320
12-16-77

Ah. 1698

COO/2627-2

MASTER

TIMONIUM ELEMENTARY SCHOOL SOLAR ENERGY HEATING AND COOLING AUGMENTATION EXPERIMENT

Final Engineering Report

Executive Summary

June 1977

Work Performed Under Contract No. EY-76-C-02-2627

AAI Corporation
Baltimore, Maryland

U.S. Department of Energy

Solar Energy

NOTICE

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $9.00
Microfiche $3.00

COO/2627-2
Distribution Category UC-59

TIMONIUM ELEMENTARY SCHOOL
SOLAR ENERGY
HEATING & COOLING AUGMENTATION EXPERIMENT

EXECUTIVE SUMMARY

Final Engineering Report

June 1977

ER-8877

Prepared for

Energy Research & Development Administration
Washington, D.C. 20545

AAI Corporation
P.O. Box 6767
Baltimore, MD 21204

REA

ABSTRACT

This report covers a two-year and seven-month solar space heating and cooling experiment conducted at the Timonium Elementary School, Timonium, Maryland.

The system was designed to provide a minimum of 50% of the energy required during the heating season and to determine the feasibility of using solar energy to power absorption-type chillers for cooling.

The area to be heated or cooled totaled approximately 8500 square feet of the center wing of the school. To accomplish this a system containing 5000 square feet of collectors, 5300 square feet of reflectors, a 15,000 gallon insulated hot water storage tank, 40,000 gallons of chilled water storage, an absorption chiller, miscellaneous plumbing, and instrumentation and controls, were installed. The system utilized untreated water (except for one time deionization of initial water supply) as a working fluid.

The collection system efficiency (without reflectors) reached a maximum of 56% on a clear day in April 1975. This was with an average water temperature of 161°F.

The collection system efficiency (with collector and reflector area totaling 9550 square feet) on a clear day in August amounted to 40.5%. This was with an average water temperature of 170°F.

Data on the work accomplished and on the system performance are presented herein.

Table of Contents

List of Figures

List of Figures (Cont'd.)

List of Figures (Cont'd.)

List of Tables

I. Introduction

On January 14, 1974 AAI Corporation received Contract Number NSF-871 from the National Science Foundation to conduct a Solar Heating Proof-of-Concept Experiment (POCE) for a public school building. This was later modified to include solar cooling.

The Energy Research & Development Administration acquired authority for management of the program on January 19, 1975 and the contract number was changed to E(11-1)-2627.

The total cost of the experiment was $1,156,384 of which AAI's share was $32,369 and the government's share $1,124,015. The work performed during the Timonium experiment was authorized by subsequent amendments to the contract.

The first phase began January 14, 1974 and continued through May 15, 1974. The initial contract authorized the design, fabrication, erection, operation and maintenance of a solar heating system.

The second phase was initiated May 16, 1974 by Amendment #2 to the contract. This authorized improvements to the instrumentation system and continued operation of the original solar heating system through May 15, 1975.

The third phase of the program was initiated October 11, 1974 by Amendment #3 to the contract. This authorized the modifications to adapt the system to include solar cooling. It also extended operation of the combined system through October 15, 1975.

The fourth phase of the program was initiated June 25, 1975 by Amendment #4 to the contract. It authorized the modifications required to adapt the solar cooling system to include chilled water storage.

The contract was extended from October 15, 1975 through October 15, 1976 by Amendment #5 to the contract. This provided the time needed to evaluate the modifications authorized by Amendment #4.

Amendment #6 to the contract was received on June 21, 1976. This authorized preparation of a report in the Special Reporting Format aspect of the NATO CCMS (Committee on the Challenges of Modern Society) Solar Energy Pilot Study.

The initial objective of the contract was to provide a means of utilizing solar energy to heat public school buildings. Subsequent amendments sought to improve the cost effectiveness of flat plate collector systems by permitting more extensive use of the annual solar cycle, that is to operate the system throughout the summer for solar cooling.

The operating characteristics of the fixed collectors as they were related to solar heating and their potential for solar cooling were identified in the summer and fall of 1974. The use of fixed reflectors in conjunction with the fixed collectors, provided the means required to consistently collect water hot enough to power an absorption chiller.

The absorption chiller was authorized in the spring of 1975. The feasibility of cooling (the firing of an absorption chiller with solar heated water) was demonstrated in the summer of 1975, thus permitting more utilization of the annual solar cycle.

Still another objective of the Timonium experiment was to determine the relative performance levels of both chilled and hot water storage systems in an operational environment. A chilled water storage system was authorized and installed in the winter of 1975 and spring of 1976. Data was collected during the summer of 1976.

The Timonium experiment was concluded October 15, 1976 and control and operation of the system assumed by the Baltimore County Board of Education.

II. Description of System

The charts, figures, and photographs on Figures ES-1 through ES-17 show the Solar Heating & Cooling System built and installed on Timonium Elementary School by AAI. A detailed description of each element of the system is contained in the main body of the report.

Data Sheet
Timonium Elementary School
Solar Heating Pilot Project

Area Center Wing (66 x 130) ------------	8580 sq ft
Solar Panel Area ---------------------	28 sq ft
Area of Solar Collector (180 panels) --------	5040 sq ft (see Note 1)
Ratio of Collector Area to Floor Area --------	.500
Storage - Hot Water Volume -------------	15,000 gal
Ratio of Storage Volume to Collector Area ----	2.98 gal/sq ft

Availability of Solar Heating (@40% eff) to Heating Requirement - %

October	300%	January	52%
November	105%	February	94%
December	50%	March	160%

Note 1: The actual area of collectors not obstructed to sunlight amounted to 4250 ft^2.

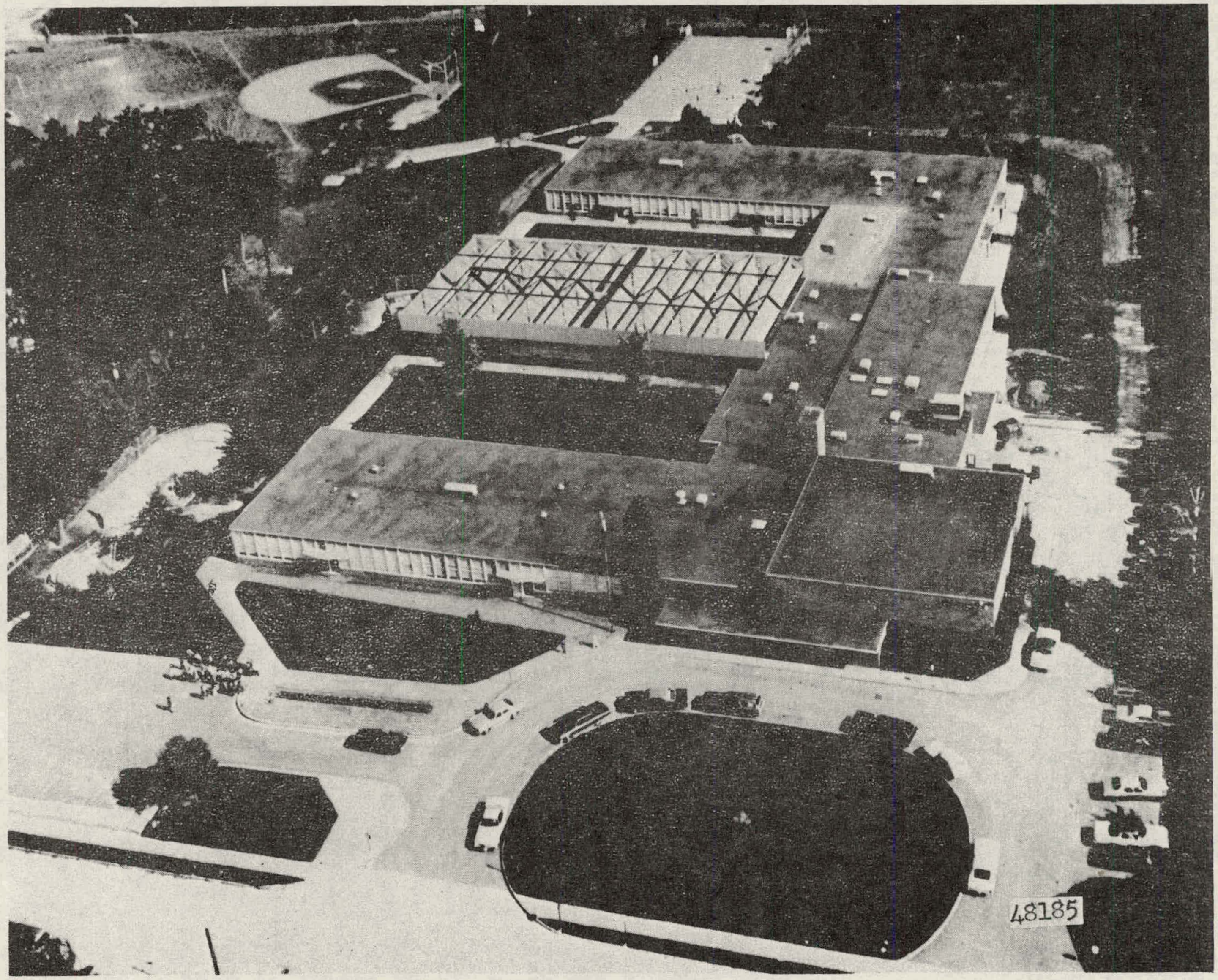


Figure ES-1. Aerial Photograph of the Timonium Solar Heating & Cooling Installation

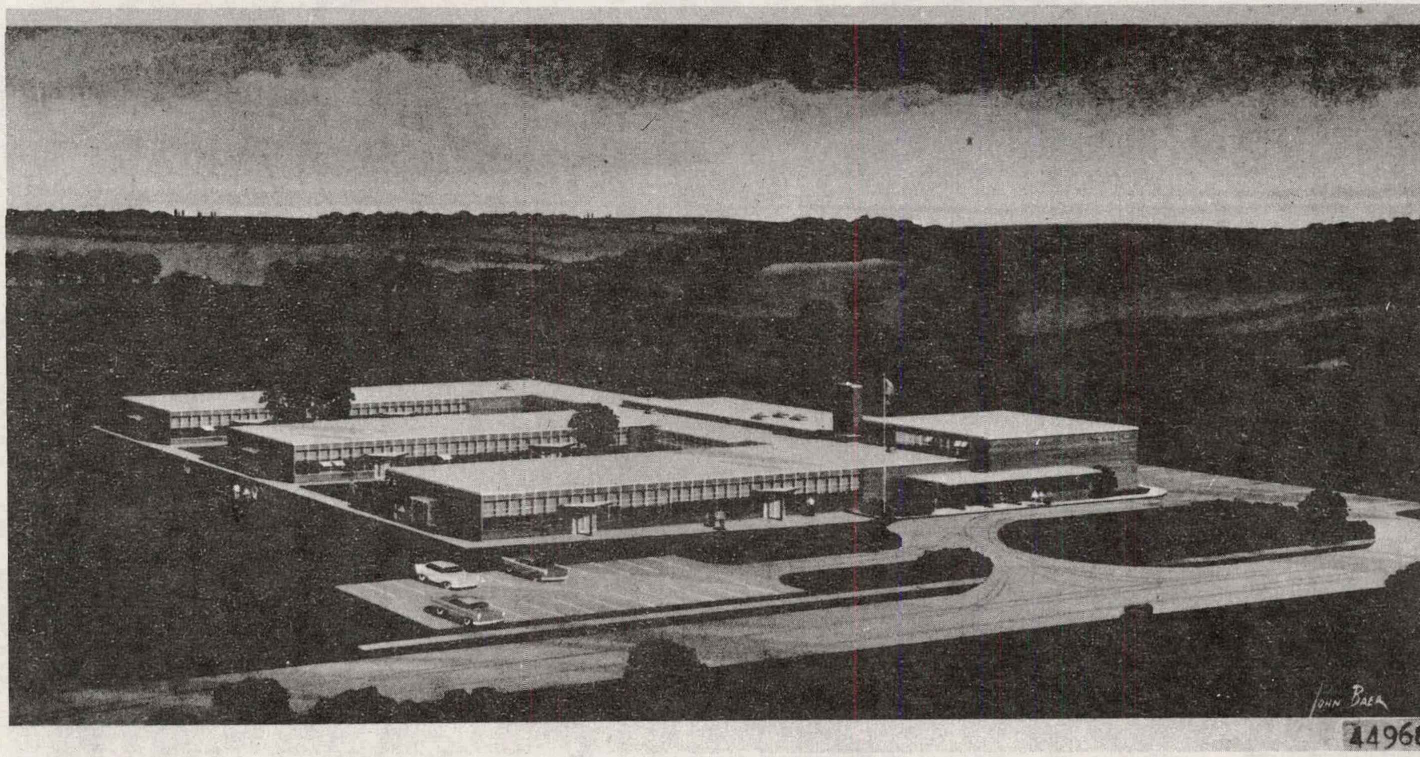


Figure ES-2. Artist's Concept of Timonium Elementary School

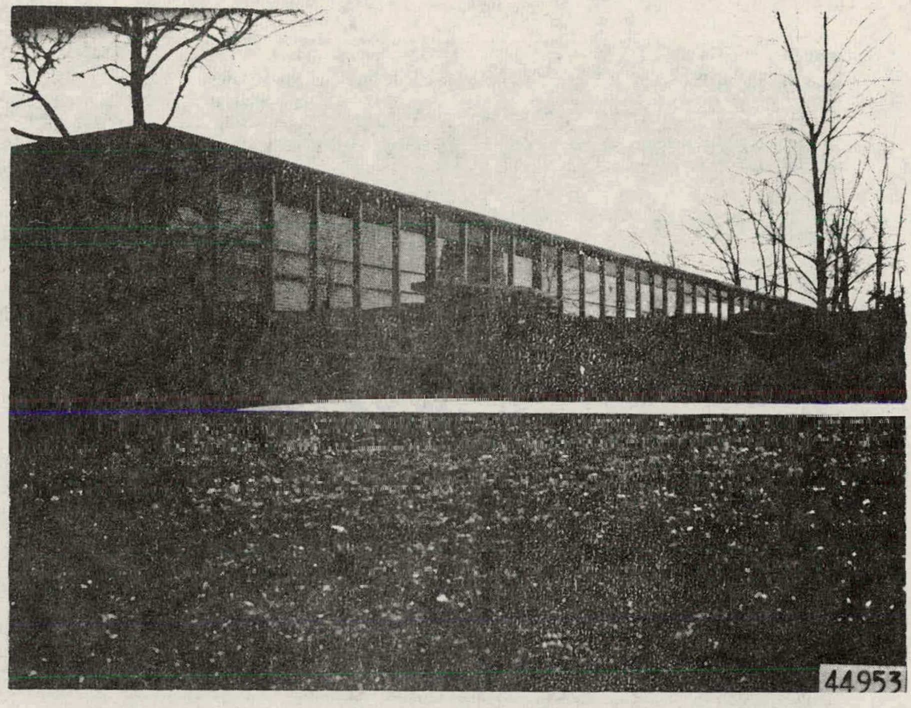


Figure ES-3. Wing of School Before Installation of Solar Collectors

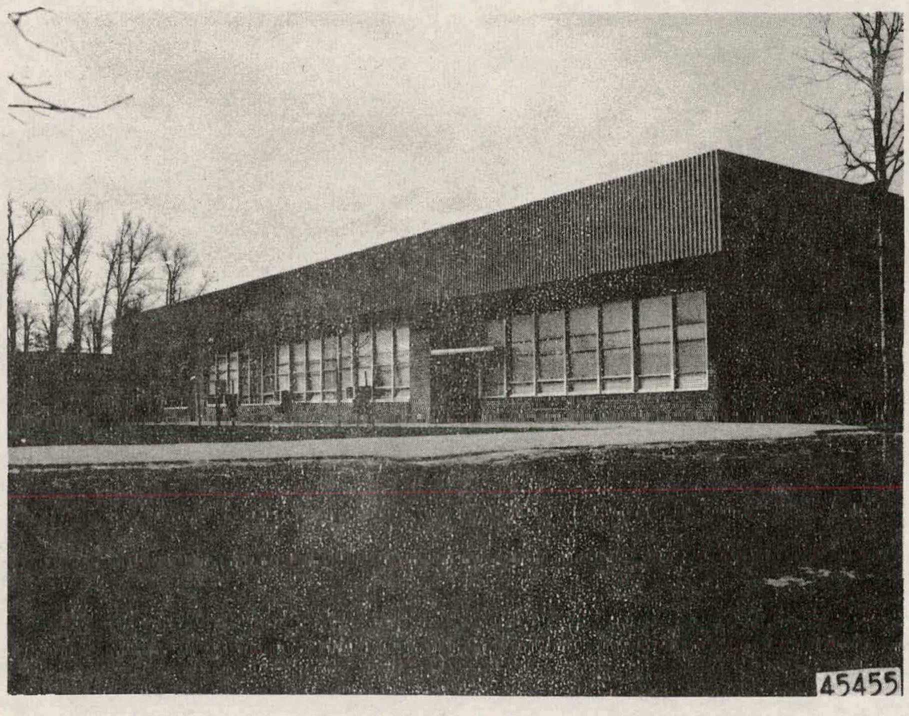


Figure ES-4. Wing of School After Solar Heating Installation Showing Screen

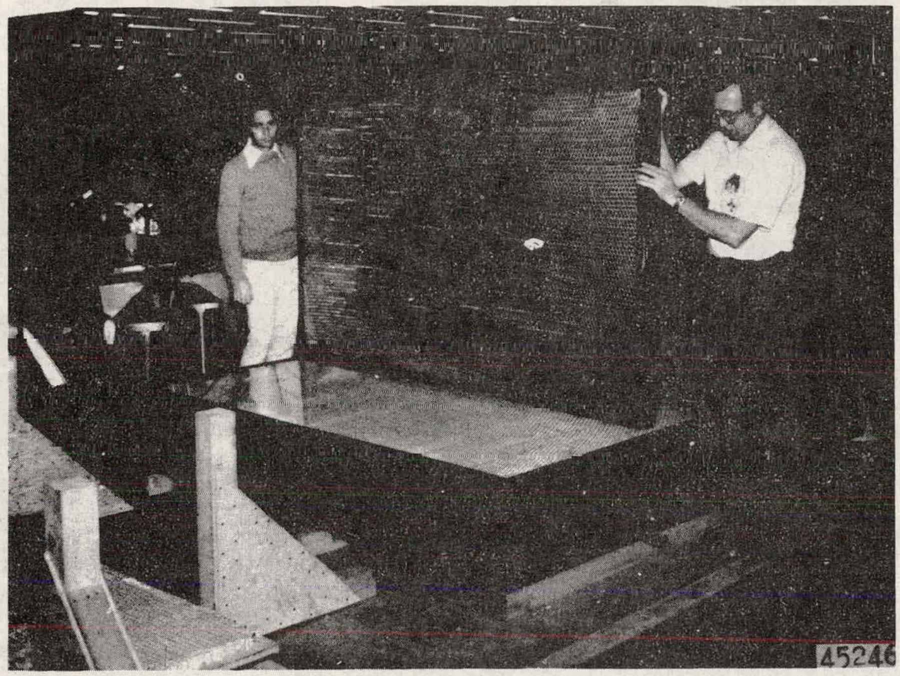


Figure ES-5. Colar Collectors in AAI Manufacturing Area

Figure ES-6. Students Viewing Construction

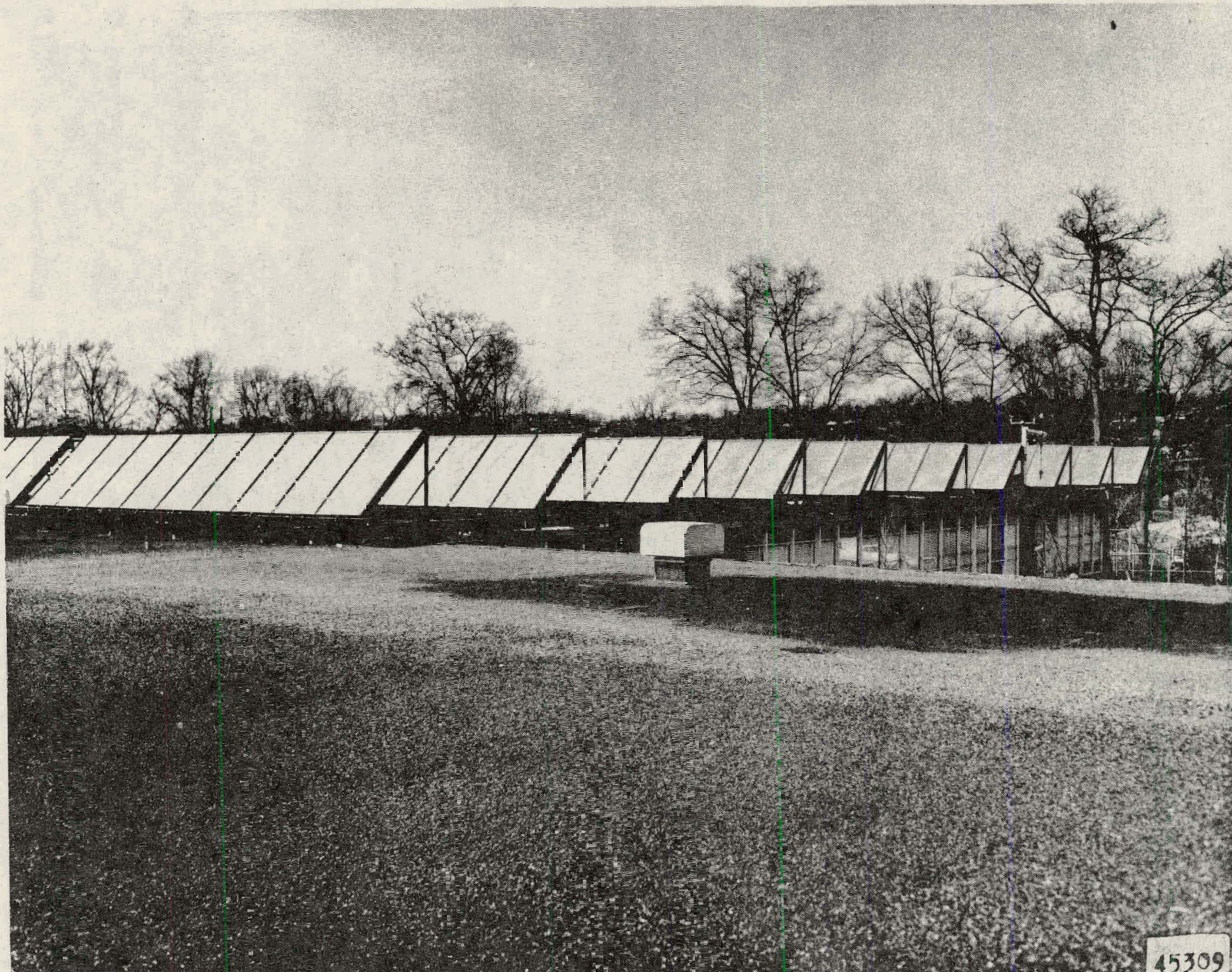


Figure ES-7. Collectors Mounted on Roof
Before Installation of Plumbing

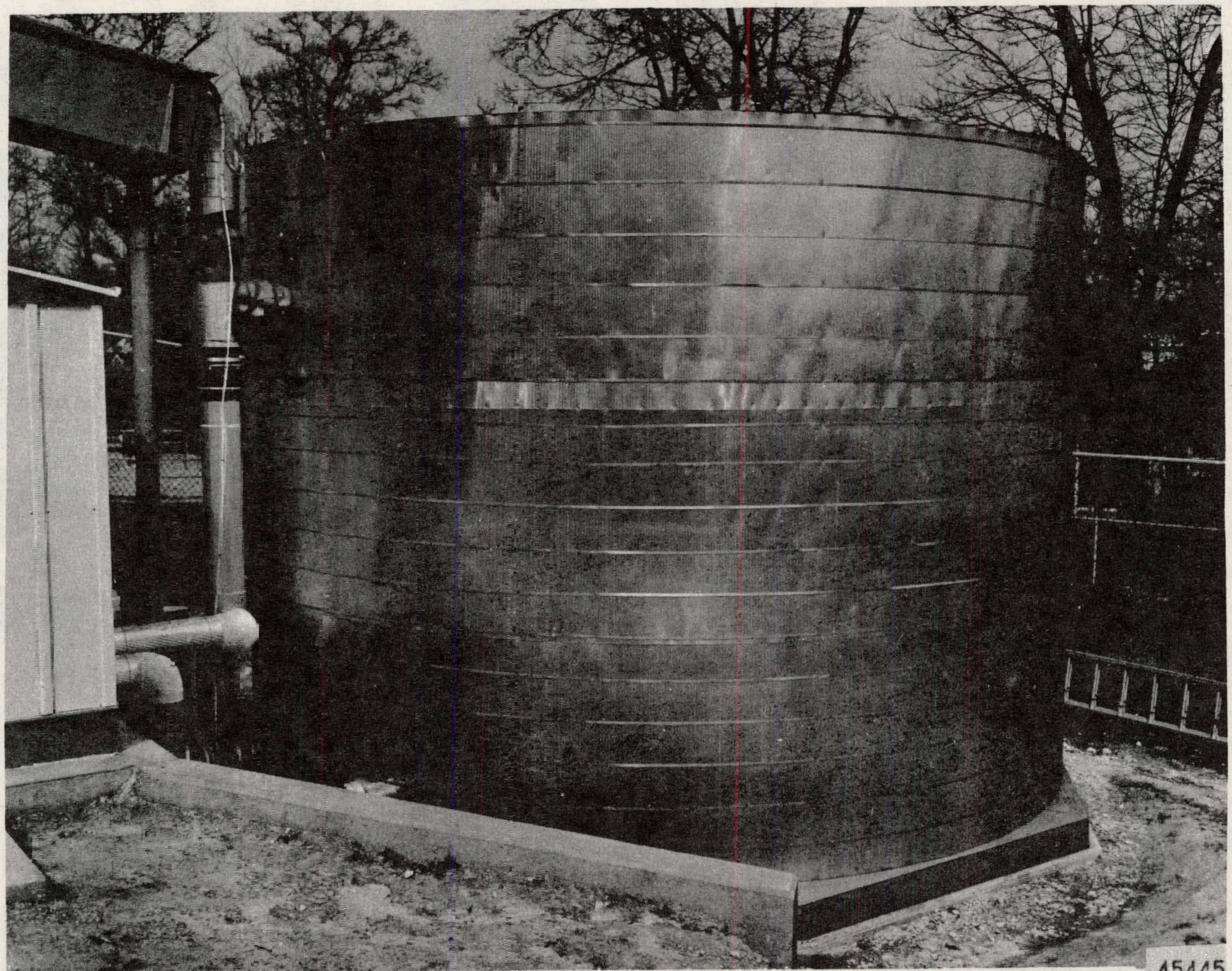


Figure ES-8. Fully Insulated Tank

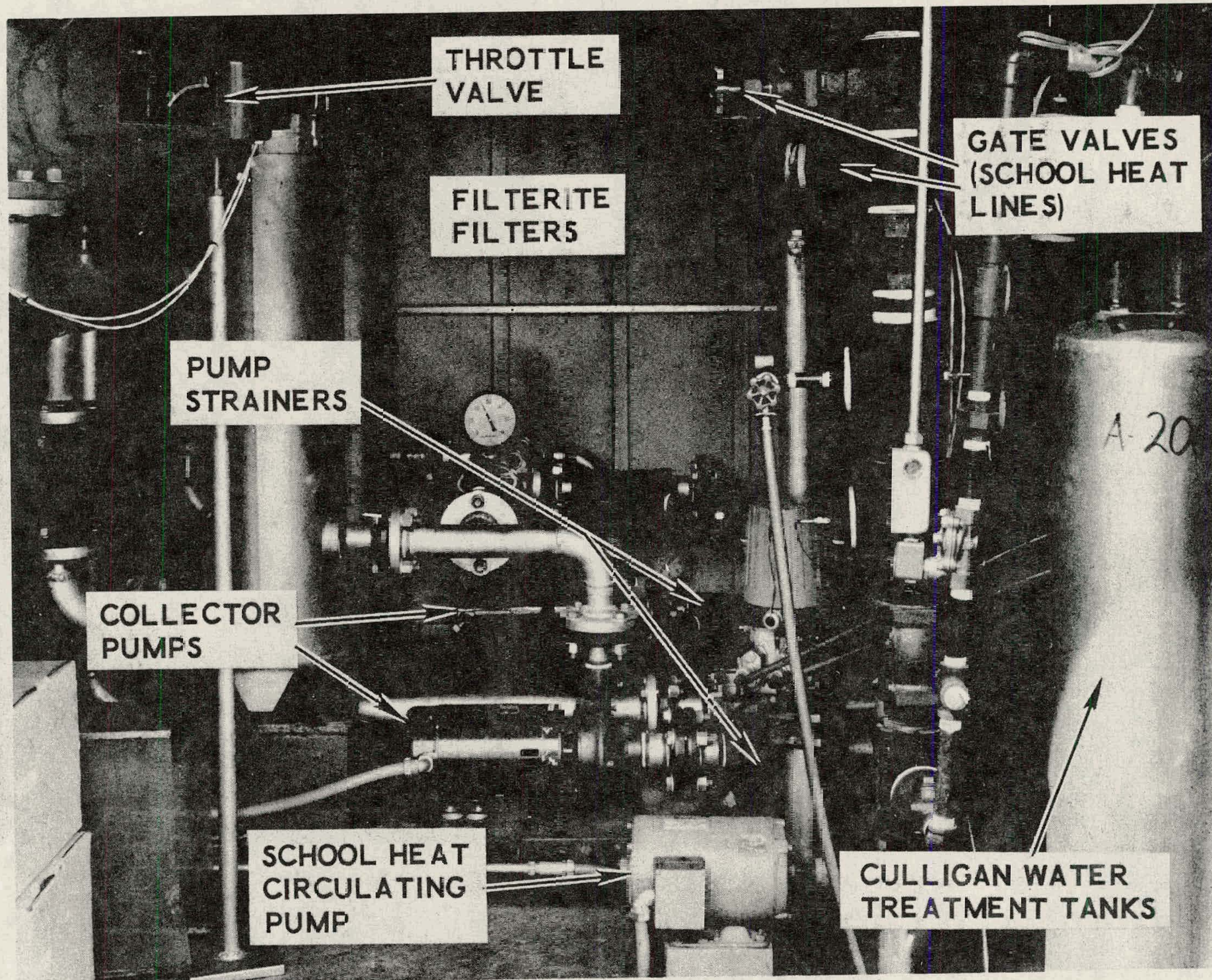


Figure ES-9. Pump House

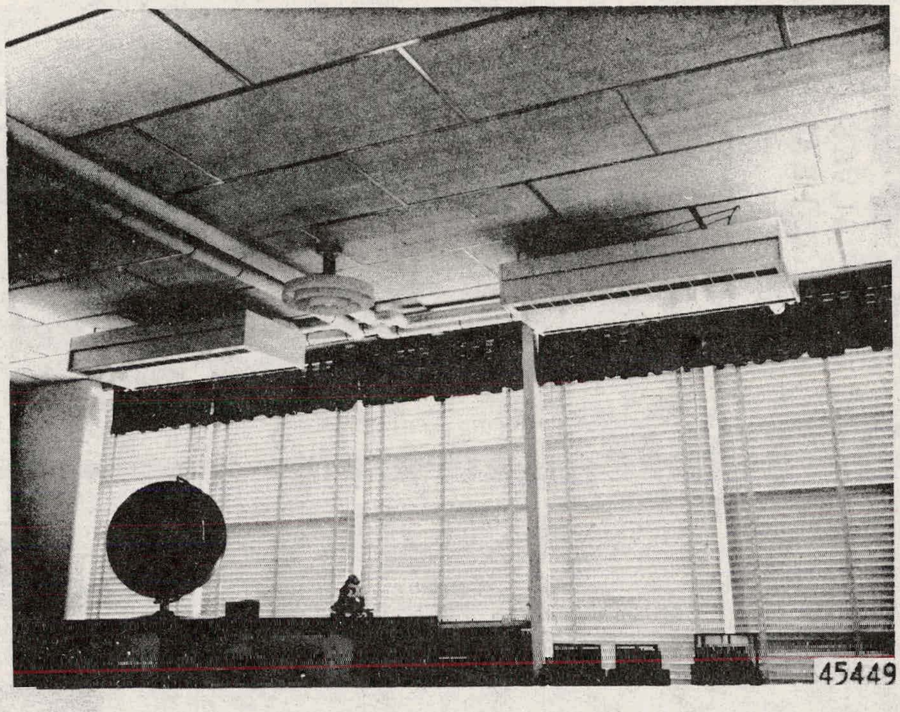


Figure ES-10. Ceiling Mounted Hot Water Convectors Added to Library to Provide Solar Heat

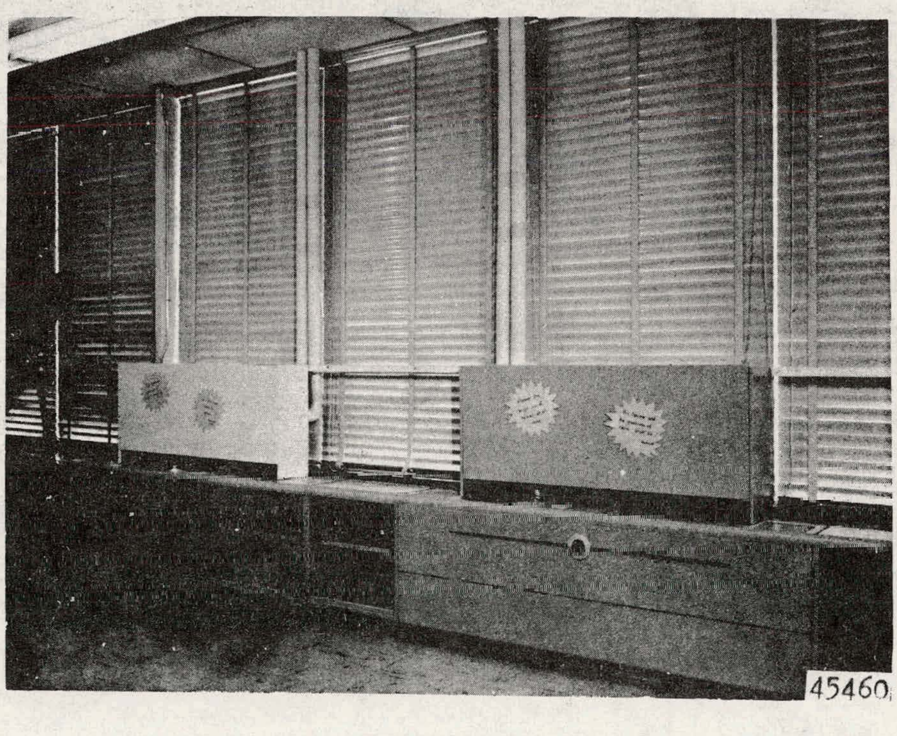


Figure ES-11. Two Hot Water Convectors Added to Typical Classroom to Provide Solar Heat

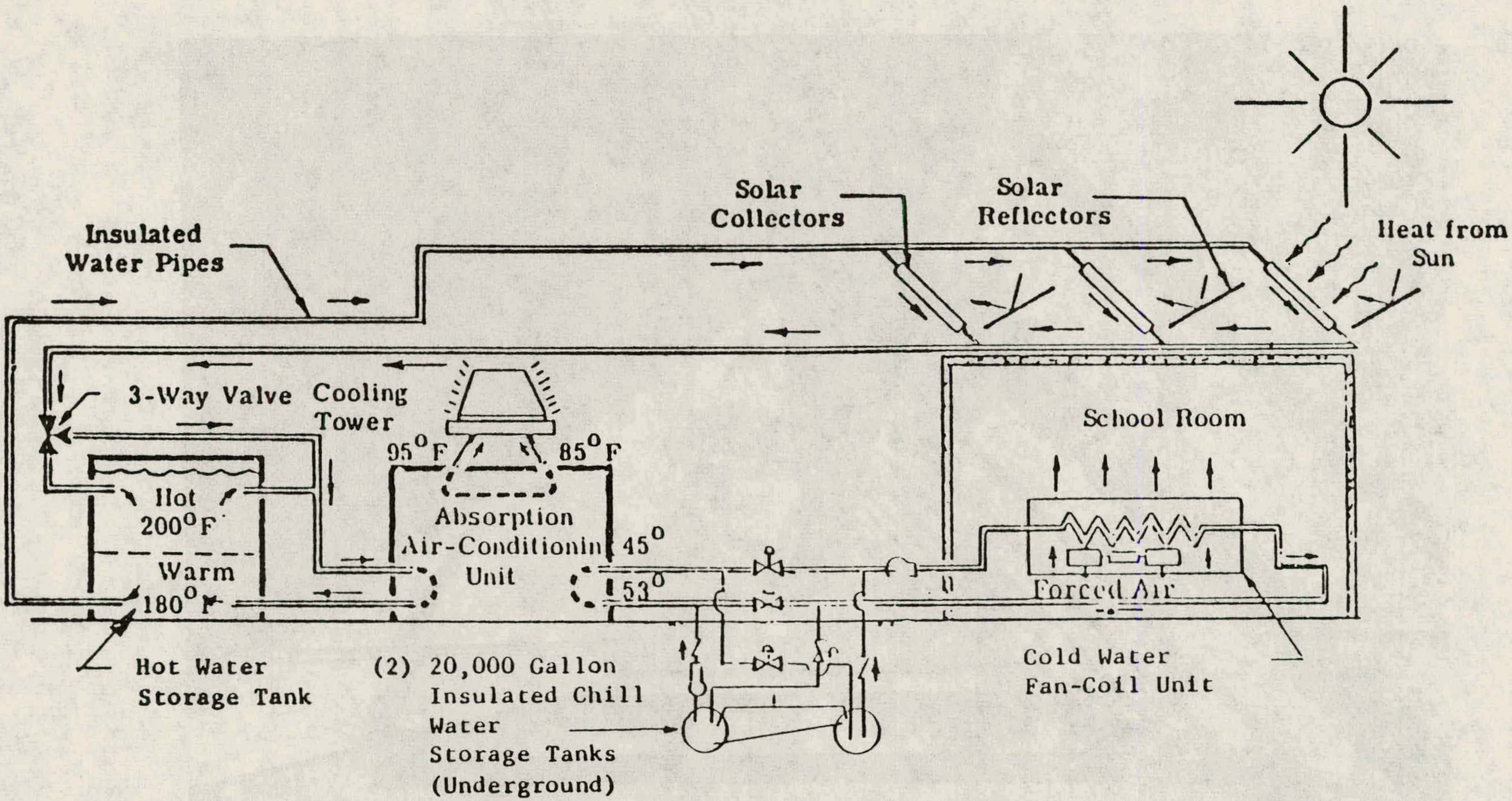


Figure ES-12. Schematic of Solar Heating & Cooling System Using Absorption Unit & Chill Water Storage

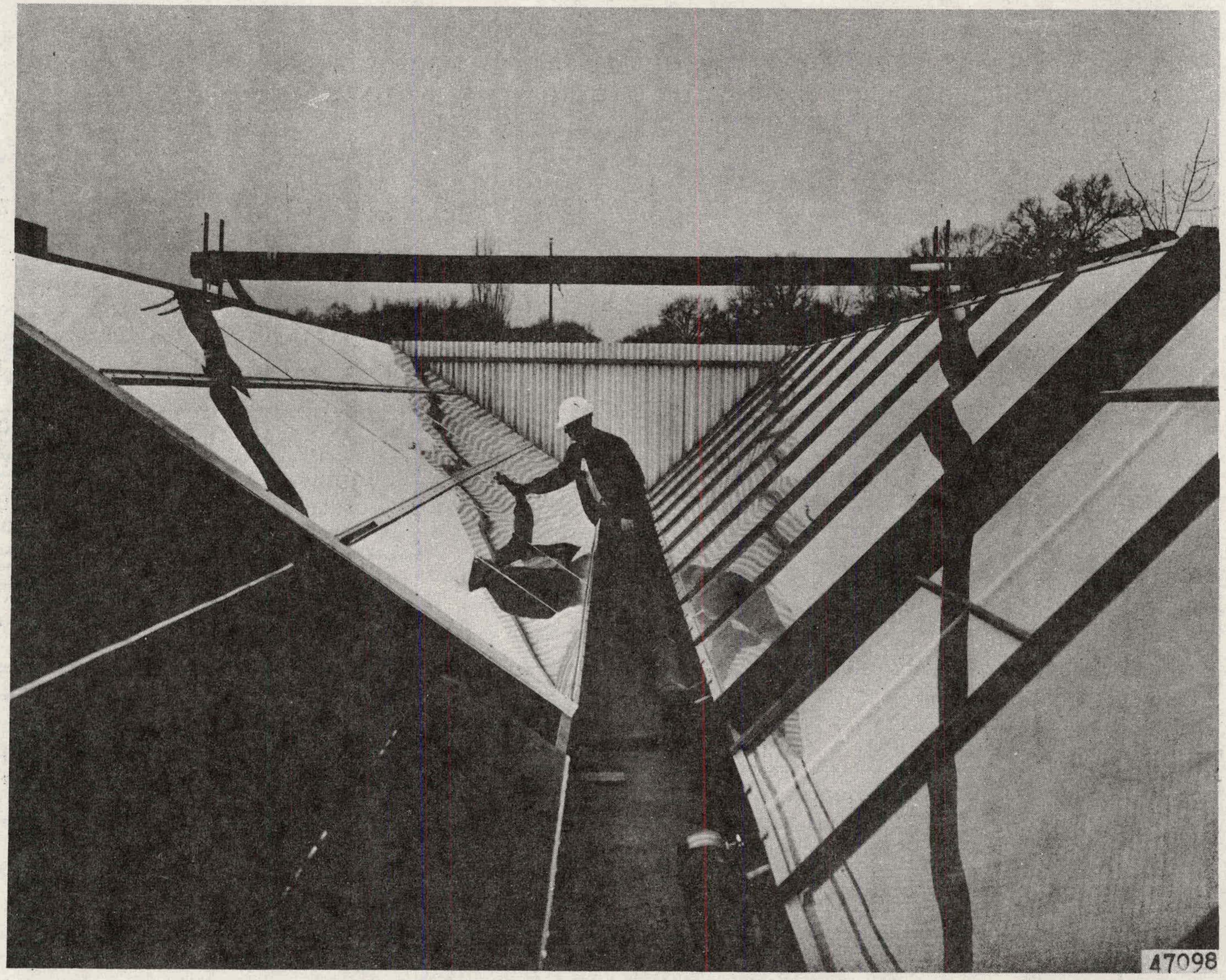
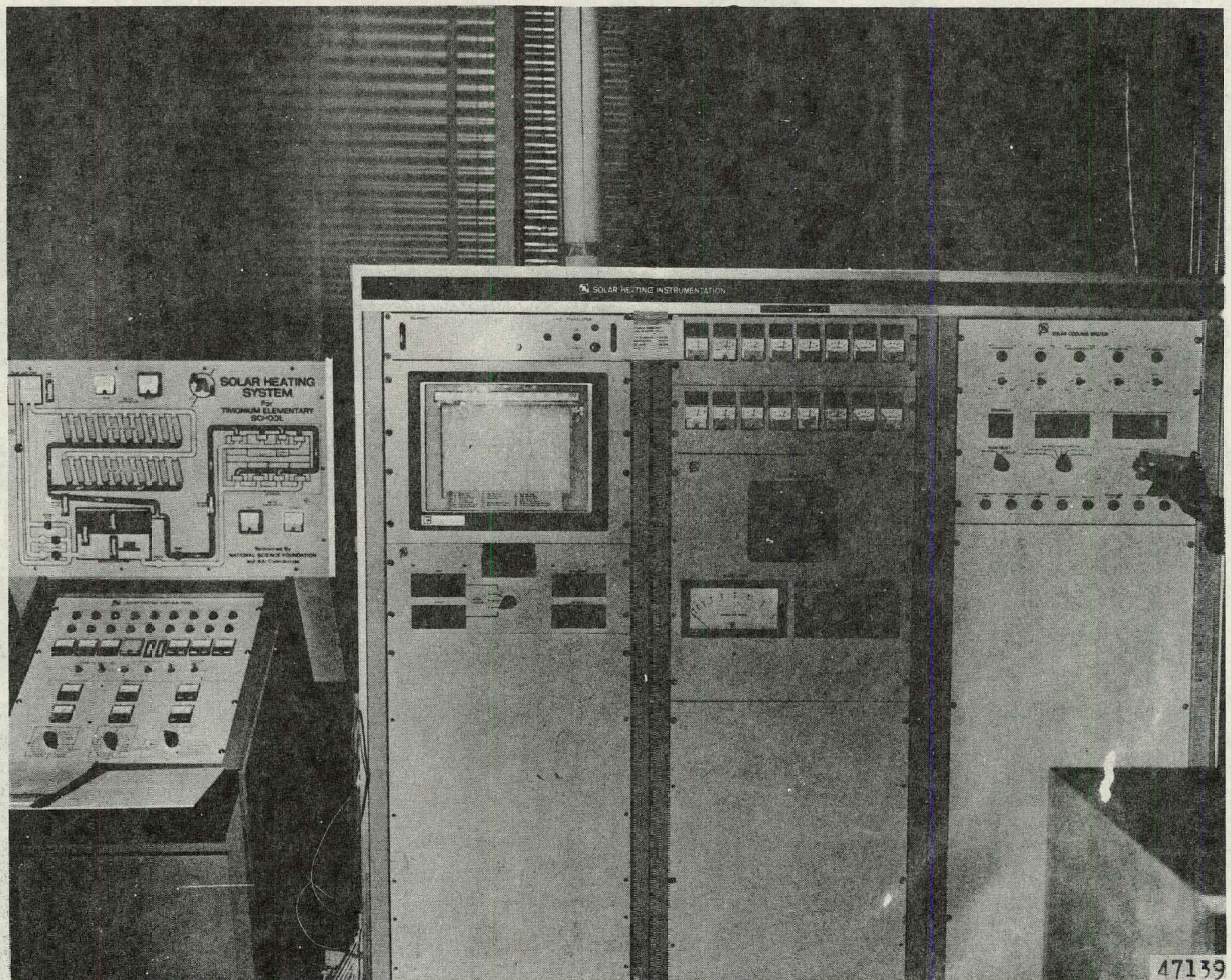


Figure ES-13. Installation of Reflectors



FigureES-14. Solar Heating & Cooling Inst·umentation

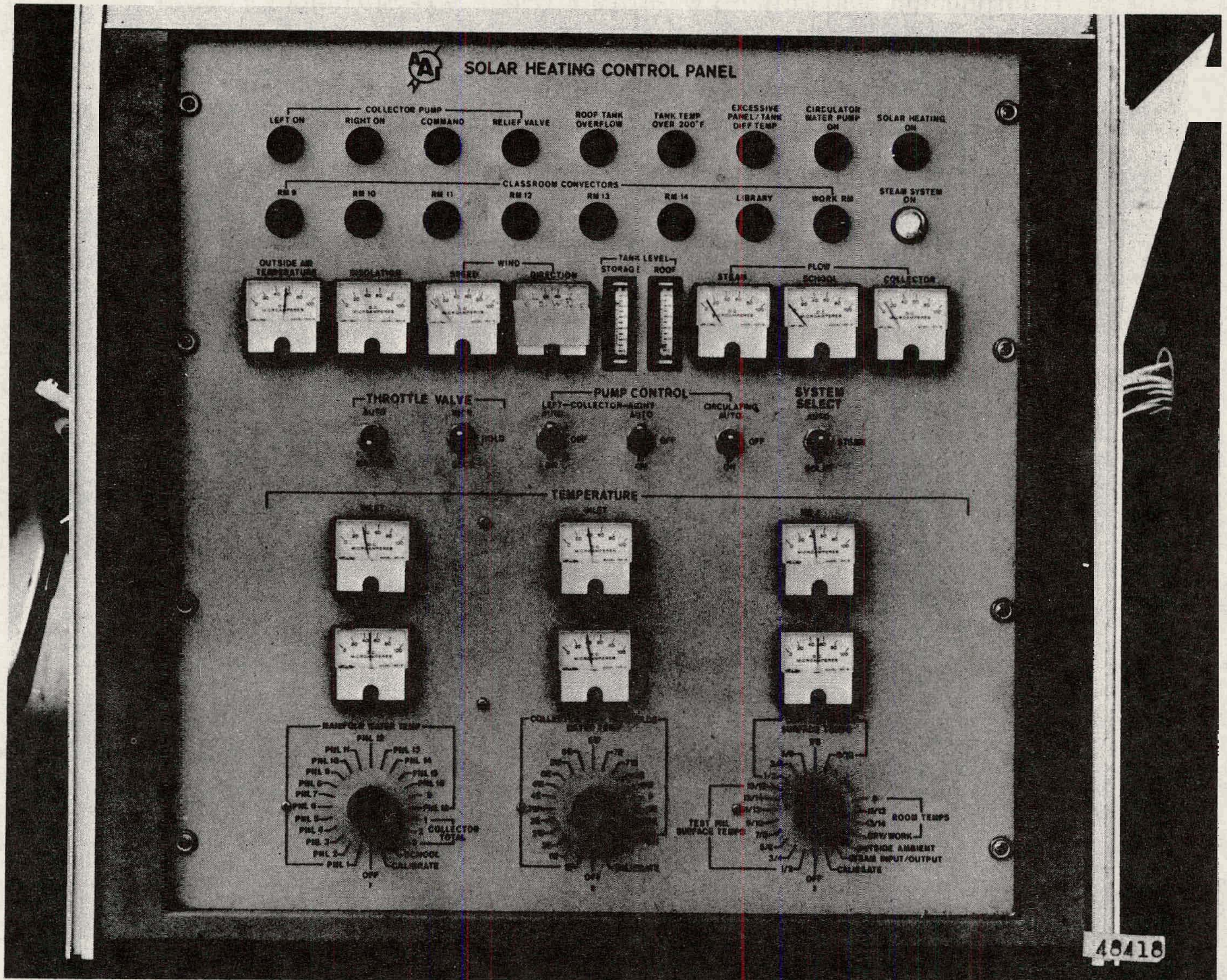


Figure ES-15. Close-Up View of Solar Heating Control Panel

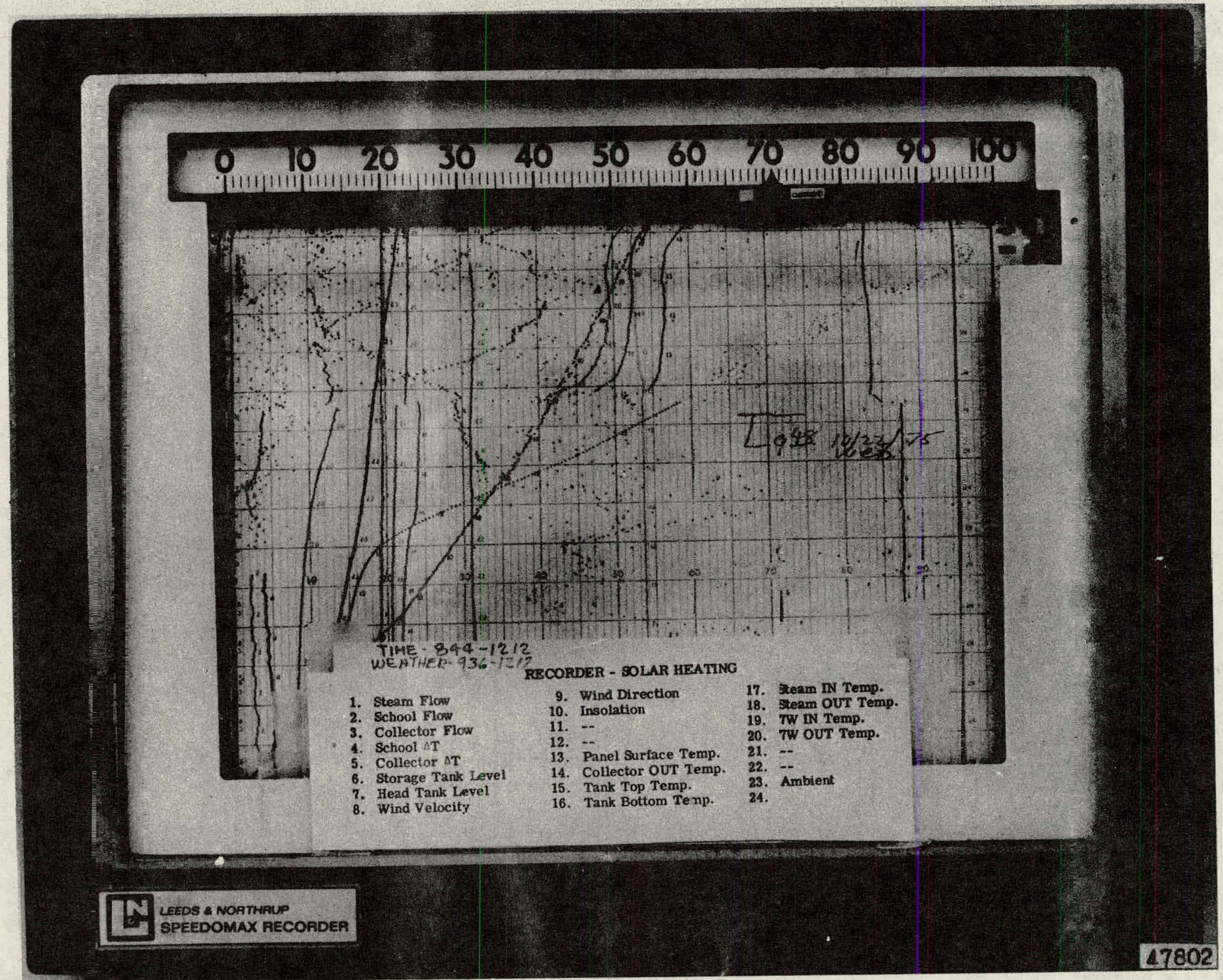


Figure ES-16. Multipoint Recorder

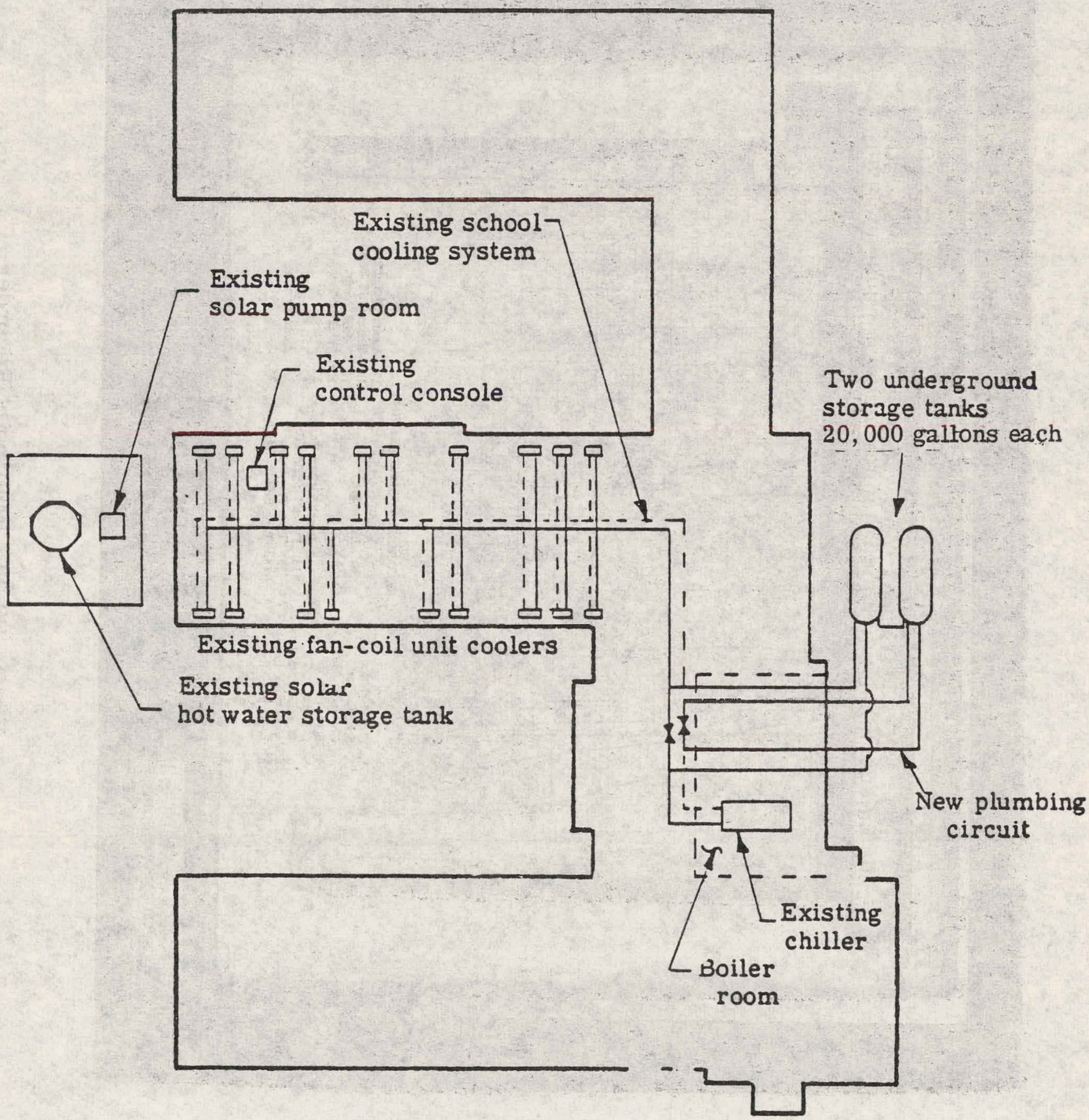
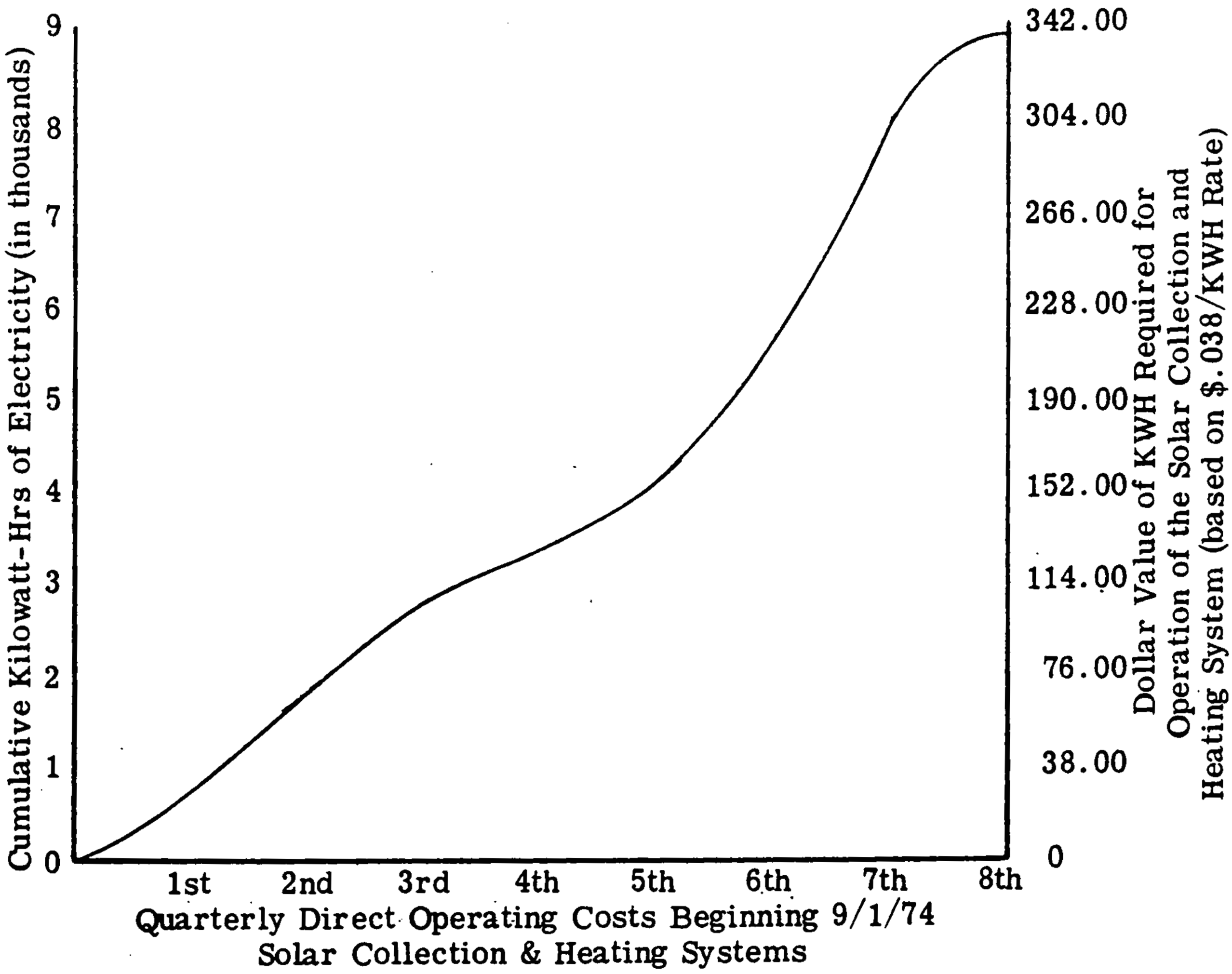


Figure ES-17. Site Layout of Chilled Water Storage Installation at Timonium Elementary School

III. Analysis of Operation

A. Direct Operating Costs of the Solar Collection and Heating Systems

Figure ES-18 shown below shows the cost of the electrical energy required to control and monitor the solar systems (cooling not included) for the period 9/1/74 through Aug. 31, 1976.



Note: Direct operating costs for cooling not included because of "oversized" chiller.

Figure ES-18

B. Fuel Savings

An estimation of the fuel oil savings for the center wing of the school is shown in Table ES-1. This saving was realized by the use of the solar collection and heating system.

TABLE ES-1. ESTIMATED GALLONS OF FUEL OIL SAVED FOR THE PERIOD 1 OCTOBER 1975 THRU 30 APRIL 1976

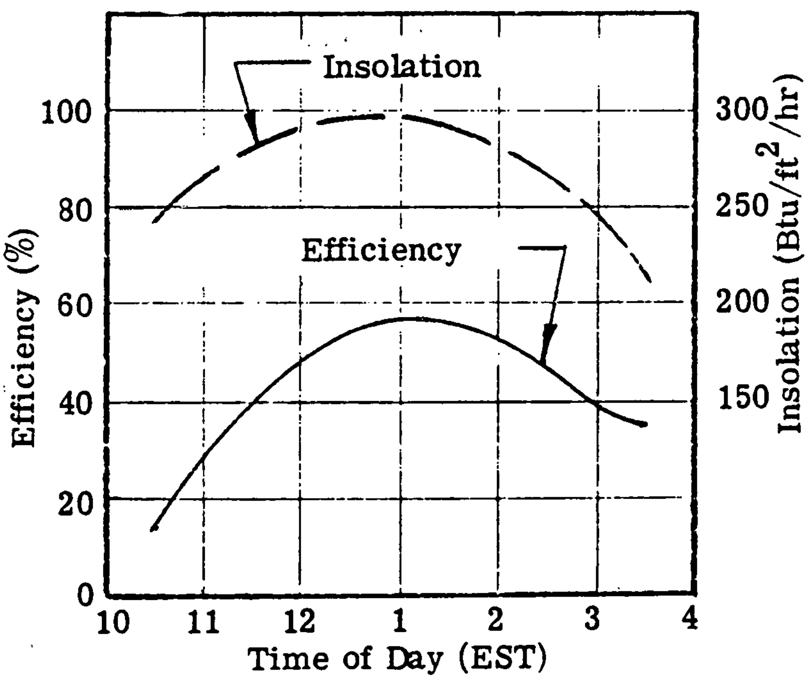
Column	#1	#2	#3	#4	#5	#6	#7	#8	#9
Month of Yr.	Avg. Amb. Temp. °F	Degree Days for Month	Grand tot. oil used by School Pwr Plant (gallons)	Net tot. after allowance for domestic hot water (gallons)	Amt of net tot attributed to center wing only (1/9 of net total) (gallons)	Est. Btu attributed to center wing equals gallons x .65 x 150,000 (btu)	Btu supplied by solar heat to center wing (btu)	% heated by solar	Gallons of oil saved
Oct 75	60°	156	1887	1116	122	11.9×10^6	11.9×10^6	100	124
Nov 75	50°	450	4525	3645	405	39.5×10^6	37.13×10^6	94	381
Dec 75	37°	868	7162	6282	698	68.3×10^6	15.8×10^6	23.1	162
Jan 76	30°	1085	9238	8358	928	90.5×10^6	19.9×10^6	22.0	204
Feb 76	44.1°	603	5281	4401	489	47.7×10^6	27.7×10^6	58.0	284
Mar 76	48.1	518	6000	5120	569	55×10^6	39×10^6	71	404
Apr 76	56.9	293	3010	2130	237	23.1×10^6	23.1×10^6	100	237

C. Solar Efficiencies

Figure ES-19 presents a graph of solar efficiency for the system at Timonium Elementary School. The date, April 17, 1975, was an ideal collecting day. The sky was clear and the wind velocity low. The graph shows how the efficiency rises and falls with insolation for a given water temperature.

Standard Time	Efficiency η	Insolation $I\ (\frac{Btu/hr}{Ft^2})$	Total Sys. Flow (gpm)	Water Temp. $\Delta T\ ^oF$
10:30 a.m.	.16	240	110	3.0
11:00	.32	257	150	8.2
11:30	.39	288	163	6.0
12:30 p.m.	.54	295	163	8.5
1:30	.56	287	160	8.7
2:00	.52	274	140	8.75
2:30	.48	262	130	8.3
3:00	.37	248	116	6.8
3:30 p.m.	.34	210	120	5.2
System turned off @ 3:30 p.m.				

Total collector area equals 4250 ft^2 (No air conditioning reflectors added)



Date: April 17, 1975
A.M. Inlet Water = 146.5^{o}F
P.M. Inlet Water = 161.0^{o}F
Outlet Water @ 160.6^{o}F
Temp. Ambient = 65^{o}F
Wind - 3 mph - North
Weather - Clear

Figure ES-19. Solar Collection System Efficiency
(Prior to addition of reflectors for air conditioning)

D. Heat Input and Output Summary

Figure ES-20 shows a typical day's operation in a Solar Heated school. Note that little or no heat is expended heating the school during the hours of 9:00 a.m. and 4:00 p.m. when the school is occupied by the students. Most of the school heating occurs at night and in the early morning hours.

Figure ES-21 displays a monthly history of the operational performance of the system. Very apparent is the lack of reserve during December and January when all Btu collected was channelled directly into the school.

TYPICAL DAY'S OPERATION OF THE TIMONIUM SOLAR HEATING SYSTEM

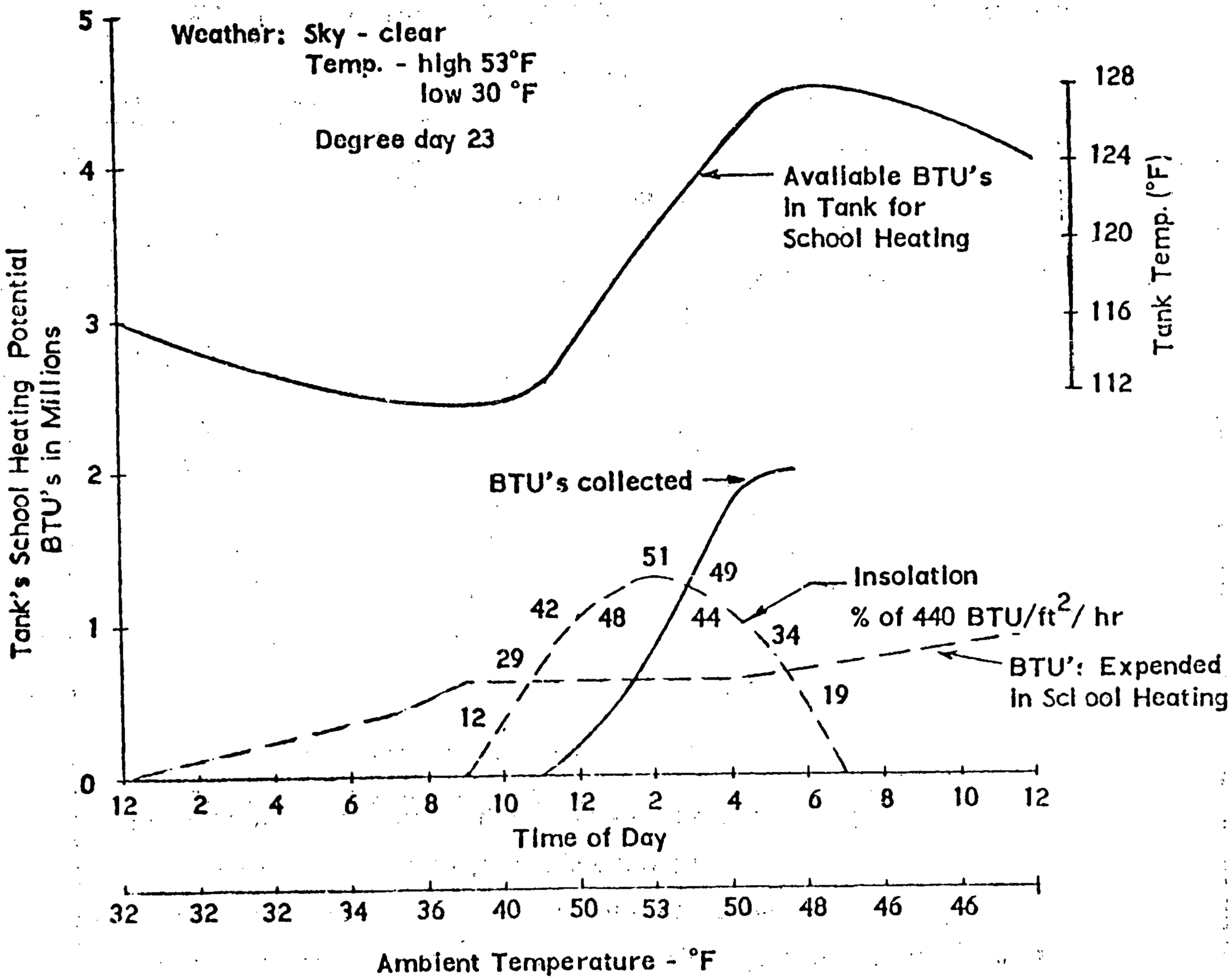


Figure ES-20

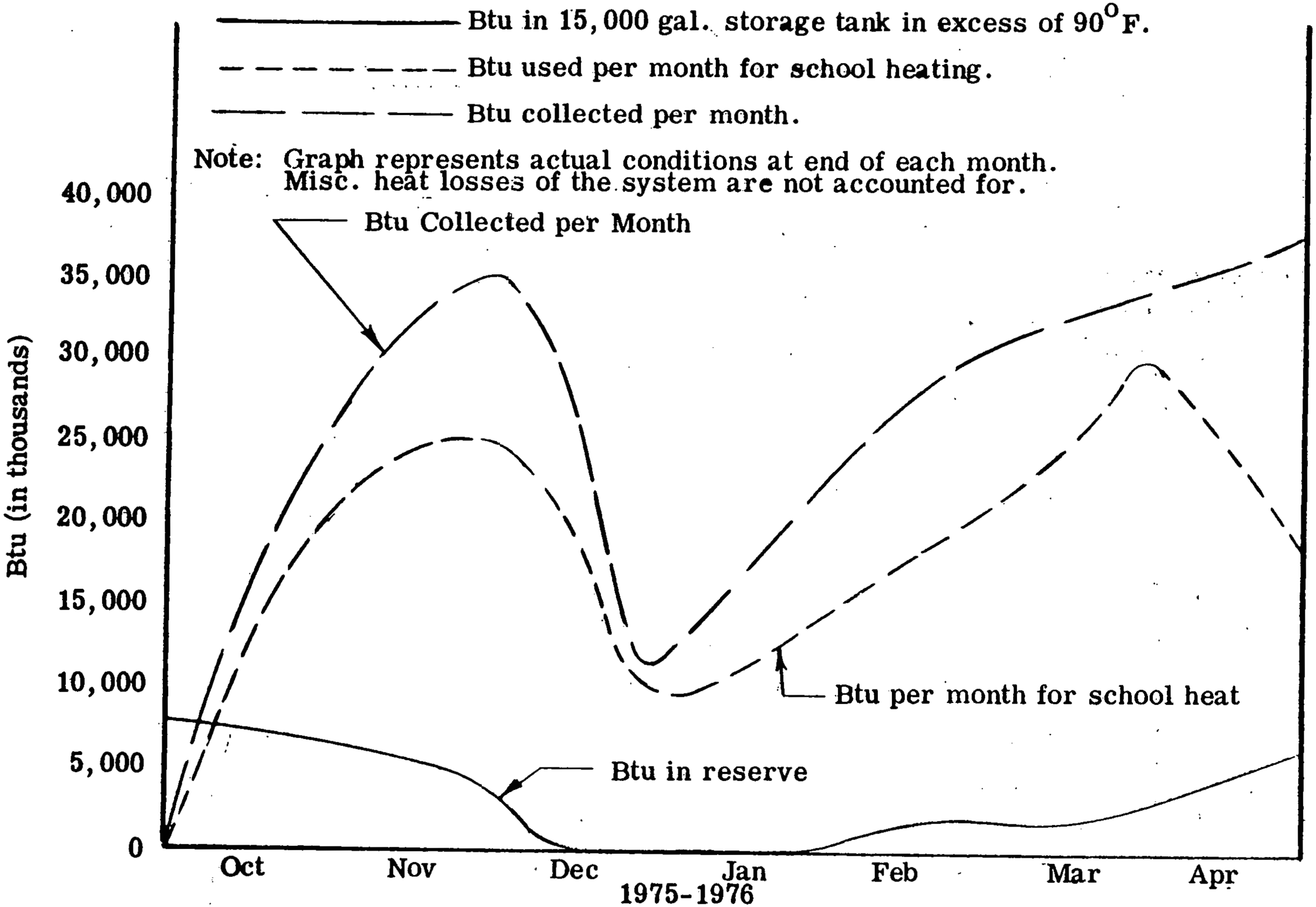


Figure ES-21. Operational Performance of the Timonium Solar Heating and Collection Systems for the period 10/1/75 thru 4/30/76.

E. Solar Air Conditioning

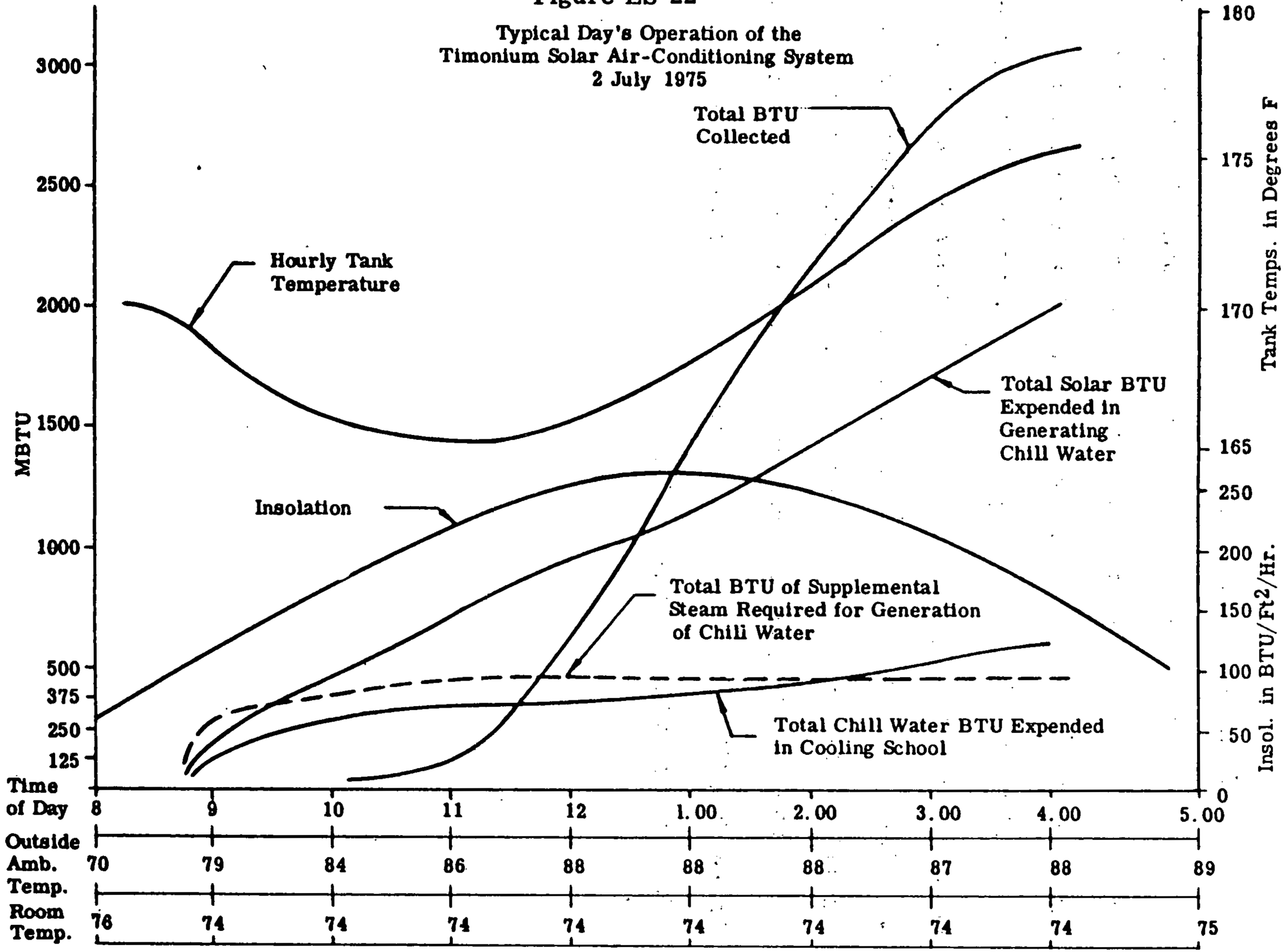
Figure ES-22 shows a typical day's operation of the Timonium Solar Air Conditioning System. The data presented is for July 2, 1975 and represents a day prior to installation of the chilled water storage system.

Figure ES-23 presents the performance of the combined chiller and chilled water storage systems. It shows the total energy required to fire the chiller, the supplementary steam consumed, the amount of cooling from the chiller and the amount of cooling from the chilled water storage tanks.

Figure ES-24 shows the operation of the solar collection system on August 18, 1975. This represents the performance with the collector-reflector combination for solar cooling.

Figure ES-22

Typical Day's Operation of the Timonium Solar Air-Conditioning System 2 July 1975



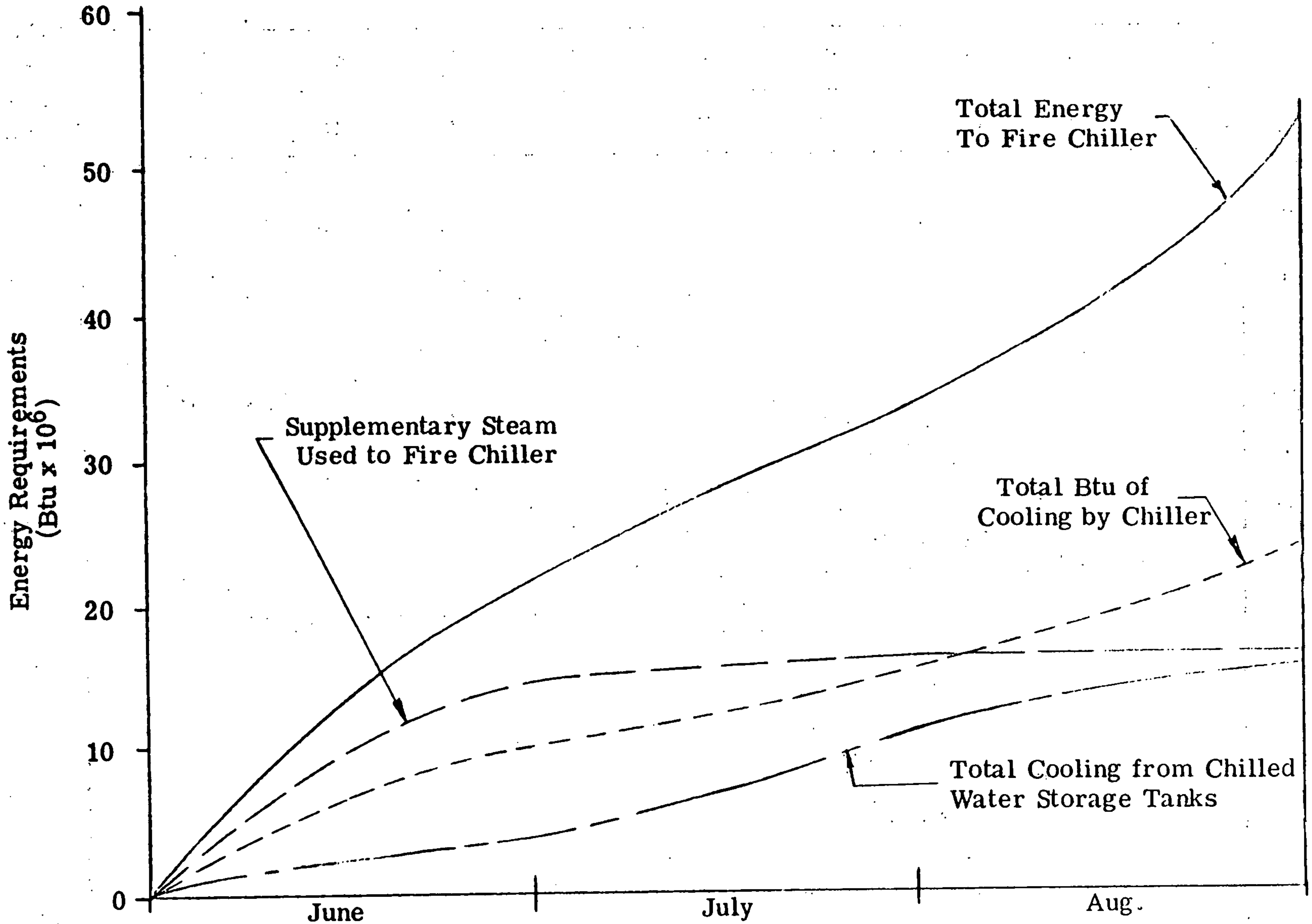


Figure ES-23. Timonium School's Energy Requirements for Period June 1, 1976 thru August 31, 1976

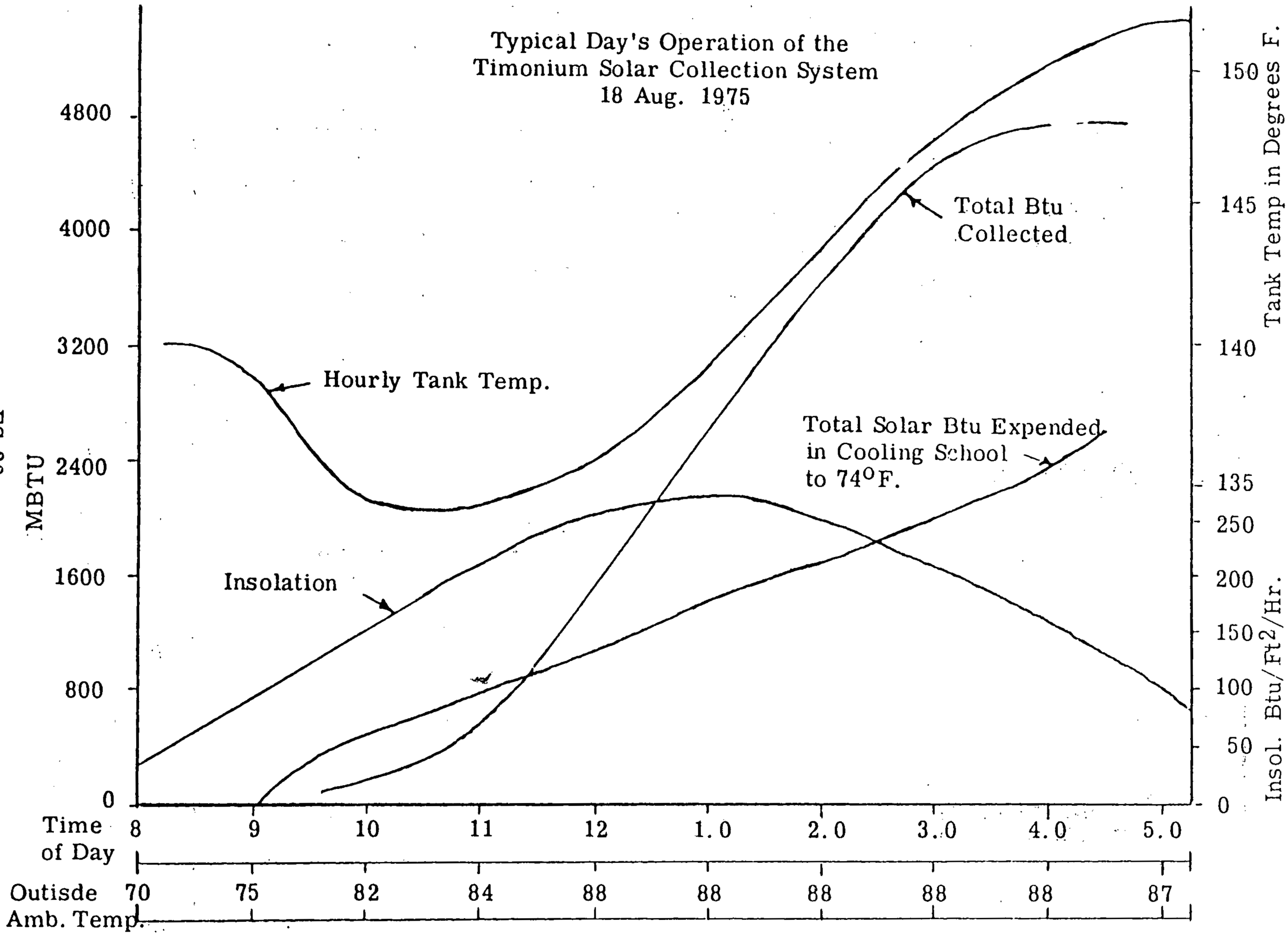

Typical Day's Operation of the
Timonium Solar Collection System
18 Aug. 1975
MBTU
4800
4000
3200
2400
1600
800
0
Tank Temp in Degrees F.
150
145
140
135
Insol. Btu/Ft2/Hr.
250
200
150
100
50
0
Hourly Tank Temp.
Total Btu
Collected
Total Solar Btu Expended
in Cooling School
to 74°F.
Insolation
Time
of Day
8
9
10
11
12
1.0
2.0
3.0
4.0
5.0
Outisde
Amb. Temp.
70
75
82
84
88
88
88
88
88
87

Figure ES-24

F. Chilled Water Storage Tank Temperature

Figure ES-25 presents the variation of the water temperature in the chilled water storage tanks for one week's cooling of the center wing of the school. The week presented is August 23 through August 29, 1976.

The heat gain during storage is the temperature increase of the stored water with no flow either in or out.

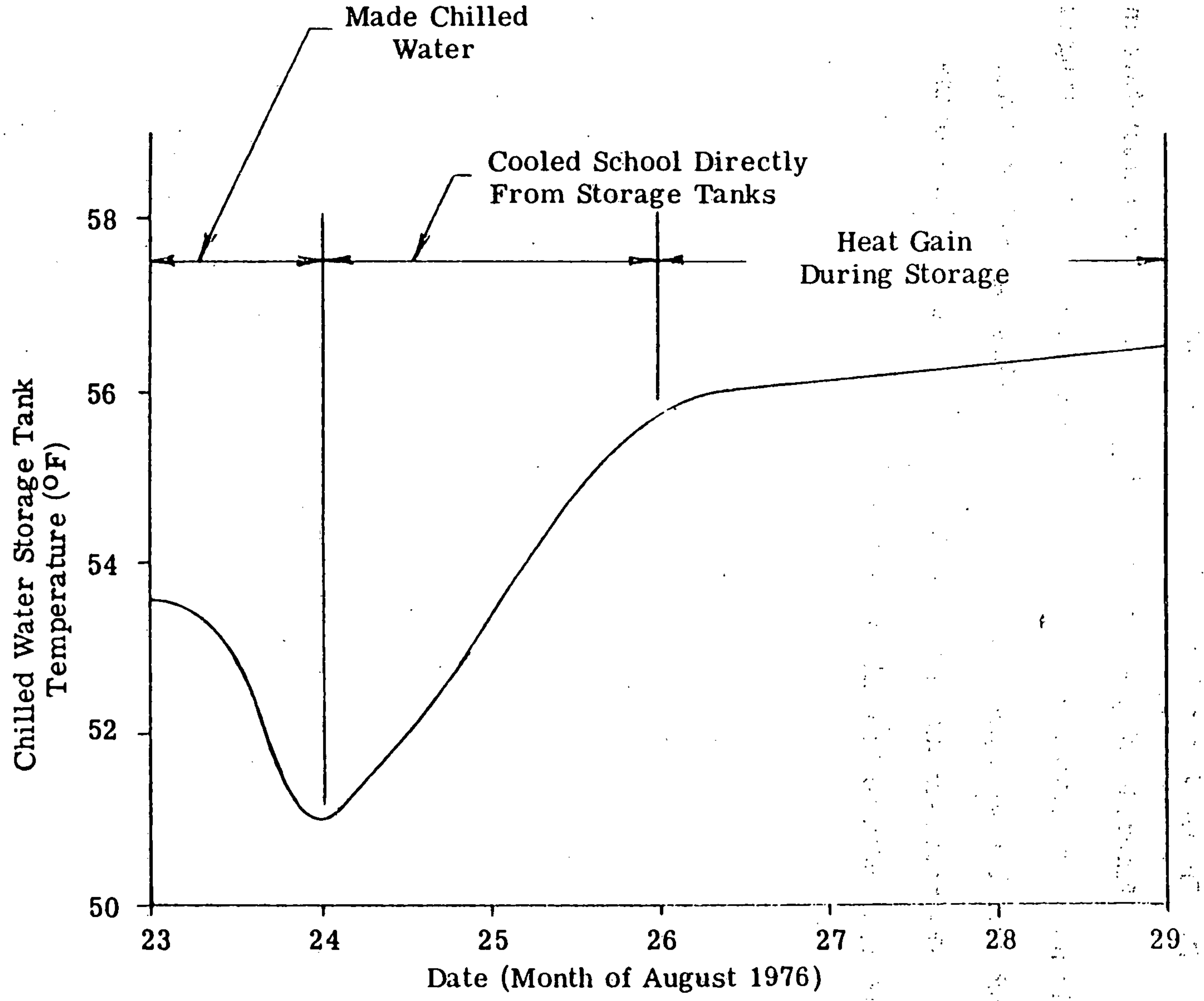


Figure ES-25. Variation of Chilled Water Storage Tank Temperature During a Typical Week's Use of the Timonium School's Solar Air Conditioning System

IV. Recommendations

A. Recommendations for Modifications to the System to Improve Performance or Producibility

- Improved System Performance

1. Improve the collector efficiency by using selective coatings.

2. Minimize glass cracking of the collectors by utilizing tempered glass and by designing the collectors to allow free glass movement to permit differential expansion of the collector parts.

3. Improve the collection efficiency by controlling the water stratification in the holding tank to allow the coldest possible water to be pumped to the collectors.

4. Strive for equal water distribution to all collectors over the range of minimum to maximum flow.

5. Provide the shortest possible distance between the hot water holding tank and the flat-plate collectors to minimize the energy lost in heating up pipes. Also keep pipe diameters to a minimum. This is particularly important at the higher water temperatures required for air conditioning.

6. Provide an automatic control logic for early morning start-up of the collector pumps, that will allow the flow to the collectors to quickly reach a steady state of positive collection.

7. Minimize heat losses due to gravity flow between the holding tank and the collection and heating system plumbing in the school by providing isolation of the holding tanks during periods of inactivity.

- Reduce Heat Loss by Radiation

  1. Provide increased insulation for the plumbing and holding tank, particularly if high temperature water is to be stored.

  2. Locate the hot water holding tank in an environment that will maintain a minimum temperature gradient during the heating and cooling seasons.

  3. Locate the collector supply and return plumbing in the building to reduce the temperature gradient between the piping and its environment.

- Improved Producibility

  1. Utilize standard steel or concrete tank for water storage.

  2. Simplify and reduce the plumbing in the pumping station as follows:

     a. Use threaded connections rather than flanges except at the interfaces of the plumbing modules.

     b. Utilize one pump and the associated components in the collector pumping station rather than the dual set-up being currently used.

V. Conclusions

1. The solar collection system at Timonium, Maryland consists of flat-plate collectors whose water is supplied by an overhead gravity-fed plumbing system. The Proof-of-Concept Experiment to solar heat and cool a public school building has resulted in the following general principles that can be applied to the future development of similar systems:

- o The heating and cooling of public school buildings through the utilization of solar energy is possible but not presently cost effective in the Timonium locality.

- o Chilled water storage provides the following operational advantages:

  a. It can provide cooling when solar heated water is unavailable to operate a chiller.

  b. It provides the option of operating the chiller when electrical costs are minimum.

  c. Limited tests indicate that thermal losses in well insulated storage tanks appear to be about one-fourth that of stored hot water. (The COP of the chiller must be considered.)

  d. Chilled water storage provides a back-up system when the chiller requires servicing.

  e. A combined chiller and storage system allows the flexibility of handling peak cooling loads for short periods with smaller cooling equipment. However, each application of chilled water storage should be studied separately to determine its actual cost effectiveness.

- o Flat-plate collectors are sufficiently efficient to warrant further development as solar energy collection devices.

- Flat-plate collectors with reflectors can provide the hotter water needed to operate absorption-type air conditioners. This combination increases the energy collected, and the daily utilization of the sun from sunrise to sunset. As retrofits, the cost of installing reflectors is not cost effective.

- Systems such as the one at Timonium Elementary School can use ordinary water without antifreeze additives.

- The all-aluminum collectors (utilizing water deionized one time only) show no evidence of corrosion in 2-1/2 years of operation.

- The epoxy adhesives exposed to the solar and hot water environments within the flat-plate collectors do degenerate.

- The absorber plate coating showed evidence of wearing thin in the 2-1/2 years of operation.

- In 2-1/2 years of operation there is no obvious evidence that untreated solar heated water cannot be pumped directly to hot water heating and cooling systems. Periodic chemical analyses of water samples taken from the reservoir show no evidence of algae or fungus growth.

- Deionized water is an effective medium for storing solar energy.

- Insulation is extremely important in minimizing the radiation losses of the collectors, the plumbing, and the storage reservoir.

I. Introduction

On January 14, 1974 AAI Corporation received Contract No. NSF-871 from the National Science Foundation to conduct a Solar Heating Proof-of-Concept Experiment (POCE) for a public school building. This was later modified to include solar cooling.

The Fnergy Research & Development Administration acquired authority for management of the program on January 19, 1975 and the contract number was changed to E(11-1)-2627.

The total cost of the experiment was $1,156,384, of which AAI's share was $32,369 and the government's share was $1,124,015. The work performed during the Timonium experiment was authorized by subsequent amendments to the contract.

The first phase began January 14, 1974 and continued through May 15, 1974. The initial contract authorized the design, fabrication, erection, operation and maintenance of a solar heating system.

The second phase was initiated May 16, 1974 by amendment #2 to the contract. This authorized improvements to the instrumentation system and continued operation of the original solar heating system through May 15, 1975.

The third phase of the program was initiated October 11, 1974 by amendment #3 to the contract. This authorized the modifications to adapt the system to include solar cooling. It also extended operation of the combined system through October 15, 1975.

The fourth phase of the program was initiated June 25, 1975 by amendment #4 to the contract. It authorized the modifications required to adapt the solar cooling system to include chilled water storage.

The contract was extended from October 15, 1975 through October 15, 1976 by amendment #5 to the contract. This provided the time needed to evaluate the modifications authorized by amendment #4.

Amendment #6 to the contract was received on June 21, 1976. This authorized preparation of a report in the Special Reporting Format Aspect of the NATO CCMS (Committee on the Challenges of Modern Society) Solar Energy Pilot Study.

The initial objective of the contract was to provide a means of utilizing solar energy to heat public school buildings. Subsequent amendments sought to improve the cost effectiveness of flat-plate collector systems by permitting more extensive use of the annual solar cycle, i.e., to operate the system throughout the summer for solar cooling.

The operating characteristics of the fixed collectors as they were related to solar heating and their potential for solar cooling were identified in the summer and fall of 1974. The use of fixed reflectors in conjunction with the fixed collectors, provided the means required to consistently collect water hot enough to power an absorption chiller. The absorption chiller was authorized in the spring of 1975. The feasibility of cooling (the firing of an absorption chiller with solar heated water) was demonstrated in the summer of 1975, thus permitting more utilization of the annual solar cycle.

Still another objective of the Timonium experiment was to determine the relative performance levels of both chilled and hot water storage systems in an operational environment. A chilled water storage system was authorized and installed in the winter of 1975 and spring of 1976. Data was collected during the summer of 1976.

The Timonium experiment was concluded October 15, 1976 and control and operation of the system assumed by the Baltimore County Board of Education.

II. WORK ACCOMPLISHED

The work performed for the Timonium School project was accomplished in the phases noted in the Introduction of this report. The state of the art was such that functional components for use in the cooling system were not commercially available. This pertained particularly to a hot-water-fired absorption air conditioner needed to match the anticipated cooling loads.

In order to demonstrate the feasibility of cooling by utilization of solar energy, an oversized standard chiller was modified to be powered with hot water at $187^{\circ}F$ or less. The cooling loads did not exactly meet expectations, consequently the absorption air conditioner functioned far below its modified capacity and resulted in reduced efficiency, thus using abnormal quantities of hot water. However, the principle of cooling by utilization of solar energy was successfully demonstrated; also the principle that absorption-type air conditioners could be fired with hot water at or below $187^{\circ}F$ without crystallization.

The continuity of all test results from this experiment was interrupted by the major construction additions throughout the program. The data presented in this section are summaries actually experienced for the periods indicated and any unusual results should be interpreted with the knowledge that constant experimentation with system parameters was taking place.

A. System Design

The design consists of four major subsystems. They are the solar collection and heating system, the air-conditioning system, the chilled water storage system, and the instrumentation and controls.

The total system is composed of the following elements:

- The Timonium Elementary School (Center Wing)
- 180 Flat Plate Collectors with a total effective area of 4200 ft^2 and 162 reflectors with a total effective area of 5300 ft^2.
- Supporting Structure
- Pump House and Plumbing System for Solar Collection and Heating.
- 15000 Gallon Insulated Hot-Water Storage Tank.
- The Class Room Unit Heaters
- Plumbing System for Air Conditioning
- 150 Ton Absorption Unit (modified to 50 tons with 187^{o}F hot water)
- Heat Exchanger
- Cooling Tower
- Two 20,000 Gallon Chilled Water Insulated Storage Tanks.
- Instrumentation and Controls for all Subsystems.

NOTE: Auxiliary heat and power was provided by the school's boilers which used #6 fuel oil to generate 5 to 12 psi steam.

1. Timonium Elementary School

The Timonium Elementary School, located at 2001 Eastridge Road in Timonium, Maryland, was chosen as the site for the AAI Proof-of-Concept Experiment. This school is representative of many United States schools, and is one of more than 300 in the State of Maryland. It is basically a one-story school with window walls on one side of each room.

Figure 2-1 shows an artist's concept of the school. The center wing was chosen for the solar experiment. The heating requirements for the remaining wings, heated by oil-fired boilers, could then be compared to the wing heated by solar energy. The total area of the school is 60,000 square feet, and the area of the solar-heated wing is 8,500 square feet.

The solar heating system, as built for the Timonium Elementary School, meets all structural and safety requirements. The design was approved by the Baltimore County School System.

Figure 2-2 shows an external view of the center wing after installation of the collection system. Figure 2-3 shows the general arrangement of the major elements of the collection system. Drawing No. 57413-40114 in Appendix I shows the piping arrangement to the classroom unit heaters.

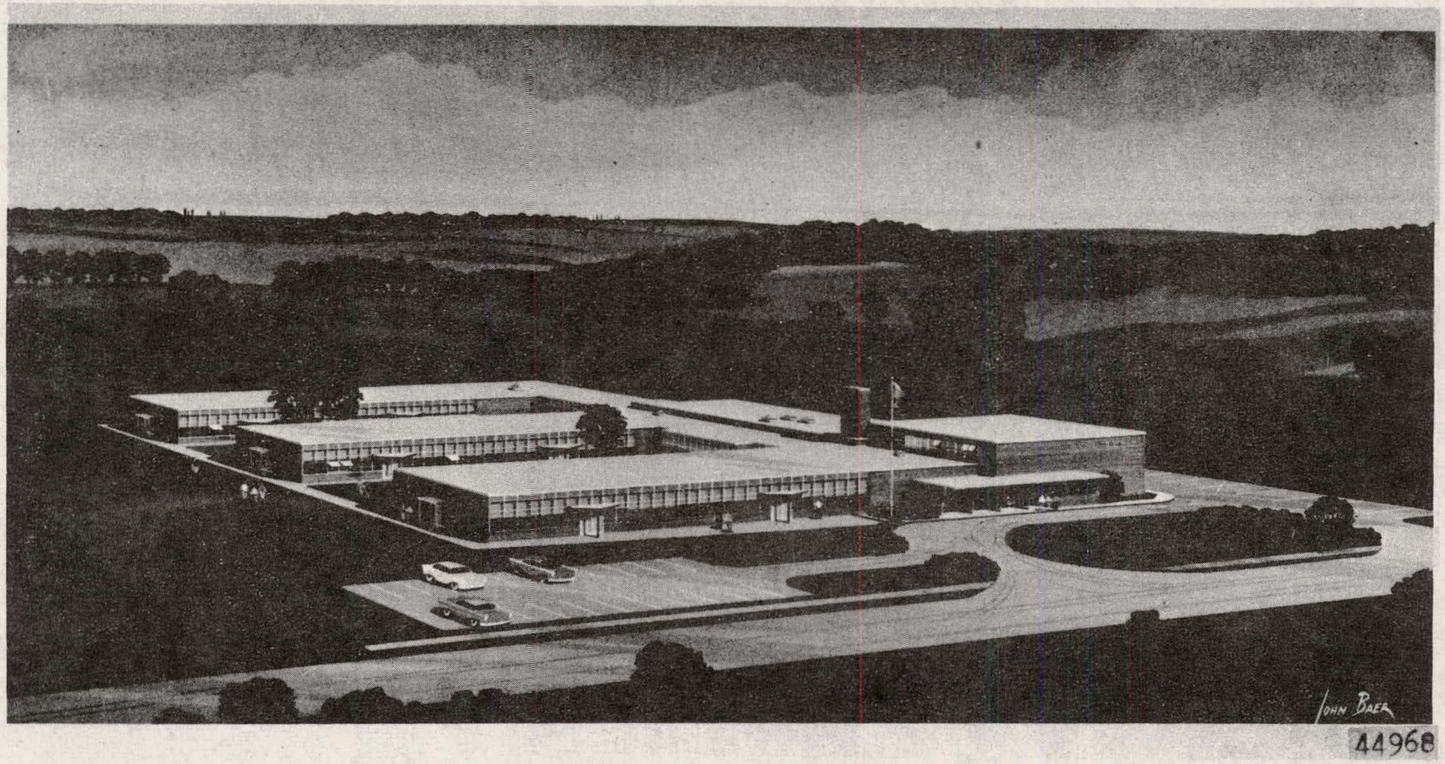


Figure 2-1. Artist's Concept of Timonium Elementary School

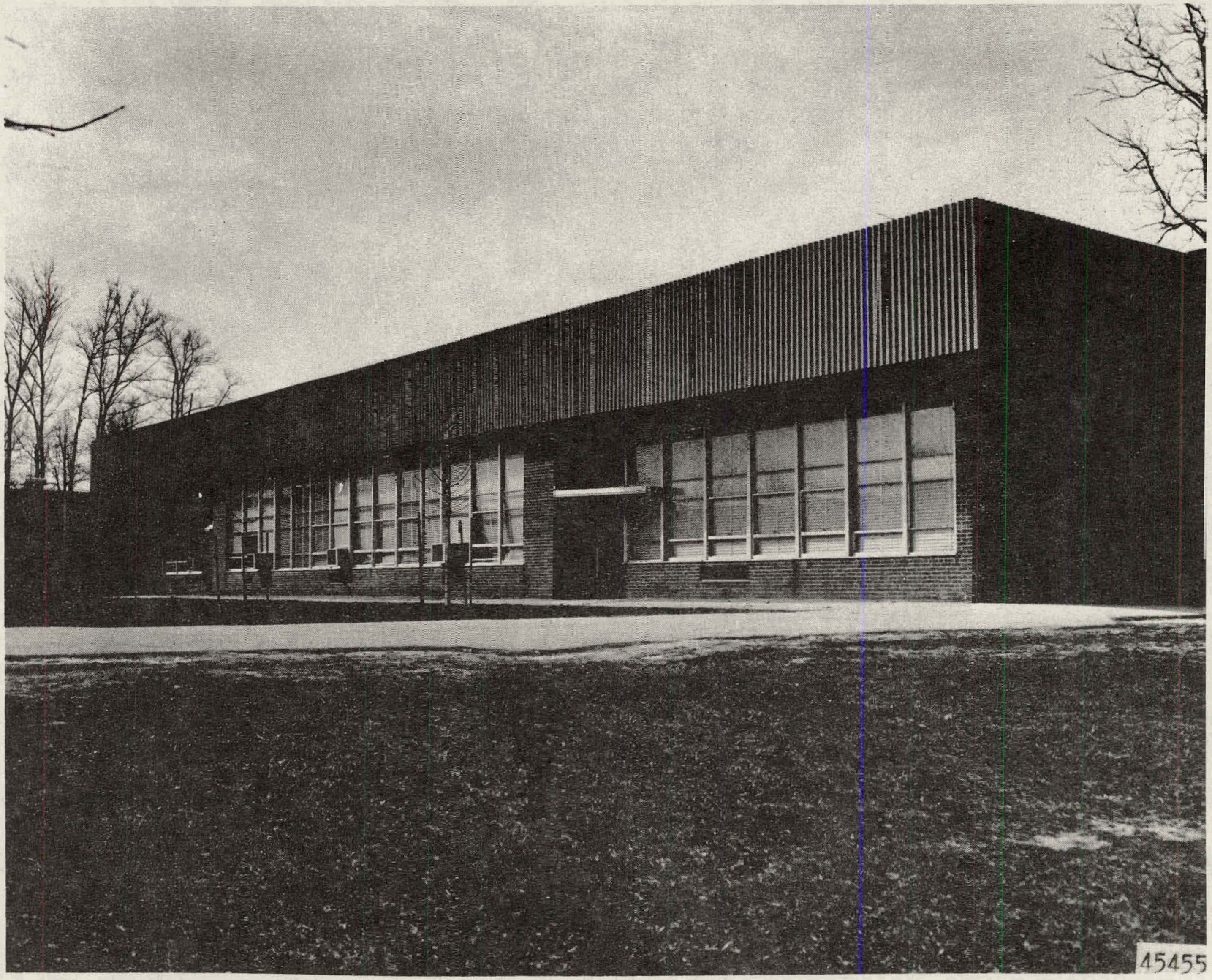


Figure 2-2. Center Wing of Timonium Elementary School After Installation of the Solar Heating Experiment

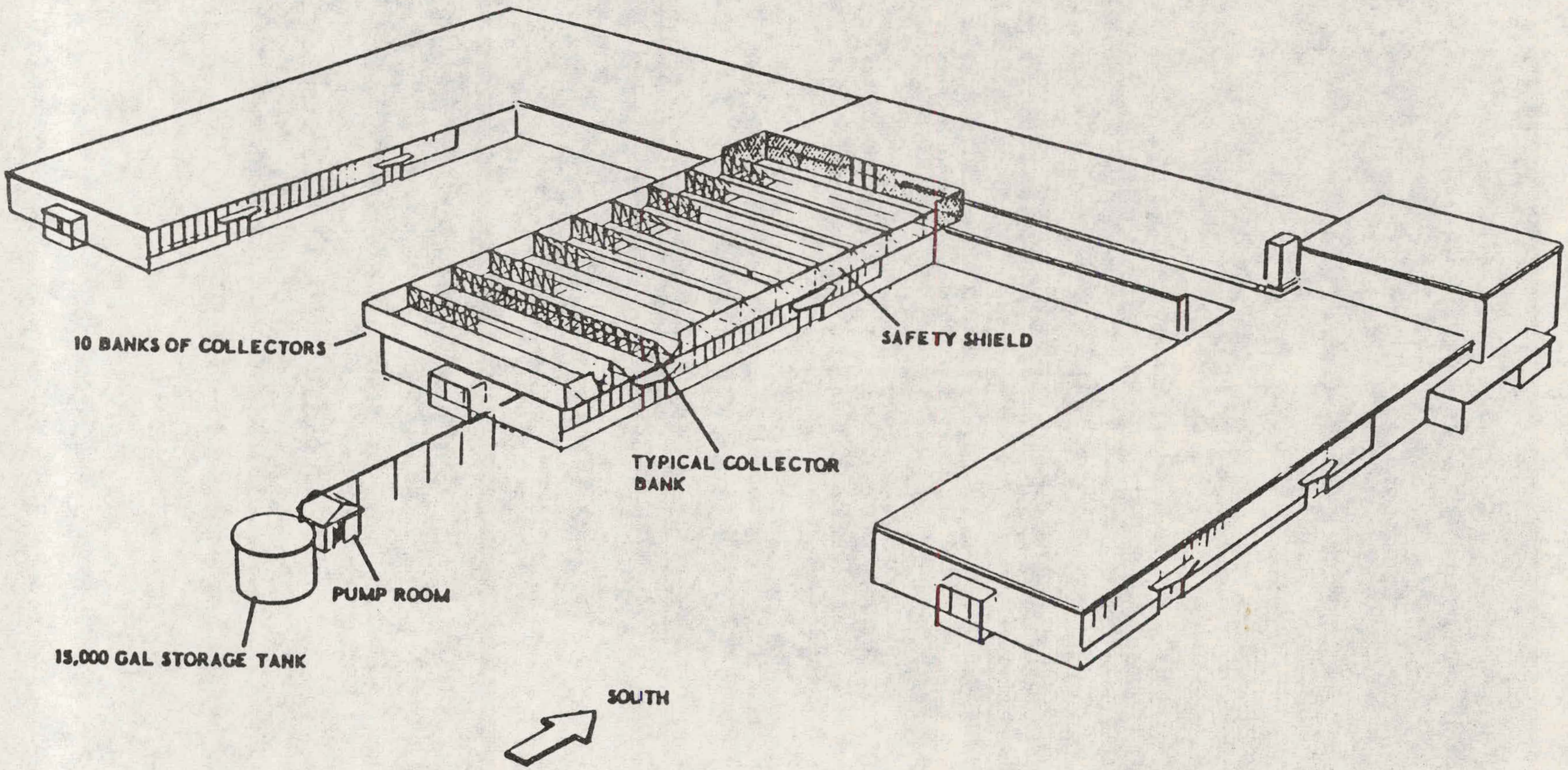


Figure 2-3. Solar Energy Experiment
Timonium Elementary School

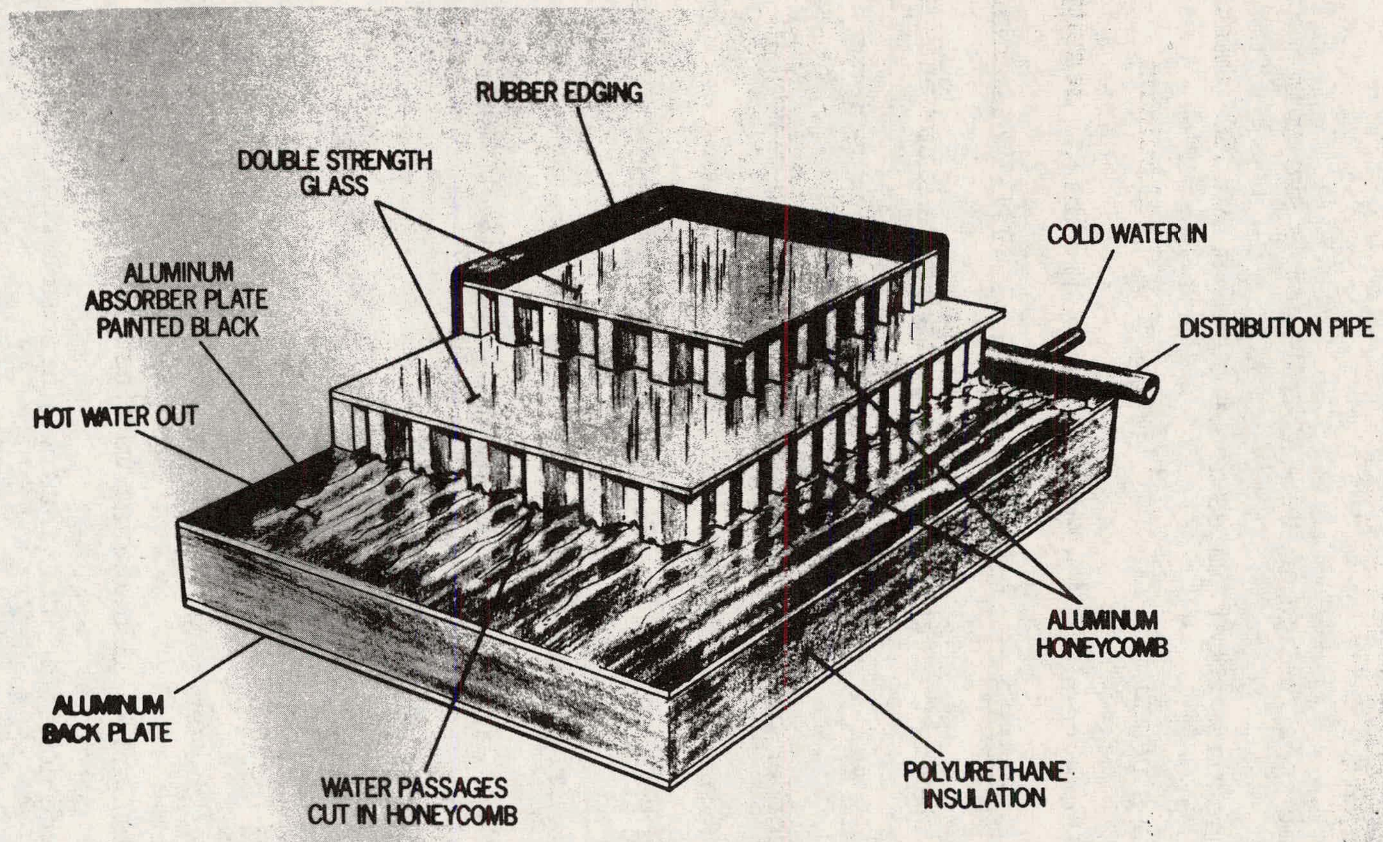
2. Solar Collectors and Reflectors

The basic construction of the AAI collector is shown in Figures 2-4 and 2-5. The glass cover plates are 4 ft by 7 ft by .100" thick low-iron-content, double-strength glass. Two layers of 3003 aluminum alloy commercial grade honeycomb (3/4" cell, .625" high, 1.8 lbs/ft^3 density) are used between the glass covers and the black .032" thick 6061-T6 aluminum alloy absorber plate. Notches are cut in the honeycomb where it contacts the absorber plate (see Figure 2-4). This permits water flow from the distribution pipe down the absorber to the return plumbing. A one-and-one-half inch thick polyurethane foam (2 lb per cubic foot) sheet of insulation is bonded to the back of the absorber plate. The front of the absorber plate is coated with black epoxy paint, BRU-TECT II, whose two parts, A-301 and B-316, are mixed equally. After polyurethane foam edging is applied, a rubber strip is applied to the edges of the collector.

The AAI collector is 4.0 ft by 7.0 ft by 2-3/8 inches thick and weighs about 90 lbs (see Figure 2-6).

Figure 2-7 shows the ten rows of eighteen collectors after they were installed on the roof, but before the plumbing was installed.

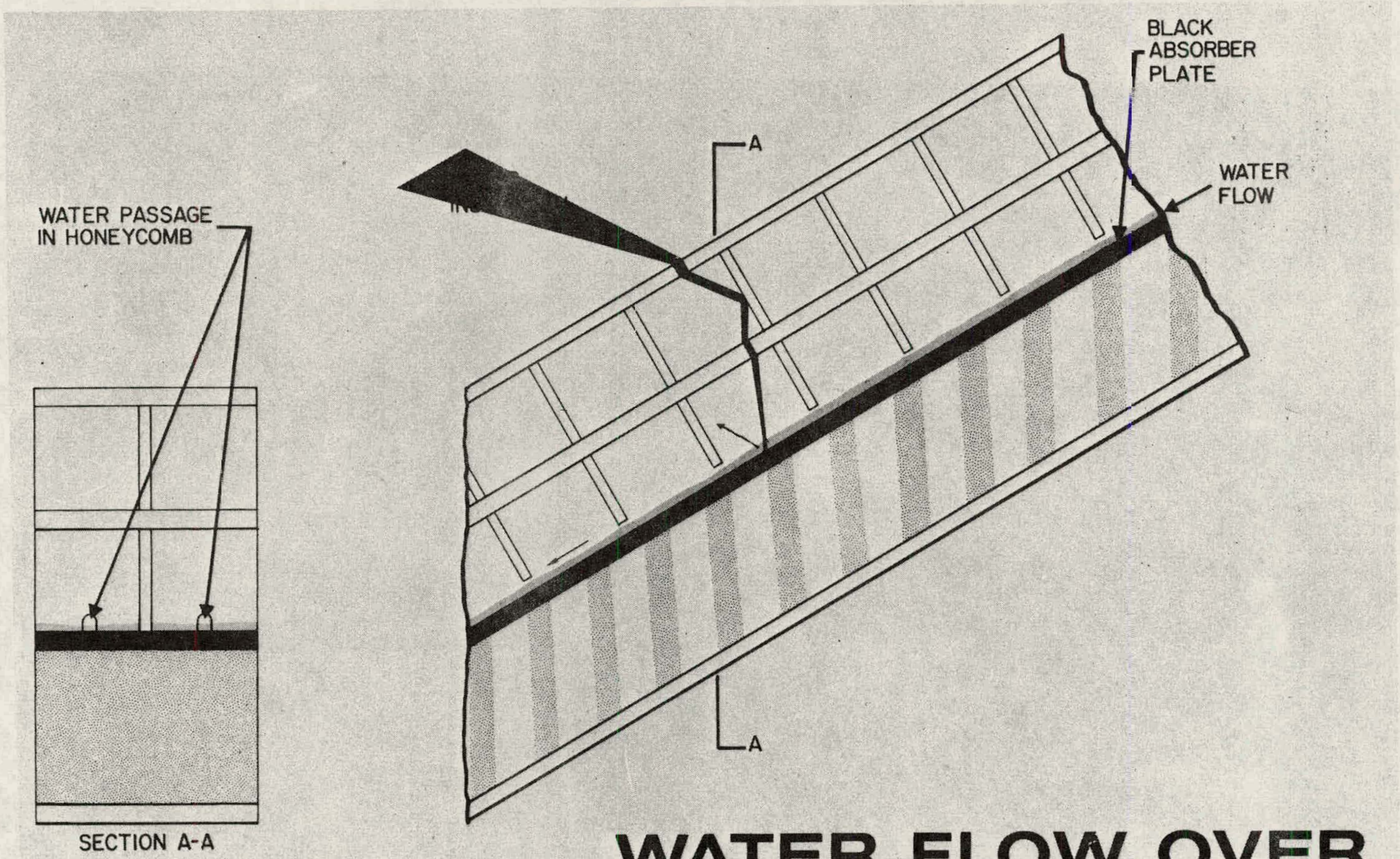
Water is fed to the collector from the top, through a rubber hose and is connected into a return duct at the bottom by a rubber hose.



CROSS-SECTION OF AAI SOLAR COLLECTOR

46527

Figure 2-4



WATER FLOW OVER ABSORBER PLATE ON AAI SOLAR COLLECTOR

46524

Figure 2-5

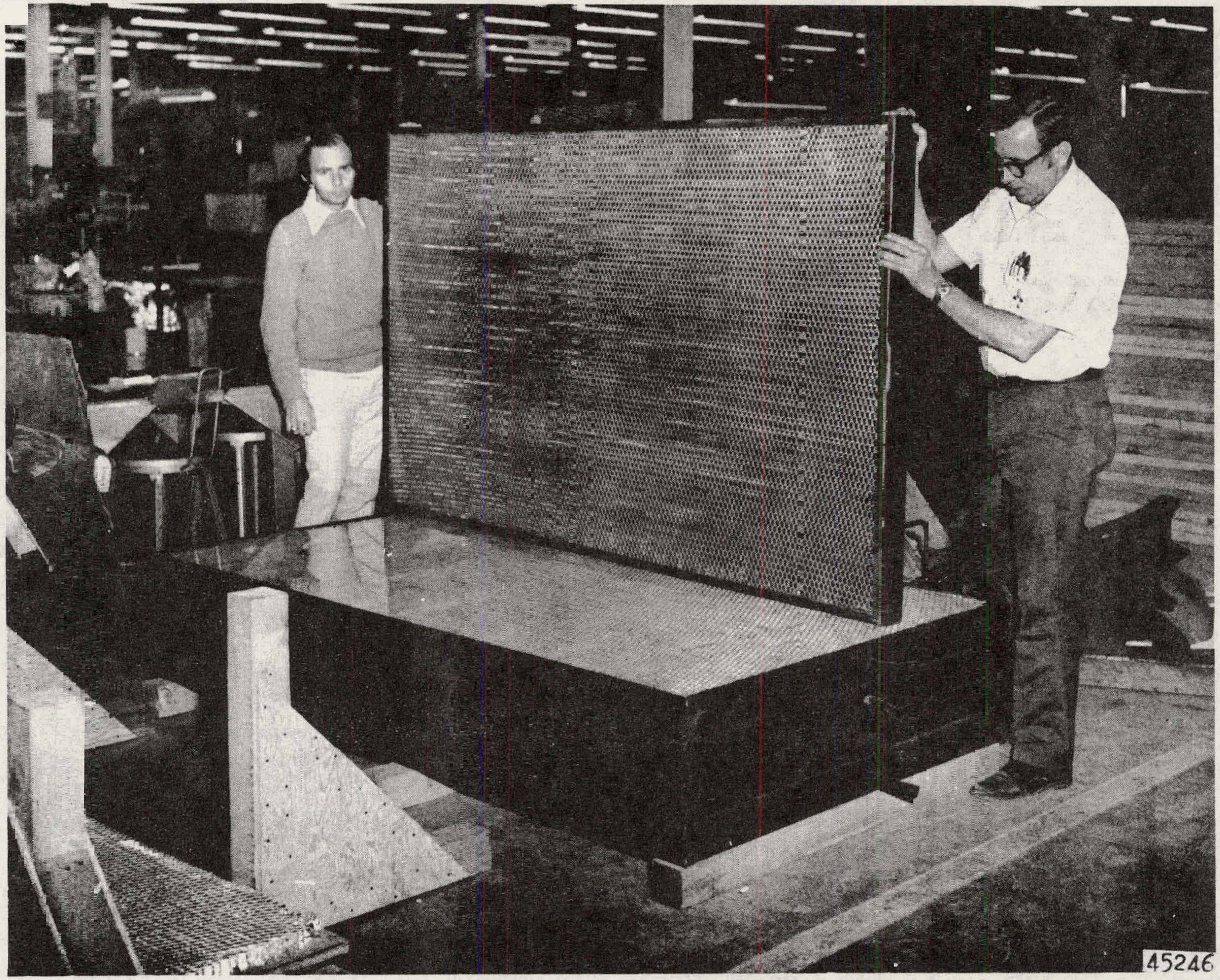


Figure 2-6. Solar Collectors in Manufacturing Area

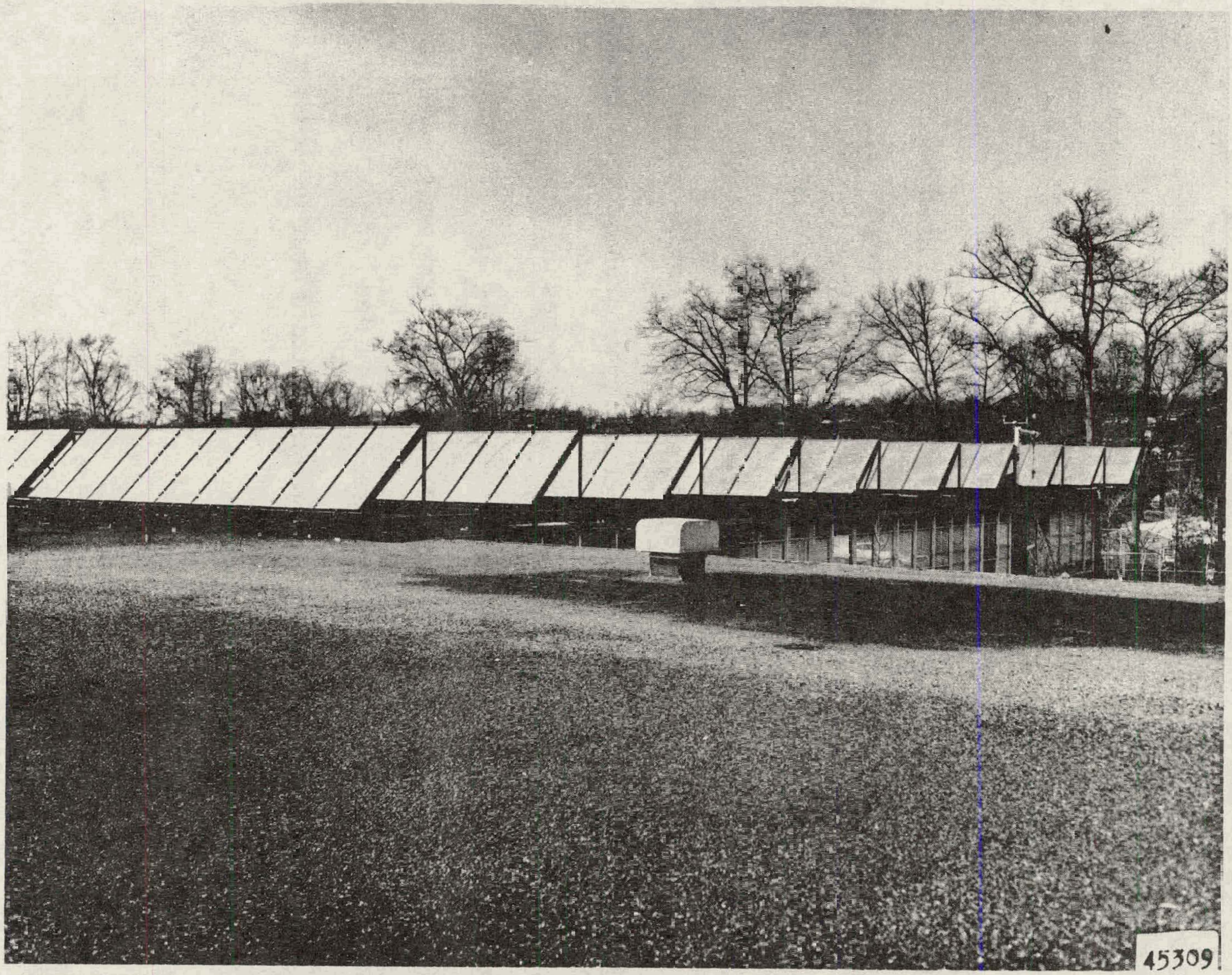


Figure 2-7. Collectors Mounted on Roof Before Installation of Plumbing

There are 180 collectors installed on the roof of the center wing of the school. They are mounted at a 45^{o} angle to the horizontal and face due south. The effective collection area is 4200 square feet. One-hundred-sixty-two (162) reflectors (5,300 ft^{2}) were later installed to permit air conditioning of the center wing. The reflectors are made of .100 inch thick float glass with a silver second surface that is protected by an epoxy coating. Each reflector is mounted opposite and facing the collector (see Figure 2-8). All reflectors are installed at a fixed 34^{o} angle to the horizontal facing north.

The reflectors direct additional solar energy onto the collectors. This extra energy boosts the collector output and produces water temperatures of $180^{o}F$ to $200^{o}F$. This hot water then provides the energy needed to power the absorption chiller. See Figure 2-9 for schematic arrangement of the reflector-collector combination. The glass reflectors are mounted on steel trusses. The trusses were lifted into position by a crane. Aluminum corrugated sheets were then placed over the truss to provide support for the mirrors.

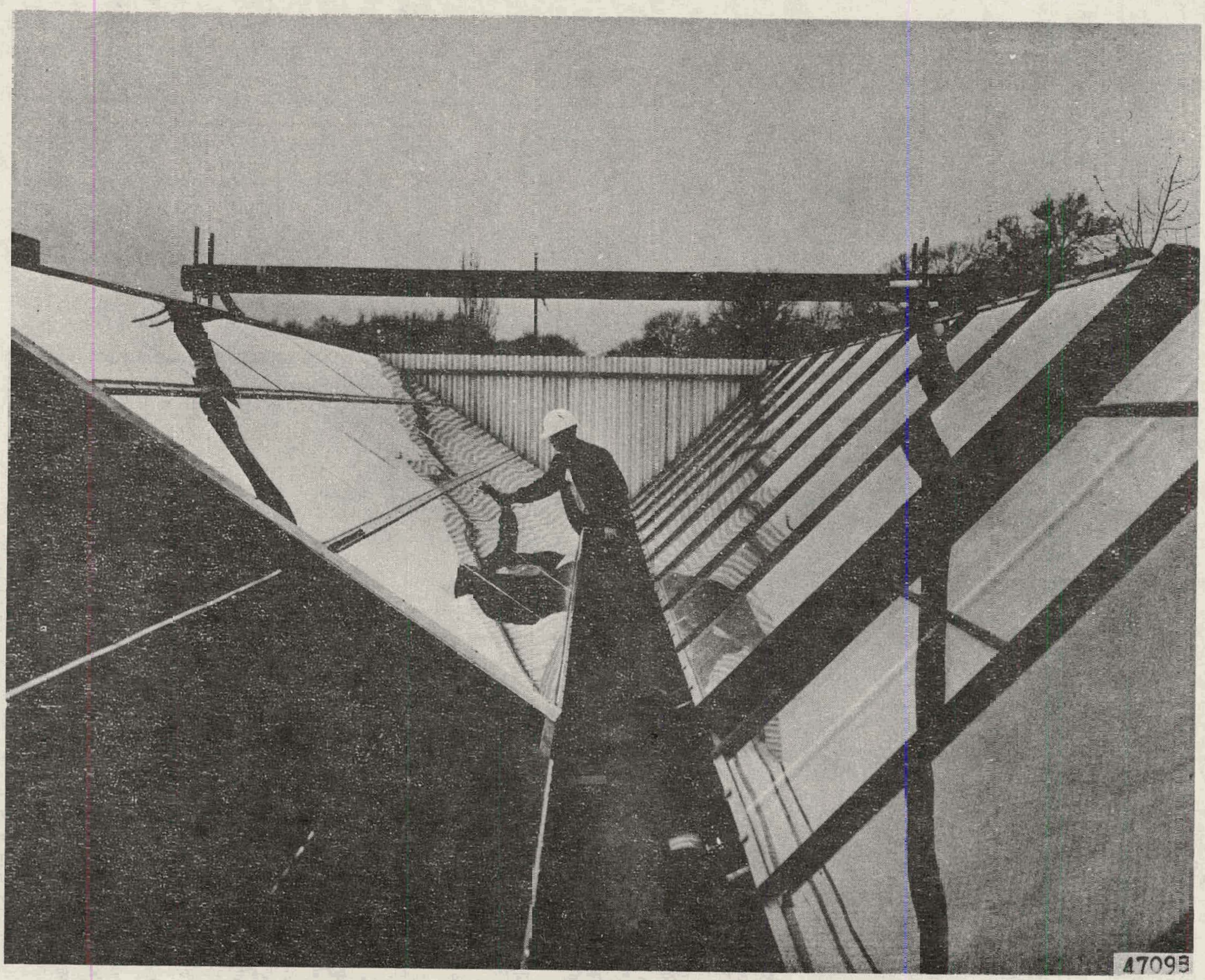


Figure 2-8. Installation of Reflectors

REFLECTION ON SOLAR COLLECTOR FOR VARIOUS SUN ANGLES

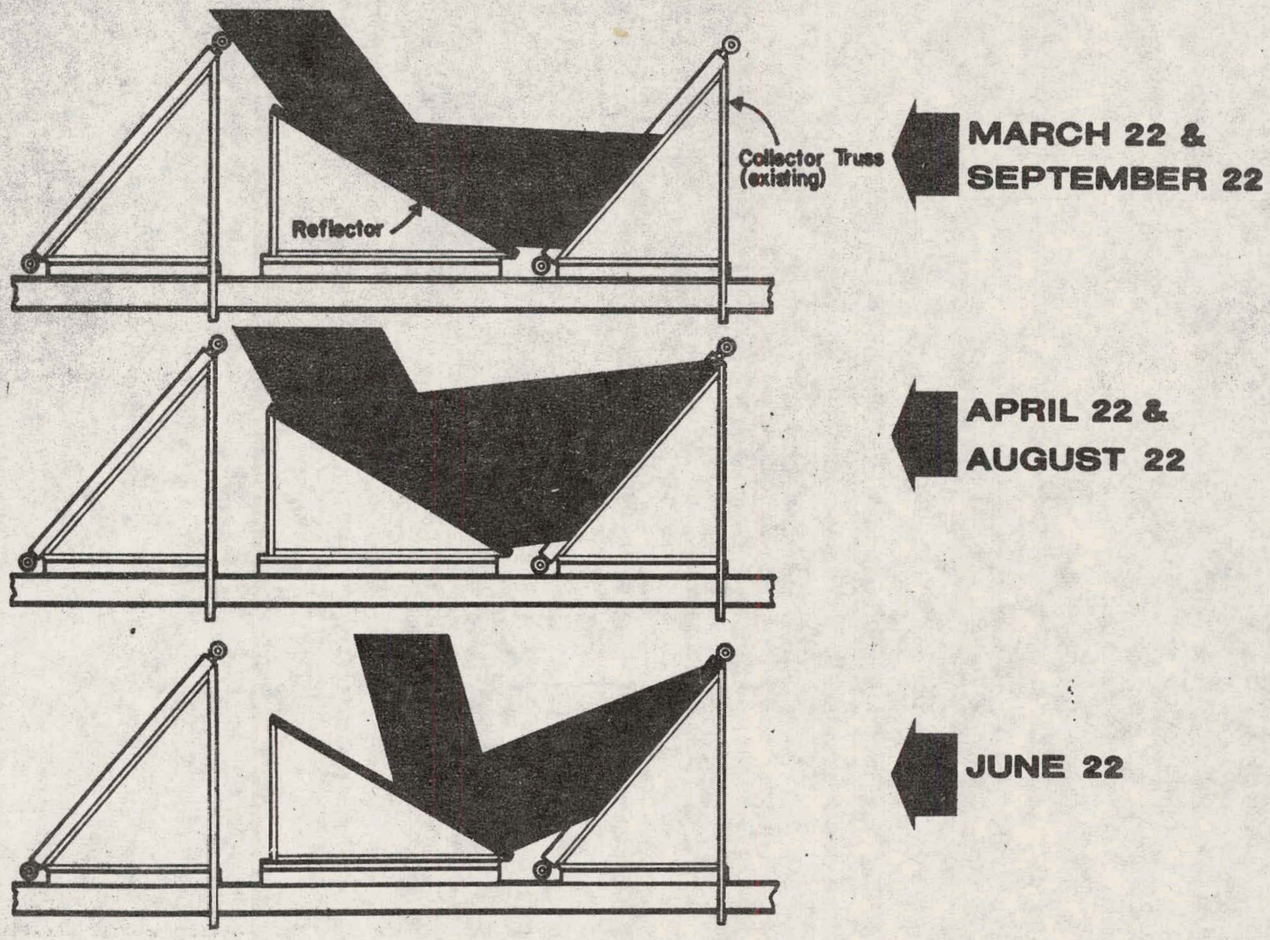


Figure 2-9

3. Supporting Structure

The solar collectors and reflectors are mounted on steel trusses which are bolted to I-beams which in turn sit on load-bearing columns. The structural details for the collector trusses are shown in Appendix I, Dwg. No. 57413-40042. The configuration of the reflector truss is similar to that of the collector. All-steel trusses were fabricated in the weld shop at AAI Corporation. They were painted with a zinc chromate rust preventative before being moved to the school site.

4. Collector Plumbing

The solar collection and heating system schematic is shown on Dwg. No. 57413-40024 in Appendix I. This depicts the arrangement of the components from the hot-water storage tank to the pump house, the school, the collectors and return. A more detailed arrangement of the collector plumbing and manifolding is shown on Dwg. No. 57413-40120 in Appendix I.

The hydronic system is "Open" or vented as opposed to a "Closed" or pressurized system. The collector allows water to trickle freely (by gravity) from top to bottom of the absorber plate where it is funnelled to an outlet in the collector to the storage tank return line.

The sequence of flow is as follows: the collector pumps lift the water to a vented head tank located approximately 30 inches above the top of the collectors. The height of the water in the head tank provides the force (head) required to cause flow through the pipes that are downhill to the collector inputs. The water then flows through the collectors and returns downhill to the hot-water storage tank. Each time the collector pumps stop, the water in the lines from the pumps to the head tank is allowed to back up through a by-pass into the storage tank and the water in the system beyond the vented head tank also returns to the storage tank. Therefore, no water remains in the system and the possibility of freezing is eliminated. This eliminates the need for adding anti-freeze to the water.

The combined capacity of both collector pumps is about 180 gallons per minute against a 45 foot head. The .1870" diameter restrictor in each collector input limits maximum total system flow to 165 gallons per minute. The system logic is designed to permit variable flow from 50 gallons per minute at morning start-up to a maximum of 165 gallons per minute about solar noon.

Aluminum pipes are used throughout the collector system to minimize the effects of dissimilar metals causing galvanic corrosion.

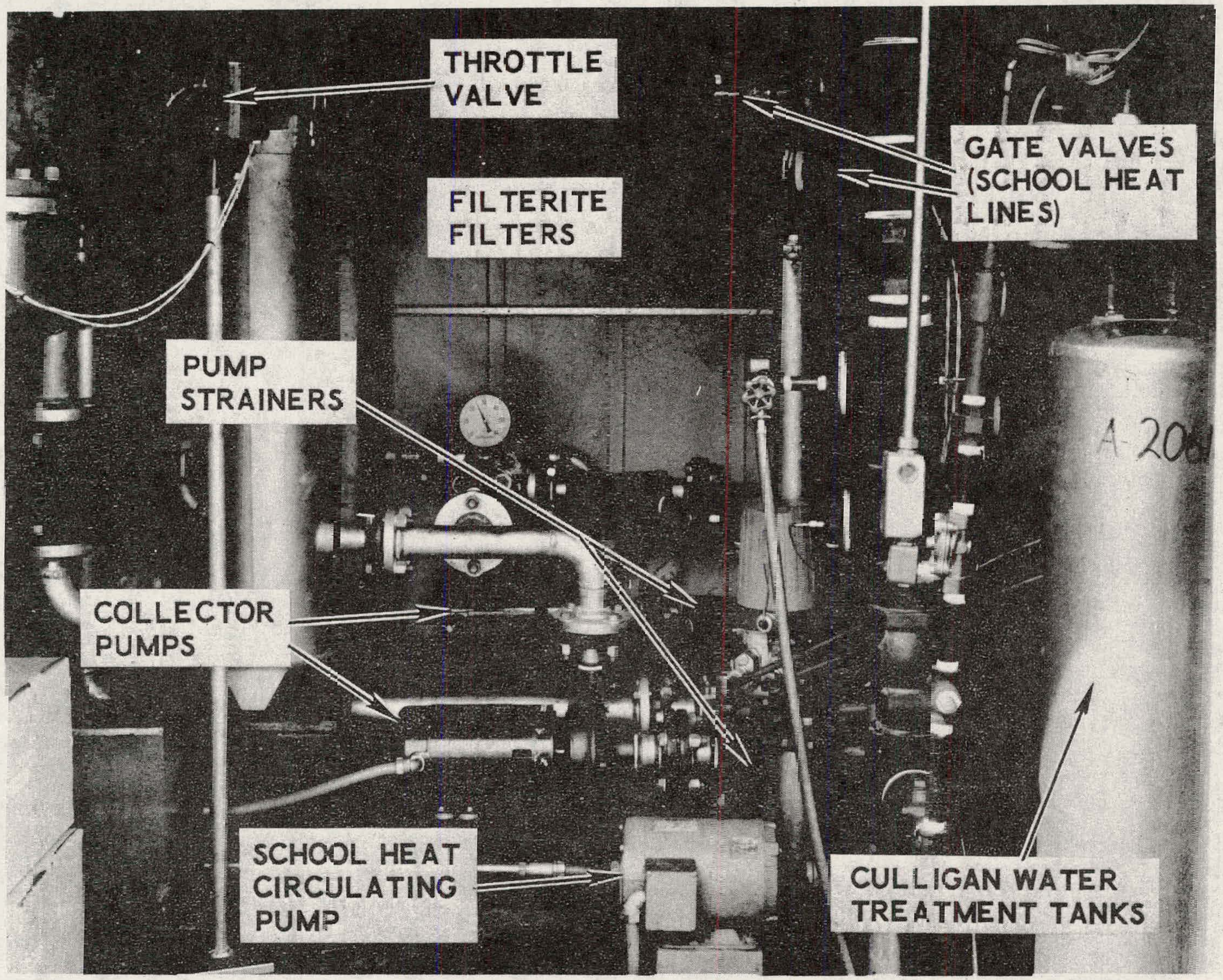
Polyurethane foam insulation 1.50 inches thick was applied to the pipes. This was covered with black building paper to protect it from the weather.

An internal view of the pump house containing the pumps, valves, filters, etc., is shown in Figure 2-10. The school unit heater pump is in the foreground, the Culligan water deionizer is on the right, and a water filter is on the left. The water supplied to the system passes through the Culligan water treatment system which deionizes the water, thus reducing chance of corrosion.

The Culligan water-conditioning system that was incorporated into the Timonium Solar Heating System was reviewed with and recommended by a local industrial concern who has experienced the corrosion type problems that are generally associated with hot water heating systems. The Culligan deionization system that was selected utilizes a strong base duo-bed deionization system to demineralize the water and was selected for the following reasons.

This system would produce a large volume of high-quality water at a low cost. Deionized water would eliminate build-up of deposited minerals in the panels due to the excessive heat. Since a lower total dissolved solids water has a lower boiling point than a higher total dissolved solids water, the water would heat faster, thus creating a more favorable situation for the operation of the solar system.

From a systems standpoint, the portable exchange deionizers were easily adapted to the job site (requiring little space) and were easily piped



RF-225

Figure 2-10. Pump House

to the system. As the solar system required make-up water the deionizers were always there to provide a high quality water. The water coming from the deionizers would have a 7.5 to 8.0 pH, thus assuring a non-corrosive water.

5. School Unit Heaters

The Timonium Elementary School is normally heated by steam with the two boilers shown in Figure 2-11. One of these boilers is usually in the standby status.

The auxiliary system supplies heat to the school rooms by passing steam into a standard heating and ventilating unit. This unit, controlled by the room thermostat, supplies steam-heated air as well as ventilating air from the outside.

The solar heating system designed for the center wing of the school uses hot water fan coil unit heaters. A separate parallel hot-water piping system was designed to supply hot water from the storage tank to twenty unit heaters of the type shown in Figures 2-12 and 2-13.

A layout of the unit heaters and their associated plumbing is located in Appendix I, Dwg. No. 57413-40114.

All pipes for the solar heaters were insulated with one inch of polyurethane foam.

The solar unit heaters are controlled by the existing thermostats located in each room of the wing.

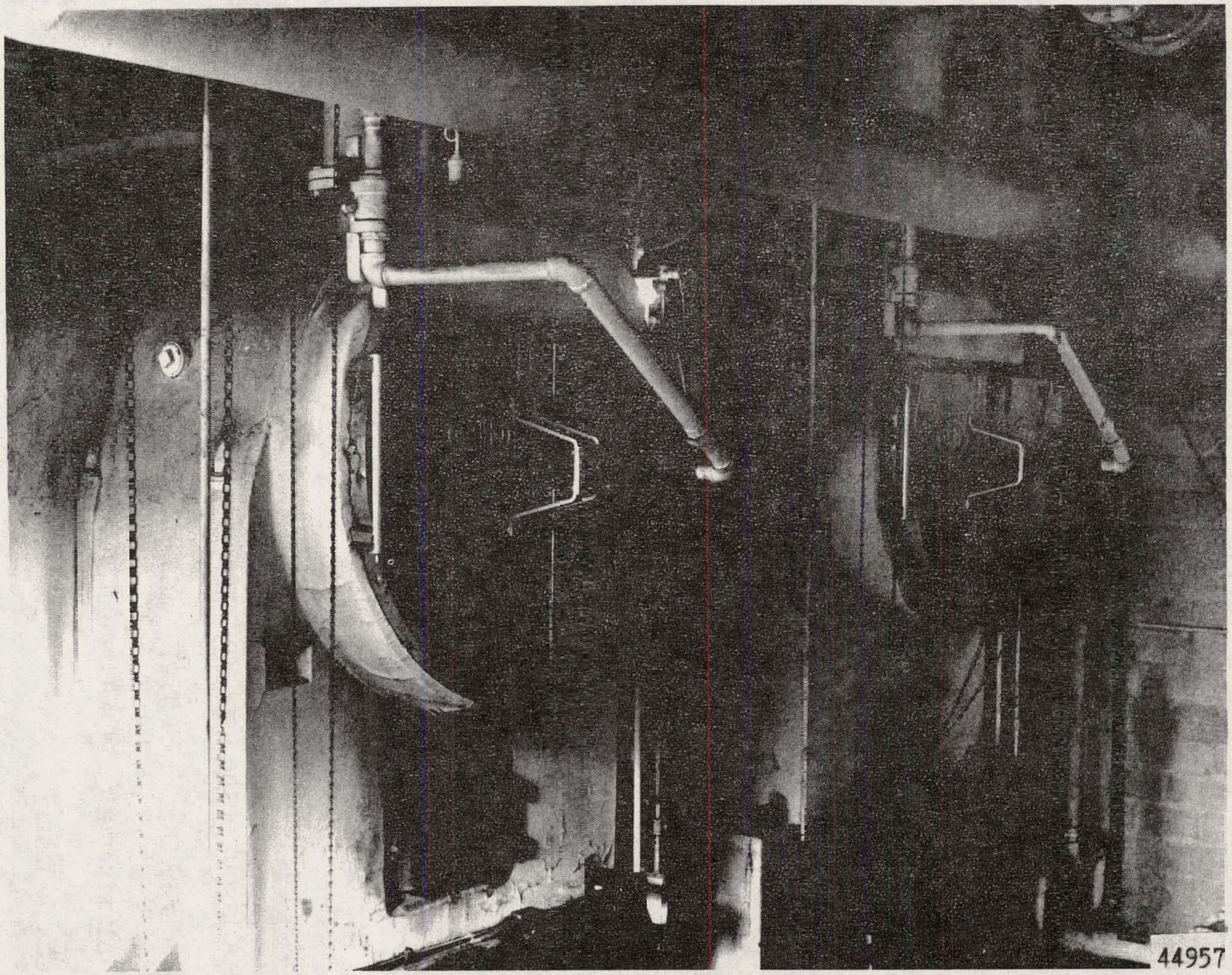


Figure 2-11. Steam Boilers Used for Heating Timonium Elementary School

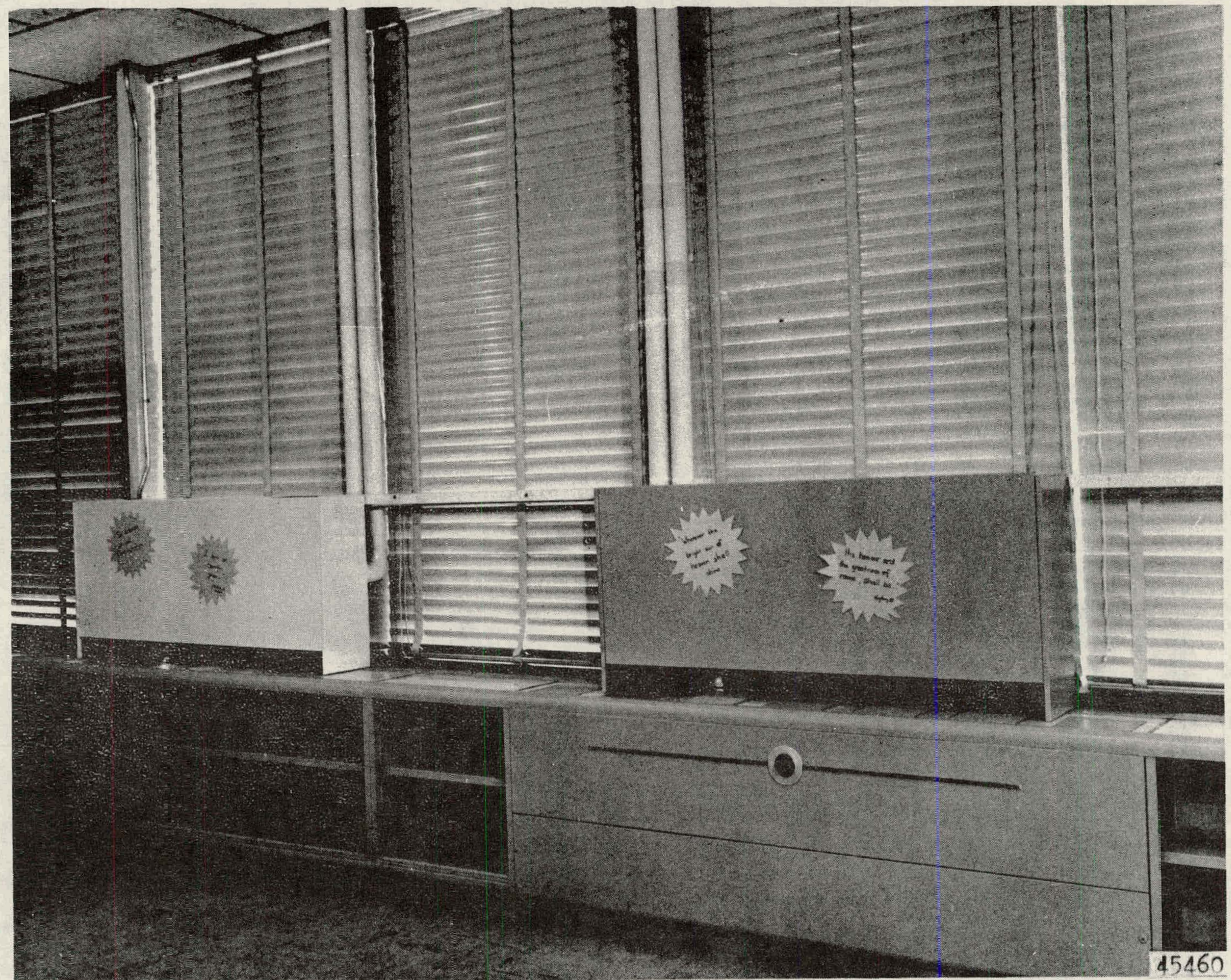


Figure 2-12. Two of the Solar Hot Water Forced Air Convectors
(Two convectors were used in the average 1000 Ft^2 classroom)

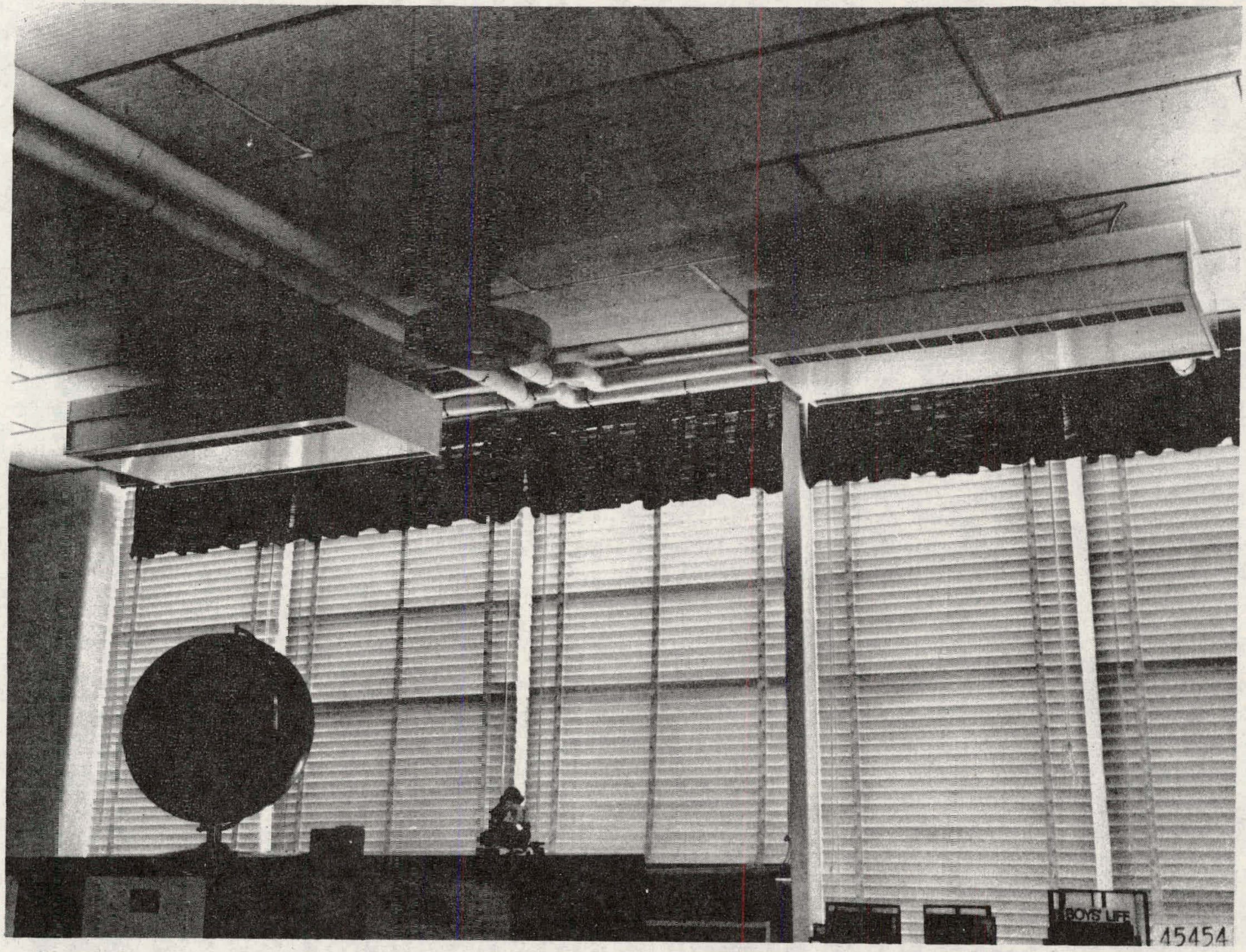


Figure 2-13. Solar Hot Water Forced Air Convectors Mounted in the Ceiling of the Library

6. Storage Tank

A 15,000-gallon capacity storage tank was designed for the system. It provides 2.98 gallons of storage per square foot of collector area. It was installed above ground about 20 feet from the center wing of the school.

The construction details of the tank may be seen in Appendix I, Dwg. No. 57413-40032, sheets 1 and 2. It is constructed solely from 6061-T6 aluminum. The sides are rolled and welded. Rolled channels are welded to the sides for lateral support.

A separator is located in the middle of the tank to aid in stratification.

The tank was transported to the site by truck and moved into position by crane. A reinforced concrete pad was prepared to support the tank which weighed about 5000 pounds empty, and 125,000 pounds filled with water. The tank was insulated as follows:

Top: 4.0 In. of block insulation covered with 0.5 in. of asphalt and a burlap mesh grid.

Sides: 4.0 in. of fiberglass batts covered with an .040 in. thick aluminum cover.

Bottom: 6.0 in. of polyurethane foam encased in a redwood lattice.

This insulation is designed to limit the temperature loss to 1.25°F in 24 hours.

The fully insulated tank is shown in Figure 2-14.

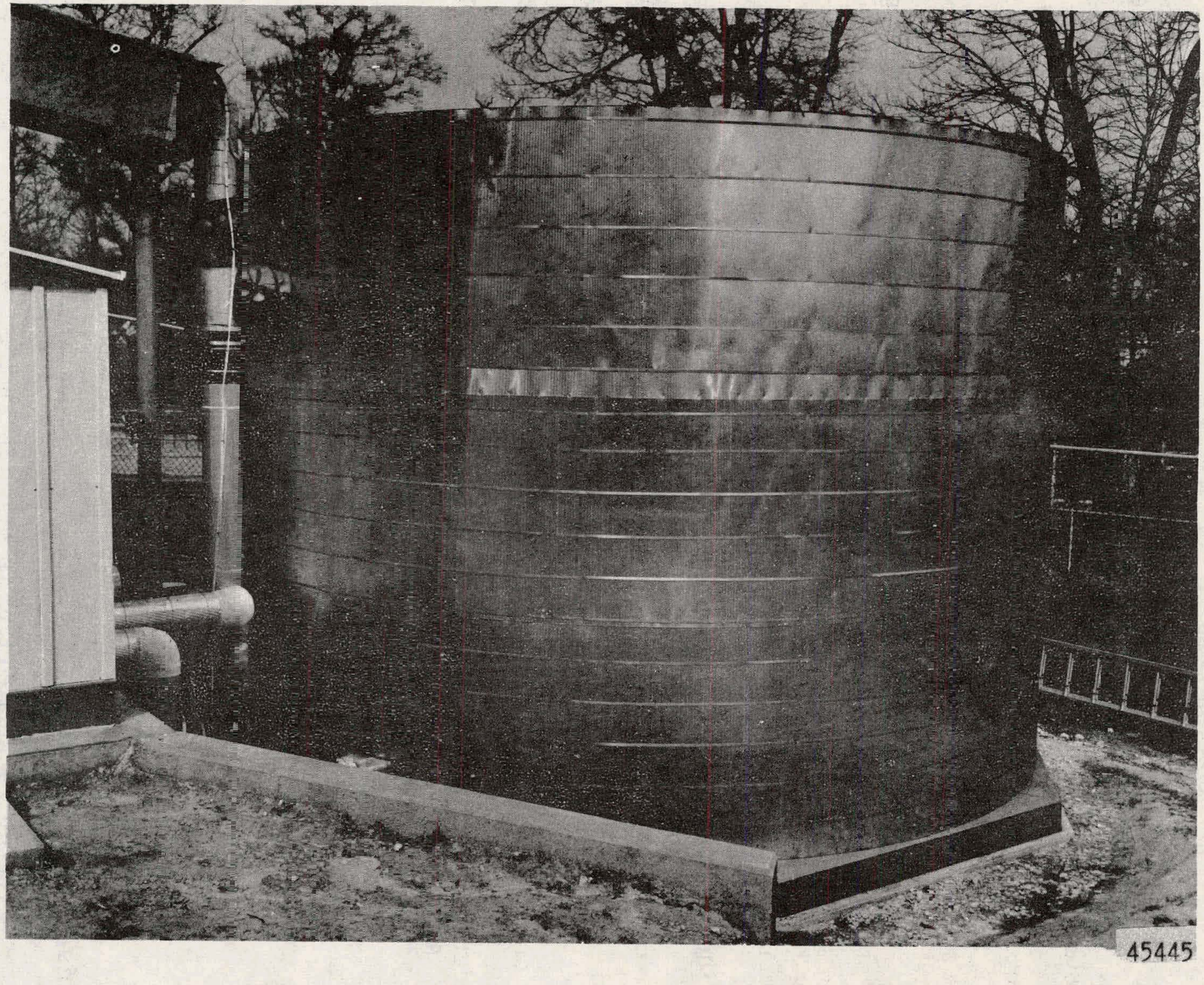


Figure 2-14. Fully Insulated Tank

7. Air Conditioning and Chilled Water Storage Plumbing

Modifications were made to the solar collection and heating systems in the Spring of 1975 to provide cooling for the center wing of the school. Additional modifications were made to the chilled water plumbing later in the Fall of 1975. This was for evaluation of a chilled water storage system. For solar cooling, 162 reflectors (5300 sq ft) were added to the collector system on the roof.

The piping to the absorption chiller (2 chilled water lines and 2 hot water lines) is mounted in the ceiling area of the center wing. This piping is designed to utilize the circulator pump, fan coil units and plumbing of the initial solar heating system. Six manually controlled shut-off valves couple these lines to the initial heating system lines.

The fan coil units in the ceiling of the library were replaced because they could not be adapted to chilled water use. Piping was also added to provide fan coil condensate drains. It was run to a common sump located in the crawl space beneath the corridor in the center wing of the school. The plumbing to the cooling tower runs from the absorption chiller up through the boiler room ceiling to the tower which is located on the roof. The cooling tower dissipates the heat removed from the chilled water by the chiller.

a. Absorption Chiller

Model ES1A2HW (Modified) - York-Borg Warner

Item	Modified to:
Design Load	From 150 tons to 50 tons
Chilled Water	150 gpm from 53°F to 45°F
Condenser Water	360 gpm from 85°F to 93.4°F
Heat Rejection	1,512,000 Btu/hr
Evaporator Passes	From 2 to 4 passes
Absorber Passes	3 passes
Condenser Passes	1 pass
Generator Passes	2 passes
Hot Water Flow	100 gpm or 169 gpm
Hot Water Supply	187°F or 180°F
Hot Water Return	168.2°F or 168.2°F
Included	Cooling tower by-pass

Figure 2-15 shows the front view of the absorption chiller. A description of how the chiller operates is shown on Figure 2-16.

b. Heat Exchanger (Steam to Water)

If 187°F solar hot water is not available for operation of the chiller, the auxiliary heating system will provide supplementary steam to a heat exchanger which is located in the hot water circuit from the storage tank to the chiller generator. The steam is obtained by tapping into the 12.00 inch diameter header of the school's boilers. The manual or automatic control of the supplementary steam provides the option of firing

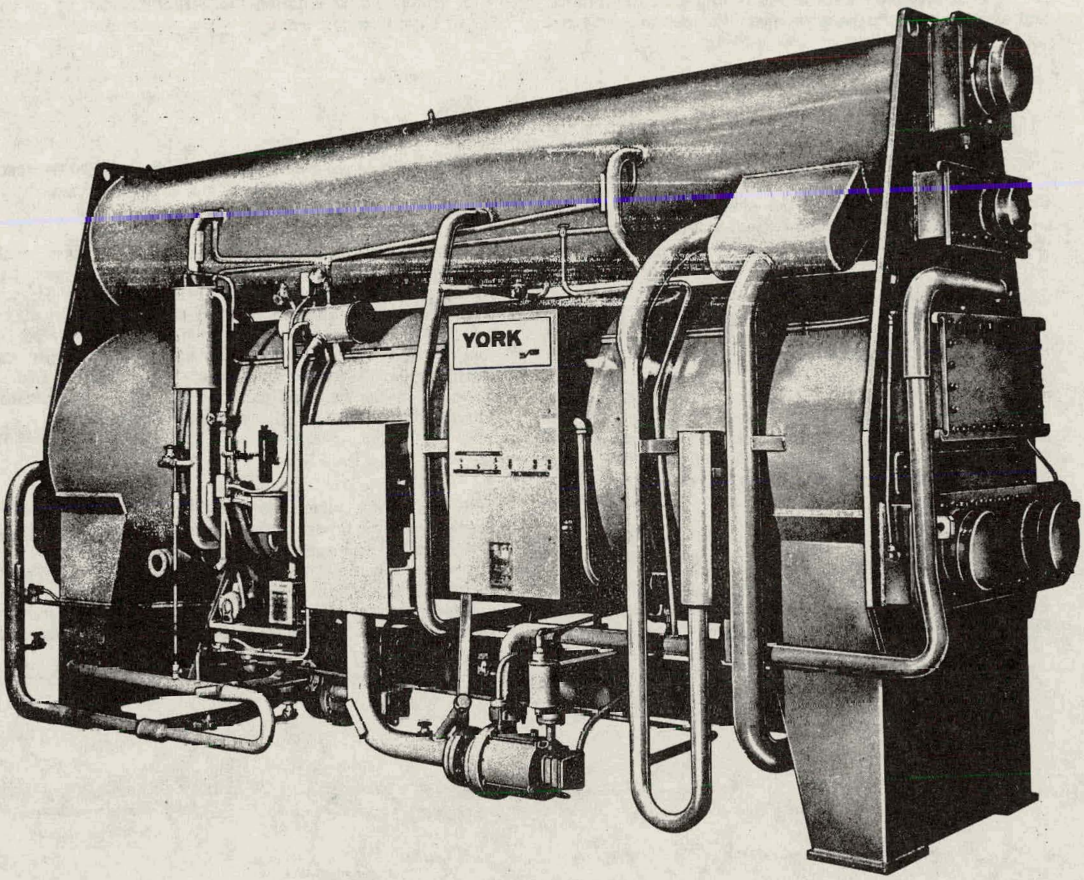


Figure 2-15. York Absorption Chiller

The principle of refrigeration is the exchange of heat, and in absorption liquid chilling, there are four basic heat exchange surfaces: the evaporator, the absorber, the generator and the condenser.

In absorption chilling, the refrigerant is water. But like any refrigeration system, absorption chilling uses evaporation and condensation to remove heat. To maintain effective evaporation and condensation, absorption chilling employs two shells which operate at different controlled vacuums.

The lower shell (Evaporator and Absorber) has an internal pressure of about one one-hundredth that of the outside atmosphere - or six millimeters of mercury, a relatively high vacuum. The vacuum allows water (the refrigerant) to boil at a temperature below that of the liquid being chilled. Thus chilled liquid entering the evaporator can be cooled for air conditioning purposes.

1

Refrigerant enters the top of the lower shell and is sprayed over the evaporator tube bundle. Heat from the liquid being chilled evaporates the refrigerant.

2

The refrigerant vapor then migrates to the bottom half of the lower shell. Here the vapor is absorbed by a lithium bromide solution. Lithium bromide is, basically, nothing more than salt water. But lithium bromide is a salt with an especially strong attraction for water. With the lithium bromide spray, it is as if hundreds of little sponges are sucking up the refrigerant vapor. The mixture of lithium bromide and the refrigerant vapor - called the "dilute solution" - now collects in the,bottom of the lower shell.

3

The dilute solution is then pumped through the heat exchanger where it is preheated by hot concentrated solution from the generator. The heat exchanger improves the efficiency of the cycle by reducing the amount of steam or hot water required to heat the dilute solution in the generator.

The dilute solution then continues to the upper shell containing the Generator and Condenser, where the pressure is approximately one-tenth that of the outside atmosphere, or seventy millimeters of mercury. The dilute solution flows over the generator tubes and is heated by steam or hot water. The amount of heat input from the steam or hot water is controlled by a valve and is in response to the required cooling load. The hot generator tubes boil the dilute solution releasing refrigerant vapor.

4

The refrigerant vapor rises to the condenser and is condensed. The liquid refrigerant flows back to the lower shell, and is once again sprayed over the evaporator. The refrigerant cycle has been completed. Now the concentrated lithium bromide solution flows from the generator back to the absorber in the lower shell ready to absorb more refrigerant. Its cycle has also been completed.

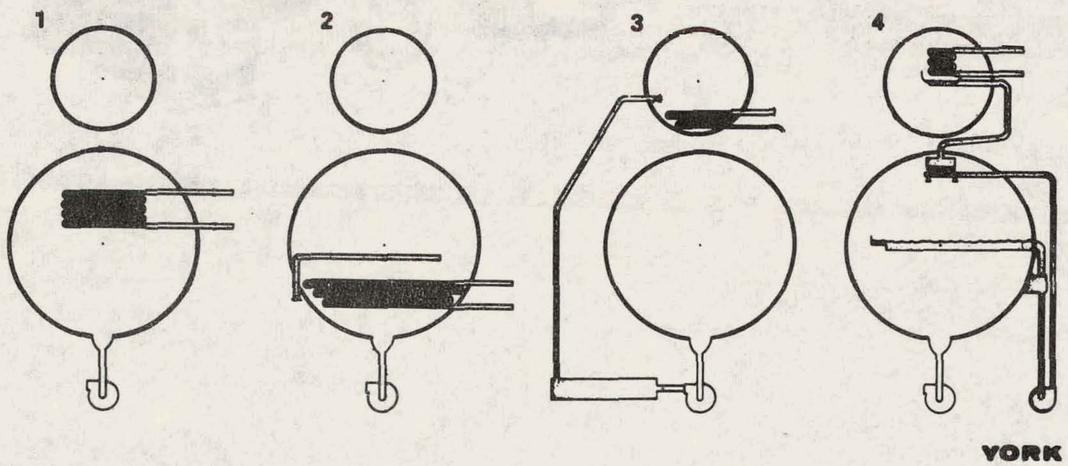


Figure 2-16. Principle of Operation of York Absorption Chiller

the chiller with an infinite range of hot water temperature to 200^{o}F. The heat exchanger is manufactured by Taco, Inc.

c. Cooling Tower

The cooling tower for the Timonium system is an "Ejector II" model J0905-B33 manufactured by Baltimore Aircoil. The unit capacity is 100 nominal tons at 300 gallons per minute for standard conditions (95^{o}F water on, 85^{o}F water off, and 78^{o}F entering wet bulb temperature).

d. Chilled Water Storage System

Two chilled water storage tanks have been incorporated into the air-conditioning system at the Timonium Elementary School. The chilled water storage installation is shown schematically in Figure 2-17 and consists of the following elements:

- Underground installation of two insulated steel tanks, each with a capacity of 20,000 gallons.
- The valving and interconnection of the two tanks into the school's chilled water piping circuit.
- Control system and instrumentation.

Chilled water is continuously generated whenever there is sufficient solar energy to power the absorption chiller. Continuous chiller operation independent of the cooling demand will provide chilled water in excess of the current cooling demand. The excess chilled water can then be stored for use when insufficient energy is available and the school wing calls for cooling.

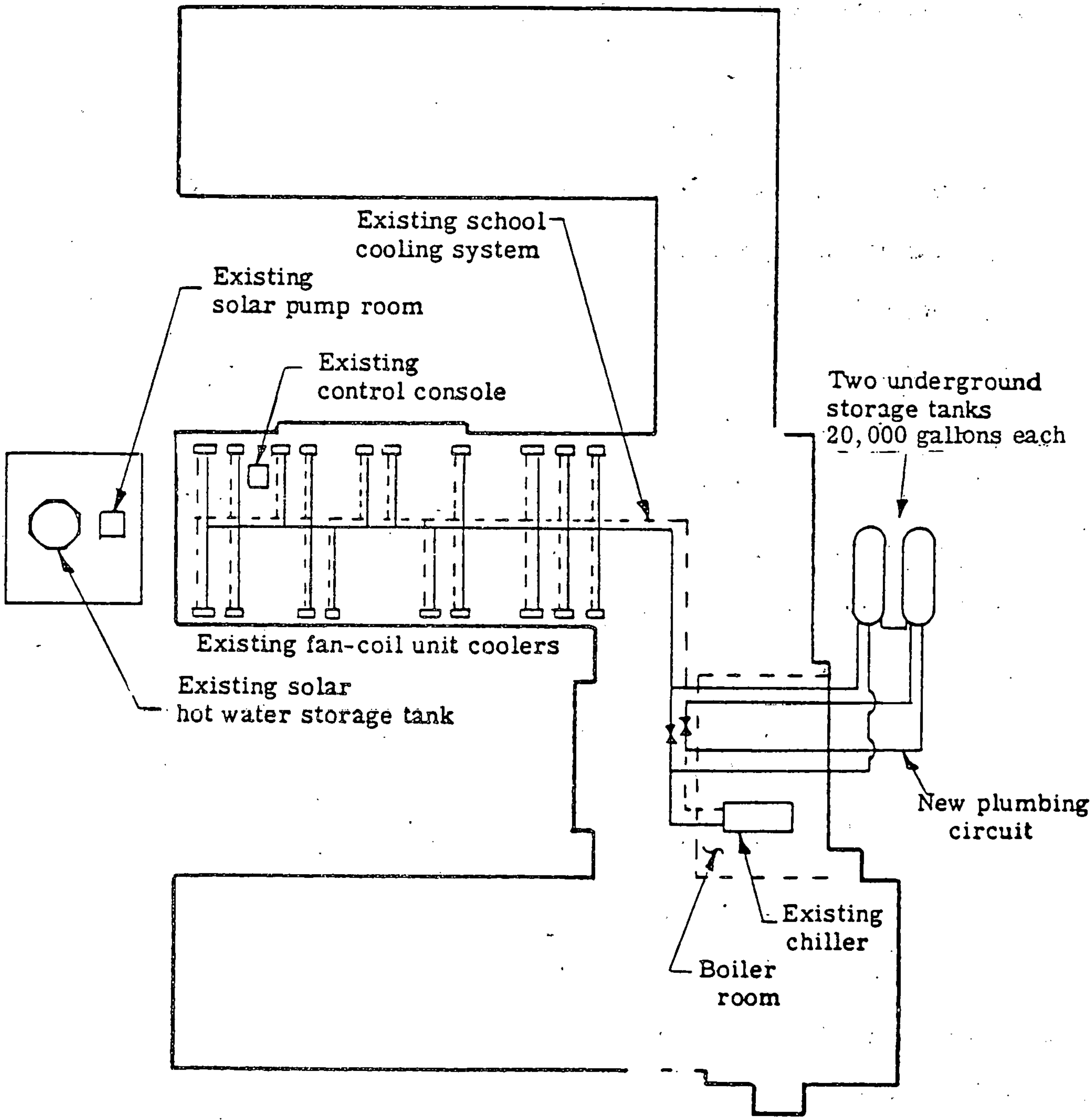


Figure 2-17. Site Layout of Chilled Water Storage Installation At Timonium Elementary School

The design is shown schematically in Figure 2-18. In this design the two 20,000 gallon chilled water tanks are interconnected to the chilled water outlet of the York chiller (absorption chiller) and the school's cooling system (fan-coil units). The two chilled water storage tanks are insulated and installed underground. One tank serves as the low temperature chilled water supply for the school's cooling system and receives the chilled water directly from the chiller unit. The other tank receives the higher temperature water from the school's cooling system and provides the supply of water to the chiller. Thus one tank will be at a lower temperature than the other.

Four insulated pipe circuits installed underground run from the storage tanks, pierce the external wall of the school's boiler room and, in the boiler room, interconnect with the existing chill water hydraulic circuits. As shown in the schematic, a pump and four pneumatically actuated electrically controlled flow valves are installed to form three basic hydraulic circuits which control the flow of chill water as follows:

- Flow from chiller to school's cooling system
- Flow from chiller to storage tank
- Flow from storage tank to school's cooling system and in addition, during periods of solar collecting, flow from chiller to tank.

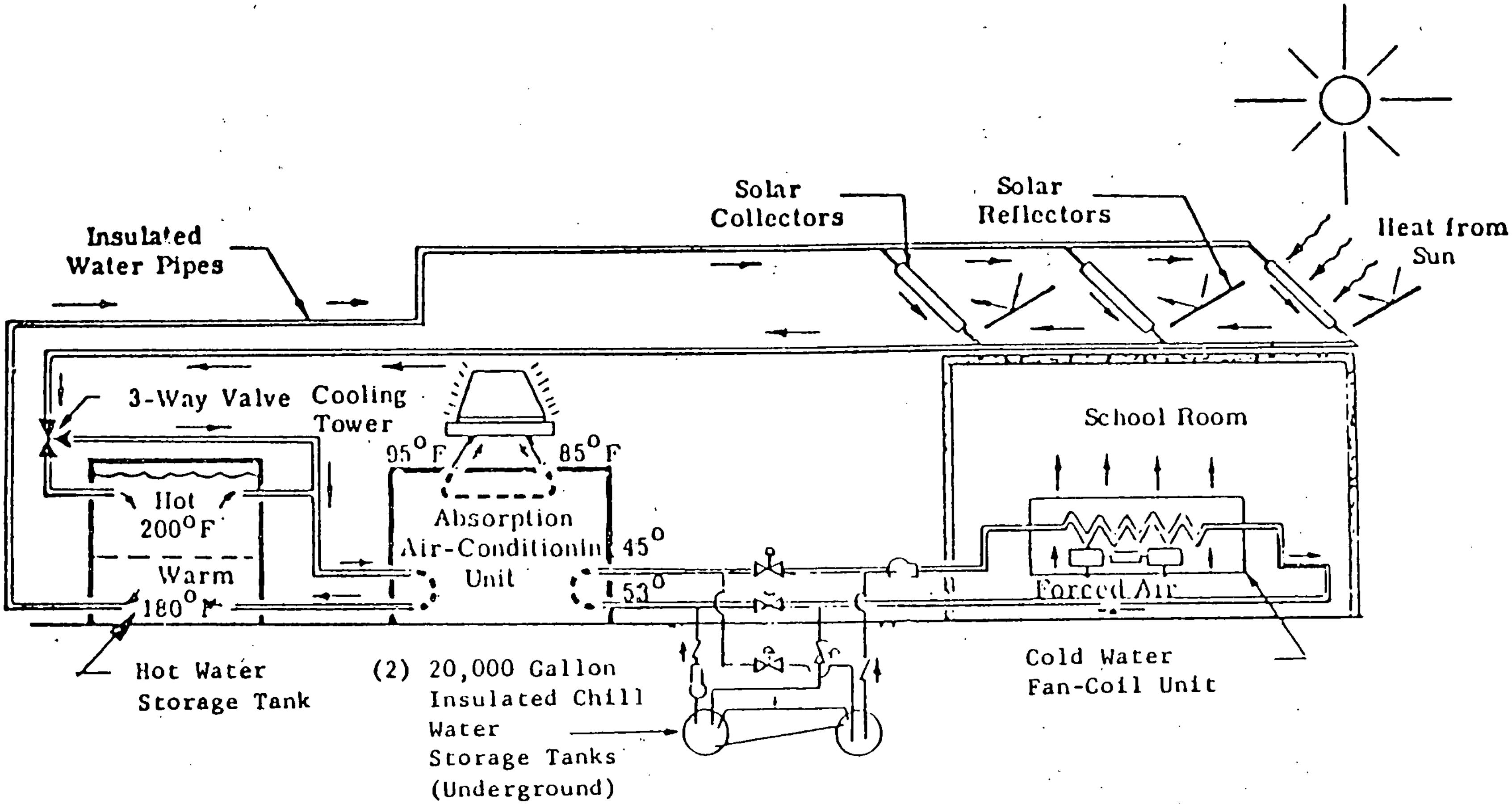


Figure 2-18. Schematic of Air-Conditioning System Using Absorption Unit & Chill Water Storage

Essentially, the above three basic circuits define the operational modes of the chilled water storage system. Selection of a particular circuit is achieved by controlling the appropriate flow valves to provide the desired hydraulic flow route. The flow valves are pneumatically actuated by compressed air from the compressor and are controlled by electrically operated valves.

The solenoids are controlled by a three-position switch mounted on the control console.

Instrumentation to measure water temperature, flow rates and tank water level are installed in the hydraulic circuits to provide a continuous monitoring of the system performance.

e. Instrumentation

The instrumentation for the combined heating and cooling system is located in room #13 of the center wing of the school. A view of the instrumentation is shown in Figure 2-19. Figures 2-20, 2-21, and 2-22 are more detailed illustrations of the air-conditioning control panel, the Multi-point Recorder, and the flowmeter readouts. Figure 2-23 shows a close-up view of the solar heating control panel. The vertical rack at the left in Figure 2-19 houses the Leeds and Northrup recorder. It monitors 19 pieces of data when in the solar heating configuration, and 20 pieces of data when in the solar cooling configuration. Chart 2-1 lists the monitored data.

A layout showing the sensor and transducer locations is shown in Appendix I on Dwg. No. 57413-40069, sheets 1 & 2.

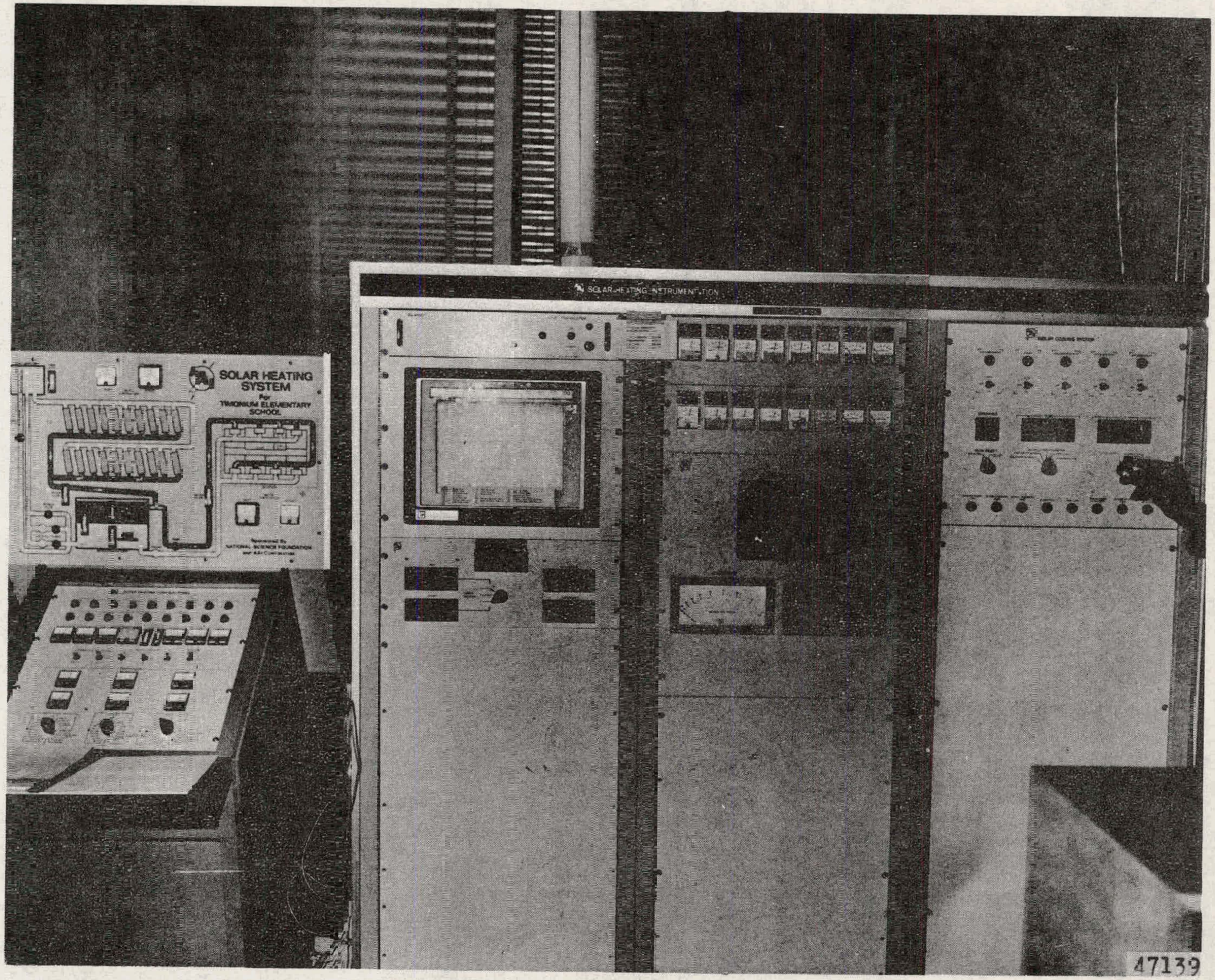


Figure 2-19. Solar Heating & Cooling Instrumentation

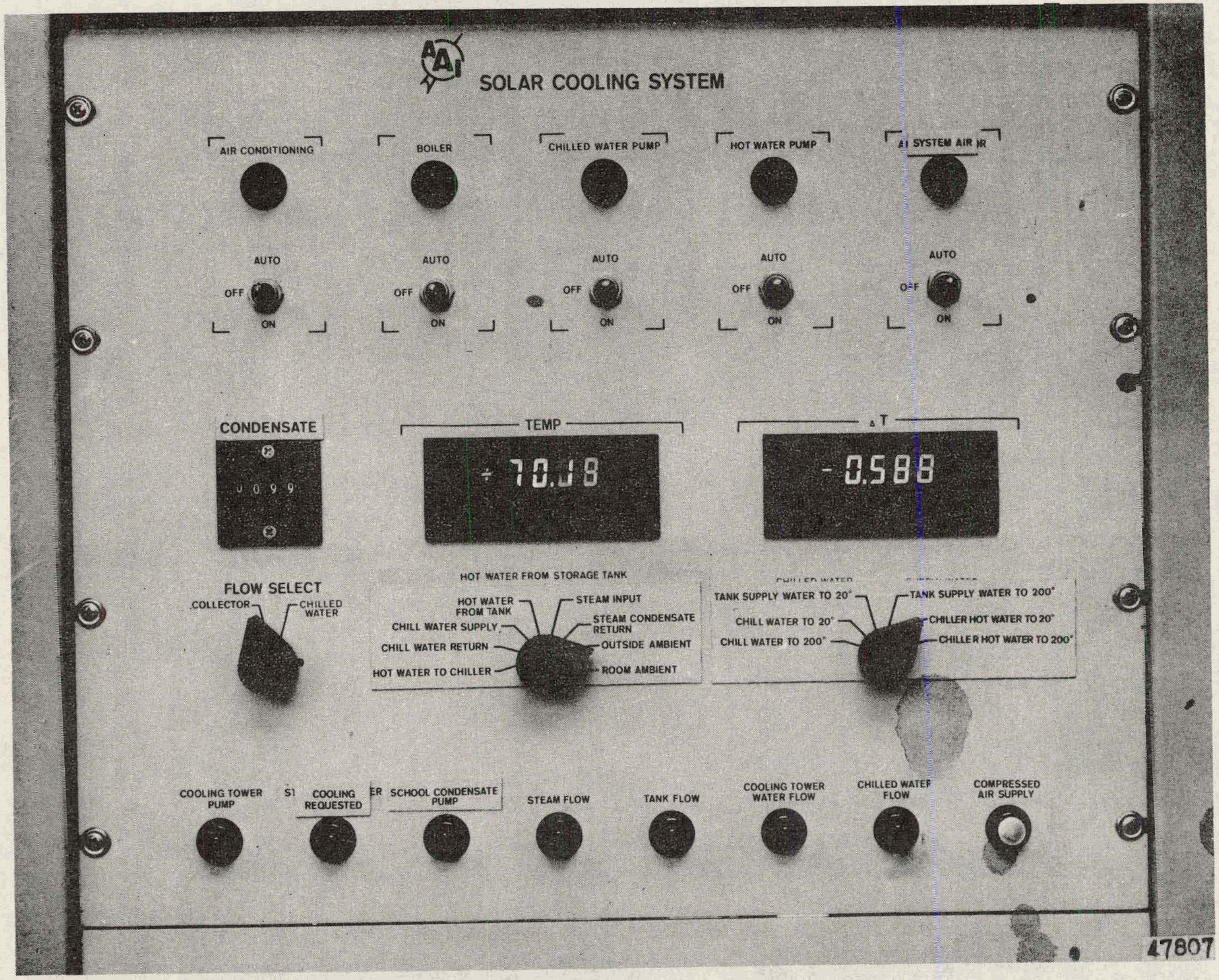


Figure 2-20. Air Conditioning Control Panel

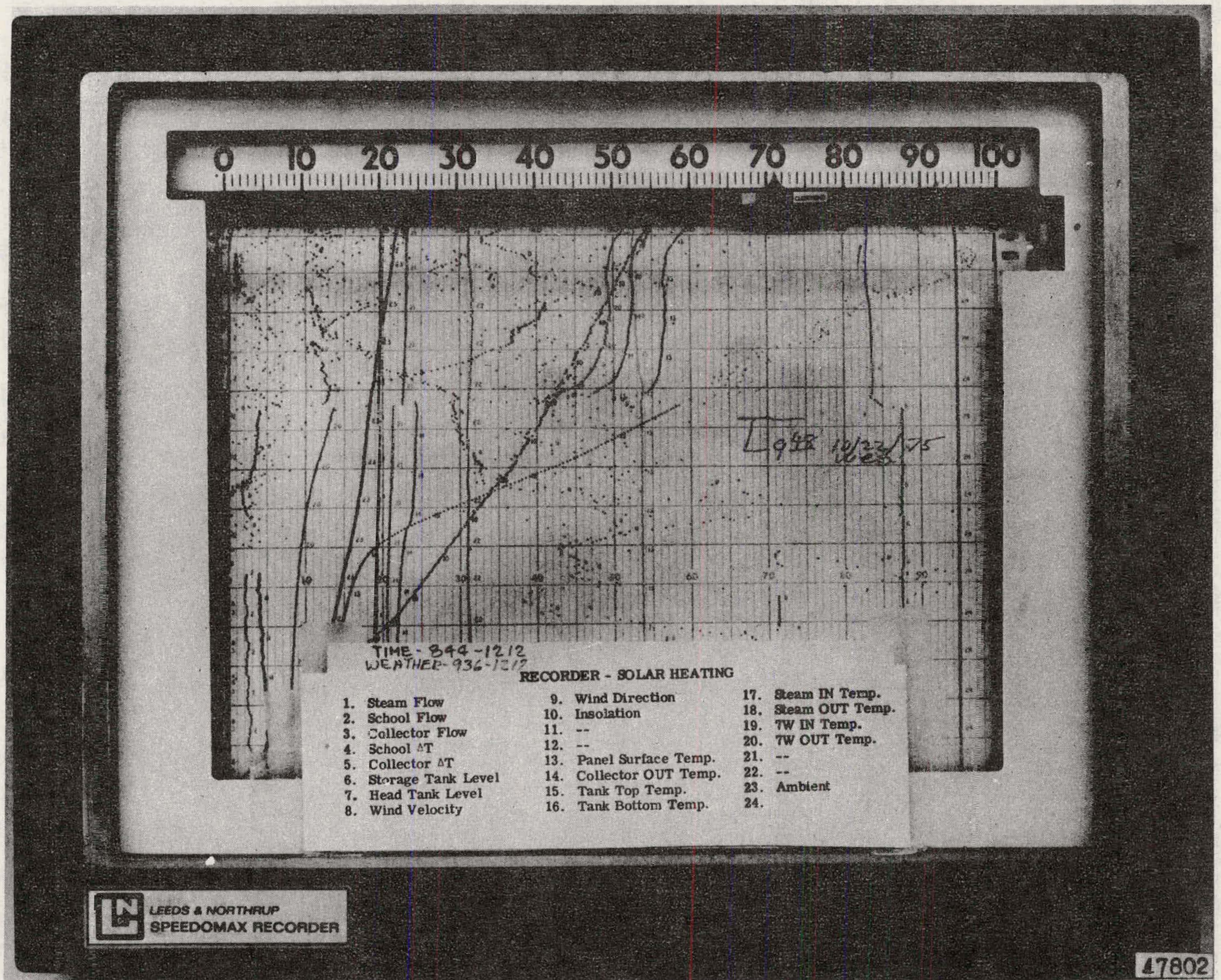


Figure 2-21. Multipoint Recorder

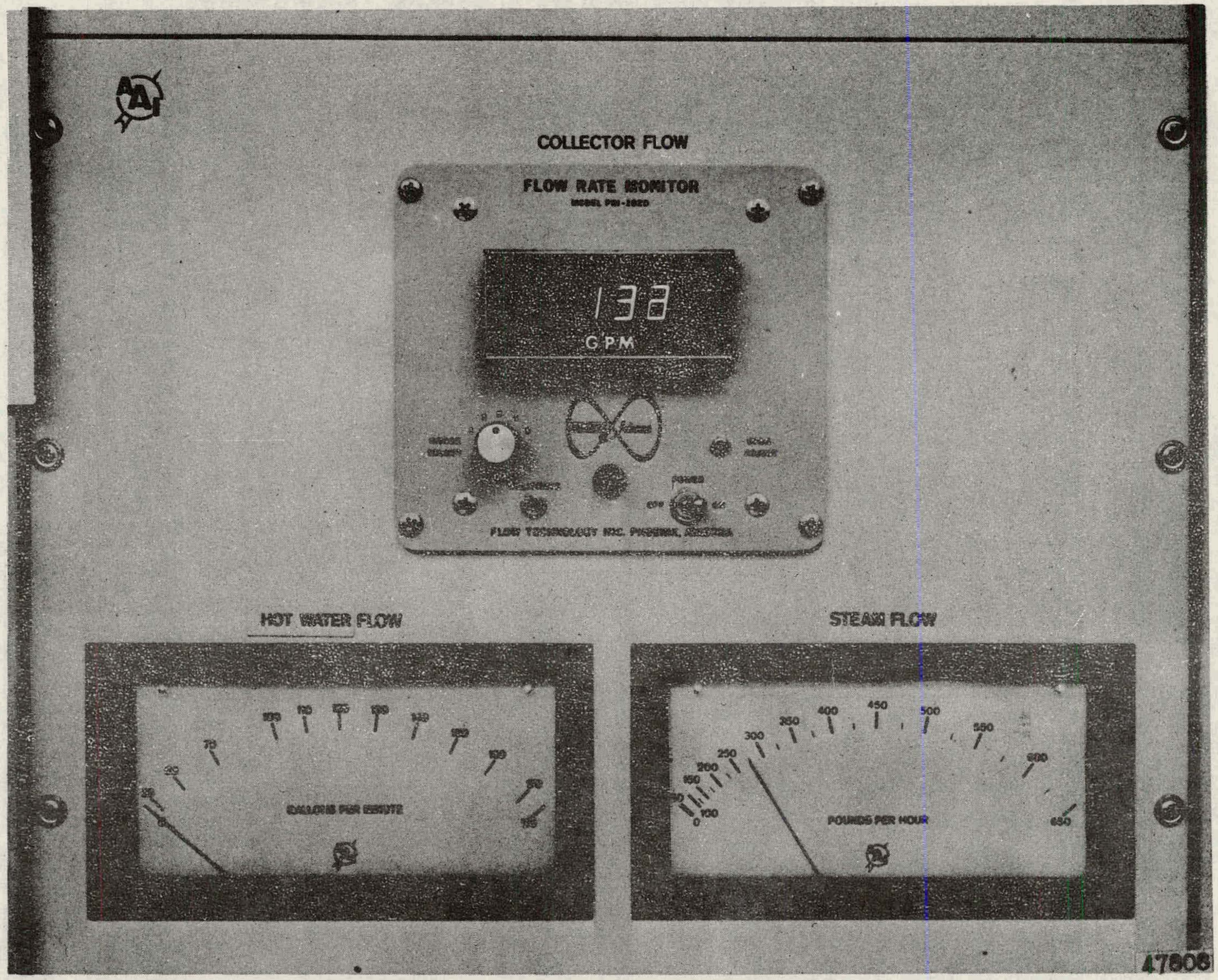


Figure 2-22. Flowmeter Readouts

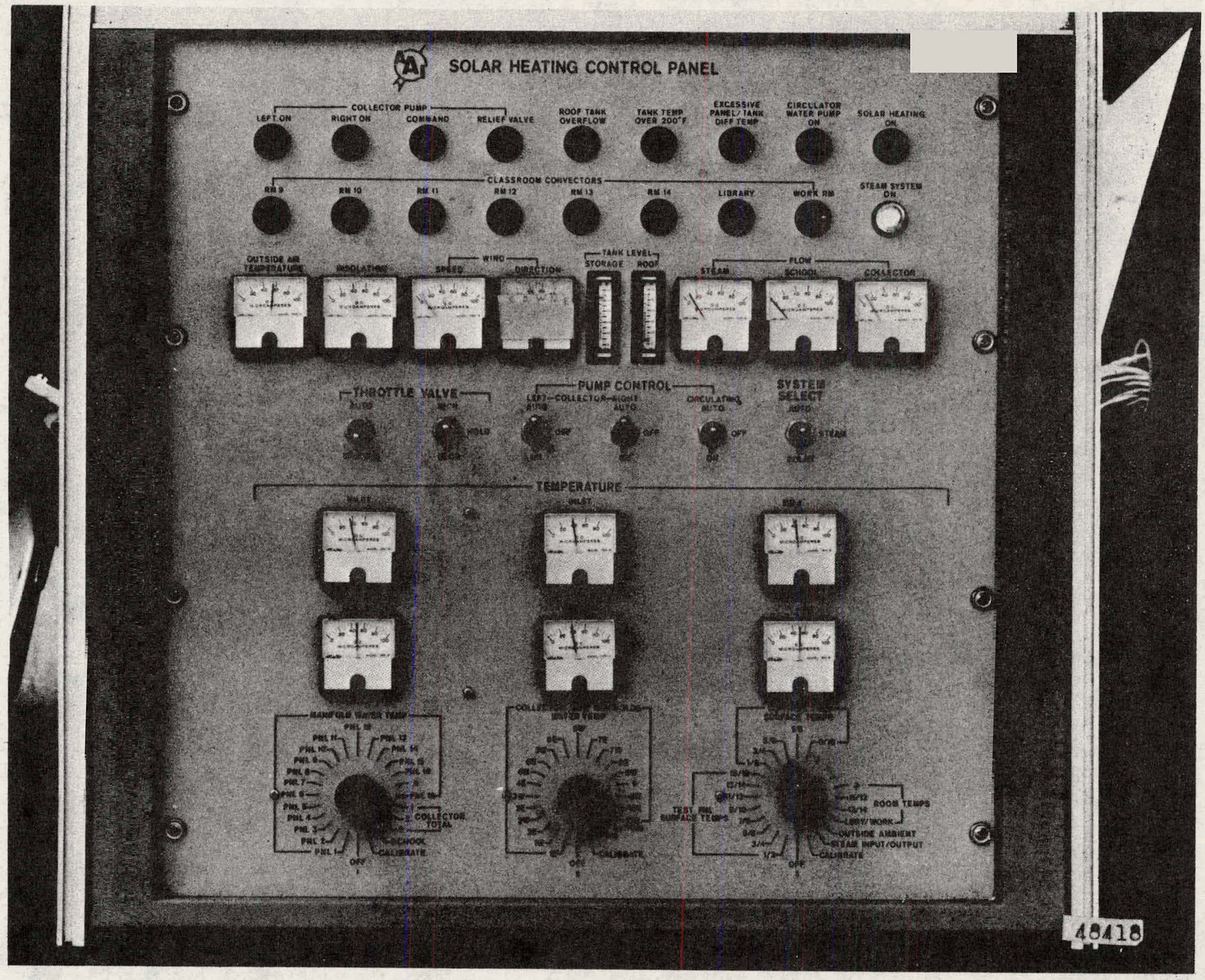


Figure 2-23. Close-Up View of Solar Heating Control Panel

Chart 2-1. Instrumentation for Timonium Elementary School

Test data that was continuously recorded on Leeds & Northrup Recorder:

Channel No.	Solar Heating Configuration	Solar Cooling Configuration
1	Steam Flow	--
2	School Flow (Hot Water)	Hot water return flow to storage tank
3	Collector Flow	Collector Flow
4	School ΔT (°C)	Storage tank supply water ΔT
5	Collector ΔT (°C)	Collector ΔT (°C)
6	Storage Tank Level	Storage Tank Level
7	Head Tank Level	Head Tank Level
8	Wind Velocity	Wind Velocity
9	Wind Direction	Wind Direction
10	Insolation	Insolation
11	--	Chilled Water ΔT (°C)
12	--	Chilled Water Flow
13	Panel Surface Temp.	Panel Surface Temp.
14	Collector Out Temp.	Collector Out Temp.
15	Storage Tank Top Temp.	Storage Tank Top Temp.
16	Storage Tank Bottom Temp.	Storage Tank Bottom Temp.
17	Steam "In" Temp.	--
18	Steam "Out" Temp.	--
19	7W "In" Temp.	7W "In" Temp.
20	7W "Out" Temp.	7W "Out" Temp.
21	--	Steam Converter "In" Temp.
22	--	Steam Converter "Out" Temp.
23	Ambient	Ambient
24	--	--

B. System Operation

The solar collection and heating system operates as follows. When the solar insolation properly heats the absorber plates, the collector pumps start the flow of water from the lower half of the storage tank through a throttling valve, through the collectors and back to the upper half of the storage tank. This flow is regulated by output-to-input instrumentation which establishes the flow rate required. If the temperature increase is less than 3^{o}F, the pumps shut down and the collectors automatically drain returning the water to the storage system.

The solar heating system provides heat to the classrooms upon demand from the classroom thermostats. This demand turns on the hot water circulator pump which draws water from the top half of the storage tank and directs it to the classrooms and through the fan coil units from where it returns to the lower half of the storage tank. (The water in the upper half of the storage tank must be 114^{o}F or above for solar heat to be provided automatically. 114^{o}F was selected as the minimum hot water temperature in order to permit maximum utilization of the solar energy collected and to provide hot water to the fan coil units at about 15^{o}F above body temperature.)

Experience at Timonium School has shown that heat supplied to the classrooms in this manner was satisfactory and drew few complaints from teachers or students.

When the storage water drops below $114^{O}F$ the auxiliary steam heating system automatically takes over until such time as the energy in the storage tank is replenished.

The solar cooling system operates as follows (see Figure 2-18). Water is pumped from the storage tank to the collector-reflector system where it is heated to $180^{O}F$-$200^{O}F$ and returned to the storage tank. The heated water from the top half of the storage tank is then pumped to the heat exchanger, then to the chiller generator, where it powers a thermodynamic cycle which uses water as the refrigerant and lithium bromide as the absorbant. This water returns to the lower half of the storage tank. Heat is extracted from the chilled water returning from the classrooms and colder chilled water is circulated to the fan coil units where the fans blow the ambient air over the cold pipes thus producing cool air. The integrated chilled water storage system permits 3 modes of operation for solar cooling and generation of chilled water for storage.

The selection of any of the operating modes must be accomplished by positioning a selector switch on a secondary cooling control panel located in the boiler room. Regardless of this selection, the cooling system is automatically controlled from the master control console in Room 13.

The solar cooling system requires seasonal preparation to permit automatic operation of the absorption chiller.

The shut-off valves in the ceiling of the corridor outside room #13 must be manually positioned to allow flow of chilled water to the fan coil units and solar heated water to the generator of the chiller.

A remote selector switch inside the air-conditioning console in room #13 must be set to COOL.

The classroom thermostats must be set to 76^{O}F (daytime) and 84^{O}F (nighttime).

The manually controlled gate valve that allows flow of steam to the heat exchanger must be opened. The steam converter temperature control must be set at 187^{O}F. (180^{O}F can be used but the flow of hot water to the generator must be increased from 111 gpm to 169 gpm.) This maintains the rated 50 tons of cooling capacity of the chiller.

The summer-winter switch must be set at "Summer". It is located in boiler room on main boiler control panel. This assures that the standby boiler will go off "line" if the outside ambient is below 72^{O}F and solar-heated water is above 169^{O}F.

If the outside ambient is above 72^{O}F and the solar-heated water is below 169^{O}F, the "Summer" position of this switch allows the boiler to come on "line" and provide supplementary steam to the heat exchanger. The "Winter" position allows the boiler to be on "Line" constantly.

For the absorption chiller to start up automatically, the outside ambient temperature must be 72^{O}F or above, one or more classrooms must call for cooling and the cooling mode selector switch on the secondary control panel located in the boiler room must be on the position "Air Condition School from Chiller."

1. Logic for Automatic Control of the Solar Collection System:

   a. Collector Pump "Start-Up" & "Shut-Down" -

Pumps are started by comparing the absorber plate surface temperature to that indicated by the two top sensors in the upper half of the storage tank. The absorber plates of 6 collectors are sampled. They are segregated to groups of 3 and two out of three in each group must have a temperature 10^{O}C greater than that of the upper half of the storage tank in order for the pumps to start up. Once the pumps start, they are locked "IN" for four minutes of operation to assure that water will reach the "Collector Out" sensors. A group of 3 sensors is located at a point in the collector return line where it contains the total discharge of the collector system. These sensors are monitored to determine collector pump shut down. If the water temperature at this point is less than 3^{O} above the bottom half of the storage tank water, the collector pumps will shut down. The pumps will automatically start or shut down if the conditions mentioned above are repeated.

b. Automatic Flow Control:

The temperature of the total water supply to the collectors is compared to the temperature of the total water returning from the collector system in order to provide automatic flow control. The flow is adjusted by electrical control of a throttling valve located in the discharge side of the collector pumps. The minimum flow of the valve is set at about 50 gpm to assure distribution of some water to the 180 collectors. This feature also allows the water in the lines from the pumps to the head tank to drain back when the pumps are shut down. The logic for control of this valve is as follows:

- For Increased Flow: The differential temperature or ΔT as determined by the sensors mentioned above must be $+11^{o}$. This is checked every 4 minutes and the throttling valve is pulsed to increase for about 2 seconds at each check until the throttling valve is wide open.

- For Decreased Flow: On cloudy days, if the differential temperature (ΔT) drops below $+7^{o}$, the throttling valve is pulsed for about 2 seconds to gradually decrease flow. This is automatically monitored every 4 minutes and the flow controlled accordingly. For a very rapid drop in differential temperature, the collector pumps will automatically shut down when the "collector out" sensors indicate a temperature which is less than $+3^{o}$ above the average temperature of the lower half of the stratified storage tank.

2. Operation of the Solar Heating System Controls

a. The solar collection and heating system controls are designed to provide three modes of operation. They are manual, semiautomatic, and automatic. The center wing is designed to be heated by both solar and auxiliary heating systems. The auxiliary system is the original unmodified steam heat initially built into the school. The solar heating system involved the addition of the hot water plumbing and fan coil unit heaters to the center wing classrooms. The Timonium experiment provides for the supplementary heat by installing a "normally open" pneumatically controlled shut-off valve in the steam trunk line to the center wing. Selection of any mode of operation of the solar heating system closes this valve and any failure of electrical power or the air compressor will allow the valve to open. This "fail-safe" provision therefore guarantees heat to the center wing in emergency cases. The auxiliary heat is also provided automatically when the solar hot water temperature drops below $114^{o}F$.

The choice of selecting either auxiliary or solar heat is made at the solar heating system control panel.

- <u>Manual Control of Solar Heating System</u>

Note: All switches referred to in all modes of control are located on the solar heating system control panel in Room #13 of the center wing of the school.

In this mode of operation, an operator positions the circulating pump switch to "ON" and the system select switch to "SOLAR". The hot water now flows constantly through the trunk lines and returns to the storage tank but is not necessarily going to the classrooms. Classroom flow is caused by each thermostat in the system. These thermostats control the pneumatically operated water valves and cause a demand only when the room temperatures match the thermostat setting. As long as the solar water is hot enough any demand for heat in the rooms will be met by solar. However, if the solar reserve is used up, and the demand remains, the rooms will begin to cool down because in the manual mode of operation the system will not stop the circulating pump and go to "auxiliary heat." An operator is required to position the circulating pump switch to OFF and system select to STEAM to get auxiliary heat.

o <u>Semiautomatic Control of the Solar Heating System</u>

This mode of operation is considered semiautomatic only in the sense that it will provide solar heat automatically, but auxiliary heat will not be supplied automatically when the solar water temperature drops below 114^{O}F (the water temperature at which the system is designed to call for steam heat).

In this mode, if any <u>one</u> of the classrooms demands heat, the room thermostat will start the circulating pump and, when the demand is satisfied, stop it. If more than one room demands heat simultaneously, the last room to be satisfied will stop the circulating pump.

If the solar water temperature is below 114°F and rooms demand heat, the thermostat will start the circulating pump, and if the heat load cannot be satisfied the circulating pump will continue to run causing the rooms to cool down. To prevent this from happening an operator must stop the circulating pump.

To obtain this mode, position the circulating pump switch to AUTO and the system select switch to SOLAR.

Note: Experience at Timonium has shown that 100°F water is about the lowest water temperature that will supply reasonable class comfort providing ventilation with outside ambient air is kept to a minimum.

- <u>Automatic Control of the Solar Heating System</u>

This is the only mode of operation that will supply an automatic supply of solar or auxiliary heat. If the hot water temperature is above 114°F, solar heat is provided; and if the hot water temperature is 114°F or lower, steam heat is provided. The same set of thermostats in the classrooms provides the room control for either solar or steam heat. For the automatic mode of operation, set the circulating pump switch to AUTO and the system select switch to AUTO.

- <u>Manual Control of Auxiliary Heat</u>

This mode of operation provides an override control of the solar system allowing isolation of the solar system for maintenance and repair and to provide auxiliary heat during extended periods of solar inactivity when the reserve is depleted. For this mode of operation, position the circulating pump switch to OFF and the system select switch to STEAM.

C. Maintenance

For the hot-water-type solar heating and cooling system, maintenance results from the hostile environmental conditions to which the system is subjected and from the rigors and physical loading induced into the system components by the operating cycle. The maintenance discussed herein is all of the operations required to retain the solar systems in serviceable condition or to restore them to operational capability.

The maintenance includes such functions as inspection, test, service, repair, clean, lubricate, replace, calibrate and operational checkout. It consists of two types - preventive and corrective.

The preventive maintenance consists of visual inspections, servicing, scheduled periodic maintenance such as cleaning, lubrication, verification of calibration, filter replacement, and preservation of equipment through performance checks.

The corrective maintenance consists of the repair and replacement of parts that failed because of malfunction or breakdown. This type of maintenance is not scheduled and is performed as required.

See Tables 2-1 and 2-2 for Preventive and Corrective Maintenance respectively.

Table 2-1. Preventive Maintenance

Item	Qty.	Reason for Maintenance	Work Performed	Frequency Required	Hours	Cost Materials
Filterite Particle Filters	3	Prevent pressure loss in system	Replace 54 filter cartridges	Every 3 mos.	2	$81.00
Collector Panels	180	To check panel condition	Inspect for deterioration	Monthly	1	--
Storage Tank Temp. Probe	1	To calibrate temp. probes	Calibration	As req'd.	4	$10.00
Culligan Tanks	3	Periodic degradation of deionizing material	Replace deionizing tanks	Every 90 days	Factory service	--
Replenish deionized water	As needed	Maintain water level in storage reservoir	Replace water lost thru evaporation	As req'd.	0	.04/liter
Heating Controls	Ctr. Wing	Periodic service	Adjustments	As req'd.	Factory service	--
Recorder	1	Periodic service	Inspect and lubricate	Every 90 days	Factory service	--
Filter screen in float level tank	1	To provide additional protection to collectors	Clean	Every 6 Mos.	2	0
Filters in feeder lines to collector banks	20	To provide insurance against loss at indiv. collectors	Added a filter in each collector bank supply line	Clean as required	4	--
Collector input & output hose connections	360	Inspected all hose connections for deterioration	Replaced all defective hoses	As req'd.	40 hrs/ year	$50.00
Pump strainers	3	Reduced flow	Clean	Annually	4	--
Hot water pump Circulating pump	1	Bearing lubrication	Lubricate	Anually	.5	--
Air Filters	20	Dirty filters	Clean or replace	Annually	2	$50.00
(bration	--	Out of calibration	Calibrate	As req'd.	As req'd.	-

Table 2-2. Corrective Maintenance

Item	Qty.	Reason for Maintenance	Work Performed	Required Frequency	Maint. Hours	Labor/cost @ $12/hr
Anemometer	1	Defective bearings	Replaced bearings	As req'd	4	48
Pyranometer	1	Lost hermetic seal	Returned to factory	As req'd	8	96
Leeds & Northrup Recorder	1	Recorder stopped running	Repaired as required	1 time	Factory Service	40
Collector pump circuit breaker	1	Defective	Repaired	1 time	2	24
School primary heating system	As req'd	Steam leaks	Repaired leaks	As req'd	4	43
Digital Readout Meter	1	Defective	Replaced meter	1	2	24
Recorder	1	"Dot" & "Number" belts not printing	Replaced belts	As req'd	2	24
Potentiometer	1	Defective	Replaced potentiometer in linearized circuit	1	4	48
Leaks on roof	As req'd	Defective input & Output connections at collector	Replaced hoses	As req'd	40	480
Improper Collector flow	As req'd	Dirty filters	Removed, cleaned & replaced filters	As req'd	40	480
Instrumentation	As req'd	Calibration	Calibrated sensors	As req'd	20 hrs/ year	240

. Analysis of Operation

A. Environmental Data

1. Climate

The climate at Timonium, Maryland is classified (TREWARTHA* - 4th Edition) as "Temperature Continental" (Dc). Timonium's latitude is in the more southerly part of the lower half of the "Temperate Continental" zone. This is a sub-classification of (Dc) known as (Dca) or that part of the "Temperate Continental" climatic belt with warmer and more humid summers.

The average annual rainfall at this location over the past 25 years has amounted to 41.7 inches, while the average annual snowfall for the past 25 years has amounted to 21.9 inches. The percentage of possible annual sunshine over a 25 year period is 57%. For the year 1975, the percentage of sunshine was 54% and for 1976 it was 57%. The mean sky cover in tenths from sunrise to sunset over a 25 year period is 5.9. In 1975 the average sky cover was 6.5 and for 1976 it was 5.9.

2. Location

Timonium, Maryland, U.S.A. is located at latitude 39°31' north and longitude 76°37' west and is 350 feet above sea level.

The terrain at this location consists of gently rolling hills and the solar installation is mounted on the roof of the school which is on the peak

* G. T. Trewartha, "An Introduction to Climate;" (McGraw-Hill, New York, 1968); A Worldwide Classification System.

of a hill. There are no geographical or industrial obstructions to the sun's rays with the possible exception of a protective fence or shield that is mounted along the northern, eastern and western perimeters of the solar installation itself. This shield obstructs the receipt of the sun's rays along the eastern and western walls during early morning and late afternoon hours. The shield is also the only deterrent to any winds that exist.

Air quality is generally rated as good. An occasional "air-stagnation" alert occurs during the summer months. Since this elementary school has a baseball diamond on its grounds, there is minor dust precipitation on the flat-plate collectors and their respective reflectors. This dust is generally cleared up by subsequent rains. Since there are many trees in the neighborhood, pollen usually settles on the solar collectors and reflectors but this also is washed off by subsequent rains.

3. Solar Radiation

A mean total insolation over a period of years cannot be reported for this project since this data was collected for less than one year. A qualified monthly total insolation can be reported for the months shown in the following chart.

The data for Timonium presented in the chart is based upon the mean hourly data collected over a 24 hour day by means of the Eppley Pyranometer mounted on a surface 45° to the horizontal and facing due south. The unit

Comparison of Insolation Data Between Timonium Elementary School and American University @ District of Columbia

Insolation Data (NOAA)* (National Climatic Center)				Insolation Data @ T.E.L.Δ		
Insolation Total for Mo. (Mean daily x no. of days/Mo. Btu/Month/Ft^2	Mean Daily Insolation Btu/day/ft^2	No. of days in Mo.	Month of Yr.	No. of Days Recorded for the Mo. @ T.E.L.	Act. Tot. Insolation for No. of days recorded per month (Btu/Ft^2)	Projected total Insolation for a Full Mo. based upon the Actual Daily Avg. x Total Days of Month (Btu/Mo/Ft^2)
18073	583	31	Jan	29	19076	21059
23856	852	28	Feb	28	24663	24663
36766	1186	31	Mar	19	19163	31267
44040	1468	30	Apr	28	38217	40946
53413	1723	31	May	13	17708	42250
56430	1881	30	June	23	33971	44313
56699	1829	31	July	18	29204	50290
50313	1623	31	Aug	25	31619	39561
40290	1343	30	Sept	--	--	--
31713	1023	31	Oct	18	22046	37945
21240	708	30	Nov	29	33173	34308
16120	520	31	Dec	27	21051	24188

* NOAA - National Oceanic & Atmospheric Administration
National Climatic Center - Asheville, N.C. 28801
Based on 39 year reporting period - at American University in District of Columbia.

Δ Timonium Elementary School, Timonium, Maryland 21093 (Measured @ 45^{o} to horizontal).

has a response time to make effective measurements and indicate the passage of clouds. Both the direct and indirect components of incident radiation are picked up by the transducer to give a composite output. Accuracy and resolution depend on system interference noise levels and the stability in the signal conditioning equipment and is on the order or 1.5% of the reading.

4. Table 3-1 gives the dry temperature, relative humidity, degree days and the wind speed and prevailing direction for the Timonium Elementary School. The normals were based on a record for a 1941-1970 period. The mean wind speed was based on a record from 1951 to 1972. The averages were taken within that particular month. Wind directions are measured clockwise from true north; 360° being north and 0° meaning calm winds.

	Dry Temperatures*		Relative Humidity %		Degree Days, Base 18°C				Wind Speed** & Prevailing Direction			
					Actual		Normal		Average		Mean	
Month	Avg. Mo.	Norm. Mo.	Avg.	Normal	Heating	Cooling	Heating	Cooling	Speed	Direction***	Speed	Direction
Mar. '74	7.33	6.0	58.0	60.75	341	2	382	0	4.65	290	5.01	WNW
April	12.94	16.81	62.25	61.0	172	13	189	0	4.56	260	4.92	WNW
May	16.61	17.61	73.75	66.5	82	32	61	39	3.98	230	4.29	W
June	20.28	22.44	79.5	69.5	8	70	0	125	3.76	280	3.89	WNW
July	24.72	24.78	68.75	69.75	0	201	0	200	3.67	270	3.67	W
Aug.	23.89	23.83	82.25	74.25	0	176	0	171	2.91	210	3.67	W
Sept.	19.72	20.28	78.25	73.0	27	72	15	73	3.04	280	3.76	S
Oct.	12.94	14.11	67.6	70.5	168	4	139	8	3.04	290	3.98	NW
Nov.	9.0	7.83	67.5	67.25	283	6	315	0	4.20	280	4.25	WNW
Dec.	4.61	1.83	68.375	68.0	422	0	512	0	3.84	300	4.20	WNW
Jan. '75	3.61	0.78	68.0	65.25	454	0	544	0	4.02	280	4.43	WNW
Feb.	3.94	1.56	63.0	64.0	400	0	470	0	3.93	280	4.78	NW
Mar.	5.61	6.0	59.375	60.75	390	0	382	0	4.78	300	5.01	WNW
April	10.22	16.81	52.375	61.0	242	2	189	0	5.23	300	4.92	WNW
May	19.1	17.61	74.25	66.5	37	62	61	39	3.13	150	4.29	W
June	22.8	22.44	73.25	69.5	1	140	0	125	3.58	230	3.89	WNW
July	24.5	24.78	76.375	69.75	0	195	0	200	3.08	230	3.67	W
Aug.	25.5	23.83	73.125	74.25	0	224	0	171	3.26	280	3.67	W
Sept.	18.89	20.28	78.75	73.0	28	47	15	73	3.35	320	3.76	S
Oct.	15.94	14.11	74.625	70.5	87	15	139	8	3.40	300	3.98	NW
Nov.	11.06	7.83	68.25	67.25	221	6	315	0	3.53	260	4.25	WNW
Dec.	3.22	1.83	68.5	68.0	474	0	512	0	3.84	310	4.20	WNW
Jan. '76	-0.67	0.78	66.375	65.25	583	0	544	0	4.29	300	4.43	WNW
Feb.	6.72	1.56	57.25	64.0	335	1	470	0	4.87	270	4.78	NW
Mar.	30.32	6.0	63.375	60.75	288	0	382	0	4.69	260	5.01	WNW
April	39.12	16.81	52.625	61.0	163	32	189	0	4.34	310	4.92	WNW

* Temperatures in °C.
** Wind Speeds in m/sec.

*** Figures for directions are measured clockwise from due north; 360° being North and 0° meaning calm winds.

Temperature & Wind Conditions

TABLE 3-1.

B. Direct Operating Costs of the Solar System.

The direct operating cost for the solar heating system is the total cost of the electrical energy that is used in the collection of the solar heat, the supply and distribution of the heat to the school, and the operation and monitoring of the control system. Specifically, the electrical energy provides the motive power for the operation of both the collector and school heating water pumps, the unit heater's circulating fans, and the electrical circuits in the control and monitoring system.

Table 3-2 presents the costs for all elements of solar heating and collection systems including that of instrumentation and control.

The costs of operating the cooling system are not included for the periods 6/1/75 through 8/31/75 and 6/1/76 through 8/31/76 simply because the expense of operating the "oversized" absorption chiller and cooling tower would not be indicative of an optimum system.

The variation in costs for similar periods in different years were caused by differences in the weather which either allowed more collection or heating time or a combination of both.

TABLE 3-2 . CUMULATIVE OPERATING COSTS FOR ALL SOLAR COLLECTION AND HEATING SYSTEM ELEMENTS

Reporting Period	Hours Collected	Hours Heated	Btu Collected	KWH Used	Cost at .038/KWH	Remarks
9/1/74-11/30/74	--	--	47×10^6	700	26.60	
12/1/74-2/28/75	150	528	44.7×10^6	1210	46.00	
3/1/75-5/31/75	180	240	62.9×10^6	850	32.30	
6/1/75-8/31/75	288	420	137.4×10^6	483	18.35	See note 1
9/1/75-11/30/75	165	1320	90.4×10^6	880	33.44	
12/1/75-2/29/76	180	725	63.3×10^6	1400	53.20	
3/1/76-5/31/76	196	1464	83.5×10^6	2550	96.90	
6/1/76-8/31/76	170	217	67.9×10^6	778	29.56	See Note 1

Note 1: The costs listed are for the collection and heating pumps only - cooling system costs for the "oversized" chiller are not included.

C. Fuel Savings

Solar heating at the Timonium School resulted in a saving of approximately 3931 gallons of No. 6 Fuel Oil for the length of the program.

The estimated savings were arrived at as follows:

- From the school's fuel record, the monthly grand total oil consumption for the fuel plant was established.

- Experiments were conducted on days that no space heating was required (classes were in session) to determine the number of gallons used for daily consumption of domestic hot water. (40 to 50 gals/day when classes were in session was the number arrived at.)

- The monthly grand total less the domestic hot water allowance for the month left the net gallons of fuel used for heating the entire school.

- By making allowances for the area and volume of the school heated, it was assumed that the center wing comprised about one-ninth of the total.

- It was assumed that the amount of fuel oil consumed per month by the power plant and attributed to the center wing would be equal to one-ninth of the difference of the monthly grand total less the domestic hot water allowance.

- The number of gallons attributed to the center wing times the boiler efficiency of .65, times 150,000 Btu/gal of No. 6 oil equals the total estimated Btu required to heat the center wing.

- The percentage of heat supplied by solar is equal to the Btu supplied by solar divided by the estimated Btu required for the school's power plant to heat the center wing.

- Gallons of fuel saved is equal to the estimated gallons required to heat the center wing by the school's power plant times the percentage of heat supplied by solar heat.

The following tabulation lists the gallons of No. 6 Fuel Oil saved during the 3 month reporting periods that are listed.

Reporting Period	Gallons of #6 Fuel Oil Saved
Mar, Apr, May - 1974	1200
June, July, Aug - 1974	No heat required
Sept, Oct, Nov - 1974	387
Dec '74, Jan, Feb - 1975	548
Mar, Apr, May - 1975	Shut down for air conditioning modifications
June, July, Aug - 1975	No space heating required
Sept, Oct, Nov - 1975	505
Dec '75, Jan, Feb - 1976	650
Mar, Apr, May - 1976	641
June, July, Aug - 1976	No space heating required
Sept, Oct 15, 1976	End of contract.

Table 3-3 lists the estimated gallons of fuel oil saved for the period 1 October 1975 through 30 April 1976. For the months indicated it lists the average ambient temperature (^{O}F), degree days of heating, amount of oil used by the school's power plant that is attributed to the school's center wing, the percent heated by solar and the gallons of fuel oil saved.

TABLE 3-3 . ESTIMATED GALLONS OF FUEL OIL SAVED FOR THE PERIOD 1 OCTOBER 1975 THRU 30 APRIL 1976

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9
Month of Yr.	Avg. Amb. Temp. ^{o}F	Degree Days for Month	Grand tot. oil used by School Pwr Plant (gallons)	Net tot. after allowance for domestic hot water (gallons)	Amt of net tot attributed to center wing only (1/9 of net total) (gallons)	Est. Btu attributed to center wing equals gallons x .65 x 150,000 (btu)	Btu supplied by solar heat to center wing (btu)	% heated by solar 7 ÷ 6	Gallons of oil saved 8 x 5
Oct 75	60^{o}	156	1887	1116	124	11.9×10^{6}	11.9×10^{6}	100	124
Nov 75	50^{o}	450	4525	3645	405	39.5×10^{6}	37.13×10^{6}	94	381
Dec 75	37^{o}	868	7162	6282	698	68.3×10^{6}	15.8×10^{6}	23.1	162
Jan 76	30^{o}	1085	9238	8358	928	90.5×10^{6}	19.9×10^{6}	22.0	204
Feb 76	44.1^{o}	603	5281	4401	489	47.7×10^{6}	27.7×10^{6}	58.0	284
Mar 76	48.1	518	6000	5120	569	55×10^{6}	39×10^{6}	71	404
Apr 76	56.9	293	3010	2130	237	23.1×10^{6}	23.1×10^{6}	100	237

D. System Economic Analysis

1. Capital Equipment Costs (actual costs for Timonium)

Table 3-4 shows a breakdown of the actual cost of installing the Timonium Solar Heating Installation as the expedited program that it was.

Table 3-5 shows estimated costs for these same items if the program would not have been expedited. The engineering and manufacturing costs were reduced 20% and procurement dollars were reduced 5%.

Further discussion of the major cost elements is as follows:

a. Solar Collectors

The costs included in this category include the collector engineering, manufacture, and temporary tooling required for manufacture of the quantity for the installation. One hundred eighty (180) collectors with 6 spares were fabricated. The total cost for the collectors, on a non-expedited basis, is projected at $106,450.00.

b. Mounting Trusses - School Modifications - Protective Screen

The costs incurred in this category were attributed to the addition of the solar heating system to a school already built. It is estimated that 10% of this cost was for the protective shielding around the rooftop installation.

Actual Capital Equipment Costs of AAI Solar Energy Proof-of-Concept Experiment (Expedited Program)

Major Category	Engineering		Manufacturing		Procurement	Total
	Approx. Hrs.	Dollars	Hours	Dollars	Dollars	Dollars
1. Collectors Including Temporary Tooling	1400	24,500	5000	67,000	35,000	126,500
2. Mounting Trusses - School Modifications - Screen	1200	21,000	2800	37,520	27,500	86,020
3. Collector Plumbing - Pump House	900	15,750	1400	18,760	22,500	57,010
4. Insulated Storage Tank	600	10,500	1200	16,080	12,500	39,080
5. School Plumbing and Convectors	400	7,000	200	2,680	60,000	69,680
6. Instrumentation	1000	17,500	1200	16,080	41,250	74,830
7. Installation	500	8,750	1000	13,400	31,250	53,400
Total	6000	105,000	12800	171,520	230,000	506,520

Table 3-4

Estimated Capital Equipment Costs
Of AAI Solar Energy Proof-of-Concept Experiment
(Costs reduced to show effect of a non-expedited program)

Major Cost Category	Engineering Reduced 20% for Non-Expedited Program		Mfg. Reduced 20% for Non-Expedited Program		Procurement Reduced 5% for Non-expedited Program	
	Hours	Dollars	Hours	Dollars	Proc. Dollars	Total Dollars
1. Collectors	1120	19,600	4000	53,600	33,250	106,450
2. Mounting Trusses	960	16,800	2240	30,016	26,125	72,941
3. Collector Plumbing	720	12,600	1120	15,008	21,375	48,983
4. Insulated Storage Tank	480	8,400	960	12,864	11,875	33,139.
5. School Plumbing and Convectors	320	5,600	160	2,144	57,000	64,744
6. Instrumentation	800	14,000	960	12,864	39,188	66,052
7. Installation	400	7,000	800	10,720	29,687	47,407
Total	4800	84,000	10,240	137,216	218,500	439,716

Table 3-5

c. Collector Plumbing - Pump House

The costs for the collector plumbing include a separate pump house which would not be required in a new school where solar heating would be part of the main heating plant. In addition, extra flow meters and valves were installed for obtaining operational data. In a new school it is estimated that this cost would be about $1.50 per square foot of collector area.

d. Insulated Storage Tank

The costs for the tank design and manufacture is included in this category. In addition, the insulation and concrete pad are included. On a non-expedited program, the capital cost of the tank was $2.10 per gallon of water storage capacity.

The storage tank cost could be reduced to about $0.60 per gallon by the use of a prefabricated, insulated tank procured from an established tank fabricator.

e. School Plumbing and Convectors

The labor for the installation of the school plumbing and convectors was performed by a subcontractor. Therefore, the labor costs shown for this category are small and the subcontract costs are high. Since the Timonium Elementary School had a steam system, a completely new hot water system was installed. In a new school with a hot water system, the cost for this category would be completely eliminated.

If an existing school with hot water heat were converted to Solar Heat, the cost for this cost element would be about 5% of those experienced.

f. Instrumentation

The instrumentation costs incurred were primarily for use in obtaining experimental data. In a new or converted school, the instrumentation costs would be about 2% of those experienced at Timonium Elementary School.

g. Installation

The installation costs were somewhat high at Timonium Elementary School because the work was done on the wing during a period when classes were in session. It is estimated that the costs would be about 90% of those experienced if the school wing were not in use.

On a new school, we estimate the installation costs would be about 20% of those at Timonium Elementary School. Instrumentation would not have to be installed and walls would not have to be pierced for pipes, for example.

2. Estimated Capital Equipment Costs for an Optimum System of 3250 Ft^2 of Collector Capacity

The capital equipment costs of a system of optimum design and efficiency are shown in Table 3-6.

The estimated 1977 cost of a system of this type is $82,500 minimum to $130,000 maximum. (These numbers are based upon the guidelines in the ERDA Design Handbook.)

Capital Equipment
Procurement Costs for Optimum System*
(3250 Sq. Ft. of Collectors)**

Major Cost Category	Minimum $	Maximum $	Cost per Ft^2 of Collector (Min.)	Cost per Ft^2 of Collector (Max.)
1. Collectors	32,500	48,750	10	15
2. Collector Support Structure	13,000	19,500	4	6
3. Pumps, Piping, Controls & Heat Exchanger	13,000	26,000	4	8
4. Storage Tank (Insulated)	6,500	9,750	2	3
5. Chiller & Cooling Tower	Δ	Δ	Δ	Δ
6. Chilled Water Storage Tank	6,500	9,750	2	3
7. Installation	9,750	16,250	3	5
TOTALS	81,250	130,000	25	40

* Taken from Solar System Costs from ERDA Solar Design Handbook.

Δ Total cost assumes that chiller and cooling tower are included in building cost.

** This is the collector area required to produce the annual equivalent Btu of the 3750 gal. of fuel oil needed to heat the center wing of the school.

TABLE 3-6

An economic analysis of this system is shown in Table 3-7

The operational and maintenance costs listed are only those items pertinent to normal system operation and are based upon experience at Timonium. It is assumed that an optimum system would have minimum maintenance. It can be calculated from these tables that the optimum system will supply about 100% of the heating and cooling requirements; i.e.,

- Total Btu Collected per Yr. (see Note 2) $= 3250\ \text{Ft}^2 \times 320\ \text{Btu/ft}^2\text{/day} \times 365$ days $= 380 \times 10^6$ Btu/yr supplied to center wing

- 90% to Heating $= .9 \times 380 \times 10^6 = 342 \times 10^6$ Btu for Heating

- Gallons of Fuel Oil Required to supply 342×10^6 Btu = $\dfrac{342 \times 10^6}{.7 \times 150{,}000} = 3{,}257$ gallons

  Gallons of Fuel Oil Required to Supply 38×10^6 Btu = $\dfrac{38 \times 10^6}{.7 \times .65 \times 150{,}000} = 557$ gallons

  Total = 3814 gallons

- Fuel Oil Savings
  Assume 1977 cost of No. 6 Oil = .40/gal
  Savings ($) = .4 x 3814 = $1525.60

Note 1: The estimated fuel requirement for the center wing was 3750 gallons; therefore, the anticipated collection capacity exceeds the requirement and this should supply 100% of the energy required.

Note 2: The Btu required to be collected annually was determined by multiplying the equivalent Btu of 3750 gal. of fuel oil by the efficiencies of the boiler and chiller. Knowing the average daily solar radiation, the required collector area was then determined.

Economic Analysis of
Optimal Heating & Cooling System
(Timonium Type)
(Based upon supplying 100% of heating and cooling)

ITEM	Procurement Costs	
	Minimum 81,250	Maximum 130,000
1. Cost per Ft^2 of Collector (3250 Ft^2)	25.00	40.00
2. Operational Costs per Year	131.00	131.00
3. Maintenance Costs per Year	105.00	105.00
4. Fuel Savings per Year*	1526.00	1526.00
5. Gallons of Oil Saved per Year	3750 gal	3750 gal
6. Btu Collected Per Year for Each Sq. Ft. of Collector (3250 Ft^2)	116,800	116,800
7. Payback Period = $\frac{\text{Procurement Cost}}{\text{Fuel Savings}}$ in years based upon fuel savings only	54 yrs.	87 yrs.

TABLE 3-7

To arrive at the payback period, the following assumptions for Timonium were made:

1. The fuel requirements for the center wing of Timonium School for the period 1 Oct. 1975 to 1 Oct. 1976 is assumed to be one-ninth of the school's total. The school's record shows a total of 32000 gallons of No. 6 fuel oil for heating and cooling consumed during this period, of which 3750 gallons is apportioned to the center wing.
2. Boiler Efficiency - .7
3. Chiller Efficiency - .65
4. Solar Radiation Available = 320 $Btu/ft^2/day$
5. Collector Area = 3250 Ft^2
6. Btu collected per year per ft^2 of collector = 116,800 Btu
7. Based upon a computer analysis approximately 10% of annual energy load is for air conditioning and 90% is for heating.
8. Cost of fuel Oil (#6) in 1977 = $.40/gal.

Knowing the fuel savings and the total procurement cost of the optimum system a payback period can be calculated according to the straightline method.

Procurement Cost	=	$81,250.00
Fuel Savings	=	$ 1,525.60 (per yr)
Payback Period (in yrs)	=	$\frac{\$81,250.00}{1525.6} = 53.25$ yrs

E. Solar Collecting and Heating System Performance

1. Collection System Efficiency

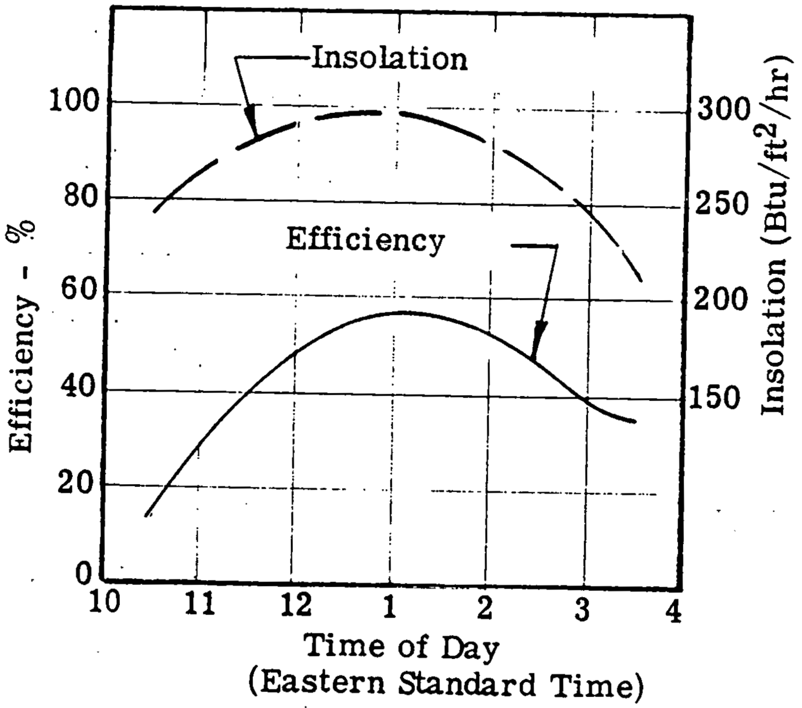
The following graph of solar collection efficiency illustrates the maximum solar heat collecting capability of the Timonium Solar Heating System. The 17 April 1975 day was essentially an ideal collecting day in that the climatic conditions and solar insolation were conducive to effective solar heat collection. To fully exploit these ideal collecting conditions, the system was operated in the manual mode which permitted fine tuning of the water flow to optimize heat transfer at the collectors. Due to the remote location of the temperature measuring instruments, the efficiencies illustrated in the graph are not the absolute efficiency of the collector array but are those representative of the overall system. The graph depicts the efficiencies of the collector system just prior to installation of the reflectors for air conditioning. The supporting data for this graph is listed in the accompanying table and this data was reduced from the Leeds & Northrup Recorder Printout for the date of April 17, 1975.

2. Typical Day's Collection Data (27 Aug. 1975 with solar reflectors functioning)

Figure 3-2 depicts a clear day's collection performance for the Timonium Solar Collection System. This is a reproduction of the actual data recorded on the Leeds & Northrup Speedomax Recorder. The following calculation of efficiency for the total system was selected for 1:00 p.m. DST when 100% of the reflector area was effective. The percentage of effective area varies as the sun rises in the sky and then sets.

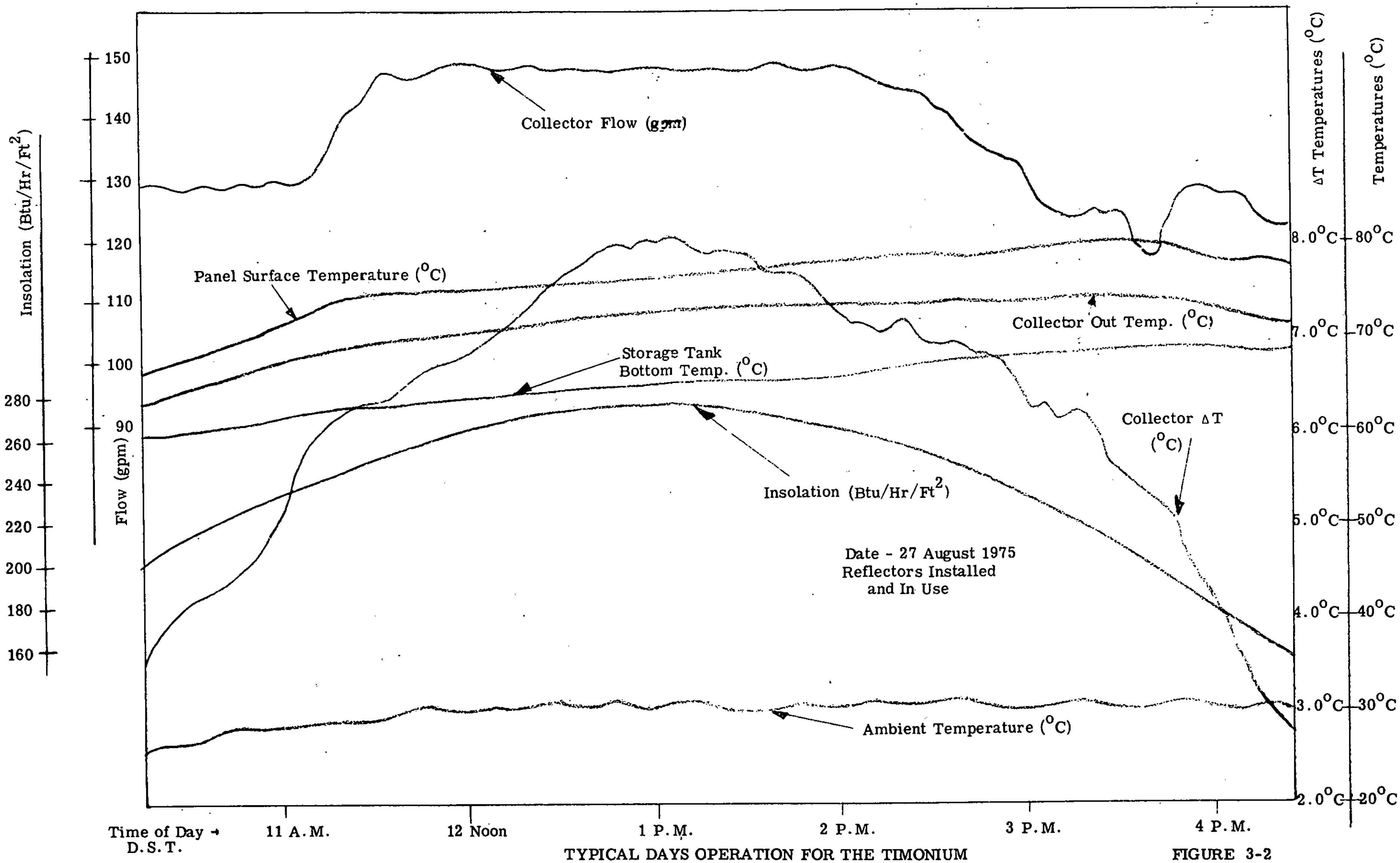
Standard Time	Efficiency η	Insolation $I\ (\frac{Btu/hr}{Ft^2})$	Total Sys. Flow (gpm)	Water Temp. $\Delta T\ ^{o}F$
10:30 a.m.	.16	240	110	3.0
11:00	.32	257	150	8.2
11:30	.39	288	163	6.0
12:30 p.m.	.54	295	163	8.5
1:30	.56	287	160	8.7
2:00	.52	274	140	8.75
2:30	.48	262	130	8.3
3:00	.37	248	116	6.8
3:30 p.m.	.34	210	120	5.2
System turned off @ 3:30 p.m.				

Total collector area equals 4250 ft^2
(No air conditioning reflectors added)



Date: April 17, 1975
A.M. Inlet Water = 146.5^{o}F
P.M. Inlet Water = 161.0^{o}F
Outlet Water @ 160.6^{o}F Avg.
Temp. Ambient = 65^{o}F Avg.
Wind - 3 mph - north
Weather - Clear

Figure 3-1. Solar Collection System Efficiency
(Prior to addition of reflectors for air conditioning)



TYPICAL DAYS OPERATION FOR THE TIMONIUM SOLAR COLLECTION SYSTEM

FIGURE 3-2

Knowing the total collector area of 4250 ft^2 (plus 5300 ft^2 of reflectors), the instantaneous efficiency at any time of day can be calculated by the following formula:

$$\eta = \frac{60 \text{ x flow (gpm) x wt. of water (lbs) per gallon x } \Delta T^{o}F}{\text{Collector Area (A) x } I_{45^{o}} \text{ (Insolation) Btu/hr/ft}^2}$$

i.e., $\eta_{1\,p.m.} = \frac{60 \times 148 \times 8.2 \times 14.58}{4250 \times 276} = .905$ or 90-1/2% (for collector area only or 40-1/2% when combining the collector area and 100% effectiveness of reflector area.

The graph presents the following information:

- o Total flow from collectors (gpm).
- o Insolation ($I_{45^{o}}$) measured at 45^{o} to horizontal plane (Btu-hr/ft^2).
- o Surface temperature of black absorber plate while water is flowing (^{o}C).
- o Combined solar array collector "out" water temperature (^{o}C).
- o Storage tank hot water temperature at bottom of tank (this is also input water to the collector array).
- o Ambient air temperature (^{o}C).
- o Collector array Delta-T ($\Delta T^{o}C$)

3. Summary of Solar Heating System Performance For the Period March 1974 to May 15, 1974

Figure 3-3 graphically presents a summary of the performance of the solar heating system for the period March 3, 1974 thru May 15, 1974. During this period there were no reflectors added to the collector array for air-conditioning purposes.

OPERATIONAL PERFORMANCE OF THE TIMONIUM SOLAR HEATING SYSTEM
FOR THE PERIOD OF MARCH 1974 TO 15 MAY 1974

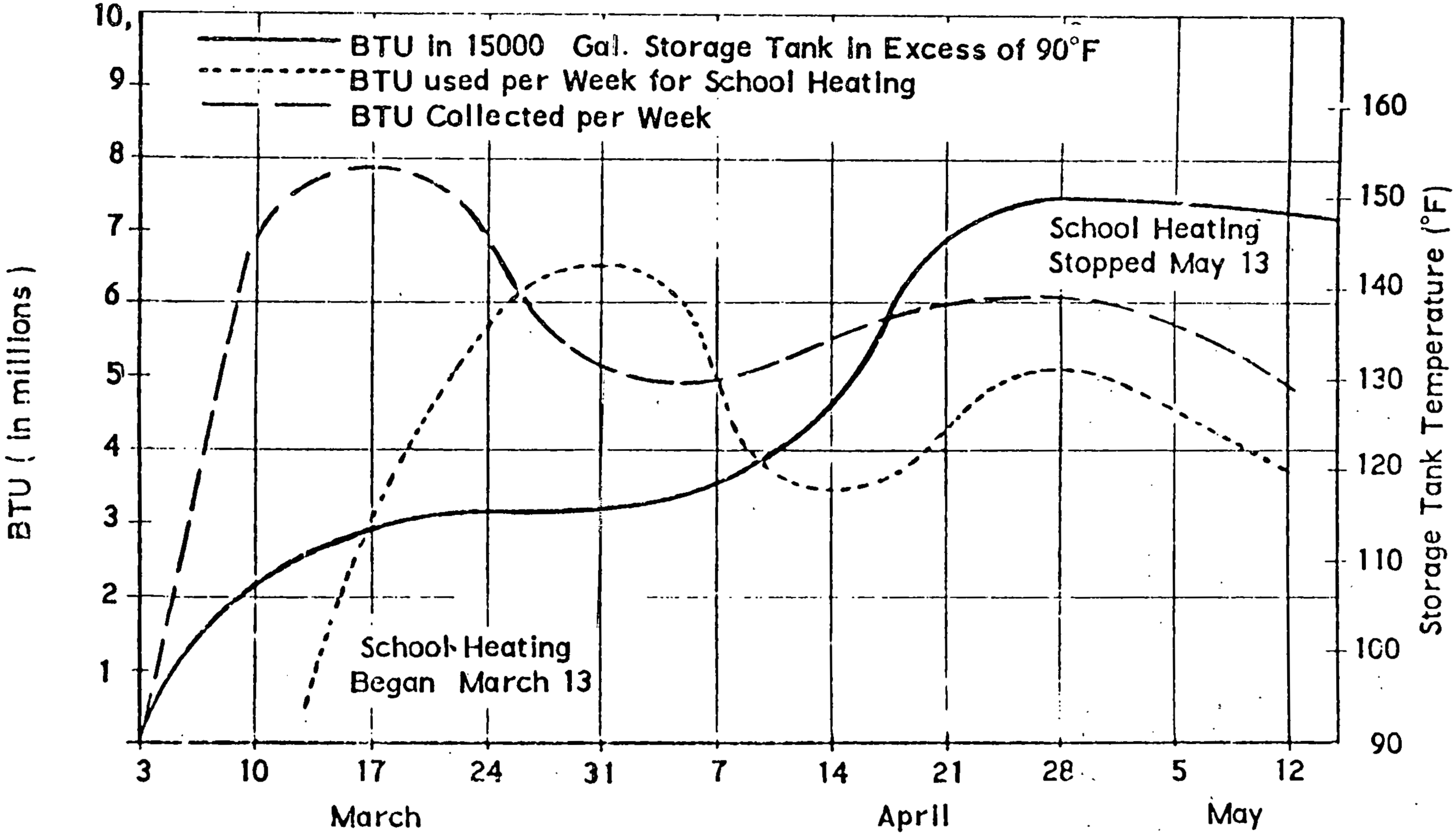


Figure 3-3

4. Solar Collector Sub System Efficiency

The solar collector subsystem includes the entire array of reflectors and collectors with their interconnecting piping and including the piping to and from the storage tank. Even though the individual collectors and reflectors are tilted, the array considered as a subsystem is assumed to be a horizontal collector since it is mounted on a horizontal roof. The area of the collector subsystem is taken to be the plan area of the roof which is occupied by the collectors and this area is presented in the plane in which the insolation is measured.

Since the insolation is measured at 45^{o} from horizontal, the collector area is the presented area of the occupied roof in a plane tilted at 45^{o} from the horizontal.

Figure 3-4 illustrates the actual efficiencies of the combined collector array at Timonium. Each symbol represents the efficiency on a clear day's performance for the months indicated. A total of 32 days was selected for the period June 1975 through March 1976. This data is then compared to the efficiency curve of a theoretical flat-plate collector with two glass plates and a black painted absorber plate. This curve (straight line) was developed by utilizing the procedures in "Low Temperature Engineering Application of Solar Energy" prepared by the Technical Committee on Solar Energy Utilization of the American Society of Heating

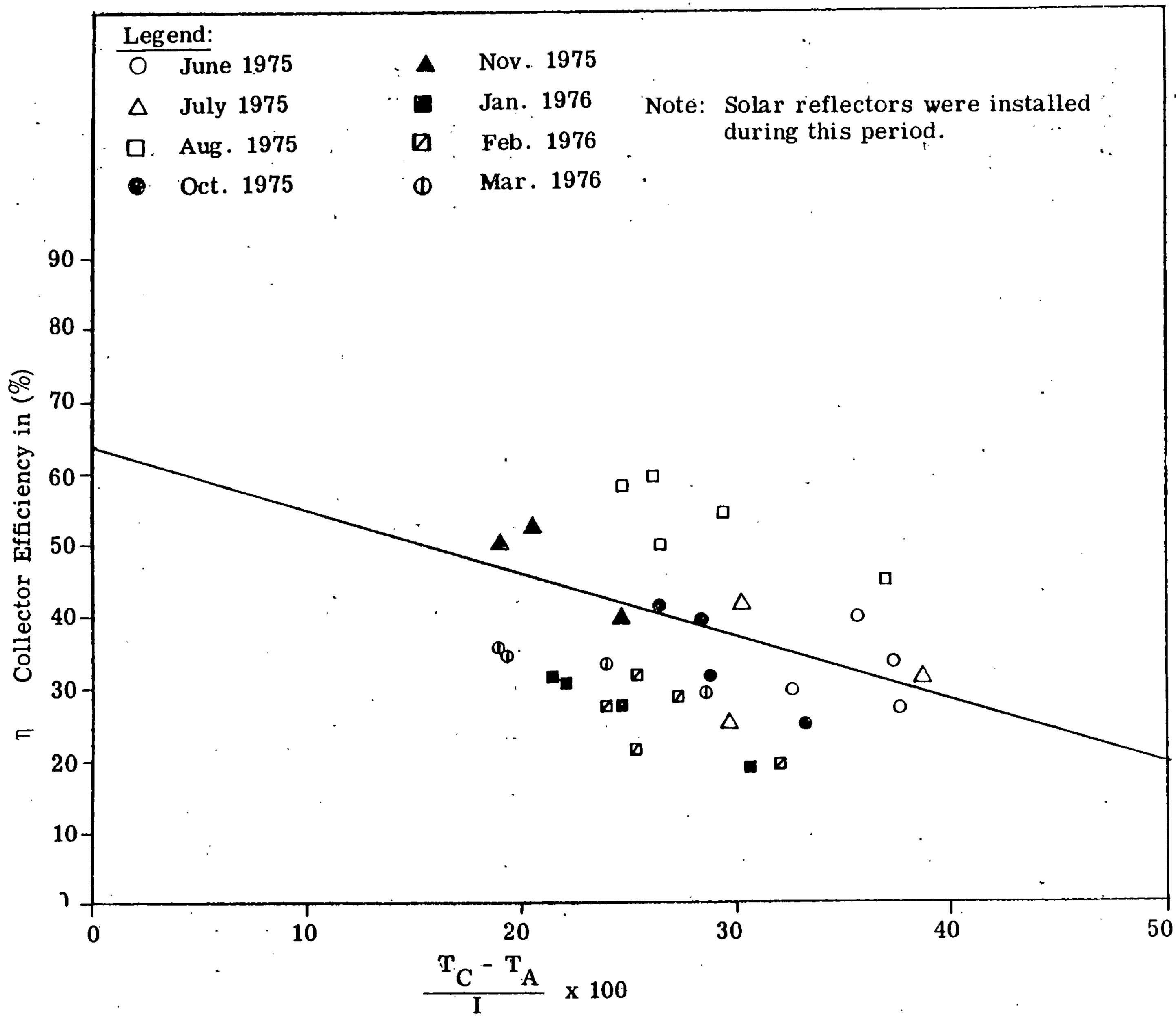


Figure 3-4. Solar Collector Subsystem Efficiency for Timonium Elementary School

Refrigerating and Air Conditioning Engineers, Inc. and edited by Richard C. Jordan. These procedures are listed in Chapter III (Design Factors Influencing Solar Collector Performance) by Austin Whillier. The points at the extreme ends of the theoretical curve were based upon the following assumptions:

- Total Insolation I_{45^o} = 250 Btu/ft^2/hr where the tilt angle of the collector equals 45^o to horizontal and it faces south.
- $T_C - T_A$ = 100 max and 0 min where T_C is the absorber plate temperature which is the average of the collector "in" and collector "out" water temperatures and T_A is the ambient air temperature.

The 32 points plotted in Figure 3-4 were calculated by means of the following formula and the data required was taken from the continuous recorder for the days selected.

$$\text{Collector Array Efficiency } (\eta) = \frac{60 \times \rho \times GPM \times \Delta T}{A \times I_{45^o}}$$

where: A = collector array area

ΔT = change in temp. of collector water "in" and "out"

ρ = weight of water per gallon (lbs)

GPM = flow in gallons per minute

I_{45^o} = insolation Btu/hr/ft^2 at a 45^o angle from horizontal.

5. Typical Day's Operation (22 March 1974)

Figure 3-5 depicts the daily operational performance with respect to environmental conditions of the solar heating system. This particular day was selected because the overall system had been sufficiently adjusted and tuned for efficient automatic operation and the climatic conditions were such that both school heating and solar collecting could be effectively employed. For this day's operation the graph summarizes the school's heating load, the quantity of solar heat collected and the effect of heat input and output on the holding tank's school heating capability.

It can be seen from the graph that the heating potential of the tank (available Btu for school heating) was approximately 3,000,000* Btu at the start of the day. During the course of the day the tank provided approximately 970,000 Btu in meeting the school's heating demand and, including the system's piping circuits, lost through radiation an additional 120,000 Btu. The collection of solar heat commenced at 10:30 a.m. and during the 7 hour operating period collected and supplied to the tank a total of 2,000,000 Btu. Since the Btu collected and supplied to the tank exceeded the total tank Btu loss by 910,000, the tank's heating potential was increased to 3,910,000 Btu at the completion of the day's operation.

* The 3,000,000 Btu is that in excess of 90°F of the storage tank. It was found that water down to 90°F could maintain Timonium's night cycle of 60°F; therefore, the heating system was often run on a semi-auto or manual mode of operation to take advantage of solar energy.

TYPICAL DAY'S OPERATION OF THE TIMONIUM SOLAR HEATING SYSTEM

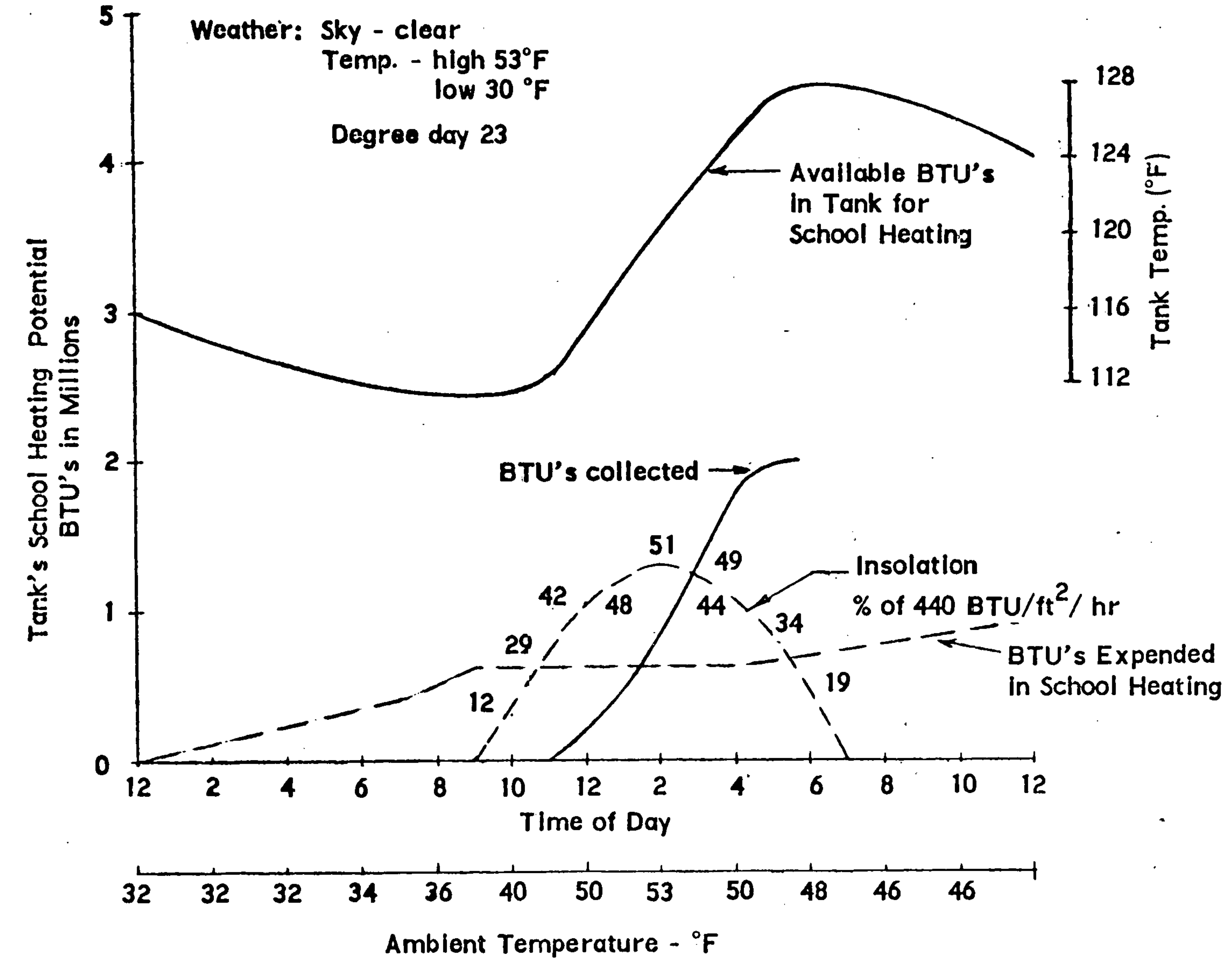


Figure 3-5

The graph of insolation is presented to show a relationship between the sun's incident energy to the collected energy for the period from sunrise to sunset. The numbers along the curve are percentages of the extraterestial radiation for mid winter (440 Btu/hr/ft^2) at one-half-hour intervals from sunrise to sunset.

Note that little or no heat is expended heating the school during the hours of 9:00 a.m. to 4:00 p.m. when the school is occupied by the students. Most of the school heating occurs at night and in the early morning hours.

6. Hot Water Storage Tank Thermal Characteristics

Figures 3-6 and 3-7 illustrate the thermal losses of the hot water storage tank for a weekly period in May 1975 and a weekly period in October 1975. The tank was isolated from the system by shut-off valves to prevent all convective currents from occurring other than the currents within the tank itself. Temperature sensors are located at 4 levels from top to bottom to aid in determining the average tank temperature. The average tank temperatures were compared from day to day to calculate thermal losses. The periods occurred at a time when there was no heat demand by the school but solar heating of the storage tank water was allowed to take place. This accounts for the increase of the average water temperature on those days that solar collection of energy was allowed to occur.

As mentioned previously the storage tank is vented to the atmosphere and it has a partial baffle which allows stratification of the water. It is capable of storing 15,000 gallons of water at $200^{\circ}F$. This amounts to 121,050 pounds of water and approximately 13.3×10^{6} Btu above a water temperature of $90^{\circ}F$ (or 10.4×10^{6} Btu above $114^{\circ}F$ which, as stated previously, is the water temperature below which auxiliary heat takes over when the system is operated in the automatic mode).

Solar heated water returns into the top of the tank while the water pumped to the collectors is drawn from the bottom of the tank.

The total flow to the collectors can be regulated from about 50 gpm to about 160 gpm. This is accomplished by means of a flow regulating valve and two constant speed pumps, each with a capacity of about 90 gpm.

The insulation was designed to limit the temperature loss to 1.25^{o}F in 24 hours under the following conditions:

Thermal Conductivity	= K = .03 per ft thickness
Thickness of Insulation:	
Top	= 4 inches
Outside	= 4 inches
Bottom	= 6 inches
Avg. Water Temperature:	= 120^{o}F
Ambient Temperature:	= 40^{o}F

Figures 3-6 and 3-7 illustrate that losses were larger. The insulation was not perfectly sealed from the varying atmospheric conditions. Condensation occurred inside the protective aluminum sheeting thereby reducing the effectiveness of the insulation.

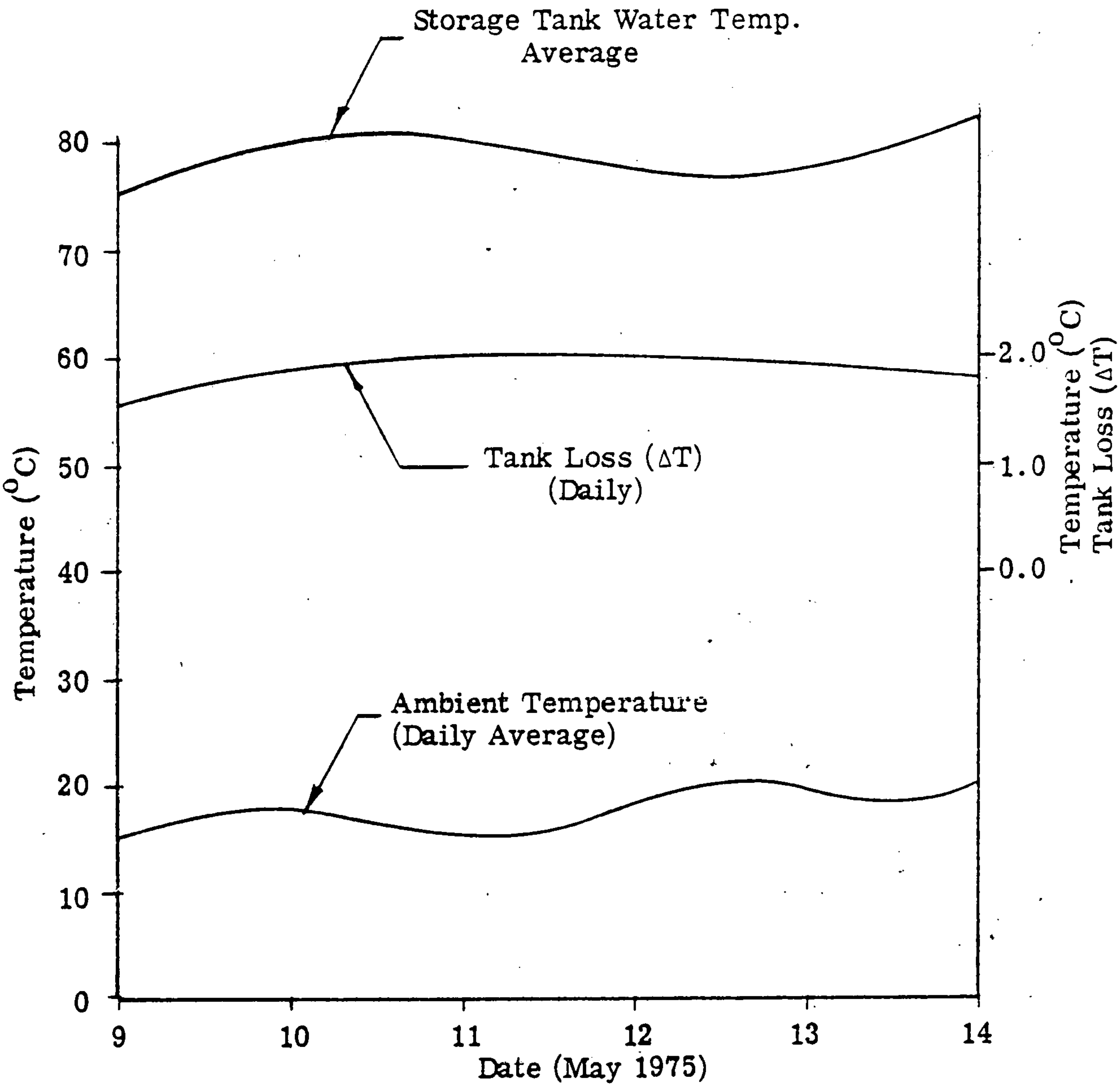


Figure 3-6. Storage Tank Thermal Losses

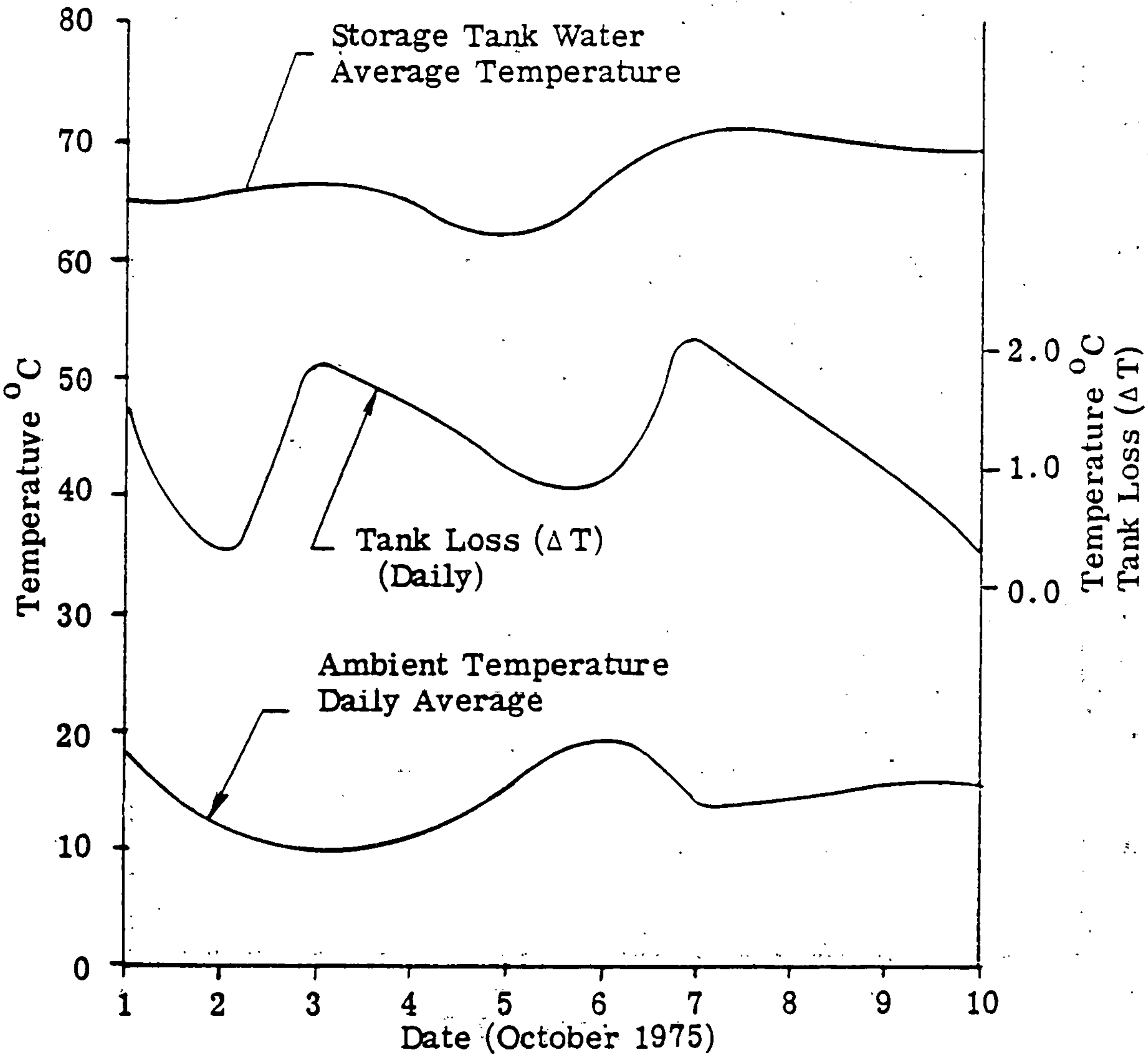


Figure 3-7. Storage Tank Thermal Losses

7. Lifetime Performance Results

Collectors: The aluminum collectors functioned in ambient temperatures ranging from $0^{o}F$ to $100^{o}F$ with winds ranging from 0 to 60 mph. The input water temperatures varied from $90^{o}F$ to $196^{o}F$. The collectors were mounted to trusses by hold-down strips from the top to the bottom of adjacent units. The edges along the top and bottom were clamped locally to the trusses in two places along each edge. These clamps resisted expansion along the length of the collectors. Neoprene rubber hose was used to connect the collectors to the aluminum supply manifold and also to the return manifold. The sections of interconnecting supply and return piping were joined by rubber couplings.

The stresses in the collectors produced by these environmental conditions caused a flexing of the collector assembly which resulted in failure of the bonded joints and gradual deterioration of the adhesives. In many cases both glass covers experienced minor cracking prior to separation of the joints.

No corrosion of aluminum materials was visually evident after 2-1/2 years of operation. Laboratory analysis of the working fluid showed that it contained elements of the epoxy adhesive that was used to assemble the collector parts.

The polypropylene filter cartridges located upstream of the collector pumps also showed evidence of the epoxy adhesive.

One aluminum part in the hot water storage tank was corroded. This was the unplated pipe containing the storage tank temperature sensors. It extended from the top towards the bottom within 3 feet of the inside wall and reached to within one foot of the bottom of the tank. The outer surface of the temperature probe contained serious pitting of uneven depths. When a black epoxy paint, the same as used on the absorber plate, was applied to the cleaned pitted surface, the corrosive action was slowed or stopped. The inside wall of the storage tank was not easily accessible for examination to determine if any corrosion was present.

Glass Damage: Inspection of the 180 solar panels on July 30, 1976 revealed the following damage:

Major Breakage	No. of Collectors
One glass plate broken	74
Both glass plates broken	32
Minor cracks in one glass plate	30

In almost all cases where only one glass plate was broken, it was the inner glass plate that was broken.

One cause of outer panel breakage was vandalism, and another was breakage during installation.

An analysis prepared by Kaman Avidyne Division of Kaman Sciences Corporation in Rpt. No. KATM-107 indicates that breakage of the inner glass is due to the thermal stress cycling induced by the heating and cooling of the collector plate.

Twenty of the damaged collectors were replaced with collectors in which the honeycomb between the glass plates was removed. Again the first plate to break was the inner plate.

A proposed solution for future designs would be to use tempered glass and allow both glass plates to be free to expand or contract.

Snow, Wind and Rain: Snow and freezing rain caused very little interruption of the solar collection system. Light snow, up to 2 to 4 inches, usually disappeared within 2 to 4 hours if the warm water was allowed to flow through the collectors. Since the collectors were mounted 45^{o} to the horizontal, the melted snow in contact with the glass would allow the bulk of snow to slide down and onto the roof of the building. In case of heavy snow build-up, the clearing process would take longer because the water return manifold at the bottom of the collectors acted as a blockage and caused the snow to back up along the lower half of the collector. If the ambient temperature were below $32^{o}F$ the clearing process at the lower 1/3 of the collectors could take several days.

Ice build-up caused by freezing rain would be cleared in a similar manner.

No manual or physical attempts were made to clear ice or snow unless a public request for a demonstration or other experiments were to be conducted. Snow or ice would remain accumulated on the reflectors at ambient temperatures below 32^{O}F. This was because no sunlight was incident upon the fixed mirrors during the winter months.

Water Leakage: The neoprene hose connections from the input manifolds to the collectors deteriorated because of the environmental conditions they were exposed to. The connections were exposed to sunlight, the flexing caused by expansion of the connected parts, and the hot water in the lines. Crazing or surface cracking would appear first, then eventual leakage. Leakage also occurred at the hose connection to the water return manifold. The water would seep around the internal connection and work its way between the foam rubber edging and the urethane foam insulation along the lower edge of the collector. The foam rubber covering also began to crack and leakage would eventually occur.

Absorber Plate: There is no visible corrosion of the coated aluminum plate after 2-1/2 years of operation. The black painted surface is wearing thin in spots and the bonded joints between the honeycomb and the flat plate are gradually disintegrating.

Collector Plumbing (Aluminum): The aluminum plumbing to the collectors was disassembled after 1 year of operation to allow installation of the trusses for the air conditioning reflectors. At this time they were oroughly flushed and no evidence of corrosion was present. All piping was interconnected by rubber hose couplings.

Insulation: The polyurethane foam insulation used in the collector is a closed cell and lightweight (2 lbs per ft^3) type. As the bonds between the honeycomb and the absorber plate deteriorated, the internal surfaces of the foam were exposed to the water and vapors. The insulation of a dismantled panel showed that the surfaces exposed to the water were wet and erosion caused fine gritty deposits into the water return lines.

The original 4 inches of fiberglass insulation on the top of the hot water storage tank was replaced because the cemented covering cracked and the fiberglass became wet. It was replaced with a 4 inch thickness of block type insulation with a circumferential metallic edging to prevent rain water from seeping down the sides of the tank.

The fiberglass batting around the sides of the storage tank was protected by overlapping aluminum strips about 36 inches wide. Condensation between the aluminum and the insulation caused it to get wet and reduced its efficiency.

There was no access to the urethane foam insulation underneath the storage tank except for the extreme outside edge. It appeared that condensation could get between the foamed insulation and its protective plastic sheet. Also, rainwater could penetrate between the plastic sheet and the concrete pad upon which the storage tank was mounted.

Pyranometer: A Black & White Pyranometer Model 8-48 manufactured by Eppley Laboratory, Inc. was used to measure the solar radiation at the Timonium installation.

The original pyranometer was shipped back to the factory for repair because of moisture condensation inside the hemispherical dome. Since repair and calibration, the instrument has functioned properly.

Flowmeters: Four flowmeters are used throughout the system. A turbine type flowmeter, Model FT-40C225-LJ (Flow Technology), is used in the collector system return line. A Fischer-Porter flowmeter Model FAL10875 is used in the chilled water system.

Foxborough Models E13DM-IKAM-2 and E13DL-IKA2 are used in the hot water to school or to absorption chiller and the supplementary steam line, respectively.

Sensors: Platinum resistance thermometers are used throughout the system for measuring temperatures. Models AP-250-250-100-2 and IP-632-100-4-2 and 2A manufactured by Templine were installed. There were no unusual problems other than normal calibration requirements.

Working Fluid: Water drawn from the city water supply was used to fill the storage tank. It was passed through deionization equipment during the initial filling operation only. No antifreeze was added to the water to prevent freezing. The one fluid circulated through the collectors, the school fan-coil heaters and the absorption chiller. Laboratory analysis of the water showed no evidence of fungus or algae but did show evidence of elements of the epoxy adhesive used to assemble the components of the collectors.

Filters: The cartridge-type filters used in the collector and school heating circuits were No. U10A10A (Polypropylene) manufactured by the Filterite Corporation. Initially 10 micron filter elements were used in the collection circuit and 30 micron in the school heating circuit. As the system aged and collectors began to break down, 100 micron size filter elements were used. The system presently uses the 100 micron size units.

Cooling Tower: A Model JO905B33 cooling tower, manufactured by Baltimore Air Coil, is used at Timonium. City water is used to fill and maintain the water level in the cooling tower. The tower was serviced twice a year. This included cleaning filters and assuring that all water jets were functioning. The tower was drained each winter.

Reflectors

No service was done to the glass mirror reflectors. The surfaces were cleansed by rain water alone. Any dust or pollen was washed away by subsequent rain. About one-tenth of one percent of silver surface deteriorated after 18 months service. This was attributed to a local breakdown in the epoxy coating over the silver. Snow accumulation was allowed to disappear naturally during the winter months since the reflectors were always shaded.

F. Solar Cooling System Performance

The solar cooling system at Timonium was installed in two phases. The absorption chiller was installed in the spring of 1975 and the chilled water storage tanks in the spring of 1976. All 1975 data presented herein is for chiller operation only and the data for the summer of 1976 will be concerned with the various modes of operation, i.e., "cool school directly from chiller" or "cool school directly from chilled water storage tanks" or "cool school and storage tanks by means of the chiller."

Table 3-8 presents the performance of the absorption chiller at various water temperature inputs to the chiller generator. The unit functioned with water inputs as low as 140°F without crystallization. The cooling loads at Timonium for the dates specified ranged from an average of 4 to 14 tons of cooling per hour. Consequently the absorber operated at a level far below its capacity, resulting in lower efficiency. The chiller was shut down every afternoon and started up each morning.

1. Absorption Chiller

Figure 3-8 presents the design conditions for the York absorption chiller Model ES1A2(H.W.) Modified. The graph illustrates the variation COP (Coefficient of Performance) with cooling load when operating under the conditions stated.

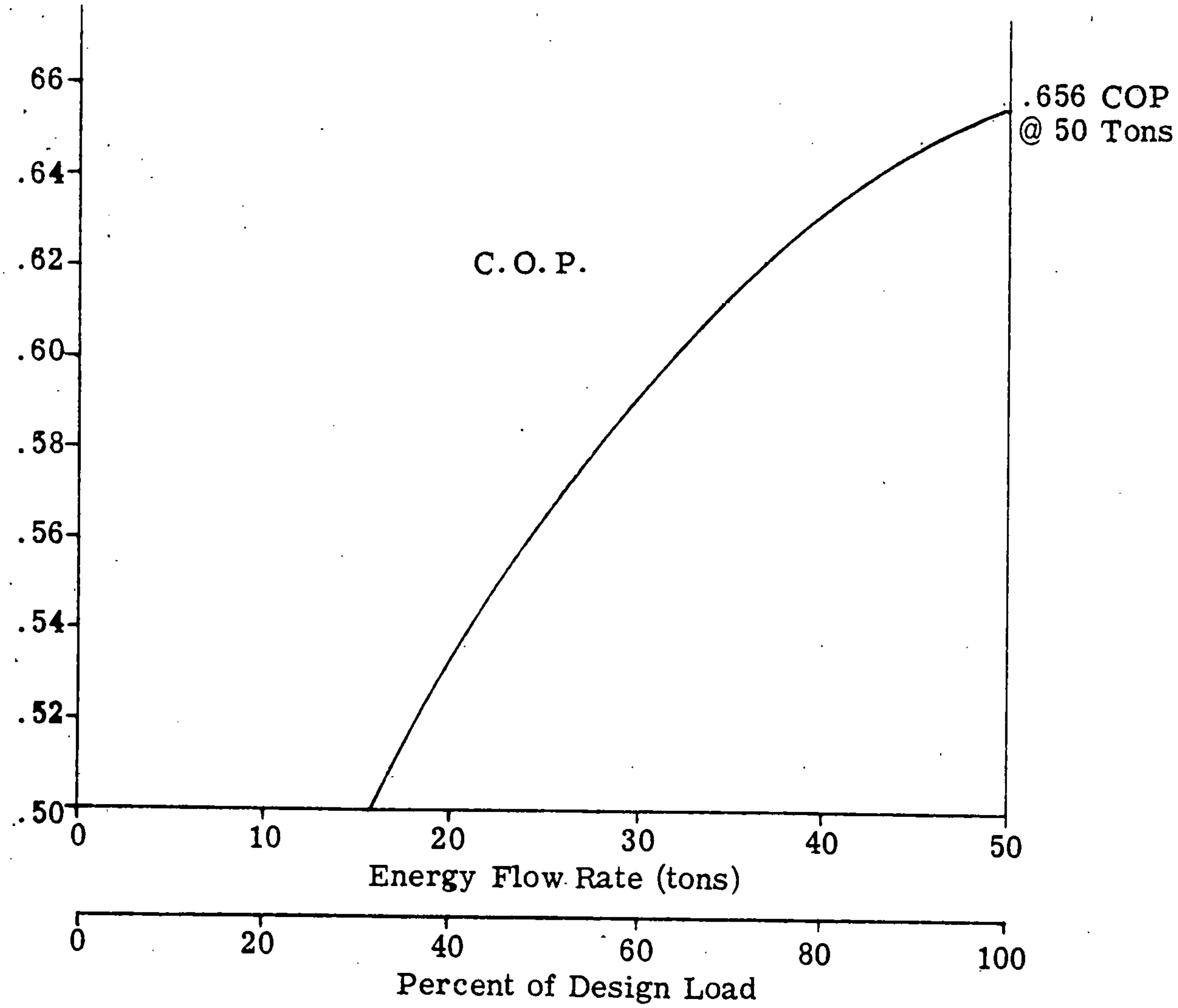
Item	1975										1976
	7/3	7/1	7/9	8/1	8/5	8/11	8/14	8/15	8/22	8/25	6/10
Water Temp. (^{o}F) to Chiller-Generator	172	184	166	178	161	172	155	147	145	140	184
Total Btu for Chiller Operation (MBtu)	1435	1334	2674	3915	2745	2235	1387	1325	1753	1507	2557
Btu Supplied by Solar Energy (MBtu)	1218	1034	343	2881	2745	2235	1387	1325	1753	1507	977
Btu Supplied by Steam (MBtu)	217	300	2331	1034	0	0	0	0	0	0	1580
Total Btu of Air Conditioning (MBtu)	451	279	892	903	980	491	324	279	449	422	716
Ambient Temp. (^{o}F)	89	78	83.2	91.4	86.2	85.2	81.6	76.1	80.3	89.3	90

TABLE 3-8. VARIATION OF CHILLER OUTPUT WITH VARIATION OF HOT WATER TEMPERATURE TO GENERATOR

Note: The time span for cooling on the dates specified averaged about 6 hours. This resulted in an average cooling load of about 4 to 14 tons/hour. Therefore the chiller was operating at an extreme disadvantage because it was originally modified to function at 50 tons/hour using a water temperature of 187^{o}F at the standard design conditions. The above data perfectly illustrates the ability of absorption chillers to operate at low water temperatures without "crystallization".

Figure 3-8. Design Conditions: York Absorption Chiller Model ES1A2 (H.W.) Modified

1. 100% Load = 50 tons
2. Chilled Water Flow = 100 gpm
3. Chilled Water Temp. = $45^{o}F$ to $53^{o}F$
4. Condenser Water Flow = 360 gpm
5. Condenser Water Temp. = $85^{o}F$ to $93.4^{o}F$
6. Hot Water Flow = 100 gpm
7. Hot Water Temp. = $187^{o}F$ supply to $168.2^{o}F$ return
8. Lithium Bromide Concentration = 55.21%



2. Heat Gain of Chilled Water Storage Tanks

Table 3-9 presents the results of a test to determine the effectiveness of the urethane foam insulation that was sprayed on the chilled water storage tanks before installing them underground. The table presents the daily increase of temperature of the 40,000 gallons of storage for the time period shown. The daily average ambient air temperature ranged from 70°F on August 19, 1976 to 81°F on August 23, 1976.

For the purpose of determining the energy change, the tank ports were sealed and no water flow into or out of the tank was allowed.

3. Seasonal History of Chilled Water Storage Tanks for the Period June 1, 1976 through Aug. 31, 1976

Table 3-10 presents a summary of the energy in storage as of June 1, 1976 as opposed to that in storage as of August 31, 1976. The balance on Aug. 31, 1976 accounts for the Btu removed from the storage tanks by the chiller to compensate for the heat added by cooling the school and heat gained through the storage tank insulation.

4. Typical Week's Use of Chilled Water Storage Tanks

The graph in Figure 3-9 shows the variation in storage tank temperature during the week of Aug. 23, 1976. It shows a drop in temperature on the first day when some chilled water was made and then an increase in temperature when the school was cooled directly from the tanks. During the latter days of the week, neither of the above functions took place. As a result the storage temperature increased gradually as energy was added by conduction through the insulated tanks.

TABLE 3-9. HEAT GAIN OF CHILLED WATER STORAGE TANKS

Date	Amb. Air Temp Daily Avg. °F	Amb. Air Temp Daily Max. °F	Combined Avg. Temp. for Both Tanks °F	Heat Gain °F
8/18/76	73	81	52.4	--
8/19/76	70	79	52.7	0.3
8/20/76	68	80	53.0	0.2
8/21/76	71	86	53.2	0.2
8/22/76	77	91	53.4	0.2
8/23/76	81	90	53.5	0.1
8/24/76	78	85	53.5	0.0

Note:

Type Insulation: 4 in. Urethane Foam (sprayed)

Storage Capacity: Two 10 ft dia steel, 20,000 gal storage tanks. Each interconnected and insulated.

Location: Underground outside of school building.

Test Conditions: Valves to tanks closed. No flow allowed. Combined average temp of each tank reported in table above.

TABLE 3-10. SEASONAL HISTORY OF THE CHILLED WATER STORAGE TANKS DURING THE PERIOD JUNE 1 THRU AUG. 31, 1976

Btu Stored on 6/1/76 (Avg. Tank Temp. = 49.5°F)	15,840,000 Btu
Heat Gain thru Tank Insulation (See Note 2)	+7,000,000 Btu
Btu Removed from Tanks by Chiller	-18,056,000 Btu
Btu Added to Storage by Cooling School	+14,000,000 Btu
Btu in Storage on 9/1/76 (Avg. Tank Temp. = 58.7°F)	18,784,000 Btu

Note 1: Capacity of chilled water storage tanks equals 40,000 gallons.

Note 2: The average temperature gain over the 90 day period amounted to .24°/day. This is determined from raw data for the period 6/1/76 thru 8/31/76. Therefore Heat Gain = .24(40000x8.0) x 91 days = 7,000,000 Btu.

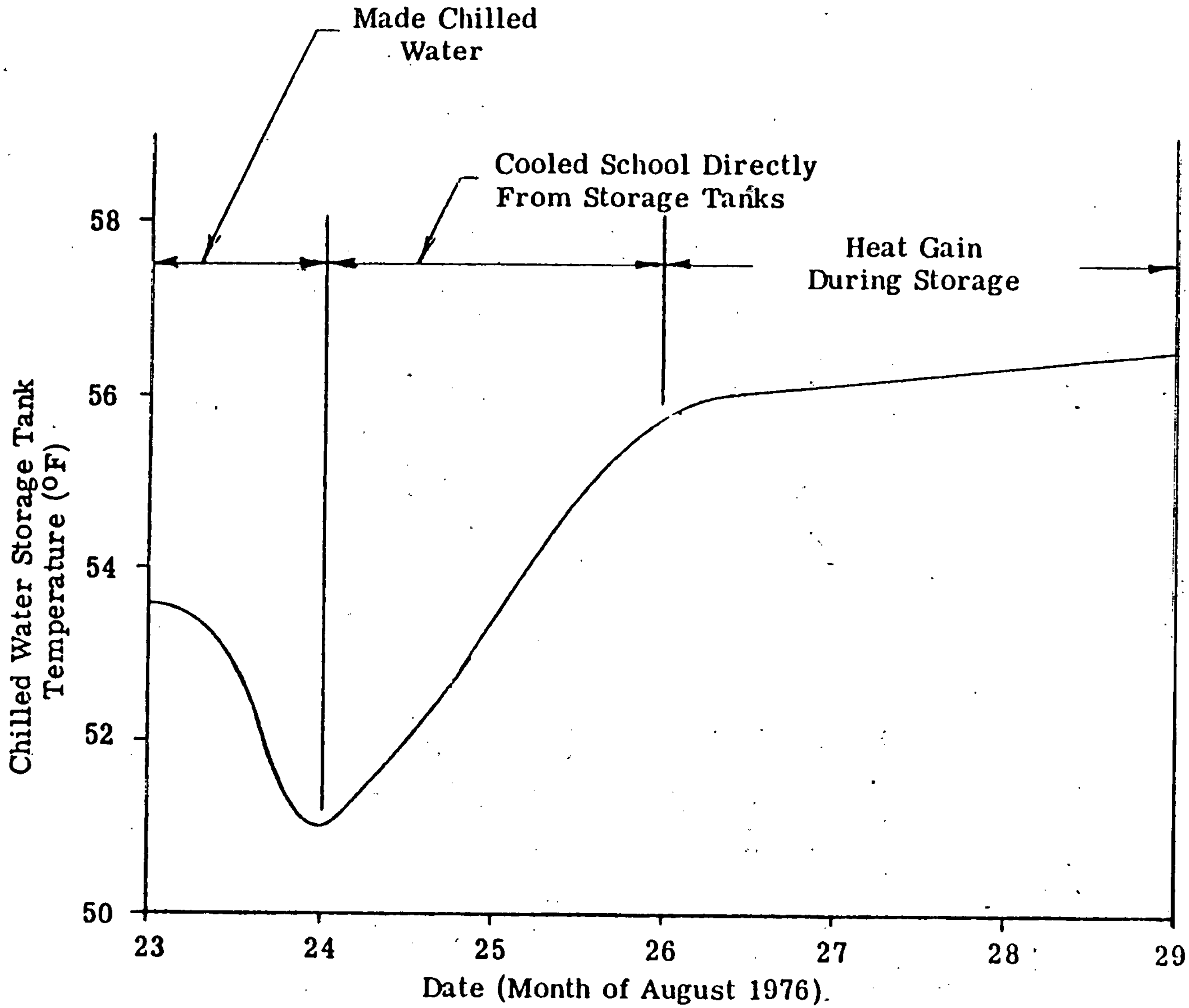


Figure 3-9. Variation of Chilled Water Storage Tank Temperature During a Typical Week's Use of the Timonium School's Solar Air Conditioning System

5. Performance of the Solar Cooling and Collection Systems for the Summers of 1975 and 1976

Tables 3-11 and 3-12 present a summary of the energy required to fire the chiller and the amount of air conditioning supplied by the chiller and chilled water storage tanks. The cooling system was turned on manually in the morning of each day requiring cooling and shut down each evening. The chiller would automatically go through its dilution cycle each time the unit was shut down.

The data in Table 3-11 represents the results of constant experimentation with the design parameters in order to determine the feasibility of operating absorption chillers with hot water temperatures at or below 187^{o}F.

The system was operated with auxiliary steam heat and, for the most part, without auxiliary heat. The hot water to the chiller tubes was the same water sent up to the collectors; that is, there was no heat exchanger in the hot water storage tank. There was no data taken to determine any deterioration in the transfer of heat within the generator unit of the chiller.

The cooling tower did not have a bleedoff system. Its water was supplied directly from the city water lines. The condenser tubes were checked after one season's operation and found to be slightly scaled. They were acid flushed in preparation for the second season.

TABLE 3-11. COOLING SYSTEM PERFORMANCE
(See Note 3)

Item	June 1975	July 1975	August 1975	June 1976	July 1976	August 1976
1. Total Btu Required for Chiller Operation		55.2×10^6	36.7×10^6	25.0×10^6	13.0×10^6	20.0×10^6
2. Btu Supplied by Solar Energy		41.0×10^6	36.7×10^6	7.0×10^6	11.4×10^6	20.0×10^6
3. Btu Supplied by Supplementary Steam		14.2×10^6	Zero	14.3×10^6	1.6×10^6	Zero
4. Percent Chiller Fired by Solar		74.3%	100%	33.0%	87.7%	100%
5. Total Btu of Air Conditioning Supplied by Chiller	See Note 2	13.22×10^6	8.9×10^6	6.0×10^6	3.5×10^6	5.3×10^6
6. Btu Utilized in Dehumidifying Center Wing of School		1.52×10^6	$.5 \times 10^6$	$.8 \times 10^6$	$.4 \times 10^6$	$.6 \times 10^6$
7. Btu Utilized in Cooling Center Wing of School		11.7×10^6	8.4×10^6	8.8×10^6	4.6×10^6	7.1×10^6
8. Number of Days Chiller Used To Make Chilled Water		20	17	12	6	8
9. Number of Days School Cooled by Chilled Water Storage Tanks		See Note 1	See Note 1	4	11	7
10. Number of Days School Cooled Directly by Chiller		20	17	7	0	4

Note 1 - Chilled water storage tanks were not installed in 1975.

Note 2 - The air-conditioning system was being calibrated and checked out during June 1975. Adequate cooling by solar power only was provided for several days of the month.

Note 3 - The data presented above is operational results at conditions other than standard design conditions for the absorption chiller.
The cooling loads at Timonium were 10 to 40% of the maximum design load. Assessment of chiller operation at hot water temperatures from 140°F to 187°F also took place.
The data above should be interpreted knowing that constant deviation from standard design conditions took place.

Item	June '75	July '75	August '75	Summer '76 June	Summer '76 July	Summer '76 Aug.
Total Incident Energy during Operation	64.2×10^6 Btu	95.2×10^6 Btu	95.2×10^6 Btu	See Note 1		
Total Collected Energy	22.2×10^6 Btu	52.7×10^6 Btu	62.5×10^6 Btu			
No. of Days Collected	14	25	20	8	9	17
Days of Downtime for Maintenance	7*	0	0	0	0	0
Days of Adverse Weather	9	6	11	22	22	14

Note 1 - The summer of 1976 had more than twice as many days of adverse weather than that of 1975. The solar energy collected in 1976 amounted to approximately 49% of that collected in 1975.

Complete energy collection data not available because of instrumentation problems.

* Checkout & calibration of air conditioning system.

Table 3-12. Solar Collection Performance

All pumps and motors were selected according to the chiller design conditions. Consequently they were oversized for the actual cooling loads experienced. As a result, the electrical operational costs experienced for the chiller, the condenser pumps, and the chilled water pumps, etc. are not representative of an optimum system for the center wing of the Timonium school. Approximately 6000 KWH were used for about 260 hours of operation during July and August of 1975 when the cooling system did not have chilled water storage. At .035 cents per kilowatt hour, this amounts to $210.00. It is estimated that in an optimum design cooling system with a .65 C.O.P. of the chiller and a 70% efficiency of the boiler, the amount of fuel oil saved (to provide 100% of cooling of the center wing for July and August 1975) would be about 333 gallons. Assuming the power required for an optimum design cooling system utilizing about 20 ton cooling capacity is about 1/3 of that experienced, the cost would be about $70.00 for the two months specified.

6. Typical Day's Air Conditioning Operation

Timonium School's energy requirements for a typical day's air conditioning utilizing both solar and steam power is shown in Figure 3-10.

A similar day's energy requirements without the use of supplementary steam is presented in Figure 3-11.

Figure 3-12 illustrates the overall performance of the solar cooling system during a typical day of air-conditioning in 1975 and prior to the installation of the chilled water storage system. It presents the variation of the hot water storage tank temperature, the total Btu collected, the insolation, the total hot water Btu consumed by the absorber, the Btu of supplemental steam consumed, and the total Btu required to cool the school, versus the time of day.

Figure 3-13 presents the performance characteristics of the solar collection system on August 18, 1975. The solar reflectors were installed and in effect at this time. The center wing of the school was air conditioned by the chiller only. The figure shows the variation of hot water storage tank temperature, the Btu collected, the insolation, and the total hot water Btu consumed by the chiller versus the time of day. No supplementary steam was consumed during this day's operation.

Figure 3-14 presents the overall solar cooling performance during the cooling season of 1976. This presents the characteristics of the combined

Timonium School's Energy Requirements
For a Typical Day's Air-Conditioning Operation

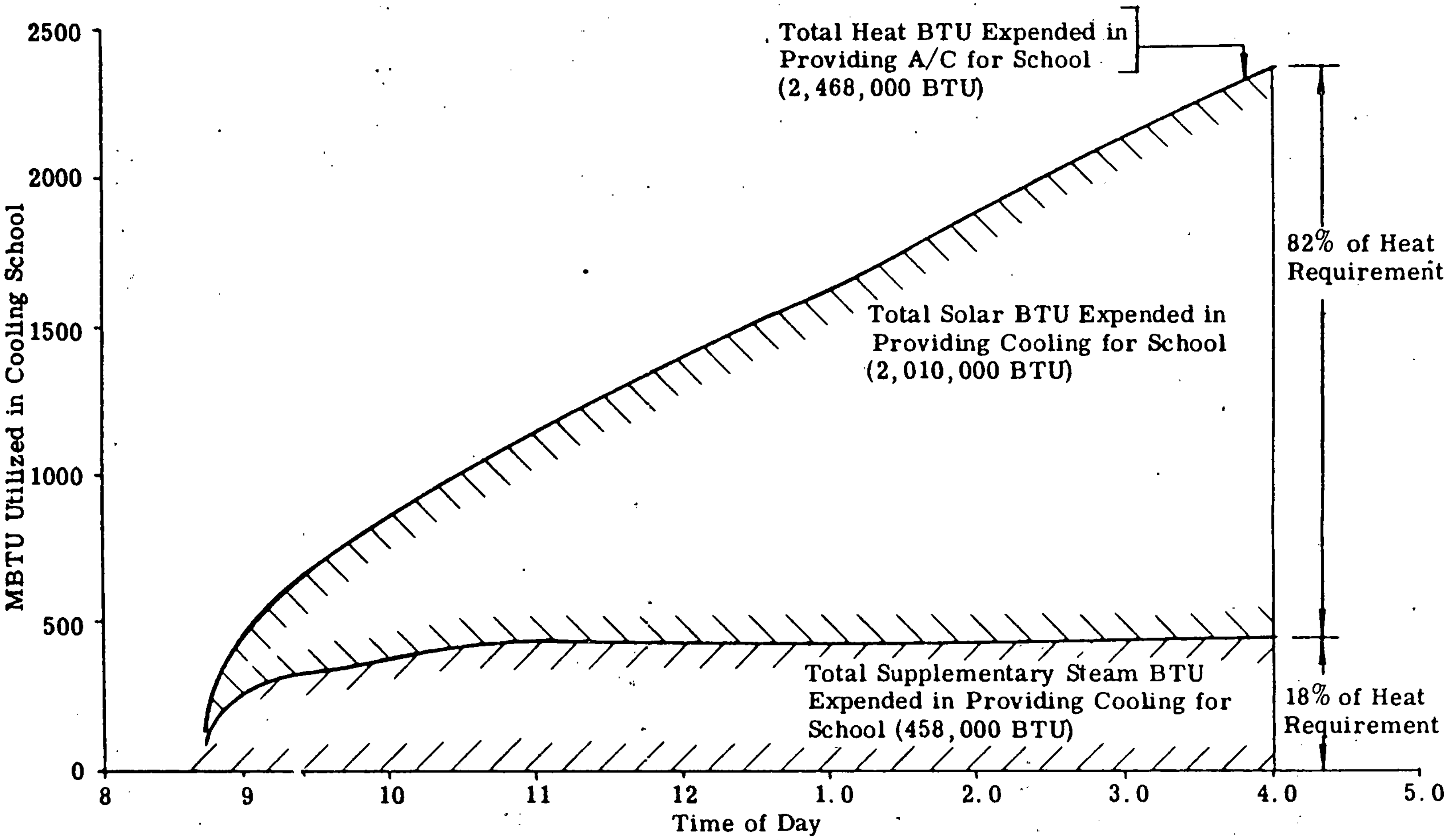


Figure 3-10

Timonium School's Energy Requirements
For a Typical Day's Air-Conditioning Operation

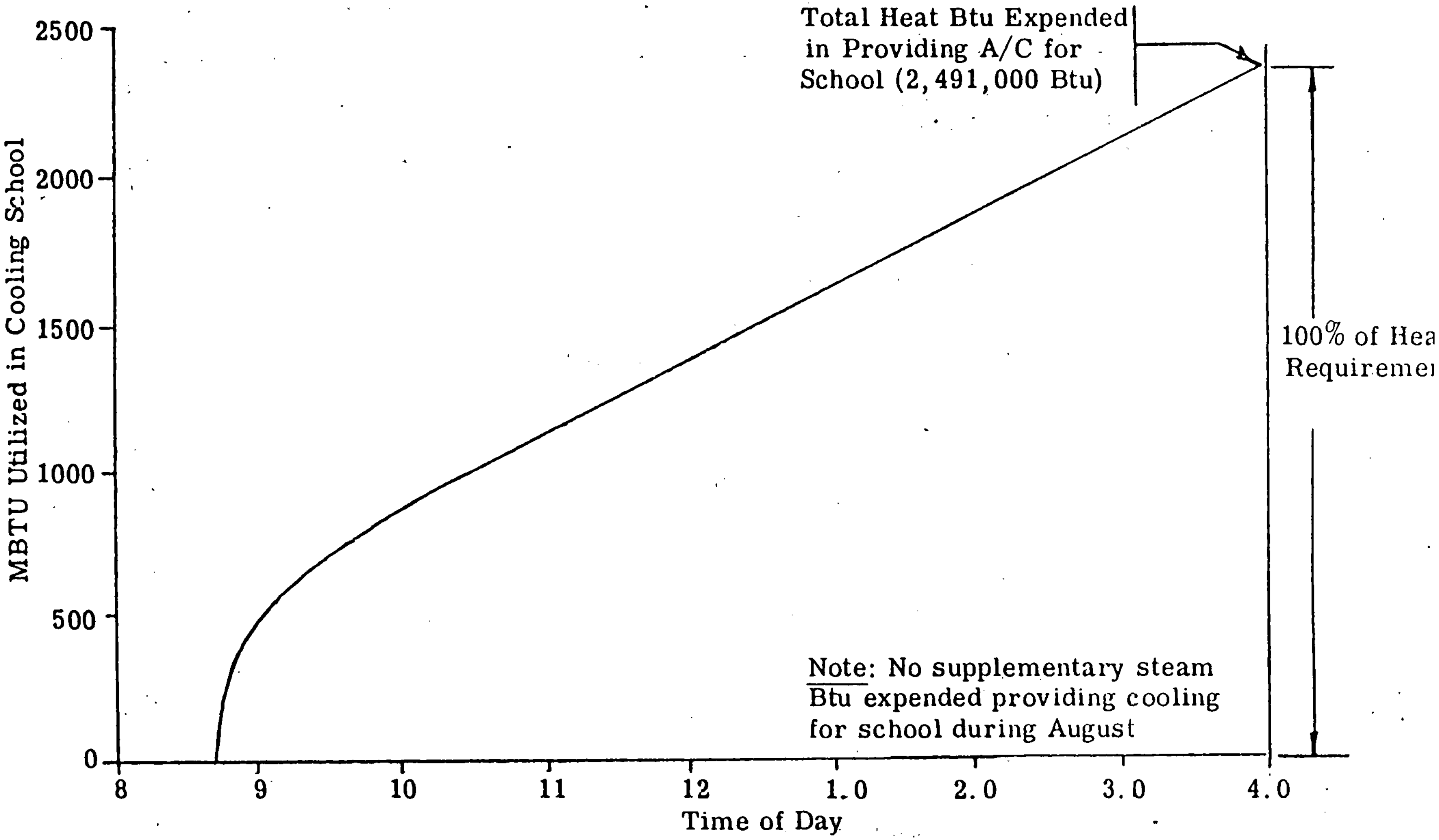


Figure 3-11

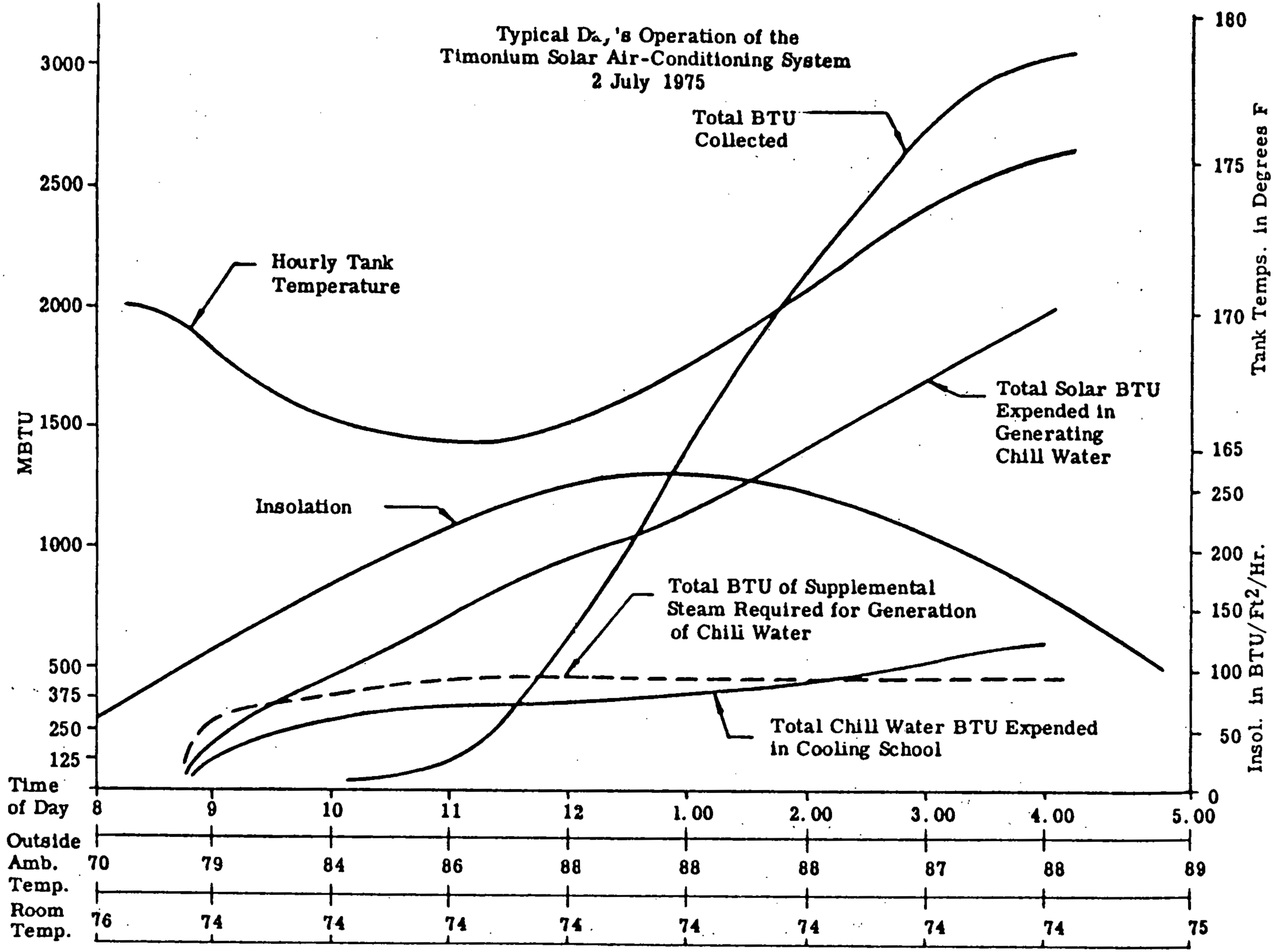
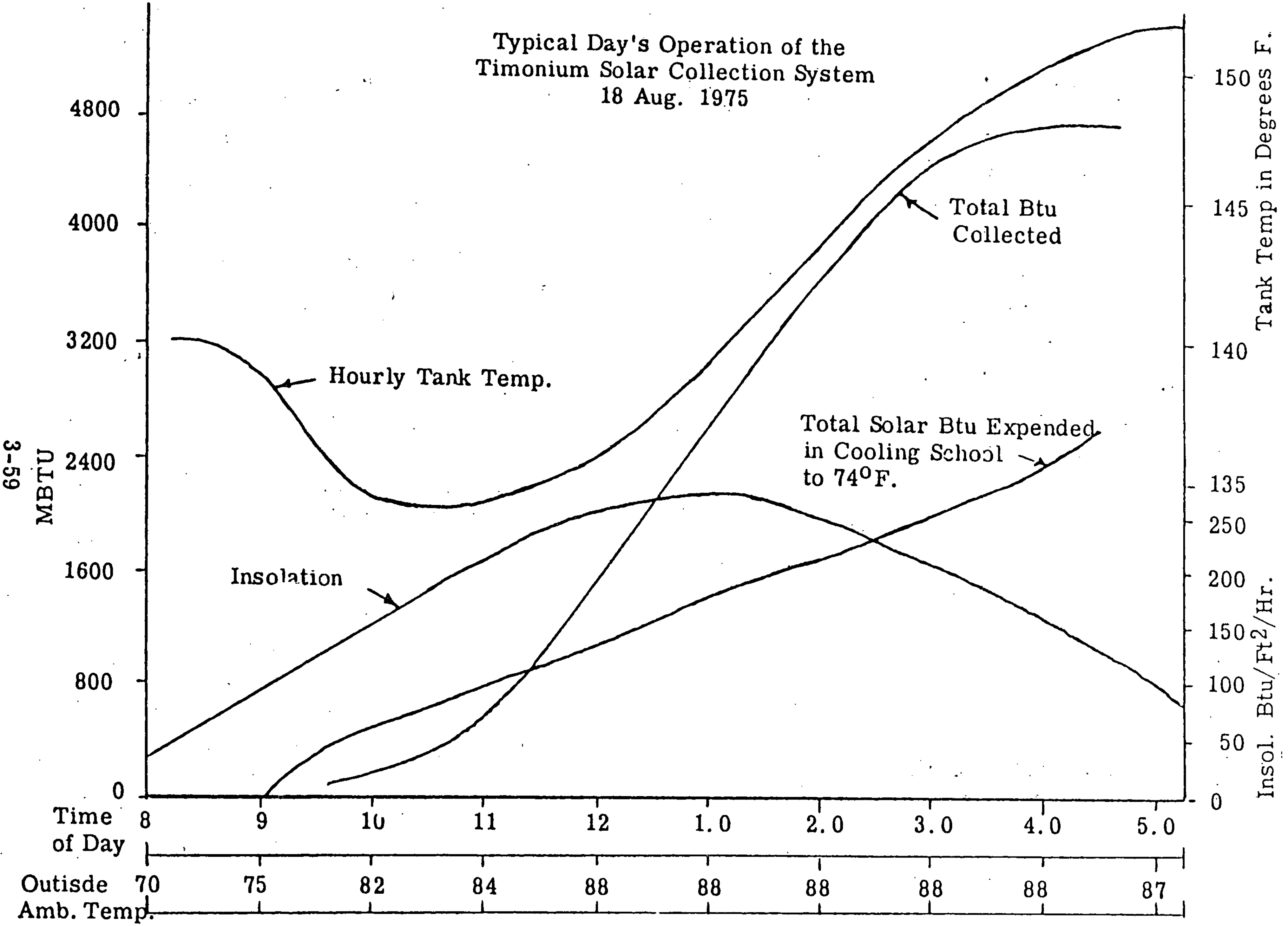

Typical Da,'s Operation of the
Timonium Solar Air-Conditioning System
2 July 1975
MBTU
3000
2500
2000
1500
1000
500
375
250
125
Tank Temps. in Degrees F
180
175
170
165
Insol. in BTU/Ft2/Hr.
250
200
150
100
50
0
Total BTU
Collected
Hourly Tank
Temperature
Total Solar BTU
Expended in
Generating
Chill Water
Insolation
Total BTU of Supplemental
Steam Required for Generation
of Chill Water
Total Chill Water BTU Expended
in Cooling School
Time
of Day
8
9
10
11
12
1.00
2.00
3.00
4.00
5.00
Outside
Amb.
Temp.
70
79
84
86
88
88
88
87
88
89
Room
Temp.
76
74
74
74
74
74
74
74
74
75

Figure 3-12



Typical Day's Operation of the
Timonium Solar Collection System
18 Aug. 1975
MBTU
4800
4000
3200
2400
1600
800
0
Tank Temp in Degrees F.
150
145
140
135
Insol. Btu/Ft²/Hr.
250
200
150
100
50
0
Hourly Tank Temp.
Total Btu
Collected
Total Solar Btu Expended
in Cooling School
to 74°F.
Insolation
Time
of Day
8
9
10
11
12
1.0
2.0
3.0
4.0
5.0
Outisde
Amb. Temp.
70
75
82
84
88
88
88
88
88
87

Figure 3-13

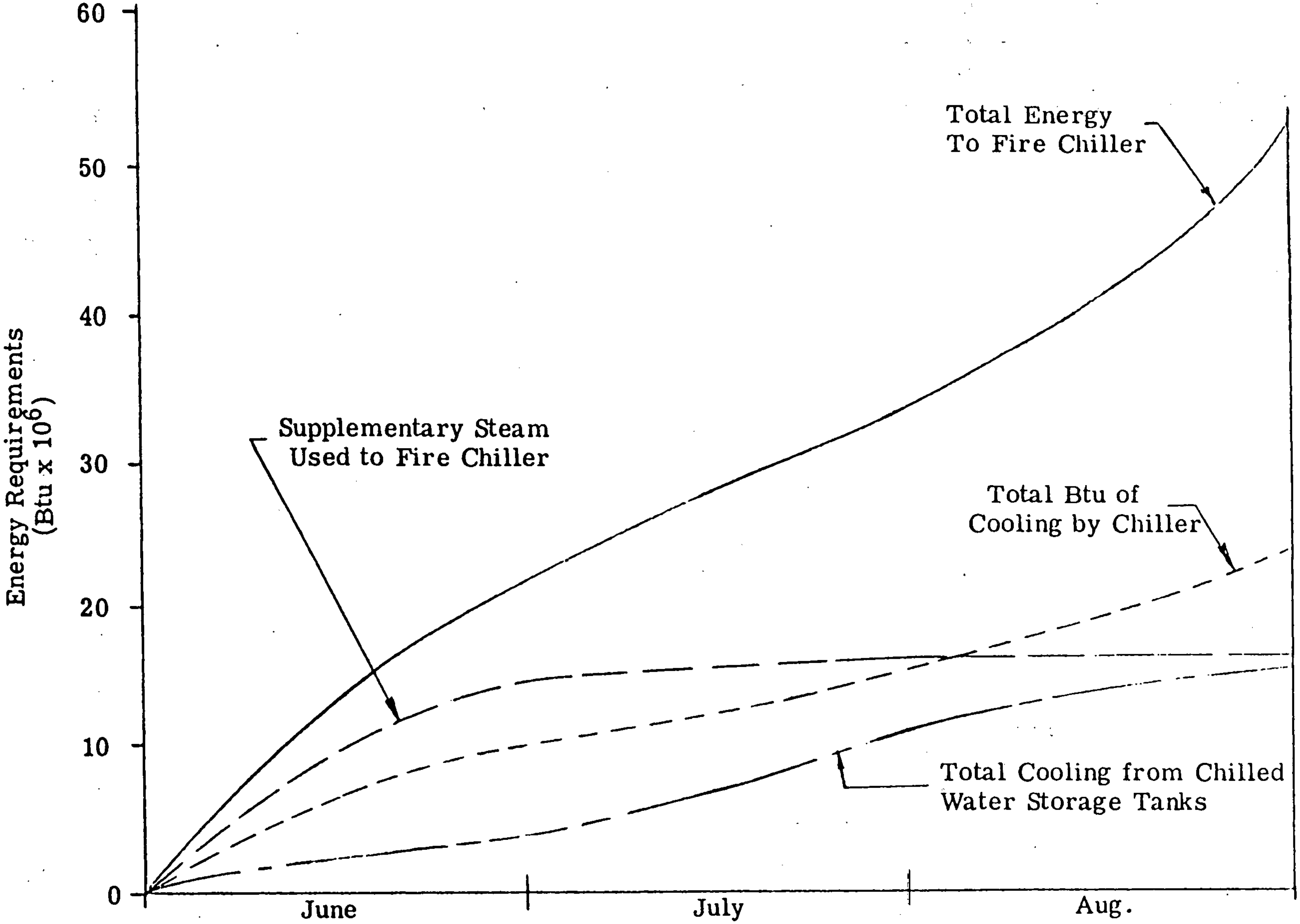

Energy Requirements
(Btu x 10^6)
60
50
40
30
20
10
0
Total Energy
To Fire Chiller
Supplementary Steam
Used to Fire Chiller
Total Btu of
Cooling by Chiller
Total Cooling from Chilled
Water Storage Tanks
June
July
Aug.

Figure 3-14

chiller and chilled water storage systems. The figure shows the total energy required to fire the chiller, the supplementary steam consumed, the amount of cooling provided by the chiller and the total amount of cooling from the chilled water storage tanks.

7. Solar Energy Collection and Utilization During Cooling Season Geometry

The solar collection system geometry for the cooling season consists of the flat-plate collectors and the flat mirror-type reflectors installed on the roof of the center wing of the school. Water is pumped to the collectors, is heated and returned to the 15,000 gallon hot water tank for storage. The collectors are installed at a fixed 45° angle to the horizontal and face due south.

The collector angle was selected in anticipation of future modifications for air-conditioning. Therefore the 45° and 34° combination is considered the optimum arrangement for the summer cooling configuration at this locality.

For comparison, the energy collected during the summer of 1974 was limited by the water distribution to the collectors. Being a gravity-fed system, the collectors did not receive a uniform flow of water at minimum flow rates. In addition, some collectors were starved because of filter restrictions. Utilization time in 1974 (the time above critical insolation I_c) varied from four-and-one-half hours to seven hours with water temperatures varying from $115^{o}F$ to $160^{o}F$. During the spring of 1975, when the reflectors were installed, all supply lines to the collectors were dismantled and cleaned. Foreign matter was found in the piping. Additional trunk line filters were installed and all individual filters to collectors were replaced. The "head" tank which supplies the pressure head to the collectors was raised from 18 in. to 30 in. The gradient of all piping from the head tank to the collectors was improved wherever possible.

The energy collected during the summer of 1975 increased significantly over that of 1974 because of improved water distribution plus the installation of the reflectors. All collectors received flow while the reflectors increased the insolation into the collectors. It was observed that the reflectors began increasing the insolation about 8:30 a.m., D.S.T. and showed a creeping effect over the collector until at solar noon the collector was totally covered, then gradually decreased to zero at about 5 to 6 p.m., D.S.T. The conditions mentioned above occurred during August. The peak or maximum coverage of the collectors varied daily as the summer progressed.

A comparison of the collector-reflector subsystem with that of just the collector subsystem used in the summer of 1974 is not possible because of the water distribution problems experienced at that time, plus the limited operation of the system because of modifications to the school library and instrumentation modifications.

No basic data comparing the efficiencies of a collector-reflector subsystem to that of just a collector subsystem is available. Comparison of the energy collected in the various years is not practical because of the possible differences in operating conditions.

Average water temperatures to the collectors varied for the summers of 1974, 1975 and 1976. The following factors contributed to the variation:

- The percent of sunshine varied considerably from year to year.
- No reflectors were installed during the summer of 1974.
- Reflectors were installed for the summers of 1975 and 1976.

Average water temperatures to the collectors for the summers of 1974, 1975 and 1976 were as follows:

Summer of 1974 - $\approx 140^{\circ}F$

Summer of 1975 - $\approx 170^{\circ}F$

Summer of 1976 - $\approx 160^{\circ}F$

The lower average water temperature to the collectors for the summer of 1976 can be attributed to the lower solar radiation incident on the system because of the adverse weather conditions experienced during June and July 1976.

The utilization time for the summers of 1975 and 1976 (the ability to collect when the insolation is above the critical insolation)* was 6 hours despite the higher collector input temperature than that in 1974.

* Critical insolation as used here is intended to mean that point in time in the morning when the sun's radiation upon the collector first becomes sufficient to heat the absorber plate to a point $10^{o}C$ above that of the temperature of the water in the bottom of the storage tank. At Timonium this would be the automatic "start-up" point of the collector pumps.

IV. CONCLUSIONS

1. The solar collection system at Timonium Elementary School consists of flat-plate collectors whose water is supplied by an overhead gravity fed plumbing system. The Proof-of-Concept Experiment to solar heat and cool a public school building has resulted in the following general principles that can be applied to the future development of similar systems:

- The heating and cooling of public school buildings through the utilization of solar energy is possible.
- Chilled water storage does provide the following operational advantages:

  a. It can provide cooling when solar heated water is unavailable to operate a chiller.

  b. It provides the option of operating the chiller when electrical costs are minimum.

  c. Limited tests indicate that thermal losses in well insulated storage tanks appear to be about one-fourth that of stored hot water. (The COP of the chiller must be considered.)

  d. Chilled water storage provides a back-up system when the chiller requires servicing.

  e. A combined chiller and storage system allows the flexibility of handling peak cooling loads for short periods with smaller cooling equipment.

  However, each application of chilled water storage should be studied separately to determine its actual cost effectiveness.

- Flat-plate collectors are sufficiently efficient to warrant further development as solar energy collection devices when operating at temperature ranges of about 100°F to 150°F.

- Flat-plate collectors with reflectors can provide the hotter water needed to operate absorption - type air conditioners. This combination increases the energy collected, and the daily utilization of the sun from sunrise to sunset. As retrofits, the cost of installing reflectors is not cost effective.

- Systems such as the one at Timonium Elementary School can use ordinary water without anti-freeze additives.

- The all-aluminum collectors (utilizing water deionized one time only) show no evidence of corrosion in 2½ years of operation.

- The epoxy adhesives exposed to the solar and hot water environments within the flat-plate collectors do degenerate.

- The absorber plate coating showed evidence of wearing thin in the 2½ years of operation.

- In 2½ years of operation there is no obvious evidence that untreated solar heated water cannot be pumped directly to hot water heating and cooling systems. Periodic chemical analyses of water samples taken from the reservoir show no evidence of algae or fungus growth.

- Deionized water is an effective medium for storing solar energy.

- Insulation is extremely important in minimizing the radiation losses of the collectors, the plumbing, and the storage reservoir.

V. RECOMMENDATIONS

A. The following recommendations reflect changes in the design which are suggested if this system or a similar one were built again.

o Improved System Performance

1. Improve the collector efficiency by using selective coatings.

2. Minimize glass cracking of the collectors by utilizing tempered glass and by designing the collectors to allow free glass movement to permit differential expansion of the collector parts.

3. Improve the collection efficiency by controlling the water stratification in the holding tank, to allow the coldest possible water to be pumped to the collectors.

4. Strive for equal water distribution to all collectors over the range of minimum to maximum flow.

5. Provide the shortest possible distance between the hot water holding tank and the flat-plate collectors to minimize the energy lost in heating up pipes. Also keep pipe diameters to a minimum. This is particularly important at the higher water temperature required for air conditioning.

6. Provide an automatic control logie for early morning start-up of the collector pumps, that will allow the flow to the collectors to quickly reach a steady state of positive collection.

7. Minimize heat losses due to gravity flow between the holding tank and the collection and heating system plumbing in the school by providing isolation of the holding tanks during periods of inactivity.

- Reduce Heat Loss by Radiation

  1. Provide increased insulation for the plumbing and holding tank, particularly if high temperature water is to be stored.

  2. Locate the hot water holding tank in an environment that will maintain a minimum temperature gradient during the heating and cooling seasons.

  3. Locate the collector supply and return plumbing in the building to reduce the temperature gradient between the piping and its environment.

- Improved Producibility

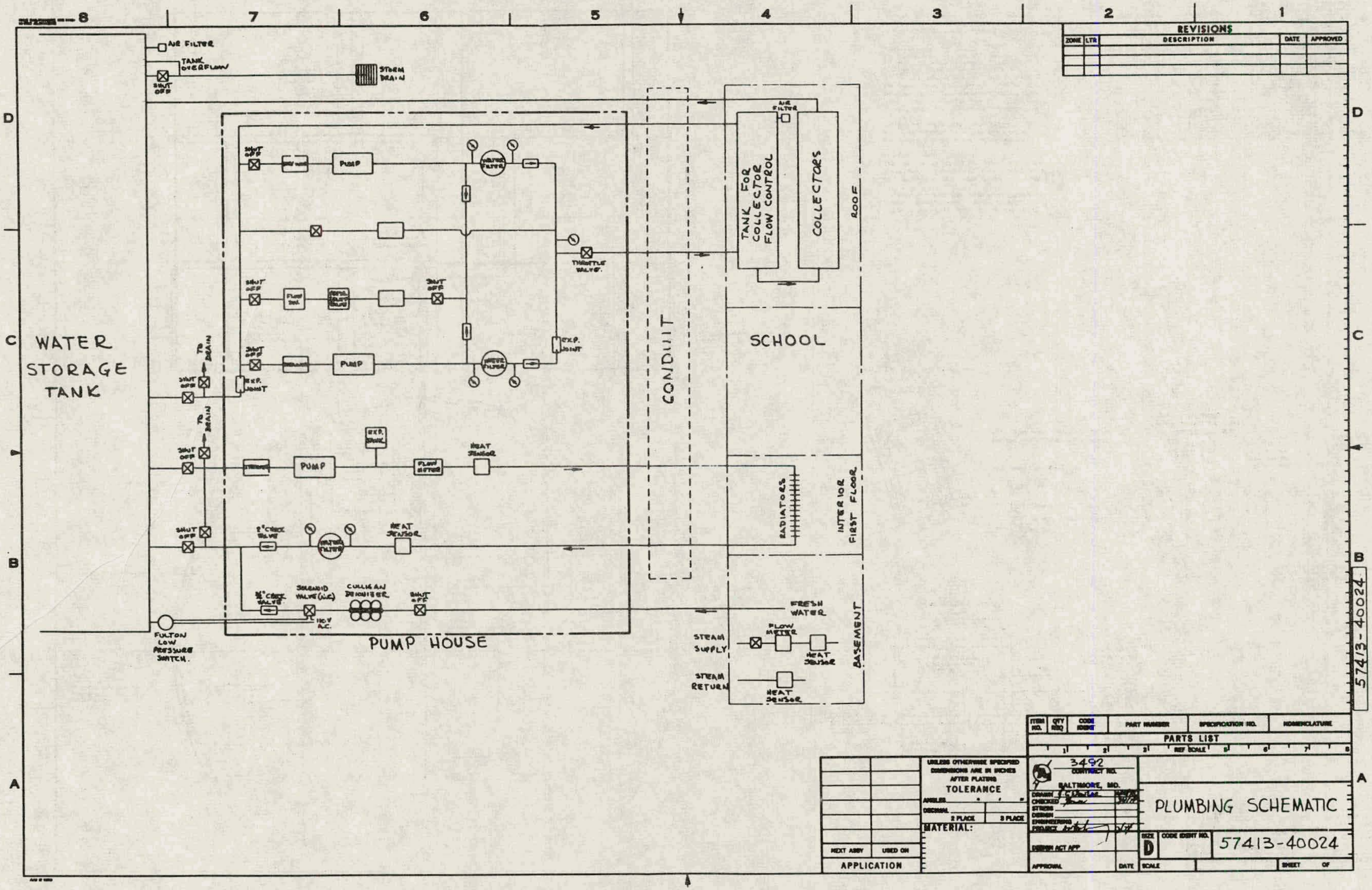
  1. Utilize standard steel or concrete tank for water storage.

  2. Simplify and reduce the plumbing in the pumping station as follows:

     a. Use threaded connections rather than flanges except at the interfaces of the plumbing modules.

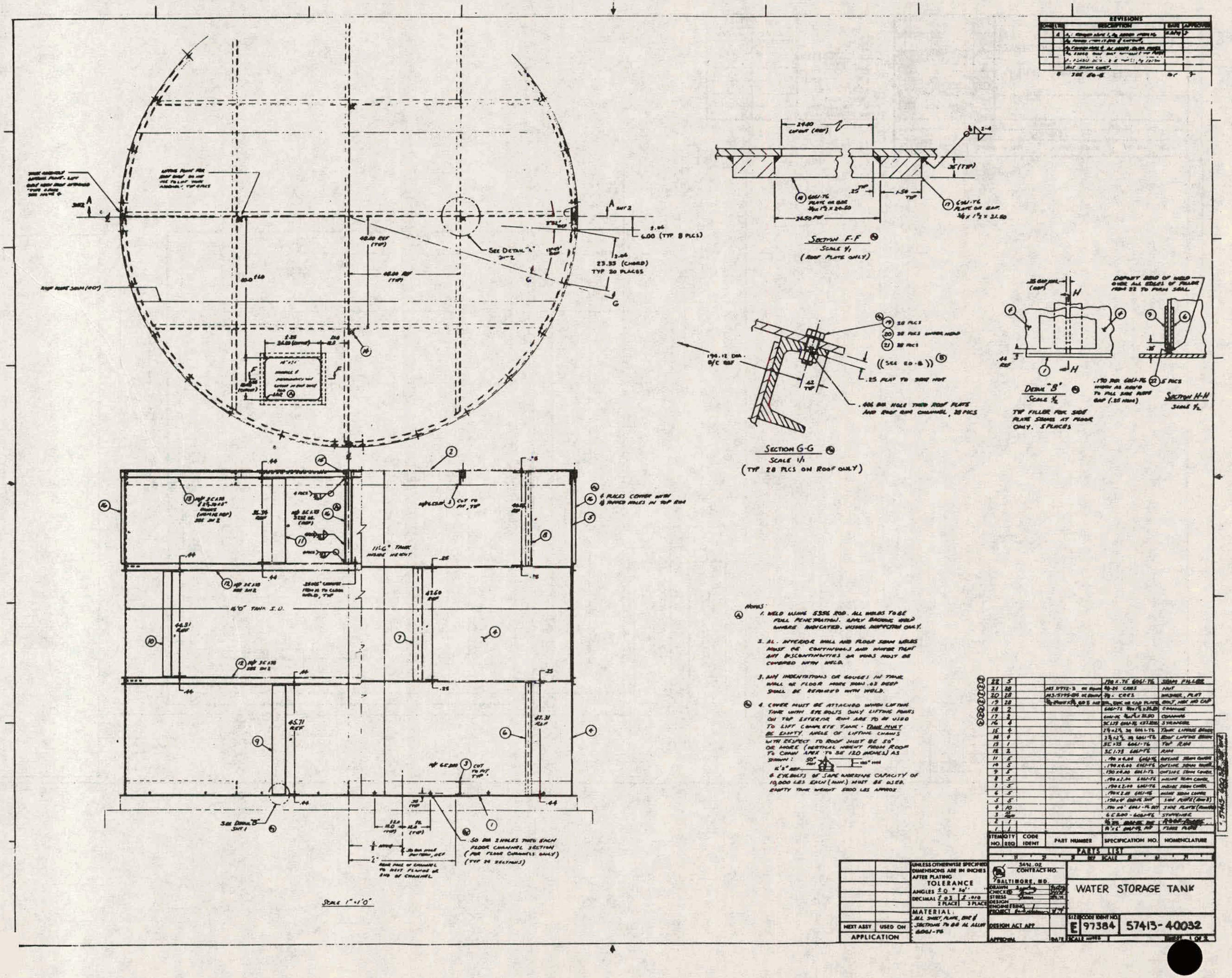
     b. Utilize one pump and the associated components in the collector pumping station rather than the dual set-up being currently used.

APPENDIX I

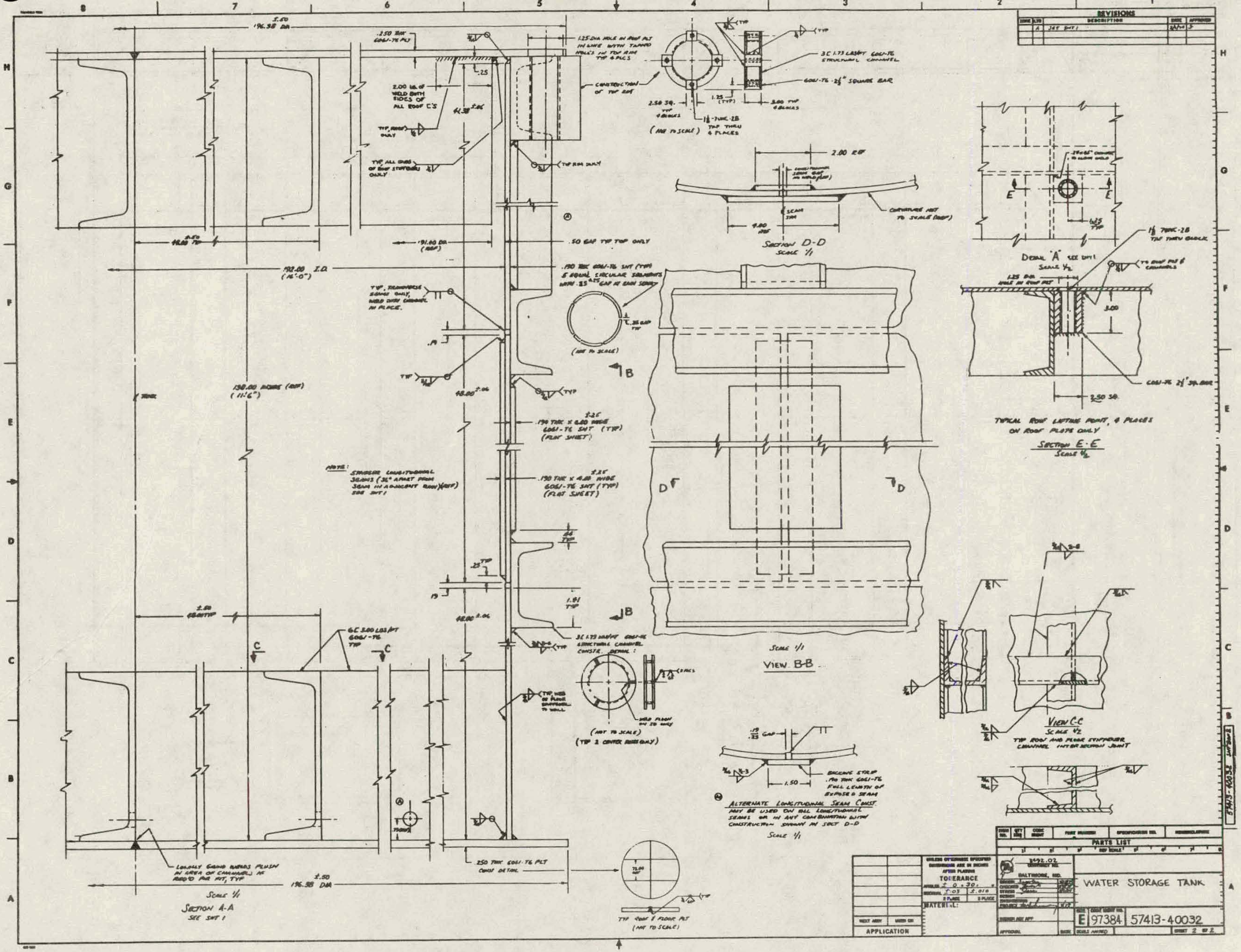


A-1

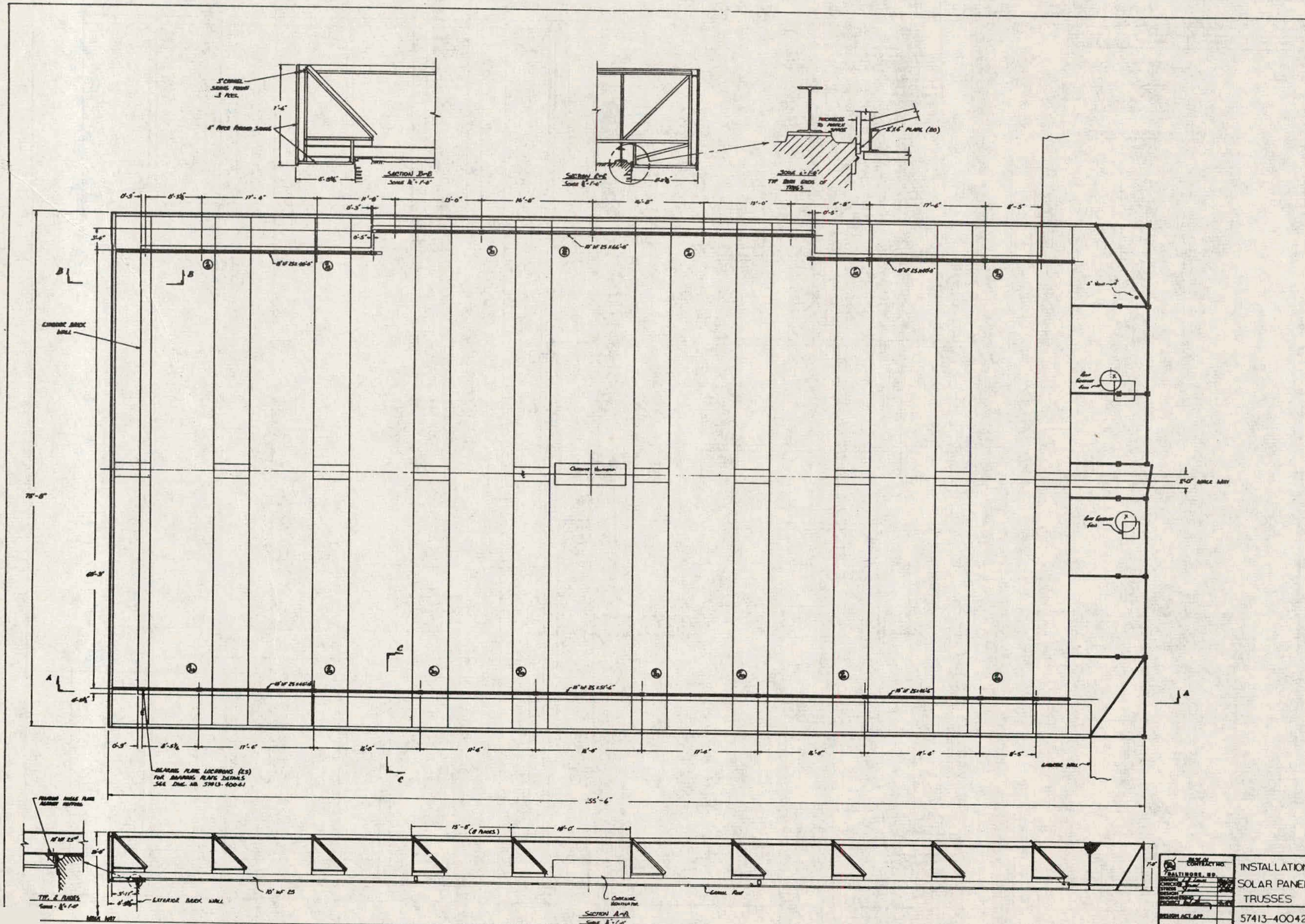
A-2



SECTION F-F
SCALE 1/1
(ROOF PLATE ONLY)
SECTION G-G
SCALE 1/1
(TYP 28 PLCS ON ROOF ONLY)
DETAIL "B"
SECTION H-H
SCALE 1"=1'0"
NOTES:
1. WELD USING 5356 ROD. ALL WELDS TO BE FULL PENETRATION. APPLY BACKING WELD WHERE INDICATED. VISUAL INSPECTION ONLY.
2. ALL INTERIOR WALL AND FLOOR SEAM WELDS MUST BE CONTINUOUS AND WATER TIGHT. ANY DISCONTINUITIES OR VOIDS MUST BE COVERED WITH WELD.
3. ANY INDENTATIONS OR GOUGES IN TANK WALL OR FLOOR MORE THAN .03 DEEP SHALL BE REPAIRED WITH WELD.
4. COVER MUST BE ATTACHED WHEN LIFTING TANK WITH EYE BOLTS. ONLY LIFTING POINTS ON TOP EXTERIOR RIM ARE TO BE USED TO LIFT COMPLETE TANK - TANK MUST BE EMPTY. ANGLE OF LIFTING CHAINS WITH RESPECT TO ROOF MUST BE 50° OR MORE (VERTICAL HEIGHT FROM ROOF TO CHAIN APEX TO BE 120 INCHES) AS SHOWN:
4 EYEBOLTS OF SAFE WORKING CAPACITY OF 10,000 LBS EACH (MIN.) MUST BE USED. EMPTY TANK WEIGHT 5800 LBS APPROX
ITEM NO.
QTY REQ
CODE IDENT
PART NUMBER
SPECIFICATION NO.
NOMENCLATURE
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING
TOLERANCE
ANGLES
DECIMAL
2 PLACE
3 PLACE
MATERIAL:
ALL SHEET, PLATE, BAR & SECTIONS TO BE AL ALLOY 6061-T6
NEXT ASSY
USED ON
APPLICATION
CONTRACT NO.
BALTIMORE, MD.
DRAWN
CHECKED
STRESS
DESIGN
ENGINEERING
PROJECT
DESIGN ACT APP
APPROVAL
DATE
WATER STORAGE TANK
SIZE
CODE IDENT NO.
E
97384
57413-40032
SCALE
SHEET
REVISIONS
DESCRIPTION


REVISIONS
SECTION D-D
SCALE 1/1
DETAIL "A" SEE SHT 1
SCALE 1/2
TYPICAL ROOF LIFTING POINT, 4 PLACES ON ROOF PLATE ONLY
SECTION E-E
VIEW B-B
VIEW C-C
ALTERNATE LONGITUDINAL SEAM CONST
SECTION A-A
SEE SHT 1
192.00 I.D. (16'-0")
196.38 DIA
PARTS LIST
TOLERANCE
MATERIAL:
APPLICATION
WATER STORAGE TANK
BALTIMORE, MD.
E 97384 57413-40032

A-4



SECTION B-B
SECTION A-A
BALTIMORE, MD.
INSTALLATION
SOLAR PANEL
TRUSSES
57413-40042

SYMBOLS/ NOTES

1. FOR SURFACE-TYPE TEMPERATURE TRANSDUCERS, USE EPOXY ADHESIVE.
2. FOR IMMERSION-TYPE TEMPERATURE TRANSDUCERS, DRILL & TAP 1/8-27 NPT. INSERT SWAGELOK MALE CONNECTOR NO. 200-1-2-BT (USE PIPE THREAD SEALING COMPOUND).
3. SURFACE-TYPE TEMPERATURE TRANSDUCER TEMPLINE INC. NO. AP-250-250-100-2
4. IMMERSION-TYPE TEMPERATURE TRANSDUCER TEMPLINE INC. NO. IP-G32-100-4-2

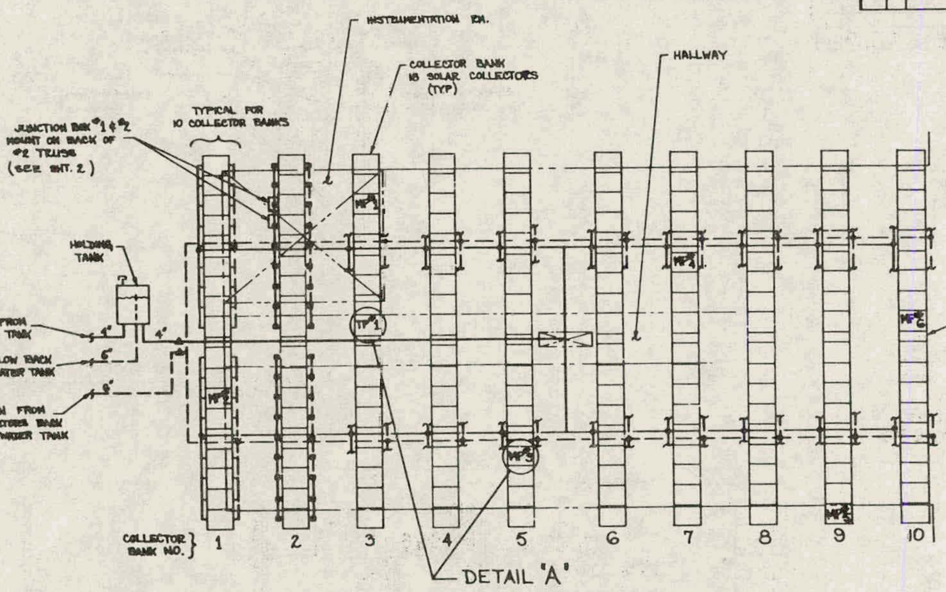
TP - TEST PANEL. SURFACE TRANSDUCERS LOCATED IN POSITIONS ①, ②, ③, ④, ⑤ & ⑥ (SEE DETAIL B), IN LOCATIONS L1 & L5 (SEE DETAIL A). ALSO, SURFACE TRANSDUCERS LOCATED IN POSITION ⑥, IN LOCATIONS L2, L3, L4 & L6.

● - WATER TEMPERATURE IN & OUT OF EACH 1/2 COLLECTOR BANK ((18) 1/2 BANKS). USE IMMERSION-TYPE TRANSDUCER. DRILL & TAP HEADER IN LOCATION INDICATED (SEE NOTE 2). TYPICAL, 36 PLACES.

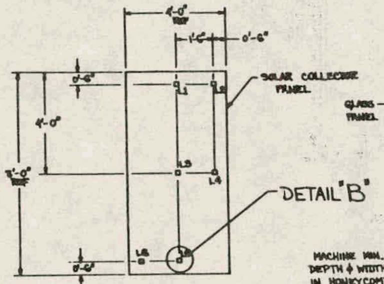
■ - WATER TEMPERATURE IN & OUT OF EACH SOLAR COLLECTOR ((9) BANK, 18 SOLAR COLLECTORS). USE IMMERSION-TYPE TRANSDUCER. DRILL & TAP HEADER IN LOCATIONS INDICATED (SEE NOTE 2). TYPICAL, 36 PLACES.

▲ - WATER TEMPERATURE IN & OUT OF TOTAL SOLAR COLLECTOR SYSTEM. USE IMMERSION-TYPE TRANSDUCER. DRILL & TAP HEADER IN LOCATIONS INDICATED (SEE NOTE 2). TYPICAL, 3 PLACES.

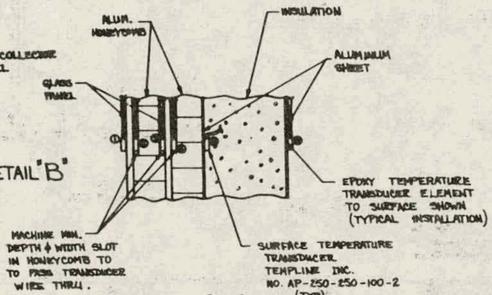
MP - MONITORING PANEL. USE SURFACE-TYPE TRANSDUCER. MOUNT TRANSDUCER IN POSITION ⑥, LOCATION L3 ONLY. TYPICAL, 6 PLACES.



COLLECTOR LAYOUT
SCALE: 1" = 10'-0"



DETAIL 'A'
NO SCALE
LOCATION OF SURFACE TEMPERATURE TRANSDUCERS



DETAIL 'B'
SCALE: FULL

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE

PARTS LIST

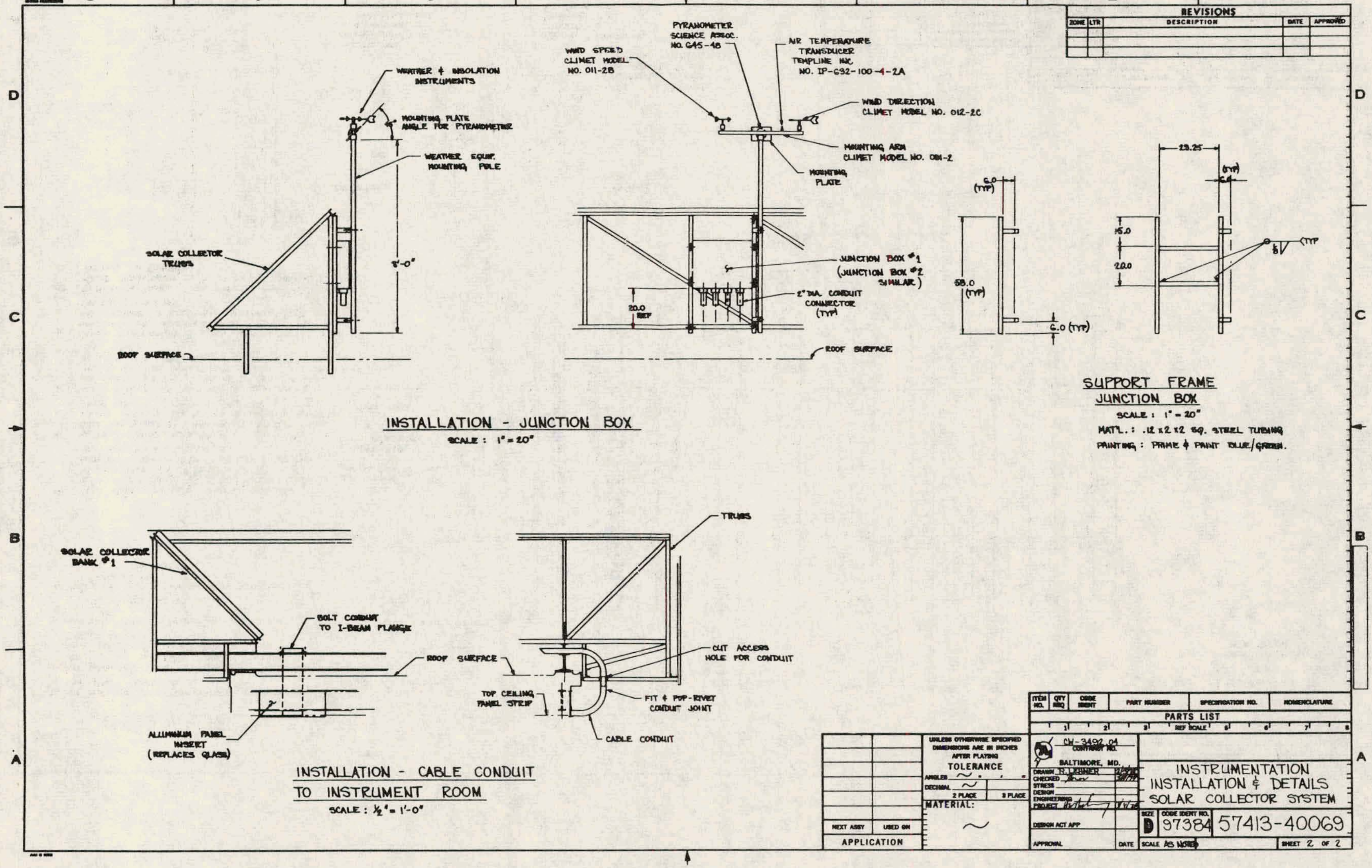
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING
TOLERANCE
ANGLES ~
DECIMAL ~
MATERIAL: ~

NEXT ASSY | USED ON
APPLICATION

CW-3492.04
CONTRACT NO.
BALTIMORE, MD.
DRAWN R. LEWISH
CHECKED
STRESS
DESIGN
ENGINEERING
PROJECT
DESIGN ACT APP
APPROVAL
DATE

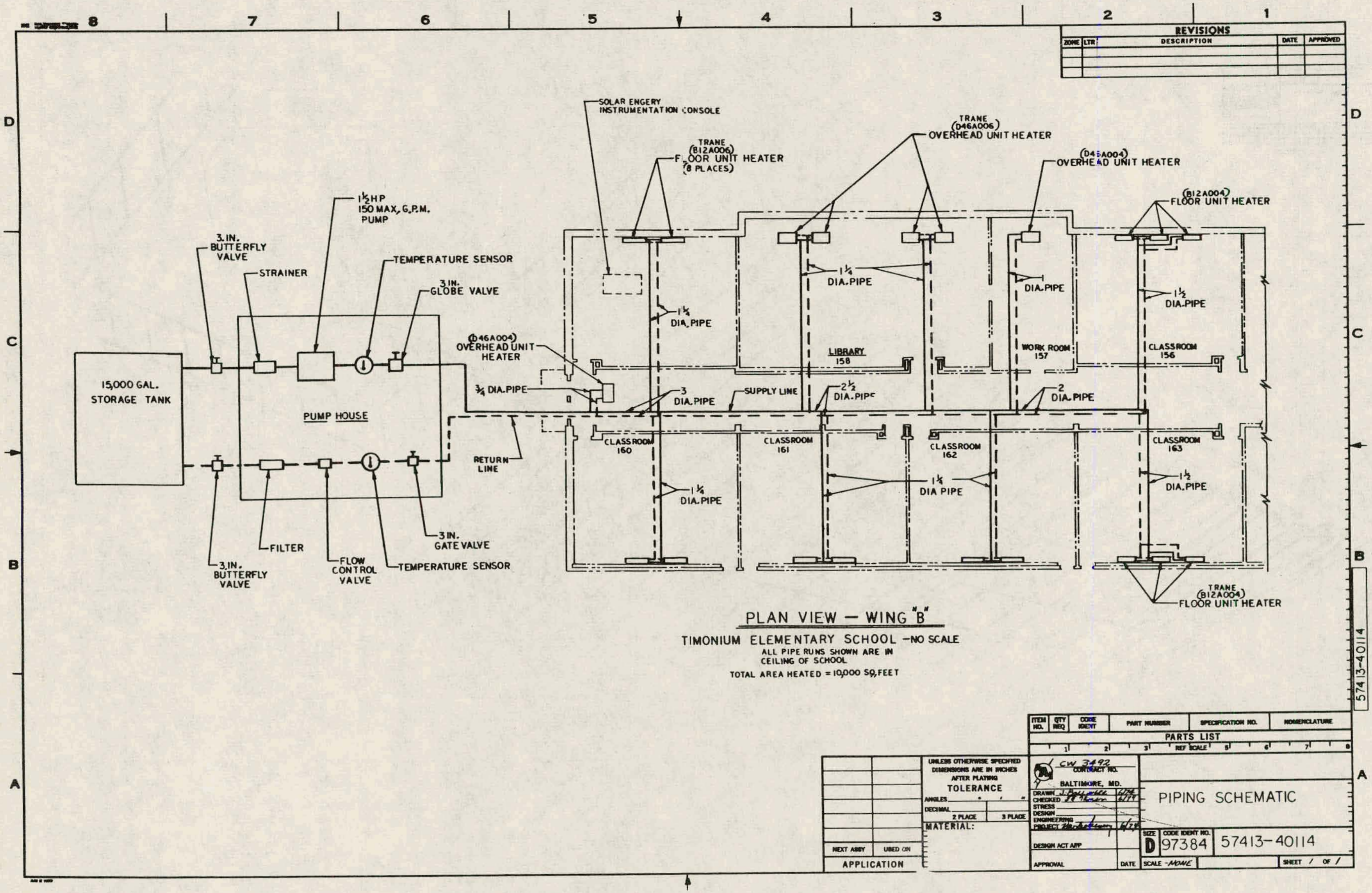
INSTRUMENTATION - LAYOUT & SCHEMATIC SOLAR COLLECTOR SYSTEM

SIZE D | CODE IDENT NO. 97384 | 57413-40069
SCALE NOTED | SHEET 1 OF 2



REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
WEATHER & INSOLATION INSTRUMENTS
MOUNTING PLATE ANGLE FOR PYRANOMETER
WEATHER EQUIP. MOUNTING POLE
SOLAR COLLECTOR TRUSS
8'-0"
ROOF SURFACE
PYRANOMETER SCIENCE ASSOC. NO. 645-48
WIND SPEED CLIMET MODEL NO. 011-2B
AIR TEMPERATURE TRANSDUCER TEMPLINE INC. NO. IP-G32-100-4-2A
WIND DIRECTION CLIMET MODEL NO. 012-2C
MOUNTING ARM CLIMET MODEL NO. 081-2
MOUNTING PLATE
JUNCTION BOX #1 (JUNCTION BOX #2 SIMILAR)
2" DIA. CONDUIT CONNECTOR (TYP)
20.0 REF
ROOF SURFACE
INSTALLATION - JUNCTION BOX
SCALE: 1" = 20"
6.0 (TYP)
58.0 (TYP)
6.0 (TYP)
23.25
(TYP)
15.0
20.0
(TYP)
SUPPORT FRAME
JUNCTION BOX
SCALE: 1" = 20"
MAT'L.: .12 x 2 x 2 SQ. STEEL TUBING
PAINTING: PRIME & PAINT BLUE/GREEN.
SOLAR COLLECTOR BANK #1
BOLT CONDUIT TO I-BEAM FLANGE
ROOF SURFACE
ALUMINUM PANEL INSERT (REPLACES GLASS)
TRUSS
CUT ACCESS HOLE FOR CONDUIT
TOP CEILING PANEL STRIP
FIT & POP-RIVET CONDUIT JOINT
CABLE CONDUIT
INSTALLATION - CABLE CONDUIT TO INSTRUMENT ROOM
SCALE: 1/2" = 1'-0"
ITEM NO. QTY REQ CODE IDENT PART NUMBER SPECIFICATION NO. NOMENCLATURE
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING
TOLERANCE
ANGLES
DECIMAL
2 PLACE 3 PLACE
MATERIAL:
NEXT ASSY USED ON
APPLICATION
CW-3492.04 CONTRACT NO.
BALTIMORE, MD.
DRAWN R. LERNER
CHECKED
STRESS
DESIGN
ENGINEERING
PROJECT
DESIGN ACT APP
APPROVAL DATE
INSTRUMENTATION
INSTALLATION & DETAILS
SOLAR COLLECTOR SYSTEM
SIZE D CODE IDENT NO. 97384 57413-40069
SCALE AS NOTED SHEET 2 OF 2

A-7

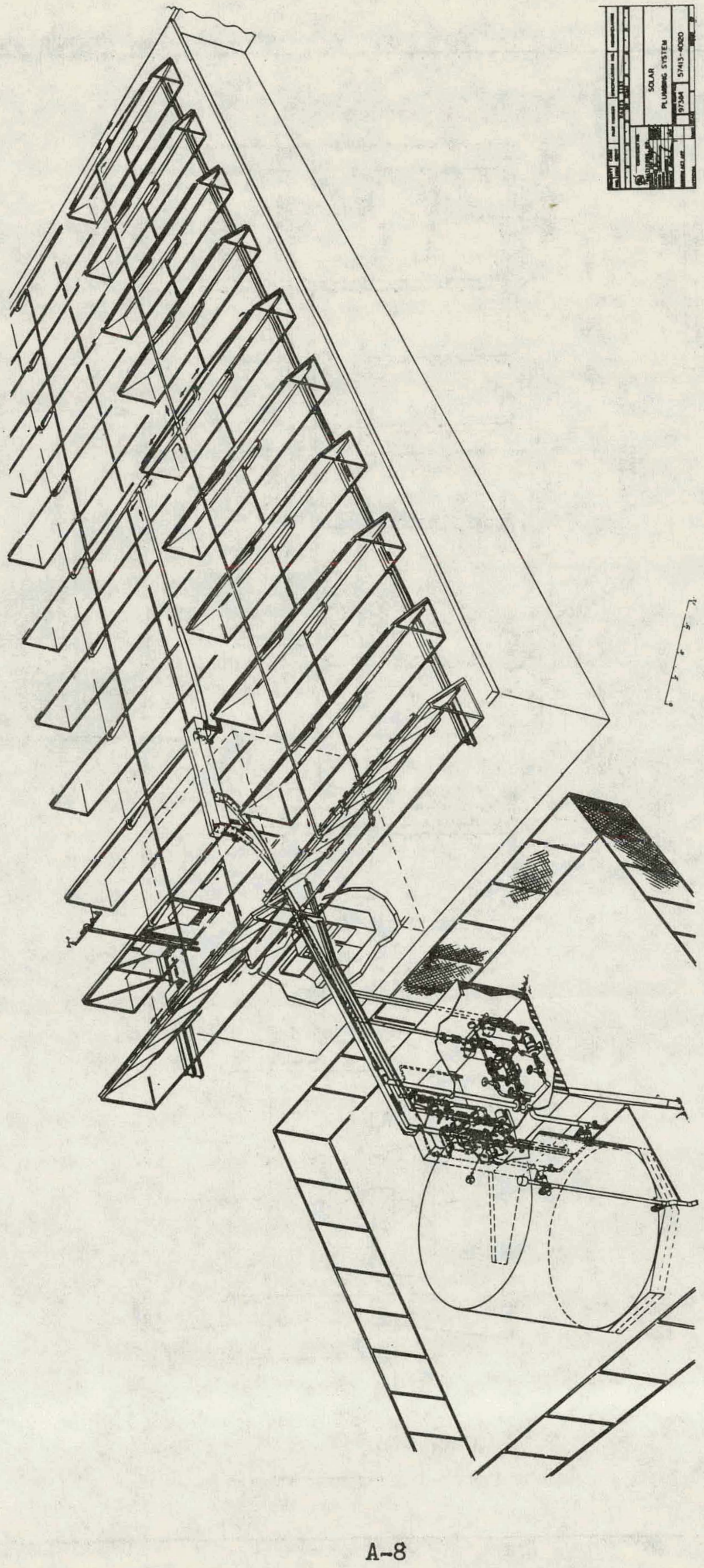


PLAN VIEW — WING "B"

TIMONIUM ELEMENTARY SCHOOL —NO SCALE

ALL PIPE RUNS SHOWN ARE IN CEILING OF SCHOOL

TOTAL AREA HEATED = 10,000 SQ.FEET



*U.S. GOVERNMENT PRINTING OFFICE: 1977-744-473/4405. Region 4.