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WEST CHESTER WORK CENTER SOLAR SPACE HEATING DEMONSTRATION PROJECT

Interim Test and Evaluation Report

MASTER

July 1979

Work Performed Under Contract No. EY-76-C-02-4048

Bell Telephone Company of Pennsylvania
Philadelphia, Pennsylvania

U.S. Department of Energy

Solar Energy

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Bell Telephone Company of Pennsylvania
One Parkway
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Prepared for

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ABSTRACT

This document reports on the test and evaluation stage of a solar space heating demonstration project. It describes an integrated system providing solar energy space heating for a 9982 sq. ft., newly built, one-story building. The building is located at 966 Matlack Street, West Goshen Township, Chester County, Pennsylvania. Functionally, the building consists of two sections: An Office and a Storeroom. The Office section is heated by solar-assisted water-to-air heat pump units. The Storeroom section is heated by an air-handling unit, containing a water-to-air coil. The system design was based on solar energy providing 62% of the heating load, with the balance to be supplied by a back-up electric boiler. The system includes 1900 active (2112 gross) square feet of flat-plate solar collectors, and a 6000 gallon above-ground indoor storage tank. Freeze protection is provided by a gravity drain-down scheme combined with nitrogen pressurization in a closed circuit.

System operation during the 1977-78 heating season disclosed some major deficiencies in both the design and installation of the system, which caused the system to freeze and required it to be shut down for prolonged periods. Several major modifications and repairs were undergone during 1978, as detailed in this report.

System operation during the 1978-79 heating season showed noticeable gradual improvement. Operation during February, 1979, which included a 15 day stretch of continuous subfreezing weather, was quite satisfactory. However, there is room for further improvements aimed at minimizing maintenance requirements and maximizing energy savings.

1.0 INTRODUCTION

In June, 1976, the generic design of the solar space heating system for the West Chester Work Center was completed by InterTechnology Corporation (ITC) as part of their "Solar Heating & Cooling of Buildings - Phase I" contract with the U.S. Energy Research and Development Administration (ERDA). The basic scheme for building heating and the sizing of the solar components was optimized by ITC and presented by ERDA to Bell of Pennsylvania in a package consisting of generic drawings and specifications. Those drawings were included as Appendix A of Reference 9.1.

The solar heated building is one of two buildings situated on a five acre lot (Figure 1). It is T-shaped (Figure 2) with one axis running south to north. It consists of an Office section at the top of the T and a Storeroom section at the stem of the T. The building is used as the home base for telephone installers, repairmen and construction workers.

To maximize collection efficiency, the solar energy collection scheme selected by ITC was an open, gravity drain-down system rather than one using a glycol antifreeze solution in conjunction with a heat exchanger. With ERDA's concurrence, Bell of Pennsylvania modified the generic design to render the system pressurized instead of open. The reasons for the modifications are detailed in Section 3.0 of Reference 9.1. The generic drawings and specifications were revised to reflect engineering changes and additional detailing necessary for guidance of the HVAC subcontractor in the proper installation of the system as designed. The drawings used for construction of this project are included in Appendix A.

The major modifications to the generic design involved the addition of a separate holding tank (300 gallon capacity), to contain the nitrogen used for pressurizing the solar collection loop. This tank also serves as the container for water which is drained out of the collector and associated piping. The addition of the holding tank necessitated additional controls to provide for refilling the collectors prior to resumption of normal solar energy collection and storage.

Following completion of the system installation, it was placed in operation for the first time in October, 1977. However, many difficulties were encountered, necessitating prolonged shutdowns during the 1977-78 heating season and the execution of major modifications over a period of several months. For this reason, it was necessary to postpone for one year the issuance of this report, which was initially intended to cover only the first six months of system operation. Thus, this report deals with the operational history over two heating seasons, from October 1977 through March, 1979. It provides details of what had to be done to improve the system operation and evaluates its performance.

2.0 SYSTEM DESCRIPTION

2.1. Design Scheme:

The design drawings for this system are included in Appendix A. The main features of the system design are:

2.1.1. The Office section of the building (approximately 145 ft. X 43 ft.) is heated in the winter and cooled in the summer by 20 unitary heat pumps.

2.1.2. The Storeroom section of the building (approximately 82 ft. X 43 ft.) is heated by a conventional fan-coil unit which uses solar heated water, backed up by an electrical boiler as needed.

2.1.3. The heat source for the heat pumps during the heating season is water heated by solar energy, backed up by an electrical boiler as needed.

2.1.4. The heat sink for the heat pumps during the cooling season is water cooled by passing through a closed-circuit cooling tower.

2.1.5. The solar array consists of eighty-eight flat plate collector panels, arranged in two equal rows. The gross area is 2112 sq. ft. and the effective collection area is 1900 sq. ft. The panels are installed facing true South, tilted at 55° from horizontal.

2.1.6. Thermal energy storage is provided by a 6000 gallon capacity tank, installed above ground in the mechanical room.

2.1.7. Auxiliary heat is provided by an 80 kilowatt electric boiler, incorporating five elements of 16 kilowatts each.

2.1.8. Heat rejection during the cooling season is provided by a closed circuit cooling tower located in the mechanical room, connected with outside air intake and discharge ducting.

2.2. System Components:

Figure (3) is a simplified flow diagram of the solar heating system. There are three main loops which are built around the 6000 gallon water storage tank:

2.2.1. The solar collection loop circulates storage water through the collector panels, using the "Solar water pump". The 300 gallon

"Holding tank" is used to store a mixture of nitrogen and water. In the solar collection mode of operation, most of the nitrogen will be in the holding tank. In the drain-down mode, water drained from the collectors and piping above the roof line will be in the holding tank. Prior to resumption of solar collection, this water is transferred to the collectors by the activation of the "Refill pump".

2.2.2. The Office heating loop circulates storage water through twenty water-to-air "Heat pump units", using the "HP units pump". During periods when the storage water temperature is below 70°F, the temperature of water fed to the heat pump units is regulated by a mixing valve which mixes water heated by the electric boiler with storage water to produce the 70°F minimum temperature required. The "Cooling tower" is activated during the cooling season to dissipate heat removed from the office space by the heat pumps.

2.2.3. The Storeroom heating loop circulates storage water through the "Fan-coil unit", using the "AHU pump". An auxiliary branch off this loop is used to supply hot water to four forced flow heaters "FFH" located in the corridors of the office section at each entrance to the building, using the "FFH pump". The "Electric boiler" which straddles this loop is activated only when the water temperature leaving the boiler is below 105°F.

2.3 System Controls:

Drawing M-5, Appendix A, describes the operation of the system controls, which consist of the following major elements:

2.3.1. Differential Temperature Controller: This is used to initiate the sequence for collection of solar energy whenever it senses a set temperature differential of 18°F between a typical absorber plate and water stored in the main tank. It will also act to shut down the solar water pump whenever the temperature differential drops below 3°F.

2.3.2. Four float switches: These are located just above the solar collectors and serve to shut down the refill pump and activate the solar water pump when they sense that all collectors have been refilled.

2.3.3. Low limit temperature sensor: Attached to a typical absorber plate, this sensor will act to initiate a drain cycle of the water to the holding tank whenever it senses a temperature below 40°F.

2.3.4. High limit temperature sensor: this sensor is located within the storage tank and acts to stop the collection of solar energy whenever it senses a temperature above 190°F.

2.3.5. Heat pump loop temperature sensor: This sensor acts to position an automatic valve that mixes heated water with return water, so that the temperature of the water supplied to the heat pump units is controlled at 70°F.

2.3.6. Heat pump units controls: Each of these units has its own integral thermostat to permit setting by the occupant of each office as desired.

2.3.7. Storeroom temperature controller: This is a wall-mounted thermostat used to position a three-way valve which supplies water to the coil in the air handling unit. It is also used to position outside air and return air dampers according to the season of the year.

2.3.8. Forced-flow heaters controls: Each forced-flow heater, used to heat the corridors of the building, is controlled by a wall-mounted thermostat which positions a three-way valve to provide the required flow of hot water to the unit.

2.4. Performance Monitoring:

In consultation with IBM-Huntsville, the instrumentation required to monitor the performance of the system, in accordance with ERDA's document "SHC-1006: Instrumentation Installation Guidelines", was selected and incorporated into the design drawings. A list of the instrumentation appears in Table (1).

In addition to the ERDA instrumentation, Bell installed a parallel read-out for 30 temperature measurements using thermocouples connected to "Series 400A Trendicators" manufactured by Doric Scientific Division of Emerson Electric Company.

3.0 OPERATIONAL HISTORY

As stated in Reference 9.2, this solar system was put in operation in October, 1977. During the early part of the 1977-78 heating season, when outdoor temperatures seldom went below freezing, there were very few operational problems. As the weather got colder, we began to experience occasions when the system would not drain automatically at the end of the day.

As shown in Section "A-A" of drawing "A-10-1" and in drawing "M-5" (Appendix A), there are four "Fisher No. 30" automatic vent valves connecting the highest point of each of four solar array sections to the nitrogen lines. These valves were intended to prevent water from entering the nitrogen piping during system operation. At times when the outdoor ambient temperature was below freezing and the system did not drain, it was discovered that drainage could be accomplished by applying heat, using an acetylene torch, to the vent valves. Thus, there was evidence that a freeze-up of water vapor within the valve ports was causing the problem. In mid December, 1977, it was decided to heat-trace these valves by wrapping electrical heat tape around them. However, before this modification was implemented, we experienced our first freeze-up damage to the collector panels.

On December 27, 1977, the first workday following a 3-day weekend during which the outdoor temperature plunged unexpectedly to as low as 17°F, two leaky panels were discovered by noticing icicles hanging underneath. Recorded data, received later from IBM (Huntsville), convinced us that the system could not be refilled completely with water, when the refill pump started automatically in response to adequate insolation on December 26, 1977. The data showed that although the refill pump continued running for 7.5 hours, water never reached the level of all four float-switches, which would have caused automatic shutdown of the refill pump and activation of the main circulating pump. It became quite evident that at least one of the four vent valves must have been blocked by frozen moisture in its port, thus preventing the normal transfer of nitrogen from the panels to the holding tank. This event necessitated a shutdown of the system between December 27, 1977 and January 24, 1978, which was the time required to implement the heat-trace installation.

Within a few days following the reactivation of the system, several additional panels started to leak, indicating that the freeze problem had not been eliminated. On February 3, 1977, it was decided to shut-duwn the system and conduct an extensive investigation.

Upon dissambling several of the hose connections between the supply headers and individual panels, it was discovered that some residual water existed in these connections several days after the system had been drained. These connections had been installed with a minimal slope and they included a device called "Balvalve-indicator" manufactured by Gerand Engineering Company. This device provides the capability to measure and adjust the flow rate through each individual panel. It can also be used as a shut-off valve. Close examination of this device disclosed that (a) it contains a small (3/16 inch) sharp edged orifice, (b) parts of the device which protrude through the insulation, thus conducting heat to the ambient, are in the immediate vicinity of the orifice. There was a strong suspicion that the minimal slope of the connection and the existence of the Balvalve were causing blockage due to ice formation, thus preventing normal operation of the system and causing some panels to freeze and leak.

Following a period of several weeks, in which we studied the alternatives available to us to remedy the problem, it was decided to modify all 88 connections between the supply headers and each panel, as shown in Figure (4), to accomplish the following:

1. Replace the "Balvalve-indicator" by a simple shut-off valve, to be installed vertically.
2. Maximize the slope of the connection in the direction of the header.

An alternative, which had been considered, was to leave the plumbing as-is and apply electrical heat-trace to all connections. While this approach would have been less costly than the plumbing modification, it was rejected because of low reliability. It was feared that any power failure or accidental break in the electrical circuit would nullify the protection against freezing. Also, this alternative would have somewhat increased the usage of electrical power needed to operate the system.

To further safeguard against possible freeze-ups in the future, the drain-down control system was modified by adding an outside air temperature sensor, which acts to initiate drain-down whenever the solar collection pump is shut down automatically while the ambient temperature is below 45°F. Prior to this modification, drain-down occurred only when a typical absorber plate temperature dropped below 40°F.

The above modifications were completed by April 20, 1978, and the system resumed normal operation for the short time left in the 1977-78 heating season. However, several leaky collector panels were valved off individually until they could be repaired or replaced.

Another problem we confronted had to do with buckling in about one-half of the flat edges in the "Rollbond" absorber plates. Both Heliotherm, the collector manufacturer, and Olin Brass, the absorber plate manufacturer, attributed the buckling to the freeze-up of water within the flow passages. Bell of Pennsylvania was not convinced that the freeze-up was the exclusive cause of the buckling, because it occurred at random. Bell commissioned a study of this phenomenon by the Franklin Institute Research Laboratories (FIRL), which concluded that the buckling resulted from both the freeze-up and inadequate allowance for differential expansion in the collector assembly. FIRL recommended that the screw holes which fasten each absorber plate to its frame be enlarged to permit some relative movement due to temperature variations.

During the 1978 summer season, the Department of Energy (DOE) Project Manager and his consultants participated in analyzing these problems and attended a site meeting on August 8, 1978, with representatives of Bell of Pennsylvania, Golz and Wick, Hummel Engineering Corporation, Heliotherm and Olin Brass. At this meeting, decisions were made to introduce further modifications to improve the system operation and reliability. Details of these modifications are discussed in Sections 4.4 through 4.9 of this report.

During the 1978-79 heating season, the system was operated in the manual mode through January 8, 1979, pending completion of a thorough check-out of its controls. Between January 9 and March 31, 1979, the operation of the system, in the automatic mode, was satisfactory, but there were minor problems associated with lack of stability of the volume of water contained in the holding tank. There was also some cycling between the refill pump and main circulating pump at the start of daily solar collection. Another problem encountered was occasional drain-down of the system at times when insolation was adequate for continuation of solar collection.

4.0 SYSTEM MODIFICATIONS

Operation of this system disclosed several deficiencies, which required certain remedies to improve its reliability and/or efficiency. A discussion of these items, in chronological order, follows:

4.1 Heat-tracing of the Vent Valves:

This improvement was the first one introduced because the need for it was quite evident from the fact that heat from an acetylene torch was occasionally needed to force the system to drain on certain days, when the outdoor temperature was below freezing. What was done physically was to wrap electric resistance wire around each of four float switches and automatic vent valves. These assemblies were then enclosed within two insulated boxes to minimize any loss of heat to the cold outdoor air surrounding them. Thermostatic surface-contact elements were provided to energize the heaters as needed to maintain the vent valves at a minimum temperature of 45°F at all times. The cost of this improvement was $4195.

4.2 Plumbing Modifications:

As discussed in Section 3.0, this modification was necessitated by the occurrence of freeze-ups even after the vent valves were heat-traced. Physically, it involved extensive rework of all the connections between the supply headers and each panel. As shown in Figure (4), the "Balvalve-indicators", which permitted the measurement and adjustment of the water flow rate to each individual panel, were eliminated. The loss of this capability was reluctantly accepted, sacrificing some efficiency for the sake of improving reliability. We shall never know whether it would have been enough to just reposition these devices in a vertical position, in lieu of eliminating them altogether. But, following a bad experience, the tendency is always to be ultra-conservative. In order to permit valving-off individual panels in case of trouble, butterfly valves were installed in a vertical position at each branch connecting the supply header to a panel. The re-worked plumbing was re-insulated, with the additional provision of a second layer of insulation around the area of the valve stems. The cost of this improvement was $11621.

4.3 Drain Control Modification:

This modification was introduced as an additional measure to protect against freezing. The original controls called for the cessation of solar energy collection when insolation is below the level required to maintain a 3°F differential between the absorber plate surface and the storage water. This was accomplished by de-activation of the circulation pump, leaving the water in a stagnant condition within the collectors and outdoor piping until the absorber plate surface temperature drops below 40°F, thus initiating a drain-down. A risk inherent in this procedure is that some elements of the outdoor piping may freeze before the absorber plate temperature sensor has had a chance to drain the system. To minimize such risk, we proceeded to add an outdoor temperature sensor, which acts to drain the system whenever the solar collection pump is inactive while the outdoor temperature is below 45°F. The cost of this improvement was $599.

4.4 Cycling of Heat Utilization Pumps:

Reference to the "Flow diagram" in sheet "M-4" of Appendix (A) shows two circulation pumps "P3" and "P4", which supply hot water to the forced-flow heaters and the air-handling unit, respectively. These two pumps were set initially for continuous operation, regardless of the need for heat by the equipment served. It was later determined that by confining the activation of these two pumps to periods when the equipment served by them need heat, we would not only save pump operational energy, but also minimize the undesirable addition of electrical heat to the storage tank. Accordingly, the pump controls were so modified. Additionally, to guard against any possible freeze-up of stagnant water in the coil of the air handling unit, which may be caused by cold air leaking through the outside air damper, a temperature sensor attached to the surface of the coil was provided to start pump "P4" if the coil temperature drops below 40°F. The modification to pump "P3" control was to activate it whenever the outdoor temperature falls below 55°F. The cost of this improvement was $1531.

4.5 Valve Sequence Improvement:

The solar collection loop controls include two sets of pneumatic valves: One set, V_A and V_B, connect the collectors to the Holding Tank and the other set, V_C and V_D, connect the collectors to the Storage Tank. The initial system control was such that while one set of valves is closing, the other set starts to open. That procedure created a situation where the two tanks become interconnected for a few seconds, resulting in some migration of water in one direction or another depending on which tank had a momentarily higher pressure. This situation was especially bad in case the water quantity in the Holding Tank became inadequate to refill the collectors completely. Under those circumstances, the refill pump would never stop and normal solar collection cannot be initiated automatically. To remedy this situation, it became necessary to introduce an automatic time delay between the sequence of operation of the two different sets of valves. The cost of this improvement was $632.

4.6 Drain Malfunction Alarm:

Due to the fact that this system is left unattended most of the time, it was deemed advisable to be able to transmit an automatic alarm, around the clock, in case the system does not drain when it should. To accomplish this, it was necessary to provide water level sensors in six out of eight risers connecting the collectors with the holding tank. These water level sensors were installed to sense whether the water level has dropped below the roof when insolation became inadequate for collection of solar energy while the outdoor temperature was below 45°F. In the event that this has not occurred within thirty minutes, an alarm is transmitted to a remote station where there is an attendant available 24 hours a day, seven days a week. The receipt of such an alarm would cause a serviceman to be dispatched to the site, in order to do what is necessary to force the system to drain before it freezes. The cost of this improvement was $2896.

4.7 Refill Pump Overtime Alarm:

When the system is operating normally, it takes about five to seven minutes of refill-pump operation to fill all of the collectors and the piping above the roof. Following this event, the refill pump shuts down automatically in preparation for the resumption of solar energy collection. There may be occasions when a system malfunction causes the refill pump to run overtime, either due to a blockage in the system or inadequate water quantity in the holding tank. Such a malfunction can be a prelude to a system freeze-up. It was deemed advisable to install a timer that would shut-down the refill pump automatically after fifteen minutes of operation, simultaneously transmitting a remote alarm similar to the one described in section 4.6 above. The cost of this improvement was $690.

4.8 Outside Air Damper Improvement:

The air handling unit serving the Storeroom had conventional outside and return air dampers. Such dampers, even in the closed position, can have air leakage rates of 15 to 25%. In order to minimize heat loss from the heating coil to outside air, it was deemed advisable to replace the existing outside air damper with a tighter one, which is guaranteed to have no more than 2% leakage rate. The cost of this improvement was $518.

4.9 General Checkout of Control System:

Following execution of all of the above modifications, and before the system was to be operated automatically, it was decided to conduct a complete checkout of the control system function at the start of the 1978-79 heating season. A technician from Honeywell was assigned to this task. Over a period of eight weeks between November 11, 1978 and January 8, 1979, approximately 210 man-hours were spent on this taskk The resulting improvements were as follows:

4.9.1. A check of the control wiring disclosed some loose connections, broken wires and incorrect wiring. All of these deficiencies were corrected.

4.9.2. Initially, the refilling of the collectors was done through both supply and return risers. This was causing some nitrogen to be trapped momentarily within at least some of the collectors, giving a false signal to the float switches "FS-1,2,3 and 4" that the collectors had been completely filled. This signal would then switch the operation prematurely from "P5" to "P1", causing the two pumps to cycle back and forth. To correct this problem, the control was modified so that following the first "Collectors Full" signal which the float switches receive, valve "V_B" closes to allow any additional water required to enter the collectors from the bottom only, thus driving any trapped nitrogen out through the automatic vent traps. A time-delay relay was also installed to keep the refill pump running for five minutes after the first "Collectors Full" signal is received. During that interval, pump "P1" would start, but any water it pumps out of the Storage Tank would be blocked by valve "V_C" being in a closed position.

4.9.3. It was discovered that valve "V_D" in the return line from the collectors to the Storage Tank opens a few seconds before valve "V_C", which connects the supply line from the storage tank to the collectors. This situation was causing the water level at float switches "FS-1,2,3 and 4" to drop momentarily, shutting down pump "P1" and re-starting pump "P5". To correct this deficiency, pneumatic restrictors were modified to slow down the opening of valve "V_D".

Following the execution of the above improvements, the system was put into automatic operation on January 9, 1979. The cost of these improvements was $8676.

4.10 Modifications Cost Summary:

To recap the items listed above, the total cost of all modifications was $31,358., broken down as follows:

Heat-tracing of vent valves	$4195.
Plumbing modifications	11621.
Drain control modifications	599.
Cycling of heat utilization pumps	1531.
Valve sequence improvement	632.
Drain malfunction alarm	2896.
Refill pump overtime alarm	690.
Outside air damper improvement	518.
General checkout of control system	8676.
	$31,358.

In addition, the Integrating Contractors' fees, for consulting work they performed in connection with these modifications, amounted to $7,024.

5.0 COLLECTOR PANEL REPAIRS

Early in 1978, it was discovered that approximately half the solar collector panels exhibited various degrees of warpage, some with slight ripples, others with out-of-plane warpage severe enough to have dislodged the plexiglas cover. In addition, seven panels developed leaks in the end waffle section. The collector manufacturer disclaimed any responsibility for the damage to the absorber plates, basing that on the occurrence of freeze-ups. An independent investigation, conducted later in September 1978 by the Franklin Institute Research Laboratory, attributed the warpage to both freezing and lack of adequate allowance for differential expansion. However, Bell of Pennsylvania did not press its case against Heliotherm on this matter.

Another defect discovered in the collector panels was relative shrinkage of the plexiglas covers, which resulted in gaps between them and their frames. The gaps were so wide as to allow rain water to accumulate inside the panels. In this case, Heliotherm agreed to provide a better seal between each cover and its frame.

In order to render all the panels operable for the 1978-79 heating season, consideration was given to either straightening out the badly-warped plates or replacing them with new ones. Economic and schedule considerations resulted in a decision to straighten out most of the warped panels, while replacing the ones which were beyond repair. The total cost for this work was $25,173, as follows:

5.1. Purchase and installation of 12 new panels: $14,969.

5.2. Removal, straightening and re-installation of 27 warped panels: $9,000.

5.3. Enlargement of the screw holes on 20 panels to accommodate differential expansion: $1,204.

6.0 SYSTEM PERFORMANCE

6.1 Historical Narrative:

Although data from 24 temperature sensors, 10 flow senosrs and 12 power sensors were accumulated continuously since October, 1977, the first meaningful performance report to be issued by IBM-Huntsville was for November, 1978. The reasons for this delay were:

6.1.1. The system operation during the 1977-78 heating season was sporadic, punctuated by two lengthy shutdowns.

6.1.2. The accuracy of the data was not considered reliable by IBM during the first year of operation. The temperature probes were partially influenced by the ambient temperature, thus needing external insulation. Some of the flowmeter data, where the flow rates change abruptly, reflected inaccuracies caused by instantaneous sampling every five minutes. Correction of this deficiency had to be accomplished by adding totalizing devices for two flowmeters.

6.1.3. Temperature differential sensors originally installed were found to be not as accurate as absolute temperature sensors. Therefore, all temperature data had to be converted to absolute readings.

IBM completed the required modifications to the site data acquisition system (SDAS) on November 2, 1978. While no meaningful performance reports were generated until then, the SDAS was very useful in providing information for trouble shooting at times when the system was malfunctioning. Typical of such useful information was knowing the timing of activation of various pumps and the simultaneous insolation rates.

6.2 Performance Parameters:

Because of the unavailability of meaningful monthly performance reports prior to November, 1978, the discussion of system performance will be confined to only five months of the 1978-79 heating season. Table (2) represents a summary of significant performance parameters for each month. Most of the terms used in this Table are self explanatory and their values were taken directly from References (9.3) through (9.7). However, the values of the following parameters, appearing in the Table, differ from those listed in the IBM Monthly Performance Reports as discussed below:

6.2.1. Solar energy used: For the purpose of this report, this parameter has been computed as the collected solar energy during the month modified by any addition or removal of energy from storage, as the case may be. Because all of the system components are located within the confines of this building, any energy losses from storage are considered to have been utilized towards satisfying the space heating load. This procedure would not be accurate in a project where the storage tank is located underground or outside the main building, in which case losses from storage are real.

6.2.2. Space heating load: For the purpose of this report, this parameter has been computed as the sum of the solar energy used, auxiliary thermal energy and system operating energy. This computation differs from the values listed in Reference (9.3) through (9.7), which were computed from direct measurements of flow rates and temperature drops of the water circulating through the various heating devices. The logic behind the procedure followed in this report is that any heat lost from the uninsulated piping system is dissipated within the building space and therefore contributes towards satisfying the space heating load. Also, it is assumed that even the energy used to run the pumps and fans is converted into heat which gets dissipated within the building space.

6.2.3. Solar fraction: This parameter is simply the ratio of solar energy used to the space heating load. Due to the fact that values for these two parameters used in this report differ from those listed in References (9.3) through (9.7), it follows that the monthly solar fraction will also differ.

6.3 Observations:

A discussion of significant observations follows:

6.3.1. Solar collection and electrical savings: A glance at the numbers listed in Table (2) shows progressive improvement in the system performance. Especially noticeable are the month-by-month increases in solar collection efficiency and electrical energy savings. These improvements can be attributed to progress in the automatic operation of the system, which permitted taking better advantage of available solar energy. There is room for further improvement in this regard because the ratio of operational incident solar energy to total incident solar energy is still too low. This ratio is a direct measure of the fraction of the time when the collection pump is active while solar energy is available for collection. In February, when this ratio was the highest achieved, it was still only 0.71. This is an indication that solar collection time could be further improved. One way to increase this ratio is to re-adjust the differential temperature controller settings (between the absorber plate and storage water) so that there will be less frequent drain-and-refill cycles on partly-cloudy days and longer periods of solar collection on sunny days.

6.3.2. Space heating load: Monthly space heating loads are expected to be proportional to the difference between average building temperature and average ambient temperature for the month. Table (2) shows that the space heating loads for November and December were much higher than would be expected on the basis of the weather. This was caused mainly by a fault in the controls of the air handling unit, used to heat the Storeroom, which made the fan run all night, drawing outside air through a leaky damper and across the heating coil. This fault was later discovered and corrected by making the fan shut down at night and by replacing the conventional outside air damper with one having less than 2% leakage.

6.3.3. Daily solar collection: The IBM Monthly Performance Reports (Reference 9.3 through 9.7) include collector performance parameters on a daily basis. Examination of these parameters indicates vividly that on clear sunny days, when the system operation is not interrupted by drain-and-refill cycles caused by intermittent reductions in insolation, it is possible to collect up to 2.2 million BTU's per day, at an average daily collection efficiency as high as 47%. This is an indication that the system has a very good potential performance, which can be enhanced by taking the necessary measures to reduce unnecessary drain-and-refill cycling on partly-cloudy days.

7.0 LESSONS LEARNED

Among the lessons learned on this project were the following:

7.1. Although "Drain-down" solar systems are inherently more efficient than those using antifreeze combined with a heat-exchanger, they require more complex controls which render them less reliable and more troublesome.

7.2. "Pressurized drain-down" solar systems require even more complex controls than "Open drain-down" systems.

7.3. When the installation of a solar system is contracted on a "Time and materials" basis, it is difficult to get the installer to make any necessary corrections at his own expense or at least without profit.

7.4. Selection of a solar collector panel should take into consideration not only thermal efficiency, but also structural integrity.

7.5. It would be highly desirable to purchase an entire solar system from a single source, if possible. Warranties on individual components purchased from several different sources have little value.

7.6. Advertised claims by control manufacturers should not be taken at face value.

7.7. Solar experience of both the consulting engineer and the installation subcontractor is vitally important.

8.0 CONCLUSION

In spite of the difficulties encountered, Bell of Pennsylvania is pleased to have cooperated with ERDA (now part of the U.S. Department of Energy) in executing this solar demonstration project. It has provided us, our consultants, suppliers and contractors with a unique opportunity to gain valuable experience in the design, construction and operation of a fairly complex solar space heating system. It is hoped that this report will be of benefit to future users of solar energy.

9.0 REFERENCES

9.1. "System Design Report", COO-4048-78-1, March, 1978.

9.2. "Construction Report", DOE/CS/4048-2, May, 1979.

9.3. "Monthly Performance Report", SOLAR/2012-78/11, November, 1978.

9.4. "Monthly Performance Report", SOLAR/2012-78/12, December, 1978.

9.5. "Monthly Performance Report", SOLAR/2012-79/01, January, 1979.

9.6. "Monthly Performance Report", SOLAR/2012-79/02, February, 1979.

9.7. "Monthly Performance Report", SOLAR/2012-79/03, March, 1979.

FIGURE 1

PLOT PLAN

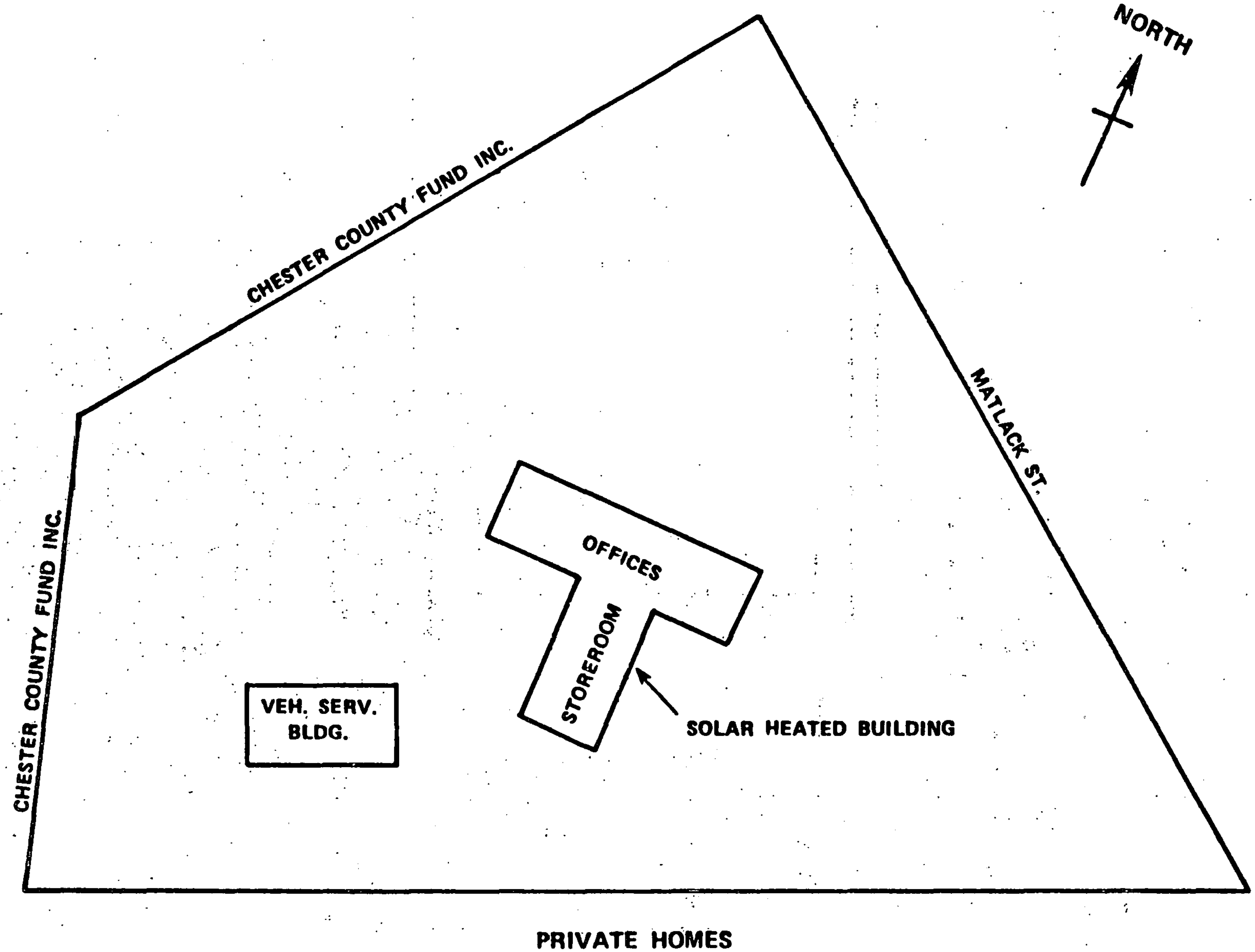


FIGURE 2

FLOOR PLAN

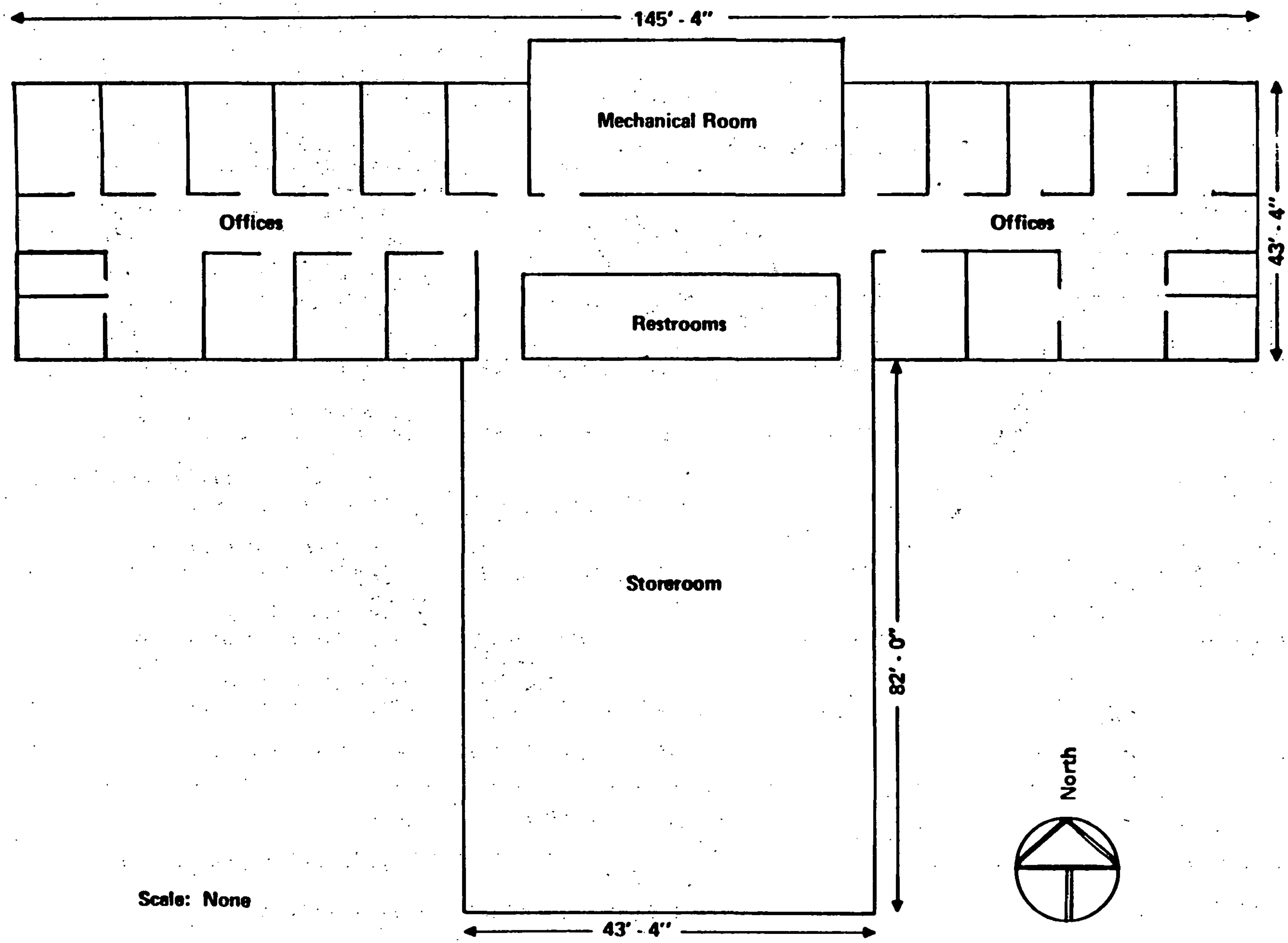
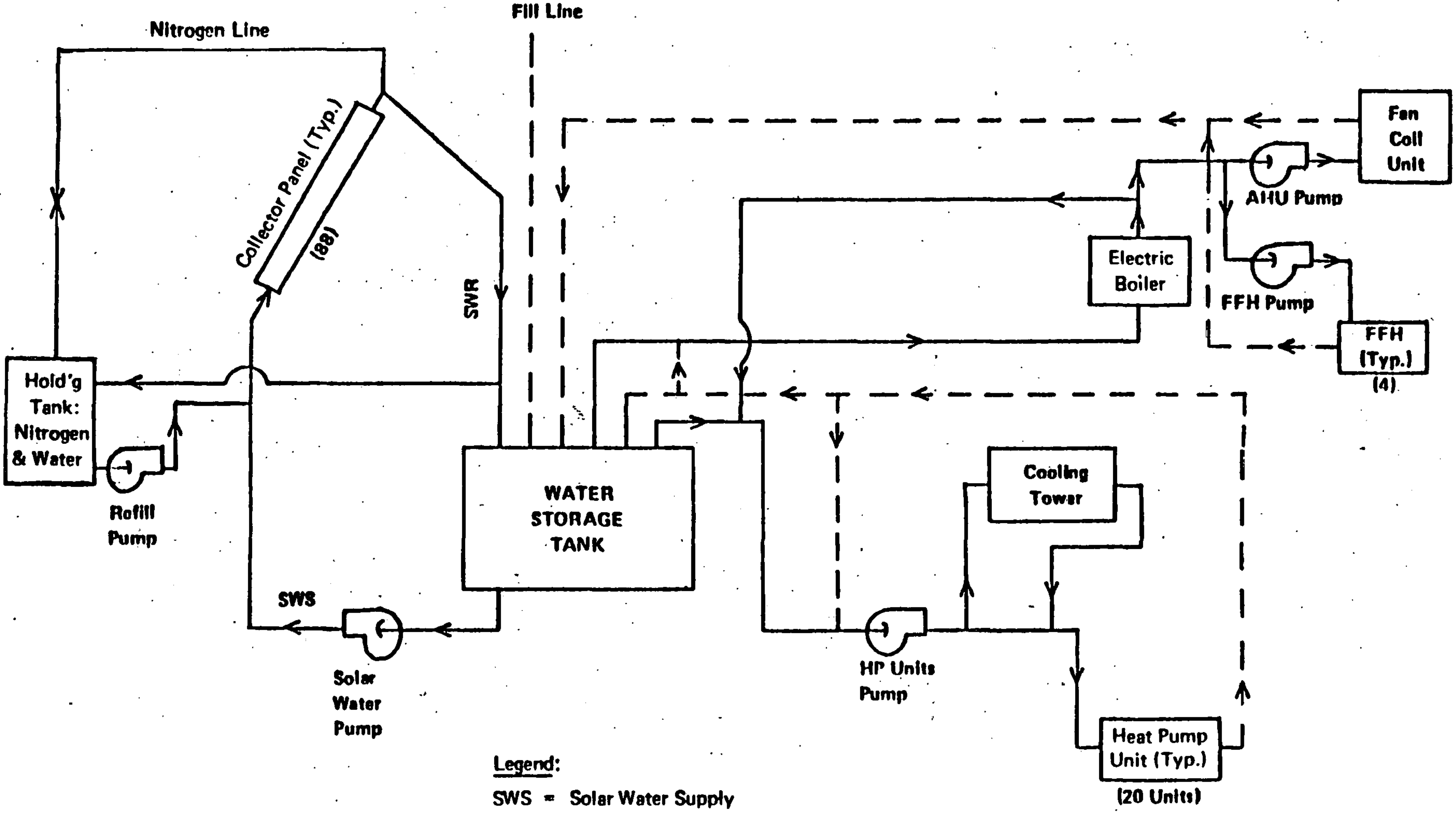


FIGURE (2)

FIGURE 3

SIMPLIFIED FLOW DIAGRAM

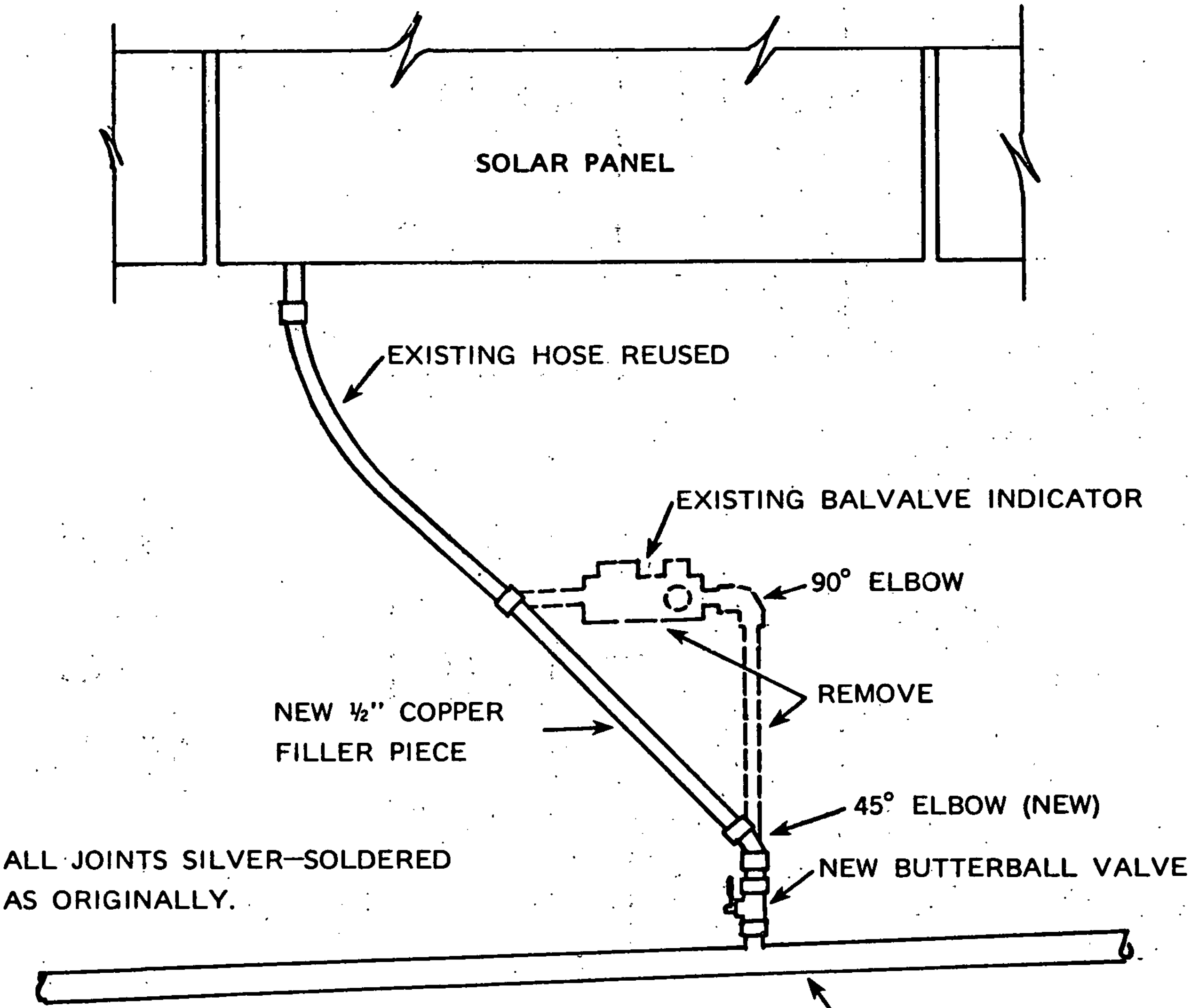


Legend:

SWS = Solar Water Supply
SWR = Solar Water Return
AHU = Air Handling Unit
FFH = Forced Flow Heaters
HP = Heat Pump

FIGURE (3)

FIGURE 4
PLUMBING MODIFICATIONS



(TYPICAL FOR 88 PANELS)
NO SCALE

Table 1
PERFORMANCE MONITORING INSTRUMENTATION

(a) Temperature Measurements

No.	Designation	Name	Range (oF) Min.	Max.	Thermowell Part No.	Probe Part No.
1	T029 (T-29)	Outside Ambient Air	-10	100	IS4	S53-P85Z36
2	T102 (T-1) (T-2)	Collector Array Inlet Water Temperature	40	180	F203U18	S57-P50Z36
3	TD102 (T-2A)	Collector Array Differential Water Temperature	0	75	F203U18	S53-P50Z36
4	T109 (T-9) (T-8)	Collector Array to Storage Tank Inlet Temperature	40	200	F203U18	S57-P50Z36
5	TD109 (T-9A)	Collector Array to Storage Tank Differential Temperature	0	75	F203U18	S53-P50Z36
6	T205 (T-5)	Storage Tank Top Water Temperature	40	200	F203U300	S53-P330
7	T206 (T-6)	Storage Tank Center Water Temperature	40	200	F203U300	S53-P330
8	T207 (T-7)	Storage Tank Bottom Water Temperature	40	200	F203U780	S53-P810
9	T421 (T-20) (T-21)	Storage Tank To FFH and AHU Loop Inlet Water Temperature	40	200	F203U18	S57-P50Z36
10	TD421 (T-21A)	Storage Tank to FFH and AHU Loop Differential Temperature	0	50	F203U18	S53-P50Z36
11	T423 (T-22) (T-23)	Storage Tank to HPU Loop Differential Temperature	40	200	F203U18	S57-P50Z36
12	TD423 (T23-A)	Storage Tank to HPU Loop Differential Temperature	0	15	F203U18	S53-P50Z36
13	TD411LO (T-11)	Lo Side Supplementary Heat (Boiler) Differential Temperature			F203U18	S53-P50Z36

No.	Designation		Name	Range (oF) Min.	Range (oF) Max.	Thermowell Part No.	Probe Part No.
14	TD411H1	(T-11A)	Hi Side Supplementary Heat (Boiler) Differential Temperature	-	-	F203U18	S53-P50Z36
15	TD427H1	(T-27)	Hi Side FFH Circ. Differential Water Temperature			F203U7	S53-P40Z36
16	TD427LO	(T-27A)	Lo Side FFH Circ. Differential Water Temperature	-	-	F203U7	S43-P40Z36
17	T425	(T-24) (T-25)	AHU Inlet Water Temperature	100	250	F203U18	S57-P50Z36
18	TD425	(T-25A)	AHU Differential Water Temperature	0	50	F20U18	S53-P50Z36
19	T413	(T-12) (T-13)	Heat Pump Loop Inlet Temperature (Heating) (Hi side)			F203U18	S57-P50Z36
20	TD413	(T-13A)	Heat Pump Loop Differential Temperature (Heating) (Lo side)			F203U18	S53-P50Z36
21	TD513*		Heat Pump Loop Differential (Cooling) (opposite of TD413)			*	*
22	TD519LO	(T-19)	Cooling Tower Differential Temperature (Lo side)			F203U18	S53-P50Z36
23	TD519H1	(T-19A)	Cooling Tower Differential Temperature (Hi side)			F203U18	S53-P50Z36
24	T628	(T-28)	Ambient Temperature Typical Office	50	85	-	S53-P85Z36

*NOTE: Measurement TD513 is the opposite sign of measurement TD413. No additional sensors are required. However, a separate channel is required in the SDAS for TD513.

(b) Flow Rate Measurements

No.	Designation	Name	Range (GPM) Min.	Design.	Max.	Model No.
25	W101 (F-1)	Collector Array Flow Rate	0	52	60	MKV-2 1/2-J01
26	W403 (F-3)	Supplementary Heat (Boiler) Flow Rate	0	97 or 45	100	MKV-2-J01
27	W410 (F-10)	Storage Tank from FFH and AHU Loop Flow Rate	25	45	55	MKV-2-J01
28	W411 (F-11)	Storage Tank from HPU Loop Flow Rate	0	52	60	MKV-2 1/2-J01
29	W412 (F-12)	Storage Tank to FFH and AHU Loop Flow Rate	0	97 or 45	100	MKV-2-J01
30	W413 (F-13)	Storage Tank to HPU Loop Flow Rate	0	52	60	MKV-2 1/2-J01
31	W408 (F-8)	Air Handling Unit Flow Rate	0	35 or Less	40	MKV-2-J01
32	W404 (F-4)	FFH Flow Rate	0	10	10	MKV-1-J01
33	W406 (F-6)	Heat Pump Loop Flow Rate	0	52	60	MKV-2 1/2-J01
34	W409 (F-9)	Cooling Tower Flow Rate	0	52	60	MKV-2 1/2-J01

(c) Power Measurements

No.	Designation	Name	Model No.
35	EP101 (KW-1)	Solar Collector Pump P-1 Power	PC5-14
36	EP105 (KW-5)	Solar Panel Refill Pump P-5 Power	PC5-14
37	EP403 (KW-3)	Forced Flow Heaters Circ. Pump P-3 Power	PC5-19
38	EP404 (KW-4)	Air Handling Unit Circ. Pump P-4 Power	PC5-5
39	EP408 (KW-8)	Air Handling Unit (AHU-1) Power	PC5-23
40	EP412	Forced Flow Heaters Total Fan Power (4 Units)	PC5-1
41	EP409 (KW-9)	Supplementary Heat Electric Boiler Power	PC5-80
42	EP402 (KW-2)	Heat Pump Units Circ. Pump P-2 Power	PC5-14
43	EP407 (KW-7)	Total Power to Heat Pump Units	PC5-62
44	EP510 (KW-10)	Cooling Tower Power Fan	PC5-53
45	EP511	Cooling Tower Pump Power	PC5-19
46	I001	Insolation	PSP

TABLE (2)

SYSTEM PERFORMANCE SUMMARY

	November 1978	December 1978	January 1979	February 1979	March 1979
Total Incident Solar Energy (Million Btu)	54.02	64.28	43.53	66.27	92.47
Operational Incident Solar Energy (Million Btu)	17.65	28.22	25.04	47.20	55.72
Collected Solar Energy (Million Btu)	8.93	13.03	11.66	21.53	21.90
Collection Efficiency (%)	16.5	20.3	26.8	32.5	23.7
Operational Collection Efficiency (%)	50.6	46.2	46.6	45.6	39.3
Energy Added to Storage (Million Btu)	0.43	0.39	-0.41	1.72	0.28
Auxiliary Thermal Energy (Million Btu)	21.11	28.10	29.57	27.15	5.32
System Operating Energy (Million Btu)	10.19	7.39	5.28	6.88	3.27
Solar Energy Used (Million Btu)	8.50	12.73	12.07	19.81	21.62
Space Heating Load (Million Btu)	39.80	48.22	46.92	53.84	30.21
Solar Fraction (%)	21.4	26.4	25.7	36.8	71.6
Collection Operational Energy (KWH)	62	89	82	133	167
Electrical Energy Savings (KWH)	113	938	1470	2898	2119
Average Ambient Temperature (°F)	52	43	38	31	51
Average Building Temperature (°F)	70	67	65	67	68

APPENDIX A

Design Drawings

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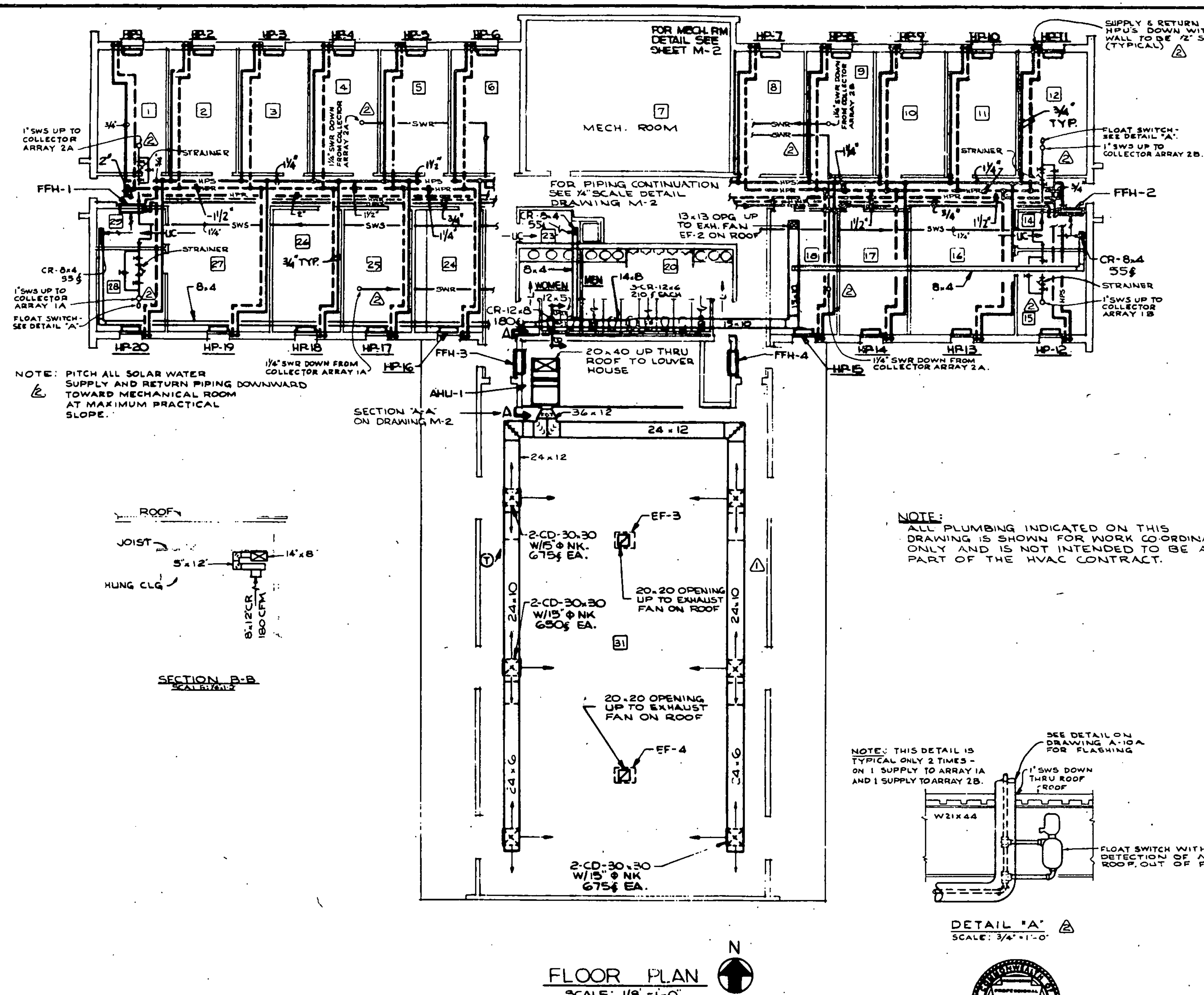


NOTE: PITCH ALL SOLAR WATER SUPPLY AND RETURN PIPING DOWNWARD TOWARD MECHANICAL ROOM AT MAXIMUM PRACTICAL SLOPE.

NOTE: ALL PLUMBING INDICATED ON THIS DRAWING IS SHOWN FOR WORK CO-ORDINATION ONLY AND IS NOT INTENDED TO BE A PART OF THE HVAC CONTRACT.

NOTE: THIS DETAIL IS TYPICAL ONLY 2 TIMES - ON 1 SUPPLY TO ARRAY 1A AND 1 SUPPLY TO ARRAY 2B.
SEE DETAIL ON DRAWING A-10A FOR FLASHING
1" SWS DOWN THRU ROOF
ROOF
W21X44
FLOAT SWITCH WITH SPDT SWITCH (FOR DETECTION OF WATER LINE BELOW ROOF, OUT OF FREEZING CONDITIONS)

DETAIL "A"
SCALE: ¾" = 1'-0"

SYMBOL LIST

DUCTWORK & PIPING

- SUPPLY DUCT
- RETURN OR EXH. DUCT
- RISE IN DUCTWORK
- ELBOW W/TURNING VANES
- GATE VALVE
- AUTO. 3-WAY VALVE
- AUTOMATIC VALVE
- BALANCING VALVE
- DIRECTION OF FLOW
- THERMOMETER W/WELL
- VOLUME DAMPER
- THERMOSTAT
- DIAMETER
- UNDERCUT
- LOUVER
- PRESSURE GAGE
- STRAINER
- CHECK VALVE
- GLOBE VALVE
- MANUAL AIR VENT
- AUTOMATIC AIR VENT (SARCO OR BAILEY)
- MOTOR
- METERING VENTURI

ABBREVIATIONS

CWS	CONDENSER WATER SUPPLY
CWR	CONDENSER WATER RETURN
HWS	HOT WATER SUPPLY
HWR	HOT WATER RETURN
SWS	SOLAR WATER SUPPLY
SWR	SOLAR WATER RETURN
CD	CEILING DIFFUSER
CG	CEILING GRILLE
CR	CEILING REGISTER
$	CUBIC FEET PER MINUTE
AHU	AIR HANDLING UNIT
NK	NECK
HP	HEAT PUMP
BTU	BRITISH THERMAL UNIT
EWT	ENTERING WATER TEMP. °F
PD	PRESSURE DROP
GPM	GALLONS PER MINUTE
EDB	ENTERING DRY BULB TEMP °F
LDB	LEAVING DRY BULB TEMP °F
RPM	REVOLUTIONS PER MINUTE
SP	STATIC PRESSURE
TDH	TOTAL DYNAMIC HEAD
BHP	BRAKE HORSE POWER
MHP	MOTOR HORSE POWER
ROT	ROTATION
DIS	DISCHARGE
FPM	FEET PER MINUTE
OV	OUTLET VELOCITY
PDV	PRESSURE DIFFERENTIAL VALVE
FFH	FORCE FLOW HEATER
TS	TIP SPEED
HPS	HEAT PUMP SUPPLY
HPR	HEAT PUMP RETURN
N.C.	NORMALLY CLOSED
N.O.	NORMALLY OPEN.
C.A.	COMPRESSED AIR

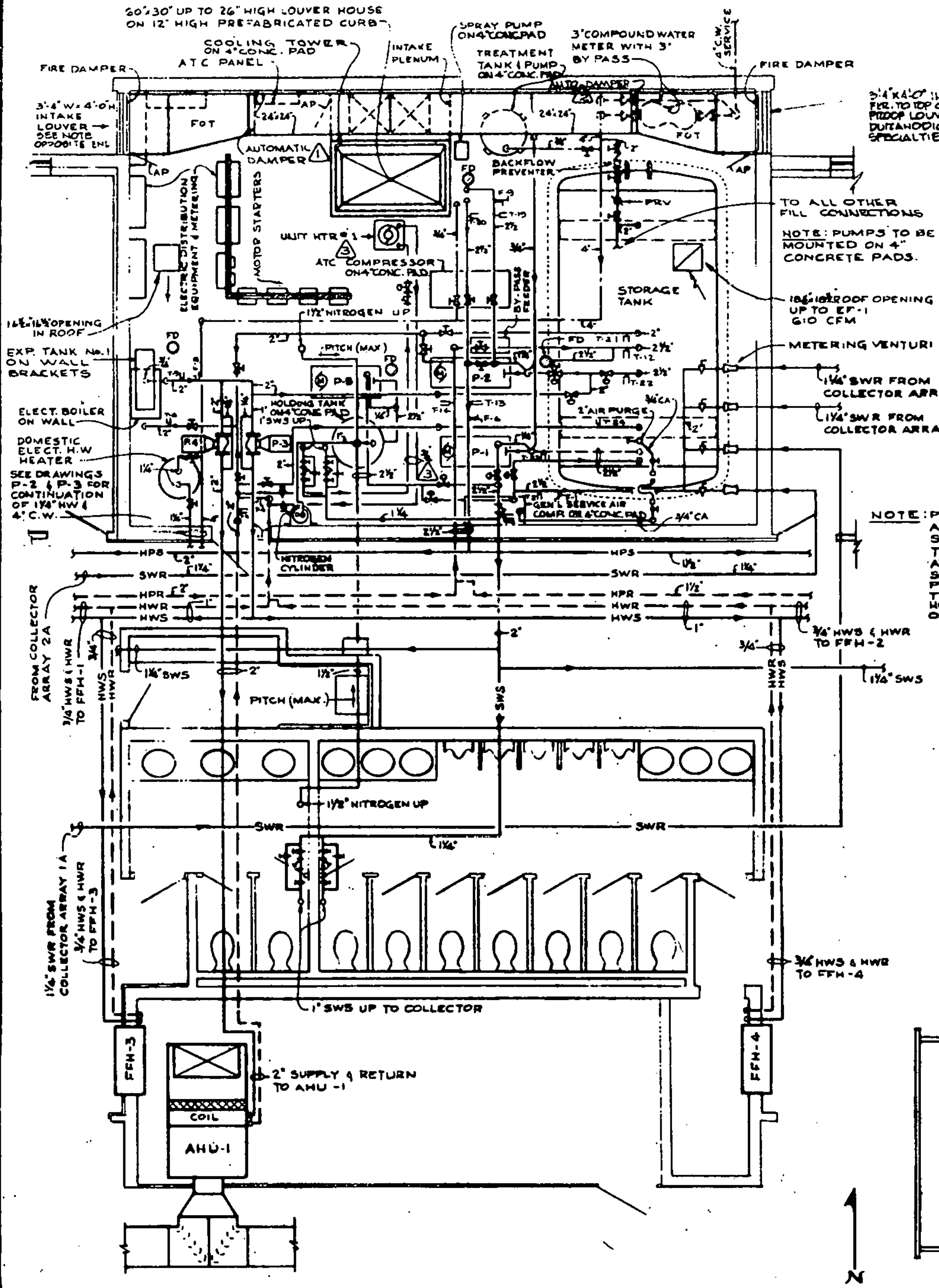
GENERAL NOTES

1. HEAT PUMP UNIT CONDENSATE DRAINS SHALL BE PIPED TO FITTING PROVIDED. SEE PLUMBING DRAWING.
2. DUCT CONSTRUCTION AND SUPPORT SHALL BE AS PER LATEST SMACNA GUIDE FOR LOW PRESSURE DUCTWORK
3. CO-ORDINATE EXACT DIFFUSER LOCATIONS WITH ELECTRICAL AND ARCHITECTURAL DRAWINGS

WALTER K. PLATT

REV.	DESCRIPTION	DATE
1	GENERAL REVISIONS AND REVISIONS TO BULLETINS 1 THRU 5	8-17-76
2	REVISED PER BULLETIN # 6	11-12-76

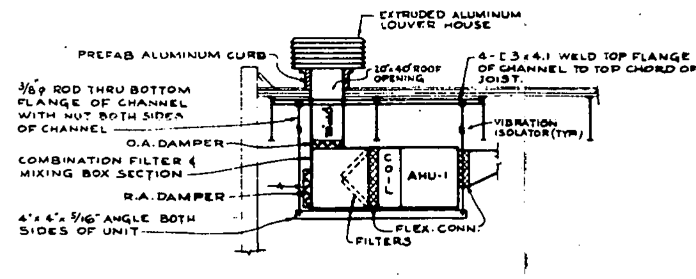
SHEET TITLE	MECHANICAL FLOOR PLAN & SYMBOL LIST
DATE	JUNE 21, 1976
SCALE	AS SHOWN
DRAWN BY	
	WEST CHESTER WORK CENTER
	BELL OF PENNSYLVANIA ONE PARKWAY PHILADELPHIA, PENNSYLVANIA
	A SOLAR ENERGY PROJECT IN COOPERATION WITH THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
SHEET NO.	M-1
JOB NO.	02009-5



PART FLOOR PLAN △2

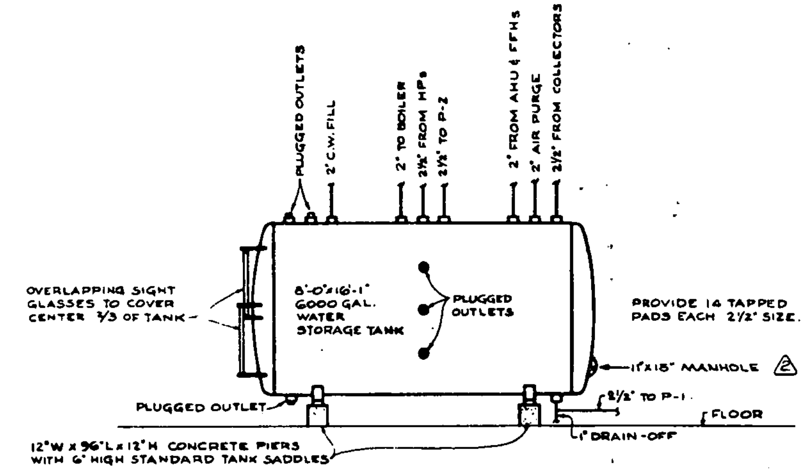
SCALE: 1/4" = 1'-0"

NOTE: PITCH ALL NITROGEN PIPING AS WELL AS SOLAR WATER SUPPLY AND RETURN PIPING TOWARD MECHANICAL ROOM AT THE MAXIMUM PRACTICAL SLOPE. NITROGEN PIPING MUST PITCH CONTINUOUSLY DOWN TO THE CONNECTION AT THE HOLDING TANK, AND BE FREE OF ALL TRAPS.



SECTION "A" - "A"

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

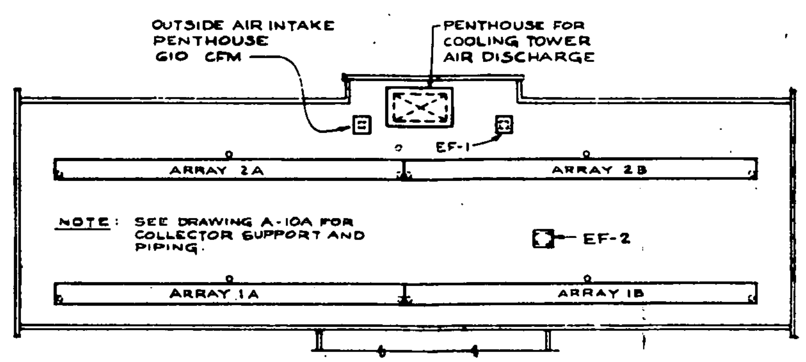


STORAGE TANK DETAIL

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

NOTE 1. EXTEND TANK FITTINGS TO CLEAR TANK INSULATION.

2. TANK SHALL BE WATER TIGHT, ALL STEEL CONSTRUCTION IN ACCORDANCE WITH APPLICABLE LOCAL CODE AND SHALL BE BUILT FOR 50 PSI WORKING PRESSURE AND SHALL BEAR ASME LABEL.



ROOF PLAN △2

SCALE: 1/16" = 1'-0"

NOTE: ALL PLUMBING INDICATED ON THIS DRAWING IS SHOWN FOR CO-ORDINATION ONLY AND IS NOT INTENDED TO BE A PART OF THE HVAC CONTRACT.

REV	DESCRIPTION	DATE
△1	GENERAL REVISIONS PLUS REVISIONS TO BULLETINS 1 THRU 5	8-17-76
△2	REVISED PER BULLETIN #6	11-12-76
△3	ADDED UNIT HEATER #1	1-31-77

SHEET TITLE: MECHANICAL ROOM PLAN AND SECTIONS

DATE: JUNE 21, 1976
SCALE: AS SHOWN
DRAWN BY:

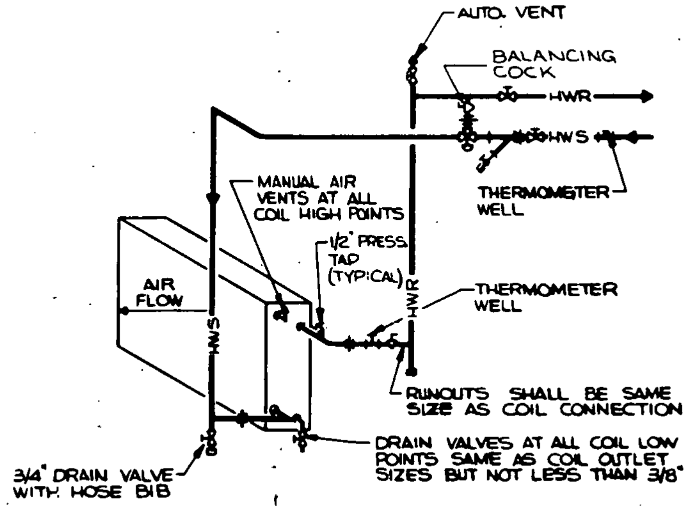
WEST CHESTER WORK CENTER

BELL OF PENNSYLVANIA
ONE PARKWAY
PHILADELPHIA, PENNSYLVANIA

A SOLAR ENERGY PROJECT IN COOPERATION WITH THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

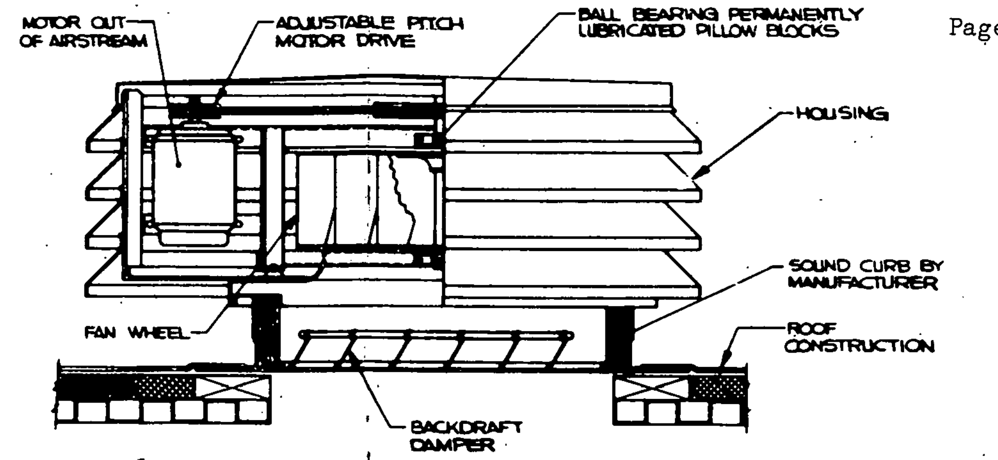
SHEET NO. M-2

JOB NO. 00009-5



HOT WATER HEATING COIL CONNECTIONS

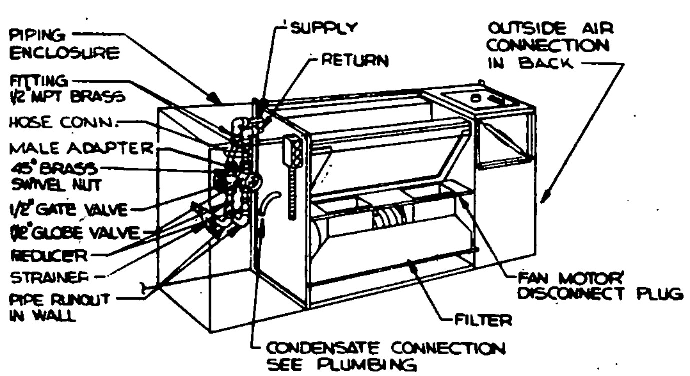
NO SCALE



EXHAUST FAN DETAIL

INTAKE PENTHOUSE SIMILAR

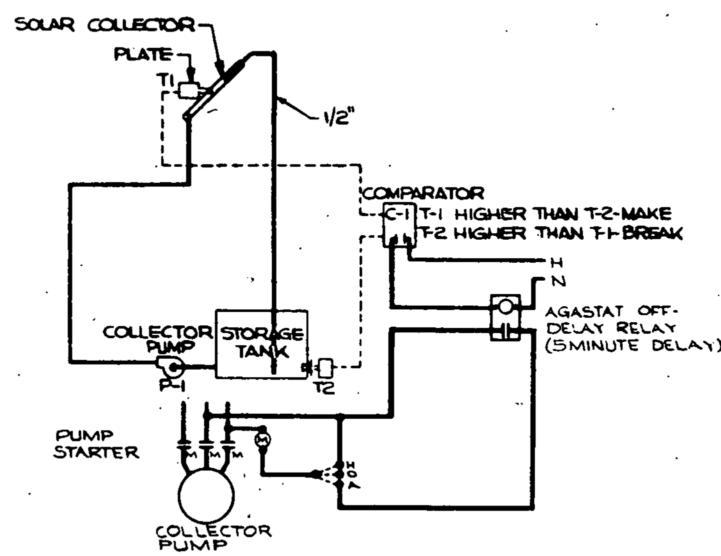
NO SCALE



NOTE: PROVIDE DUCT CONNECTIONS TO LOUVER FOR OUTSIDE AIR INTAKE.

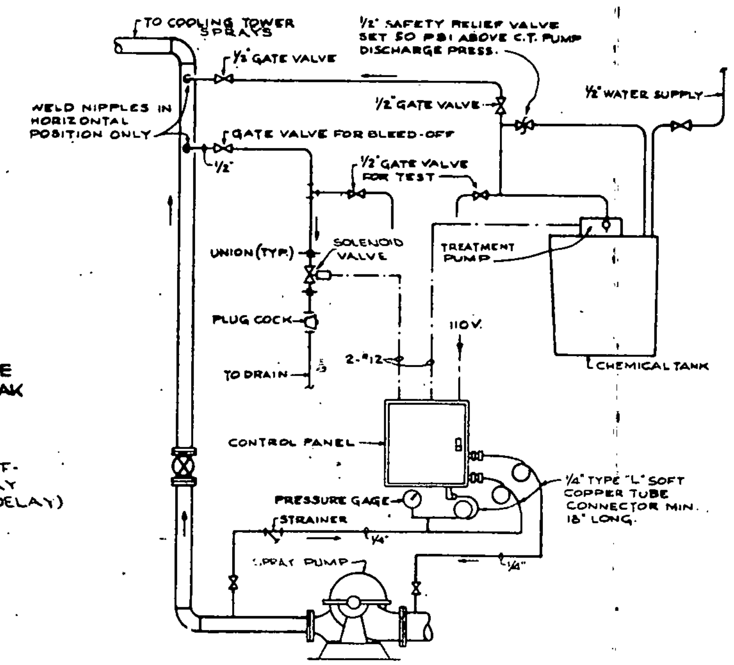
HEAT PUMP DETAIL

NO SCALE



STORAGE TANK PUMP CONTROL DETAIL

NO SCALE



COOLING TOWER SPRAY CHEMICAL FEED SYSTEM WITH CONDUCTIVITY CONTROLLED BLEED-OFF

△2 NO SCALE

NOTE: ALL PLUMBING INDICATED ON THIS DRAWING IS SHOWN FOR WORK COORDINATION ONLY AND IS NOT INTENDED TO BE A PART OF THE HVAC CONTRACT.

REV.	DESCRIPTION	DATE
△1	GENERAL REVISIONS AND REVISIONS TO BULLETINS 1 THRU 5	8-17-76
△2	REVISED PER BULLETIN # 6	11-12-76

SHEET TITLE: DETAILS	DATE: JUNE 21, 1976; SCALE: AS SHOWN; DRAWN BY	WEST CHESTER WORK CENTER; BELL OF PENNSYLVANIA, ONE PARKWAY, PHILADELPHIA, PENNSYLVANIA	A SOLAR ENERGY PROJECT IN COOPERATION WITH THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
SHEET NO. M-3	JOB NO 00009-5		

FACTORY FABRICATED AIR HANDLING UNIT SCHEDULE

UNIT NO.	FAN DATA: CFM	FAN DATA: S.P.	FAN DATA: MAX. O.V. FPM	FAN DATA: BHP	FAN DATA: MAX. FAN WHEELS	MOT. DATA: MHP		HEATING COIL DATA: AIR S.P.	AIR EDB	AIR LDB	WATER GPM	WATER PD MAX	WATER EWT	MAX. FACE VELOCITY	REMARKS	FILTERS TYPE
AHU-1	4000	2½"	1455	2.74	1	3		1/2"	50	85	31	1'	110	533	—	2" THROW AWAY

NOTE: STATIC DEFLECTION TO BE 1."

HEAT PUMP SCHEDULE

PUMP NO.	SERVICE	NOM CFM	OUT-SIDE AIR C.F.M.	GPM	PD FT. H_2O	SUMMER: EWT °F	SUMMER: ENT. AIR TEMP DB	SUMMER: ENT. AIR TEMP WB	SUMMER: TOTAL COOLING CAP (BTUH)	SUMMER: COMP INPUT KW	SUMMER: FAN KW	SUMMER: HEAT OF REJECTION	SUMMER: LWT °F	WINTER: EWT °F	WINTER: EAT °F	WINTER: HEATING CAP (BTUH)	WINTER: COMP INPUT (KW)	WINTER: FAN INPUT (KW)	WINTER: HEAT OF ABSOR (BTUH)	WINTER: LWT °F
HP3,19	CLERICAL AREAS	420	70	3.5	5.6	92	82.5	69.1	14,231	1.77	.13	20,188	103	70	70	19,000	1.66	.13	12,930	62.6
HP2-10,12 14-18,20	ALL OTHER ROOMS	230	40	1.9	6.0	92	82.5	69.1	7,210	1.11	.09	11,088	103	70	70	10,800	1.10	.09	6740	62.9
HP1,11	2 EXT. ROOMS NORTH SIDE	270	40	2.3	6.2	92	82.5	69.1	9,769	1.24	.09	14,055	103	70	70	13,000	1.24	.09	8500	62.6

FAN SCHEDULE

FAN NO.	SERVICE	PERFORMANCE DATA: CFM	SP WG	TS FPM	RPM	BHP	CONSTRUCTION DATA: TYPE FAN				MOT. DATA: MHP	REMARKS	NOTES
EF-1	MECH. ROOM	610	.25	2850	750	—	CENTRIFUGAL ROOF EXHAUSTER				1/6	V-BELT DRIVE	
EF-2	TOILETS & JC	975	.375	3705	975	—	CENTRIFUGAL ROOF EXHAUSTER				1/4	V-BELT DRIVE	
EF-3	STORAGE	2155	.25	3165	605	—	CENTRIFUGAL ROOF EXHAUSTER				1/4	V-BELT DRIVE	
EF-4	STORAGE	2155	.25	3165	605	—	CENTRIFUGAL ROOF EXHAUSTER				1/4	V-BELT DRIVE	

COOLING TOWER SCHEDULE ⚠2

LOCATION	AMBIENT WB °F	GPM	EWT	LWT	P.D. PSI	FAN MOTOR H.P.	PUMP MOTOR H.P.	MAXIMUM OPERATING WEIGHT, LBS
ROOF	78	52	103	92	.2	5	1/3	3000

TANKS

EACH OF THE FOLLOWING SHALL BE A.S.M.E. CONSTRUCTED FOR 50 PSI WORKING PRESSURE AND SHALL BEAR THE A.S.M.E. LABEL. TANKS SHALL HAVE GAUGE GLASSES AS REQUIRED TO COVER THE CENTER 2/3 OF EACH TANK.

EXPANSION TANK Nº 1 – NOMINAL 18 GAL. HORIZONTAL, 12" DIA. x 36" LONG.

HOLDING TANK – NOMINAL 300 GAL. VERTICAL, 30" DIA. x 96" HIGH.

GEN'L SERVICE AIR COMPRESSOR

AIR COMPRESSOR SHALL BE EQUAL TO GARDNER-DENVER MODEL ACA 2 x 2½, 4 CU. FT. PER MIN. AT 150 PSI, 888 RPM ¾ HP MOTOR, V-BELT DRIVE WITH BELT GUARD.

PUMP SCHEDULE ⚠2

PUMP NO.	SERVICE	PERFORMANCE DATA: GPM	TDH FT.	RPM	BHP	CONSTRUCTION DATA: TYPE PUMP	DESIGN PRESSURE	MOT. DATA: MHP	REMARKS
P-1	SOLAR COLLECTOR	52	46	1750	—	CENTRIFUGAL END SECTION	—	2	
P-2	HEAT PUMPS	52	46	1750	—	CENTRIFUGAL END SUCTION	—	2	
P-3	FORCED FLOW HEATERS	10	20	1750	—	INLINE CIRCULATOR	—	1/3	
P-4	AIR HANDLING UNIT	35	20	1750	—	INLINE CIRCULATOR	—	1/2	
P-5	REFILL PUMP	48	50	1750	—	CENTRIFUGAL END SUCTION	—	2	

⚠5 UNIT HEATER Nº 1 – TRANE MODEL "P" SIZE 80, 1/15 H.P. MOTOR, 120V.-1φ, 1150 RPM NOMINAL RATING OF 38.5 MBH WITH 200F WATER ON 20 TD DROP 3.97 GPM WILL OPERATE WITH 110F WATER ON REDUCED OUTPUT.

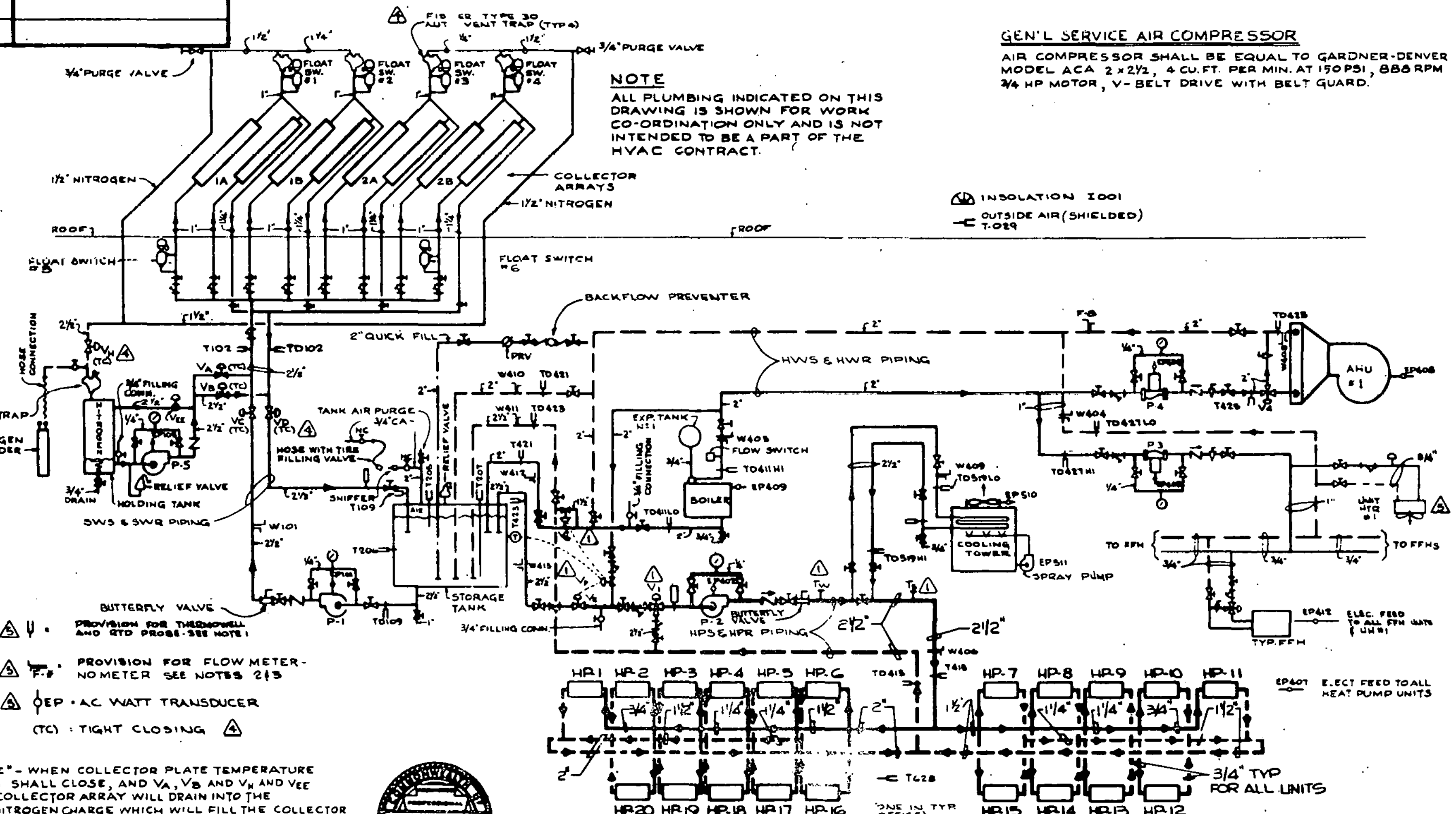
FORCED FLOW HEATERS SCHEDULE

UNIT NO.	FAN DATA: CFM NOMINAL	EXT. S.P.	RPM MAX.	AIR-ON HEATING: COIL EDB	WATER GPM	WATER P.D. FT.	WATER EWT	CAPACITY (BTU/HR.) APPROX.	MOTOR WATTS	REMARKS
FFH-1	200	—	1100	60°	1	0.24	110	6000	85	—
FFH-2	200	—	1100	60°	1	0.24	110	6000	85	—
FFH-3	200	—	1100	60°	1	0.24	110	6000	85	—
FFH-4	200	—	1100	60°	1	0.24	110	6000	85	—

⚠5
NOTE 1 – IN ADDITION TO THE PROVISION FOR THERMOWELL AND PROBE AT EACH OF THESE INDICATED POSITIONS PROVIDE A THERMOMETER MOUNTED IN A SEPARABLE WELL AS SPECIFIED.

NOTE 2 – IN ADDITION TO THE PROVISION FOR FLOWMETER, NEARBY EACH OF THESE INDICATED POSITIONS BUT PROPERLY SEPARATED PROVIDE A BARCO OR EQUAL FLOW VENTURI AS SPECIFIED.

NOTE 3 – PROVISIONS FOR THERMOWELLS AND FLOWMETERS SHALL BE AS SPECIFIED IN INSTRUMENTATION INSTALLATION GUIDELINES AS PREPARED BY ERDA.



⚠5 PROVISION FOR THERMOWELL AND RTD PROBE – SEE NOTE 1

⚠5 F-# PROVISION FOR FLOW METER-NOMETER SEE NOTES 2 & 3

⚠5 EP · AC WATT TRANSDUCER

(TC) : TIGHT CLOSING ⚠4

NOTE

ALL PLUMBING INDICATED ON THIS DRAWING IS SHOWN FOR WORK CO-ORDINATION ONLY AND IS NOT INTENDED TO BE A PART OF THE HVAC CONTRACT.

⚠4 ⚠2 NOTE:
"AUTOMATIC ARRAY DRAINAGE" – WHEN COLLECTOR PLATE TEMPERATURE IS 40F OR BELOW, V_C AND V_D SHALL CLOSE, AND V_A, V_B AND V_H AND V_{EE} SHALL OPEN WHEREUPON THE COLLECTOR ARRAY WILL DRAIN INTO THE HOLDING TANK DISPLACING THE NITROGEN CHARGE WHICH WILL FILL THE COLLECTOR ARRAY AND THE PIPING ABOVE THE ROOF. WHEN THE COLLECTOR PLATE TEMPERATURE RISES ABOVE THE STORAGE TANK TEMPERATURE, VALVE V_{EE} SHALL CLOSE AND THEN THE REFILL PUMP SHALL BE STARTED AND SHALL RUN UNTIL STOPPED BY FLOAT SWITCHES NUMBERED 1, 2, 3 AND 4, AT WHICH TIME VALVES V_A, V_B AND V_E SHALL CLOSE AND VALVES V_C AND V_D SHALL OPEN. FLOAT SWITCHES 1 THRU 4 TO BE WIRED IN SERIES.

WALTER K. PLATT

⚠5 ⚠3 ⚠2 FLOW DIAGRAM
NO SCALE

NOTE: IN ALL PIPING BUT AUTOMATICALLY DRAINED SOLAR COLLECTOR PIPING, PROVIDE AUTO. AIR VENTS ON ALL HIGH POINTS AND WHERE INDICATED ON DRAWINGS. PROVIDE DRAIN-OFFS AT ALL LOW POINTS.

REV.	DESCRIPTION	DATE
1	GENERAL REVISIONS AND REVISIONS TO BULLETINS 1 THRU 3	8-17-76
2	REVISED PER BULLETIN #6	11-12-76
3	REVISED INSTRUMENTATION LAYOUT	12-8-76
4	ADDED VENT TRAPS, GEN. REVISIONS	1-5-77
5	REVISED INSTRUMENTATION PER ERDA, ADDED UNIT HEATER #1	1-31-77

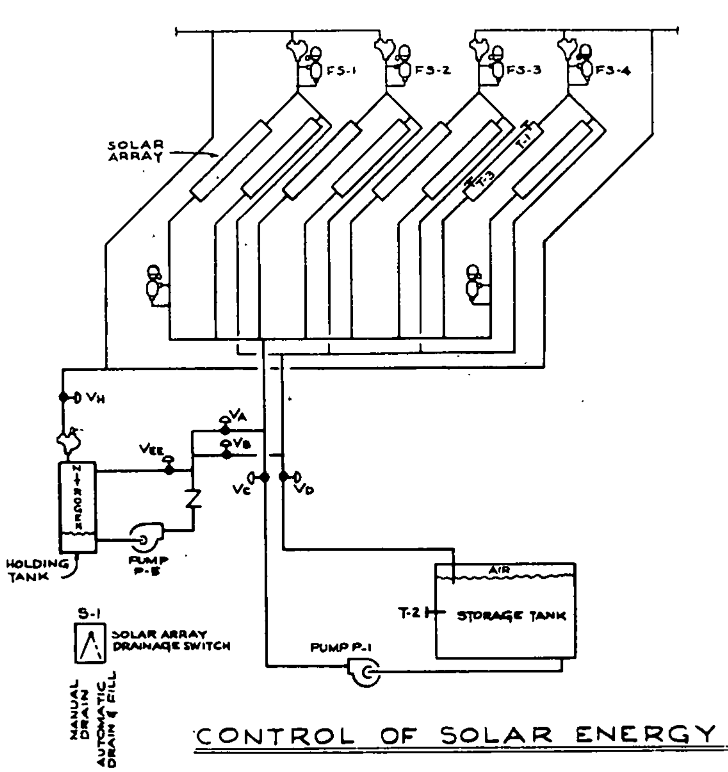
SHEET TITLE: EQUIPMENT SCHEDULES & FLOW DIAGRAM

DATE: JUNE 21, 1976
SCALE: AS SHOWN
DRAWN BY

WEST CHESTER WORK CENTER
BELL OF PENNSYLVANIA
ONE PARKWAY
PHILADELPHIA, PENNSYLVANIA

A SOLAR ENERGY PROJECT IN COOPERATION WITH THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

SHEET NO. M-4
JOB NO. 00009-5



WITH SWITCH S-1 INDEXED TO "MANUAL DRAIN"

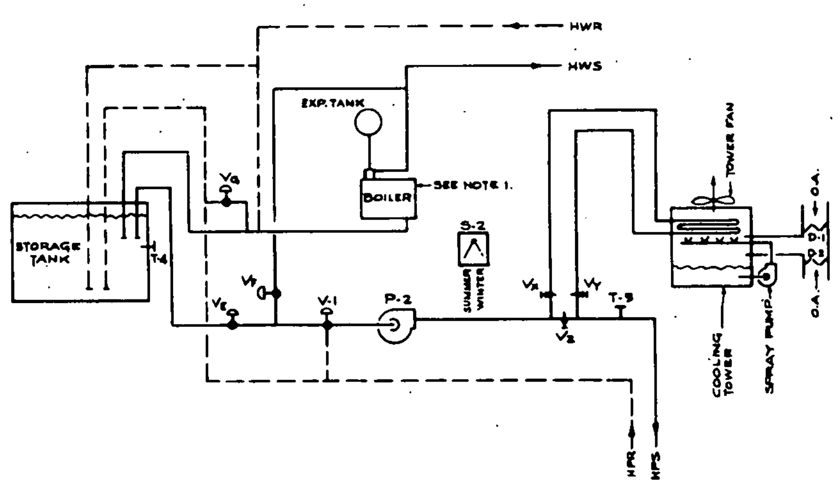
1. VALVES V_C AND V_D SHALL BE HELD CLOSED, VALVES V_A, V_B, V_{EE} AND V_H SHALL BE HELD OPEN.
2. PUMPS P-1 AND P-5 SHALL BE INOPERABLE.

WITH SWITCH S-1 INDEXED TO "AUTOMATIC DRAIN AND FILL"

ASSUMING ARRAY TO BE DRY, DRAINED INTO HOLDING TANK, VALVES V_C AND V_D HELD CLOSED, VALVES V_A, V_B, V_{EE} AND V_H HELD OPEN, SUBSEQUENT OPERATION SHALL BE AS FOLLOWS:

3. WHEN ARRAY TEMPERATURE SENSED BY T-1 RISES ABOVE STORAGE TANK TEMPERATURE SENSED BY T-2 BY AN ESTABLISHED DIFFERENTIAL (18° OR AS LATER SELECTED), VALVE V_{EE} SHALL CLOSE AND PUMP P-5 SHALL START. WHEN SOLAR ARRAY IS COMPLETELY FILLED AS SENSED BY FLOAT SWITCHES FS1 THRU FS4 PUMP P-5 SHALL BE STOPPED AND VALVES V_A, V_B AND V_H SHALL BE CLOSED AND VALVES V_C AND V_D SHALL BE OPENED. VALVE V_{EE} SHALL BE HELD CLOSED WHILE VALVES V_A AND V_B ARE CLOSING; AFTER V_A AND V_B ARE CLOSED VALVE V_{EE} SHALL OPEN.
4. WHEN ARRAY IS COMPLETELY FILLED AS SENSED BY FLOAT SWITCHES FS1 THRU FS4 PUMP P-1 SHALL BE OPERABLE
5. WHENEVER ARRAY TEMPERATURE SENSED BY T-1 IS GREATER THAN STORAGE TANK TEMPERATURE SENSED BY T-2 BY AN ESTABLISHED DIFFERENTIAL (18° OR AS LATER SELECTED), PUMP P-1 SHALL START.
6. WHENEVER DIFFERENTIAL SENSED BY T-1 AND T-2 (T-1 BEING THE HIGHER) FALLS BELOW AN ESTABLISHED DIFFERENTIAL (3° OR AS LATER SELECTED), PUMP P-1 SHALL STOP
7. WHENEVER STORAGE TANK TEMPERATURE RISES ABOVE 190F. PUMP P-1 SHALL NOT OPERATE
8. WHEN ARRAY TEMPERATURE SENSED BY T-3 DROPS TO 40F OR AS LATER SELECTED, VALVES V_C AND V_D SHALL BE CLOSED, VALVES V_A, V_B, V_H AND V_{EE} SHALL BE OPENED WHICH WILL CAUSE ARRAY TO DRAIN BY GRAVITY INTO HOLDING TANK. PUMPS P-1 AND P-5 SHALL BE HELD OFF.

CONTROL OF SOLAR ENERGY COLLECTION SYSTEM



YEAR - ROUND OPERATION

1. SWITCH S-2 INDEXES SYSTEM TO "SUMMER" OR "WINTER" OPERATION.
2. WHEN THE STORAGE TANK TEMPERATURE DROPS TO 70 F. OR AS LATER SELECTED (SENSED BY T-4), VALVES V_F AND V_G SHALL OPEN AND VALVE V_E SHALL CLOSE THEREBY PERMITTING BOILER TO BE HEAT SOURCE.
3. VALVES V_X, V_Y AND V_Z ARE MANUALLY POSITIONED.
4. VALVE V-1 SHALL BE POSITIONED FULL OPEN TO HEAT PUMP RETURN WATER WHENEVER PUMP P-2 IS NOT RUNNING.

WITH S-2 INDEXED TO "SUMMER"

5. COOLING TOWER OUTSIDE AIR DAMPERS D-1 AND D-2 SHALL OPEN.
6. MANUAL VALVES V_X AND V_Y SHALL BE OPENED, V_Z SHALL BE CLOSED.
7. COOLING TOWER SPRAY PUMP AND FAN ARE MADE OPERABLE.
8. ON A RISE IN TEMPERATURE TO 85F T-5 SHALL START COOLING TOWER SPRAY PUMP, ON A FURTHER RISE TO 90F T-5 SHALL START COOLING TOWER FAN.
9. V-1 SHALL BE HELD POSITIONED TO FULL FLOW FROM HEAT PUMP RETURN LINE (CLOSED TO HEAT SOURCES OF STORAGE TANK & BOILER).

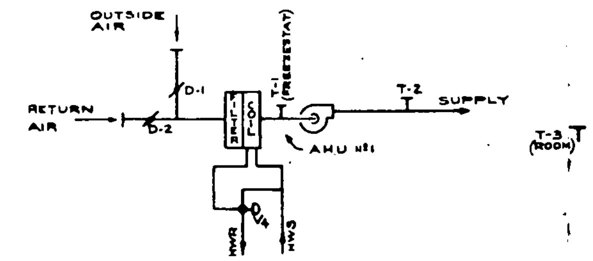
WITH S-2 INDEXED TO "WINTER"

10. COOLING TOWER OUTSIDE AIR DAMPERS D-1 AND D-2 SHALL BE HELD CLOSED.
11. MANUAL VALVES V_X AND V_Y SHALL BE CLOSED, V_Z SHALL BE OPEN.
12. COOLING TOWER SPRAY PUMP AND FAN SHALL BE HELD OFF.
13. ON A FALLING TEMPERATURE T-5 (SET 75F OR AS LATER SELECTED) SHALL GRADUALLY POSITION V-1 TO PASS HEAT SOURCE WATER (STORAGE TANK OR BOILER) TO PUMP P-2.

NOTE 1:

BOILER CONTROLS, INCLUDING LEAVING WATER TEMPERATURE, ARE FACTORY INSTALLED INTEGRAL WITH THE BOILER.

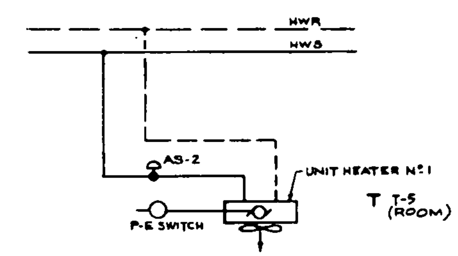
CONTROL OF HEAT PUMP LOOP SUPPLY AND RETURN



YEAR - ROUND OPERATION

1. ON A RISING TEMPERATURE T-3 GRADUALLY CLOSES V-4 TO THE COIL. ON A FURTHER RISE, AND AFTER V-4 IS FULLY CLOSED TO THE COIL, T-3 SHALL GRADUALLY OPEN D-1 SIMULTANEOUSLY GRADUALLY CLOSING D-2. T-2 SHALL OVERRIDE T-3 TO PROVIDE A LOW LIMIT ON AIR LEAVING UNIT.
2. WITH AHU Nº1 NOT RUNNING, D-1 SHALL BE HELD CLOSED, D-2 HELD OPEN, AND V-4 SHALL BE POSITIONED TO PASS HWS THRU THE COIL.
3. T-1, ON LOW TEMPERATURE, SHALL STOP AHU Nº1, CLOSE D-1, OPEN D-2 AND POSITION V-4 TO PASS HWS THRU. THE COIL.

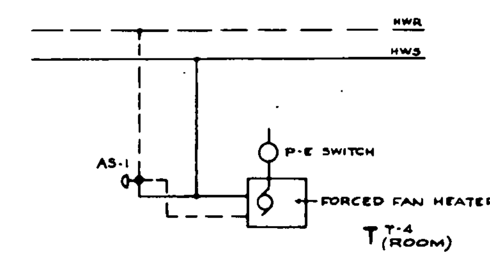
CONTROL OF AHU Nº1



YEAR - ROUND OPERATION

1. ON A FALLING TEMPERATURE T-5 SHALL START UNIT HEATER FAN MOTOR AND FULLY OPEN VALVE AS-2.

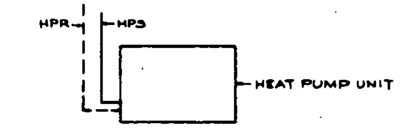
CONTROL OF UNIT HEATER Nº1



YEAR - ROUND OPERATION

1. ON A RISING TEMPERATURE T-4 SHALL GRADUALLY POSITION AS-1 TO BYPASS COIL. WHEN AS-1 IS FULLY CLOSED UNIT FAN SHALL STOP.

CONTROL OF FORCED FLOW HEATERS FF1 THRU 4

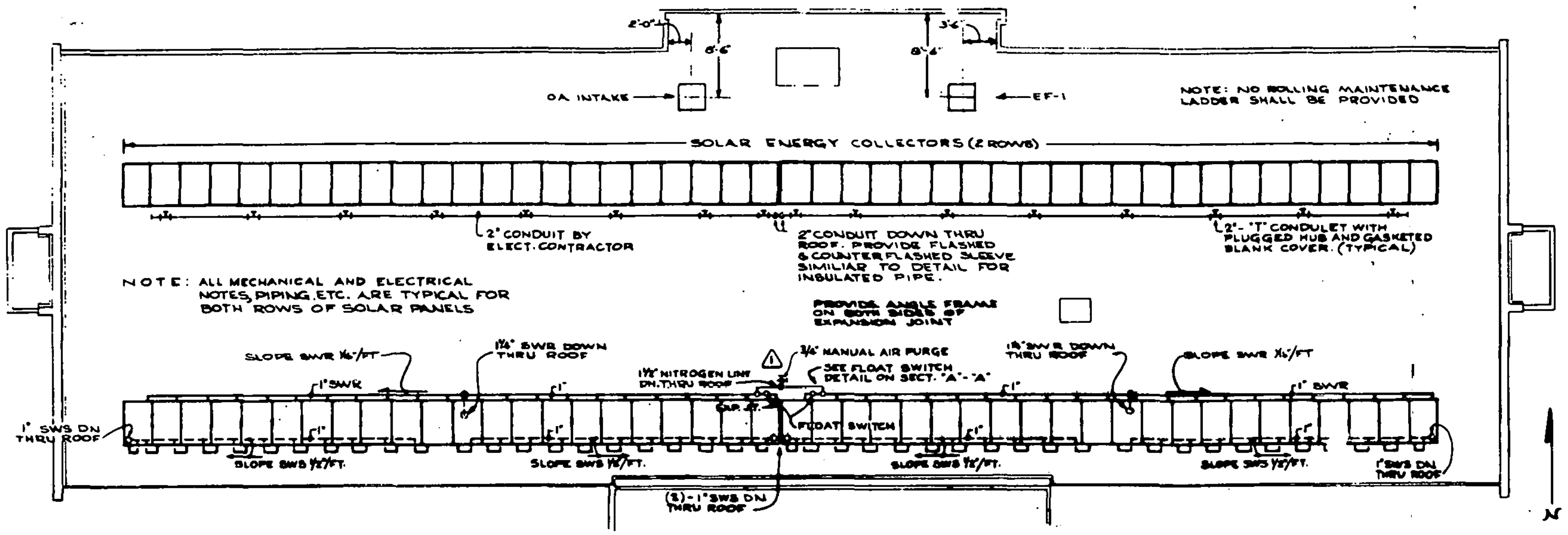


EACH HEAT PUMP UNIT SHALL HAVE FACTORY INSTALLED INTEGRAL THERMOSTAT, AUTOMATIC HEATING/COOLING CHANGEOVER FEATURE, OFF-HI-LOW SPEED SWITCH AND PROVISION FOR RANDOM STARTING OF THE UNITS. AFTER THE OCCUPANT HAS SELECTED THE DESIRED SETTING ON THE THERMOSTAT, THE UNIT WILL PROVIDE HEATING OR COOLING AS NEEDED TO MAINTAIN THE SET POINT.

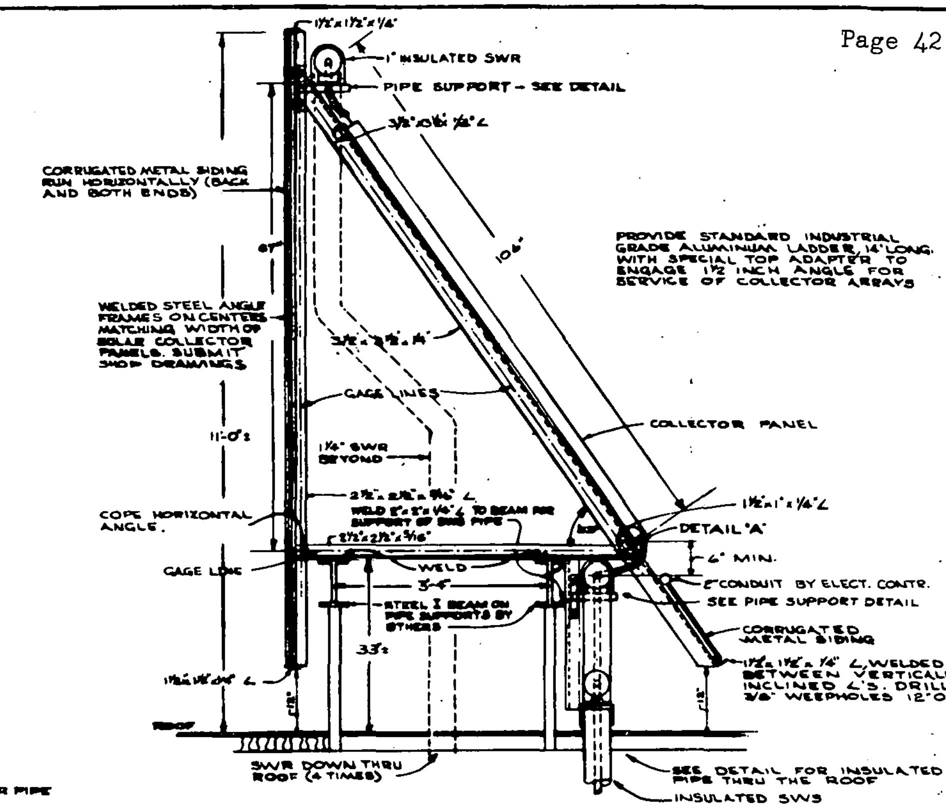
HEAT PUMP UNIT CONTROL

REV.	DESCRIPTION	DATE	SHEET TITLE
			TEMPERATURE CONTROL DIAGRAMS

DATE APRIL 28, 1977	WEST CHESTER WORK CENTER	A SOLAR ENERGY PROJECT IN COOPERATION WITH THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
SCALE NONE	BELL OF PENNSYLVANIA ONE PARKWAY PHILADELPHIA, PENNSYLVANIA	SHEET NO. M-5
DRAWN BY G & W		JOB NO. 00009-5



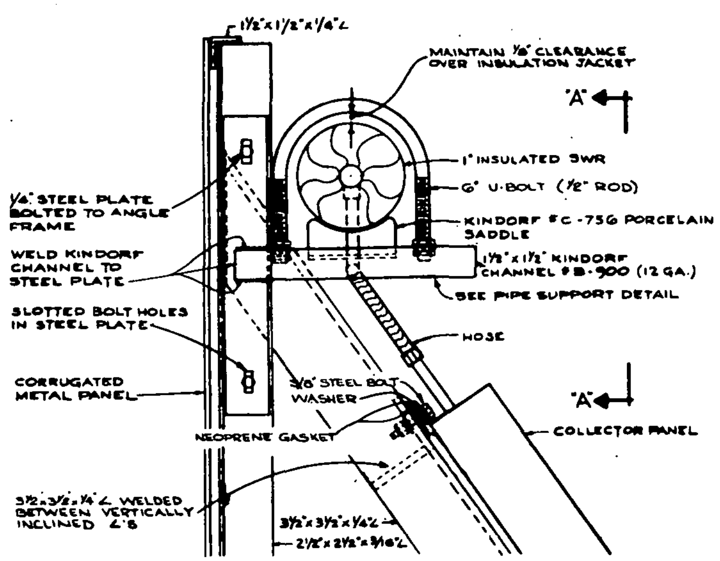
PART ROOF PLAN



COLLECTOR PANEL DETAIL

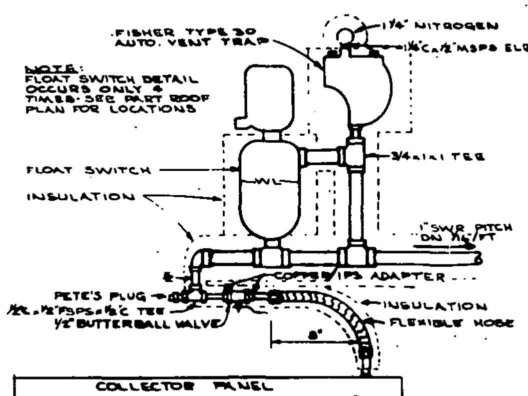
NOTES:

1. CORRUGATED METAL SIDING MUST BE PROVIDED AND ATTACHED TO VERTICAL AND HORIZONTAL MEMBERS. SIDING TO BE RUN IN HORIZONTAL DIRECTION.
2. PAINT CORRUGATED METAL SIDING AND ALL EXPOSED METAL AND PIPING ABOVE THE ROOF WITH ONE COAT PRIMER AND TWO COATS MAB #4-5M FLAXSEED ENAMEL.
3. ALL BOLTS ARE 3/8" Φ ASTM A307 WITH NUTS.
4. STRUCTURAL STEEL: ASTM A 36
5. CONSTRUCTION:
   a) ANGLE FRAME TO BE ERECTED PLUMB
   b) TEMPORARY BRACING IN LONGITUDINAL DIRECTION SHALL BE PROVIDED PRIOR TO INSTALLATION OF METAL SIDING.
   c) CONSTRUCTION SHALL CONFORM TO A.I.S.C. 7th ED.



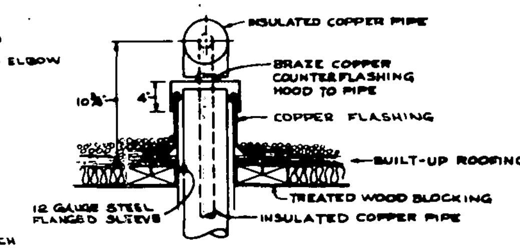
TYPICAL RETURN CONNECTION AND PIPE SUPPORT

SCALE: 3"=1'-0"



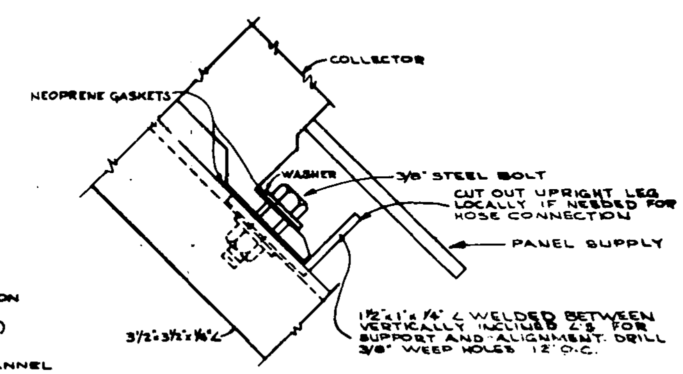
SECTION "A"-"A"

SCALE: 1½"=1'-0"



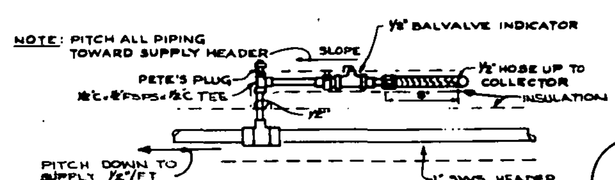
DETAIL OF INSULATED PIPE THRU THE ROOF

NO SCALE



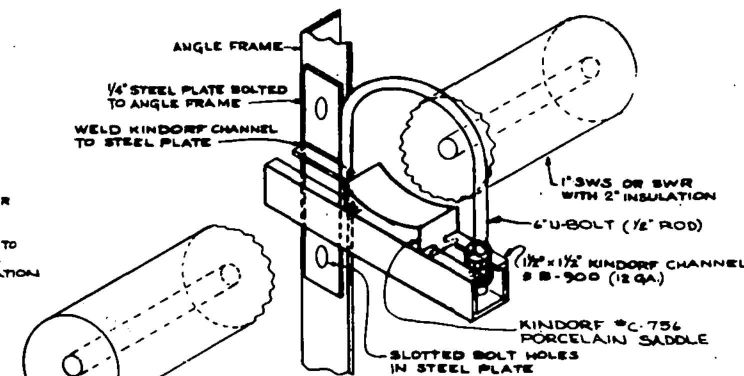
DETAIL "A"

NO SCALE



TYPICAL SUPPLY CONNECTION

SCALE: 1½"=1'-0"



NOTE: PIPE SUPPORT DETAIL IS TYPICAL FOR SUPPLY AND RETURN PIPING. SUPPORTS TO BE ON 6'-0" CENTERS.

PIPE SUPPORT DETAIL

NO SCALE

GOLZ & WICK
CONSULTING ENGINEERS
PHILADELPHIA, PENNSYLVANIA

REVISED SECTION A-A

WEST CHESTER WORK CENTER
MATLACK ST. WESTGOSHEN TWP. CHESTER CO. PENNA
THE WRIGHT/KLETT ASSOCIATION · ARCHITECTS

OFFICE & STORAGE BUILDING

PART ROOF PLAN COLLECTOR DETAILS

SCALE AS NOTED DRAWN G&W DATE 11-12-76

BT-17

A-10A (PART OF BULLETIN #6)