valve, refrigerant to water heat exchanger, refrigerant controls, water to air heat exchange coil and backup resistance heating element. A centrifugal blower shall be provided with a direct drive motor, which shall be two speed and oversized to deliver the design CFM after air duct pressure drop.
- Wiring: All wiring shall be installed in accordance with the latest National Electric Code (NEC). The minimum wire size for power circuits shall be #14 solid copper. No splices or joints shall be permitted in feeder or branches except at outlet or accessible junction boxes. All wire shall have type THW insulation.
- All control and monitoring wiring shall be color coded or have colored tracer. Each wire run shall have a different color. White shall be used for neutral only.
- Storage: Construction of the wood tank shall be in accordance with structural requirements to resist outward pressure of the volume of water to be stored. Waterproofing shall be provided by "Sure Seal" EPDM liner as manufactured by the Carlisle Tire and Rubber Company. Plumbing penetrations of the tank shall be sealed by prefabricated tank seals supplied by the tank manufacturer.
- Solar Window: Solar window glazing shall be 1/4" thick type G Plexiglas as manufactured by Rohm and Haas. Glazing shall be cut to

47 9/16" x 47 9/16" for insertion into 4'x4' modular window gasket. Glazing material shall be neoprene zipper gasket and aluminum channel manufactured by Standard Products Co. of Port Clinton, Ohio. Gaskets shall be custom molded to job specifications based on multiples of 4'x4' squares. Corners, tees, and edge flashing shall be supplied by the manufacturer.