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UNITED STATES SPECIAL FORMAT REPORT: REPORT OF THE GEORGE A. TOWNS ELEMENTARY SCHOOL SOLAR HEATING AND COOLING PROJECT, ATLANTA, GEORGIA

July 1976

Work Performed Under Contract No. E(11-1)-2628

Westinghouse Electric Corporation
Baltimore, Maryland

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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CCMS SOLAR ENERGY PILOT STUDY:

Solar Heating and Cooling Systems in Buildings

UNITED STATES SPECIAL FORMAT REPORT

REPORT OF THE GEORGE A. TOWNS ELEMENTARY SCHOOL SOLAR HEATING AND COOLING PROJECT ATLANTA, GEORGIA

Prepared by

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For the

Energy Research and Development Administration
Division of Solar Energy
Washington, D.C. 20545

July 1976

This report was prepared according to the Special Reporting Format developed by the CCMS Solar Energy Pilot Study. The text of the Special Reporting Format is found at the end of this document.

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I. GENERAL DESCRIPTION OF SYSTEM PROJECT AND ENVIRONMENT

A. OBJECTIVE OF PROJECT

Under contract to the U.S. Energy Research and Development Administration, Westinghouse Electric Corporation has undertaken the design, construction and performance analysis of an experimental solar heating and cooling system to accommodate a building of approximately 3,000 m^2 in area. Associates in this effort are:

- Westinghouse Electric Corporation, Prime Contractor
  Program Management and Construction Management
- Burt, Hill & Associates,
  Solar Architectural Design
- Dubin-Bloome Associates, P.C.
  Mechanical Engineering Design
- Georgia Institute of Technology
  Instrumentation System Design

The objectives of the experiment are to:

- Make a significant contribution to solar design, technology and acceptability.
- Conduct an advanced experiment on an integrated large-scale solar heating and cooling system, determine its performance, reliability and maintainability, and compare these actual results with predicted performance.
- Identify subsystem interface problems that cannot adequately be predicted by theoretical analysis.
- Operationally test major components and identify improvements required.
- Identify cost reducing materials and techniques which may improve the economic viability of solar heating and cooling systems.

As an experimental vehicle, the system was not designed for, and is not recommended for identical replication. The system has been provided with a highly sophisticated degree of flexibility, particularly in the thermal storage and collector fill and drain subsystems, and in the multiple modes of total system operation. This flexibility, which simplifies the conduct of discrete experiments, would not be required in a prototype system.

In order to identify potential areas of cost reduction as mandated by the objectives, the designers took risks which might normally be unacceptable to conventional builders. Some of these risks have resulted in significant, cost-effective discoveries. Others have resulted in disappointments requiring correction. Lessons learned as a result of successes and failures are included in the technical sections of this report.

The design phase commenced in May 1974 and was completed in August 1974. Construction commenced in March 1975 and was completed in September 1975. Drawings of the as-built configuration are contained in Appendix A. Figure 1 is a photograph of the collector array as installed and operating. The system was then operated in various modes during a test period from October 1975 to January 1976. During the one-year cycle from February 1976 through January 1977 the system is being operated while its performance is closely monitored and analyzed. A Final Report of system construction and performance analysis is to be delivered in Feburary 1977.

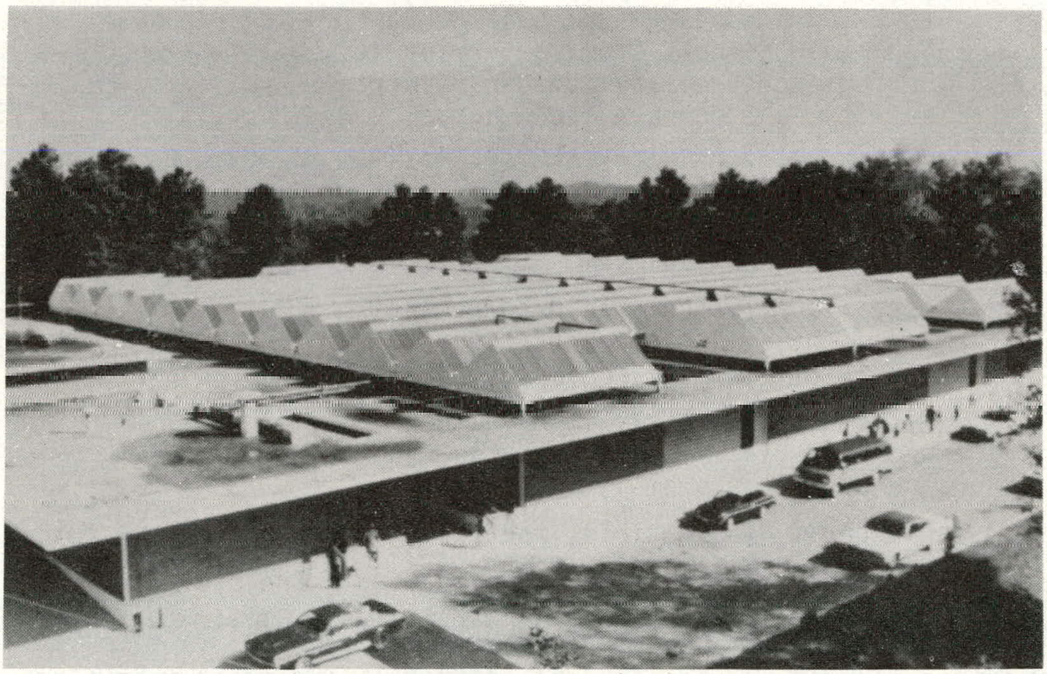


Figure 1. Solar Collector Array

B. ENVIRONMENT

1. Climate

a. Brief Description of Climate

According to Trewartha's 1968 classification of climate, Atlanta's regional climate is Subtropical - Humid. Four distinct seasons exist, with the sum of the mean temperature occurrences in spring and fall contributing to about twice as much in yearly importance as summer and winter temperatures.

In the summer, rainfall is abundant due to increased frequency of thunderstorms. Relative humidity is very often high, sometimes reaching 95% even in evening periods.

In the winter, temperatures decrease, but not significantly. Gentle rainfall is perhaps the rule with snowfall being the exception in this climate region.

b. Annual Rain and Snowfall

The annual rainfall is 122 mm, and the annual snowfall is 5.10 mm.

c. Mean Percentage of Possible Sunshine

J	F	M	A	M	J	J	A	S	O	N	D	Annual
48	53	57	65	68	68	62	63	65	67	69	47	60 Percent

2. Location

a. Latitude and Longitude

33° - 47' N Latitude

84° - 30" W Longitude

b. Location With Respect to Obstructions and Geographic Features

There are no neighboring sun or wind obstructions that would affect the performance of the solar collector. There are also no significant geographic features.

c. Air Quality

The air quality of Cobb County, Georgia, is measured at two sites: Marietta and Smyrna. These measurements began on July 1, 1971, and ran consecutively until July 1, 1975. The annual geometric mean is 59 micrograms of particulate matter per cubic centimeter rated at 25°C at 1 atmosphere. With the Towns Elementary

School site up wind from Atlanta throughout most of the year, and the Georgia state legal air pollution limit being 150 micrograms of particulate matter per cubic centimeter, the air quality is generally good. Over one year of observation, there has been no detectable accumulation of particulate on collector glazing.

3. Solar Radiation

Table 1 shows the total radiation, which is direct + diffuse ($\overline{H}$), background diffuse, and $\overline{H}_1$ which is calculated geometrically as $\overline{H}$ minus background diffuse. $\overline{H}_1$ is a modified value used in solar calculations.

Table 1. Solar Radiation

	MJ/day/m^2		
Month	$\overline{H}$	Diffuse	$\overline{H}_1$
JAN	9.63	1.806	7.824
FEB	12.26	2.302	9.958
MAR	16.20	2.997	13.208
APR	20.52	3.816	16.704
MAY	22.74	4.093	18.647
JUN*	23.62	4.228	19.392
JUL	22.75	4.141	18.61
AUG	21.56	3.874	17.686
SEP	17.25	3.207	14.043
OCT	14.66	2.639	12.02
NOV	11.33	2.118	9.212
DEC	8.54	1.585	6.955

* These values are a correction of the values printed in Table 1-1 of Appendix to "Low Temperature Engineering Applications of Solar Energy"

These values came from "Low Temperature Engineering Applications of Solar Energy", prepared by the Technical Committee on Solar Energy Utilization of the American Society of Heating, Refrigerating and Air Conditioning Engineers Inc. They represent a condensation of data accumulated by the United States Weather Bureau over a 25-year period. The particular time intervals of data collection are not available.

The solar insolation at the Towns Elementary School site is measured by an Eppley Pyranometer. This is a concentric ring pyranometer which uses a thermopile to measure the temperature difference between an outer silver ring which is coated with highly reflective magnesium and an inner ring which is coated with lampblack. The center disk was also whitened and the entire assembly was supported horizontally within a spherical bulb of optical quality glass.

The measurement taken with the Eppley Pyranometer is of $\overline{H}$ or the direct solar radiation plus the background diffuse solar radiation. In general use, without frequent calibration, the accuracy of the data is about $\pm$ 5%. If dust collects on the spherical glass bulb, or if frost, snow or internal moisture conditions are not immediately corrected, higher percentages of error are incurred.

This collected data is then mathematically modified to place it in the form required to be representative of actual insolation data. It should be noted, however, that although many stations are tabulating data, none is complete over the measuring period of 25 years. Therefore, the data should be considered qualitative, rather than quantitative.

4. Ambient Temperatures and Humidity

Mean monthly dry bulb temperatures and relative humidity observed over 86 years in the Atlanta region are shown in Table 2.

The Degree Day (D.D.) measurement is the number of degrees the average daily temperature is below a base of 65°F. (65°F - average daily temperature) = D.D.

The SI system, however, uses 19°C as a degree day base instead of 18.33°C which would be a direct conversion from the Fahrenheit system. Because of this condition, the accurate representation of a D.D. in SI units would require the re-analysis of the distribution of average daily temperatures, over the recording period for Atlanta. This is beyond the scope of this report. Therefore, the D.D. base was redefined at 18.33°C to allow direct conversion from the Fahrenheit system. The D.D. is the daily summation for an entire month of the base, 18.33°C minus the average daily temperature. Total yearly degree days °C = 836.

The dry and wet bulb temperatures are measured by a Hygro-thermometer. This is an instrument that measures both air temperature and relative humidity simultaneously and gives direct readings.

Table 2. Ambient Temperature and Humidity

Month	Mean Dry Bulb Temp. °C	Percent Mean Relative Humidity	Degree Days
JAN	3.33	70	180
FEB	1.66	70	144
MAR	8.61	70	123
APR	15.0	62	47
MAY	19.72	72	7
JUN	21.38	70	0
JUL	26.94	75	0
AUG	25.83	75	0
SEP	28.05	75	5
OCT	16.38	70	36
NOV	6.38	70	117
DEC	3.33	71	177

5. Wind

Average monthly wind velocity and direction is displayed in Table 3. The wind velocity and direction is recorded by a model F 420C 4-cup anemometer made by the Electric Speed Indicator Company and mounted on a 20-foot tower.

Table 3. Mean Wind Velocity and Direction

Month	Velocity (m/sec.)	Direction (degrees)
JAN	4.92	315.0
FEB	5.36	292.0
MAR	5.36	315.0
APR	4.92	292.5
MAY	4.02	315.0
JUN	3.58	315.0
JUL	3.58	225.0
AUG	3.58	315.0
SEP	3.58	67.5
OCT	4.02	292.5
NOV	4.47	315.0
DEC	4.47	315.0

C. SYSTEM DESCRIPTION

1. Qualitative Description

The Atlanta School Project, as it is known, is part of a national program to utilize solar energy in buildings. The Atlanta Project addresses the need for actual performance data of the solar heating and cooling of buildings. The national interest in the results of the experiment dictated the selection of a site appropriate to widespread application. Therefore, an important criteria was balanced heating and cooling requirements within a growing area of the country. The Atlanta area met these requirements as shown in Figure 2. The George A. Towns Elementary School was selected for ease in incorporating a solar heating and cooling system within an existing mechanical and structural system. System design was completed and construction begun in March of 1975. Currently, performance data is being collected for incorporation into a final report.

The George A. Towns Elementary School, location as shown in Figure 3, was built in 1962. The building was heated by hot water supplied by a gas-fired, low-pressure boiler and distributed

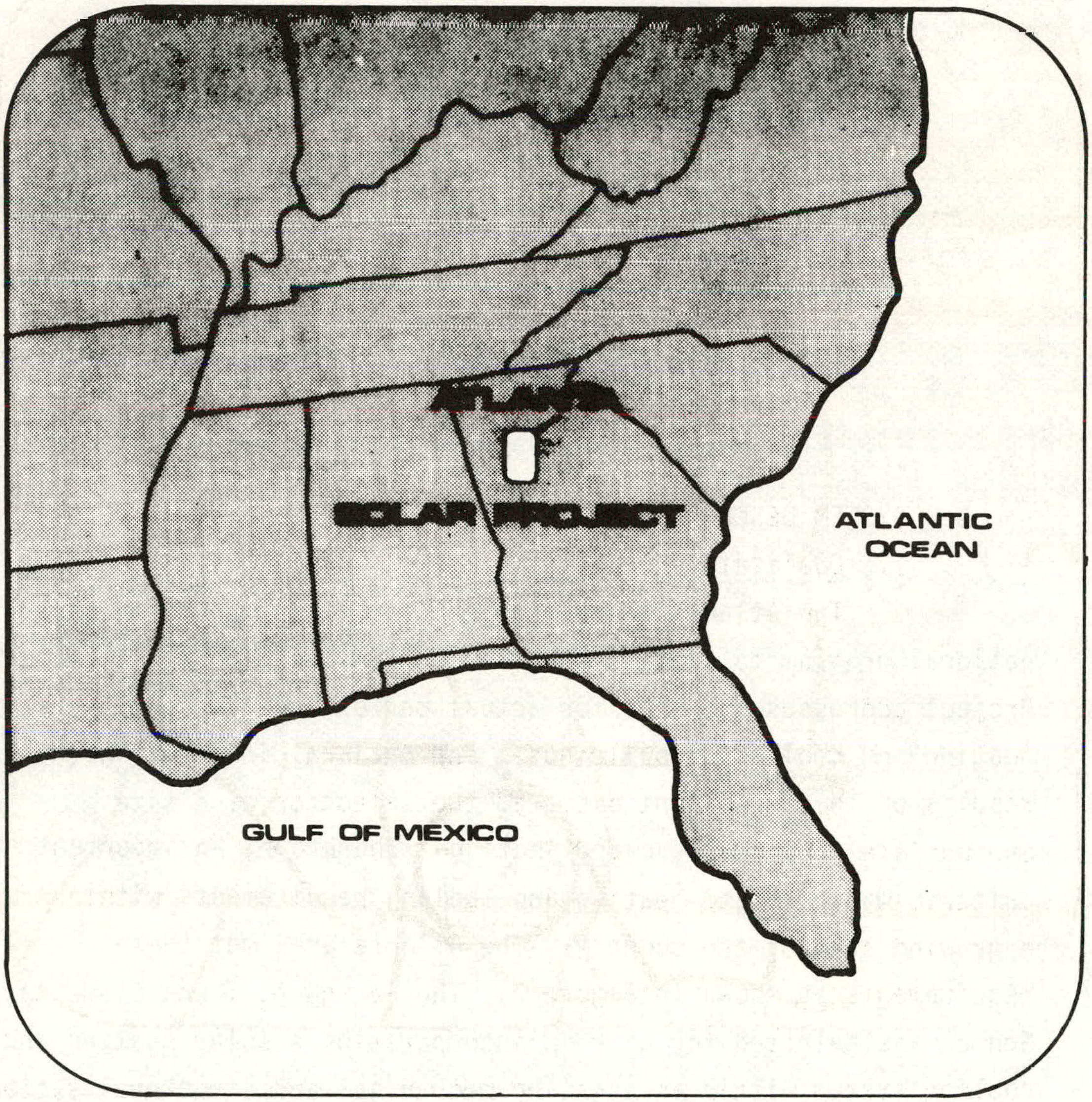


Figure 2. Atlanta Solar Project Location

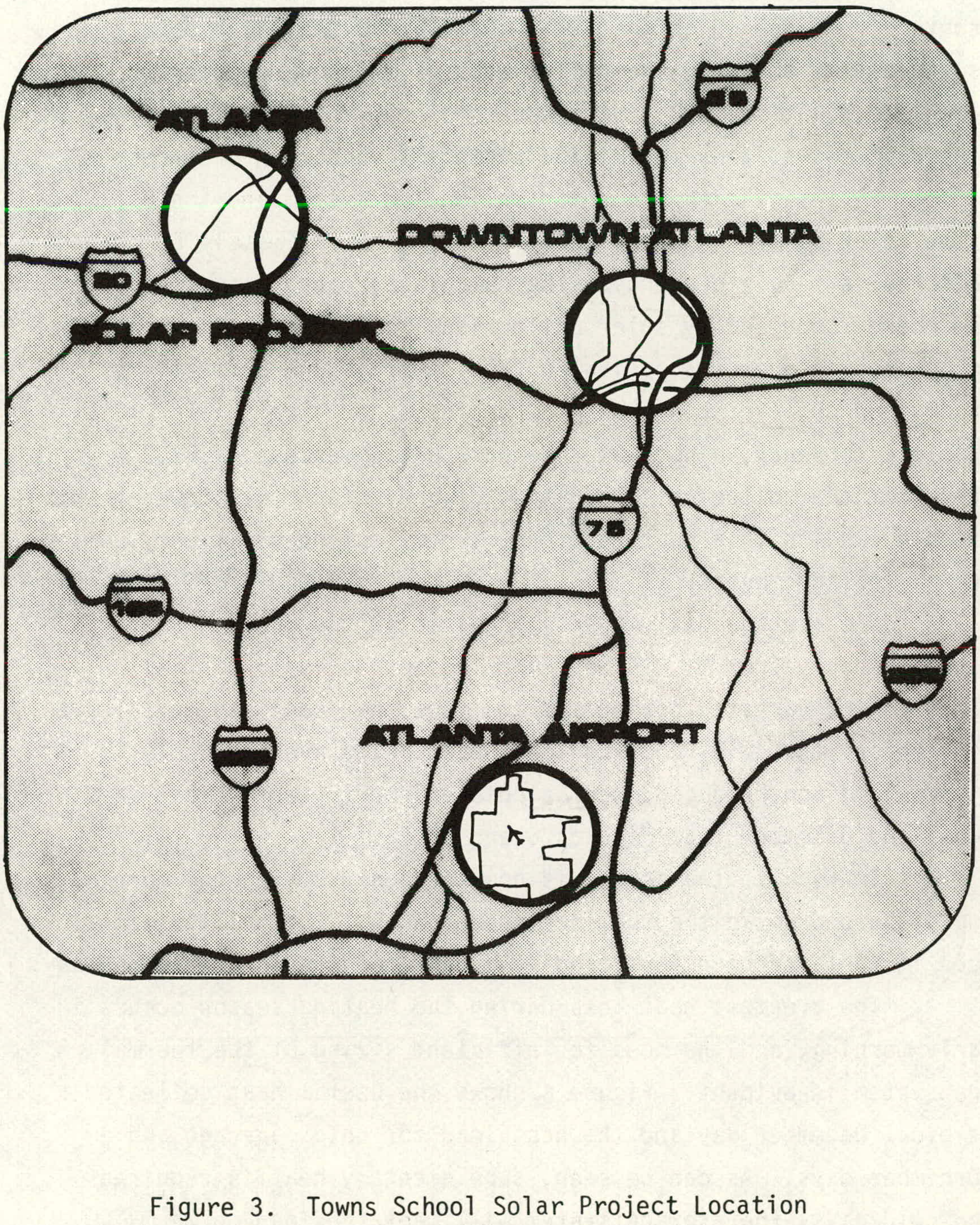


Figure 3. Towns School Solar Project Location

through a 2-pipe system to room unit ventilators. It was not air-conditioned, though the original design anticipated the addition of a chiller in the future.

The one-story building is positioned in approximately a northsouth direction, which made it easy to array the solar collectors in a southerly direction. The roof area is 2,973 square meters, ample room to mount the 962 square meters of collectors well away from the roof edges, thus minimizing potential vandalism problems.

By interfacing the solar collection system and the building load, the solar system is capable of providing approximately 60 percent of the school's required energy. The calculated energy required, and the energy supplied by solar collection, are shown in Figure 4. The large drop in energy supplied in the summer is due primarily to the absorption chiller. In order to run the absorption chiller with reasonable efficiency, a hot water temperature in excess of 82.2°C is required from the collector. Operation of the solar collectors at this temperature results in a sharp decrease in collection efficiency during the summer cooling months.

The average daily energy required in the cooling season drops considerably from May to September because of only partial occupancy in the vacation period and the fact that most students leave at noon, before the daily cooling load peaks. The average daily energy required and produced, was calculated hourly for typical days in August and December (see Figures 5 and 6).

In August, the school is operated only during the morning, causing a sharp drop in the cooling load at noon. The chilled water produced in the afternoon is stored in a tank for use the following day.

The greatest heat loss during the heating season occurs in the early morning, and the need for efficient sizing of the thermal storage system is evident. Figure 6 shows the useful heat collected on a typical December day and the heat load for cold, average and warm December days. As can be seen, supplementary heat is required only on cold days--the storage system will meet the load on warm December days.

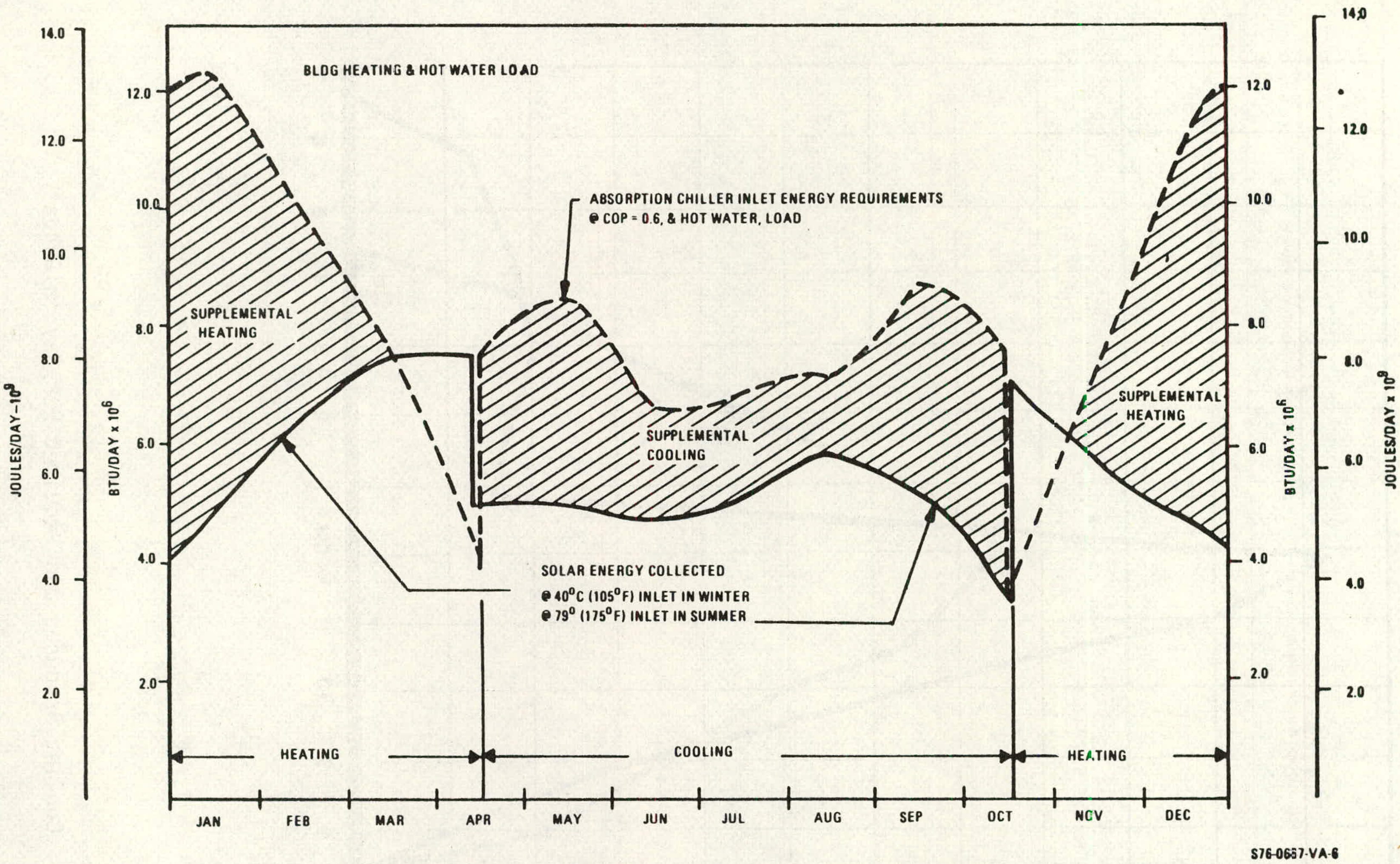


Figure 4. Average Monthly System Performance and Building Load (Predicted)

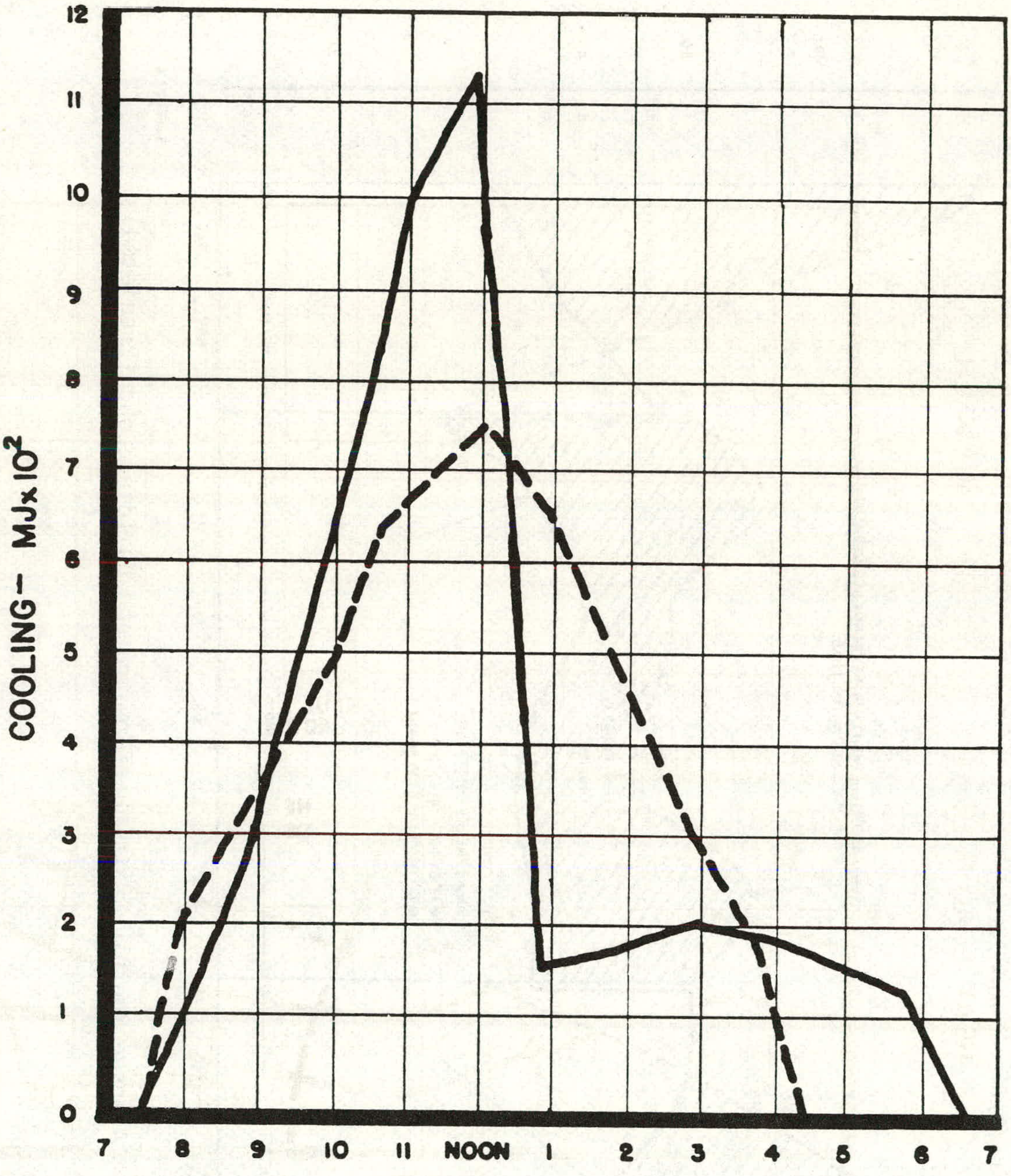


Figure 5. Cooling Produced and Required Per Day in August

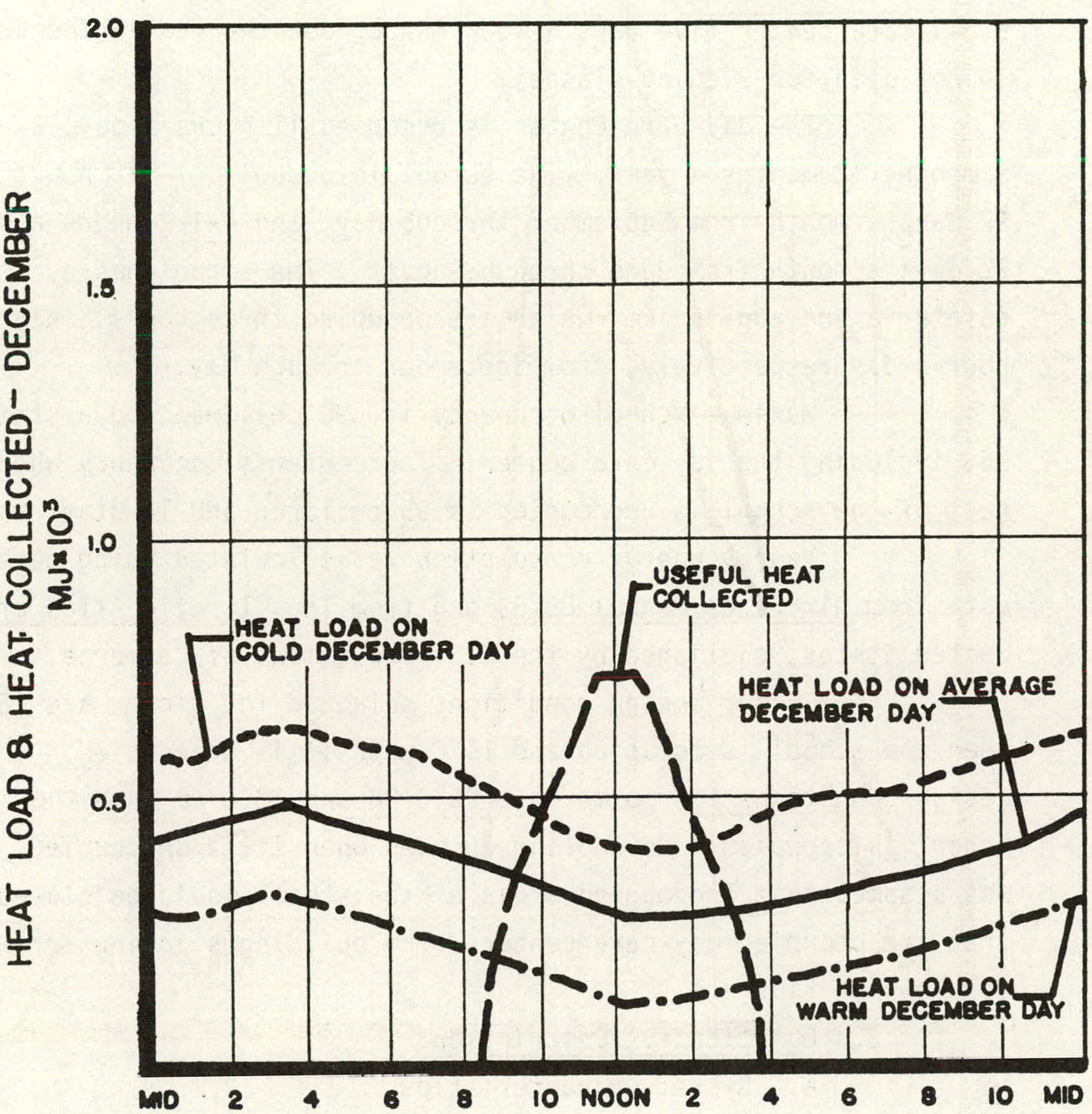


Figure 6. Heat Produced and Required in December

To determine the percentage utilization of solar energy, the school's yearly energy requirements for heating and cooling were analyzed. These requirements are directly related to the schedule of use. The normal school year is September through May. Summer school is held from June through August. Part of the school is also used as a day-care center five days a week throughout the year. The school is not used for evening classes.

The day-care center is occupied 11 hours a day, 22 days a month, 12 months a year. The school is occupied 7-1/2 hours a day, 22 days a month from September through May, and 4-1/2 hours a day, 22 days a month from June through August. The school has a cafeteria and auditorium, which are occupied three hours a day and one hour a day respectively, from September through May.

Maximum school occupancy is 590 children and a staff of 56, including the day-care center. The center's occupancy when the rest of the school is unoccupied is 95 children and 14 staff members.

Yearly energy consumption was calculated using weather data from Air Force Manual 88/8, and from The Climatic Atlas of the United States, published by the U.S. Department of Commerce.

Indoor design conditions selected for winter are 20°C when the school is occupied and 14°C when it is unoccupied. The design conditions for summer are 26°C DB and 18°C WB when the school is occupied. No cooling is used when it is unoccupied. It was assumed that unoccupied areas of the school would be closed off from the occupied day-care center. The building's zoning arrangement is shown in Figure 7.

2. Quantitative Description

a. System Characteristics

The HVAC/solar collection system has five basic parts whose relationship depends on the changing conditions of outdoor and indoor environments:

1) Solar Collectors

An 86.4 cm by 193 cm flat-plate high-temperature collector was specified. It is well-built, efficient and relatively inexpensive.

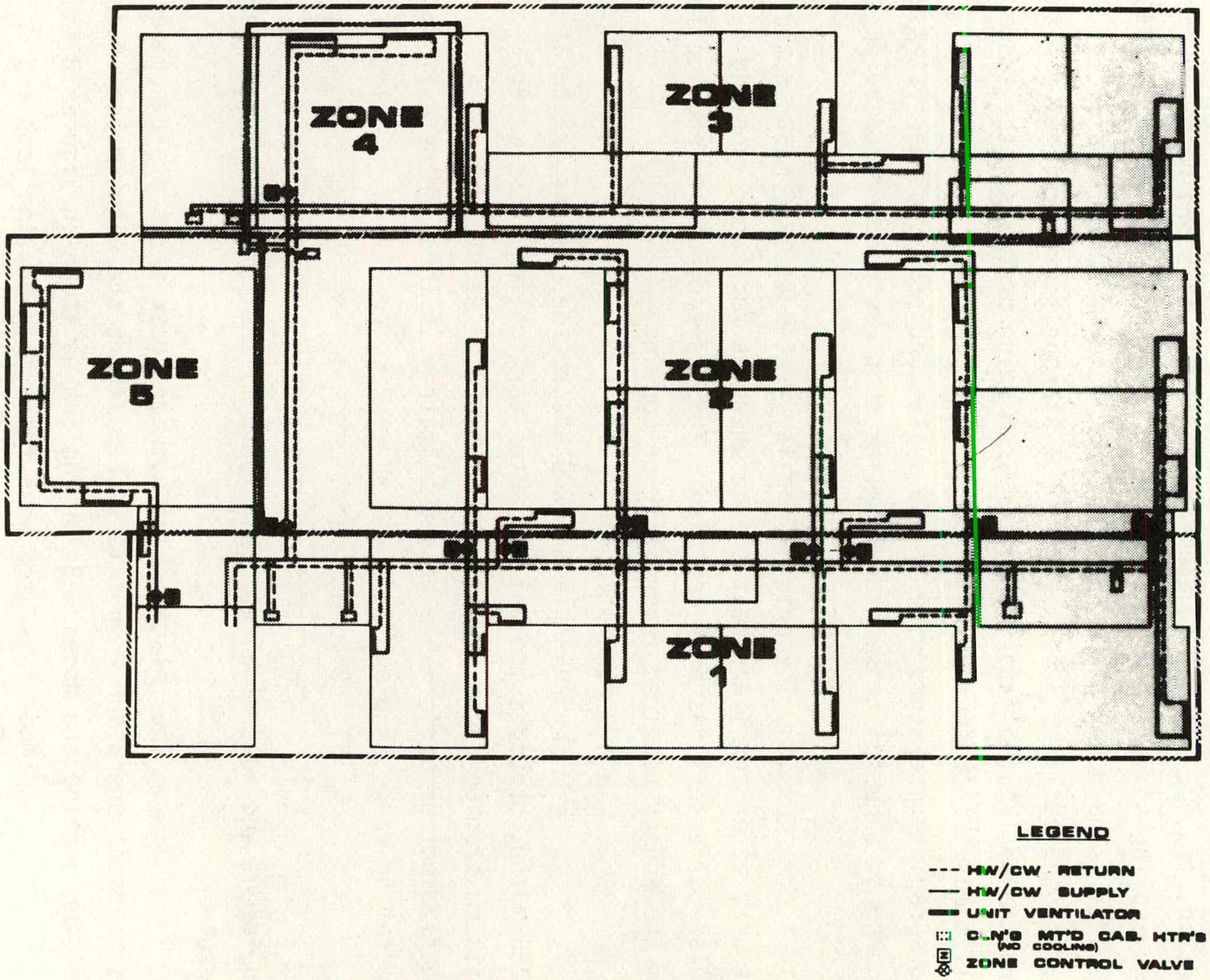


Figure 7. Zoning Diagram

2) Thermal Storage

The storage system consists of three 56,800 liter insulated steel tanks located underground. During the heating season, 170,400 liters of water are available to store heat. During the cooling season, one tank is used to store chilled water (6.67°C - 12.2°C). The other two tanks store hot water (82°C - 93.3°C) to supply the chiller. The use of three storage tanks prevents the thermal inertia of 170,400 liters of water from being present in the system at all times. Introducing solar heated water into one tank allows a more rapid temperature rise in the system and provides the system with energy at a useful temperature earlier than would otherwise be possible.

3) Boiler

The original boiler, rated at 2216 MJ/hr output, is used as an auxiliary heat source when the hot water supplied by the solar collectors has been depleted. This is adequate to provide 100% of the energy required for heating or cooling.

4) Absorption Chiller

An Arkla WF-1200 absorption chiller, rated at 1266 MJ/hr, provides the chilled water for cooling. The water/ lithium bromide cycle is operated with 82°C - 93.3°C water. A coefficient of performance of approximately .6 through the anticipated operating range is predicted.

5) Building Load

Infiltration, heat loss and gain, people, equipment and solar load all contribute to the total amount of energy required.

The relationships between these parts are described as modes of operation. In this system, there are eight modes--Modes 1-4 for heating and Modes 5-8 for cooling as shown in Figures 8 and 9.

Mode 1 is used when there is a heating load and solar energy is available for collection. Hot water is delivered from the solar collectors to storage and transferred from there to the building load.

When there is no heating load but solar energy is available, Mode 2 is employed. This usually occurs on days when the

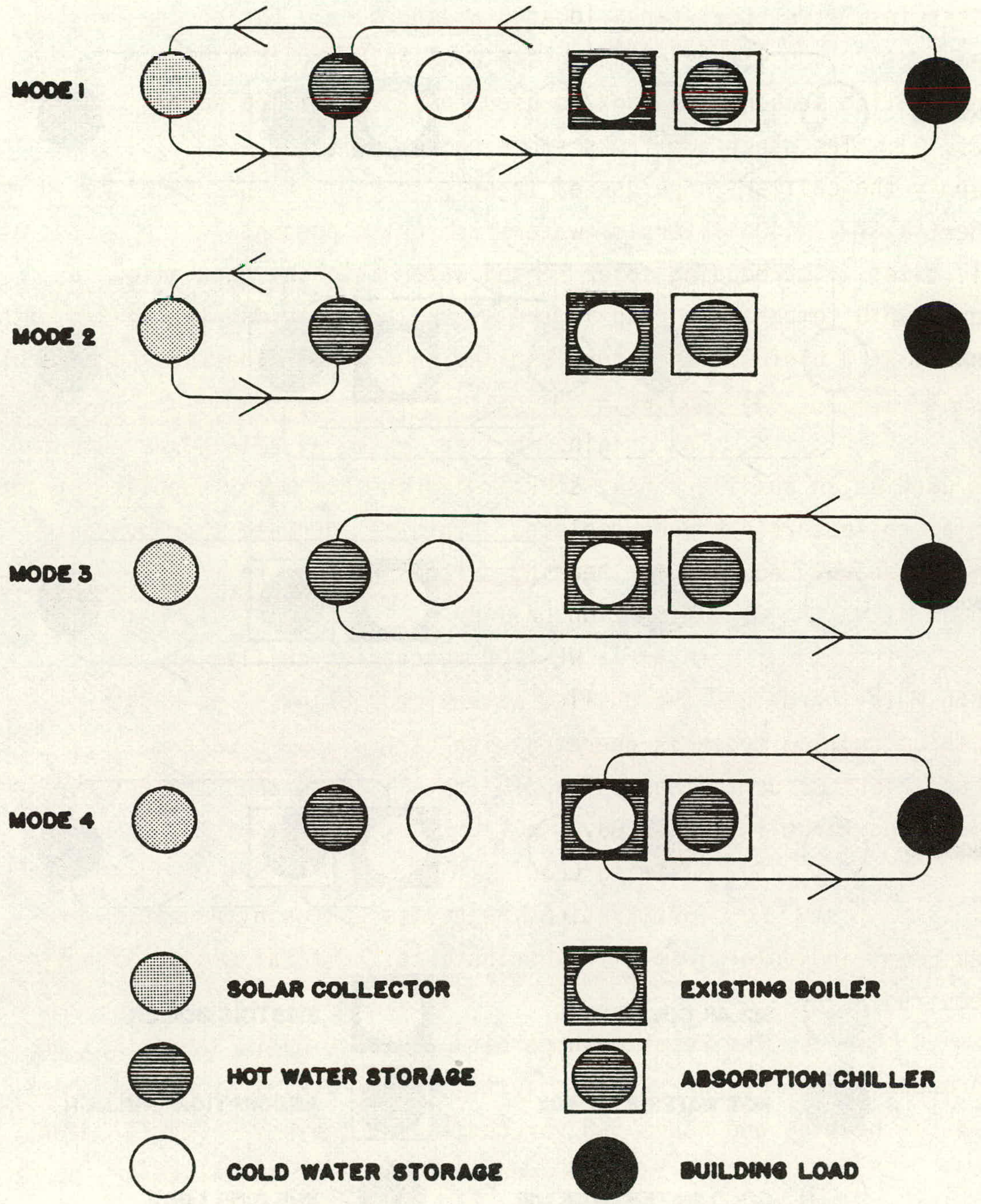


Figure 8. Heating Modes

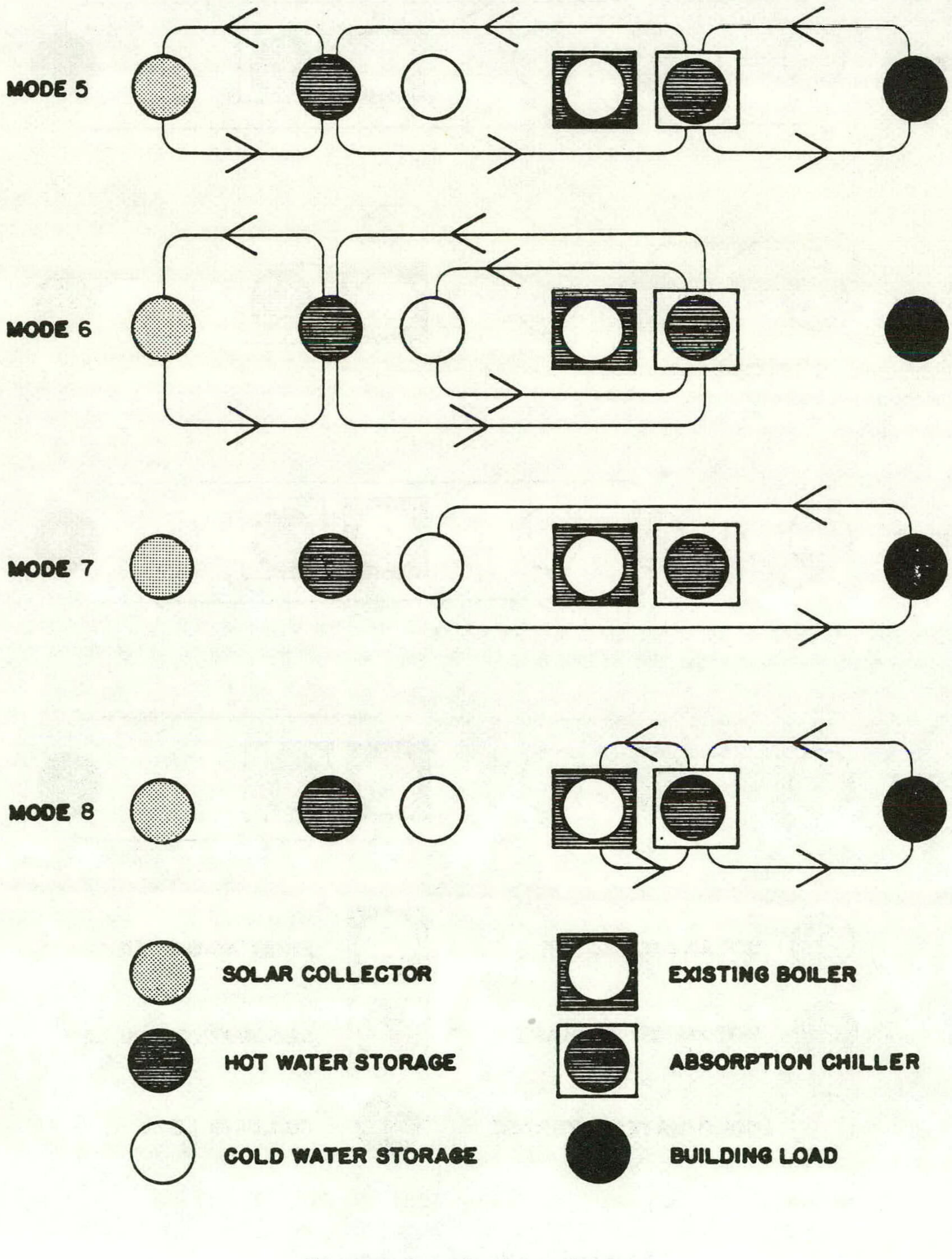


Figure 9. Cooling Modes

school is unoccupied and does not require heat, or in the spring and fall when heating is not continuously required. The heat stored can be used the following day. The hot water collected goes to storage, and the cooler water returns to the solar collector.

Mode 3 is used when there is a building heating load and heat is available in storage but no solar energy is available. Hot water is piped to the building load. Cooler water returns to hot-water storage. This mode normally occurs at night.

Mode 4 is conventional and is used when the storage tanks do not have enough heat to satisfy the building's demands. This could occur when neither solar energy nor storage capacity is available for heat production. In Mode 4, the water is heated by the boiler.

Mode 5 is used when the collectors produce enough hot water to run the absorption chiller. The hot water is transferred to storage and then to the absorption chiller where it generates chilled water to supply the building load. The building is occupied in this mode.

Mode 6 is used when there is no building cooling load but adequate sunshine for heat production. This mode differs from Mode 5 in that the chilled water produced is transferred to storage rather than to the building load. This mode is used primarily on weekends.

Mode 7 is normally employed when there is a building cooling load and chilled water in storage. The stored chilled water can be used by itself or in conjunction with solar heat collection and chiller operation. It is most likely to be used when the school is occupied after an unoccupied day. The chilled water from storage is used to supply building loads directly.

Mode 8 us used when no solar energy is available from the storage tanks in either hot- or chilled-water form. In this circumstance, the boiler can supply directly the energy needed to operate the absorption chiller.

b. Collector Orientation

The selection of the Towns Elementary School was based in part on the optimal orientation of the existing school. The school is aligned only 1°-32' east of due south as shown in Figure 10. This orientation allowed for a good integration between the solar system and the structure.

To achieve maximum efficiency in a solar collection system, several design variables should be optimized.

One of the first variables to be investigated is the optimum tilt and direction of the collectors. Generally, when heating is the dominant load, collectors have been placed in a due south direction and tilted at an angle equal to the latitude +10 degrees. But such variables as system selection, building type and size, and occurrence of interior loads can vary this general rule significantly. Taking these variables into consideration, calculations can be made to determine the amount of solar energy that can be collected hourly at various collector tilt angles.

At the Atlanta school, the best heat production was achieved at a 45-degree tilt and a reflective surface in front of each row of collectors. Calculations indicated that the reflective panels, could increase solar radiation input to the collectors by 30 percent. See Figure 11.

The reflective panels are made of aluminized mylar sheets, bonded between clear mylar, all bonded to .953 cm tempered hardboard. The lightweight, waterproof, resilient panel has a reflective index of .74. The end of each row of collector/reflector panels is enclosed to minimize heat loss and wind-loading problems. The entire array is mounted .6096 meters above the roof surface to permit routine roof maintenance and repair. Covering more than half the building roof area, the collectors provide a sunshade that is expected to decrease the cooling load by about 139.3 MJ/hr of refrigeration.

A treated wood truss system was selected to support the collector and reflector panels. Advantages of this type of construction include low initial cost, long life, relatively few maintenance needs,

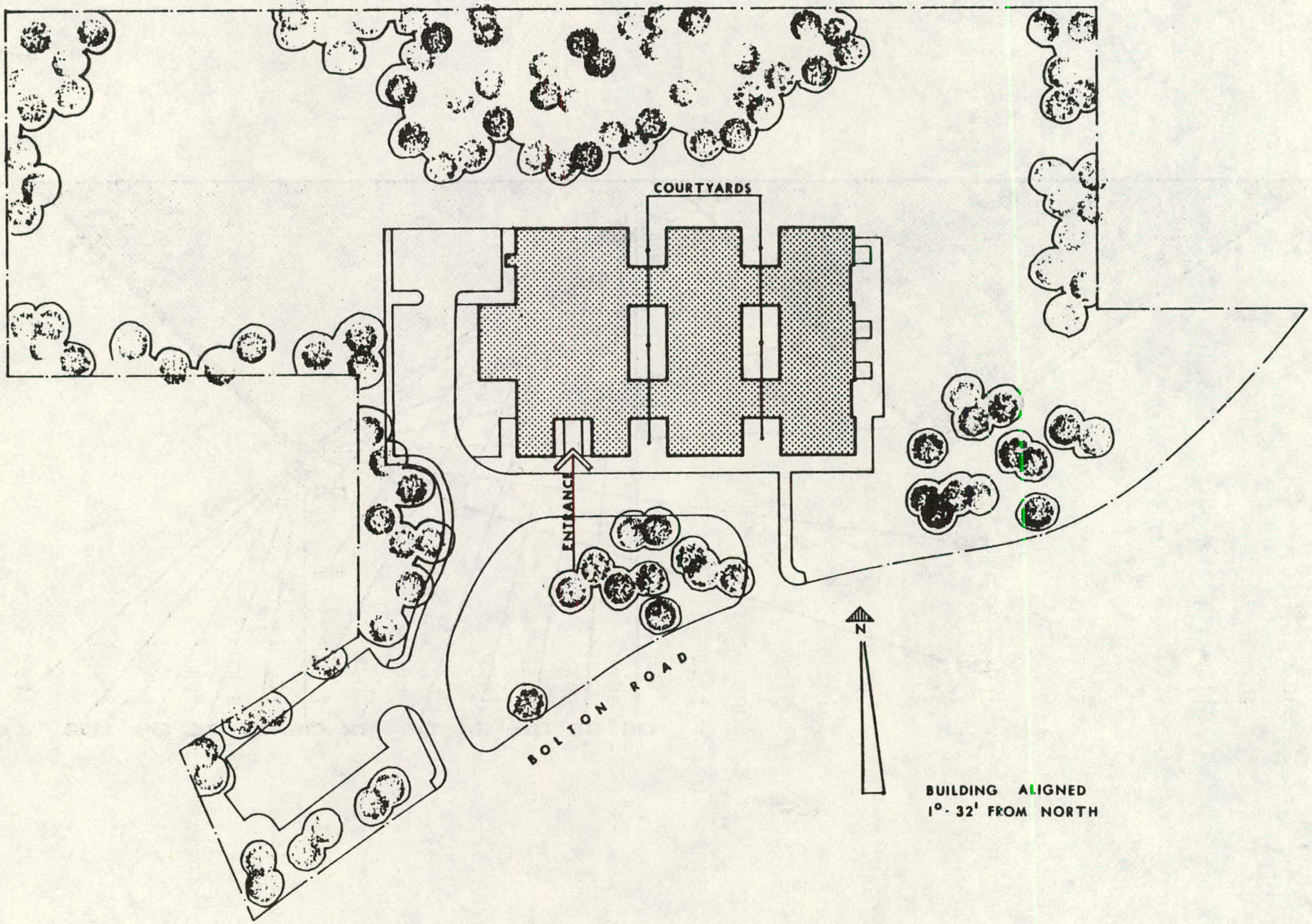


Figure 10. Towns Elementary School Site Plan

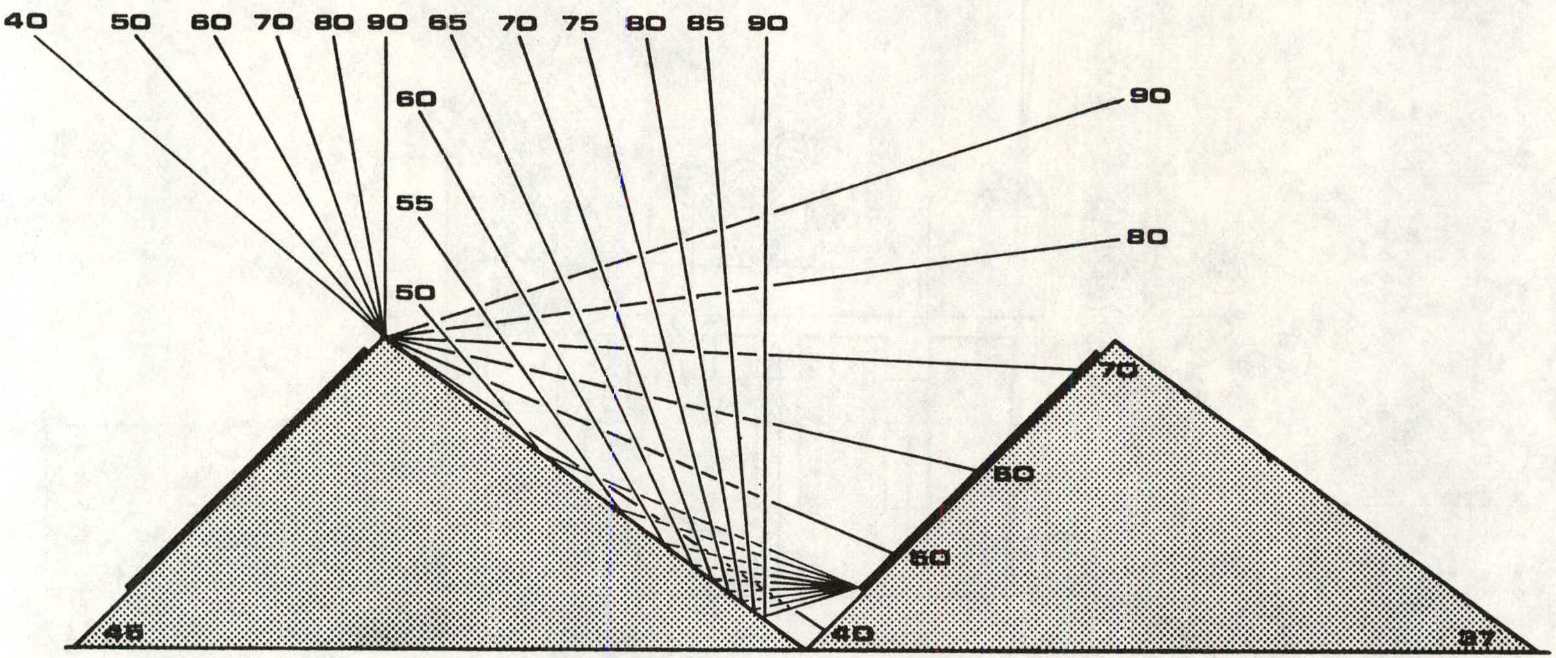


Figure 11. Collector/Reflector Configuration

ease of workability and ability to be mass produced by local tradesmen. See Figure 12.

Photographs of collector installation on the truss system, and the installed reflector array are shown in Figures 13 and 14.

3. Control System Description

a. General

The total system operation can be separated into two basic aspects, and the control system can best be described by addressing each aspect separately and in sequence. These are (1) solar hot water collection and storage, and (2) the distribution and use of stored hot water for heating and cooling. Refer to Appendix A.

The solar collector operation is designed to obtain the highest possible heat production and output by the use of three storage tanks and a variable speed pump. In the winter heating season, hot water is stored in all three tanks with Tank 1 being the warmest and Tank 3 the coldest. In the summer cooling season, Tank 2 and 3 are used for hot water storage, with Tank 2 the warmest and Tank 3 the coldest. Tank 1 is manually isolated from the solar hot water collection and storage subsystem and used for chilled water storage.

1) Filling the Solar Collectors

The solar collectors may be manually or automatically filled by the use of AUTO-DRAIN-FILL switch S2. This circuit includes an adjustable override sensor, FZ1, which prevents the collectors from filling when ambient air temperature is below a preselected setting. This safety feature precludes the initiation of fill when filling water may freeze in exposed piping enroute to the collectors. FZ1 is set at -4°C (25°F), and may be changed as operational experience is gained.

With switch S2 in the Fill position and the ambient air temperature warmer than the setting of FZ1, the fill cycle is initiated.

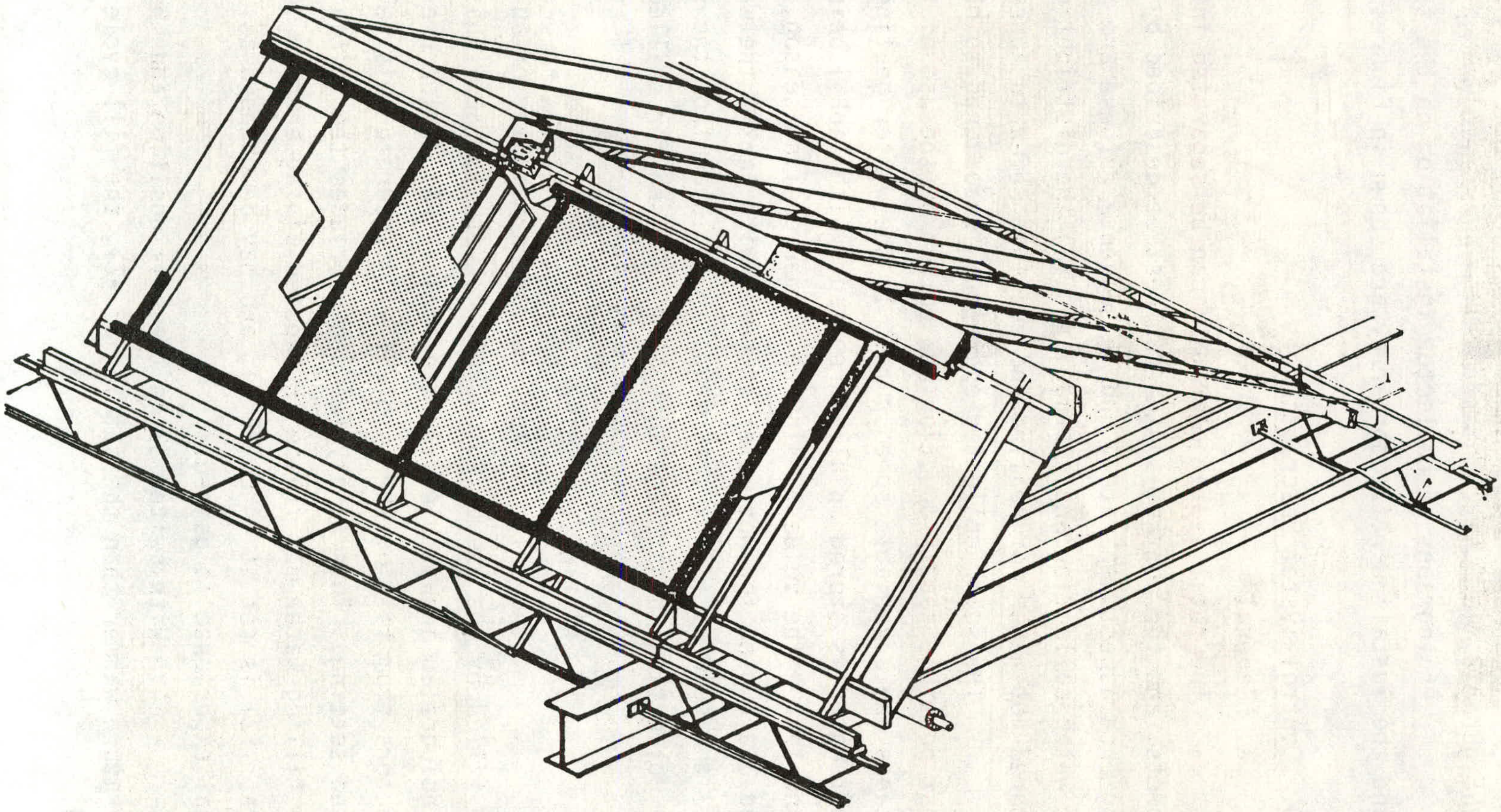


Figure 12. Isometric View of Collector and Framing

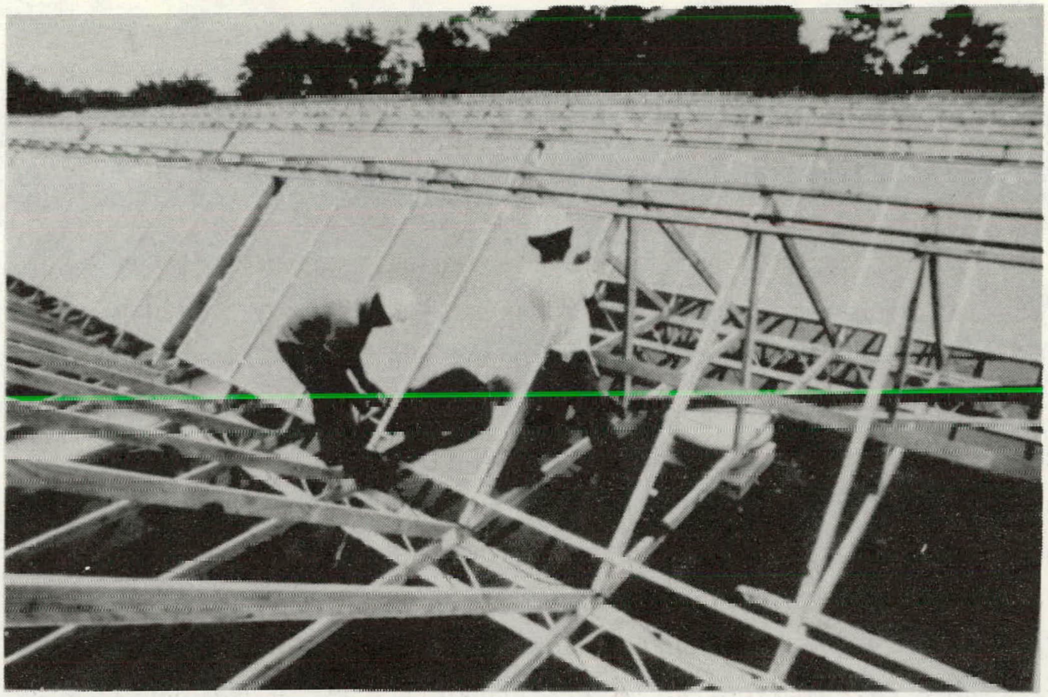


Figure 13. Collector Installation

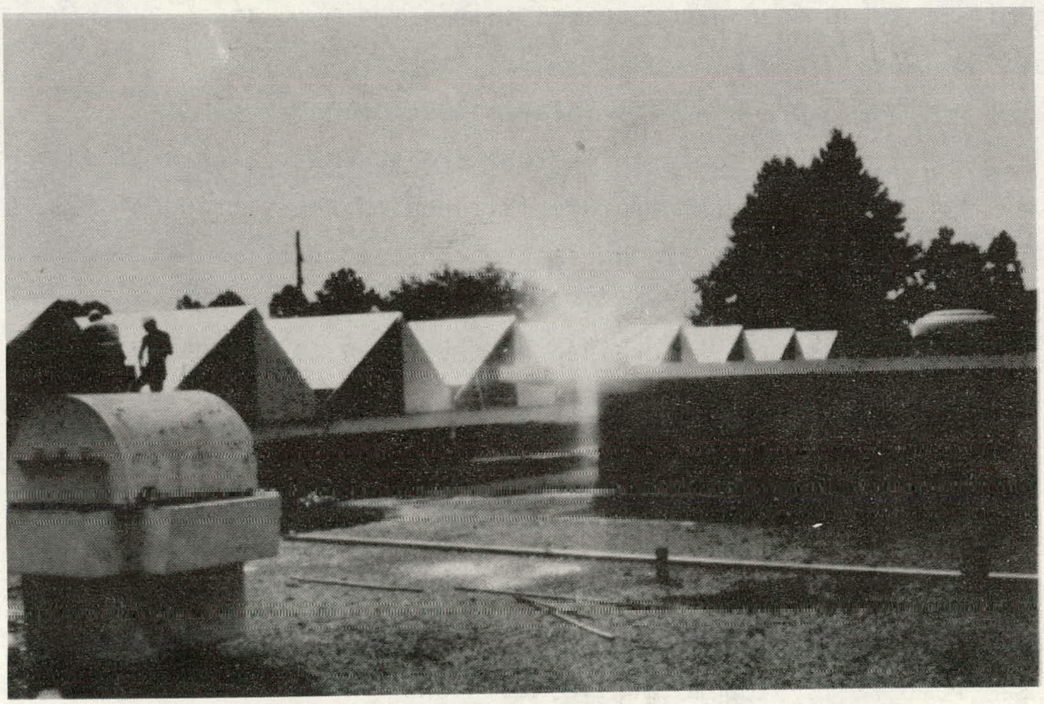


Figure 14. Installed Reflector Array

With switch S2 in the AUTO position, the solar collectors will automatically fill when (1) ambient air temperature is warmer than the setting of FZ1 and (2) sensor TSS detects that collector plate temperature is 11°C (20°F) warmer than the water presently stored in the colder of Tanks 2 or 3.

With the fill cycle manually or automatically initiated as described above, the solar collectors are filled as follows: Valves CV-2 and CV-2A are opened, valve CV-1 is closed, and fill pump P1 will start and pump water from the Holding Tank into the collector panels through both the supply and return piping. Nitrogen will be displaced from the panels through the vent piping and back into the holding tank. When the water level reaches Level Switch LC1 in the Header Tank, valves CV-2 and 2A will close and pump P1 will stop. Valves CV-3 and 4 will open and variable speed pump P2 will commence circulating the water through the collector panels.

Make-up water to the collector system will be controlled by level control LC3 in the Holding Tank. This level control admits make-up feed water to maintain a minimum water level in the Holding Tank.

2) Draining The Solar Collector

The solar collectors are automatically drained whenever the outdoor air temperature falls below the setting of FZ1. This will occur regardless of the setting of switch S2.

With switch S2 in the AUTO position, the solar collectors are automatically drained whenever the collector outlet water temperature falls below the temperature of the collector supply water.

With switch S2 in the DRAIN position the solar collectors are drained.

With the drain cycle manually or automatically initiated as described above, the solar collectors are drained as follows: Pump P2 is stopped, valves CV-3 and 4 are closed, and valves CV-1, CV-2 and CV-2A are opened. The water in the solar collectors is drained by gravity into the Holding Tank. When water has been drained below the roof level, level control LC2 lights a "DRAINED" light on the Control Panel. The system will remain in this configuration until it is desired to refill the collectors and again begin operation.

The Holding Tank is maintained at approximately 139 Kpa (20 psig) by pressurized nitrogen gas.

b. Solar Heat Collection and Storage

When the solar collectors have been filled with water, variable speed pump P2 will start and circulate at minimum speed.

1) Heating Season

With SUMMER-WINTER selection switch S3 in the WINTER position, the operation and control of the collector/storage circuit will be as follows:

Assume all tanks are below a useful temperature of 40°C (105°F) at startup.

Pump P2 will run at minimum circulation rate with Valves CV-6, CV-22, and CV-9 open and all other storage valves closed. The speed of Pump P2 is controlled to maintain a water temperature differential of 5.5°C (10°F) between the inlet and outlet of the collectors. Water then circulates from the pump through the collectors and, bypassing the storage tanks, back to the inlet of the pump.

When the collector outlet temperature is warmer than Tank 1, CV-6 will close and CV-6A and CV-7A will open. CV-9 and CV-22 remain open. The solar heated water will now circulate through Tank 1.

When Tank 1 reaches 60°C (140°F), CV-6A and CV-7A will close and CV-6 will open, isolating Tank 1. Valves CV-7B and CV-8A will open and Valves CV-22 will close, allowing Tank 2 to be heated. Solar hot water in Tank 1 may now be used to heat the building.

Since Tank 1 will be decreasing in temperature and Tank 2 will be increasing in temperature, the two tanks will be joined together when their temperatures become equal. When this occurs, CV-6 will close, and CV-6A and CV-7A will open thus connecting Tanks 1 and 2, and allowing the solar-heated water from the collectors to circulate through both tanks.

When Tanks 1 and 2 reach 60°C (140°F), CV-6 and CV-22 will open, and CV-6A, CV-7A, CV-7B, and CV-8A will close isolating Tanks 1 and 2. Valve CV-9 will close and CV-8B and CV-9A will open, allowing Tank 3 to be heated. Tanks 1 and 2 will be supplying any load at this time.

Since Tanks 1 and 2 will be decreasing in temperature and Tank 3 will be increasing in temperature, all three tanks will be joined together when Tank 3 temperature is equal to that of Tanks 1 and 2. When this occurs, bypass valves CV-6, and CV-22 will close and CV-6A, CV-7A, CV-7B, and CV-8A will open. Bypass valve CV-9 is already closed and CV-8B and CV-9A are open, so at this time all three tanks are being heated by the solar collectors and are available to supply the heating load.

2) Cooling Season

With SUMMER-WINTER selector switch S3 in the "SUMMER" position, and storage Tank 1 manually isolated and used for chilled water storage, the operation and control of the collector/storage circuit will be as follows:

Assume both Tanks 2 and 3 are below the useful temperature of 82°C (180°F) at startup.

Pump P2 wil run at minimum circulation rate with bypass valves CV-6, CV-22, and CV-9 open, and all other storage valves closed. Water from the collectors will recirculate around this loop until it is heated by the sun to a temperature warmer than Tank 2. The speed of pump P2 is controlled to maintain a water temperature differential of 5.5°C (10°F) between the inlet and outlet of the collectors.

When the collector loop is warmer than Tank 2, valve CV-22 will close, and CV-7B and CV-8A will open, CV-6 and CV-9 remain open, and all other storage valves remain closed. The solar heated water will now circulate through Tank 2.

When Tank 2 reaches 90.5°C (195°F), CV-22 is opened and CV-7B and CV-8A will close. Valve CV-9 will close, and CV-8B and CV-9A will open, allowing Tank 3 to be heated. Tank 2 can supply firing hot water to the generator of the absorption chiller at this time.

Since Tank 2 will be decreasing in temperature and Tank 3 increasing in temperature, they will be joined together when the temperature of both tanks become equal. When this occurs, CV-22 will close, and CV-7B and CV-8A will open. Bypass valve CV-9 is already closed and CV-8B and CV-9A are open, so at this time both Tanks 1 and 2 are being heated by the solar collectors and are available to supply hot firing water to the generator of the absorption chiller.

c. Use of Solar Heat

The use or storage of any available solar heat is determined by AUTO-UNOCCUPIED selector switch S4, timeclock C1, override timer OT1, and SUMMER-WINTER selector switch S3 as follows:

1) Heating Season

With SUMMER-WINTER selector switch S3 in the WINTER position, valves CV-18 and CV-19 are open A-AB for heating and closed B-AB (cooling). Valve CV-17 is closed A-AB. The solar heat usage is then controlled by AUTO-UNOCCUPIED selector switch S4, time clock C1, or override timer OT1 as follows:

2) Occupied

With switch S4 in the AUTO position, and the time clock C1 in the OCCUPIED cycle, hot water circulating Pump P7 is started and runs continuously, and all building unit ventilators are energized.

If the temperature of the storage tanks is below useful temperature 40°C (105°F), the heating system operates from the gas-fired boiler. Valves CV-20B and CV-21 are closed, isolating the storage tanks from the building load. CV-20A and CV-23A are open, all distribution valves in Valve Pit No. 1 are closed, and the boiler is placed in operation automatically. Valve CV-23 modulates to maintain a pre-set hot water temperature to the building unit ventilators.

When the temperature of Tank 1 is raised by solar heat collection to a useful level of 40°C (105°F), the boiler is de-energized, CV-20A and CV-23A are closed, and valves CV-20B and CV-21 are opened. The stored solar heat in Tank 1 is now available to heat the building load.

As Tanks 2 and 3 are raised to a useful temperature, the control logic operates the supply solar hot water to the building heating load as follows:

If the solar collectors are operating through Tank 1 only, the building return, through CV-19 and CV-20B, is directed through Tank 1 only. Valve CV-12 is open, and all other distribution valves in the Valve Pit No. 1 are closed.

If the collectors are operating through Tank 2 only, the building return is still directed through Tank 1, as described above.

When the solar collectors are operating through both Tanks 1 and 2, CV-12 is closed and CV-11 is opened, and the building return is directed through Tanks 2 and 1.

If the solar collectors are operating through Tank 3 only, the building return is still directed to Tank 2 and 1, as described above.

When Tanks 1, 2, and 3 are equal in temperature and the solar collectors are operating through all three tanks, valve CV-10 is opened and CV-11 is closed and the building return is directed through Tank 3, 2, and 1. In this configuration CV-11, CV-12 and CV-14 are closed.

Controlling the building return in the above sequence assures that the hottest water available in the storage tanks always goes to the load, and that the return water from the load will never go to a tank that is colder than the return. This control logic also ensures that the solar energy is directed to the load as soon as one storage tank is heated to a useful temperature, rather than waiting for all three tanks to be so heated. This provides a quick recovery thermal storage capability.

Once all three storage tanks are joined to supply the heating load, they remain in this configuration until all three tanks cool below the useful heating temperature of 40°C (105°F). At this time, the boiler comes on to supply the heating load as described in the second paragraph under Occupied, above. Also at this time, the solar collector loop switches to operate through Tank 1 only, recommencing the storage tank heating sequence described in a preceding section.

3) Unoccupied

With switch S4 in the UNOCCUPIED position, or in the AUTO position with time clock C1 in the UNOCCUPIED cycle, the hot water circulating pump P7 is deenergized, the boiler is OFF, and all unit ventilators are deenergized.

Should sufficient solar heat be available during the UNOCCUPIED cycle, it will be stored in Tanks 1, 2 and 3 for later use as previously described.

During the UNOCCUPIED cycle, the building Zone Night Thermostats operate as required to maintain the reduced night temperature in their respective zones. This is accomplished by energizing the Zone unit ventilators and starting hot water circulating pump P7. With P7 in operation, the hot water for the building load is provided from stored hot water in Tanks 1, 2 or 3, or by the boiler as previously described. During the UNOCCUPIED cycle the existing Zone Override Timers may be manually operated to return the respective Zone to Occupied operation for a selected interval.

4) Cooling Season

During the cooling season, Tank 1 is manually isolated from the solar collection system and is used for chilled water storage. Tanks 2 and 3 are used for hot water storage, but at higher temperatures than during the winter season. This high temperature solar heated water if available, is used to fire the absorption chiller generator.

With SUMMER-WINTER selector switch S3 in the SUMMER position, valves CV-18 and CV-19 are open B-AB for cooling and closed A-AB (heating). Valve CV-17 is closed A-AB.

The decision to cool the building with chilled water directly from the absorption chiller, or with chilled water stored in Tank 1, is determined by the AUTO-UNOCCUPIED selector switch S4, and the building time clock C1 or override timer OT1 as follows:

5) Occupied

With switch S4 in the AUTO Position and the time clock C1 in the OCCUPIED cycle, chilled water circulating pump P6 is started and runs continuously, and all unit ventilators are energized.

If the temperature of the stored chilled water in Tank 1 is below 15°C (60°F), it is used to cool the building. Valve CV-15 is closed, CV-16 is open and the chilled water flow is from the storage tank through CV-16, through B-AB of CV-18 to the building. The return flow from the building is through AB-B of CV-19, through pump P6, through B-AB of CV-17 and back to Tank 1. The chiller is off.

When Tank 1 has warmed up to 15°C (60°F) and the stored chilled water is no longer sufficient to cool the building, the controls switch to provide chilled water directly from the chiller to the load. Valve CV-15 is opened and CV-16 is closed, diverting the flow of pump P6 from Tank 1 to the chiller. The chiller is then started.

When the absorption chiller is started, high temperature hot water pump P4 is started and runs continuously. Condenser water pump P5 and the cooling tower fans are controlled to operate as required to maintain the selected condenser water temperature to the chiller.

The high temperature hot water from pump P4 to the chiller is provided as follows:

If the stored hot water in Tank 2 is above 82°C (180°F), CV-12 is closed and CV-11 and CV-14 are open, all other distribution valves are closed. The hot water flow is from Pump P4 through the chiller, from the chiller through CV-11 to Tank 2, and from Tank 2 through CV-14 back to P4.

When Tank 2 reaches 90°C (195°F), it is isolated and allowed to provide hot water to the absorption chiller as previously described. The solar collectors are now switched over and allowed to operate through Tank 3 only.

When the temperature of Tank 3 is equal to Tank 2 they are joined together to provide hot water for the absorption chiller. CV-10 is opened and CV-11 is closed, and all other distribution valves remain in their previous position.

At this time the solar collectors are operating through both Tanks 2 and 3.

If the solar heated water available in Tank 2 is below 82°C (180°F), the controls operate to secure high temperature hot water for the absorption chiller from the boiler. All tank distribution valves CV-10 through CV-14 are closed. CV-20A, CV-20B, and CV-21 are opened, and the boiler is fired. The flow is now from pump P4 through the chiller, through CV-20B, CV-20A, through the boiler and back to P4 through CV-21.

6) Unoccupied

With switch S4 in the UNOCCUPIED position, or the AUTO position with time clock C1 in the UNOCCUPIED cycle, no cooling is provided to the building. This situation prevails at night, and at all times on weekends and holidays. During the UNOCCUPIED cycle, the absorption chiller, pumps P4, P5, and P6, the cooling tower fan and the unit ventilators are all deenergized. Also during this cycle, the collection storage of high temperature hot water in Tanks 2 and 3 will occur automatically when sufficient solar energy is available.

The chilled water storage OFF-AUTO selector switch S5 is provided to allow operational generation and storage of chilled water in Tank 1 during this cycle as follows:

Selector switch S5 is in the AUTO position.

If the solar heated hot water in Tank 2 is above 82°C (180°F), and the temperature of Tank 1 is above 10°C (50°F), chilled water generation and storage will occur. Valve CV-17 is open A-AB for storage, and closed B-AB. CV-15 and CV-16 are open, and the absorption chiller and pumps P4 and P6 are started. Condenser water pump P5 and the cooling tower fan operate as required.

The chilled water flow is from pump P6 through CV-15, through the chiller and CV-16 to Tank 1, from Tank 1 through

AB-A of CV-17, through AB-B of CV-19 and back to P6.

When the stored chilled water in Tank 1 is cooled below 10°C (50°F), or if the solar heated water in Tank 2 falls below 82°C (180°F), the chilled water storage cycle stops.

Valve CV-17 is closed B-AB and opened A-AB, CV-15 and CV-16 are closed, the chiller, and pumps P4, P5, and P6, and the cooling tower fans are deenergized.

With chilled water storage AUTO-OFF selector switch S5 in the OFF position, the previously descirbed chilled water storage cycle will not occur.

4. Measurement System Description

a. General

The solar heating and cooling system at the Towns Elementary School in Atlanta has been divided, for analysis purposes into five main areas. These are; solar collectors, thermal energy storage, absorption cooler, gas fired hot water boiler for auxiliary energy and the building itself. Since energy balance models provide the basis for detailed performance analysis, the measurement subsystem has been designed to provide essential raw data. Using sensor data from actual operating conditions in the system, the analytical models are being used to determine component and overall efficiencies for the various control modes.

b. Data Requirements

The measurements being monitored and recorded in real time for the analytical studies are:

- Environmental
  - Insolation, total on a surface parallel to the collectors, and total in the horizontal plane.
  - Temperature, outside ambient.
  - Relative humidity.
  - Wind velocity and direction.
- Collector System
  - Temperature, total array inlet and outlet

- Temperature, Single Collector with and without Plates with Reflector Augmentation.
- Mass Flow Rate, Total Array

- Storage System
  - Temperature, each tank at top, middle and bottom
  - Pressure, each tank
  - Water Level, each tank
- Absorption Air Conditioner, Solar
  - Generator, Inlet and Outlet Water Temperature, and Mass Flow Rate.
  - Chilled Water, Inlet and Outlet Water Temperature, and Mass Flow Rate
  - Condenser Cooling Water, Inlet and Outlet Temperature, and Mass Flow Rate.
- Auxiliary Energy Supply (Boiler natural gas)
  - Heating, Input and Outlet Energy
  - Cooling, Input and Outlet Energy
- Pumps and Fans
  - Electrical Energy
- Domestic Hot Water
  - Heat Exchanger, Inlet and Outlet Water Temperature and Mass Flow Rate
  - Auxiliary Energy (Heater natural gas)
- Building
  - Zone Temperatures and Relative Humidities
  - Load Inlet and Outlet Water Temperature and Mass Flow Rate

- Miscellaneous
  - pH, Collector Fluid
  - Equipment Maintenance Records
  - Building Occupancy, Electrical load, and any other parameters which may affect overall energy requirements

c. Data Acquisition System

A digital computer based data acquisition system has been designed for the Atlanta experiement. The system employs a minicomputer at the school site for direct control of the measurements process and makes use of a larger, more powerful computer on the Georgia Institute of Technology campus for mass data storage and performance analysis. These two machines are connected by means of a leased telephone line. The arrangement is shown schematically in Figure 15.

The communication and control instructions are run as a "foreground", real-timing program in the on-campus computer's Real Time Executive routine. Received data is stored in files on a cartridge disc using a File Manager utility package. The RTE provides multiprogramming capability so that concurrently with data acquisition, programs may be run in the "background" memory area to examine old or currently open data files. In this way performance analysis programs may be run concurrently with communications programs. Both paper tape and card input can be handled at the central machine and a high speed 80-column line printer is is available for output listing.

d. On-Site Data Gathering

The site data acquisition system handles up to 60 three-wire, guarded channels of dc voltage at up to 100 volts with 10 microvolt resolution. Appropriate conditioning electronics are provided to accommodate signals from temperature, flow, environmental and meteorological sensors. The system, with its interface to the mini-computer is shown in Figure 16.

Several features deserve further explanation. The Teletype is used to enter program directives as well as to provide

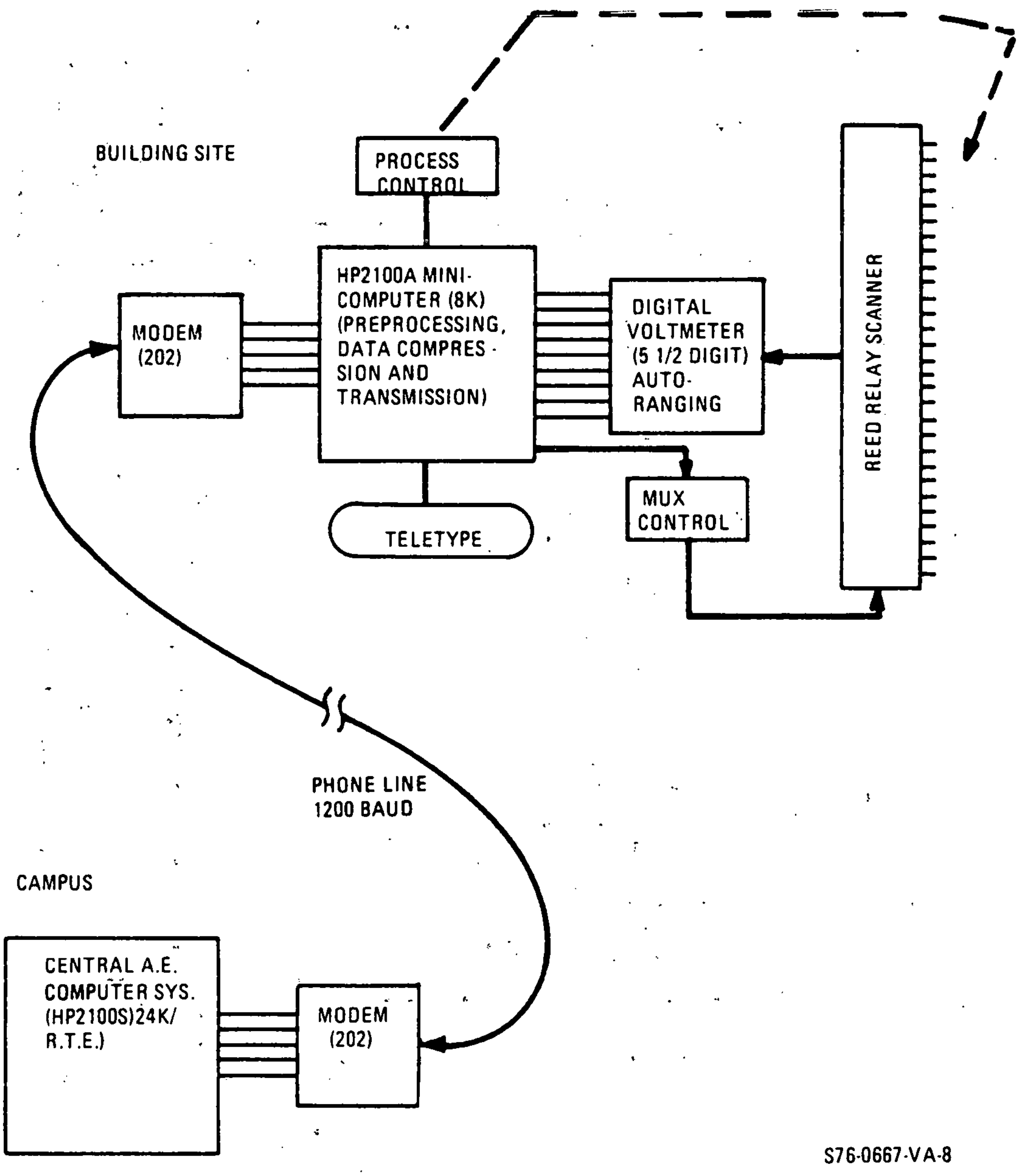


Figure 15. Data Acquisition Schematic

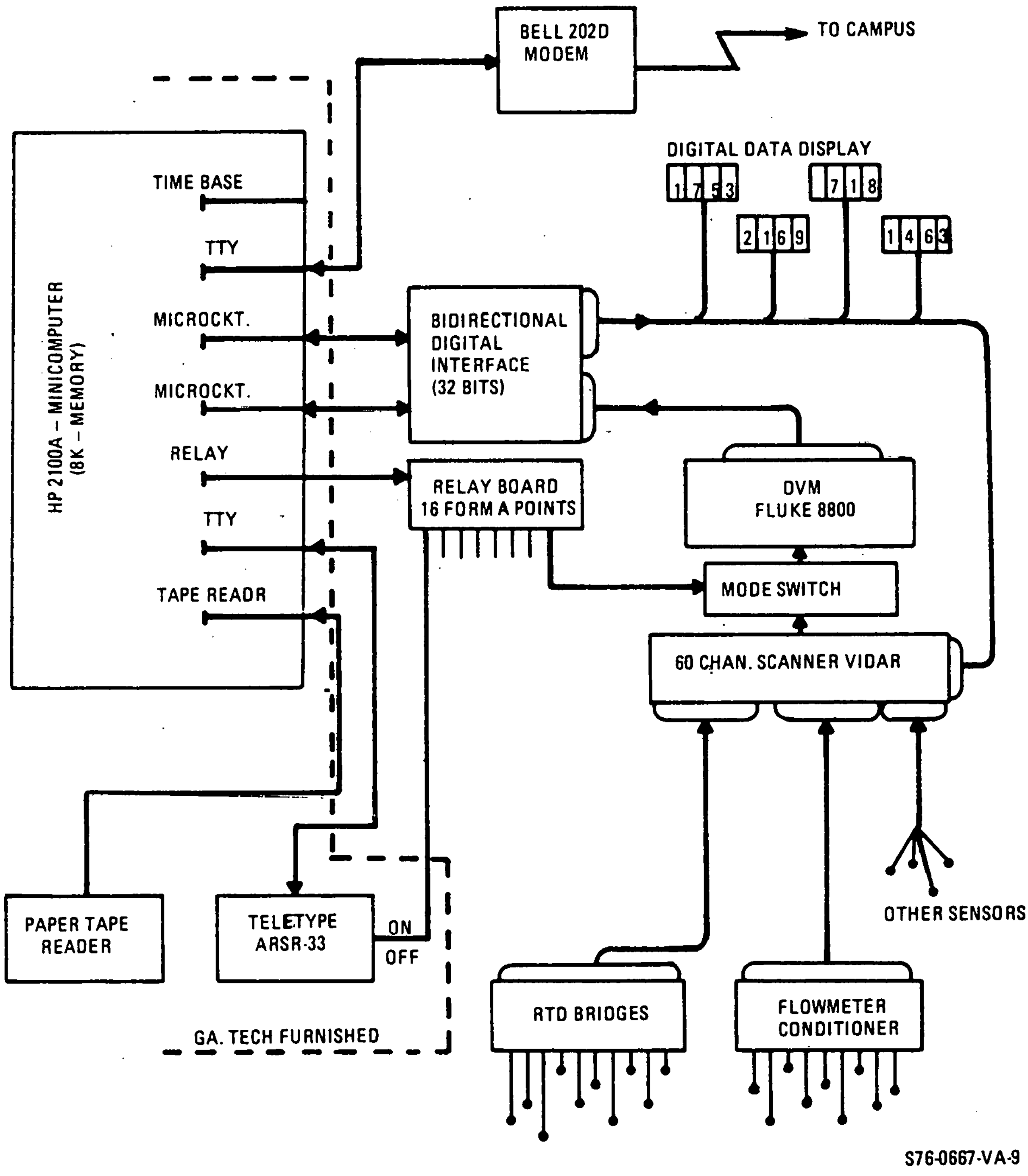


Figure 16. Site Data Acquisition Schematic

detailed reports of system operation. For rapid display of operating parameters, the Teletype prints out each of the 60 channels of information every 15 minutes.

The 60 channel reed relay scanner (Vidar Autodata 616) and digital voltmeter (Fluke 8800A) operate under direct computer control. The scanner is basically a random access unit and a channel address must be supplied for each measurement to be made. The voltmeter is triggered shortly after scanner switch closure and the resultant reading transferred to the computer. This configuration provides the capability to selectively adjust sampling rates on individual channels to suit the measurements requirements. The basic sampling interval is 30 seconds. These samples are averaged over the 15 minute interval, and the 15-minute average is utilized for analysis.

The connection to the campus computer is made via a standard bitserial terminal interface connected to a Bell 202 series MODEM. In this way the communication interface appears identical to a conventional terminal (Teletype for example) and programming is correspondingly simplified. A 1200 baud service was selected for rapid yet accurate and relative economical data transfer.

Finally, a crystal controlled time base (clock) is included as an interface circuit in the computer. This circuit provides periodic hardware interrupts to the computer at program selectable intervals of from 100 microseconds to 1000 milliseconds. The time base is used to clock all measurements tasks at selected intervals and for convenience is set initially to local time.

e. External Environmental Data Sources

In addition to the insolation and meteorological data monitored and recorded on site, environmental data from the Department of Commerce and the solar and meteorological station at Georgia Institute of Technology is being used. The Georgia Tech facility is located only about 5 miles from the Towns school and provides more extensive environmental data than that collected on site. Of three pyranometers, one is used to measure the unfiltered, indirect, solar energy falling on a horizontal surface. A second pyranometer is equipped with four optical filters to measure solar energy in particular spectral bands. The third pyranometer is mounted on a vertical plane to measure solar energy from the southerly direction. A pyrheliometer on an equatorial mount is used to measure the direct solar energy.

The insolation and wind sensor outputs are amplified and sent to a 16 channel analog multiplexor. The unit is controlled by a GRI 909 computer which can select the particular sensor that is to be fed through the multiplexor and sampled by an analog-to-digital converter in the computer. The computer stores this data on a digital incremental tape recorder which is subsequently processed at the main campus computer facility. Refined data is placed in disc files for access by various campus users. Eight of the 16 channels are used by the existing data collection system, and the remaining 8 channels are free to sample additional channels for data.

Meteorological data are obtained by two thermistors, a wind velocity meter, and a wind direction meter. The two thermistors are used to measure the differential temperature as a function of height by mounting the two sensors on a fifty-foot tower. The wind velocity and wind direction are measured by wind sensors mounted on the tower. These data sources external to the project site are used only as required in the event of a temporary loss of on-site environmental data.

II. SYSTEM THERMAL PERFORMANCE

A. CALCULATED DESIGN PERFORMANCE

Figure 17 graphically depicts the estimated system thermal performance and building loads based on mean daily energy quantities averaged over each of the twelve months. The following items are used to evaluate system thermal performance.

1. Space Heating, Cooling, and Domestic Hot Water Load

The space heating and cooling load was computed using the ASHRAE crack method. The average rate of infiltration was taken to be 1 air change per hour and ventilation was 7 liters/sec of fresh air per person. Indoor design temperatures are 20°C (68°F) heating and 25°C DB/18°C WB cooling. A COP of 0.6 for the absorption chiller was used. Hot water for the cafeteria and wash rooms was taken to be 1055 MJ/day during the school year and 740 MJ/day during the summer, when the school is used only as a day car center. The average daily building and hot water loads are depicted as the dashed line in Figure 17.

2. Collector Insolation

a. Horizontal Insolation

The Liu and Jordon method was used to determine hourly values of incident solar radiation based on long term daily averages. In Atlanta, Georgia, the measured values of insolation on a horizontal surface are listed in Table 4.

Table 4. Total Horizontal Insolation in Atlanta

Month	Horizontal Daily Insolation MJ/m^2	Horizontal Daily Insolation Btu/ft^2
JAN	9.6	848.
FEB	12.3	1080.
MAR	16.2	1427.
APR	20.5	1807.
MAY	22.8	2003.
JUN	23.5	2068
JUL	22.8	2003.
AUG	21.6	1898.
SEP	17.2	1519.
OCT	14.7	1291.
NOV	11.3	998.
DEC	8.5	752

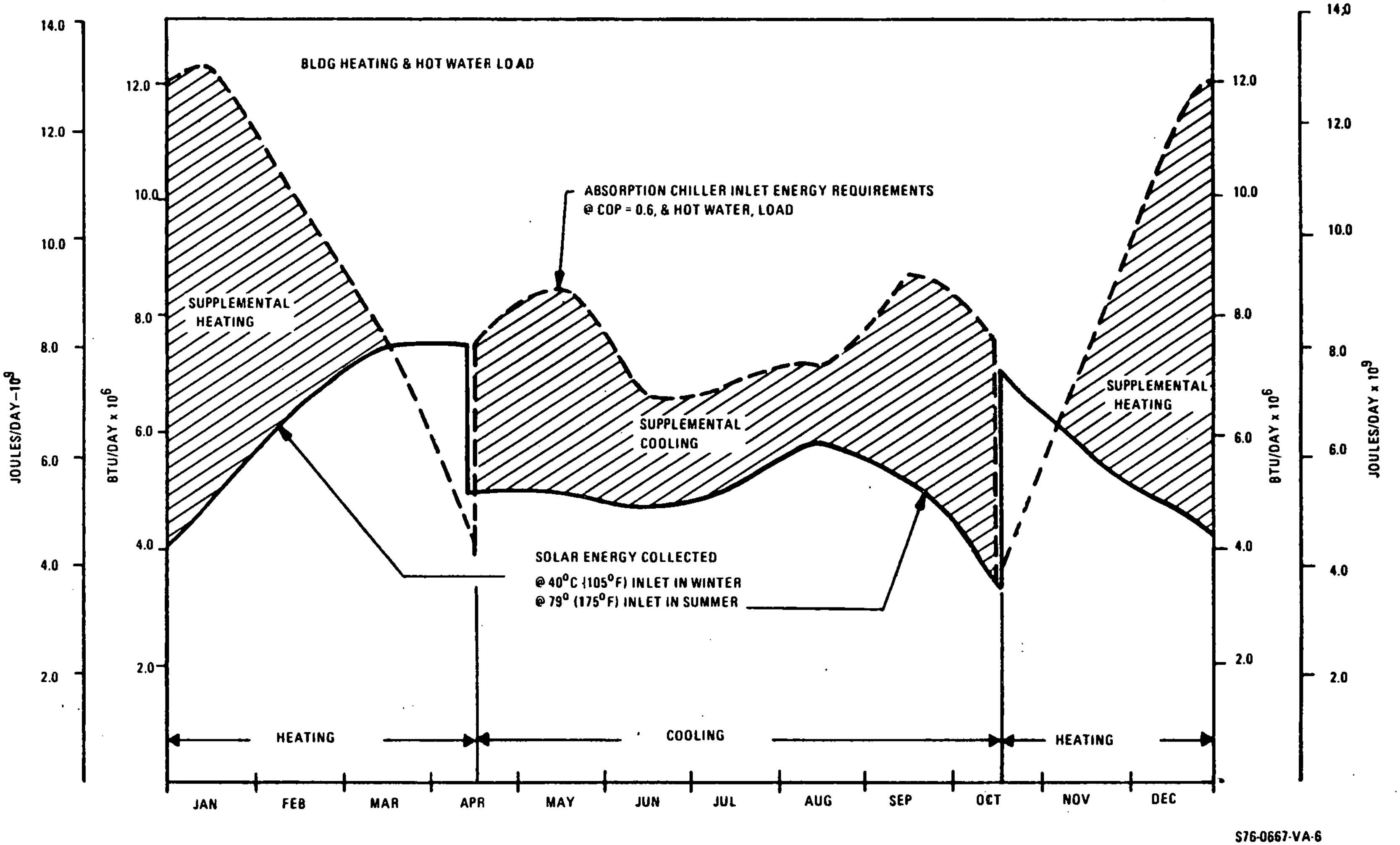


Figure 17. Average Monthly System Performance and Building Loads (Predicted)

b. Insolation on Plane of Collectors

Sun altitude angles and azimuth angles were calculated for each day light hour for the mid-day of the representative month to allow the computation of hourly radiation on a tilted surface (I_{T_t}). The effective angles of incidence were derived as shown in the accompanying calculations for each representative hour for the various days studied.

Altitude = 17° @ 7:30 a.m. March 15

Azimuth = 76° @ 7:30 a.m. March 15

$\cos \theta T$ = incident angle on a tilted surface

= COS (altitude) x COS (azimuth) x SIN (Collector tilt)

+ SIN (altitude) x COS (Collector tilt)

= (COS 17° x COS 76° x SIN 45°) + (SIN 17° x COS 45°)

= .37

ARC COS .37 = 68.28°

The average hourly incident radiation on the tilted surface (I_{T_t}) may then be computed using the following formula:

$$I_{T_t} = \frac{(\cos \theta T)}{(\cos \theta h)} (\bar{I}_{T_h} - \bar{I}_{dh}) + 1/2\,(1 + \cos (\text{Tilt})\ \bar{I}_{dh}$$

Where $\bar{I}_{T_h}$ = hourly total horizontal insolation

$\bar{I}_{dh}$ = hourly diffuse insolation

θh = incidence angle on a tilted surface, degrees

= (90°) - altitude) = 90° - 17° = 73°

Therefore:

$$I_{T_t} = \left(\frac{\cos 68.28}{\cos 73}\right) (55.65 - 12.67)$$

$$+ 1/2\,(1 + \cos 45)\,(12.67)$$

$$= 54.59 + 10.81$$

$$= 67.85\ \text{Btu/ft}^2\text{/hr}$$

$$= 214.0\ \text{W/m}^2$$

Figure 18 depicts the yearly incident radiation for the 45° tilt, both with and without reflectors for clear and average days.

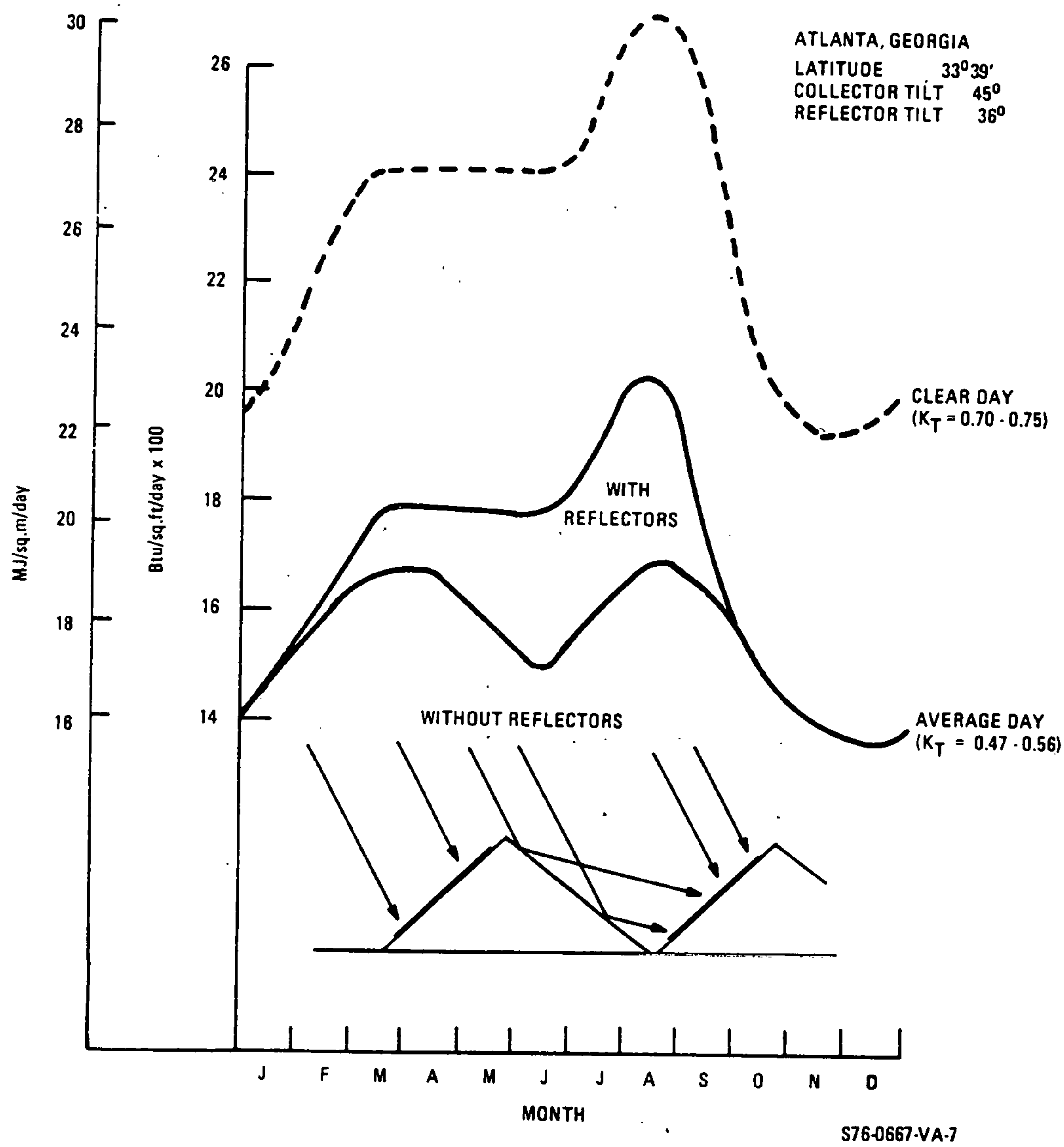


Figure 18. Incident Solar Radiation for Clear and Average Days

c. Reflector Augmentation

Figure 19 illustrates the percent increase in solar flux as a function of sun altitude angle. The top line is the amount of radiation incident on the reflector. The center line illustrates the loss due to the reflectivity (.76) and the bottom line is the amount incident on the collector. This takes into account the additional optical losses of the two glass plates.

3. Solar Energy Collection

The amount of useful solar energy collected throughout the year is depicted by the solid line in Figure 17. The lower shift in energy collection from April 15 through October 15 is due to the increase in collector inlet temperature required to operate the absorption chiller. The inlet temperature shift is from 40°C (105°F) for winter heating to 79°C for summer cooling.

4. Solar Energy Use

The building heating and hot water loads from March 15 to April 15 and October 15 to November 15 are less than the energy collected, as depicted in Figure 17. During these mild periods, the solar system operates only when the storage tanks cannot supply the building requirements. For the remaining ten months of the year, solar energy is collected and stored whenever the collector plate temperature is greater than the storage temperatures.

5. Supplemental Energy Requirements

The cross hatched areas in Figure 17 shows the amount of supplemental energy required during the heating and cooling seasons. The supplemental heat energy is produced in a gas-fired hot water boiler whenever the solar system cannot satisfy the building heating or cooling loads. It can be seen from Figure 17 that on a seasonal basis, 564×10^9 Joules of boiler output are required for heating and 600×10^9 Joules are required for cooling.

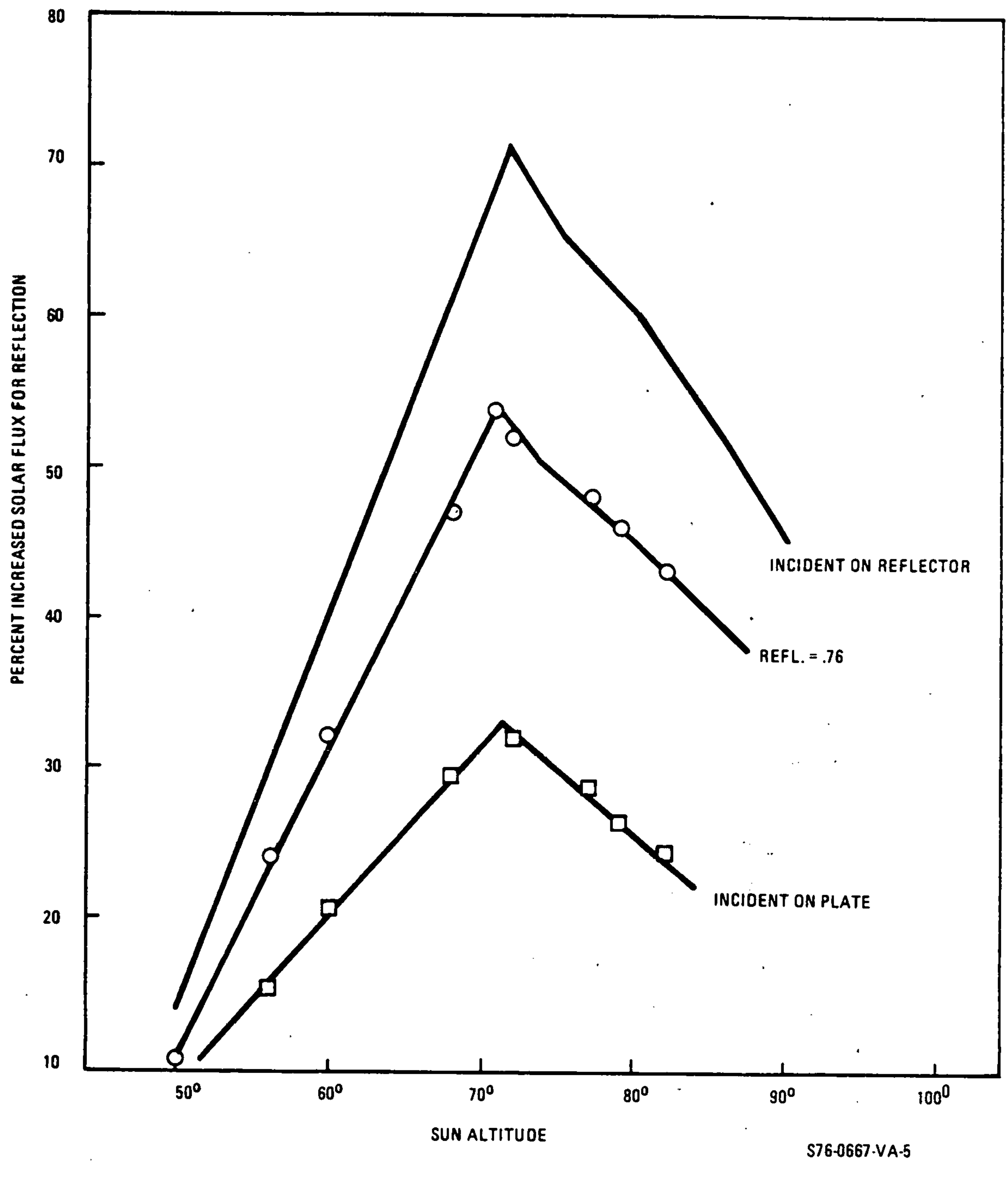


Figure 19. Reflector Performance

B. MEASURED PERFORMANCE

Since the instrumentation monitoring system was not turned on until February 1, 1976, it is not possible at this time to assess the long-term performance of the system. Furthermore, there are gaps in the data collection due to interruptions caused by system checkout. For these reasons, only selected days of operation are discussed.

1. Solar Radiation Measurements

Figure 20 is a plot of incident solar radiation measured on the 45 degree tilted surface for collectors with and without reflectors. The day was a particularly sunny day in March.

2. Collector Heat Production

Figure 21 is a comparison of actual collector performance with predicted results for a sunny day in February. The predictions are based on the Hottel, Whillier and Bliss derivation for flat-plate solar collector performance. Note that the higher predictions in the morning hours indicates that the thermal capacitance of the system was not properly accounted for in the computer program.

3. Reflector Performance

Figure 22 is a comparison of measured heat production for collectors with and without reflectors. On a daily basis, the results indicate a 40 percent increase in useful energy production for collectors with reflectors for this time period on February 20, 1976.

C. SOLAR CONTRIBUTION TO ENERGY AND FUEL SAVINGS

Table 5 is a listing of the predicted average daily energy and fuel savings along with the percent solar contribution by month.

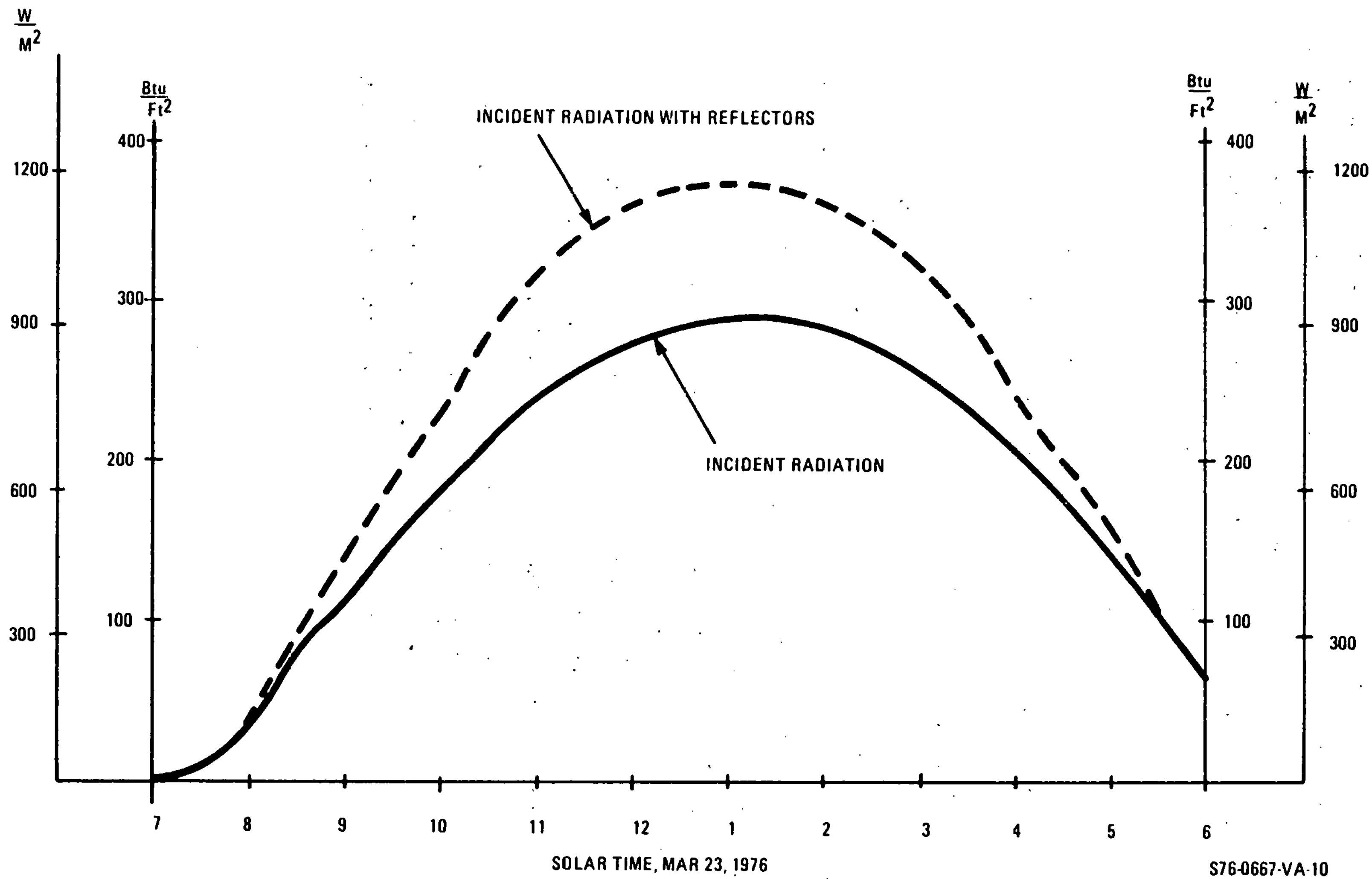


Figure 20. Incident Solar Radiation, March 23, 1976

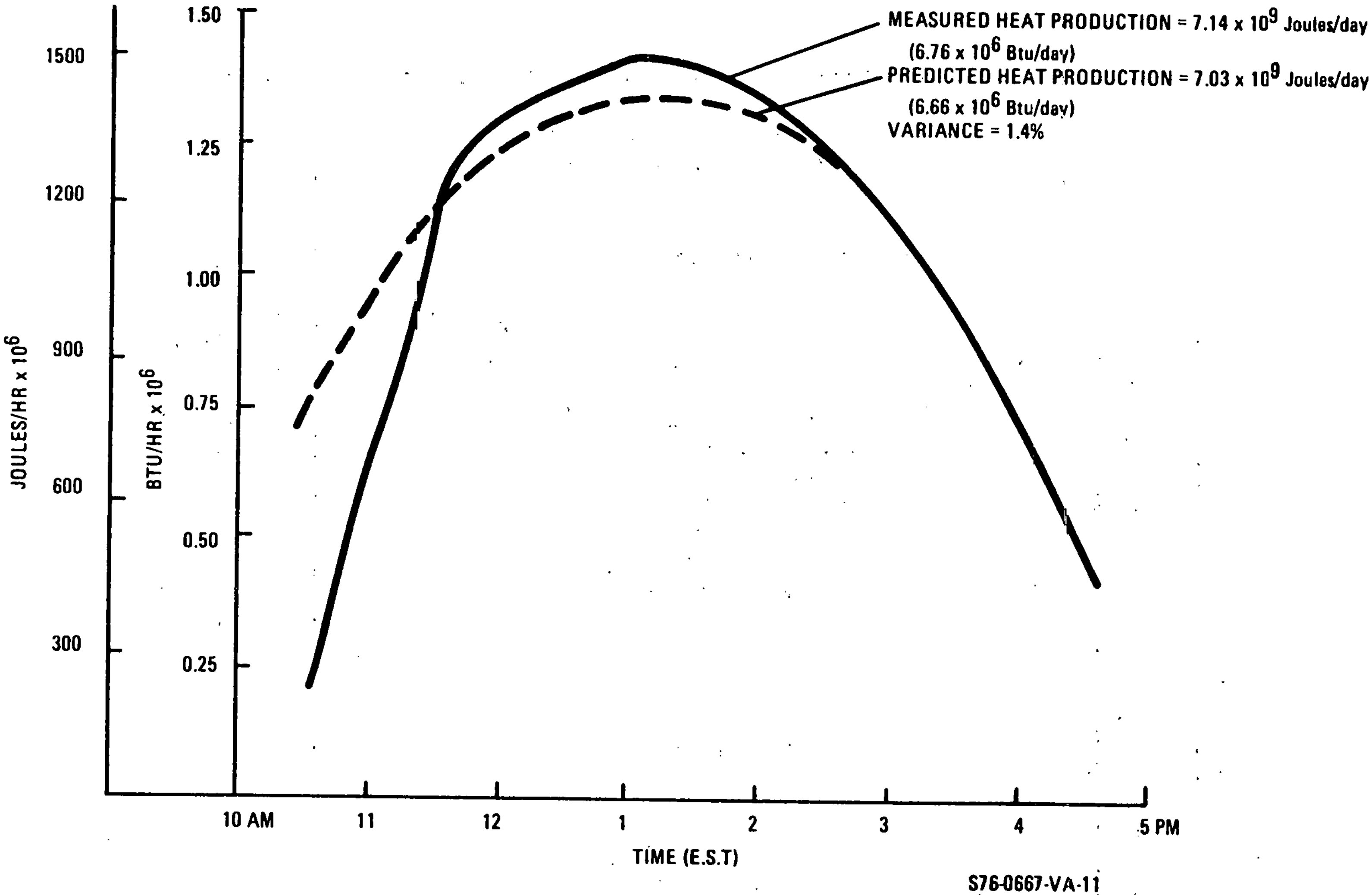


Figure 21. Predicted and Actual Collector Heat Production, February 20, 1976

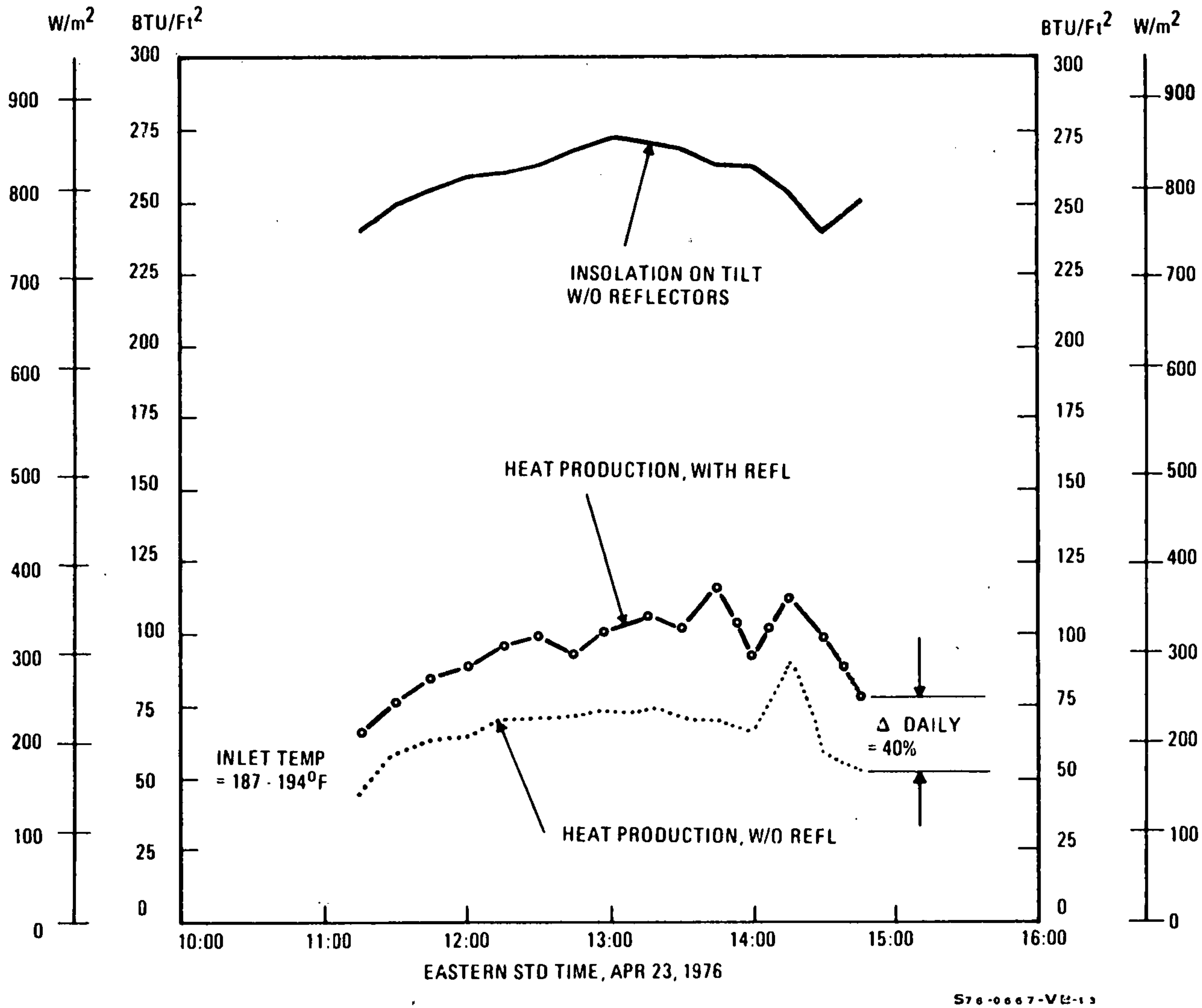


Figure 22. Measured Collector Heat Production With and Without Reflectors

Table 5. Energy Savings, Fuel Savings, and Solar Contribution

Month	Average Daily Energy Savings		Average Daily Fuel Savings @ 60% Boiler Efficiency		Percent Solar Contribution
	Joules x 10^6	Btu x 10^6	Meters^3 gas/day	10^3 ft^3 gas/day	
Jan	5845	5.54	214	9.23	45
Feb	6858	6.50	251	10.83	65
Mar	7934	7.52	291	12.53	95
Apr	5212	4.94	191	8.23	66
May	5212	4.94	191	8.23	57
Jun	4937	4.68	181	7.80	71
Jul	5328	5.05	195	8.42	73
Aug	6140	5.82	225	9.70	82
Sep	5349	5.07	196	8.45	58
Oct	3693	3.50	135	5.83	46
Nov	6235	5.91	229	9.55	81
Dec	5381	5.10	197	8.50	46

Yearly percent solar heating and hot water contribution = 63 percent

Yearly percent solar cooling and hot water contribution = 64 percent

Yearly energy saved = 2.04×10^{12} Joules (1.94×10^9 Btu)

Yearly fuel saved = 9.15×10^4 m^3 (3.23×10^6 ft^3) gas

III. SYSTEM ECONOMIC ANALYSIS

A. SOLAR SYSTEM COSTS

All costs in this System Economic Analysis, Section III, are in U.S. dollars, 1975. The total installed Material and Labor cost (not including design, instrumentation, data analysis, etc) of this system was:

Labor and Incidental Materials	$215,500
Major Material Components	$228,463
TOTAL	$443,963

The cost to design this system and its interface was $63,959.

B. LABOR COSTS

Skilled labor rates on this project, including overhead and profit to the subcontractor, averaged $15.125 per man-hour. Unskilled labor rates for the performance of general construction work (earthwork, masonry, painting, carpentry, etc.) and collector installation averaged $9.075 per man-hour. Total labor costs by work category, including incidental materials and equipment rentals, were approximately:

Labor Category	Cost
Mechanical/Electrical	$125,240
General Construction	52,930
Collector Installation	15,500
Steel Erection	7,290
Control System Design & Ass'y	14,540
TOTAL LABOR & INCIDENTALS	$215,500

A General Contractor was not employed to supervise the subcontractors. This effort was performed as a collateral duty of the Westinghouse Project Manager. The low bid received from a General Contractor for this effort was $20,000, which may be added to the above total at the discretion of the reader.

No figures are readily available on the total man-hours of labor involved in this project. However, the labor to mount the collectors on the erected trusses, and to connect by flexible hose the collectors to the header pipes was monitored.

A four-man team averaged 22 minutes per collector, or 691 man-hours for the mounting of 576 collectors over a period of 34 working days. This does not include the labor of unloading the crates of collectors, uncrating, pre-positioning collectors about the roof, trash disposal and collector caulking.

C. MATERIAL COSTS

This solar system was retrofitted to an existing, 13 year old building. Materials required to interface the system to the building include an absorption chiller, its associated cooling tower, pumps, valves and piping, and a steel grid required by the building owner to support the collector array above the building roof. These components are not parts of a solar system, but are included in Table 6 for information to the reader.

Table 6. Material Costs

Item	Quantity	Solar System Costs	Non-Solar Costs	Inter-face Costs
Piping and Wiring		$39,505	$ 2,558	$ 2,558
Absorption Chiller	1 @ 1266 MJ/hr		17,229	
Storage Tanks	3 @ 56,775 ℓ ea.	17,940		
Holding Tank	1 @ 6,056 ℓ	1,517		
Corrosion Inhibitor	2,498 ℓ	6,534		
Solar DHW Heater	1 @ 757 ℓ	1,176		
Cooling Tower	1 @ 3747 MJ/hr		4,527	
Pumps	6 each	6,482	430	430
Reflective Mylar	1,003 m^2	5,720		
Collector Framing		15,000		
Earth Fill		900		
Solar Collectors	586 @ 1.58 m^2 ea	65,927	1,145	
Steel Grid	25,400 kg			19,645
Control Valves	22 each	6,382		1,418
Control Logic Subsystem		5,940		
Misc. Services & Mat'ls		4,800		700
TOTAL MATERIALS	$228,463	$177,823	$25,889	$24,751

D. OPERATING COSTS

Operating costs for the solar system, other than routine system maintenance reported in Section G following, consist solely of the electricity required to drive the system pumps and fan. Based upon electric usage during three months of winter heating operation, it is estimated that the annual requirements will be:

Solar Collection and Storage	kWh/mo	mo/yr	kWh/yr
Winter Heating Season	1,854	6	11,124
Summer Cooling Season	2,568	6	15,408
ANNUAL TOTAL			26,532 kWh
ANNUAL COST AT $.0332/kWh			$881

E. ECONOMIC FACTORS AND SELLING PRICE

This experimental system was not designed for, and is not recommended for identical replication. Performance experience to date consists of three months of operation in the heating mode, and two weeks of operation in the cooling mode while using a storage tank as a dummy cooling load. Therefore, no life-cycle economic analysis is attempted at this time.

F. EXPECTED SELLING PRICE OR COSTS

The mechanical system as designed is of such an individual nature that there is little likelihood of any appreciable mass production cost savings. With the exception of the collectors, all of the components of the system are standard items and are not expected to decrease in value with increased demand.

The greatest improvements in system costs will be the refinement and increased efficiency in system design and incorporation. The Atlanta Project is of an experimental nature and as such included items which can be eliminated in a more standard application. A significant reduction in cost would be achieved if the solar system was incorporated into new construction, rather than being fitted into an existing building. In new construction, the mechanical equipment would be placed in close proximity to the thermal storage tank and the collector area, eliminating expensive insulated piping. In new construction, the collector array would be integrated within the roof construction, saving in this case the cost of the steel substructure. A reduction in thermal storage to two tanks of optimized size with a simplified control and valving arrangement could reduce costs appreciably with little reduction in performance. Listed below is a summary of possible material and labor savings.

POSSIBLE COST SAVINGS

Structural Steel Grid	26,930	
Earth Moving	900	
Storage Tanks and Holding Tank	7,500	
Piping, Pumps and Wiring	35,640	
Piping Insulation	5,000	
Displaced Roofing Materials	15,000	
Controls and Control Valves	10,000	
Total	71,000	= 16% of $443,963

G. MAINTENANCE FREQUENCY AND COSTS

The building on which this solar system is integrated has a maintenance/custodian who performs routine maintenance on the pre-existing gas furnace and gas domestic hot water heater, and their two associated pumps. He will now be required to perform routine maintenance on six additional self-lubricating pumps, to change one quart of oil each year in the cooling tower fan bearing, to drain the water from the cooling tower each Fall and to refill it each Spring. Additionally, he will test the inhibitor concentration in the solar collector water every two months, and add corrosion inhibitor as necessary.

No solar collector panels have been damaged by vandalism, or have required replacements due to weather during the 11 months since they were installed. It is assumed that an average of one collector must be replaced each year. Maintenance costs are estimated as:

	Cost/Yr
Inhibitor, 100 ℓ/yr	$300
Collector Panel, ℓ/yr	185
Collector Replacement, labor & Minor Materials	75
Lubrication	15
Water, make-up for cooling tower and storage	30
Nitrogen Gas	110
ANNUAL COST	$715

IV. SUBSYSTEMS PERFORMANCE

A. SOLAR COLLECTORS

1. Physical Configuration

The PPG Baseline Collectors was one of the first commercially mass-produced collectors available. The baseline collector, modified to include an ALCOA selective coating on the aluminum absorber plate, was selected for this project. The solar collector is shown in Figures 23 and 24.

a. Cover Panes

Two panes of 3.2 mm tempered float glass is used for cover plates. The solar ultraviolet energy transmitted is 75.4%, solar infrared energy transmitted is 78.1%, and total solar energy transmitted through the glass is 83.8%. These measurements were obtained using the Cary-14 instrument.

b. Solar Absorber Panel

The abosrber panel is constructed of aluminum 1100-type alloy by the Olin Corporation under the trade name ROLL-BOND®. This flat-plate, of two bonded aluminum sheets, is nominally 1.5 mm thick. Limited areas between the two sheets are expanded to provide internal fluid passages. This design utilizes 13 identical flow passages arranged in parallel, for a flow rate of 1.14 liters/min through the panel. The passages are 1.27 cm wide, .64 cm high and on 6.35 cm centers. The manifold is 2.54 cm wide and 1.27 cm high. The overall size of absorber panels is 86.4 cm x 193.0 cm.

c. Absorber Surface

An optically selective coating (α = .94, ε = .34 in the visible solar spectrum) was applied by ALCOA Corporation in a proprietary process.

d. Backside Insulation

7.62 cm of fiberglass insulation is attached to the backside of the solar absorber to reduce heat loss from the back of the absorber plate. The density of this fiberglass is 24 KG/m^3.

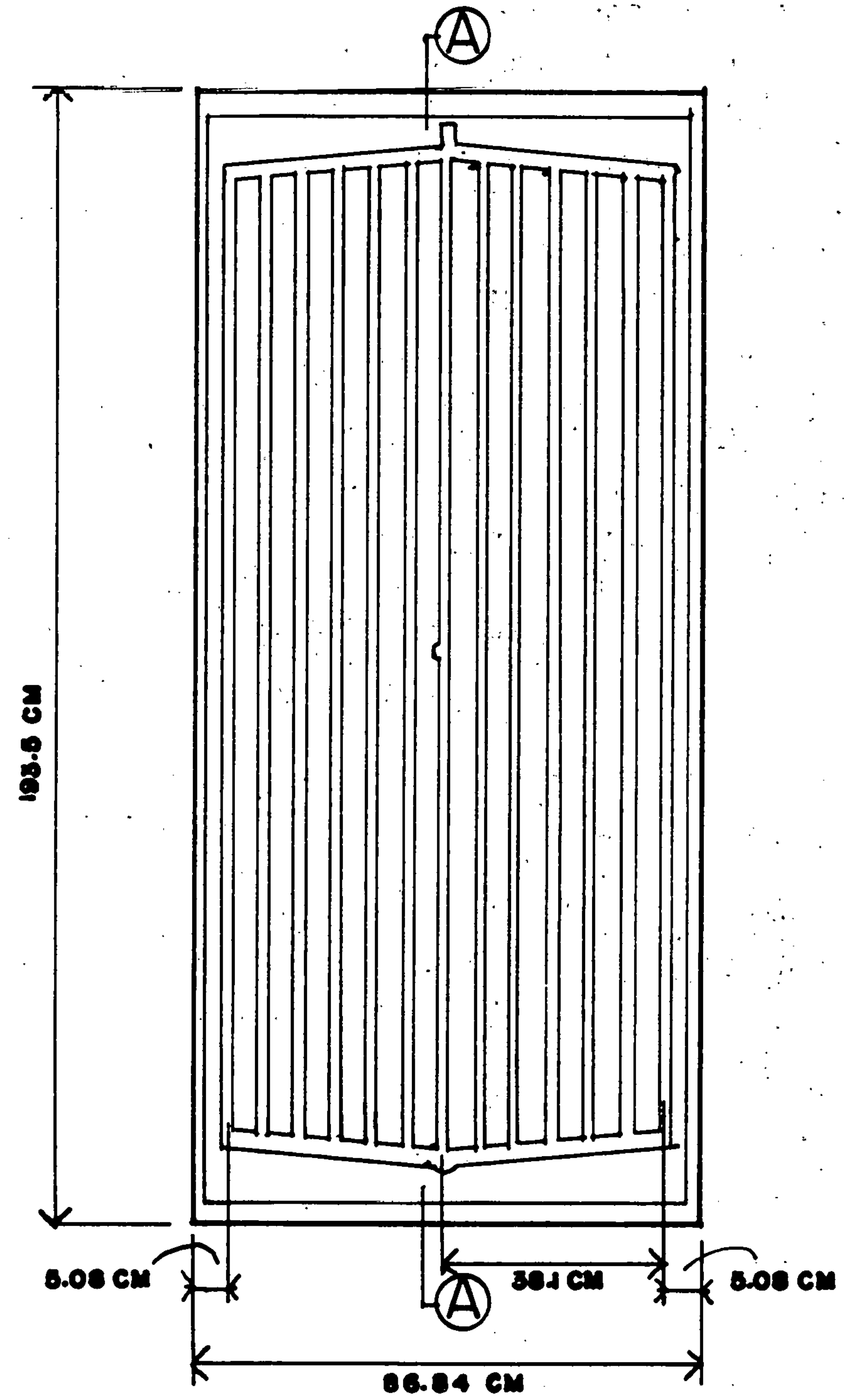


Figure 23. PPG Baseline Solar Collector

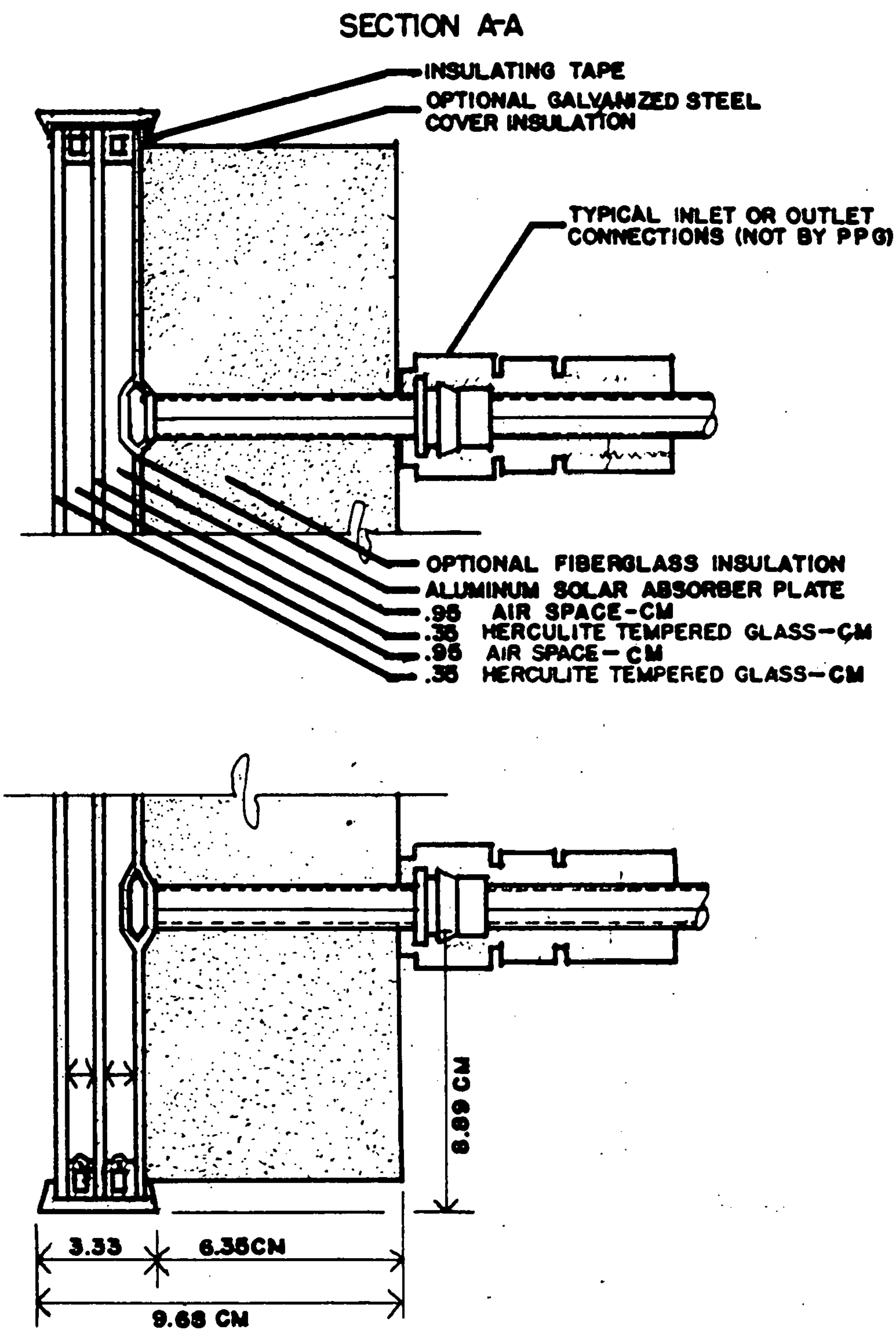


Figure 24. Solar Collector Detail

2. Thermal Performance Characteristics

a. Collector Efficiency

Figure 25 is a plot of the collector efficiency versus ΔT/Incident Solar Radiation for the entire range of operation. The wind velocity for this analysis is 4.5 m/sec.

b. Pressure Drop Through Collectors

Figure 26 depicts the pressure drop through a collector panel. The circulating fluid is water.

c. Optical Efficiency

Figure 27 is a plot of the calculated optical efficiency versus incident angle for the double glazed collector used in this experiment.

d. Thermal Loss Coefficient

Figure 28 depicts the calculated thermal loss coefficient as a function of mean plate temperature for windspeed of 4.5 m/sec.

B. HEAT TRANSFER SUBSYSTEM

1. Physical Configuration

The piping throughout the system is black iron, Schedule 40. To the extent possible, Victaulic flanges and fittings were used at all joints and connections. Otherwise, threaded joints were employed. There are no welded joints or fittings. All piping associated with the collector subsystem is sloped for gravity drain down to the holding tank and to preclude nitrogen pockets in the collectors or related piping. The solar collector loop is provided with a 207 kPa relief valve, and the building heating and cooling load loops are provided with expansion tanks, 207 kPa relief valves and vacuum breakers.

All piping is insulated with 38 mm fiberglass insulation, finished indoors with an all-service jacket and a coating of white vinyl paint, and outdoors with a black mastic weathertight jacket. Underground piping is insulated as described above for outdoor service, then wrapped in a double layer of 25 kg roofing paper and coated with tar pitch paint. Storage tank insulation is described in a

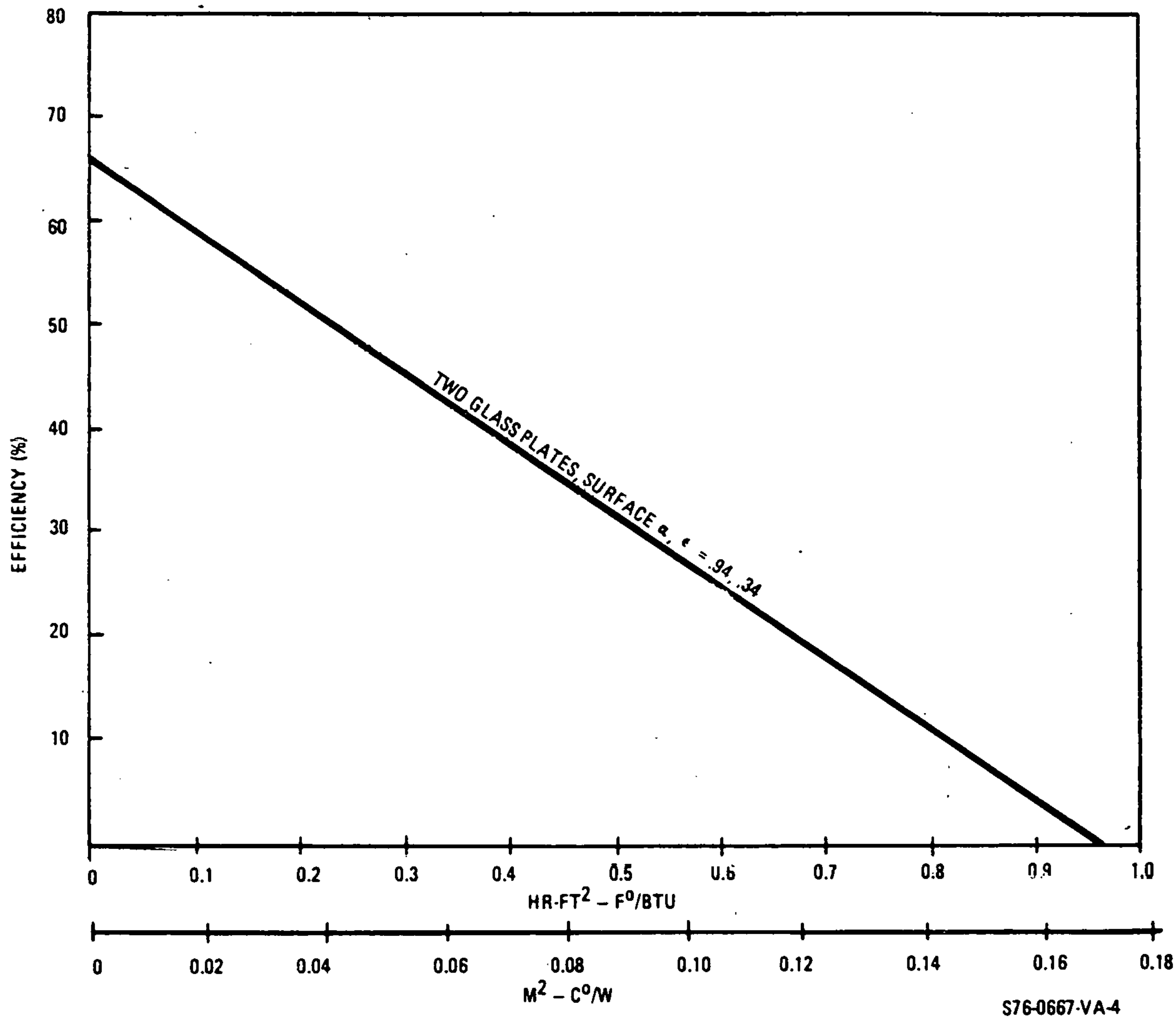


Figure 25. Collector Efficiency

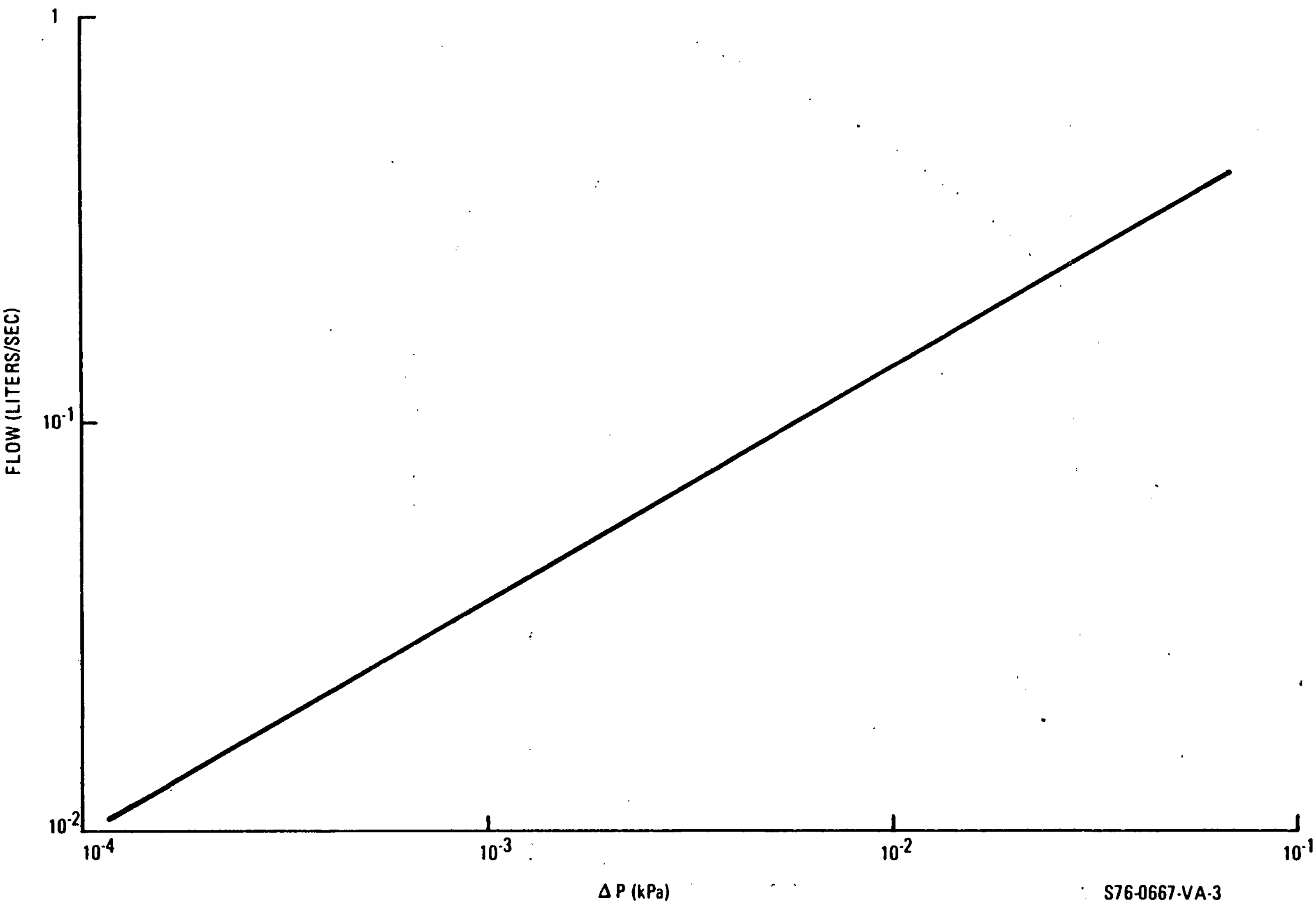


Figure 26. Pressure Drop through Collector Panel

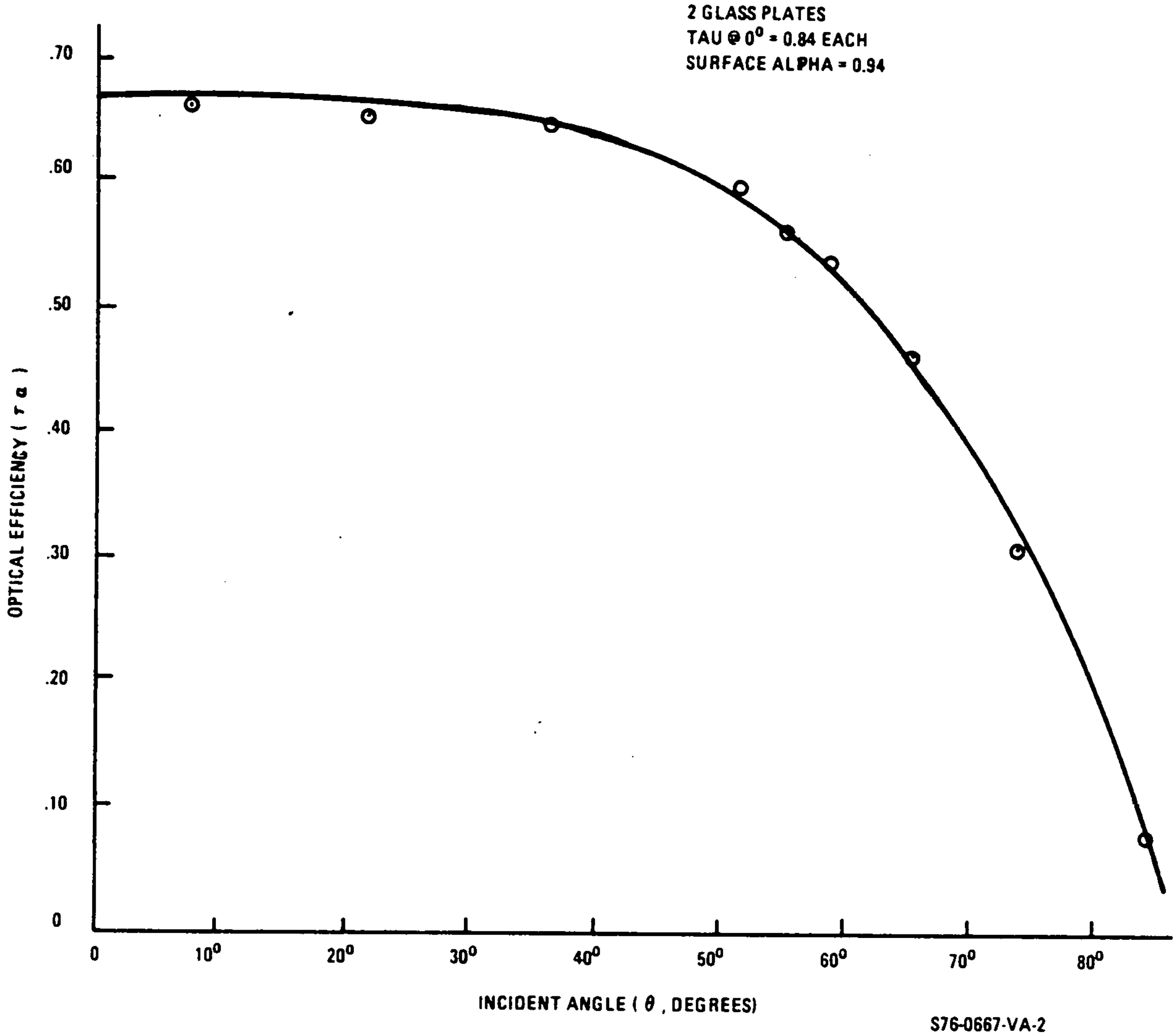


Figure 27. Optical Efficiency of Double-Glazed Collector

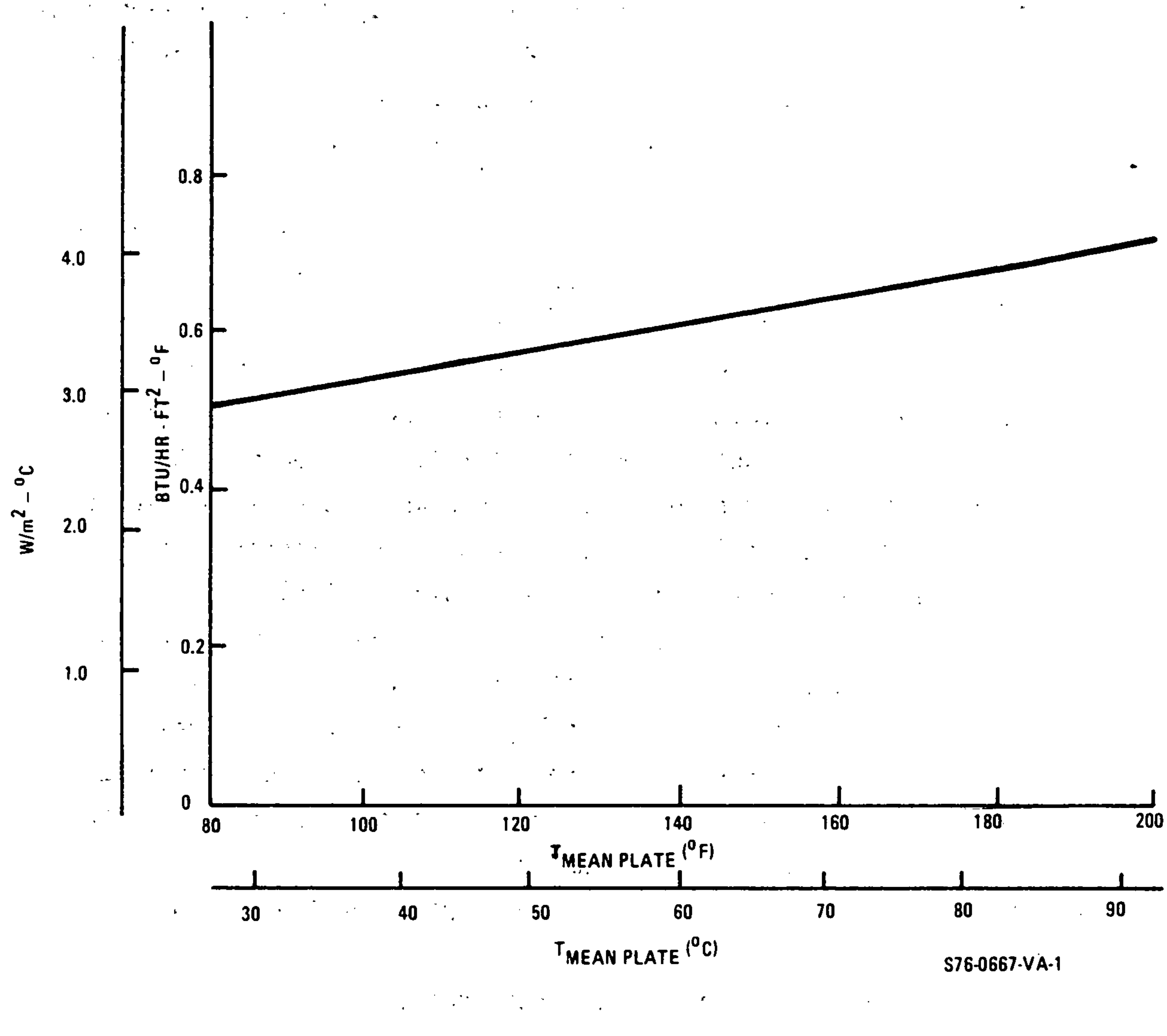


Figure 28. Collector Overall Thermal Loss Coefficient

following section entitled Thermal Energy Storage Subsystem.

Control valves in the system at points where bi-directional flow or bi-directional, bubble-tight closure is required, are Norriseal valves procured from the Norris Division of the Dover Corporation. Otherwise, commercial-grade valves procured from the Barber-Colman Corporation are employed. All control valves, with the exception of the modulating valve in the boiler by-pass line, are of the normally-open or normally-closed type and are spring-loaded, selected and installed to fail-safe into a winter-heating-from-boiler mode in the event of electrical or control air pressure failure. Similarly, the collector subsystem control valves operate to drain the collector array in the event of such failure. All valves are pneumatically operated by a nominal 138 kPa air pressure control line network. The compressor air tank reservoir contains an adequate reserve to operate the control valves for 2 to 8 days after compressor failure, depending upon the mode of operation.

With the exception of the unit ventilators in each room of the building, the sole heat exchanger in the system is a copper coil in the 757 liter solar domestic hot water pre-heater. An aquastat in this tank controls a small pump which circulates stored hot water through the coil and back into storage, attempting to maintain the potable water in the tank at 57°C (135°F).

Each collector is connected to nipples on the supply and return header pipes by a short length of silicone rubber hose, FC 252-08, manufactured by the Aeroquip Corporation. This hose is highly flexible, clamps easily without taking a permanent compression set, and operates to 160°C with a burst pressure of 2,068 kPa. The hose is clamped to the collector and header nipples by an Oetiker two-ear clamp. The clamp is tightened by pinching the two ears with hand pinchers.

While the silicone connector hoses serve to isolate electrically the aluminum absorber plates from the remainder of the multi-metal heat transfer subsystem, three other features of this subsystem are desgined to minimize corrosion of the aluminum absorbers.

These are a Getter column, a nitrogen purging system, and a corrosion inhibitor.

The piping between the variable speed circulating pump and the collector array inlet is provided with a Getter column or sacrificial anode. This column is a 1.83 meter length of removable 7.62 cm diameter piping which contains a perforated CPVC tube loosely packed with medium grade aluminum wool which is sacrificed to any attack by heavy metal ions.

To protect the aluminum absorbers from attack by oxygen, a nitrogen purging method replaces all air in the closed-loop collector fill and drain subsystem. As water is pumped from the holding tank to fill the collectors, nitrogen in the collectors is forced to a collector array header tank and thence, via a vent pipe, down into the holding tank. When the collectors are drained, water entering the holding tank forces nitrogen up the vent pipe and down into the collectors. Nitrogen pressure in the collectors and holding tank is maintained at 138 kPa by two 22.7 kg bottles of nitrogen which also make up the small amount of nitrogen dissolved into the water and lost by leakage. This purge method is shown in simplified schematic in Figure 29. Not shown are the float valves in the header tank and holding tank which prevent collector overfill, or the valves and lines by which the storage tanks and variable speed circulating pump connect to the collector array supply and return mains.

A corrosion inhibitor, NUTEK 876, produced by the Nuclear Technology Corporation of Amston, Connecticut is added to the water in this solar system. This liquid compound is suited specifically for the protection of ROLL-BOND® aluminum solar collector panels at a concentration of 14.7 parts of NUTEK 876 to 1,000 parts of water. This compound is a pH neutral, non-toxic, biodegradable corrosion inhibitor which contains no halogens, alkalies or chromates. It provides a mono-molecular protective film to the wetted surfaces of all metal components in the solar collectors, and heat transfer, storage and air-conditioning subsystems.

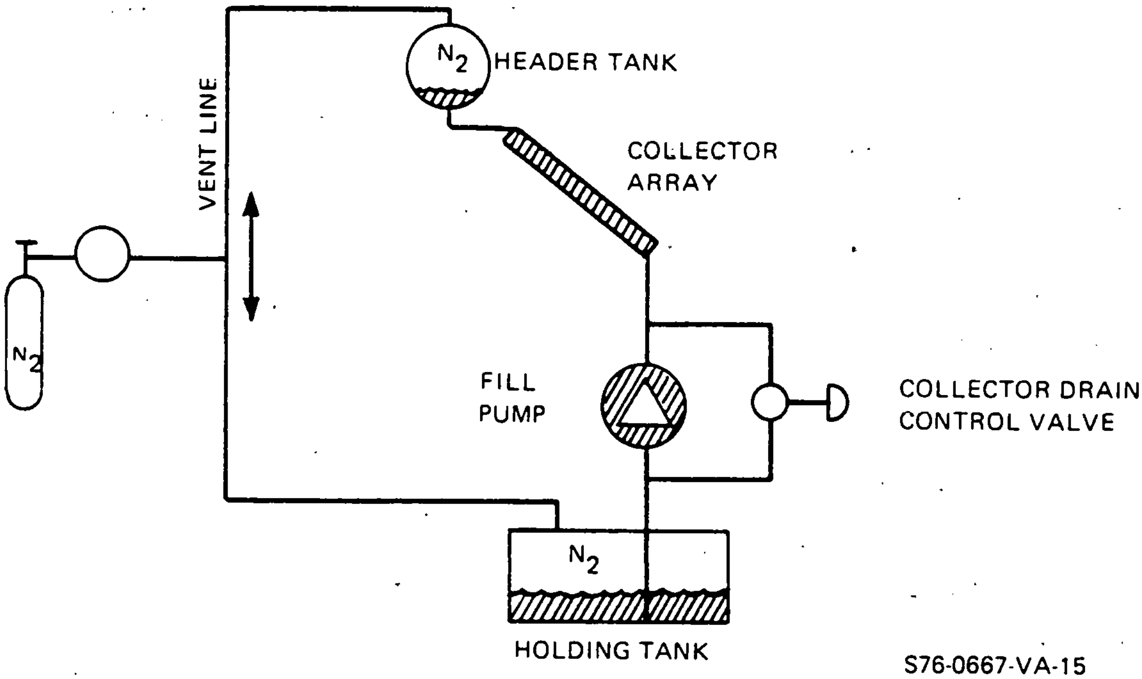


Figure 29. Nitrogen Purge System

2. Thermal Performance Characteristics

Thermal performance of the various major components in this subsystem are discussed in the sections pertaining to those components.

The Victaulic pipe fittings used in this system have proven to be most satisfactory and represent a significant cost saving in installation labor and materials. Several commercial-grade, "tight closing", poppet-type control valves proved to be unsuitable in bi-directional flow situations, and in situations where bubble-tight (water-tight and air-tight) closure was essential. These were replaced with bubble-tight butterfly-type valves which provided the additional benefit of a high C_v.

The silicone hose is performing exceedingly well, and no water leaks are experienced at the connections clamped by the two-ear clamps. This type clamp was selected because it is very inexpensive and can be quickly applied at a minimum cost in labor. The cost savings achieved were well worthwhile in this collector array. Although no leakage occurs, some leakage could be tolerated onto the open roof of the school building. In installations where little or no leakage is tolerable, silicone hose might be applied over nipples which have been formed in accordance with Society of Automotive Engineers Standard SAE J962a, Style B, and clamped with a lined screw-type clamp described by SAE J536, Type F.

In the original design of the thermal energy storage subsystem, the storage tanks are always completely filled. A holding tank, a collector fill pump and associated control valves and piping were then necessary to receive and hold the collector fluid when the collectors are drained down. In subsequent changes to the thermal energy storage subsystem, each tank is now provided with an air void expansion space, and each tank is interconnected to the other with a common, open fluid line and vent line. This provides the capability for selectively balancing the water levels and air pressure among the hot water tanks. It would now be possible to drain the collectors into one, two, or all three storage tanks, and to charge the expansion void in each tank with nitrogen rather than compressed air. This would enable the collectors to be filled directly from the storage tanks by the variable speed circulating pump, and to drain down into the storage tank(s), eliminating the need for the holding tank, fill pump, and associated valves piping and controls while retaining the nitrogen purge capability.

The NUTEK-876 corrosion inhibitor appears to be performing most satisfactorily. Tests performed by Nuclear Technology Corporation with system water samples disclose an aluminum corrosion rate which, if averaged over the wetted interior surface of the 576 absorber plates, would yield an expected plate service life well in excess of the expected service life of the remainder of the solar system, or indeed of the school building on which it is installed. However, this averaged corrosion rate does not accommodate for localized aluminum pitting, and several collectors will be removed and destructively analyzed to determine the nature and extent of any corrosion in the aluminum absorber plate water tubes.

C. THERMAL ENERGY STORAGE SUBSYSTEM

1. Physical Configuration

Thermal storage of solar energy is accomplished by the use of three uninsulated steel tanks, each containing a maximum of 56,775 liters of treated water. The fluid is potable water, mixed with 14.7 parts of NUTEK-876 per 1,000 parts of water. NUTEK-876 is a non-toxic, water based corrosion inhibitor produced by Nuclear Technology Corporation of Amston, Connecticut. The inhibitor is specifically designed to protect aluminum solar collector panels from corrosive attack by air and water, and appears to be working most satisfactorily in this system.

The three storage tanks are interconnected in two seasonal modes. In the summer cooling mode, Tank 1 is used for excess chilled water storage, and Tanks 2 and 3 store solar hot water which is used to drive the absorption chiller. In the winter heating mode, all three tanks are used for storage of solar hot water. The daily and seasonal operation of these tanks is described in greater detail in Section I.C.3,c., CONTROL SYSTEM DESCRIPTION.

Each of the three cylindrical storage tanks is 8.2 meters in length and 3.0 meters in diameter. The shell is 8mm thick, and the dished end heads are 9.5 mm thick. The pipe and sensor fittings, and access manhole are shown in Figure 30. Each tank has an exterior coating of asphaltum paint and is uninsulated. The tanks are air tight, have been pressure tested to a gauge pressure of 380 kPa at the top of the filled tank, and have a design strength estimated in excess of 690 kPa. The tanks are nominally operated with a water level down .71 meters from the top of the tank. The expansion void in the top of the tank is precharged with air to a gauge pressure of 125 kPa. Each tank is equipped with an air pressure and water level gauge, an instrumentation sensor for measuring temperatures at the top, middle and bottom of the fluid mass, and an additional temperature sensor at the center of the fluid mass which is used by the control system.

The three tanks are buried underground on a hillside, 38 meters from the building. The bottom of the excavation for the tank

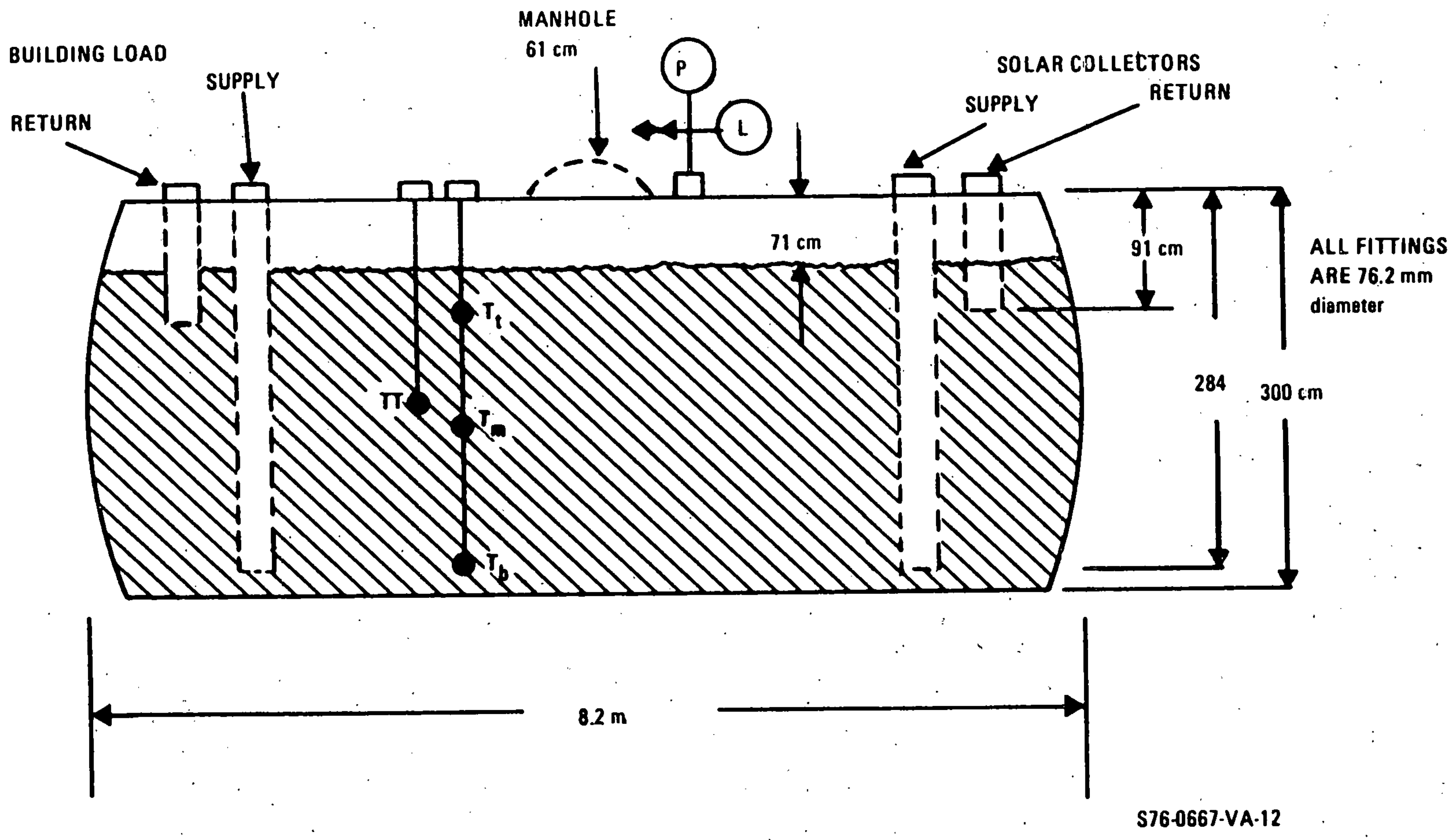


Figure 30. Thermal Energy Storage

field was provided with a perforated plastic pipe drainage network which discharges down the hillside to a storm drain. This drainage network was covered with a level bed of 5 cm diameter rock to a depth of .45 meters. The three tanks were set side by side on this bed, .5 meters apart. A vertical wall, 2.4m high by 8.5m long, of 10 cm thick polystyrene foam insulation (Bead Board) was erected between Tank 2 (which always contains hot water) and Tank 1 (which contains chilled water in the summer). The excavation was then filled with 5 cm rock level to the top of the tanks. The insulated supply and return water lines were then connected to each tank. A rectangular, cement block caisson, 1m high, was constructed to enclose the manhole and sensor fittings over each tank. The entire area above the three tanks was then covered with a 9m by 12m layer of 10 cm thick polystyrene foam insulation board. This was covered by approximately 0.3m of earth, contoured as a low mound over the tank field. This mound was then covered by two layers of 0.10 mm thick plastic sheet (Black Visqueen) as a surface watershed. This, in turn, was covered by approximately 0.5m of topsoil. Each of the three tank caissons was covered by a sloped, hinged redwood cover, 1.2 m by 2.1 m in size.

The original design specifications required that each tank be fabricated, tested and stamped in accordance with the ASME Code for Unfired Pressure Vessels, Section VIII, with an interior finish of four coats of epoxy resin, and exterior insulation of 10 cm thick fiberglas rigid mat and asphaltum coatings. The low bid to supply this configuration was $38,948 for three tanks, and was unacceptably high. Calculations indicated that, if the tanks could be protected from contact with ground water, the insulating qualities of the air/rock configuration described in the preceding paragraphs would be degraded, but acceptably comparable to those specified in the original design. The installed configuration, as described in preceding paragraphs, cost a total of $18,735.

A 5,920 liter, cylindrical holding tank, 1.5 m in diameter by 3.35 m long, is also buried in the storage tank field. The construction/insulation of this tank is identical to the main storage tanks, except that it has but a single collector fill/drain pipe which joins the collector array supply and return pipes on the roof. This line contains the fill pump (see Figure 29). In the afternoon, as the collector outlet temperature drops to the temperature of the storage tanks (say 60°C - 95°C), no more heat can be collected into storage. The collector circulating pump stops, and valves operate to drain the more than 2,300 liters of hot water into the holding tank for overnight storage. When the collector plate temperature next exceeds the temperature of the storage tanks, the fill pump operates to fill the collectors with hot water from the holding tank. This drain and fill method protects the collectors from freezing by draining them when useful heat cannot be collected, and preserves the heat remaining in the collector field from loss by night radiation from the collectors.

A water level control sensor in the holding tank operates to maintain a minimum water level in the tank by admission of make-up feed water. In this manner, the proper amount of water is maintained in the collector and storage subsystems.

2. Thermal Performance Characteristics

System performance monitoring commenced on February 1, 1976 and thermal storage performance data gathered during the months of February, March and April has been analyzed. During this short period, hot water storage temperatures in the range of 40° - 96°C (104° - 205°F), and chilled water storage temperatures in the range of 9° - 14°C (48° - 55°F) have been observed and roughly assessed. Because of the highly transitory nature of the variables affecting the thermal storage subsystem operating characteristics, and the short monitoring period to date, no attempt will be made to hazard an estimate of annual, dynamic characteristics at this time.

In order to achieve a gross estimate of thermal performance, consider the following. In early May, the temperature of chilled water stored in Tank 1 had been reduced to 10°C (50°F) by the first solar operation of the absorption chiller. By this time, the hot water stored in Tanks 2 and 3 had been raised to 85°C (195° - 205°F). All solar collection, chilled water production, and stored water utilization was then terminated, and the tanks were allowed to remain dormant in order to determine the heat loss and gain characteristics under this cooling mode configuration. Temperature at the top, middle and bottom of each storage tank were recorded every 15 minutes until the rate of heat loss/gain of all three tanks reached a steady rate within the temperature ranges of interest. During the ensuing nine hours, the following characteristics were measured:

Tank	Water Mass		Average Temp.		ΔT/9hr		Heat Gain/Loss	
	Kg	Lbs	C°	F°	C°	F°	MJ/day	MBtu/day
1	44,542	98,197	13.4	56.10	+.35	+.63	+174.1	+.165
2	43,247	95,342	81.9	179.40	-.79	-1.43	-384.0	-.364
3	43,483	95,862	73.1	163.54	-.52	-.93	-251.1	-.238

From these data, some very gross estimates can be made. In this discrete, dormant situation, the loss rate of heat from hot water stored in Tanks 2 and 3 totaled 635.1 MJ/day (0.602 MBtu/day), or about 12 percent of the 5,212 MJ (5 MBtu) total heat collected by the solar system on an average day of operation in May. This heat loss is recovered during the first half-hour of solar collection on the following average day.

If 5,212 MJ perday are collected into storage, and 635.1 MJ per day are lost from storage, then 4,577 MJ remain available for the generation of chilled water. At a modest chiller COP of 0.5, 2,288 MJ of chilled water could be generated and stored on an average day. If 174.1 MJ of cooling are lost from Tank 1 during the day, this would represent the loss of about 7.6 percent of the chilled water produced during the 24 hour period. The remaining 2114 MJ would satisfy about 41 percent of the estimated daily cooling load in March.

As a gross estimate of thermal storage subsystem performance in the cooling mode, it would appear that about 12 percent of the stored heat and about 8 percent of the stored cooling would be lost to the earth each day, under the conditions described above. The flow of heat from Tank 2 into Tank 1 in the cooling mode degrades significantly the thermal storage subsystem efficiency. No attempt is made to estimate the storage efficiency in the heating mode. However, losses will be reduced considerably as all three tanks are reverted to hot water storage in the range of 41°C - 74°C.

Thermal storage performance characteristics will be refined and reported as the system is operated through the cooling season, and well into the next heating season, to February 1977.

D. AIR CONDITIONING SUBSYSTEM

1. Description of Physical Configuration

The Towns School building unit ventilator system was originally designed and installed to accept both hot water for winter heating, and chilled water for summer cooling. The machinery room was designed with floor space to accommodate an absorption chiller, but this chiller unit was never installed. To provide for solar cooling, a water-fired ARKLA WF-1200 absorption chiller was procured and installed in the machinery room, and a companion Marley #8605 cooling tower was installed just outside the machinery room.

Cooling is produced through the operation of a closed-loop cycle of evaporation and absorption of a Lithium Bromide and water solution within the evacuated, factory-sealed chiller. Cooling tower water is pumped through an internal heat exchanger in the condenser portion of the chiller, and returns in a closed loop to the cooling tower to discharge the heat removed from the building.

The chiller has a nominal rating of 1266 MJ/hr and can be driven to about 10% beyond that rating by use of hot water from the existing school furnace. It is expected that the chiller will produce a nominal 1013 MJ/hr when operating from stored solar energy and will meet the cooling load during more than 60% of the cooling season. The remainder of the peak cooling load will be met by using hotter firing water from the school furnace.

The chiller is designed to operate at generator input temperatures of from 93°C to 121°C, and to produce chilled water output temperatures as low as 4°C. The cooling tower has the capacity to remove and reject 3747 MF/hr. By slightly oversizing the cooling tower, it was possible to achieve a condenser water approach temperature of from 2.5 to 3.5°C above the wet bulb temperature, with 3.0°C being achievable during more than 75% of the operating hours in Atlanta. This is a 1.5° to 2°C improvement over a cooling tower whose rated capacity just macthes that of the absorption chiller, but this improvement is at the expense of a larger fan motor which requires 1.865 kW more power.

The chiller's internal generator is fired by stored solar hot water from Tanks 2 and 3. When the temperature of the stored hot water drops below the useful minimum of 82°C, the control system automatically selects 107°C hot water from the school furnace to fire the chiller. When the solar collector subsystem raises Tank 2 and 3 above 88°C, the control system again selects firing water from storage. The chiller has an integral solution circulating pump and a solenoid-controlled solution by-pass line which precludes crystalization of the LiBr-Water solution in the event of a sudden drop in firing water temperature. (The normal shut-down procedure for the chiller is to stop the firing water circulating pump.)

Chilled water is circulated to the school's unit ventilators, when the building is occupied, at a nominal 10°C. This chilled water is taken from storage in Tank 1, if available at or below that temperature. Otherwise, cooling water is taken directly from the output of the chiller. The building is not cooled when it is unoccupied. Excess solar hot water collected over weekends, holiday periods, and late afternoons, is converted to chilled water and stored for later use. Such conversion during weekdays commences after 1500 in the afternoon, when greater cooling tower efficiency may be expected. The school furnace is never used to generate chilled water for storage.

See the section entitled Control System Description for a more detailed account of the configuration and operation of the air-conditioning subsystem.

2. Thermal Performance Characteristics

As of this writing, the chiller has been operated for a period of two weeks during start-up tests, and the air-conditioning subsystem has been exercised in all modes. In mid-May, firing water at 82° - 88°C was stored in Tanks 2 and 3. The chiller was operated from the school furnace and from stored hot water, and exercised to produce chilled water directly to the building load, and into storage. All components and controls operated satisfactorily. Unfortunately, the temperature sensors measuring the chilled water produced, and the flow meter measuring the firing water flow rate from storage/ furnace were inoperative and neither qualitative nor quantitative measured performance data can be reported at this time.

When operating the absorption chiller from stored solar hot water at 82°C, typical operating conditions of the unit will be:

Generator Temperature	82°C	Firing Water Input
Condensor Temperature	92°C	
Absorber Temperature	24°C	
Evaporator Temperature	9°C	Chilled Water Output

It can be shown that, under these conditions, the chiller COP = .61[1]. The expected daily and seasonal thermal performance of the air-conditioning system is as shown in Figures 31 and 32. Figure 33 graphically illustrates the relationships of the four major temperature variables, as cited above, and the nominal operating envelope. Also shown are the conditions under which solution crystallization is approached. Although the WF-1200 will not crystalize, it is still desirable that the theoretical conditions for crystallization be avoided. To maximize the chiller COP, T_A and T_C should be reduced by the lowest possible cooling water (and hence the oversized cooling tower), and T_G

[1] "Solar Heating and Cooling Experiment for a School in Atlanta - Design Report", NTIS PB 240 611, Westinghouse Electric Corporation Special Systems, December 1974.

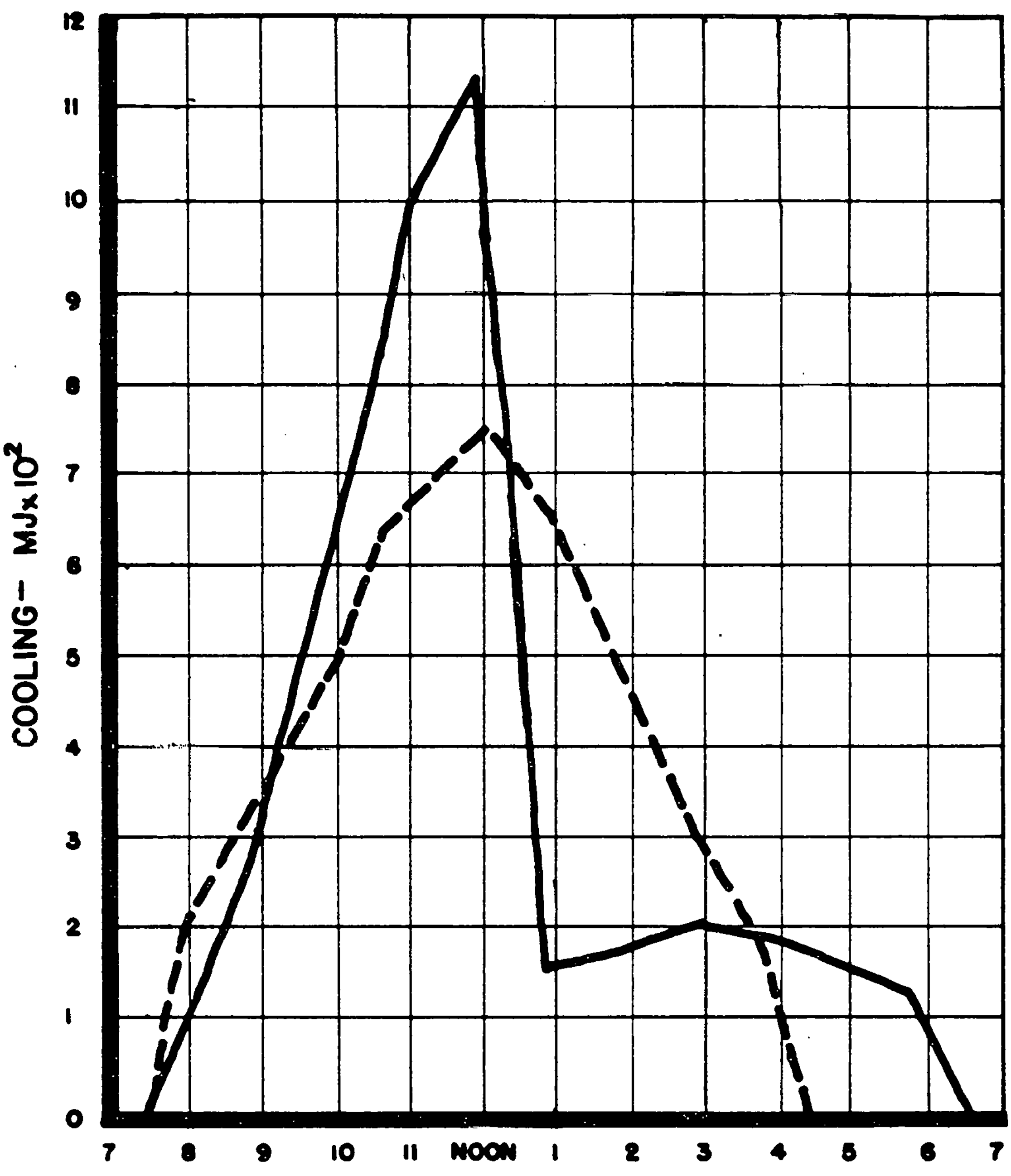


Figure 31. Cooling Produced and Required Per Day in August

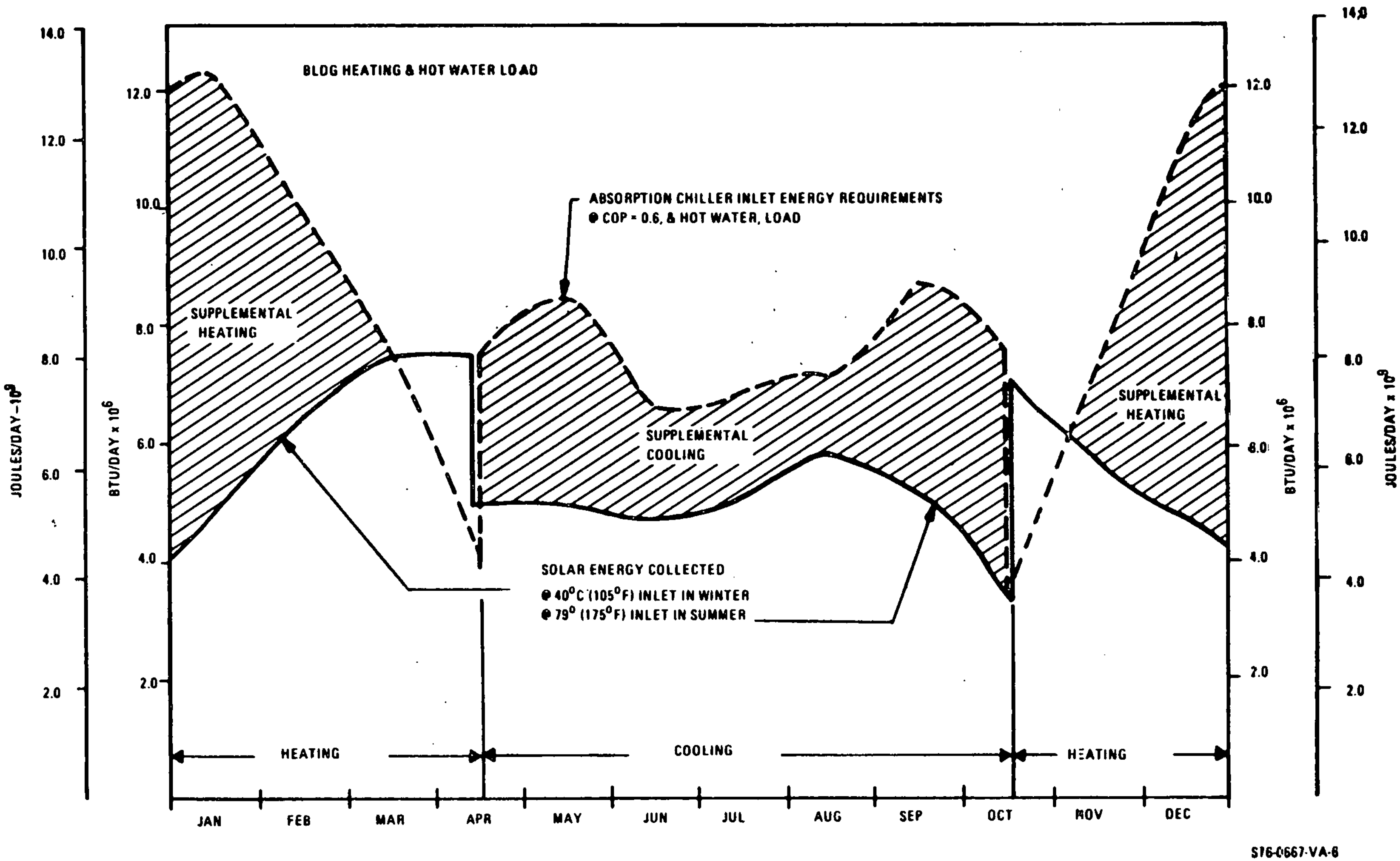


Figure 32. Average Monthly System Performance and Building Loads (Predicted)

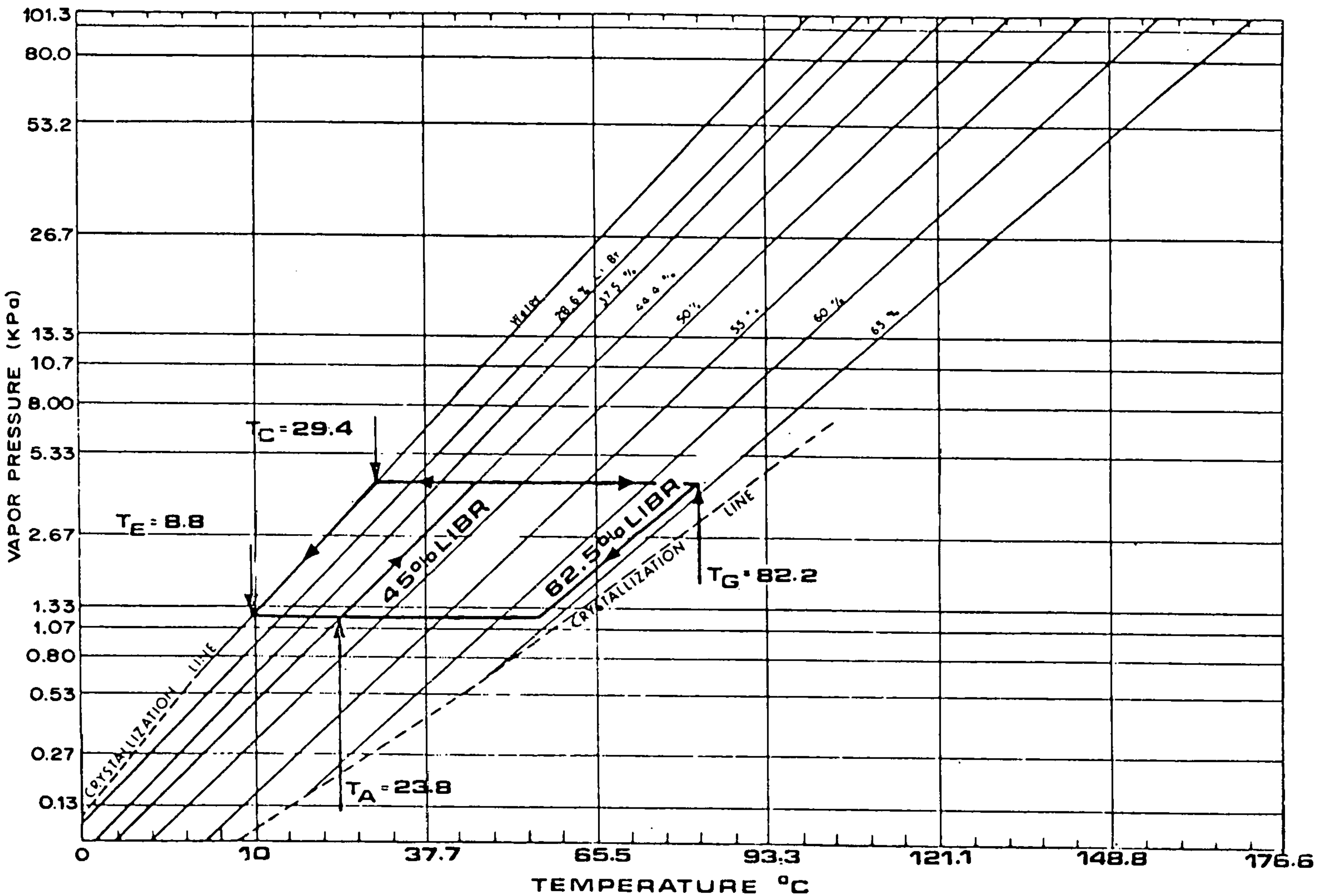


Figure 33. Nominal Chiller Operating Regime

should be maximized, consistent with the operating efficiencies of the flat-plate collector. Figure 34 shows the important relationship between T_G and T_C as they affect cooling capacity. It is expected that, in this Atlanta system, the chiller will operate in the solar mode at about 80% capacity. Figure 35 illustrates the COP of various refrigeration cycles within the regime of generator temperatures achievable by flat-plate collectors. Most significant is the constancy of the LiBr-Water absorption COP at generator temperatures above 66°C, and the rapid derating of performance below that temperature.

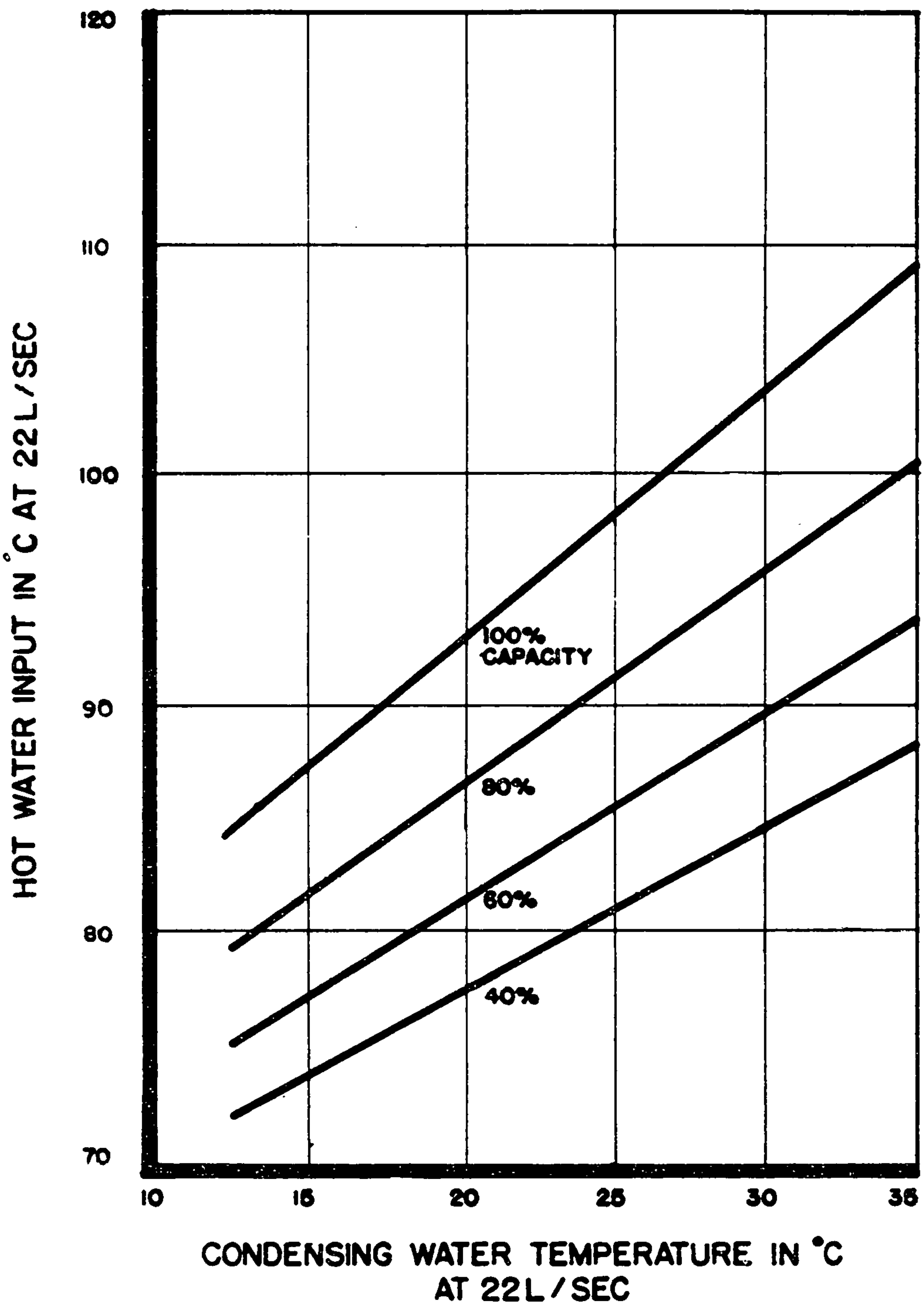


Figure 34. Performance of the Absorption Chiller

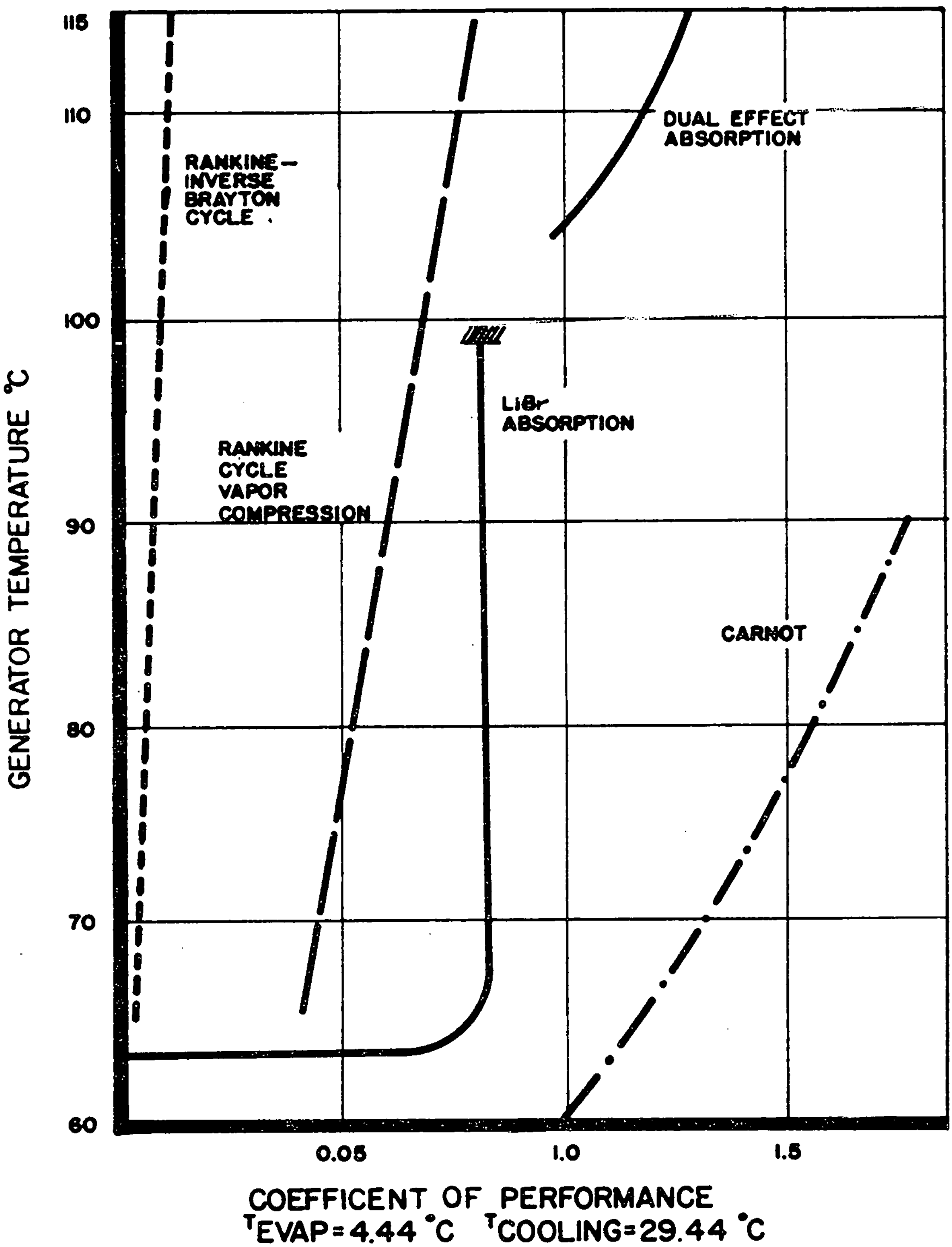
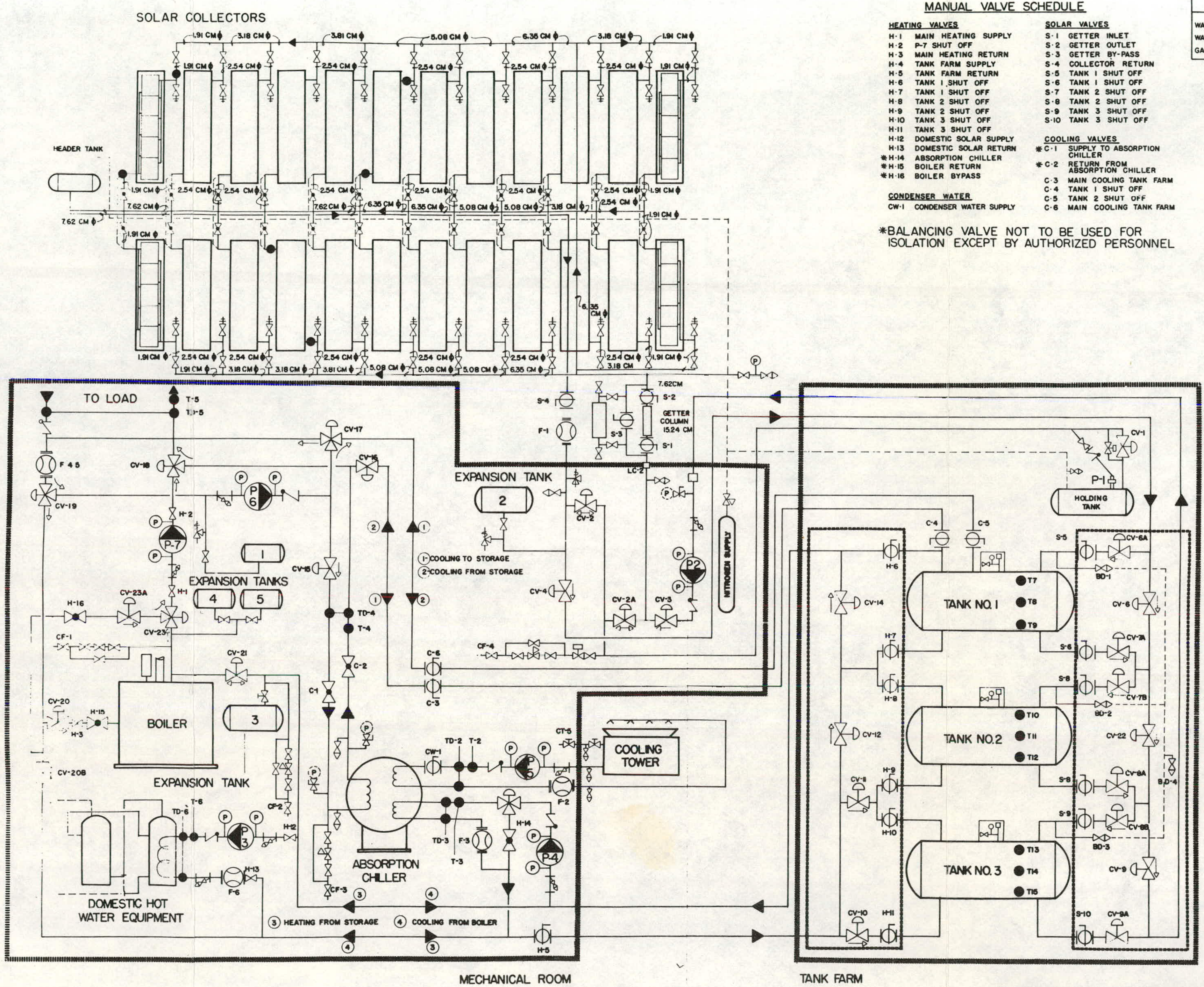


Figure 35. Comparison of Various Refrigeration Cycles

APPENDIX A -- SYSTEM DRAWINGS



MANUAL VALVE SCHEDULE

HEATING VALVES

- H-1 MAIN HEATING SUPPLY
- H-2 P-7 SHUT OFF
- H-3 MAIN HEATING RETURN
- H-4 TANK FARM SUPPLY
- H-5 TANK FARM RETURN
- H-6 TANK 1 SHUT OFF
- H-7 TANK 1 SHUT OFF
- H-8 TANK 2 SHUT OFF
- H-9 TANK 2 SHUT OFF
- H-10 TANK 3 SHUT OFF
- H-11 TANK 3 SHUT OFF
- H-12 DOMESTIC SOLAR SUPPLY
- H-13 DOMESTIC SOLAR RETURN
- *H-14 ABSORPTION CHILLER
- *H-15 BOILER RETURN
- *H-16 BOILER BYPASS

CONDENSER WATER

- CW-1 CONDENSER WATER SUPPLY

SOLAR VALVES

- S-1 GETTER INLET
- S-2 GETTER OUTLET
- S-3 GETTER BY-PASS
- S-4 COLLECTOR RETURN
- S-5 TANK 1 SHUT OFF
- S-6 TANK 1 SHUT OFF
- S-7 TANK 2 SHUT OFF
- S-8 TANK 2 SHUT OFF
- S-9 TANK 3 SHUT OFF
- S-10 TANK 3 SHUT OFF

COOLING VALVES

- *C-1 SUPPLY TO ABSORPTION CHILLER
- *C-2 RETURN FROM ABSORPTION CHILLER
- C-3 MAIN COOLING TANK FARM
- C-4 TANK 1 SHUT OFF
- C-5 TANK 2 SHUT OFF
- C-6 MAIN COOLING TANK FARM

*BALANCING VALVE NOT TO BE USED FOR ISOLATION EXCEPT BY AUTHORIZED PERSONNEL

STORAGE TANKS PRESSURIZATIONS

WATER TEMP.	4.4	9.9	23.8	37.7	51.6	65.5	79.4	93.3	104.4	115.5	°C
WATER LEVEL	78.74	78.74	76.2	76.2	73.66	73.66	71.12	68.58	66.02	63.5	CM
GAUGE PRESSURE	86	86	90	97	103	110	124	138	152	172	kP

AUTOMATIC VALVE SCHEDULE

CV NO.	POSITION	PRESSURE GAUGE NO.	
1	N.O.		
2	N.O.		
2A	N.O.		
22	N.O.		
7B	N.C.		
8A	N.C.		
20A	N.O.		
20B	N.C.		
6	N.O.	6	
6A	N.C.	6	
7A	N.C.	6	
21	N.C.	7	
18	N.O. B TO AB	8	3 WAY
19	COOLING MODE	8	
8B	N.C.	9	
9	N.O.	9	
10	N.C.	10	
11	N.C.	11	
12	N.C.	12	
14	N.C.	14	
15	N.C.	15	
16	N.C.	16	
17	N.O. B TO AB	17	3 WAY
3	N.C.	18	
4	N.C.	18	
23A	N.O.		

CV NO. LOCATION OF CONTROL VALVE, REFER TO FLOW DIAGRAM & BARBER COLMAN DRAWING ATLANTA-86280, SHEET NO. 1 OF 9

POSITION VALVE POSITION WITH ZERO GAUGE PRESSURE

PRESSURE GAUGE NO. AS IDENTIFIED IN BARBER COLMAN CONTROL PANEL NO. 2

SYMBOL LIST

- GATE VALVE
- CHECK VALVE
- TWO PORT AUTOMATIC CONTROL VALVE
- THREE PORT AUTOMATIC CONTROL VALVE
- PUMP
- IN LINE STRAINER
- PRESSURE RELIEF VALVE
- PRESSURE REDUCING VALVE
- DRAIN COCK WITH HOSE UNION CONNECTOR
- VENT PIPING (NITROGEN)
- BUTTERFLY VALVE
- PRESSURE GAUGE
- PRESSURE GAUGE TAPPING
- FLOW TRANSDUCER
- TEMPERATURE SENSOR
- TEMPERATURE DIFFERENTIAL SENSOR
- CONTROL SENSORS
- BALANCING VALVE

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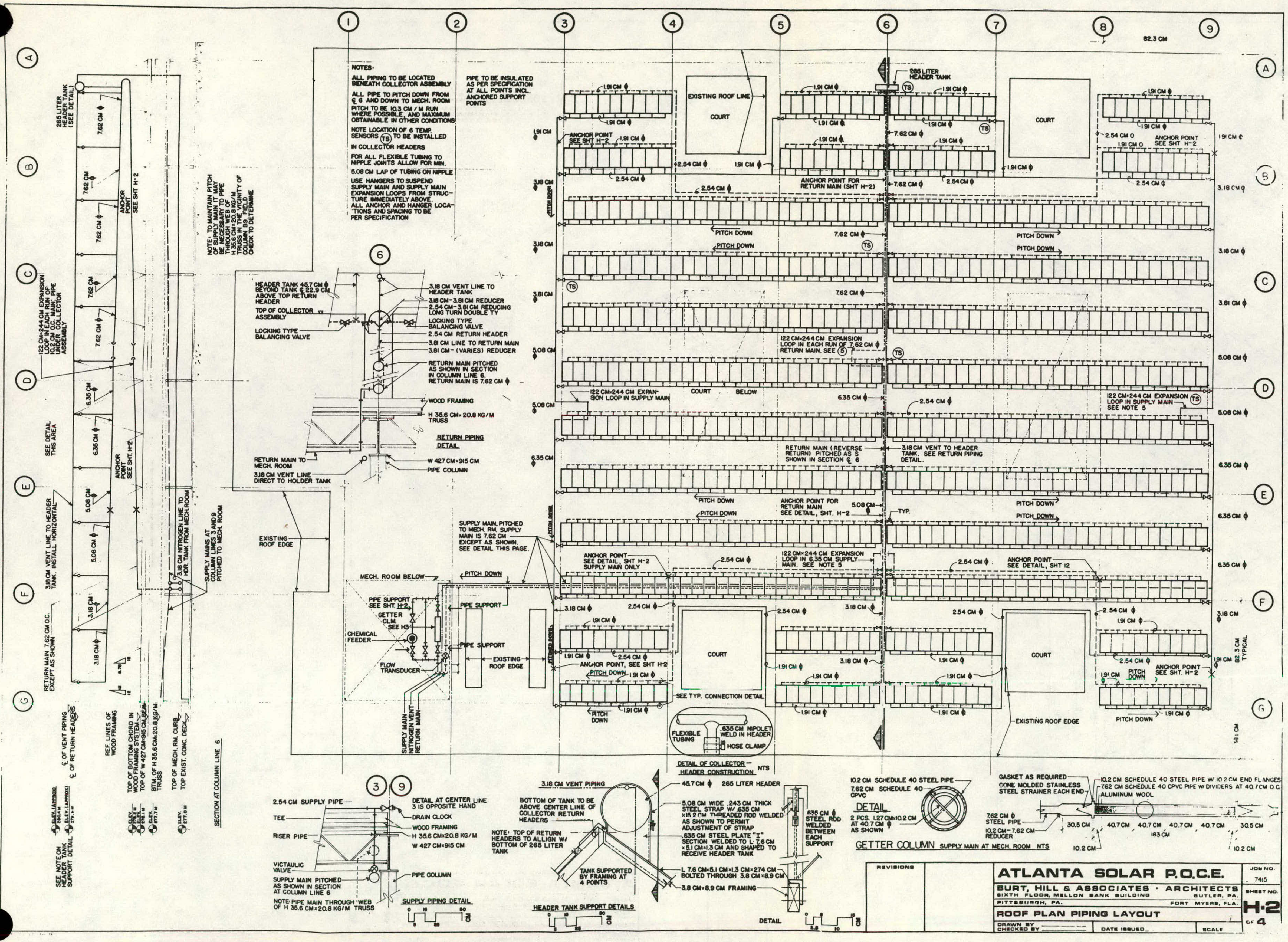
		SOLAR INTERFACE FLOW DIAGRAM	H-1 OF 4
		DRAWN BY ______ CHECKED BY ______ · DATE ISSUED ______ · SCALE	



NOTES:
ALL PIPING TO BE LOCATED BENEATH COLLECTOR ASSEMBLY
ALL PIPE TO PITCH DOWN FROM ℄ 6 AND DOWN TO MECH. ROOM
PITCH TO BE 10.3 CM / M RUN WHERE POSSIBLE, AND MAXIMUM OBTAINABLE IN OTHER CONDITIONS
NOTE LOCATION OF 6 TEMP. SENSORS (TS) TO BE INSTALLED IN COLLECTOR HEADERS
FOR ALL FLEXIBLE TUBING TO NIPPLE JOINTS ALLOW FOR MIN. 5.08 CM LAP OF TUBING ON NIPPLE
USE HANGERS TO SUSPEND SUPPLY MAIN AND SUPPLY MAIN EXPANSION LOOPS FROM STRUCTURE IMMEDIATELY ABOVE. ALL ANCHOR AND HANGER LOCATIONS AND SPACING TO BE PER SPECIFICATION
PIPE TO BE INSULATED AS PER SPECIFICATION AT ALL POINTS INCL. ANCHORED SUPPORT POINTS
265 LITER HEADER TANK
EXISTING ROOF LINE
COURT
PITCH DOWN
ANCHOR POINT FOR RETURN MAIN (SHT H-2)
122 CM×244 CM EXPANSION LOOP IN SUPPLY MAIN
RETURN MAIN (REVERSE RETURN) PITCHED AS SHOWN IN SECTION ℄ 6
3.18 CM VENT TO HEADER TANK. SEE RETURN PIPING DETAIL.
SUPPLY MAIN PITCHED TO MECH. RM. SUPPLY MAIN IS 7.62 CM EXCEPT AS SHOWN. SEE DETAIL THIS PAGE.
MECH. ROOM BELOW
PIPE SUPPORT
GETTER CLM.
CHEMICAL FEEDER
FLOW TRANSDUCER
EXISTING ROOF EDGE
SEE TYP. CONNECTION DETAIL
FLEXIBLE TUBING
6.35 CM NIPOLET WELD IN HEADER
HOSE CLAMP
DETAIL OF COLLECTOR HEADER CONSTRUCTION NTS
RETURN PIPING DETAIL
SUPPLY PIPING DETAIL
HEADER TANK SUPPORT DETAILS
GETTER COLUMN SUPPLY MAIN AT MECH. ROOM NTS
SECTION AT COLUMN LINE 6
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ROOF PLAN PIPING LAYOUT
JOB NO. 7415
SHEET NO. H-2 OF 4
REVISIONS
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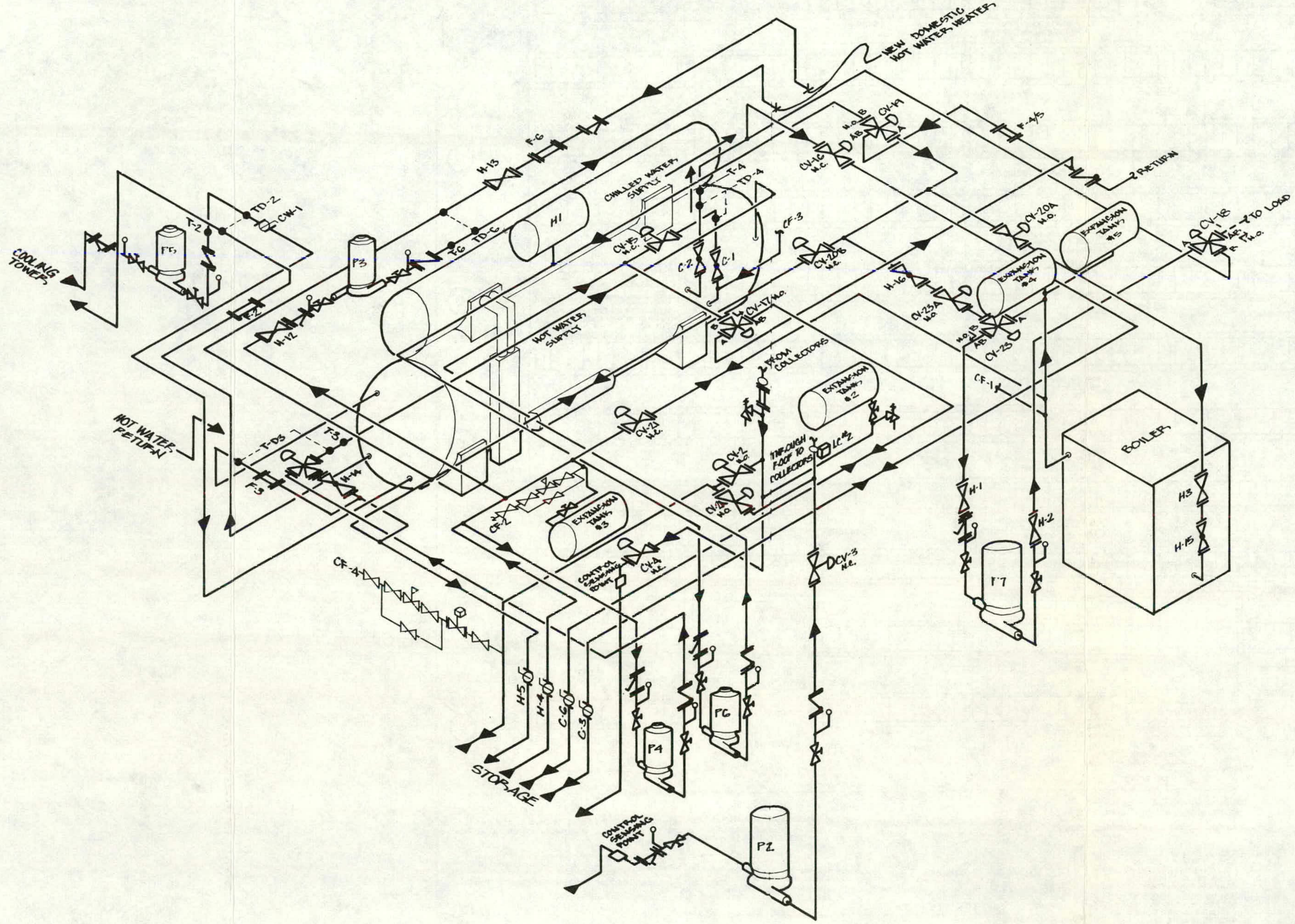

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		PIPING DIAGRAM ISOMETRIC · MECH. RM.	H·3 of 4
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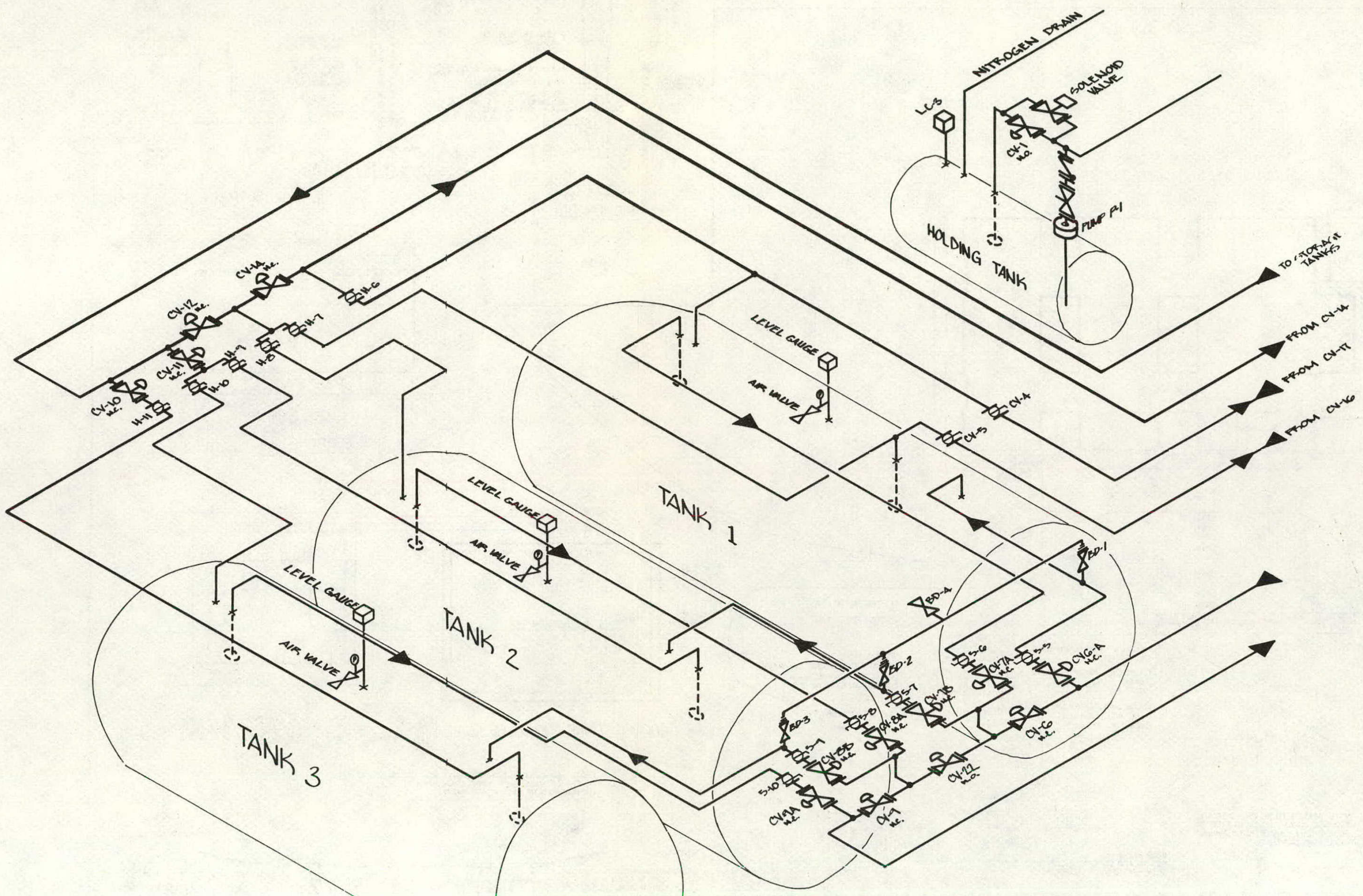
A4



PUMPS

NO.	VOLUME LITER/ SEC.	HEAD METERS	REMARKS
P-1	4.73	10.67	HOLDING TANK PUMP
P-2	9.46	18.28	SCR SPEED CONTROL DOWN TO 3.15 L/S AT 30.48 CM
P-3	.63	6.9	HOT WATER HEATER PUMP
P-4	17.66	22.86	GENERATOR PUMP
P-5	22.07	21.34	CONDENSER WATER PUMP
P-6	15.7	36.57	CHILLED WATER PUMP

EXPANSION TANKS

NO.	TYPE	EXPANSION CAPACITY	TOTAL CAPACITY	PRE-CHARGE PRESSURE
1	AIR CUSHION	569 L	1137 L	34.5 KN/ M²
2	" "	73 L	200 L	" "
3	" "	182 L	200 L	" "
4	" "	53 L	160 L	" "
5	" "	53 L	160 L	" "

HOLDING TANK
5990.24 KG, 172.4 KN/ M² WORKING PRESSURE

MAIN STORAGE TANK
3 AT 56093 KG, 172.4 KN/ M² WORKING PRESSURE
BURIED UNDERGROUND AND INSULATED AS SHOWN
ON DRAWING NO. 1

INSULATION
ALL EXPOSED PIPING FITTINGS & VALVES INSULATED WITH FIBERGLASS
SECTIONS WEATHERPROOFED AND CLAD WITH 1 MM STAINLESS STEEL JACKET

10.08 M³ EXPANSION NEEDED EQUALLY BETWEEN 3 STORAGE TANKS
EXPANSION = 3.36 M³ / TANK.

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PIPING DIAGRAM ISOMETRIC· TANK FIELD

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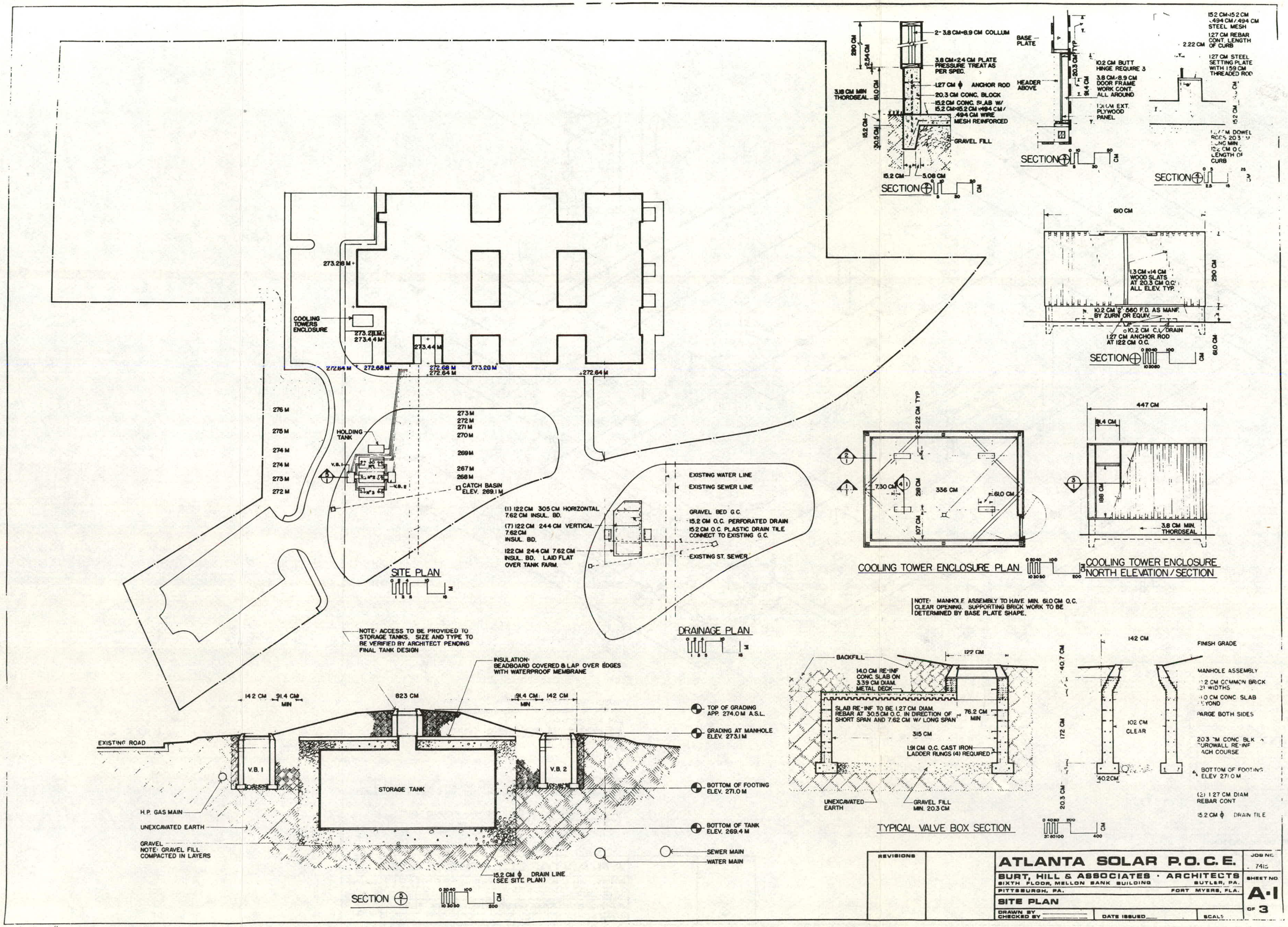
SITE PLAN
DRAINAGE PLAN
COOLING TOWERS ENCLOSURE
HOLDING TANK
CATCH BASIN ELEV. 269.1 M
EXISTING WATER LINE
EXISTING SEWER LINE
GRAVEL BED G.C.
15.2 CM O.C. PERFORATED DRAIN
15.2 CM O.C. PLASTIC DRAIN TILE CONNECT TO EXISTING G.C.
EXISTING ST. SEWER
NOTE: ACCESS TO BE PROVIDED TO STORAGE TANKS. SIZE AND TYPE TO BE VERIFIED BY ARCHITECT PENDING FINAL TANK DESIGN
INSULATION: BEADBOARD COVERED & LAP OVER EDGES WITH WATERPROOF MEMBRANE
EXISTING ROAD
STORAGE TANK
V.B. 1
V.B. 2
H.P. GAS MAIN
UNEXCAVATED EARTH
GRAVEL NOTE: GRAVEL FILL COMPACTED IN LAYERS
TOP OF GRADING APP. 274.0 M A.S.L.
GRADING AT MANHOLE ELEV. 273.1 M
BOTTOM OF FOOTING ELEV. 271.0 M
BOTTOM OF TANK ELEV. 269.4 M
SEWER MAIN
WATER MAIN
15.2 CM DRAIN LINE (SEE SITE PLAN)
SECTION
COOLING TOWER ENCLOSURE PLAN
COOLING TOWER ENCLOSURE NORTH ELEVATION / SECTION
NOTE: MANHOLE ASSEMBLY TO HAVE MIN. 61.0 CM O.C. CLEAR OPENING. SUPPORTING BRICK WORK TO BE DETERMINED BY BASE PLATE SHAPE.
TYPICAL VALVE BOX SECTION
BACKFILL
FINISH GRADE
MANHOLE ASSEMBLY
GRAVEL FILL MIN. 20.3 CM
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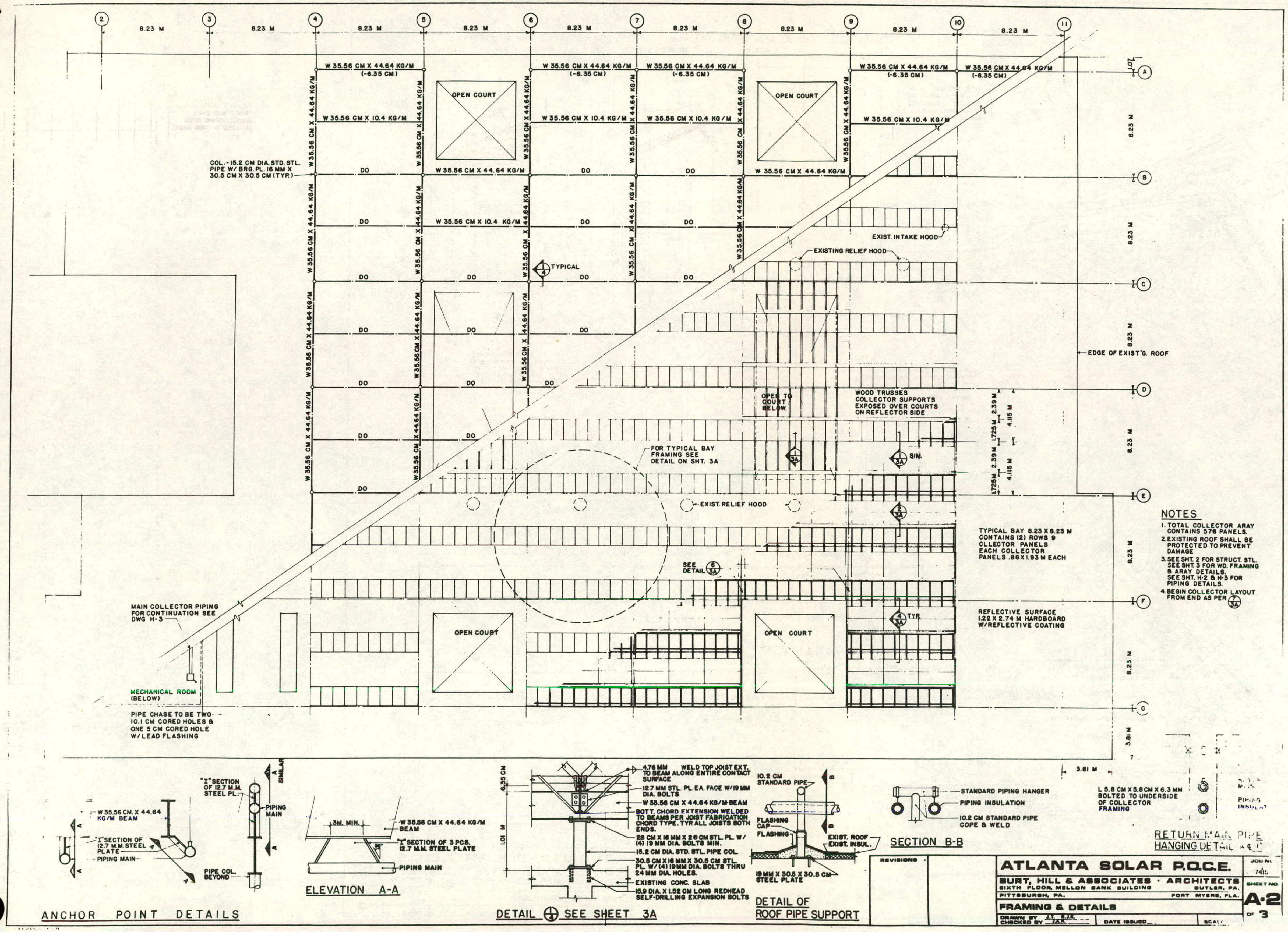

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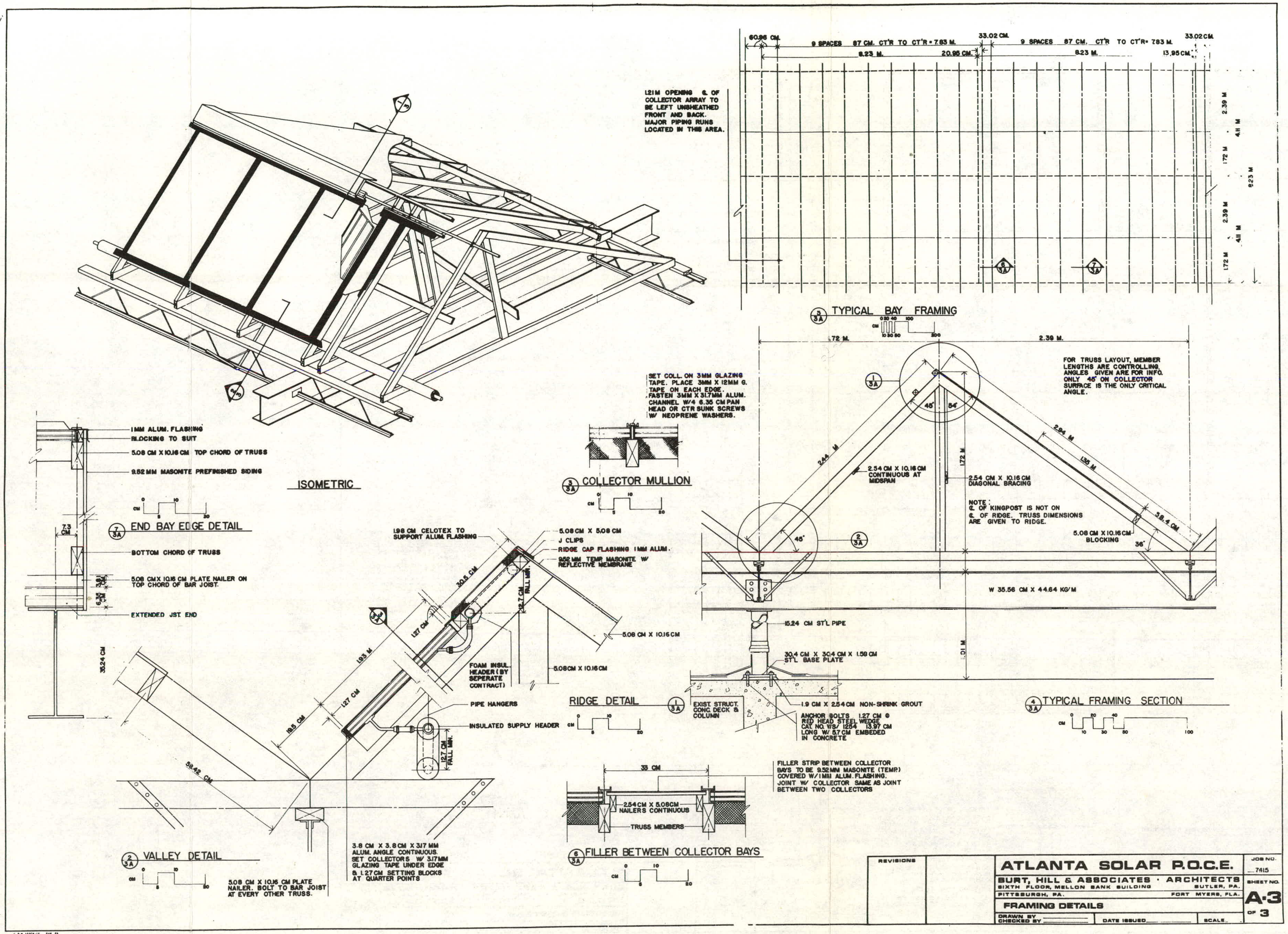
FRAMING & DETAILS
REVISIONS
SHEET NO.
A-2
of 3
DATE ISSUED
NOTES
1. TOTAL COLLECTOR ARAY CONTAINS 576 PANELS.
2. EXISTING ROOF SHALL BE PROTECTED TO PREVENT DAMAGE
3. SEE SHT. 2 FOR STRUCT. STL. SEE SHT. 3 FOR WD. FRAMING & ARAY DETAILS. SEE SHT. H-2 & H-3 FOR PIPING DETAILS.
4. BEGIN COLLECTOR LAYOUT FROM END AS PER
TYPICAL BAY 8.23 X 8.23 M CONTAINS (2) ROWS 9 CLLECTOR PANELS EACH COLLECTOR PANELS .86 X 1.93 M EACH
REFLECTIVE SURFACE 1.22 X 2.74 M HARDBOARD W/REFLECTIVE COATING
EDGE OF EXIST'G. ROOF
OPEN COURT
W 35.56 CM X 44.64 KG/M
W 35.56 CM X 10.4 KG/M
(-6.35 CM)
DO
8.23 M
TYPICAL
COL.-15.2 CM DIA. STD. STL. PIPE W/ BRG. PL. 16 MM X 30.5 CM X 30.5 CM (TYP.)
EXIST. INTAKE HOOD
EXISTING RELIEF HOOD
OPEN TO COURT BELOW
WOOD TRUSSES COLLECTOR SUPPORTS EXPOSED OVER COURTS ON REFLECTOR SIDE
FOR TYPICAL BAY FRAMING SEE DETAIL ON SHT. 3A
EXIST. RELIEF HOOD
SEE DETAIL
MAIN COLLECTOR PIPING FOR CONTINUATION SEE DWG H-3
MECHANICAL ROOM (BELOW)
PIPE CHASE TO BE TWO 10.1 CM CORED HOLES & ONE 5 CM CORED HOLE W/LEAD FLASHING
ANCHOR POINT DETAILS
ELEVATION A-A
DETAIL SEE SHEET 3A
DETAIL OF ROOF PIPE SUPPORT
SECTION B-B
RETURN MAIN PIPE HANGING DETAIL
W 35.56 CM X 44.64 KG/M BEAM
"I" SECTION OF 12.7 M.M. STEEL PL.
PIPING MAIN
PIPE COL. BEYOND
"I" SECTION OF 3 PCS. 12.7 M.M. STEEL PLATE
3M. MIN.
4.76 MM WELD TOP JOIST EXT. TO BEAM ALONG ENTIRE CONTACT SURFACE
12.7 MM STL. PL. EA. FACE W/19 MM DIA. BOLTS
BOTT. CHORD EXTENSION WELDED TO BEAMS PER JOIST FABRICATION CHORD TYPE. TYP. ALL JOISTS BOTH ENDS.
15.2 CM DIA. STD. STL. PIPE COL.
EXISTING CONC. SLAB
15.9 DIA. X 1.52 CM LONG REDHEAD SELF-DRILLING EXPANSION BOLTS
10.2 CM STANDARD PIPE
FLASHING CAP
FLASHING
EXIST. ROOF
EXIST. INSUL.
19 MM X 30.5 X 30.5 CM STEEL PLATE
STANDARD PIPING HANGER
PIPING INSULATION
10.2 CM STANDARD PIPE COPE & WELD
L 5.8 CM X 5.8 CM X 6.3 MM BOLTED TO UNDERSIDE OF COLLECTOR FRAMING



1.21M OPENING ℄ OF COLLECTOR ARRAY TO BE LEFT UNSHEATHED FRONT AND BACK. MAJOR PIPING RUNS LOCATED IN THIS AREA.
60.96 CM.
9 SPACES 87 CM. CT'R TO CT'R = 7.83 M.
8.23 M.
20.96 CM.
33.02 CM.
9 SPACES 87 CM. CT'R TO CT'R = 7.83 M.
8.23 M.
13.95 CM.
33.02 CM.
2.39 M
4.11 M
1.72 M
8.23 M
2.39 M
4.11 M
1.72 M
TYPICAL BAY FRAMING
ISOMETRIC
1MM ALUM. FLASHING
BLOCKING TO SUIT
5.08 CM X 10.16 CM TOP CHORD OF TRUSS
9.52 MM MASONITE PREFINISHED SIDING
END BAY EDGE DETAIL
BOTTOM CHORD OF TRUSS
5.08 CM X 10.16 CM PLATE NAILER ON TOP CHORD OF BAR JOIST.
EXTENDED JST END
35.24 CM
SET COLL. ON 3MM GLAZING TAPE. PLACE 3MM X 12MM G. TAPE ON EACH EDGE. FASTEN 3MM X 31.7MM ALUM. CHANNEL W/4 6.35 CM PAN HEAD OR CTR SUNK SCREWS W/ NEOPRENE WASHERS.
COLLECTOR MULLION
1.72 M.
2.39 M.
FOR TRUSS LAYOUT, MEMBER LENGTHS ARE CONTROLLING. ANGLES GIVEN ARE FOR INFO. ONLY 45° ON COLLECTOR SURFACE IS THE ONLY CRITICAL ANGLE.
45°
54°
2.44 M
2.54 CM X 10.16 CM CONTINUOUS AT MIDSPAN
1.72 M
2.54 CM X 10.16 CM DIAGONAL BRACING
2.95 M
1.30 M
NOTE: ℄ OF KINGPOST IS NOT ON ℄ OF RIDGE. TRUSS DIMENSIONS ARE GIVEN TO RIDGE.
5.08 CM X 10.16 CM BLOCKING
36°
W 35.56 CM X 44.64 KG/M
15.24 CM ST'L PIPE
30.4 CM X 30.4 CM X 1.58 CM ST'L BASE PLATE
1.01 M
EXIST. STRUCT. CONC. DECK & COLUMN
1.9 CM X 2.54 CM NON-SHRINK GROUT
ANCHOR BOLTS 1.27 CM ⌀ RED HEAD STEEL WEDGE CAT. NO. WS/ 1254 13.97 CM LONG W/ 5.7 CM EMBEDED IN CONCRETE
TYPICAL FRAMING SECTION
1.98 CM CELOTEX TO SUPPORT ALUM. FLASHING
5.08 CM X 5.08 CM
J CLIPS
RIDGE CAP FLASHING 1MM ALUM.
9.52 MM TEMP. MASONITE W/ REFLECTIVE MEMBRANE
30.5 CM
12.7 CM FALL MIN.
5.08 CM X 10.16 CM
1.27 CM
193 M
FOAM INSUL. HEADER (BY SEPERATE CONTRACT)
5.08 CM X 10.16 CM
RIDGE DETAIL
PIPE HANGERS
INSULATED SUPPLY HEADER
1.27 CM
18.5 CM
12.7 CM FALL MIN.
58.42 CM
VALLEY DETAIL
5.08 CM X 10.16 CM PLATE NAILER. BOLT TO BAR JOIST AT EVERY OTHER TRUSS.
3.8 CM X 3.8 CM X 3.17 MM ALUM. ANGLE CONTINUOUS. SET COLLECTORS W/ 3.17MM GLAZING TAPE UNDER EDGE & 1.27 CM SETTING BLOCKS AT QUARTER POINTS
33 CM
2.54 CM X 5.08 CM NAILERS CONTINUOUS
TRUSS MEMBERS
FILLER STRIP BETWEEN COLLECTOR BAYS TO BE 9.52MM MASONITE (TEMP.) COVERED W/1MM ALUM. FLASHING. JOINT W/ COLLECTOR SAME AS JOINT BETWEEN TWO COLLECTORS
FILLER BETWEEN COLLECTOR BAYS
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RECOMMENDED

CCMS SOLAR ENERGY PILOT STUDY

REPORTING FORMAT FOR

HEATING AND COOLING SYSTEMS IN BUILDINGS

August 1975

The objective of this special reporting format is to assure that sufficient information is provided to enable the reader to make his own assessment of the performance of a solar heating and/or cooling system and to relate that performance, which was carried out in one particular climate and economic environment, to a different climate and economic environment.

All details of the format are to be followed as completely as possible. In addition, information on all related back-up reports is requested, including specific instructions on how they may be obtained.

FORMAT FOR REPORTING SYSTEM PERFORMANCE

I. General Description of System Project and Environment

A. Objective of Project

- o Brief description of objective and strategy of project, including duration and major milestones.

B. Description of the Environment - each section to be included if appropriate

1. Climate

- o Brief description of type of climate, according to the Trewartha* worldwide classification system.
- o Annual rain and snow fall (mm per year).

---

* G. T. Trewartha, An Introduction to Climate (McGraw Hill: New York, 1968).

- o Description of typical sky conditions relative to "clear sky"; either average daily sunshine hours, number of sunshine hours per year, the percentage of maximum possible sunshine hours or annual average cloud cover fraction may be used.

2. Location

- o Latitude, longitude, and altitude (in m) of system.
- o Description of the configuration of the location and distance from solar or wind obstructions or significant geographic features (sea, mountains, etc., in km).
- o Comment on air quality, i.e. dust precipitation.

3. Solar Radiation

- o Mean monthly global (total) and, if relevant, diffuse insolation on a surface whose orientation is described. The number of years over which this mean is defined should be specified, as well as the time intervals of the data.
- o Description of the measurement equipment.

4. Ambient Temperatures

- o Mean monthly dry and wet bulb temperatures (relative humidity may be used in place of wet bulb temperature).
- o Number and basis of degree-days of location.
- o Description of the measurement equipment.

5. Wind

- o Average monthly wind speed and prevailing direction (0 - 360° from North towards East).
- o Description of measuring equipment.

C. Description of System

1. Qualitative Description

- o Description of the entire system, as well as the solar system, by narrative, photographs, or drawings.

2. Quantitative Description

- o Description of the system performance characteristics, including schematic drawings.
- o Orientation* and inclination+ of collectors.
- o Control system descritpion, performance characteristics, and location within the system. The operating modes should be described.
- o Measurement system description, performance characteristics (such as precision and repeatability), and location within the system.

II. System Thermal Performance - The information in sections A, B, C and D is essential and therefore should be as complete as possible.

A. Daily, Monthly and Annual Values** of the Mean Daily (Tabular or Graphical Form)

- o Total energy required (thermal load, heating or cooling, on system).
- o Supplemental energy required (amount, kind, and purpose).
- o Solar energy incident on collectors.++

---

* Angle between the projection of the sun's rays, at solar noon, on the horizontal plane and the projection of the normal to the collector on the horizontal plane.

\+ Angle between horizontal and normal to collector.

** The monthly value of the mean daily quantities is the most important of the three. Daily values may be provided as optional information.

++ It is suggested that this be based on (at least) hourly values of the global (and/or direct, if appropriate) insolation measured in the plane of the collectors. If the global insolation is only measured on a horizontal surface, it should be so provided and the method used to determine the amount incident on the plane of the collectors should be described.

- o Solar energy collected.
- o Solar energy used.

The criteria for the use of supplemental energy must be described.

B. Record of the Quality of Thermal Performance of the System (e.g. departure from the design temperature over reporting period)

C. Solar Contribution to Energy Requirements - daily, monthly and annual values* of percent solar contribution to the energy requirements.

D. Monthly and Annual Energy or Fuel Savings - based on primary fuel (state type).

E. Energy and Mass Balances

This information is of secondary importance in that it is this information that is used to determine the quantities reported in II A. If possible, it is suggested (optional) that a typical day be used to show:

- o Significant energy flow rates - additions and losses.
- o Significant mass flow rates - additions and losses.
- o Temperature and pressure at critical locations.
- o Temperature drop and pressure drop across major components.

III. System Economic Analysis

The following costs and factors should relate to the solar portion of the project but could also be specified for the entire project.

---

* The monthly value of the mean daily quantities is the most important of the three. Daily values may be provided as optional information.

A. Total Cost of the Solar Portion of the System - with a specific definition made of the interface between the solar and non-solar portions of the system. If possible, separate design costs from component and installation costs.

B. Labor Costs - in man-hours and in local currency, for the installation of the system.

C. Materials Costs - in weight or volume as appropriate and in local currency.

D. Operational Costs - including supplemental energy costs, in local currency.

Since operational costs depend on the assumed system lifetime, it is suggested that the assumed system lifetime be stated along with the depreciation rate.

E. Local Economic Factors - such as inflation, interest rates and amortization periods.

F. Expected Selling Price or Costs - assuming that the system or solar components are mass produced.

G. Maintenance Frequency and Costs - in hours and material.

H. User Reactions and Comments

FORMAT FOR REPORTING SUB-SYSTEM PERFORMANCE

A. Solar Collectors

1. Description of Physical Configuration

- Description of solar collectors by narrative, photographs, and drawings, including collector materials, design, dimension, and construction.

2. Thermal Performance Characteristics

- o Collector efficiency curves (efficiency as a function of average fluid temperature or inlet coolant temperature, ambient air temperature, solar radiation normal to the collector, and wind speed) or equivalent collector performance indication (such as heat production) for several days that typify the full range of operation of the system.
- o Pressure drop through collectors.
- o Optical efficiency vs. incident angle, daily, monthly, and annual optical efficiency.*
- o Thermal loss coefficient as a function of the difference between the ambient and the mean plate temperature, for known wind speeds.*

3. Lifetime Performance Characteristics

- o Corrosion
- o Leakage
- o Hot spots
- o Breakage
- o Stability of collector working fluid

B. Heat Transfer Sub-system

1. Description of Physical Configuration

- o Description of heat transfer sub-system by narrative, photographs, and drawings. Specify construction materials and working fluids.

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* Optional information to be included if known.

2. Thermal Performance Characteristics*

- o Inlet and outlet temperatures on both sides of exchanger.
- o Inlet and outlet pressures on both sides of exchanger.
- o Mass flow rates on both sides of exchanger.
- o Pumping power.

C. Thermal Energy Storage Sub-systems

1. Description of Physical Configuration

- o Description of thermal energy storage sub-system by narrative, photographs, and drawings.
- o Specify construction materials and working fluids, location within system, insulation details (material and construction), mass and volume of storage sub-system, storage duration and/or energy stored at same temperature.

2. Thermal Performance Characteristics*

- o Mean temperature, hourly and daily, of the immediate surroundings.
- o Thermal loss or gain, hourly and daily.
- o Storage capacity.
- o Inlet and outlet temperatures and pressures.
- o Flow rates and pumping power.
- o If phase change materials are used, specify compound and thermal characteristics.

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* This information is of secondary importance in that it is this information that is used to determine the quantities reported in II A. If possible, it is suggested (optional) that a typical day be used to show:

- o Significant energy flow rates - additions and losses.
- o Significant mass flow rates - additions and losses.
- o Temperature and pressure at critical locations.
- o Temperature drop and pressure drop across major components.

D. Air-Conditioning Sub-system

1. Description of Physical Configuration

   - Description of air-conditioning unit by narrative, photographs and drawings.

   - Type of sub-system - heat pump, absorption, passive, etc.

   - Heat rejection method.

2. Thermal Performance Characteristics

   - Capacity at design inlet (to air-conditioning unit) temperature.*

   - Capacity+ and coefficient of performance COP curves (inlet temperature as variable).*

   - Sensitivity of the capacity and COP to variations in inlet temperature, evaporation temperature, wet and dry bulb temperature.

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* Condenser, absorber and evaporator temperatures should be stated.

\+ Including the ratio of sensible to latent heat removal.

The international System (S.I.) will be used exclusively* with the following recommendations:

- Pressure - given in Kpa.
- Temperature - ^{o}C
- Energy - MJ and/or Kwh
- Energy Flow Rate - Kw, w
- Solar Radiation - the intensity will be given in W/m^2, the hourly, daily, monthly or annual totals will be given in MJ/m^2 day averaged over a day, month, or year.
- Wind Speed - m/sec
- Mass Flow Rate - l/sec or kg/sec

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* According to the resolutions of the Converence Générale des Poids et Mesures, 1960.