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ABSTRACT

This report describes an experimental solar heating system, complete with thermal storage and controls, that has met all the heating requirements of five detached classrooms of the Fauquier High School in Warrenton, Virginia. The objectives of the experiment were to (1) demonstrate that solar energy can be used to provide a substantial part of the energy requirements of a public school, (2) determine the fuel/energy savings from the use of this system, (3) provide a sound economic basis for projecting costs and cost/benefits from the use of solar energy, and (4) determine figures for performance, and the maintenance and operational costs of the system. Figures and text fully present the specifications of the system. (Author/MLF)

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Solar Energy School Heating Augmentation Experiment

Design Construction and Initial Operation

ITC Report No. 090974
December 4, 1974

2

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FOREWORD

The Fauquier High School in Warrenton, Virginia is receiving from the sun all of the heat required to meet the heating loads of five mobile type, detached classrooms. The cost to the school for heating these classrooms is approximately 25 cents per day, the cost of the electrical energy required to operate the pumps and controls. Except for the relatively small amount of electricity required, the Fauquier High School will receive, for the life of the system, a safe, non-polluting, non-interruptible form of useful and renewable energy at a price unaffected by the constantly increasing price of fossil fuels and without effect on the U. S. balance of payments. At some future date this solar heating system will be turned over to the school. No special training or skills will be required to operate or maintain the system.

I. Summary

On 22 January 1974 InterTechnology Corporation received a contract to design, construct, and operate a solar heating system, complete with thermal storage and controls with sufficient heating capacity to serve the heating load requirements for five detached classrooms of the Fauquier High School in Warrenton, Virginia. On 19 March 1974, the system was declared operational and classroom heating with solar energy began. Since that date, all of the heating requirements of the classrooms have been met with solar energy except for brief periods during which the system was shut down for modifications. The solar collector constructed under this contract, Figure 1, is believed to be the largest single planar array of solar collectors in the world. Efficiencies integrated over full day heating operations have ranged from 40 to 60 per cent.

The solar heating system consists of a 2,540 square foot collector with a net absorber area of 2,415 square feet, made-up of 105 collector modules, 3 moduels to a row, in 35 rows and two 5,500 gallon concrete transformer vaults for storage of water. The collector modules have been assembled on a support structure 126 feet by 26 feet. The structure consists of steel pipe and angle iron set in concrete trenches and individual footings. The structure was designed to withstand winds in excess of 100 mph. The thermal storage system was sized to meet the heat loads of the classrooms for a minimum of 5 days. The total thermal storage system, using 10,000 gallons of water (no ethylene glycol or other anti-freeze is used) as a storage meida, will provide sufficient heat to meet the heat load requirements of the classrooms for approximately 12 days without sunlight, under average winter conditions. The calculated relaxation rate for the thermal storage system is approximately 1°F per day, starting at 150°F.

FIGURE I ITC SOLAR COLLECTOR

The 5 detached classrooms contain a total of 4,100 square feet of classroom area. Four of the classrooms were heated with baseboard electric heating systems. One of the classrooms, the oldest of the five, is equipped with both an oil-fired and a baseboard electric heating system. The selection of a group of detached classrooms has made possible accurate measurement of all energy inputs which will provide an excellent basis for evaluating the performance of the solar heating system. Space heating is provided by two water-air convectors with two-speed air circulation fans in each classroom.

The general topography at the school site provides a hillside near the detached classrooms. The hillside runs nearly east-west. The collector structure was placed high enough on the hillside to insure that the gymnasium, located immediately to the south, would not shade the collector. The collector structure was oriented due south and tilted at an angle of 53 degrees to the horizontal. The tilt angle of 53 degrees was selected to provide maximum winter heating capability for this particular geographical location and heating season weather conditions.

II. Objectives

The objectives of the program were as follows:

A. Demonstrate that solar energy can be used to provide a substantial part of the energy requirements of a public school.
B. Determine the fuel/energy savings from the use of this system.
C. Provide a sound economic basis for projecting costs and cost/benefits from the use of solar energy.
D. Determine figures for performance, and the maintenance and operational costs of the system.

III. Engineering Design

A. Design requirements, January

1. Heating load

   Annual heating load requirements are shown in Table I. The average daily heat load for January is shown in Table II. The maximum total heating load in January for the five classrooms is 32 million Btu.

2. Storage requirements

   The design of the system was to insure meeting the heating load requirements for five consecutive days of non-collector operation, or slightly in excess of 5 million Btu. Using water as the storage medium at a Δt of 60°F, a storage system of 10,000 gallons was required.

3. System requirements

   Total heat losses in the system are as follows:

	Btu x 10^6 / mo.
Space Heat Requirement	32.1
Tank Losses	22.0
Line Losses	2.6
Total Heat Requirements	56.7

4. Collector requirements

   The Washington, D. C. area receives a January average daily total (horizontal) radiation of 632 Btu/day-ft^2. At an angle of incidence of 53° this becomes approximately 1,500 Btu/day-ft^2. At an efficiency of 50% approximately 750 Btu/day-ft^2 can be delivered to storage or space heating. Using this as a basis the collector size requirement becomes:

$$\frac{56.7 \times 10^6 \text{ Btu/month}}{23{,}250 \text{ Btu/month-ft}^2} = 2{,}439 \text{ ft}^2 \text{ required.}$$

TABLE I

NSF SOLAR PROJECT

SUMMARY OF HEAT LOADS, FAUQUIER HIGH SCHOOL TRAILERS

Room No.	Area ft^2	Calcualted Design Btu/hr (0°-70°F)	Load for Equipment Selection 75% max (17°-70°F)	Estimated 1973 Heat Load 4276 D D Btu x 10^{-6} Max Design[1] (ASHRAE)	Estimate (1973)	Actual[2] (1973)	Water Flow Required, GPM, for 10°F drop per pass Design	Estimated	Existing Baseboard Heaters
727	936	40,358	30,300	61.20	44.4	Thermostats Turned Down at Night People Load 9.2	8.07	5.06	12.000 kw 40,956 Btu/hr
725	936	40,358	30,300	61.20	44.4		8.07	6.06	12.000 kw 40,956 Btu/hr
723	800	36,551	27,400	54.75	40.2		7.31	5.48	12.000 kw 40,956 Btu/hr
729	936	37,489	28,489	56.11	41.8		7.50	5.69	11.010 kw 37,543 Btu/hr
721	500	51,725	38,800	77.43	57.0		10.3	7.76	4 kw + Oil 13,652 Btu/hr
Total	4,100	206,648	155,289	310.69	227.8	182	41.25	37.23	Plus Oil 174,063 Btu/hr

1 Assumed electric heating insulation standards, 0°F-70°F

2 Individual trailer heat load data not available.

TABLE II

FAUQUIER HIGH SCHOOL, DETACHED CLASSROOMS
JANUARY HEATING REQUIREMENTS

Room No.	Actual Total Energy Requirements, Btu x 10^6	Correction For Lighting 6%, Btu x 10^6	Actual 1973 Heating Load, Btu x 10^6	January Heating Load, Btu x 10^6 (18.7%)	Average Daily Load, January, Btu x 10^6
727	35.8	1.9	33.7	6.3	0.20
725	35.8	1.9	33.7	6.3	0.20
723	32.0	1.9	30.1	5.6	0.18
729	32.8	1.9	30.9	5.8	0.19
721	45.3	1.9	43.4	8.1	0.26
Total	181.7	9.5	171.8	32.1	1.03

B. Collector plate

1. Materials

   Materials considered for this project are as follows:

   a. Aluminum ROLL-BOND
   b. Copper tube on copper plate
   c. Brass tube on brass plate
   d. Iron pipe on iron plate
   e. Aluminum tube on aluminum plate
   f. Steel Platecoil

   Aluminum ROLL-BOND was selected for the following reasons.

   a. The plates could be fabricated and delivered in accordance with schedule, and design requirements.
   b. The chemical etch selective coating was developed for use with aluminum.
   c. The cost for preformed ROLL-BOND plates, with integral tubes, was approximately 50% less than the estimated cost for the alternatives listed above.

2. Hydraulics

   The straight thru, single pass plate design was made to insure uniform water flow through the plate, and minimum pressure drop. Spacing was determined to provide optimal heat transfer between the plate and the fluid.

3. Flow patterns were calculated to yield a pressure drop per plate of 0.3 psig, at a flow of 2 gallons per minute.

4. Selective coatings

   The following coating techniques were evaluated for the ROLL-BOND panels:

   a. Anodize
   b. Paint
   c. Chemical etch

The α/ϵ ratio of approximately 3 for the chemical etch coating was superior to that which could be expected with paint and anodized coatings. Panels tested showed excellent resistance to heat and humidity on a protracted basis.

C. Site Plan

1. Site selection

The Fauquier High School detached classrooms were selected for this experiment for the following reasons:

a. Work could be accomplished on a mutual non-interference basis.
b. Ease of isolating energy consumption and requirements. The classrooms are totally independent of the school heating system. Four classrooms are heated by electric baseboard heaters, and one by electricity and kerosene. Electrical input to these electrically-heated units is metered separately from the rest of the school system.
c. The location is less than one mile from ITC offices for ease of frequent site visits.
d. The total area to be heated, was compatible with the space available for the location of the collector.
e School authorities agreed with the selection and offered their enthusiastic cooperation.

2. Collector location

Three locations were considered for the collector:

a. On top of existing school buildings
b. On top of the detached classrooms
c. Detached from the buildings

The hill site detached from the classrooms, was selected for the following reasons:

a. Minimum interference with classroom activities.
b. Immediate approval by the school board, since construction would not significantly interface with school buildings and classrooms.

c. Immediate approval and granting of building permit by county authorities
d. Increased aesthetic and visual impact
e. Relative isolation from human traffic, yet plainly visible
f. The mobile home type, detached classrooms would require additional structural support and elaborate tie-downs to prevent overturning in high winds
g. The hill site provided a location free of shadows from other buildings, with nearly perfect orientation and had no projected use by the school because of the steep slope

3. Thermal storage location

Location of the storage tanks was dictated by the locations of existing water mains, drain tiles and accessiblity for the heavy tank-setting equipment.

4. Space heating requirements

The system was sized to provide <u>all</u> of the heat requirements to the 5 classrooms during the heating season. The storage system was sized to provide heat for at least 5 days without operating the collector.

5. Control room/pump house

The original plan to locate the control room in the collector structure was changed in favor of the decision to build a separate building (Figure 2) and combine the control room with the pump house. The location of the buried tanks offered a convenient location as well as the basic floor structure for the combined control room and pump house.

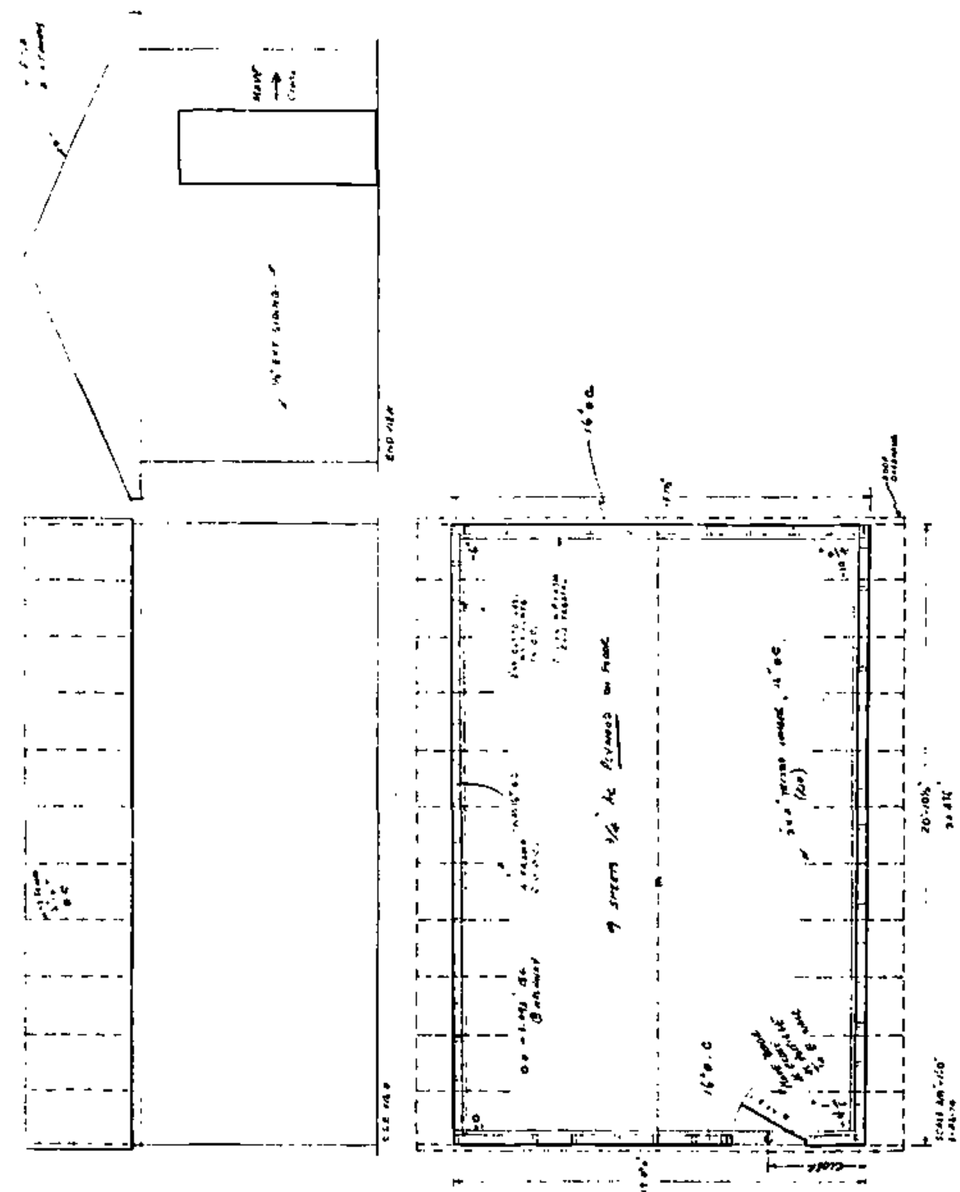
D. Thermal storage

1. Capacity

The heating load of the space and the 5-day storage requirements indicated that a storage of 5×10^6 Btu or a tank size of approximately 10,000 gallons was required to meet this requirement.

FIGURE 2

CONTROL ROOM/PUMP HOUSE



2. Materials

Materials considered for the storage system were as follows:

a. Steel

b. Fiberglass

c. Concrete

The concrete tank was the only tank available to meet the schedule requirements. Two 5,500-gallon transformer vaults were used as the storage system.

3. Insulation

To prevent thermal losses to the ground, the tanks were installed and insulated as follows:

a. Bottom

1) Ten-inch concrete pad

2) Two layers of pentaclorophenol-treated 2 by 12-inch boards

3) One layer of 4-inch foam glass

b. Sides

1) Four inches of polyurethane foam, with a waterproof barrier of fiberglass and mastic

2) One layer of pentaclorophenol-treated 2 by 12-inch boards

c. Top

1) Four inches of polyurethane foam, with a waterproof barrier of fiberglass and mastic

2) Two layers of pentaclorophenol-treated 2 by 12-inch boards

E. Hydraulics

1. Pumps (Figure 3)

The maximum pump capacity of the primary circulation system, assisted by a submerged pump, is about 60 gpm. From actual operating experience a flow rate range of from 30 to 40 gpm will result in a loss of thermal efficiency of about 1% while increasing the COP of the system by as much as 100%. Due to the nature of the storage

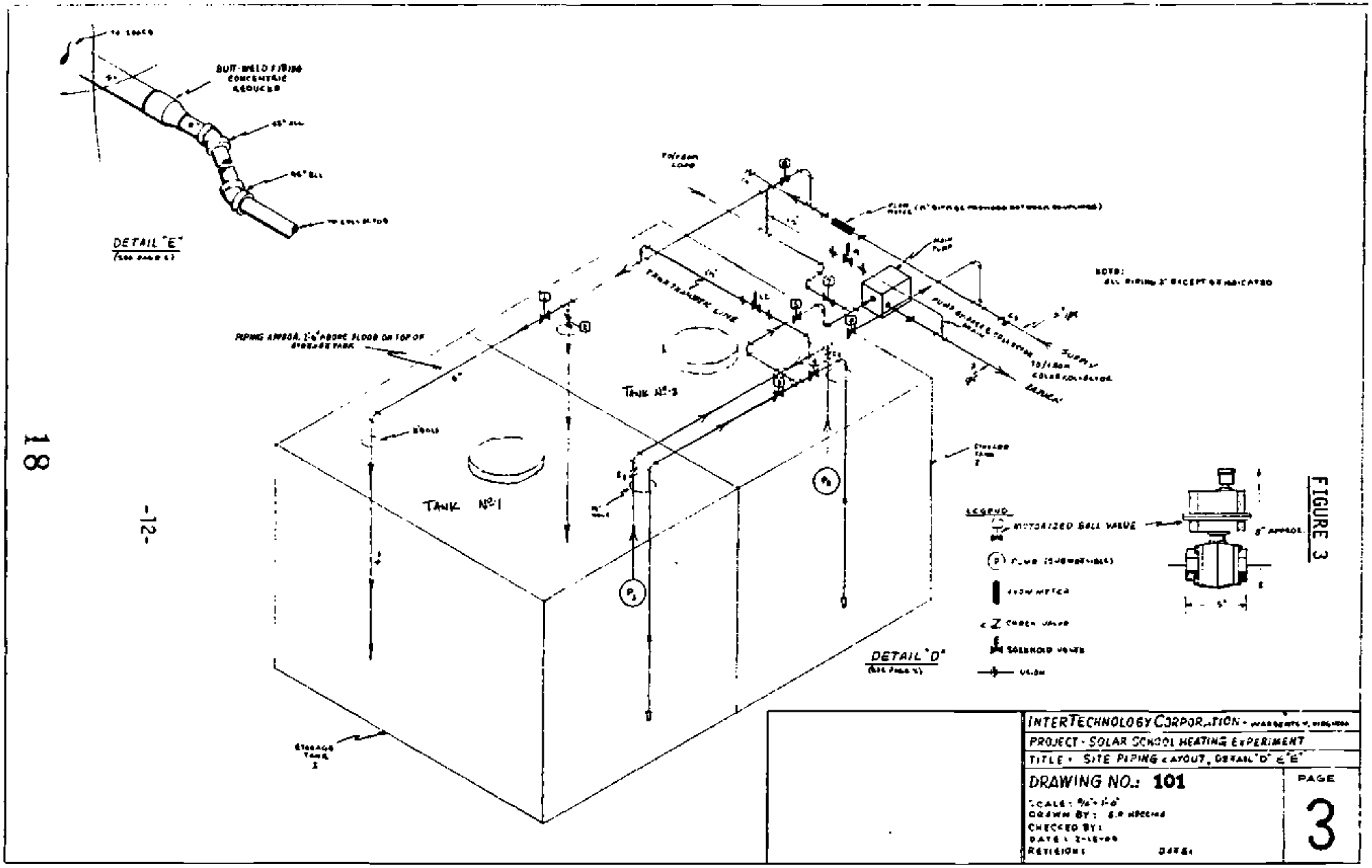

DETAIL "E"
DETAIL "D"
TANK No 1
TANK No 2
LEGEND
INTERTECHNOLOGY CORPORATION
PROJECT - SOLAR SCHOOL HEATING EXPERIMENT
TITLE - SITE PIPING LAYOUT, DETAIL "D" & "E"
DRAWING NO.: 101
PAGE
3

FIGURE 3

tank (only top access), net positive suction head could not be guaranteed at the primary circulation pump inlet. The design employed was for submerged pumps. Only one particular pump, manufactured by the Becket Company, was found that would meet performance requirements, continuously immersed in water at temperatures up to 200°F.

2. Valves

   Ball valves were selected throughout the system for three reasons:

   a. Low pressure drop
   b. Motorized valve actuators are easy to control and maintain
   c. Availability

3. Piping

   Ordinary black steel, schedule 40, pipe was used throughout the system. Only untreated pipe could be obtained in time to meet schedule requirements. Pipe sizes are shown in Figure 4.

F. Pipe insulation

Four types of insulating material were used in the system.

1. Underground insulation

   Two types of insulation material were used for underground insulation.

   a. 1 1/2-inch foam glass, covered with mastic, installed by C. E. Thurston & Sons, Inc.
   b. 1 1/2-inch polyurethane foam, covered with fiberglass and mastic, installed by Johns-Manville Corporation.

2. Aboveground

   The aboveground piping was insulated with 1 1/2-inch Johns-Manville Flame-Safe fiberglass pipe insulation. The hose connections were insulated with 3/8-inch Johns-Manville Aerotube foamed plastic insulation.

G. Space heating

Space heating is provided by two water-air convectors with high- and low-speed circulating fans in each classroom. The convectors are

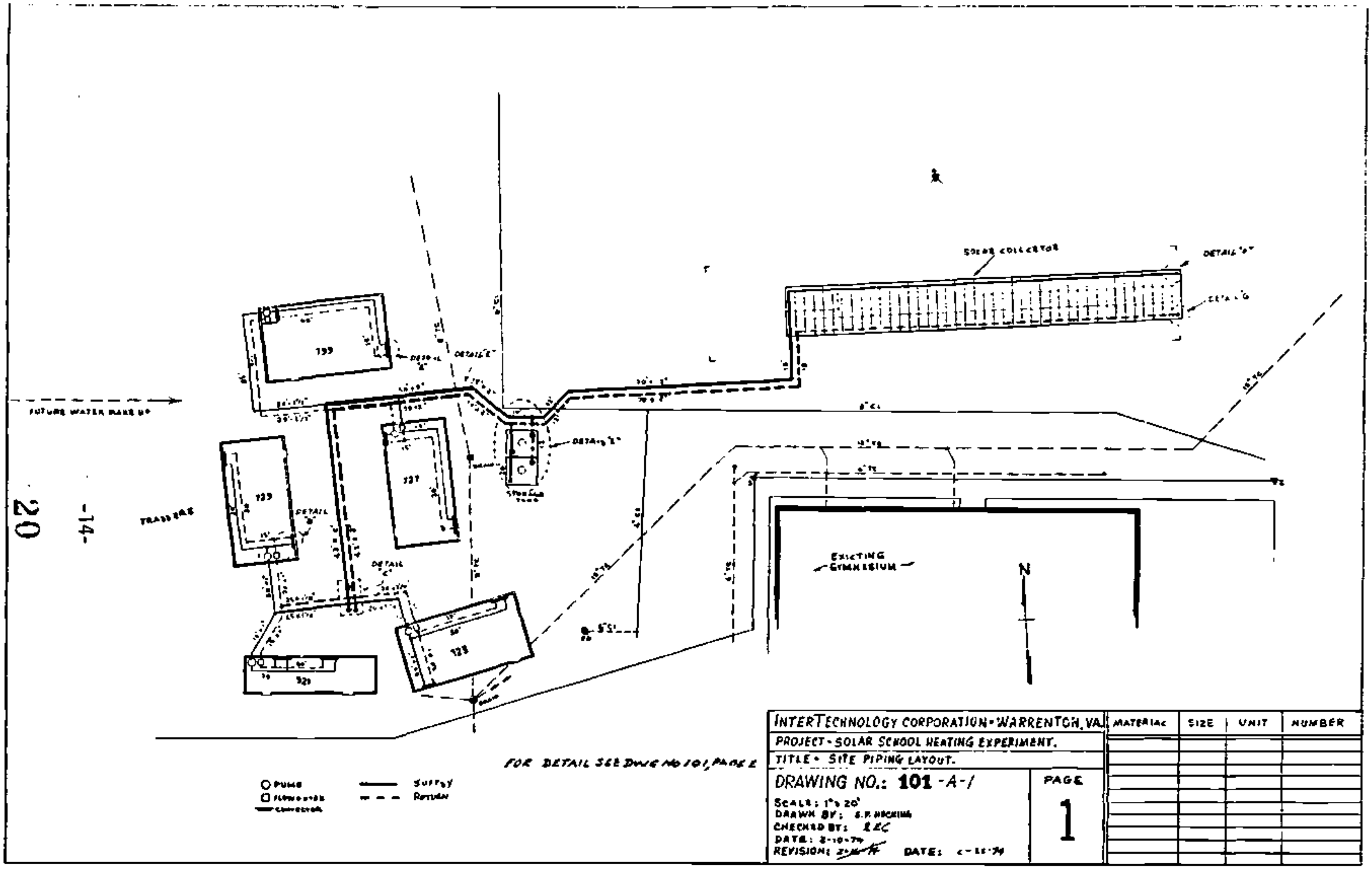


FIGURE 4 SITE PIPING LAYOUT

Young model CH85. Each classroom is provided with a Red Baron, 1/12 hp circulating pump (Figure 5). The room system is controlled by the two temperature-setting room thermostats. When the room thermostats are activated three simultaneous events occur:

a. The room solenoid opens
b. The room circulating pump starts
c. The convector fans start (Thermoswitches were employed but discarded as unsatisfactory.)

Response time of the system is such that temperatures can be raised from 30°F to 72°F with an inlet temperature of approximately 140°F in all rooms in approximately one hour.

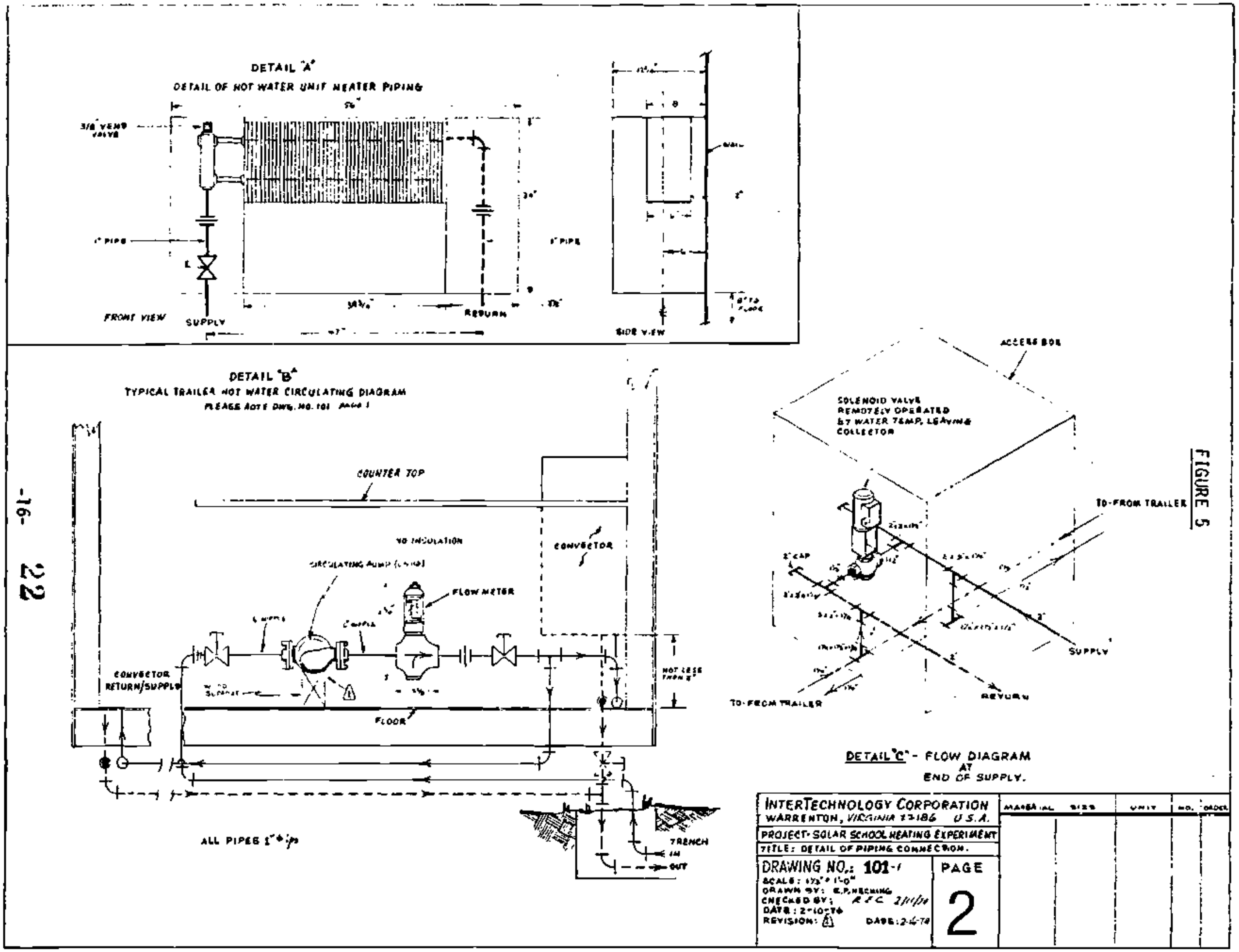
H. Collector box construction

1. Materials

   Wood was selected as the basic material for the collector box primarily because of availability and delivery schedule. Since boxes made from wood required little or no tooling it was possible to delay the final design of the box until final sizing of other components. The boxes were protected with one coat of primer and two coats of a latex house paint.

2. Insulation

   Three inches of Johns-Manville Spin Glass FSK (reinforced foil and paper) type 814 was selected for the bottom of the box. This particular form of fiberglass insulation has suitable structural properties to carry the load of the collector plate. The R value for type 814 insulation at a mean temperature of 100°F is approximately 13. The side wall structure of the box was designed to support each glazing and reduce edge losses from the collector plate. The estimated R value range for the side walls is between 2 and 3. For construction details of the box see Figure 6.



DETAIL "A"
DETAIL OF HOT WATER UNIT HEATER PIPING
3/8" VENT VALVE
1" PIPE
SUPPLY
RETURN
FRONT VIEW
SIDE VIEW
DETAIL "B"
TYPICAL TRAILER HOT WATER CIRCULATING DIAGRAM
COUNTER TOP
NO INSULATION
CONVECTOR
FLOW METER
CONVECTOR RETURN/SUPPLY
FLOOR
TRENCH
IN
OUT
ALL PIPES 1"
ACCESS BOX
SOLENOID VALVE REMOTELY OPERATED BY WATER TEMP. LEAVING COLLECTOR
TO-FROM TRAILER
SUPPLY
RETURN
DETAIL "C" - FLOW DIAGRAM AT END OF SUPPLY.
INTERTECHNOLOGY CORPORATION
WARRENTON, VIRGINIA 22186 U.S.A.
PROJECT- SOLAR SCHOOL HEATING EXPERIMENT
TITLE: DETAIL OF PIPING CONNECTION.
DRAWING NO.: 101-1
DRAWN BY: E.P. HECHING
CHECKED BY: RFC 2/11/74
DATE: 2-10-74
REVISION: 1
DATE: 2-6-74
PAGE
2
MATERIAL
SIZE
UNIT
NO.
ORDER

FIGURE 5

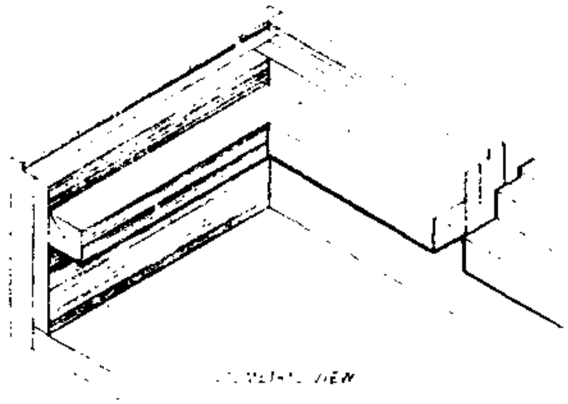


FIGURE 6

Solar Collector Box

(Dimensions Shown in Figure 6 Continued)

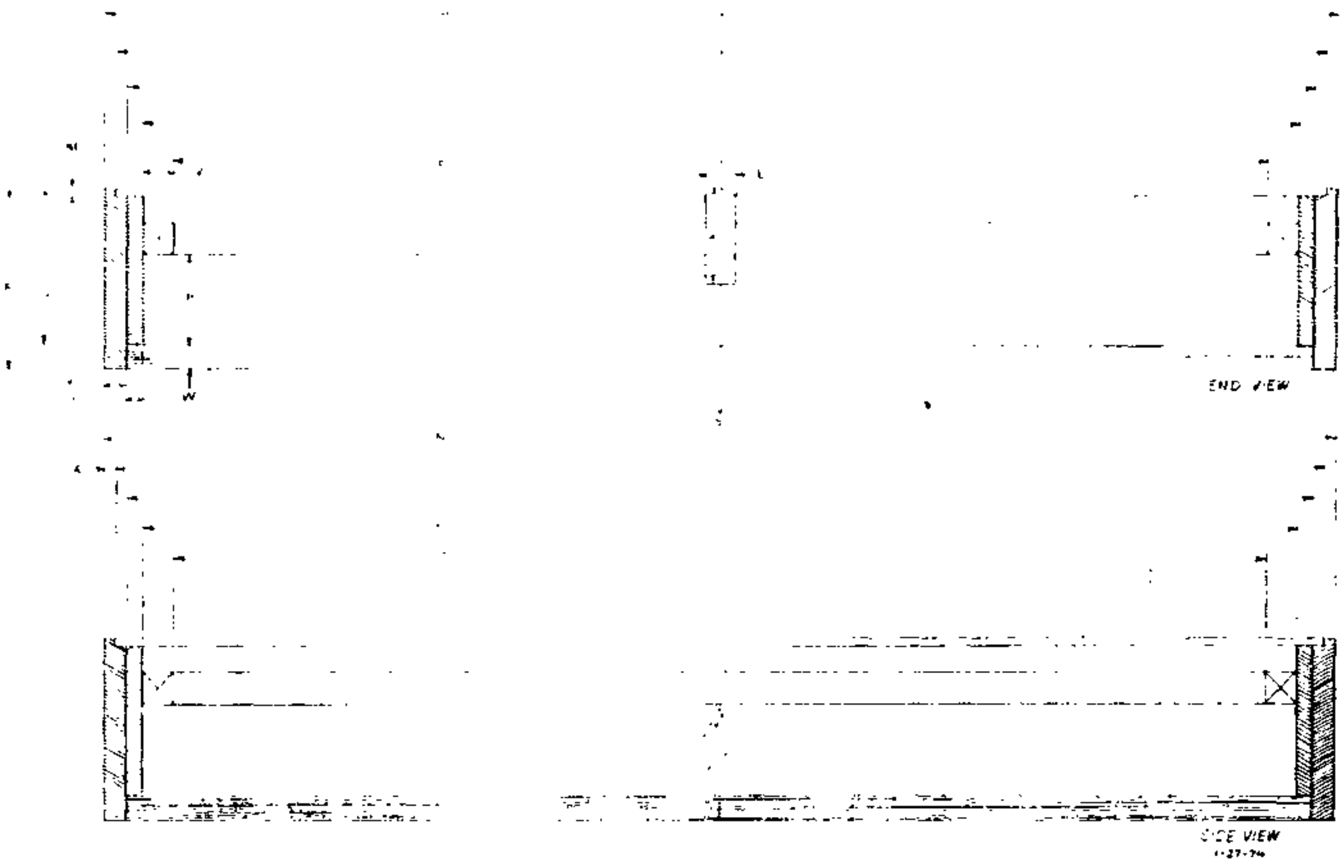


FIGURE 6

SOLAR COLLECTOR BOX (CONTINUED)

DIMENSIONS

A = 41 inches

B = 40 1/4 inches

C = 39 1/2 inches

D = 38 1/2 inches

E = 36 1/2 inches

F = 6 inches

G = 5 1/4 inches

H = 3 inches

K = 3 1/4 inches

L = 2 inches

M = 1/4 inch

N = 97 1/2 inches

O = 96 3/4 inches

P = 96 inches

R = 95 inches

S = 93 inches

T = 3/4 inch

U = 1/2 inch

V = 1 inch

W = 3/4 inch

X = 3/8 inch

3. Glazing

Two glazings of double strength, 1/8-inch thick, glass with approximately one inch air space between panes were selected. No attempt was made to purchase special quality glass, such as low iron content, etc. The time available for delivery of glass dictated the use of standard commercial grades and sizes. Approximately 33% additional glass pane "lights", were ordered to allow for breakage. The breakage was considerable less than the 33% anticipated. Excess glass panes will be used for routine maintenance.

I. Collector support structure

1. Tilt angle

A tilt angle of 53° to the horizontal was the largest angle justifiable for heating only based on direct insolation integrations throughout the heating season. Since the performance versus tilt angle curve is almost flat at tilt angles of latitude ± 15° for direct insolation and the winter time insolation for the Warrenton, Virginia area is almost totally direct, a tilt angle of latitude plus 14° was selected to maximize the visual impact.

2. Orientation

For a case of symmetry of overcast around solar noon, the optimum azimuthal orientation is true south in the northern hemisphere. This conclusion was verified by computer analysis. The 180° true orientation was determined using the star Polaris as a reference, by transit shot.

3. Materials

The collector support frame was made from vertical iron pipe, cross braced with angle iron, Figures 7 and 8. The face was decked with 2-inch by 8-inch fir stringers and sheathed with 1/2-inch plywood. The plywood was covered with one layer of roofing paper prior to

<u>FIGURE 7</u>

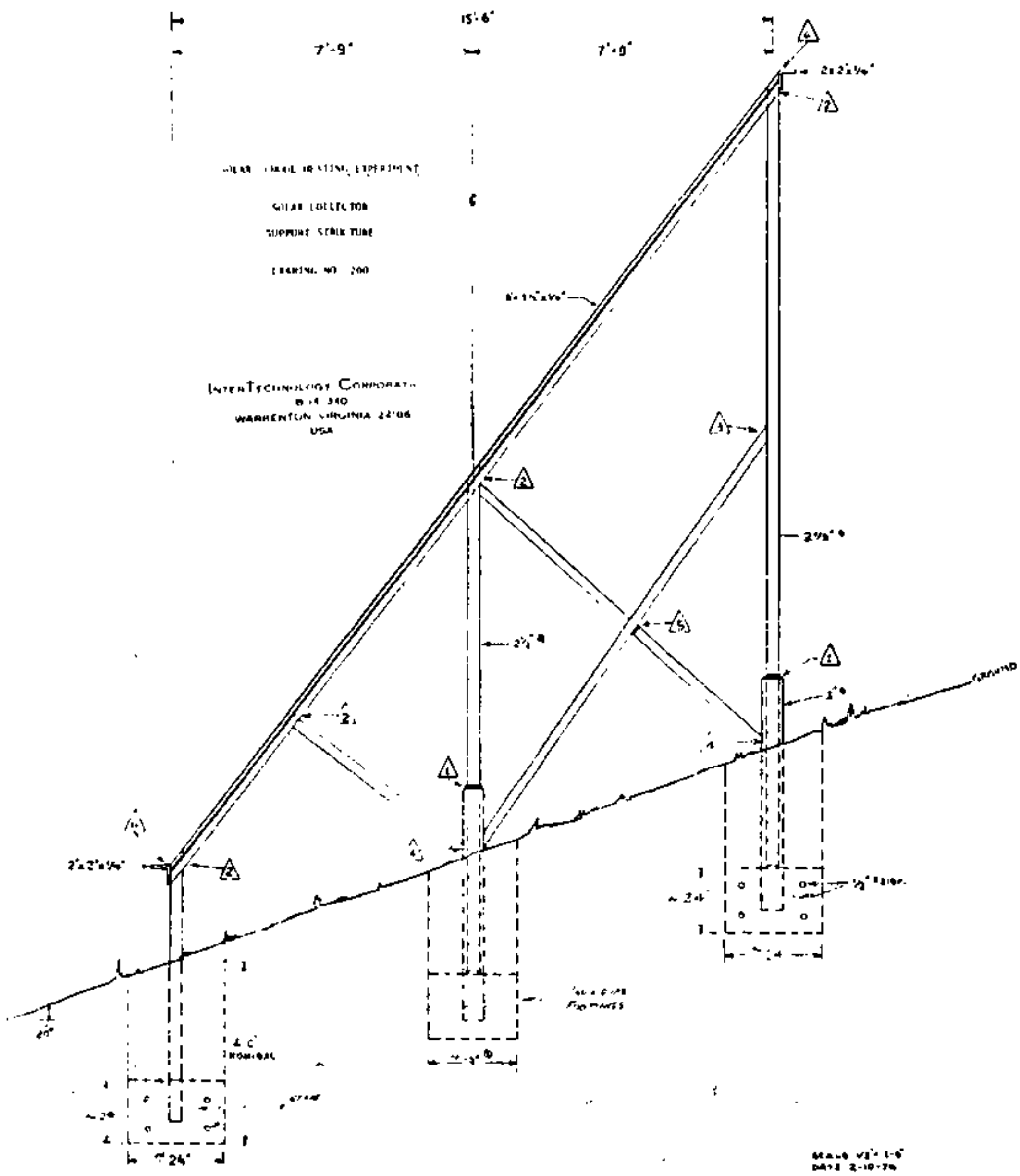
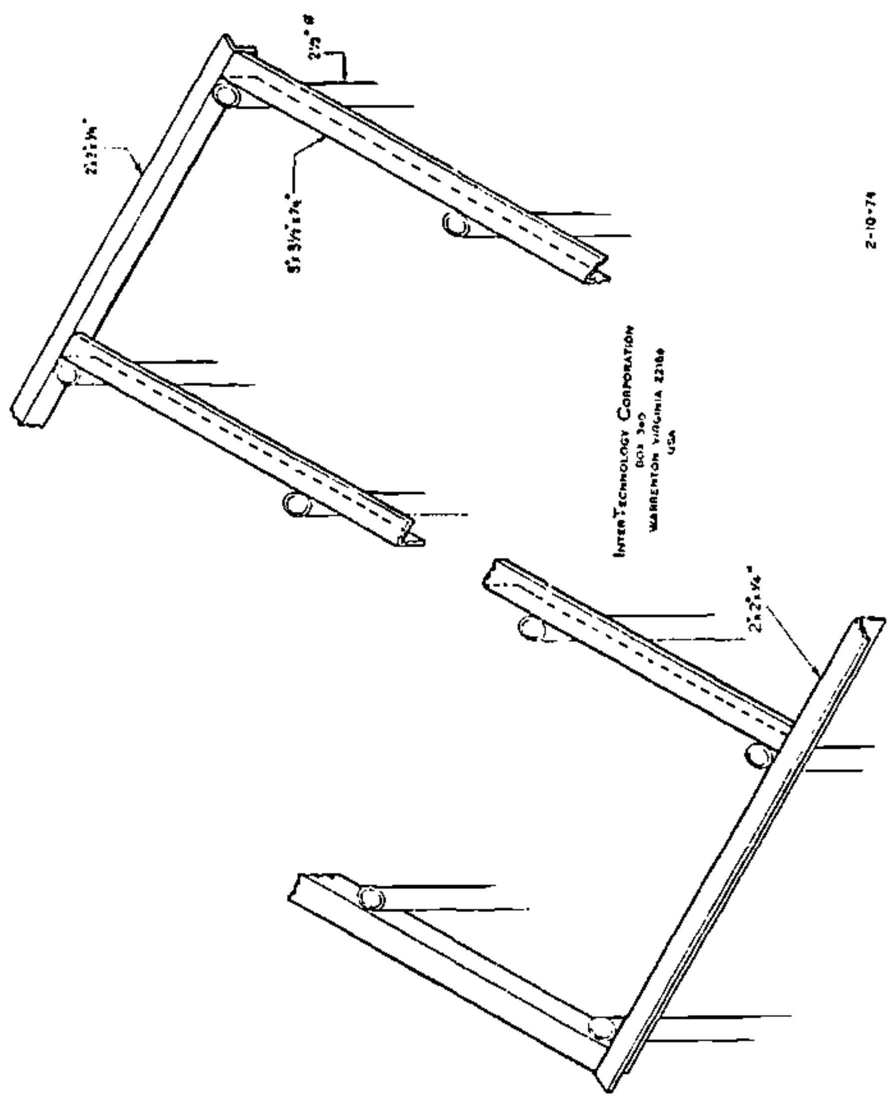


FIGURE 8

COLLECTOR SUPPORT STRUCTURE



installing the boxes. A similar construction was used for the back and ends with 2 by 4-inch girts to which plywood was nailed.

4. Structural requirements

   The total wind loads on the structure, 94,350 pounds, were found to be almost double the static load, 47,150 pounds, with a 100 mph wind normal to the face of the collector. The structure was designed and constructed to withstand wind speeds in excess of 100 mph. To insure proper foundation support Soil analyses were performed by Law Engineering Testing Company. The results of their analyses is contained in their report dated 31 January 1974 (see Appendix A).

J. Operational controls

1. Description of operation

   The operation of the system is keyed to the plate temperature, storage tank temperatures and space heating demands. All indicator lights can be independently tested with a single, 2-position switch. The system can be operated manually as well as in the fully automatic mode. The Automated Control System permits operation in any one of the eleven modes while requiring no decisions or actions by the operator except in the case of power failure. See Appendix B for detailed discussion. When the key is in the "automatic" position, it can be removed. In that position, the manual controls are inoperative, preventing tampering with or damage to the system by unauthorized or unqualified persons. Since the use of antifreeze is detrimental to overall system performance, no antifreeze is employed and a self-draining feature was selected and incorporated as one of the modes of operation. In actual test runs the collector has been found to drain into one of the storage tanks (always the same tank) in approximately 80 seconds.

2. Modes

The system was designed to operate in eleven modes of operation: seven basic modes and four emergency modes (Figure 9).

3. Theory of operation

Peripheral to the electronics of the system are the electromechanical motorized ball valves, the solenoid valves and the pumps. The motorized valves each contain two motors which turn a gear-driven master shaft with a nylon cam attached. Two microswitches ride the cam. One switch employs its set of contacts for AC control to the motors. The other switch is used to indicate valve position. Each motorized valve is connected to the system by hard wiring to the acess panel. Travel of a valve is initiated by a relay. The relay is latched by a manual or automatic command and through the AC microswitch, power is supplied to the valve drive motor. When the motor causes the valve to reach the open position the cam causes the AC continuity to be broken by the microswitch contacts. For the valve to be returned to the closed position the relay is unlatched causing the AC to flow through the closed set of contacts on the valve AC microswitch. The solenoid valves are straightforward with no feedback for indication. They are controlled by latching relays, and the relays themselves generate the display indication. The pumps are operated in like manner except that a secondary power relay handles the load for each pump. In this way separate circuit breakers may be utilized to disable the current to a pump if and when the need arises. The room pumps are almost within a closed system in themselves. Each room thermostat causes power to be applied through a relay to its associated solenoid valve, room pump, and motor-blown convector. (See Figures 10,11).

FIGURE 9

FAUQUIER HIGH SCHOOL SOLAR HEAT EXPERIMENT

AUTOMATIC MODE OPERATING CONDITIONS

	MODE NUMBER	MODE DESCRIPTION	SPACE NEEDS	SYSTEM PUMPS Tk.1	Tk.2	Main	CONTROLLED VALVES											
			RP-(1-5)	P1	P2	P3	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
UNIQUE MODES	1	HEATING SPACE FROM COLLECTOR	ON	OFF	OFF	ON	C	C	C	C	C	C	0	C	C	C	C	C
	2	HEATING SPACE FROM STORAGE TANK 1	ON	ON	OFF	OFF	0	C	C	C	C	0	C	C	C	C	C	C
	3	HEATING SPACE FROM STORAGE TANK 2	ON	OFF	ON	OFF	C	0	C	C	C	0	C	C	C	C	C	C
	4	HEAT FROM COLLECTOR TO STORAGE TANK 1	OFF	ON	OFF	ON	0	C	C	C	0	C	C	0	C	C	C	C
	5	HEAT FROM COLLECTOR TO STORAGE TANK 2	OFF	OFF	ON	ON	C	0	C	C	0	C	C	0	C	C	C	C
	6	HEAT FROM COLLECTOR TO STORAGE TANK 1 & SPACE	ON	ON	OFF	ON	0	C	C	C	0	C	C	C	C	C	C	C
	7	HEAT FROM COLLECTOR TO STORAGE TANK 2 & SPACE	ON	OFF	ON	ON	C	0	C	C	0	C	C	C	C	C	C	C
				P1	P2	P3	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
SPECIAL MIXED MODES	8	EMERGENCY OVERHEATING OF COLLECTOR		ON	ON	ON	0	0			0		0				0	
	9	DRAIN COLLECTOR						0						0	0	0		
	10	COLLECTOR START UP		ON or	ON	ON	0 or	0			C							
	11	TANK WATER TRANSFER																0

LEGEND: 0 = OPEN; C = CLOSED; BLANK = DON'T CARE

FIGURE 10

ROOM THERMOSTAT AND ROOM PUMP RELAY WIRING

2/27/74

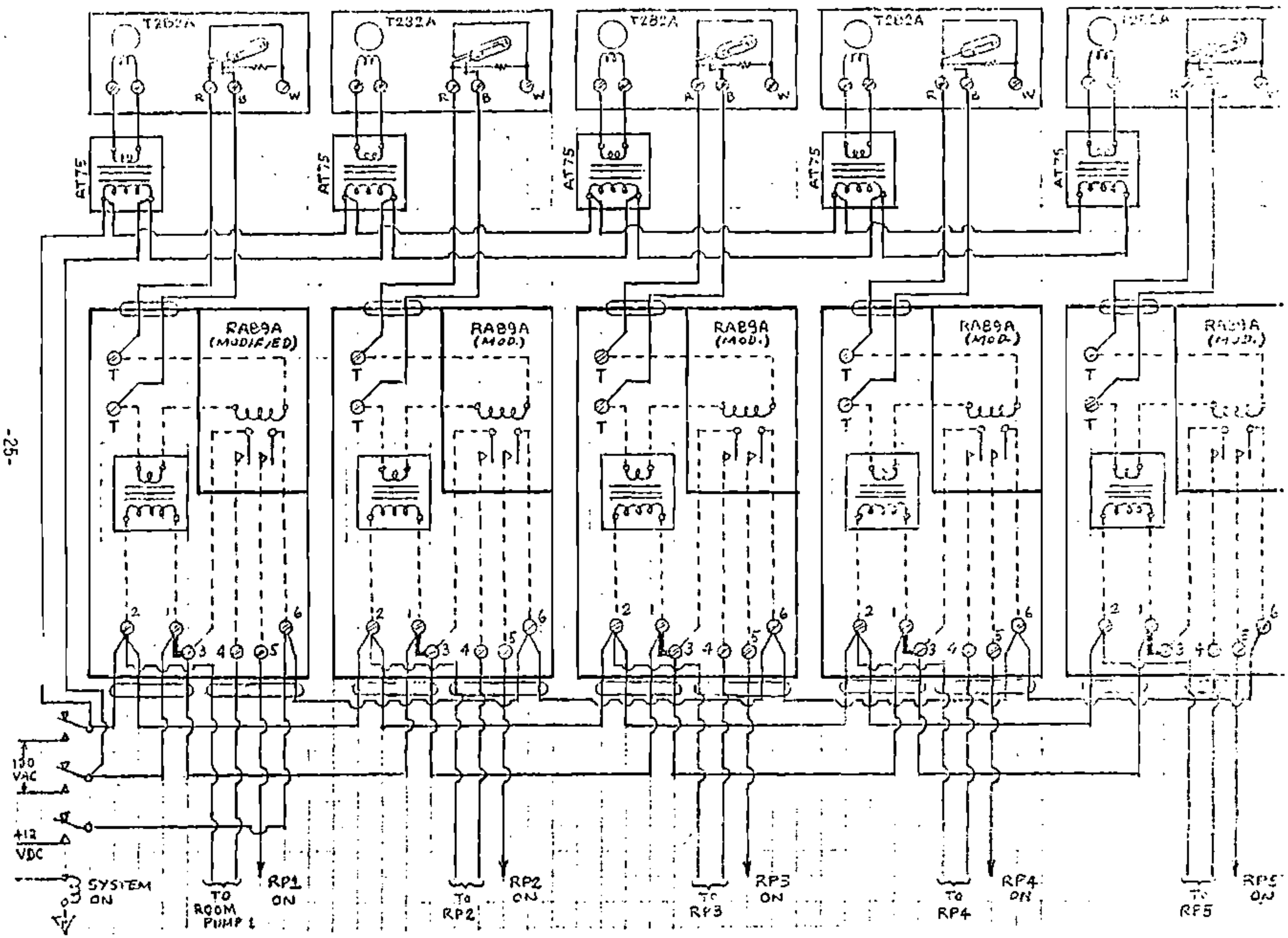
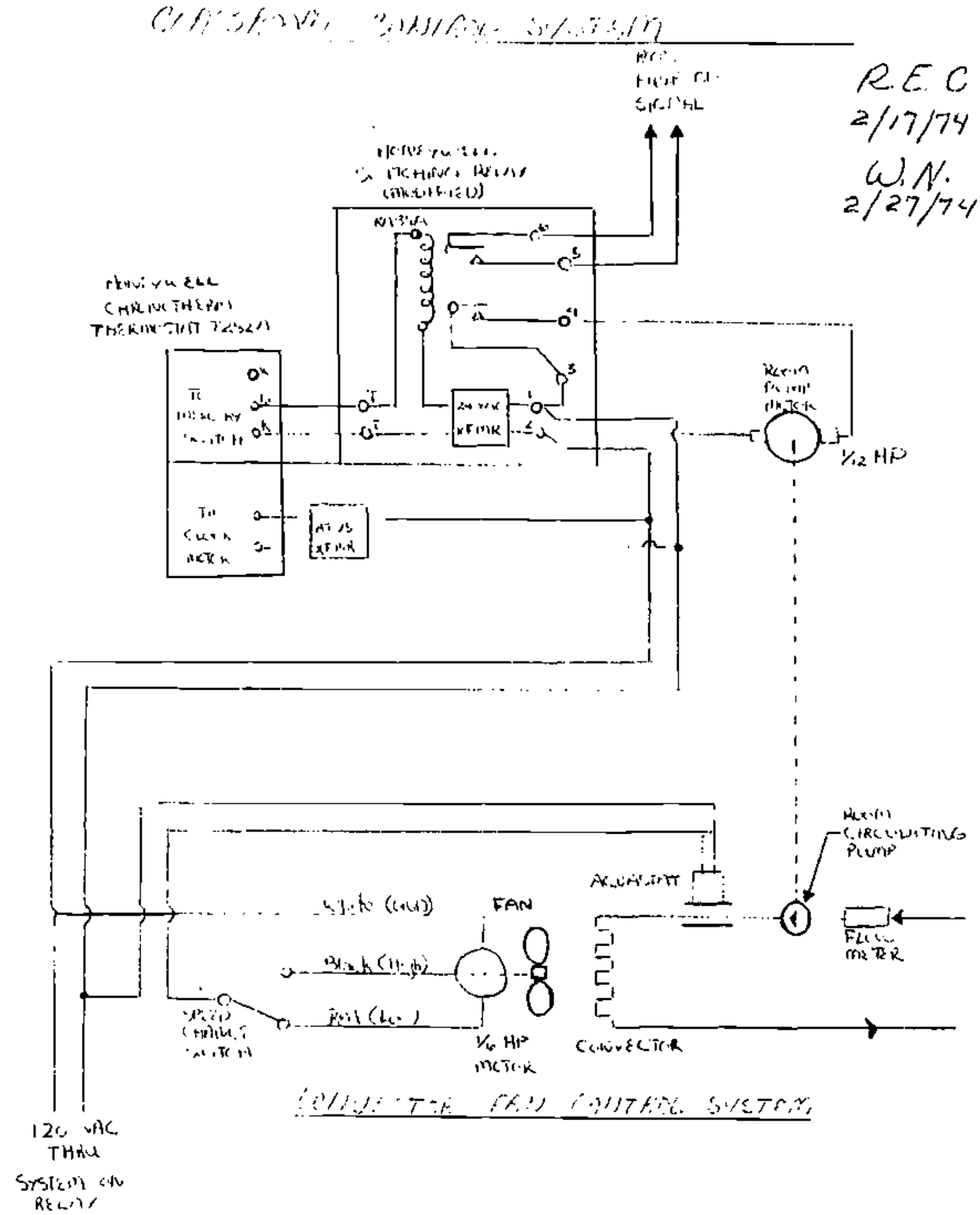


FIGURE 11


R.E.C
2/17/74
W.N.
2/27/74
½ HP
FAN
FLOW METER
CONVECTOR
⅙ HP MOTOR
120 VAC THRU SYSTEM ON RELAY

The sensor array bears the responsibility for accepting temperature data from tanks, collector and ambient temperature. Its purpose is to make decisions as to operating mode based on these temperatures.

Each probe signal is amplified by a differential input amplifier with a gain of one thousand. From there the signal passes through an integrator with a period of approximately one millisecond and a gain of one. The signal then drives a temperature meter (except in the case of ambient temperature) and is also applied to a summing amplifier. Each summing amplifier has an input common to all others and that is the ambient temperature signal or factor. This factor is algebraically added to each of the other three temperature inputs to give ambient corrected probe signal. The signal then enters one of the comparators. There are nine comparators in the sensor chassis showing the temperature differences between the tanks, tanks and collector, and high and low set points. The comparator outputs are used to drive subminature relays for lamp indication of comparator states and also the relay logic into the chasses. The relay logic determines the operating mode and drives the power switching logic matrix on the relay chassis.

K. Instrumentation and controls

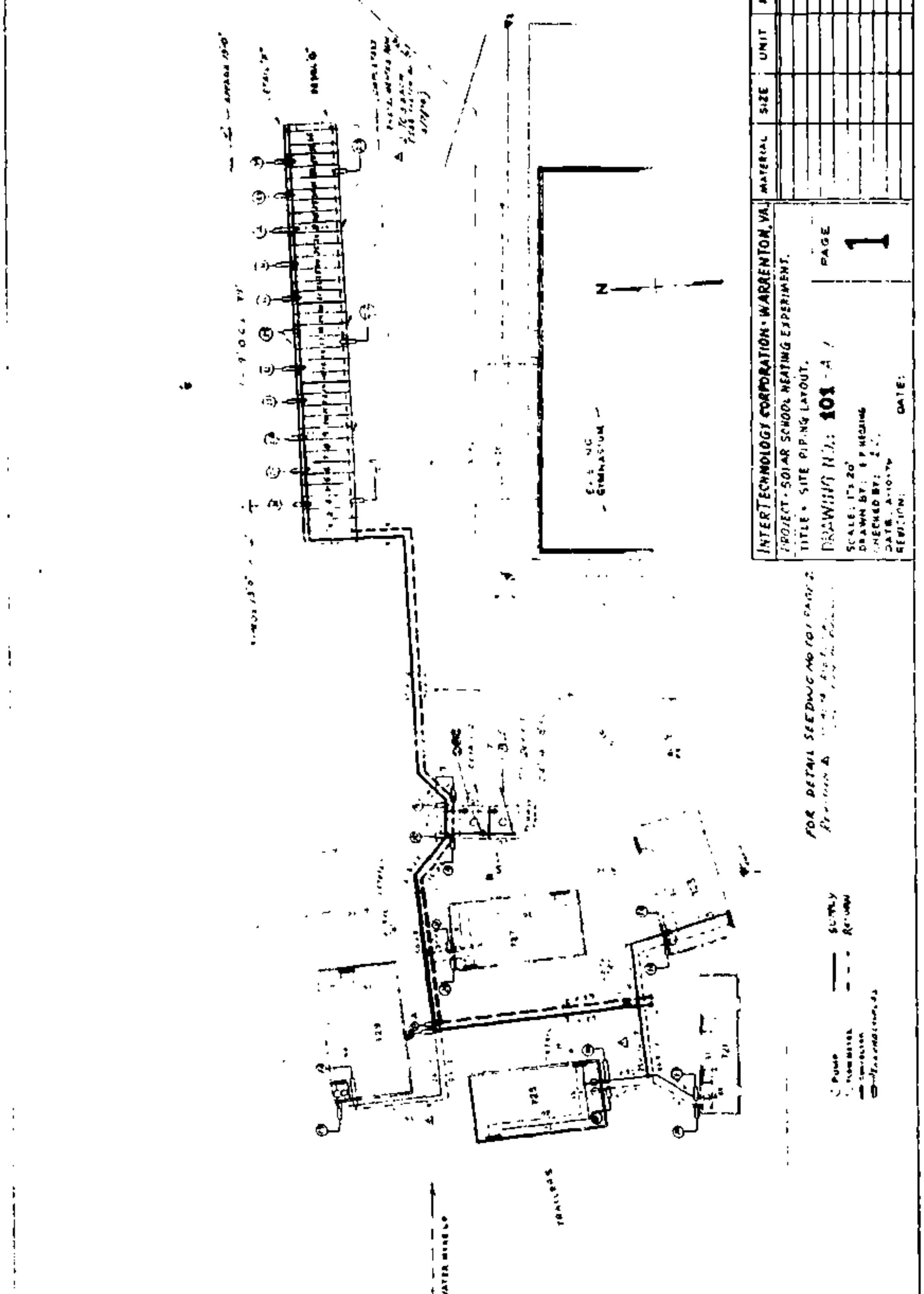
1. General description and list of instrumentation used:

   The instrumentation design for the Fauquier High School Solar Heating Project is based on both the operational and experimental requirements. Economy dictated the least instrumentation which would meet the test and evaluation requirements of the program. The instrumentation considered necessary to meet the objectives of the program is shown in the following list:

a. 1-Digitrend 210 multi-point data logger
b. 2 Guzzinta flow meters; three plug-in locations
c. 35 Monitor flow meters
d. 2 plug-in temperature and pressure gauges (used in conjunction with item b)
e. 2 pyrheliometers, Hy Cal Model P-8405, 180° quartz globe covered
f. Wind speed/direction indicator
g. Ashcroft pressure gauges
h. Valve position and pump status analog panel with manual control switches
i. Watt-hour meter
j. 85 Copper-Constantan thermocouples
k. 5 Honeywell clock, 2-setting day/night thermostats

2. This instrumentation is used to provide the following data:
   a. Temperature
      Temperature measurements are made throughout the system as shown in Figure 12.
   b. Flow
      Flow measurements are made at four locations
      1) Main return line from the collector
      2) Return and supply lines to and from storage tanks
      3) Return line from each collector run.
   c. Pressure
      Pressure measurements are made in two locations:
      1) Main circulating pump
      2) Submerged pump return and supply lines
   d. Solar flux
      Solar flux measurements are made in two planes:
      1) Horizontal
      2) 53° from the horizontal (the plane of the collector)

FIGURE 12


INTERTECHNOLOGY CORPORATION • WARRENTON, VA.
PROJECT • SOLAR SCHOOL HEATING EXPERIMENT.
TITLE • SITE PIPING LAYOUT.
DRAWING NO.: 101
PAGE
1
DATE:
MATERIAL
SIZE
UNIT
NUMBER
N
GYMNASIUM
FOR DETAIL SEE DWG NO 101 PAGE 2
SUPPLY
RETURN
TRAILERS

e. Wind speed/directon

   Wind speed and direction measurements are indicated continuiously.

f. Valve position and pump condition

   Indications of positions and operating conditions are displayed on the schematic control board (Figure 13).

g. Watt-hour meter

   Indicates the electrical energy consumption of the system, including all applicable electrical devices in the buildings being heated.

3. Experimental instrumentation

   a. Solar flux measurements are made on the horizontal plane and in the plane of the collector faces (53°). Measurements are made in the two planes to determine the direct and scattered (or diffuse) components of the solar insolation, and to verify the total available solar energy as a basis for performance figures. Efficiency calculations are based on flux measurements in the plane of the collector.

   b. Temperature measurements

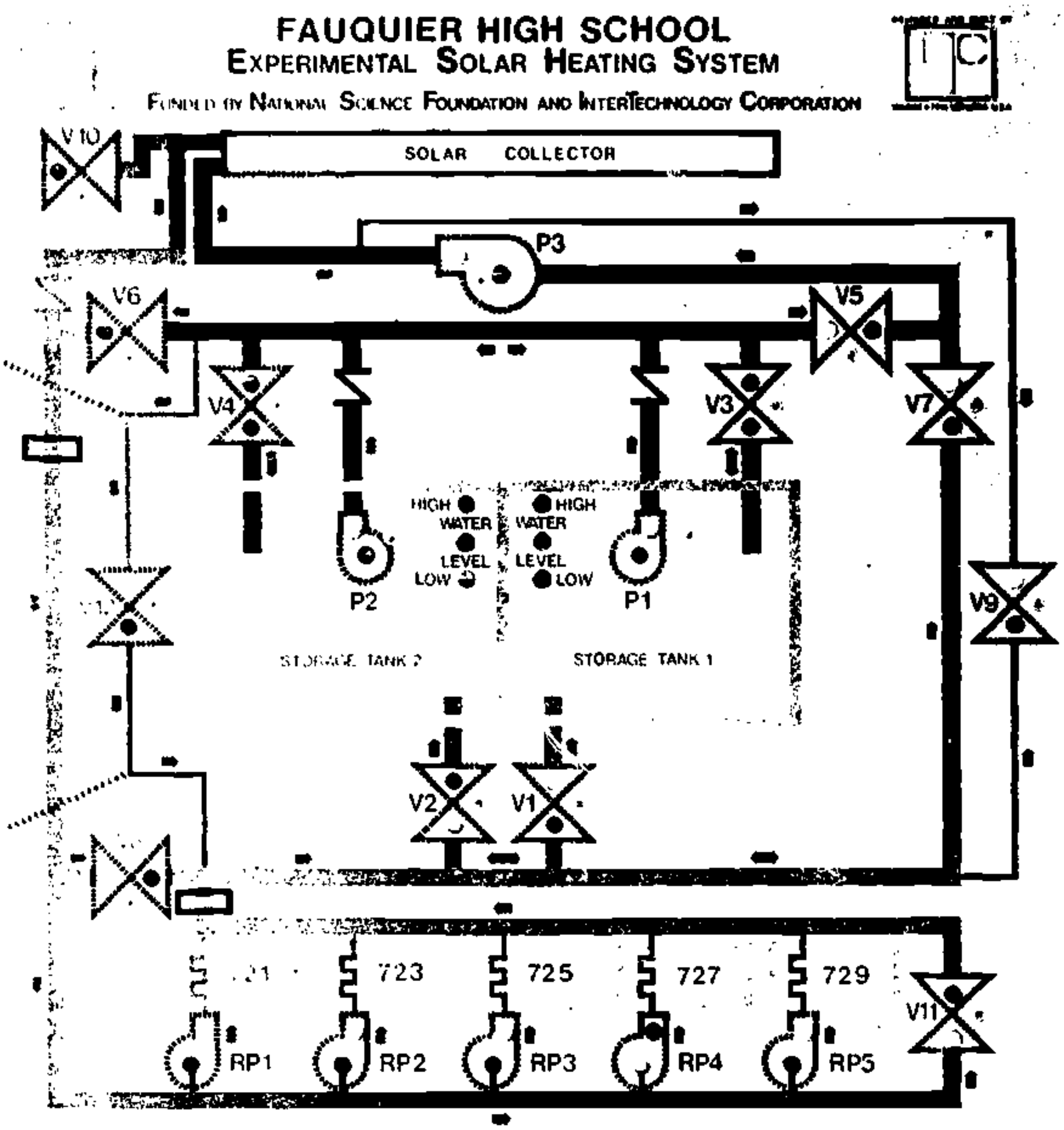
      1) Single and double glazing

         Temperature measurements are made on single and double-glazed collector runs to determine the effectiveness of the second layer of glazing.

      2) Plates

         Two collector runs are instrumented with seven thermocouples on each of the three plates in the run. The purpose is to determine the temperature and flow distribution on the plates and the performance of the selective coating (Figure 12, location 21, 22, 23).

FIGURE 13



CONTROL SYSTEM SCHEMATIC

3) Piping runs

Piping runs are equipped with thermocouples at several points to determine the heat losses in the piping systems. Two insulation materials were used in the underground piping. Thus, a comparison can be made between the two materials.

4) Tank

Three thermocouples are equally spaced vertically in Tank No. 1. The purpose is to determine the thermal stratification within the storage tank. The average of these three temperature measurements can be used to estimate heat losses through the walls of the tanks.

5) Anemometer

Measurements of the wind direction and velocity are taken to assist in determination of the convective loss component during collector operation.

4. Automated control instrumentation

a. Start-up and shut-down

The system will turn-on and continue operation as long as the preselected plate temperature is 10°F higher than the water temperature in either tank. Classrooms will receive heat when called for by pre-set day-night thermostats when the plate temperature is 100°F or higher. The plate temperature is measured by a thermocouple, wired to the automated control box and to the data logger recorder.

b. Automatic drain

The system will drain from the collectors into the tanks when the plate temperature reaches 40°F. The plate temperature is measured and relayed as described in 4-a above.

IV. Construction

A. Thermal storage

Thermal storage is provided by two 5,500-gallon concrete transformer vaults purchased from the Smith Cattlegard Company of Midland, Virginia. The tank was modified to provide three access holes in the top of the tank--one 30-inch manhole with cover and two 8-inch diameter holes in diametrically opposite corners. Tank 2 has one 8-inch hole and one 12-inch hole. For more details, see Figure 14.

The transformer vault was placed below ground upon a 10-inch slab of concrete after covering the slab with two layers of pentaclorophenol-treated 2 by 12-inch boards and 4 inches of foamglass insulation. The transformer vaults are constructed in four sections as shown in Figure 15. The periphery of the tanks was insulated with 4-inch waterproofed polyurethane from C. E. Thurston & Company. The polyurethane insulation was protected by a layer of pentachloraphenol-treated 2 by 12 inch boards. The 2 by 12's extended above the ground level. The top of the tank was insulated with waterproofed polyurethane and 2 layers of pentaclorophenol-treated 2 by 12-inch boards.

B. Collector support structure

1. Footings

Full length, steel reinforced concrete footings were poured for the front and back pipe supports. Two pairs of holes were cut in the support pipe 90° apart. A 12-inch section of reinforcing steel was inserted in each pair of holes with the ends bent to insure that they would stay in place. This reinforcing steel was at ground plus 3 inches and ground plus 15 inches. The front footings had 2 1/2-inch diameter pipe driven into the ground and 24 yards of

FIGURE 14
THERMAL STORAGE TANK

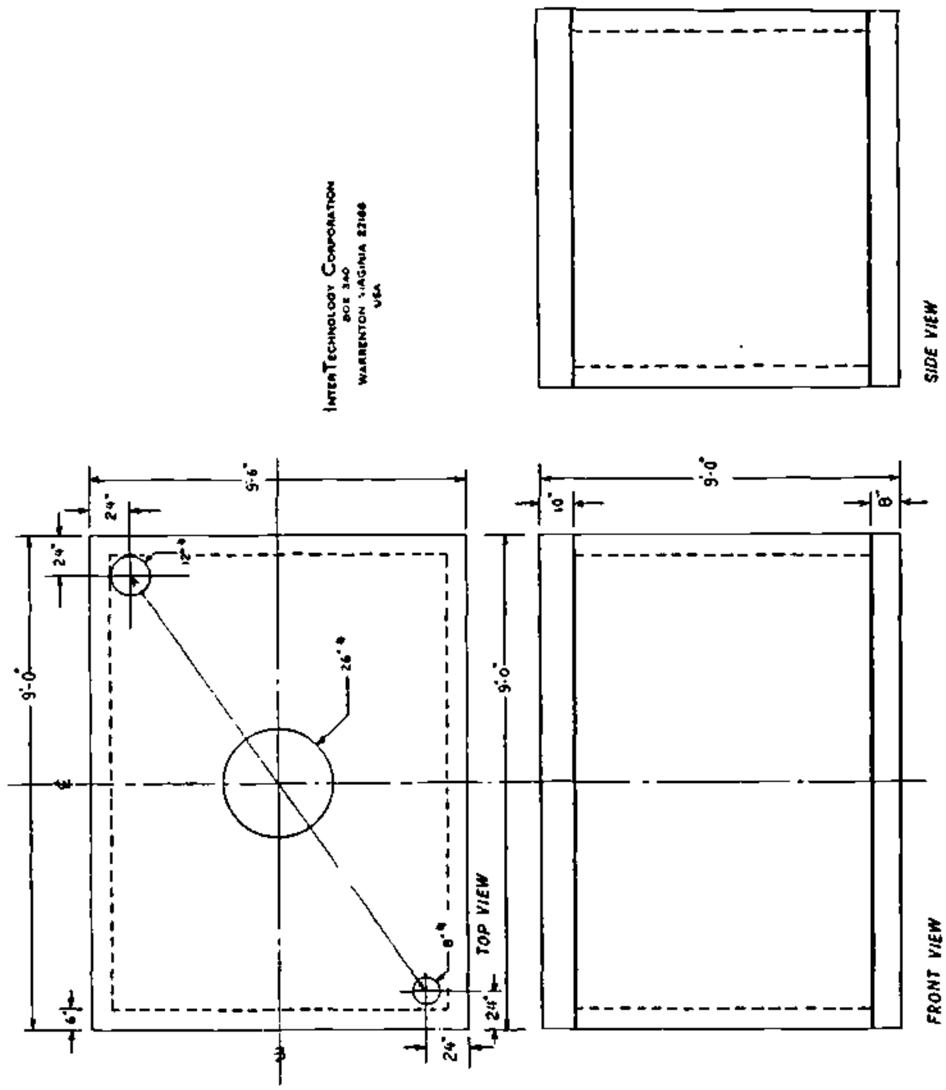
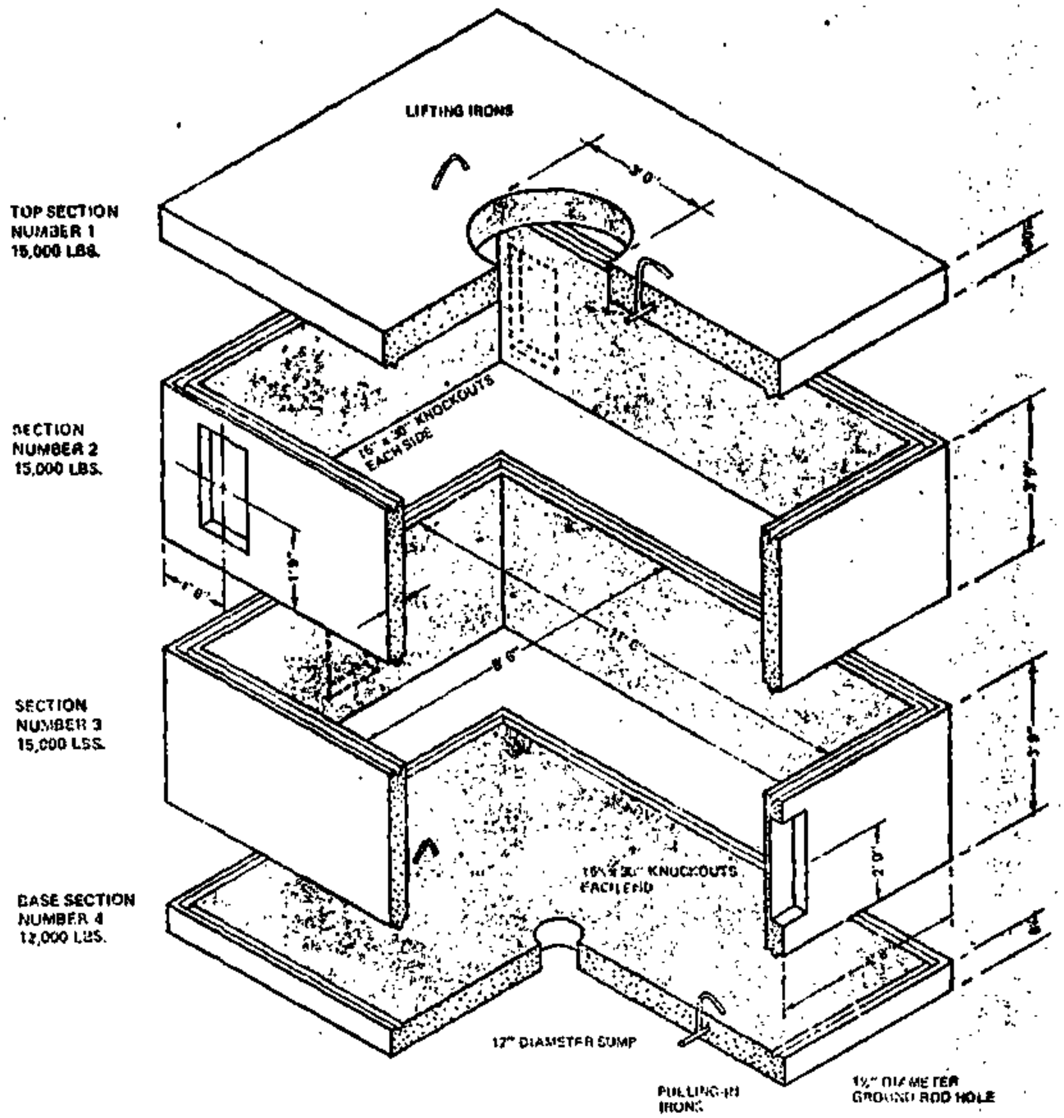


FIGURE 15



PLEASE USE MODEL NUMBER WHEN ORDERING.

IF KNOCKOUT LOCATIONS ARE TO BE CHANGED FROM STANDARD, PLEASE SUPPLY WORK SHEET WITH ORDER SHOWING DESIRED LOCATIONS.

[illegible] UNLESS OTHERWISE INSTRUCTED

UTILITY VAULT	ERSI SST
INSIDE DIMENSIONS 8'6" x 11'6" x 7'6"	
MODEL NUMBER 1290	

concrete poured into the ditch. The back footings used 3-inch pipe driven into the ground and 21 yards of concrete poured into the ditch.

The center footings were installed by drilling 14-inch diameter holes, driving 3-inch diameter pipe (with reinforcing steel as explained above) and the hole filled with prepared redimix concrete.

2. Collector face

   The 3-inch pipe tops were trimmed to eliminate the uneven edges from the pipe driving operation and 2 1/2-inch pipe inserted in excess of the height required for the base structure.

   The collector face was established by a longitudial length of 2 by 2 by 1/4-inch angle iron at the front and back pipes. Cross bracing was provided by welding 3 1/2 by 3 by 1/4-inch angle iron to the pipe to provide additional support. One quarter-inch holes were burned on the collector face planes to facilitate the bolting of the 2 by 8-inch girts to the angle iron. The girts were placed on 2-foot center lines perpendicular to the 3 by 3 1/2 by 1/4-inch angle iron face. One half-inch A/C exterior grade plywood was then nailed to the 2 by 8-inch girts. A layer of 60 pound roofing paper was installed to provide a waterproof layer under the collector boxes.

3. Collector ends and back

   Three eighth-inch bolts were welded to the pipes at 2-foot centers. Two by fours were bolted to these bolts to provide a nailing base to close in the structure. One half-inch A/C exterior plywood was used to close in the building.

4. Flashing

Sheet metal was installed at the wood junctures and the water line and pipe openings in the collector face.

C. Collector modules

1. Box

The collector box was made from plywood and fir. All joints were secured with galvanized nails and waterproof glue. The boxes were painted with one coat of commercial grade sealer and two coats of exterior grade latex paint. Three inches of Spin-Glas Board were lightly bonded to the bottom of each box. The aluminum collector plate was placed on the aluminum face of the Spin-Glass Board and held down with wooden blocks, nailed to the sides of the box.

2. Plate

The collector plate was manufactured by Olin Brass, East Alton, Illinois in accordance with ITC design requirements. The tube and header design of the 36 inch by 92 inch plate is considered proprietary to ITC. Several plates were hydrotested by Olin Brass and found to fail at approximately 250 psi prior to installation. A selective coating was applied by a chemical etch process.

3. Box assembly

Center glass supports were provided by 1 by 1 by 1/16-inch aluminum tee bars. Glass was installed on a 3/8-inch wide Tremco tape and caulked in place with Tremco mono elastomer. A 24-hour waiting period was required between the glazing layers to allow degassing of the elastomer. A minimum of 1/8-inch gap at all edges was allowed for expansion of glazings. Approximately 3/4-inch was allowed for longitudial expansion of the collector plate. Coupling between boxes was made by use of Gates 3/4-inch heater hose, and the final assembly was made on site. Installation of boxes required three configurations--top, bottom and middle. The middle section was sent to the site unglazed. Glazing was applied in place after the run was connected.

4. Collector assembly

   Three boxes are connected end-to-end to make up a collector run. This provides 69 square feet in a run. Boxes are connected to the lower header by use of 3/4-inch heater hose and a 3/4-inch ball valve. Valves were installed at both ends of the run for ease in maintenance. Flow meters were installed between each upper box and header. The flow meters are used to both measure and balance the flow in the runs.

D. Plumbing

1. Storage to collector

   Two-inch, schedule-40 pipe was used throughout this portion of the system. The piping from storage to the collector is underground and insulated with 1 1/2-inch foamglass, installed by Johns Manville. Aboveground insulation is 1 1/2-inch fiberglass insulation. Hoses were insulated with 3/8-inch Aerotube.

2. Storage to space

   Two-inch schedule-40 pipe was used for the primary piping, stepped down per Figure 4 at the rooms. Insulation to the first branch is 1 1/2-inch foamglass. The balance of the run is 1 1/2-inch polyurethane, with a waterproof coating similar to that used on the storage tanks.

3. Storage manifold

   The storage manifold is made up of 2-inch, schedule-40 pipe, as shown in Figure 3.

4. Pumps

a. Primary circulation pump

Bell & Gossett, series 15, Model 17T, 1 1/2 hp motor, 220 volt

b. Two immersible boost pumps

Becket, 150 M-Ht, suitable for pumping 200°F water, 1/2 hp motor, 220 volt

c. Five classroom pumps

Taco, Product No. UN110, 1/12 hp motor, 115 volt

5. Space heating

Pumps, valves and controls are hidden in all but one case in cabinets or space that was available in the rooms. Two Young model CH-85 convectors were installed in each room to balance the heating distribution. A 1/12 hp Taco Red Baron pump was installed in each room. A solenoid provides water control to the rooms and each convector is provided with a fan to aid in the heat transfer. The convectors are sized so that water temperature of 100°F can be used. The room schematic is shown in Figure 5.

V. System Performance

A. The solar heating system has demonstrated the ability to meet 100% of the heating load requirements of the classrooms since start-up on 19 March 1974. Since the sytem has not been tested during the more severe winter months of January and February only estimates can be made as to performance over the total heating season. Based on the data accumulated since start up the estimated cost of operation of the solar heating system electrical equipment using current electrical utility rates is approximately $50 for a complete heating season. This cost could be reduced by replacing the 1 1/2 hp primary circulation pump specifically selected to meet the actual pumping requirements of approximately 3/4 hp, and dispensing with the room pumps which are not essential.

B. For a fixed geometry of the flat plate solar collector, its heat collection efficiency is a function of the following variables:

1. Solar flux on horizontal surface
2. Amount of cloud cover. This affects the direct and diffuse components of incoming solar radiation.
3. Effective absorptance--transmittance product for solar radiation
4. Emissivity of collector plate for long wavelength radiation
5. Transmittance of cover plates for long wavelength radiation and the number of cover plates
6. Inlet temperature and physical properties of the working fluid
7. Temperature of ambient air
8. Speed of ambient air

C. The geometry of the collector plates is fixed by specifying their tilt angle from horizontal and the azimuthal angle. The ITC Solar Collector for Fauquier High School, Warrenton is tilted at 53° to the horizontal and faces south for maximum heat collection during the winter months.

D. Figures 16 and 17 show the theoretical instantaneous heat collection efficiency of the ITC designed collector. The following assumptions (based upon available data and measurements) were made in the theoretical model:

1. The effective absorptance--transmittance product is 0.7 and is independent of the angle of incidence. This product is based on the average over the wave lengths of the solar spectrum.
2. The emissivity of the collector plate for long wavelength radiation is 0.3.
3. The emissivity of the two cover plates for long wavelength radiation is 0.88.
4. The radiation falling on horizontal surface is treated as though all of it is beam radiation. This is a reasonable approximation on clear days because the scattering of solar radiation is mostly forward scattering on clear days.
5. The sky temperature is the same as ambient temperature during the daylight hours.

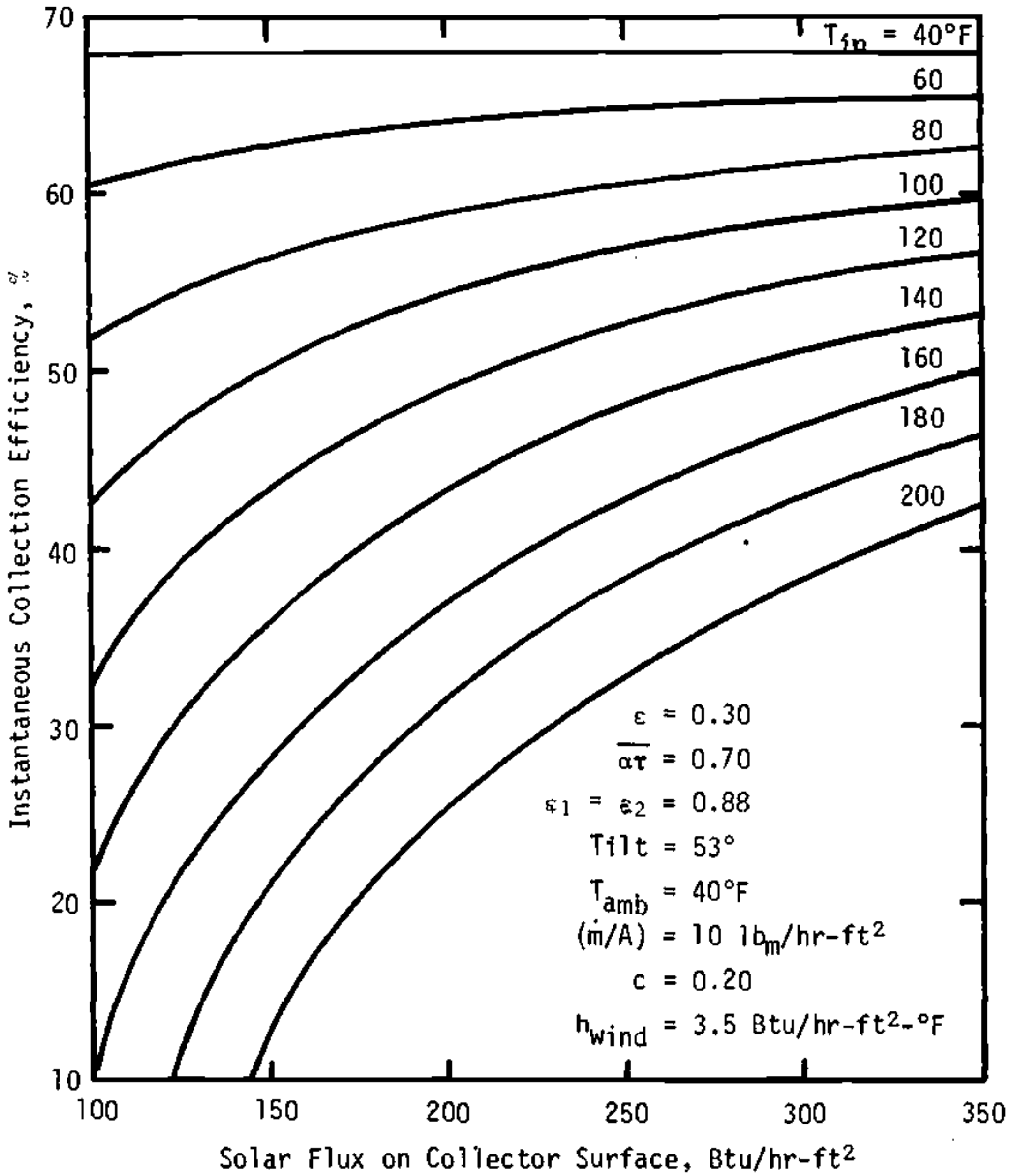


FIGURE 16 VARIATION OF INSTANTANEOUS EFFICIENCY WITH SOLAR FLUX FOR CONSTANT INLET TEMPERATURE

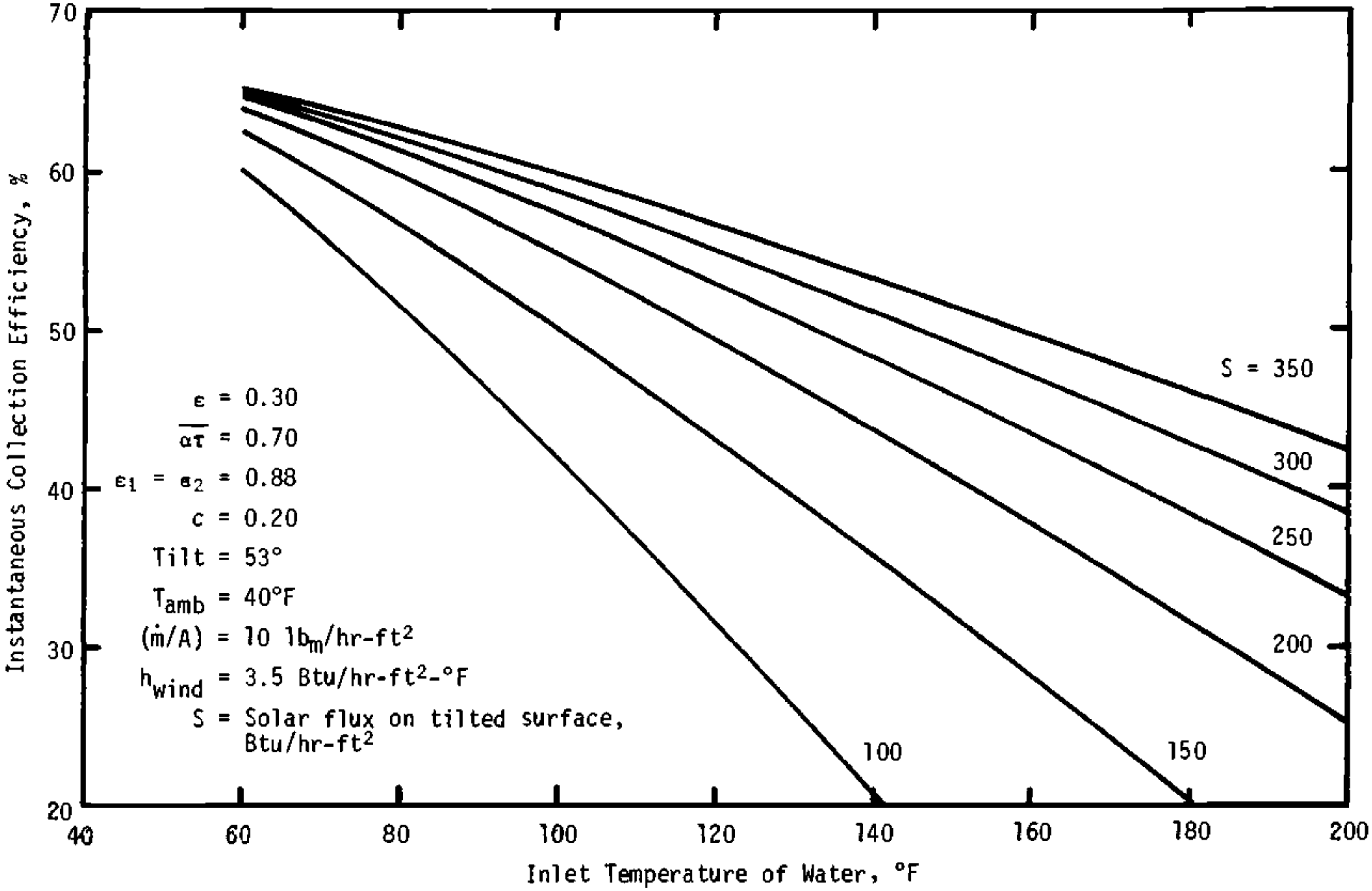


FIGURE 17 VARIATION OF INSTANTANEOUS EFFICIENCY WITH INLET TEMPERATURE FOR CONSTANT SOLAR FLUX

E. Figure 18 is a plot of the overall collector heat loss coefficient as a function of the collector plate temperature for the conditions mentioned with the curve. Figure 21 is a comparison of the experimental instantaneous efficiencies of ITC solar collector with the theoretical efficiencies. The theoretical efficiencies were obtained from the following equation:

$$\eta = F_R \left[\overline{\alpha\tau} - U_L \, (T_p - T_{amb})/S \right]$$

with $F_R = 0.96$ and $\overline{\alpha\tau} = 0.7$ and U_L values were obtained from Figure 3 corresponding to the average temperature of the collector plate. All the points on Figure 19 should ideally lie on the 45° line. Figures 20, 21, and 22 are the experimental data plots of ITC solar collector. Each plot is accompanied by a summary of the performance on the particular day. For the performance data plots on 20, heat balance calculations are also given on the accompanying sheet.

VI. Problems Encountered and Solutions

A. Thermal Storage

Upon initial filling of the 2 storage tanks the Number 1 Tank was found to leak as much as one foot per day. Subsequent draining and caulking the tank joints with Devcon epoxy slowed the leak enough so that the system could operate but leakage of 1 to 2 inches per day persisted. Tank Number 2 did not leak at temperatures below 140°F, but when that temperature was exceeded, leakages of 6 to 12 inches per day were observed.

The Number 1 Tank was emptied and the sides and bottom coated with a Devcon epoxy sealer. The tank did not exhibit any leakage at ambient

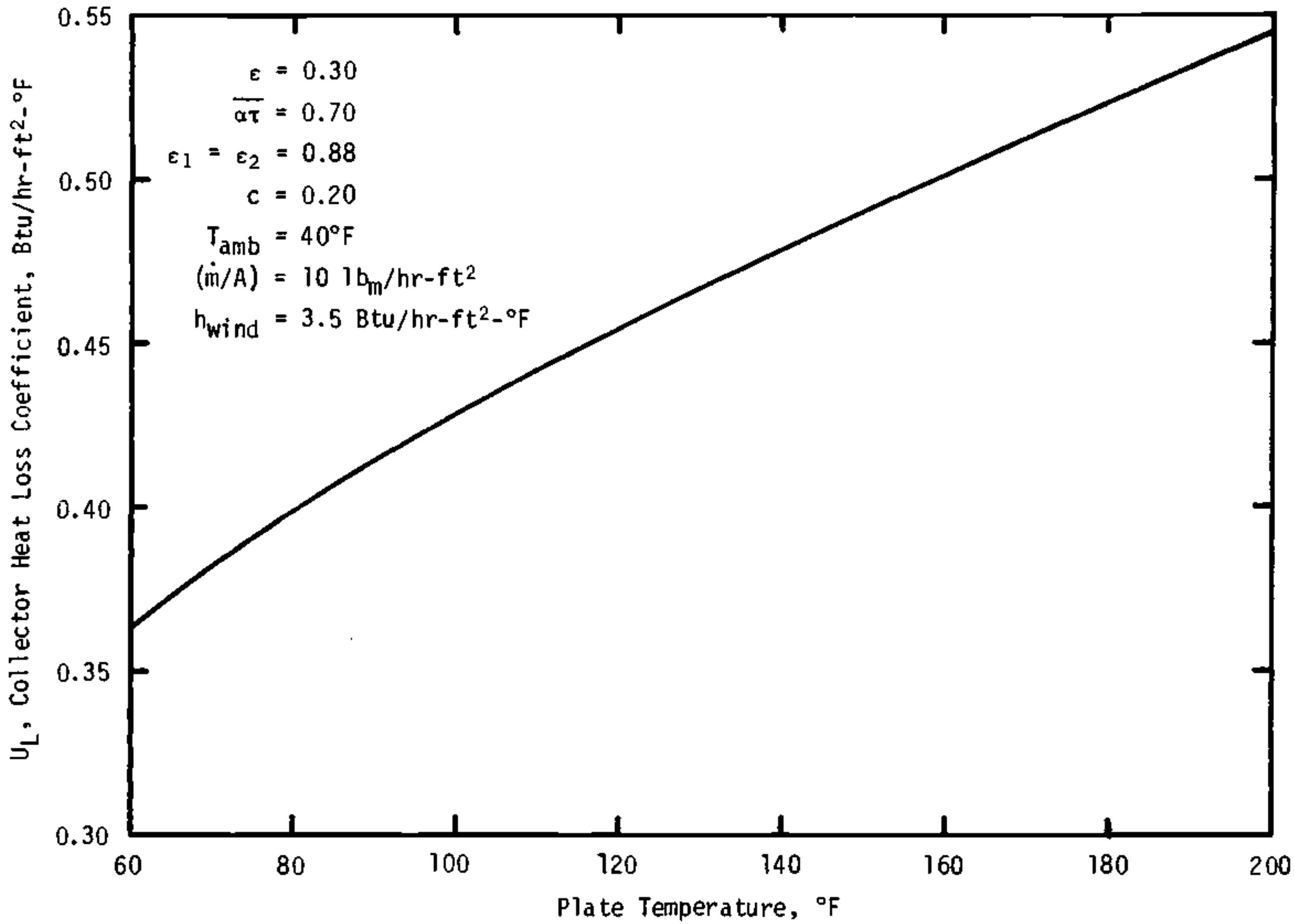


FIGURE 18 THEORETICAL HEAT LOSS COEFFICIENT

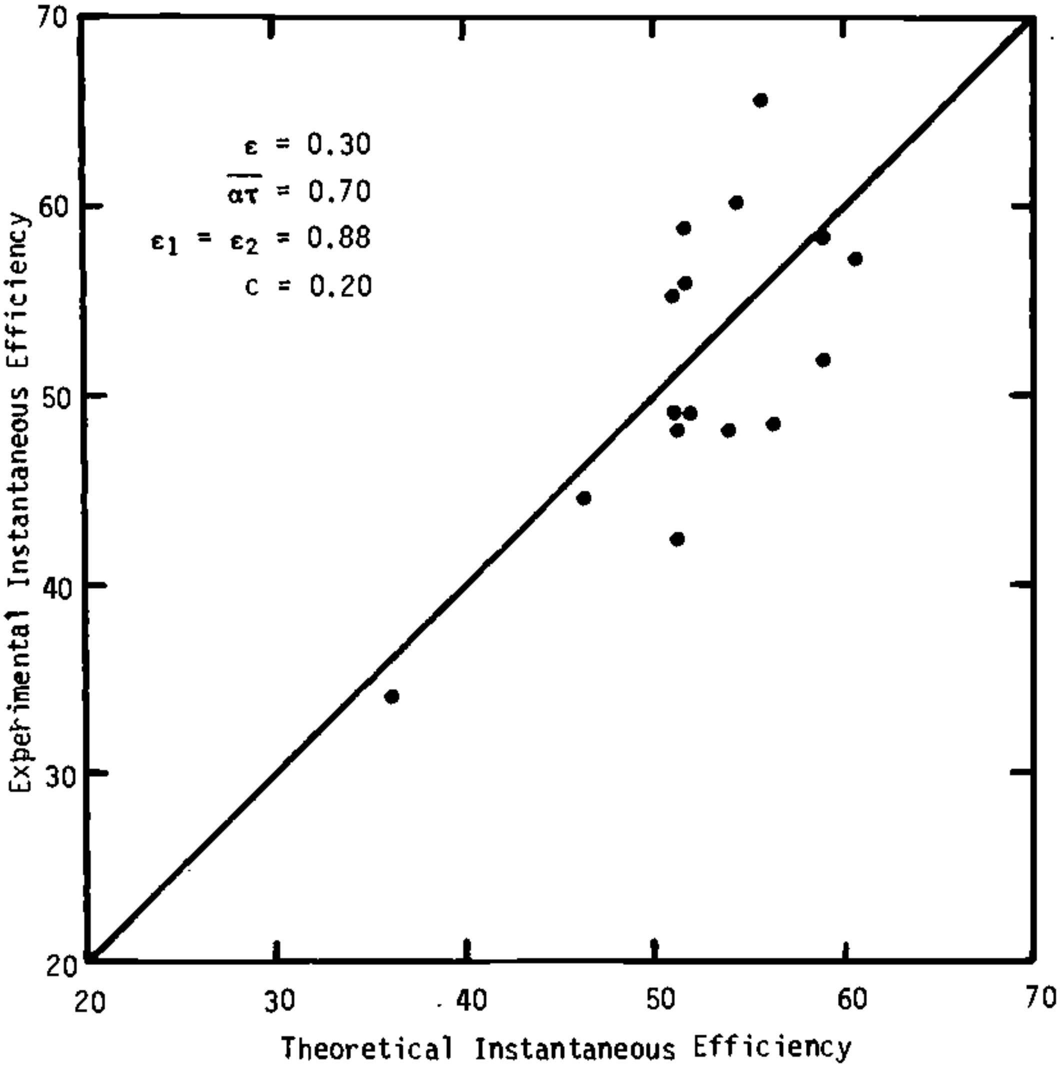


FIGURE 4.19 COMPARISON OF EXPERIMENTAL WITH THE THEORETICAL EFFICIENCIES

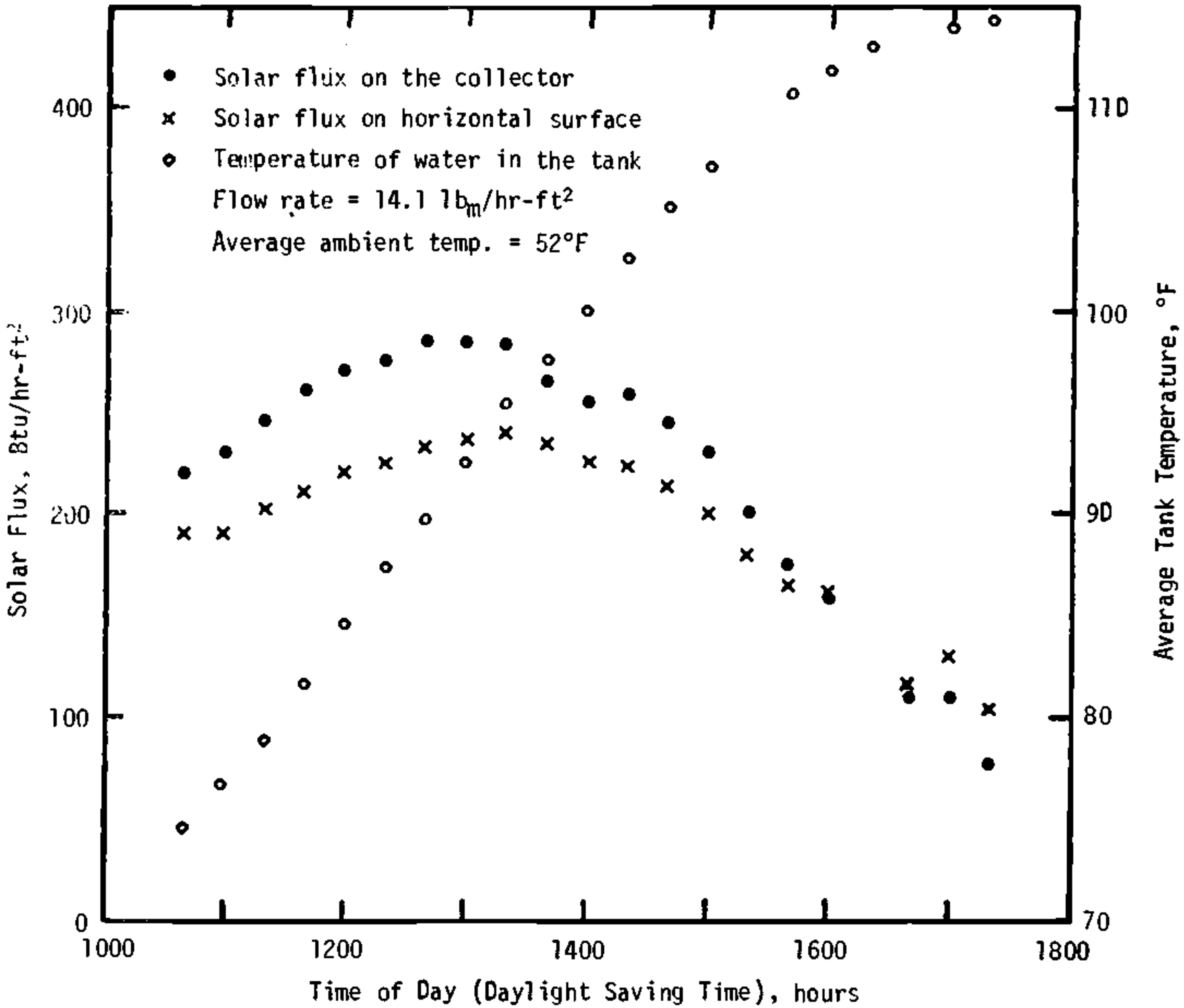


FIGURE 20 ITC COLLECTOR PERFORMANCE ON MARCH 26, 1974

SUMMARY OF ITC SOLAR COLLECTOR PERFORMANCE
ON MARCH 26, 1974 FROM 1040 TO 1720 HOURS:

Average inlet temperature	= 94°F
Average ambient temperature	= 52°F
Mass flow rate of water	= 14.1 lb/hr-ft^2
Solar energy incident on the collector	= 1450 Btu/ft^2/day
Total collector area	= 1914 ft^2
Total solar energy incident on the collector	= 2.77 x 10^6 Btu/day
Temperature rise of water in the tank	= 39.8°F
Mass of water in the tank	= 37600 lbs
Heat capacity of water storage tank	= 5000 Btu/°F
Total heat collected	= 1.70 x 10^6 Btu/day
Heat collection efficiency over the whole day	= 61.4%

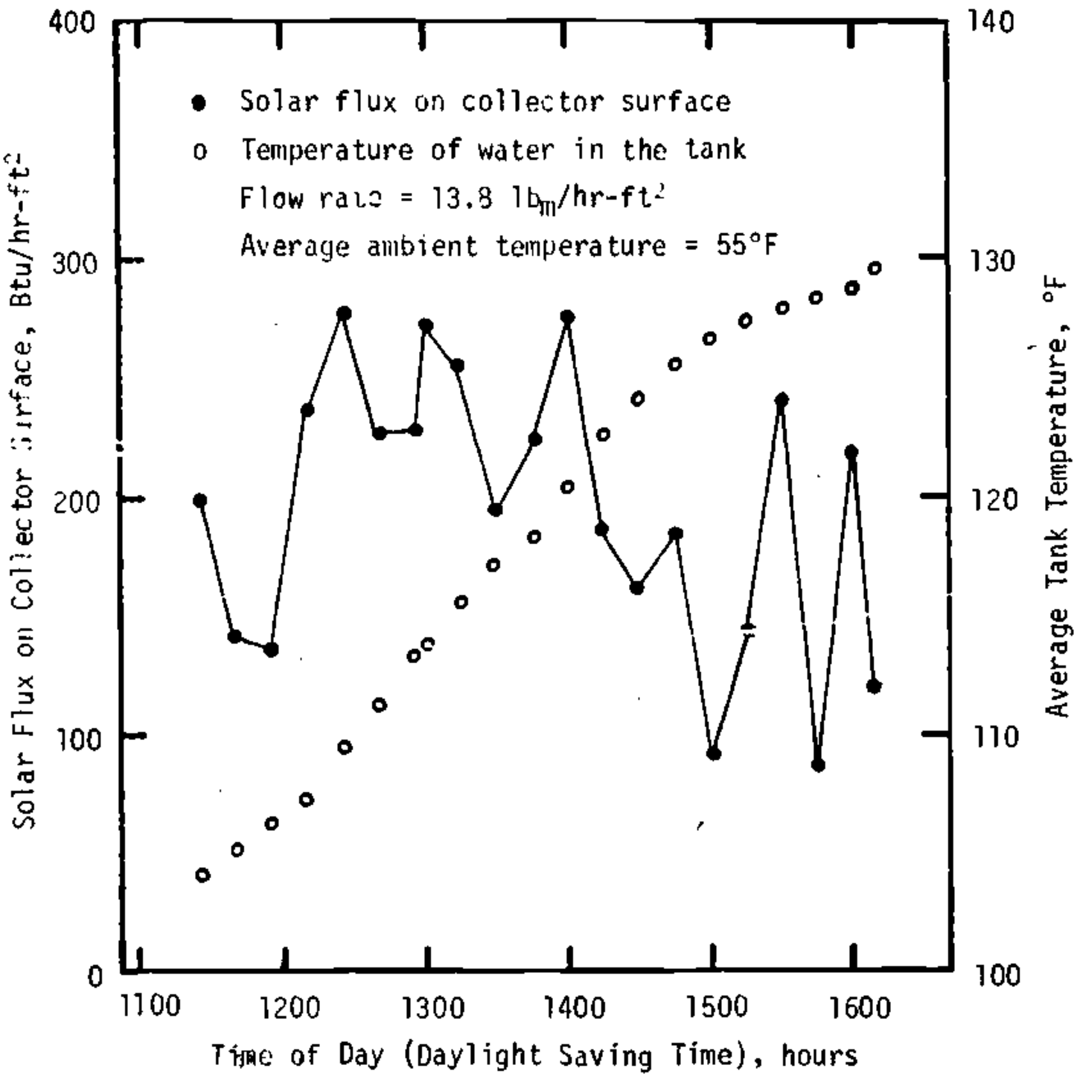


FIGURE 21 ITC COLLECTOR PERFORMANCE ON MARCH 27, 1974

SUMMARY OF ITC SOLAR COLLECTOR PERFORMANCE
ON MARCH 27, 1974 FROM 1125 TO 1610 HOURS:

Average inlet temperature	= 117°F
Average ambient temperature	= 55°F
Mass flow rate	= 13.8 $lb_m/hr\text{-}ft^2$
Solar energy incident on the collector	= 900 $Btu/ft^2/day$
Total collector area	= 2244 ft^2
Total solar energy incident on the collector	= 2.02×10^6 Btu/day
Temperature rise of water in the tank	= 25.4°F
Mass of water in the tank	= 37600 lbs
Heat capacity of water storage tank	= 5000 Btu/°F
Total heat collected	= 1.08×10^6 Btu/day
Heat collection efficiency over the whole day	= 53.4%

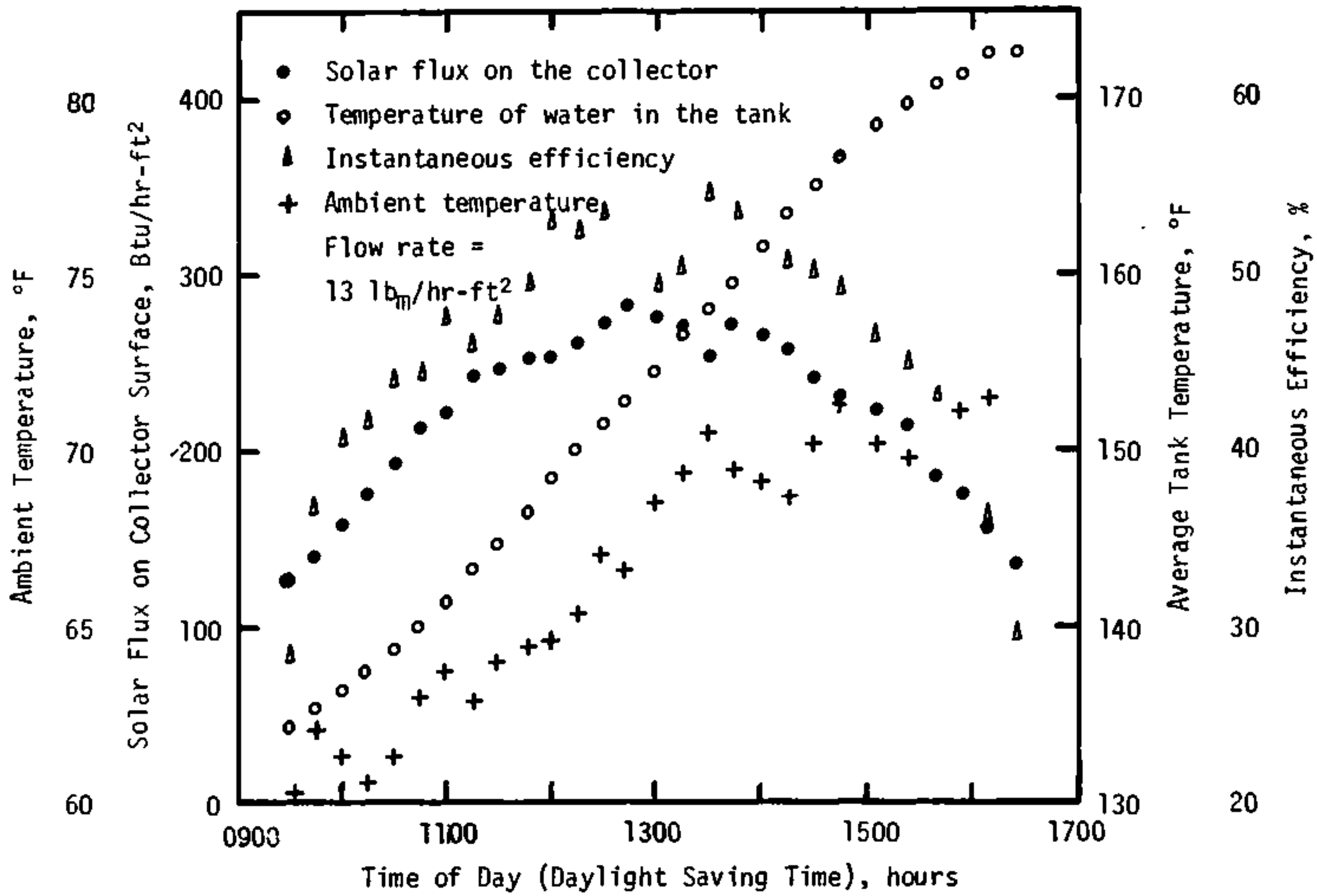


FIGURE V22 ITC COLLECTOR PERFORMANCE ON APRIL 18, 1974

SUMMARY OF ITC SOLAR COLLECTOR PERFORMANCE ON APRIL 18, 1974 FROM 0930 TO 1626 HOURS:

Average inlet temperature	= 153°F
Average ambient temperature	= 66°F
Mass flow rate of water	= 13 lb/hr-ft^2
Solar energy incident on the tilted surface	= 1520 Btu/ft^2/day
Total collector area	= 2415 ft^2
Q_i = Total energy incident on the collector	= 3.67 x 10^6 Btu/day
Temperature rise of water in the tank	= 38.4°F
Mass of water in the tank	= 42600 lb_m
Heat capacity of the water storage tank	= 5000 Btu/°F
Q_c = Total heat collected	= 1.83 x 10^6 Btu/day
Heat collection efficiency over the whole day	= 49.8%

Time integration of water flow rate times the instantaneous change in water temperature gives total heat input to the tank to be = 1.74 x 10^6 Btu. Ideally this should equal Q_c but differs from it by 5%.

temperatures. Upon running the system and reaching a temperature of 140°F, the tank started leaking at the rate of Tank Number 2. This leak did not seal off at the lower temperature as Tank Number 2, but continued to leak. It appears that thermal expansion of the tank is causing the leaking condition. Had we used a butyl seal, we would not have encountered this problem.

B. Condensation

Some condensation has been noted to appear between the layers of glazing. No attempts were made during construction to provide a dry atmosphere. As the plates heat up the condensation disappears. Condensation has produced no measurable effect on system performance.

C. Space Heating

The original design for space heating had the following elements:

1. Circulating pump
2. Circulating fans controlled by water temperature

   When operating the collector, water was forced into the rooms, through the non-rotating pumps and effectively negating the off thermostat. As the water pipes heated, the circulating fans were activated and the rooms heated independent of thermostat settings.

   To alleviate this problem, the room flow meter fittings were removed and solenoids were installed. The solenoids were coupled with the pump-thermostat controls. This effectively controlled the heat input into the rooms, however, control of the circulating fans remained a problem. The inexpensive aquastat controls apparently lacked sensitivity and would not start or stop automatically at a constant temperature. This was remedied by coupling the circulating fan to the pump-thermostat controls.

D. Glass breakage

Glass breakage has been minimal, only one act of vandalism has occur-red. Three panes were broken in the installation process and four panes have been broken by unknown causes.

VII. Total System Cost

The approximate cost for engineering design, fabrication of collector modules, construction, and operation through 15 May 1974 are shown below. An attempt has been made to show as separate cost elements the cost of major components of the system.

A.	Labor and materials	
1.	Engineering, design & supervision	$123.000*
2.	Construction, labor	51,000
3.	Materials	40,000
4.	Controls and instrumentation	
	a. Experimental	15,000
	b. Operational	4,000
5.	Plumbing components	
	pumps. valves, room convectors	5,000
6.	Major subcontracts, labor & materials	
	a. Welding	5,000
	b. Electrical	6,000
	c. Plumbing	5,000
	d. Insulation	10,400
	e. Collector	13,200
7.	Miscellaneous equipment & supplies	23,000
8.	Total	$297,137**

* approximate figure

** final figure

B. Estimated cost for major components of the system

1.	Collector support structure, labor and materials	$80,000
2.	Collector modules, 105 units installed plus prototype test units and spares	41,000
3.	Storage tanks (2) installed	11,000
4.	Control room/pump house labor and materials	3,000

The cost of a second system of equal heating capacity but without the controls and instrumentation required for experimentation and data collection would be approximately $60,000. The significant cost reduction compared to the total cost of this system is based on the following assumptions:

a. Engineering design would not be required;

b. Learning experience would certainly reduce construction and collector fabrication cost;

c. Premium overtime pay would not be required;

d. Expensive substitution of components and equipment would not be required, and performance would be improved;

e. The collector assembly would not have been installed in a single plane; and

f. Reflectors could be utilized to enhance the system performance.

IX. Conclusions

Since start up on 19 March 1974, the overall performance of the Fauquier High School Solar Heating System has proven that solar heating can readily and conveniently be incorporated into existing public schools as the primary source of heat. Although it is not anticipated that the system will be fully turned over to the school system for operation and maintanence until mid-1975, sufficient operating experience has been accumulated to indicate that existing school personnel will be capable of continued operation of the system without prolonged training. Based on the thermal performance of the heating system during the 1973-74 heating season, we believe all of the future heating requirements of the solar heated classrooms can be met with solar heat, except for unexpected down time for repairs and unusually severe winter conditions. There have been thus far no equipment failures which would have caused a shut-down.

The operation of the system during periods of hot weather and high insolation has demonstrated that storage temperatures as high as 180°F can be maintained during summertime operation without modification to the collector. Dry plate temperatures of about 350°F have been measured.

The system is, therefore, potentially capable of providing the hot water needed for absorption air conditioning.

In addition the system has demonstrated the ability to survive, without damage, prolonged exposure to summertime insolation conditions while completely shut down. This is a capability of definite importance since cooling and heat dumping by water circulation is both expensive and unreliable and the need for protection of large areas of solar collectors employing some form of covering is totally unacceptable from both reliability and cost standpoints.

Up to December of 1974, the solar system has provided <u>all</u> of the heat for the 5 classroom buildings, except for one day, due to local flooding conditions on 2 December 1974. The maintenance problems thus far have been minor and have required only readily available, routine skills.

Indeed, the economics of a school solar heating installation ITC extrapolaters, under conditions of mass production and on a larger individual scale, to be about $7.50 per square foot of collector and $3.20 per million Btu <u>delivered</u>.

A comparable heat cost for No. 2 fuel oil would be about $4.50/million Btu delivered at present oil prices (about 38¢/gallon). For electric heat, the cost is $3.00/million Btu delivered /1¢/kwh. At 4¢/kwh this is about $12/million Btu delivered. Electricity and fossil fuels can only cost more in the foreseeable future.

Our school experiment has verified predictions of maintenance problems and frequency based upon neither combustion nor fuel pumps nor fuel tanks, etc. We can say categorically that maintenance of the mechanical equipment will be markedly less in down-time and in total cost for solar as compared to combustion systems. ITC estimates maintenance costs to be less than 1/4th of those for combustion systems, and down time due to equipment failure to be about 1/10 of that for combustion systems.

Still further, no new skills are required for such maintenance personnel.

APPENDIX A

LAW ENGINEERING TESTING COMPANY
Geotechnical and Materials Engineers
WASHINGTON, D. C., OFFICE
P. O. DRAWER QQ / 7913 WESTPARK DRIVE / McLEAN, VIRGINIA, 22101 / (703) 790 5700

January 31, 1974

Inter Technology Corporation
Post Office Box 340
Warrenton, Virginia 22186

ATTENTION: Dr. G. C. Szego, P.E.
President

SUBJECT: Soils and Foundation Site Inspection Report
Solar Collector
Warrenton, Virginia
Your Job No. C-853
LETCO Project No. W-4-647

Gentlemen:

Law Engineering Testing Company is pleased to have assisted you with the Soils and Foundation Inspection for the Solar Collector, Warrenton High Scoool, Warrenton, Virginia now under construction.

Due to the accelerated pace for the construction of this facility our Soils and Foundation Inspection was limited to a brief examination of test pits and site conditions, prior to pouring, by one of our senior soils engineers.

We understand that the Solar Collector will be founded on a fill slope standing at about 20°. We have been informed that the fill was placed as recently as one year ago with the majority of the fill being approximately 11 years old. The Solar Collector will be placed at an angle of 53° with the horizontal. The dimensions of the collector are 126 feet by 15 feet 6 inches. The major dimension will be normal to the dip of the slope.

The Solar Collector will be supported by 88 columns on a grid of 6 feet longitudinally by 5 feet 2 inches in its minor length as shown on the attached sketch. Two long strip footings, 2.5 feet in width and 10 inches in depth, will support the 22 uppermost and lowermost columns of the Solar Collector. The remaining 44 central columns will be supported on three feet diameter short caisson type footings.

We were also informed that the dead weight of the Solar Collector is 50 kips, the total weight of the footings 136 kips, and the live load is estimated conservatively to be 50 kips, normal to the collector.

Under normal circumstances a soils and foundation evaluation would have required the drilling of several test borings a minimum of 5 to 10 feet below proposed foundation levels. During drilling operations undisturbed soil samples would have been recovered for testing in our soils laboratory. Groundwater levels would have been determined and Standard Penetration Tests would have been performed to obtain an index to soil strength and density.

Our soils engineers would have evaluated all data collected and made appropriate soils and foundation recommendations with emphasis on soil bearing capacity, groundwater problems and slope stability analysis results. This information would have been used to design the foundations.

Due to time restrictions on your construction schedule, the above steps were not taken. Our senior soils engineer made evaluations and recommendations based on a very limited amount of data. This judgement was the best available under the circumstances. We, obviously, cannot assume responsibility for unforeseen occurrences caused by subsurface conditions that are unknown at this time.

Our soils and foundation inspection can be summarized as follows:

1. Four test pits were dug to proposed foundation levels at various locations as shown on the attached Test Pit Location Plan.

2. Fill was noted only in Test Pits Number 2 and 3. The results can be summarized as follows:

Test Pit No.	Thickness of Fill (Feet)	Description of Virgin Material	Total Depth of Test Pit (Feet)
1	None noted	Reddish brown SILT, trace of fine sand, some decomposed shale, red and black mineral staining; dry	5.0
2	1.5 to 2.5	Same as above	6.0
3	0.5 to 1.5	Same as above	6.0
4	None Noted	Same as above	5.0

3. Pocket Penetrometer Tests were performed at the bottom of all Test Pits. In all cases unconfined compression strength estimates were in excess of 1.0 TSF. This indicates that the soil bearing capacity will be adequate for the expected 200 psf footing pressure.

4. Verbal recommendations were given to Inter Technology personnel at the site indicating that:

   a. Proposed footings should be founded on virgin material similar to that described in No. 2 above, to avoid risk of differential settlement.

   b. The bottom of the footings should be founded a minimum of 24 inches below finished grade in order to minimize the risk of frost heave.

   c. Fill material encountered in the Test Pits dug is unsuitable to support the proposed foundations.

We appreciate the opportunity to have been of service to you, and hope to remain your soils consultant in future projects.

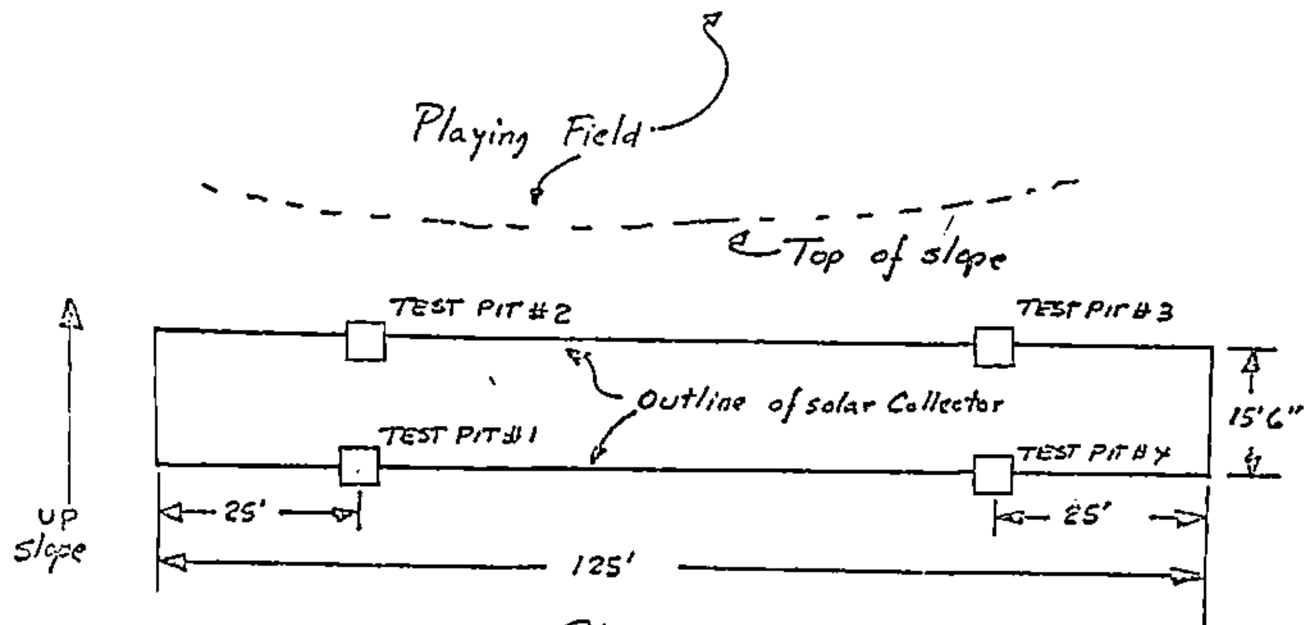
Very truly yours,
LAW ENGINEERING TESTING COMPANY

Vukoslav E. Aguirre
Vukoslav E. Aguirre, P.E.
Senior Soils and Foundation Engineer

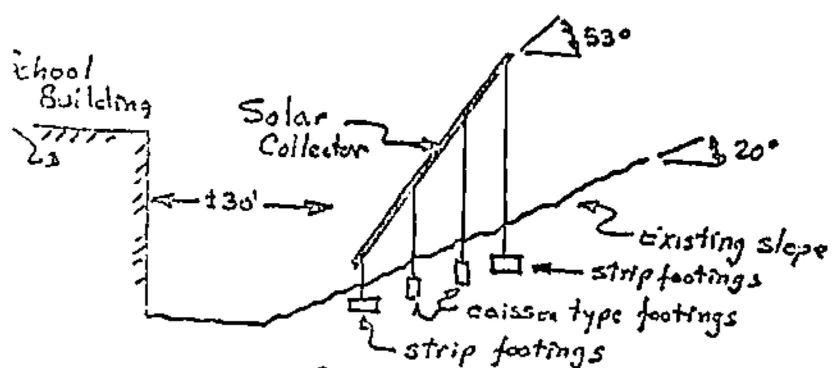
Ralph E. Brown
Ralph E. Brown, Ph.D., P.E.
Chief Engineer

Enclosure

VEA/ab



Plan View



Cross Section

TEST PIT LOCATION PLAN
Solar Collector
WARRENTON, VA.
LETCO JOB No. W-4-647
JAN 29, 1974
LAW ENGINEERING TESTING COMPANY

APPENDIX B

AUTOMATED CONTROL SYSTEM

The ITC solar heat controller is essentially an assemblage of solid state analog electronics, solid state logic, and relay logic for power switching. Its purpose is to employ certain select inputs either probe-sensed or manually initiated, and use them to cause a logic matrix to select certain electro-mechanical devices and operate them. The system operates automatically except when overridden and controlled by the operator.

Located on the controller are a main power switch, a +5 VDC logic supply switch, a 12 VDC relay supply switch, a mode control keyswitch, a throttle/mode simulation switch, and a throttle pushbutton.

On the bottom center of the controller front panel is located the main power switch. All power supplied to the circuitry power supplies is controlled by this switch. When it is in the off position all circuits in the unit are dead.

At the bottom right of center on the controller front panel are the sensor supply switches. The leftmost switch controls power to the +5 VDC supply which in turn supplies power to subminature logic relays on the sensor chassis and associated indicator lamps. That on the right controls power to the ± 15 VDC supply which goes to the analog circuitry in the sensor chassis.

Between the display supply lamps is the lamp test switch. Pressing the switch toward the left causes all of the lamps on the left of the display board to light. Pressing the switch to the right lights all of the righthand side of the display board. This function enables the lamps on the display board to be tested even though the system is in operation. This is essential if some question should arise concerning the controlled condition of any of the functions represented on the display board.

The knob located below the lamp test switch is simply a dimmer control for all lamps on the display board. Turning it clockwise causes the lamps to glow at full brightness.

The keyswitch located at the right center panel of the controller will allow an operator to select either an automatic, a manual, or a manual service condition. In the center or automatic position, the temperature sensors control the system. In the manual position, the operator selects the functions to be actuated from toggle switches on the display board. The service position allows the operator to simulate an operating mode by depressing a rear panel pushbutton or allows individual throttling of valves.

Above the keyswitch is located a toggle switch which allows the operator when he is in the service position to select mode simulation and operate from the back panel or to select mode throttling which is accessible from the front panel.

To the right of the Service Select Switch is located the Throttle Switch. When the Service Select Switch is in the service position, this pushbutton controls the off-on flow of current to the motorized valves. To use the throttle, a valve must be commanded from the display board.

There are several displays on the controller front panel. There is a display lamp for each power supply voltage, ready conditions for heating, mode conditions, and temperature comparisons. There are also temperature meters, one for each tank and one for the collector array.

The main power supply chassis is located in the bottom position of the cabinet. It contains all of the power supplies for the operation of the remainder of the electronics in the unit except for the power relays.

The relay chassis is the center chassis in the unit. It contains all of the power switching relays for the system and the power supply necessary to drive those relays and relays elsewhere in the unit. It has on its rear panel the mode simulation pushbuttons.

In the Sensor Logic chassis are found probe amplifier cards, comparator logic cards, mode logic cards, summing amplifier cards, integrator cards, and indicators. It is responsible for taking probe temperature inputs and automatically generating control signals which place the system in some particular mode or modes of operation.

On the rear of the sensor chassis are found probe amplifier zeroing potentiometers, high-low set point potentiometers, collector dump set point potentiometer, integrator gain potentiometers, and meter zero potentiometers. In the rear of the relay chassis will be found the manual mode simulation pushbuttons.

Located on the Relay Chassis is a diode matrix tailored to the decision diagram for the system. With individual inputs representing the various modes, the proper valves and pumps are switched on by means of the power relays. These can be simulated by the pushbutton switches on the rear of the chassis.

There are two logic cards, *per se*, on the sensor chassis but an integral part of the decision-making process is also dependent upon the operation of the comparator cards and the other analog conditioning which precedes the sensing various temperatures within the system. The logic cards accept comparison decisions made in the analog portion and by the use of subminiature logic relays choose the appropriate operating mode for the system.

A companion unit in a sense is the Datel 210 data logger which includes its own printout and visual display. Its purpose is accurately to record many of the variables which determine system operation and efficiency. It is used as a check to determine that the controller is operating the system properly.

Mounted near the system controller unit is the system display board. It illustrates graphically and schematically the basic components of the solar heating system which are controlled by the electronics (see Figure 15).

Located on the display board are status lamps, two for each symbol or function which is controllable. One lamp is green, signifying a go, open or running condition. The red lamp beside each function indicates a no-go, closed, stop condition of that particular function in which symbol it is located. There are twenty of these pairs of lamps on the board plus two sets of three lamps, each set of three showing a water level condition in a tank. There are two reds for the two high water level conditions, two greens for the two satisfactory water level conditions, and two reds for each low water level condition in a tank. Therefore, there are two reds and one green light for each tank.

For each power supply in the electronics there is a lamp displaying the presence of an operating voltage. There is a lamp signifying presence of an AC input to the unit, and a status lamp, green for a system containing sufficient heat to perform its duties, or amber for a system too cold at the moment to supply heat. There is a green light for each individual mode of normal operation. There are lamps showing the outcome of the temperature comparisons made in the sensor chassis and a temperature display showing the temperature relationship between Tank 1, Tank 2 and the control plate.

Near each controlled function shown on the display board is a toggle switch. When the system is in the manual or service operation they are effective in setting a condition of operation for each function. When in the service position the "select" toggle switch must be in the "valve control" position for the toggle switches on the display board to function. By pushing a display board toggle switch toward a red or green lamp the condition represented by that lamp will be implemented. That lamp will be lighted when that condition is effected. On motorized valves, both display lamps will light on a function when a valve is in transit between conditions. In the service toggle position, a motorized valve can transit only when a display board toggle switch is pushed and the valve throttle button is depressed.

Each symbol and some colors on the display board have a specific representation. All symbols labeled with a "V" and suffixed by a number are valves. All symbols prefixed with a "P" or an "RP" and suffixed by a number are pumps. The "Z" -shaped figures are check valves allowing flow only in the direction of nearby arrows. Small rectangles are flowmeters. Rectangles with "700" series numbers are classrooms and convectors. Lines connecting these symbols together are of three colors: green lines for water pumped from tanks or from the return loop; blue lines for all return water; and red lines for "sourced" water which is normally always hot. There are strings of arrows showing hook-up points for "make-up" and "drain" water lines.

Operating temperature range:	0° - 40° C
Probe Temperature range:	0° - 100° C
AC input from mains:	120 VAC ± 10%
Probe input range:	0 - 10 mv DC

The bulk of the electronics are contained in three chassis which are mounted in a relay rack. There is a power supply chassis which mounts at the bottom, a relay chassis which mounts in the middle and above the power supply chassis, a sensor chassis which mounts at the top of the rack and above the relay chassis.

The display board is mounted by the use of two door-type hinges and a padlock hasp. The board may be attached to the wall by leveling the board and screwing the hinges into the wall and attaching the hasp. The three cables must be routed so that they are accessible to those from the controller.

At the end of two wire bundles protruding form the rear of the power supply chassis are two connectors, one of which joins a connector from the relay chassis and the other joins a connector from the sensor chassis. From the relay chassis are connectors S3-S which join mating plugs coming from the wiring panel behind the access door in the corner above the operating consol. Three connectors mate with those attached to the display board. One connector mates with that connector remaining from the sensor chassis. The AC power cord from the power supply chassis is to be plugged into an outlet.

All sections of the electronics package are internally grounded so that no other grounding or ground bussing are needed unless there occurs some shock hazard or noise pick-up between the controller and other pieces of equipment in the system. If that should occur then ground strapping of the offending items to the controller power supply chassis are in order.

The only signals introduced into the controller at all externally are those generated by the thermocouple probes originating elsewhere in the system and the thermostats in the classrooms.

There are the three types of control for the system. The manual control is for the purpose of setting up the system function-by-function by use of the control board only. The service control is for the operator who wishes to either simulate an operating mode regardless of the conditions of the system, or to have manual control from the control board with the ability to throttle each motorized valve as it is employed. In the automatic control the controller takes over the system operation and is governed by the temperatures sensed at the external probes. Automatic control should only be used when there is no malfunction of the system or no special conditions exist which would exceed the logic abilities of the controller.

In manual mode all controlling is done by the operator by the use of the toggle switches on the control display board on the wall. The toggle switch is momentarily pressed toward the actuation state desired and the controller implements the command. In this way the system is set up on a step-by-step basis as the operator sees fit. He may change conditions of the various functions at any time this way even while the system is running.

The automatic mode leaves little for the operator to do. All conditions likely to be encountered by the system are dealt with by the controller. If conditions suitable for operation of the system are not present, then the system will shut down or not start up. The system performs the required functions for draining the system if freeze conditions exist or if the system becomes too hot.

The service mode was meant primarily for checking the controller for a sensor chassis failure, as an expedient in setting up an operating mode irrespective of the system temperature conditions, and for the purpose of throttling motorized valves open or closed to affect rate of flow in various pipes within the system.

APPENDIX C

Additional data for the period of 28 March through 26 April 1974.

The definition of symbols appearing on the data sheet are:

HR	Time of day
ST	Solar flux on the solar collector which is tilted at 53° and faces south, Btu/hr-ft^2
SH	Solar flux on horizontal surface, Btu/hr-ft^2
MDOT	Water flow rate, lb_m/hr-ft^2
TIN	Inlet temperature of water, °F
TOUT	Outlet temperature of water, °F
TAMB	Ambient Temperature, °F
EFFT	Theoretical instaneous efficiency
EFFE	Experimental instantaneous efficiency

****** MARCH 28, 1974, CLEAR DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
1111	222	181	13.2	128.3	135.9	54.3	0.490	0.418
1121	229	188	13.2	129.6	137.3	54.7	0.495	0.446
1131	232	192	13.2	130.5	138.6	55.8	0.497	0.461
1141	239	195	13.2	131.4	139.8	56.5	0.501	0.468
1151	239	197	13.2	132.6	141.3	56.5	0.497	0.478
1201	246	198	13.2	133.7	142.7	57.4	0.501	0.482
1211	244	200	13.2	134.8	144.1	57.6	0.497	0.507
1216	24[illegible]	199	13.2	138.5	144.7	58.6	0.498	0.497
1227	243	204	13.2	135.9	146.3	58.8	0.494	0.519
1237	242	206	13.2	135.0	147.8	59.5	0.491	0.530
1247	244	205	13.2	138.6	149.5	59.0	0.490	0.595
1255	251	208	13.2	139.6	149.5	59.4	0.492	0.522
1320	250	203	13.2	141.8	151.5	59.5	0.486	0.514
1330	238	204	13.2	142.9	151.5	62.1	0.480	0.479
1341	205	183	13.2	144.0	152.6	60.6	0.443	0.557
1351	235	205	13.2	145.0	154.2	62.8	0.473	0.516
1358	230	199	13.2	145.6	155.1	62.4	0.467	0.548
1406	227	196	13.2	146.7	156.0	64.2	0.465	0.544
1418	234	203	13.2	147.8	157.5	62.4	0.464	0.548
1429	212	188	13.2	148.6	157.3	64.4	0.445	0.538
1444	193	180	13.2	150.1	157.5	64.8	0.419	0.505
1449	169	159	13.2	150.3	156.2	64.6	0.383	0.466
1510	159	148	13.2	151.2	159.1	63.9	0.360	0.658
1520	125	118	13.2	151.2	154.4	65.3	0.284	0.342

****** APRIL 3, 1974 . PARTLY CLOUDY DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
1115	159	154	13.4	109.2	114.4	68.2	0.543	0.441
1130	249	205	13.4	110.3	119.5	68.0	0.565	0.496
1145	267	214	13.4	111.9	122.7	67.6	0.586	0.543
1201	201	182	13.4	113.9	123.4	70.7	0.562	0.636
1216	154	137	13.4	115.3	125.8	71.4	0.526	0.910
1232	252	212	13.4	117.0	125.2	71.8	0.578	0.441
1247	278	230	13.4	118.6	130.5	73.8	0.586	0.575
1300	303	246	13.4	120.6	131.2	72.5	0.586	0.470
1315	293	243	13.4	121.6	132.6	74.8	0.586	0.504
1330	121	116	13.4	123.8	131.9	75.0	0.460	0.902
1346	131	141	13.4	124.9	129.7	76.8	0.479	0.498
1417	291	244	13.4	127.2	138.4	76.6	0.576	0.515
1448	246	202	13.4	130.8	140.5	77.5	0.552	0.531
1503	246	204	13.4	132.3	141.6	79.2	0.552	0.510
1535	174	159	13.4	133.2	138.2	79.2	0.503	0.388

****** APRIL 10, 1974. CLEAR DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
930	123	133	9.9	113.2	115.2	38.8	0.365	0.159
945	137	156	9.9	113.4	117.3	39.9	0.396	0.285
959	157	173	9.9	114.1	119.3	40.3	0.429	0.328
1014	178	190	9.9	114.4	121.3	39.9	0.455	0.379
1029	198	203	9.9	115.2	123.3	42.1	0.478	0.404
1044	216	216	9.9	116.1	125.2	42.4	0.492	0.419
1059	231	223	9.9	117.1	127.9	43.5	0.502	0.462
1114	248	231	9.9	118.6	130.3	44.2	0.511	0.465
1129	263	237	9.9	120.0	132.4	44.1	0.515	0.466
1144	272	242	9.9	121.5	134.8	44.4	0.517	0.483
1200	283	247	9.9	123.3	137.1	45.0	0.519	0.484
1215	282	249	9.9	125.1	138.6	45.5	0.516	0.472
1230	284	251	9.9	126.7	141.3	46.6	0.515	0.507
1245	286	249	9.9	128.3	143.1	48.2	0.515	0.510
1300	291	250	9.9	129.9	144.0	47.7	0.513	0.476
1316	294	252	9.9	131.5	146.3	47.7	0.511	0.496
1330	291	252	9.9	133.3	147.9	48.4	0.506	0.494
1345	283	253	9.9	134.8	149.2	49.5	0.500	0.503
1400	281	251	9.9	136.6	153.4	48.9	0.494	0.488
1415	282	246	9.9	135.0	145.3	49.3	0.492	0.359
1431	275	240	9.9	138.9	149.2	49.8	0.485	0.369
1446	258	231	9.9	140.4	149.9	50.9	0.474	0.365
1501	249	224	9.9	142.0	150.3	51.8	0.465	0.349
1516	237	213	9.9	142.9	151.5	51.3	0.451	0.359
1532	225	202	9.9	143.4	151.2	51.6	0.442	0.335
1547	213	189	9.9	144.1	150.8	52.9	0.426	0.309
1617	175	162	9.9	144.9	149.7	53.1	0.376	0.274
1633	155	147	9.9	145.4	149.2	54.1	0.342	0.240
1646	139	134	9.9	145.4	148.8	54.0	0.304	0.243
1701	122	119	9.9	145.6	147.2	54.7	0.257	0.131
1715	108	107	9.9	145.6	146.1	56.1	0.223	0.049

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****** APRIL 11, 1974. PARTLY CLOUDY DAY ******

HR	ST	SH	MOOT	TIN	TOUT	TAMB	EFFT	EFFE
1100	180	165	12.6	142.0	145.6	56.8	0.414	0.252
1115	106	124	12.6	142.9	145.0	59.7	0.242	0.256
1130	230	213	12.6	143.4	149.2	61.2	0.470	0.315
1145	197	173	12.6	144.3	150.1	59.0	0.429	0.367
1200	216	197	12.6	145.4	151.9	60.6	0.449	0.378
1216	268	231	12.6	146.7	159.3	58.8	0.484	0.591
1227	265	230	12.6	147.8	157.5	59.4	0.460	0.462
1231	271	236	12.6	148.3	158.0	59.5	0.482	0.452
1246	285	242	12.6	149.5	160.3	59.7	0.489	0.476
1251	284	242	12.6	150.3	160.9	61.3	0.489	0.471
1301	285	240	12.6	151.9	162.5	60.6	0.485	0.469
1321	286	242	12.6	153.5	163.8	60.4	0.481	0.451
1337	272	238	12.6	155.1	165.6	61.0	0.468	0.483
1353	257	226	12.6	156.9	166.5	61.7	0.453	0.468
1409	135	127	12.6	157.6	163.4	63.3	0.268	0.539

****** APRIL 12, 1974. PARTLY CLOUDY DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFI	EFFE
1030	137	147	12.8	150.1	153.3	61.7	0.307	0.304
1045	175	192	12.8	150.3	155.3	66.0	0.396	0.368
1100	174	186	12.8	151.0	153.9	66.2	0.394	0.212
1115	137	151	12.8	151.5	154.2	65.7	0.316	0.252
1130	192	193	12.8	151.7	156.0	67.3	0.419	0.288
1145	171	160	12.8	152.2	157.1	66.2	0.383	0.364
1201	235	208	12.8	153.3	161.1	67.3	0.458	0.422
1216	127	139	12.8	154.0	157.8	68.0	0.284	0.382
1232	176	179	12.8	154.2	157.1	58.7	0.391	0.210
1247	281	242	12.8	155.3	164.1	63.4	0.489	0.401
1300	276	240	12.8	156.0	165.0	63.5	0.484	0.417
1315	231	207	12.8	157.3	162.9	69.6	0.448	0.309
1331	193	182	12.8	158.5	163.6	70.5	0.444	0.335
1346	264	243	12.8	159.4	167.0	71.2	0.472	0.366
1401	263	232	12.8	160.7	169.9	71.4	0.468	0.446
1417	264	228	12.8	162.1	170.6	71.4	0.465	0.410
1433	241	214	12.8	163.4	171.9	73.0	0.446	0.449
1448	270	240	12.8	164.1	172.8	72.5	0.466	0.410
1504	257	226	12.8	165.7	173.3	71.8	0.450	0.377
1520	252	220	12.8	166.6	174.4	72.5	0.445	0.394
1530	173	153	12.8	167.5	171.5	72.1	0.342	0.294
1545	77	86	12.8	167.9	167.5	72.5	-0.050	-0.060
1555	69	87	12.8	167.7	165.9	71.6	-0.137	-0.332

****** APRIL 15, 1974 . CLEAR DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
1340	272	251	13.0	162.1	177.1	65.0	0.460	0.715
1345	269	245	13.0	162.9	176.5	66.2	0.456	0.662
1400	273	247	13.0	164.3	176.2	66.7	0.455	0.541
1415	271	245	13.0	166.6	177.1	65.0	0.447	0.501
1431	251	236	13.0	168.4	177.6	65.7	0.424	0.476
1446	251	233	13.0	169.9	179.1	66.9	0.423	0.475
1501	250	237	13.0	171.0	178.3	65.7	0.416	0.384
1518	228	218	13.0	172.0	178.3	66.4	0.390	0.360
1533	194	187	13.0	173.1	179.3	66.2	0.340	0.410
1549	195	187	13.0	174.0	179.3	66.9	0.338	0.349
1604	179	176	13.0	174.8	179.3	65.8	0.304	0.327
1620	159	160	13.0	175.3	178.9	66.4	0.259	0.295
1636	142	147	13.0	175.8	178.2	66.0	0.208	0.214
1651	130	135	13.0	176.0	177.3	66.9	0.168	0.126
1707	114	119	13.0	176.2	175.8	63.1	0.081	-0.041
1723	98	104	13.0	176.0	174.4	65.3	-0.001	-0.215

****** APRIL 17, 1974   CLEAR DAY ******

HR	ST	SH	MOJT	TIN	TOUT	TAMB	EFFT	EFFE
1015	169	188	13.0	153.5	162.7	57.9	0.328	0.320
1030	184	198	13.0	159.6	164.7	58.6	0.353	0.357
1045	201	206	13.0	160.7	166.5	59.5	0.377	0.374
1101	215	213	13.0	162.0	168.4	58.6	0.390	0.392
1115	223	216	13.0	162.9	170.2	61.2	0.408	0.422
1130	241	223	13.0	163.9	171.9	59.2	0.413	0.429
1152	241	222	13.0	166.1	174.8	59.0	0.407	0.467
1200	245	226	13.0	166.5	175.5	60.6	0.412	0.460
1215	256	239	13.0	168.4	177.6	63.3	0.424	0.468
1231	257	237	13.0	169.9	179.4	63.5	0.421	0.483
1246	266	239	13.0	171.5	180.9	63.9	0.425	0.459
1300	271	243	13.0	172.9	182.3	64.8	0.428	0.450
1315	266	243	13.0	174.6	183.9	63.1	0.415	0.459
1331	264	245	13.0	176.2	185.2	64.5	0.411	0.445
1346	264	242	13.0	177.6	186.6	65.5	0.409	0.445
1402	261	235	13.0	179.1	187.9	65.7	0.402	0.441
1417	252	230	13.0	180.3	188.6	62.8	0.383	0.439
1433	237	227	13.0	181.6	189.9	67.8	0.373	0.456
1445	238	226	13.0	182.7	189.9	65.7	0.366	0.395
1500	231	213	13.0	183.9	190.4	67.6	0.358	0.366
1515	220	208	13.0	184.8	190.6	66.9	0.338	0.342
1531	205	197	13.0	185.5	190.8	67.6	0.314	0.332
1547	184	177	13.0	186.3	190.6	66.0	0.268	0.306
1602	137	136	13.0	186.8	189.9	68.4	0.141	0.291
1618	148	151	13.0	187.0	189.3	71.4	0.188	0.207

****** APRIL 22, 1974. MEDIUM CLOUD COVER ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
900	97	120	13.3	98.8	101.8	67.3	0.518	0.420
915	75	94	13.3	99.1	100.9	65.3	0.459	0.319
931	72	90	13.3	99.7	101.7	66.6	0.453	0.367
945	125	151	13.3	100.0	105.1	68.7	0.552	0.533
1001	134	157	13.3	100.9	105.1	69.3	0.559	0.408
1015	178	203	13.3	102.0	108.9	70.9	0.587	0.510
1030	184	199	13.3	103.3	110.5	72.0	0.588	0.519
1045	146	150	13.3	104.7	112.1	72.7	0.564	0.671
1101	92	111	13.3	106.0	110.5	74.1	0.504	0.651
1117	130	141	13.3	106.9	111.2	73.6	0.546	0.442
1132	212	217	13.3	108.0	115.2	75.7	0.595	0.450
1148	108	126	13.3	109.0	112.3	74.1	0.513	0.397
1204	131	140	13.3	109.8	114.4	75.0	0.540	0.475
1219	126	141	13.3	110.8	117.7	76.5	0.556	0.720
1230	113	127	13.3	111.6	123.1	78.3	0.526	1.349

****** APRIL 23, 1974. CLEAR DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFI	EFFE
1045	206	226	9.2	118.2	130.6	61.2	0.522	0.553
1100	223	234	13.3	119.7	129.7	61.7	0.535	0.600
1115	239	241	9.2	121.3	134.4	63.5	0.533	0.504
1130	246	246	13.3	123.1	133.7	63.0	0.541	0.572
1141	251	250	13.3	124.3	135.3	63.9	0.542	0.581
1142	252	250	13.3	124.5	135.7	63.1	0.541	0.587
1157	256	254	13.3	126.5	137.8	64.0	0.540	0.586
1213	262	258	13.3	128.3	140.2	66.0	0.542	0.600
1228	263	257	13.3	130.3	142.3	66.7	0.539	0.608
1230	265	257	13.3	130.8	142.5	66.9	0.539	0.586
1245	267	258	13.3	132.4	144.7	67.1	0.536	0.608
1301	267	259	13.3	134.6	146.7	66.6	0.529	0.599
1317	265	257	13.3	136.4	148.5	68.4	0.528	0.603
1330	270	259	13.3	138.0	149.9	68.2	0.526	0.583
1345	271	262	13.3	139.8	151.3	70.3	0.526	0.564
1401	264	255	13.3	141.8	153.0	70.0	0.517	0.560
1417	256	253	13.3	143.4	154.2	71.1	0.510	0.560
1433	271	292	13.3	145.0	155.5	72.1	0.517	0.510
1448	254	259	13.3	146.7	157.1	71.8	0.502	0.544
1504	237	235	13.3	147.9	157.5	71.2	0.455	0.534
1520	230	236	13.3	149.5	158.2	72.3	0.478	0.498
1536	219	223	13.3	150.6	158.5	71.6	0.463	0.480
1552	202	213	13.3	151.5	158.9	72.5	0.446	0.484
1607	207	219	13.3	152.6	159.4	73.2	0.454	0.438
1623	52	64	13.3	153.1	153.1	69.3	-0.234	0.000

****** APRIL 25, 1974. CLEAR DAY ******

HR	ST	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
915	103	144	9.8	91.6	95.2	46.0	0.462	0.342
930	116	163	9.8	92.3	97.2	45.5	0.479	0.410
1000	144	198	9.8	93.6	101.7	47.7	0.517	0.552
1030	177	223	9.8	96.1	106.7	49.5	0.542	0.586
1100	211	241	9.8	98.8	111.6	49.8	0.554	0.593
1131	233	251	9.8	102.2	116.2	50.4	0.557	0.591
1201	245	258	9.8	105.8	120.9	52.2	0.557	0.603
1230	251	260	11.4	109.4	123.4	53.1	0.555	0.640
1300	254	260	11.4	113.4	127.8	54.3	0.549	0.648
1330	255	262	11.4	117.1	131.4	54.9	0.542	0.637
1400	246	256	11.4	121.3	135.1	57.6	0.532	0.643
1431	231	246	11.4	124.9	137.7	58.1	0.515	0.632
1502	222	242	11.4	128.5	140.0	58.3	0.501	0.591
1533	191	215	11.4	131.0	140.9	62.2	0.475	0.592
1604	169	215	11.4	133.3	141.4	66.4	0.455	0.546
1635	81	119	11.4	134.8	136.2	62.8	0.194	0.203
1706	116	149	11.4	135.7	139.5	68.4	0.355	0.373
1245	245	242	13.3	113.0	122.0	77.7	0.597	0.486
1301	132	139	13.3	114.6	119.1	75.6	0.522	0.451
1317	219	224	13.3	116.2	124.7	78.6	0.582	0.513
1330	92	113	13.3	117.3	122.4	77.0	0.450	0.726
1346	75	92	13.3	117.9	120.0	75.0	0.381	0.383
1402	66	88	13.3	117.9	119.3	75.6	0.349	0.288
1415	55	75	13.3	118.0	118.9	75.9	0.285	0.217
1430	37	49	13.3	118.2	118.2	73.8	0.069	0.000

****** APRIL 26, 1974. CLEAR DAY ******

HR	SF	SH	MDOT	TIN	TOUT	TAMB	EFFT	EFFE
915	105	142	11.4	121.5	123.1	58.6	0.362	0.176
930	114	156	11.4	122.0	124.9	58.8	0.352	0.289
1000	139	190	11.4	123.3	129.2	60.6	0.434	0.488
1031	171	214	11.4	125.2	133.2	61.3	0.471	0.530
1102	205	227	11.4	127.4	137.3	61.5	0.497	0.551
1133	229	236	11.4	130.1	141.3	64.9	0.515	0.556
1204	237	251	11.4	133.5	145.6	64.6	0.509	0.581
1230	246	254	11.4	136.6	149.2	65.7	0.508	0.577
1301	244	251	11.4	140.7	153.3	66.4	0.498	0.589
1330	245	248	11.4	144.1	156.7	66.9	0.490	0.587
1401	243	245	11.4	148.1	160.0	69.4	0.483	0.559
1432	235	242	11.4	151.3	162.3	71.4	0.473	0.532
1504	216	226	11.4	154.2	164.1	72.0	0.448	0.523
1536	180	204	11.4	157.1	165.0	73.4	0.400	0.501
1608	154	160	11.4	158.7	164.8	76.3	0.359	0.452
1640	122	144	11.4	159.5	163.0	78.4	0.284	0.302

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