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LOW COST BARE-PLATE SOLAR AIR COLLECTOR

By
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September 1980

Work Performed Under Contract No. FG02-79R510143

Rom-Aire Solar Corporation
Avon Lake, Ohio

U.S. Department of Energy

Solar Energy

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Midwest Appropriate Technology Small Grants Program
Grant Number DE-FG02-79R510143

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SUMMARY

The Midwest Appropriate Technology Small Grants Program awarded ROM-AIRE Solar Corporation grant #DE-FG02-79R510143 to develop a low cost, bare-plate solar collector for preheating ambient air. This type of solar heating system would be applicable for preheating ventilation air for public buildings or other commercial and industrial ventilation requirements. Another promising application would be agricultural and industrial air drying processes.

Cost and performance are the two criteria that must be considered before solar energy will be utilized for a specific application. The purpose of this project was to develop a low cost, bare-plate collector, determine its performance for a variety of climatic conditions, analyze the economics of this type of solar collector and evaluate specific applications.

Two prototype collectors were designed, fabricated and installed into an instrumented test system. Tests were conducted for a period of five months. Results of the tests showed consistent operating efficiencies of 60% or greater with air preheat temperature uses up to 20^{o}F for one of the prototypes.

The economic analyses indicated that an installed cost of between \$5 and \$10 per square foot would make this type of solar system economically viable. For the materials of construction and the type of fabrication and installation perceived, these costs for the bare-plate solar collector are believed to be attainable. Specific applications for preheating ventilation air for schools were evaluated and judged to be economically viable.

INTRODUCTION

Preheating ambient air is an application made to order for solar energy. Outside air must be preheated before it is introduced into public buildings for ventilation requirements during the heating season. Outside air is also preheated before it is used for various industrial and agricultural drying and ventilating applications. For most of these applications large rooftop areas or adjacent ground areas are available for the installation of active solar energy systems for preheating air before it is introduced into the normal heating and distribution system. For this application to be accepted by the user the cost of solar energy must be competitive with the cost of the alternate energy. This report describes the design and performance of a unique, low cost, bare-plate solar collector for preheating ambient air. The energy produced by this solar collector system is projected to be cost effective when compared to alternate energy fuels.

The Midwest Appropriate Technology Small Grants Program provided ROM-AIRE Solar Corporation a grant (DE-FG02-79R510143) to develop a bare-plate solar collector to preheat air.

The purpose of the Midwest Appropriate Energy Technology Program is to conserve or replace conventional energy resources (eg. natural gas, oil, LPG, etc.) used in the region without adverse environmental effects. The program encourages the development of new technology for this purpose. A prerequisite of the program is that the project selected should have potential benefits for the community in which the project takes place.

Ohio and the other five midwestern states in the region are net importers of energy. Ohio produces less than one-third of the energy it consumes. The state has abundant coal reserves but Ohio coal, which currently is used predominately by industry and electric utilities, is high sulfur coal and its future use will be determined by environmental requirements. Ohio has limited oil and natural gas reserves, producing only about 5% of its annual consumption. About one-half of the industrial and practically all of the residential and commercial heating demands must be supplied with imported oil and natural gas from other states and foreign countries. Increasing demand for these environmentally clean fuels has increased fuel prices. Recent severe winters have also produced temporary fuel shortages and subsequent interruptions in business and commerce. Particularly hard hit by the energy situation have been the schools. High fuel costs have created financial problems in many school districts. With fuel prices continuing to increase and fuel supplie dependent on out-of-state producers, the problems associated with shortages and cost appear to be continuing problems for the forseeable future.

The community benefits for this project would be derived from replacing a portion of the fuel requirements for school buildings and other public buildings through the use of solar energy to preheat ventilation air. It is estimated that Ohio schools consume the equivalent of more than six million gallons of fuel oil annually for ventilation requirements. Solar energy could replace more than 50% of this demand.

The purpose of this grant was to develop a low cost, bare-plate solar collector for preheating ambient air. The design of the collector required an analysis of the heat transfer and flow characteristics of the solar absorber using low cost materials that could be easily fabricated. Following the design, two prototype systems were fabricated and installed at the roof test site. Both systems were instrumented to provide sufficient data to determine their performance for a variety of outside test conditions. These data were collected, processed and analyzed with the aid of a computer. The results of the system tests were then used to predict the cost and performance of a bare plate solar collector system for a specific air preheating application. An economic analysis was made to determine if the solar system was cost competitive with conventional energy sources. Based on these results, conclusions are made regarding the feasibility of the project and what improvements should be made.

Appendix A presents photographs of the test collectors, system and equipment. Appendix B describes and specifies the instrumentation and data acquisition system. Appendix C describes and lists the computer programs developed for this project. Appendix D presents the test data.

ANALYSIS

Two criteria must be considered before solar energy will be utilized for a specific application. They are cost and performance. Both of these criteria were evaluated analytically before proceeding with the test phase of the project.

Economic Analysis: There are many methods for evaluating the economics of solar energy applications. The method used herein is for illustrative purposes. The decision to make any capital investment is dependent on tax laws, interest rates and projections of the future, which precludes a universal method of evaluation. Reference 1 presents a method that determines what the cost of the solar energy system should be in order to be economically viable. For economic viability Reference 1 considers the value of energy produced annually by a square foot of solar collector, the payback period for the system, the time value of money and the time value of escalating fuel costs. The economic expression that determines the present value of the energy saved by the solar system is:

$$V_o = \sum_{j=1}^{n} \frac{(1+F)^j}{(1+I)^j} P_o$$

where

- n = period of analysis or the payback period, years
- I = value of money or discount rate
- F = annual fuel price escalation rate
- P_o= value of energy saved in first year, \$
- V_o= present value of energy displaced for n years, \$
- j = any particular year, 1 through n

The payback period, defined as the period of time required for the solar user to come to an even cash position with the alternate fuel user, will vary with each investor. Business generally requires paybacks of five years or less while government bodies might consider up to ten years or more. The value of money varies appreciably but for the last decade an annual rate of 8% has been reasonable. For the last decade fuel prices have escalated at 13% annually. The value of energy saved in the first year is determined by:

$$P_o = \frac{E_s}{E_f} C_f$$

where E_s is the annual useful energy produced by the solar collector. For residential solar space and water heating systems this has averaged between 100,000 and 200,000 BTU/Ft^2-yr, depending on the location. For ventilation air preheating applications the useful energy would probably be somewhat less since the systems are not used in the summer months. 75,000 BTU/Ft^2-yr is a reasonable estimate. E_f is the useful energy content of the alternate fuel, which for #2 fuel oil and a boiler efficiency of 70% the value is about 90,000 BTU/gal. The cost of #2 fuel oil currently is about $1.00 per gallon.

Solving these equations for two payback periods results in the following:

	Period A	Period B
n , years	5	10
I , %	8	8
F , %	13	13
P_o, $	.83	.83
V_o, $	4.78	10.78

which shows that for a payback period of five years the installed cost of the solar system should not exceed $4.78 per square foot, but if the payback period is 10 years the installed cost of the solar system could be as high as $10.78 per square foot.

For the typical solar system on the market today, these installed costs could not be achieved. Current installed costs are running between $25 and $50 per square foot. However, an installed cost of between $5 and $10 per square foot is not unreasonable for the bare-plate solar collector considered in this project. Manufacturing costs should be less than $2 per square foot (compared to current collector costs of more than $5 per square foot) and with a mark up of a factor of five to reflect installation and marketing costs, the installed cost to the consumer should be less than $10 per square foot.

This analysis indicates that the economics of this project are not unreasonable and, in fact, are within the domain of economic viability.

Solar Collector Design

A solar collector is a device that absorbs solar thermal energy, transfers a portion of this energy to a working fluid which is in intimate contact with the absorber plate and loses the remainder to the surroundings. The useful heat produced by the solar collector is equal to the energy absorbed by the absorber surface less the heat losses from the surface to the surroundings, or:

$$Q = A_c \left[H\tau\alpha - U (T_p - T_a) \right] \qquad (1)$$

where

Q is useful energy delivered by collector, BTU/hr

A_c is total collector area, ft^2

H is the solar energy received on the outer surface of the sloping collector structure, $BTU/HR \cdot Ft^2$

τ is the fraction of the incoming solar radiation which reaches the absorbing surface

α is the fraction of the solar energy reaching the surface which is absorbed by the absorbing surface

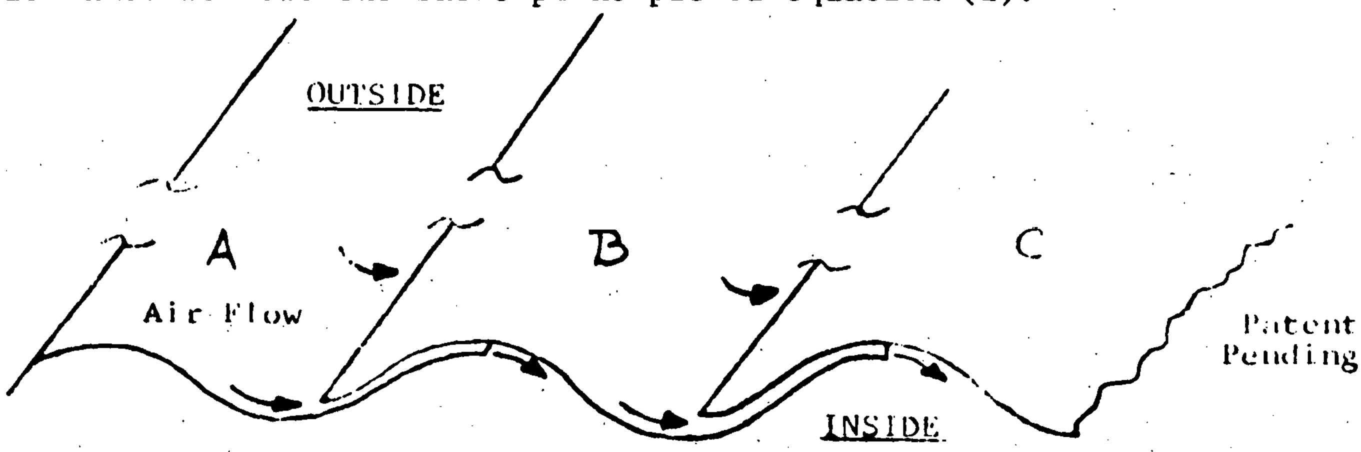
U is the overall heat loss coefficient, $BTU/HR \cdot FT^2 \cdot {}^oF$

T_p is average temperature of the outer surface of the absorber plate, ^oF

T_a is atmospheric temperature, ^oF

Most commercially available flat-plate solar collectors marketed today flow the working fluid, either air or liquid, in back of the absorber surface and have one or more transparent covers, usually glass, mounted in front of the absorber surface. For a representative single glass collector, both τ and α are valued at about 0.9 and U is about 1.0. If air is the working fluid and ambient air flows across the back side of the absorber plate and cools it to within about 20°F of the fluid, then the heat loss to the surroundings is minimal and the amount of useful energy produced by the collector will be approximately the product of τ and α or somewhat less than 81% of the impinging solar radiation, H. Removing the transparent cover converts it into a bare-plate collector and has the effect of increasing τ to 1.0 but also increasing the heat loss coefficient U to as high as 10. The result is that the useful energy produced by the collector is drastically reduced. Reference 2 indicates that bare-plate collectors of this conventional type of design could achieve peak efficiencies of only about 35%. This analysis makes it apparent that a conventional type of bare-plate collector could probably not be used effectively to heat air because of the low operating efficiency.

The solar air heating system for this project is based on a unique proprietary design for a bare-plate solar collector. It is significantly different from the conventional design but its performance follows the basic principle of equation (1).



Sketch 1. Bare-Plate Collector Assembly

Sketch 1 illustrates the basic structure of the collector and the air flow pattern. A and B are corrugated metal sheets that overlap and are fastened together to form a rigid structure. The arrow indicates the direction of air flow through the collector. The surfaces of A and B are coated on both sides with a black, weather resistive coating to enhance the absorption of solar radiation. The solar energy incident on surfaces A and B is absorbed and converted into thermal energy. Air flow is induced by a blower located inside the structure. The flowing air, indicated by the arrows, passes over the outside of surface A and into the annular passage created by the overlap of surfaces A and B and enters inside the structure below surface B. High film heat transfer coefficients are generated over the total length of the air stream because of the relatively high velocity of the stream and because of the entrance and exit effects of the annular passage. The heat transfer is also enhanced by the high thermal conductivity of A and B, which would probably be fabricated from aluminum or any light weight, low cost, high conductivity metal with the necessary structural strength. Heat is conducted from the absorbing surface in all directions to areas where the air flow cools the surface. This redistribution of heat reduces the tendency for hot spots and effectively reduces the average temperature of the collector surface, thereby reducing radiation losses to the atmosphere. The high thermal conductivity also makes all surfaces, in effect, heat transfer surfaces supplying heat to the incoming air flow, greatly increasing the effective heat transfer surface area compared to the absorption surface area of a conventional bare-plate collector.

In terms of the basic solar collector heat transfer equation (1), this unique design of a bare-plate collector enhances the transfer of useful heat to the flowing air stream by effectively reducing the absolute values of U and T_p. The absorber plate temperature, T_p, is lowered because both the film heat transfer coefficient and the effective heat transfer surface area adjacent to the air stream are increased. The overall heat loss coefficient, U, is reduced because both radiation and convection losses are lower. Lower radiation loss is due to the lower average plate temperature while the lower convection losses are due to the inward flow of air which traps the heat losses and converts them into beneficial heat gains. The overall result is that the useful heat delivered by the collector is increased because the heat losses from the absorber surface to the surroundings are minimized by the flow and heat transfer characteristics of the collector.

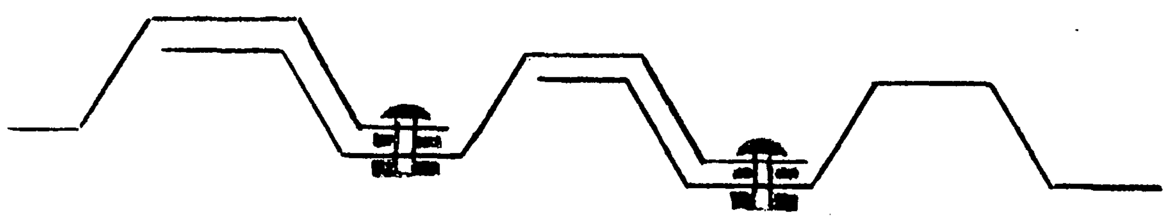
The basic characteristics of the bare-plate collector can be adapted to a variety of geometric shapes and materials of construction. However, the economic criterion of low cost must be considered. Aluminum, which has a high thermal conductivity and is commercially available at a relatively low cost, is probably the best material of construction. At current prices of about $1 per pound for thin, painted sheet, the material cost for a bare-plate collector would be less than $1 per square foot. Aluminum is readily fabricated into a variety of shapes and sizes. This ease of fabrication would keep production costs low, assuming large volume production techniques would be applicable.

PROCEDURE

The plan used to complete this project included the fabrication of two different bare plate collectors, the installation of two instrumented test systems at an appropriate site and processing the data generated by the tests.

Fabrication: Two different types of test collectors, one a flat plate and the other a tube structure, were designed and fabricated for this project. In both designs low cost aluminum sheet was used in a manner that could be readily adapted to mass production techniques in order to meet the economic cost constraints.

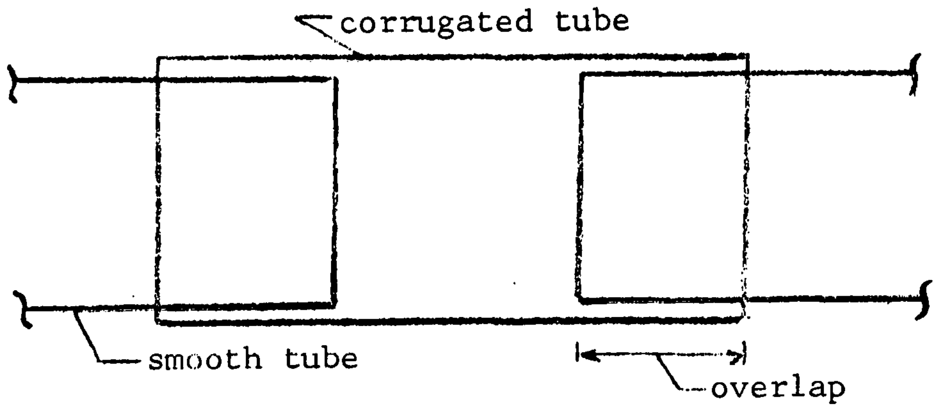
Photo 1 of Appendix A shows a closeup of the flat plate structure while Photo 3 shows the total structure assembled into a tri-frame unit. The structure consists of overlapping strips of embossed and corrugated aluminum sheet. This sheet is a commercially available roofing and siding material. Each strip includes seven corrugated surfaces which overlap adjoining strips in a pattern shown in Sketch 2:



Sketch 2. Plate Assembly

Screws and washers were used to maintain the 1/8-inch space between the overlapped strip. Air flow is turbulent as it flows under six of the seven exposed surfaces, resulting in good heat transfer. Both sides of the corrugated strips were painted with a flat black Sherwin-Williams Polane paint. Absorptivity and emissivity measurements were 0.94 and 0.89, respectively.

Photo 2 shows a closeup of the tube structure. It consists of alternate surfaces of smooth and corrugated aluminum sheet that were fabricated into 5-inch diameter tubes. The tubes overlap in a pattern shown in Sketch 3:



Sketch 3. Tube Assembly

The height of the corrugations determines the spacing between the overlapping portion of the tubes. A commercially available sheet having a corrugated dimension of 1/16-inch was used. Air flow between the overlapping surfaces was about 1,000 feet per minute, resulting in turbulent heat transfer conditions. The diameter of the tubes was determined by calculating the circumferential temperature gradients that would exist assuming a constant air flow and insolation rate. For the twenty mill thick aluminum sheet used, the optimum tube diameter would range between 4 and 6 inches, depending on the intensity of the insolation. Optimum was defined as the diameter that would minimize the temperature gradient between the sun-side and back-side of the tube. As with the plates, both sides of the aluminum sheet were painted a flat black having the same absorptivity and emissivity, i.e. 0.94 and 0.89, respectively.

Installation: The test site was the flat roof of a small, one-story commercial office building located in Avon Lake, Ohio, a suburb of Cleveland. Photos 3,4 and 5 of Appendix A show the test systems installed on the roof. The roof is unobstructed by trees or other buildings and therefore recieves solar radiation and wind throughout the day. The roofing material is black asphalt roll roofing which is a good solar absorber.

The tube collector was assembled into an array shown by Photo 4. The five-inch diameter by one foot long tubes were assembled into thirty tubes, each eight feet in length. One end of the tube was sealed off and the other end was connected to a central header duct made of insulation board with an R value of 8 and covered with sheet metal painted black. Photo 5 illustrates the header duct and tube connections to it. The total tube array therefore consists of thirty tubes, 5-inches in diameter by eight feet long, resulting in a total projected surface area exposed to direct solar radiation of 100 square feet. The tube array is mounted onto a wood frame that positions it two feet above the roof deck. The purpose of this was to eliminate snow effect and to minimize roof effect so that the performance truly represents the collector.

The flat plate collector was assembled into a tri-frame structure as shown by Photo 3. Each side is 3 feet by 8 feet, tilted at a 45° angle above the horizontal. The air inlets face the roof to prevent rain or snow from entering the structure. The floor and ends of the structure are made of insulation board with an R value of 8 and covered by sheet metal painted black. A tri-frame structure was chosen so that the effects of diffuse radiation on the north side could be evaluated.

Testing: The information necessary to evaluate the bare plate collector is the thermal performance of the system for a variety of weather conditions. This requires the ability to make both an instantaneous and average heat balance on the system. Figure B.1 of Appendix B shows the test scheme used to evaluate the performance of the bare-plate collector systems. Referring to this figure and to Photos 3 and 4, outside air is pulled through the overlapping surfaces of the bare-plate collectors. The collector surface is heated by solar radiation and this heat is transferred to the flowing air stream. The collector structures, both tube and frame, serve as an air collection header. For the tube array this heated air flows from each tube header into a central air header, then through a mixing screen and a flow nozzle into a blower where it is exhausted to the outside. Temperature measurements of the heated air are made at various locations in the central header, at the mixing screen and at the outlet of the flow nozzle. An anemometer measures the velocity of the air leaving the nozzle. Since the nozzle provides a constant velocity cross-section, the measured air velocity can be used to calculate the volume of air flowing through the collectors.

For the frame structure the air is pulled into the structure by a blower mounted at one end, and then exhausted through a mixing screen and then through a six-inch diameter by five feet long pipe to the outside. The length to diameter ratio of the pipe is sufficient to provide a uniform air velocity at the pipe outlet. This was affirmed by mapping the velocity profile with a portable anemometer. Temperature measurements of the heated air were made at the inlet to the blower and in the long tube from the blower. Flow measurements were made at the outlet of the exhaust tube using a portable anemometer. In later tests the tubes were disconnected from the tube array header duct, the tube openings sealed off and the frame structure connected to the flow system of the tube array. This permitted the frame system to be tested under continuous flow monitoring conditions.

In addition to the flow and temperature measureemtns, a pyranometer was used to measure the solar insolation on the roof and a wind meter monitored the speed and direction of the wind over the roof test site. All of this information, in the form of millivolt signals, was conducted through shielded cables to a datalogger that was located inside the building. The datalogger transformed the instrument signals into a digital signal that was either printed out on a tape or transferred to a computer. The computer was programmed to store the information, retrieve it from storage, process the data into a performance evaluation and summarize the information. Details and specifications for the instrumentation and data processing equipment are presented in Appendix B. The computer programs developed for the project are described and listed in Appendix C.

The test systems became operational in late February of 1980. The systems were operated and data compiled until mid-June when the project ended. During a typical test day the system was operated for thirty-minute time periods. A complete data scan would require two minutes. For each two-minute period a heat balance would be calculated and the instantaneous operating efficiency would be determined. After thirty minutes the computer would average the results of each two-minute data scan and calculate the average efficiency or performance of the system. The test operator would visually monitor the weather during the test period to characterize it, e g. cloudy, partly cloudy, or clear, and determine if the weather conditions remained constant. These data are presented in Appendix D.

RESULTS AND DISCUSSION

Test data for the bare-plate solar collector systems investigated by this project are summarized in Appendix D. Data collection began in late February, 1980 and continued until mid-June when the project year ended. Fortunately this time span included a variety of weather conditions typical of winter, spring and summer for a northern U.S. climate. The winter and spring data would be representative of air preheating applications for public and commercial buildings in a northern climate, while the spring and summer data would be typical of operations that would be expected for agricultural or industrial drying applications. Figures 1.a. through 1.d. graphically show the operating efficiency of the various tube and plate solar collector systems that were tested during the five month period.

The tube collector was tested in two configurations representing minimum and maximum overlapping of the concentric tubes. Referring to Figures B.3 and B.4 the minimum overlap tube had a primary air flow passage of 2½ inch length while the primary air flow passage length was 5 inches for the maximum test system. Conversely, the length of exposed single wall tubing was 7 inches and 2 inches, respectively. The test data show a significant difference in performance. The minimum overlap tube collector had an average system efficiency of 12% compared to 28% for the maximum overlap tube. A careful inspection of the data indicates that both systems operated under similar climatic conditions, i.e. solar insolation, ambient temperature and wind speed and direction.

The reason for the difference is illustrated in Figures 2 and 3, which show the wall temperature profiles for the two collectors. For the minimum overlap case, the high wall temperature in the region that has no primary air flow shows that this collector area, representing the 7-inch length of single wall tube, contributes very little to the transfer of solar heat to the air stream. For the maximum overlap case, the wall temperatures are very nearly constant throughout the length of the tube which shows that most of the tube is absorbing solar heat and transferring it to the primary air stream. This comparison illustrates the importance of achieving good wall-to-air heat transfer in those regions of the collector receiving solar energy. For the bare tube collector this indicates the necessity for nearly complete overlapping of the concentric tubes to achieve maximum efficiency.

The plate collector was tested in four different configurations. The first had the tri-frame mounted directly on the roof with both the north and south sides open. Average operating efficiency for these tests was 60% for winter-type operation and 80% for summer-type operation. It is postulated that roof effect was responsible for the significant difference in performance. A second configuration was the result of insulating and sealing off the north side of the tri-frame which reduced the average operating efficiency to 53%. To evaluate the roof effect a third configuration in which the tri-frame was mounted two feet above the roof onto the tube array test stand was tested. With both north and south sides open to air flow the average operating efficiency for this configuration was 60%. The final configuration in which the north side was insulated and sealed, resulted in an average operating efficiency of 41%.

Figure 4 shows a typical wall temperature gradient for the plate collector. The gradient is only 5°F, similar to the tube maximum overlap collector, illustrating again the importance of primary air flow across the surfaces receiving the solar radiation. An obvious improvement for the plate collector would be to increase the overlap to include the surface adjacent to thermocouples T-12 and T-13.

Inspection of the test data reveals several factors that affect the performance of the tube and plate collector systems. One of the variables that was expected to have a significant effect on performance was wind speed and direction. An attempt was made to statistically correlate the wind data with operating efficiency. The result was that there was no correlation. A possible explanation for this anomoly is that the boundary layers of air adjacent to the surfaces of the collector and adjacent to the roof are sufficient to negate the effect of wind. Another possibility is that there was not enough wind data taken to obtain statistically meaningful results.

Insolation, or the intensity of the solar radiation, did not appreciably affect the operating efficiency of either the tube or plate collectors. In fact, the efficiency improved somewhat for the tube collectors with lower insolation. This was probably caused by the increased contribution of diffuse radiation, as a fraction of the total insolation, on the unexposed or back side of the collectors. Another reason is the higher surface temperatures in the single wall tube area for higher values of insolation would increase radiation and convection heat losses, thereby reducing efficiency.

Air flow per unit area of collector surface was different for each of the configurations tested because of design and test limitations. The tube collectors operated at 2.5 cubic feet per minute per square foot of collector projected surface area (CFM/ft^2) at minimum overlap and 3.5 CFM/ft^2 at maximum overlap. This difference is evidenced by the approach temperatures shown in Figures 2 and 3. The higher air flow would also be a factor for the improved performance of the maximum overlap tube collector. The plate collectors operated at 4 CFM/ft^2 and 8 CFM/ft^2, depending on whether the north side of the collector was open or sealed. The effect of a lower air flow through the plate collector was investigated. The starred data, listed in Appendix D, for June 13 represent a flow of about 3 CFM/ft^2, resulting in an efficiency of 10 percentage points lower and a 5°F increase in outlet air temperature

Roof effect, or the contribution of the large, black roof acting as a solar absorber that heats the air adjacent to it, appears to be a significant factor for the higher performance of the plate collector. The roof mounted plate collector operated at 60% efficiency for the winter months when both the sun altitude and the radiation intensity were lower, compared to 80% for a typical summer period of high sun altitude and insolation. Mounting this same collector two feet above the roof reduced the operating efficiency to 60% for the same summer period.

A comparison of the tube and plate collectors always shows the plate collector is superior. Improvements in the tube collector, such as increasing the overlap to 100% and increasing the flow per unit area, would improve the performance t› probably the 30 to 40% range Increasing the overlap would also minimize the radial thermal gradient, which for these tests was about 30°F, front to back, resulting in lower heat losses from the back side.

Improvements in the plate collector would include increasing the overlap to nearly 100%, adjusting the air gap for optimum flow per unit area, and determining whether the collector should be a tri-frame with both north and south sides open or only the south side open. Why the collector should operate better with both sides open is an anomoly. The reasons could be a combination of roof effect and diffuse radiation, but the results of this test are not conclusive. The results do show that this type of collector will operate at system efficiencies of 60% and higher.

A part of this project was to apply a bare-plate collector system for preheating air to a public building and evaluate its performance. The evaluation will be done on the basis of 1 CFM of ventilation air for a building located in Cleveland, Ohio, operating 10 hours each day for 21 days each month. For every degree (°F) of preheat, the energy required each month is 227 BTU. It will be assumed that the bare-plate solar collector, operating at 60% efficiency can preheat the air up to a maximum of 20°F. The following table gives the average daytime temperature, the total energy required to preheat the air to 70°F, and the energy contributed by solar up to the maximum of 20°F preheat.

Month	Air Temp, °F	Q Total, BTU/mo.	Q Solar, BTU/mo.
Oct	63	1589	1589
Nov	48	4994	4540
Dec	36	7718	4540
Jan	33	8399	4540
Feb	35	7945	4540
Mar	44	5902	4540
Apr	58	2724	2724
May	68	454	454
		39725	27467

The bare-plate solar collector will be sized to provide 4540 BTU for the worst solar month, which is December. A surface, facing south at 55° tilt angle, in Cleveland will receive 747 BTU/ft^2 each day. Multiplying this by 21 days and 60% efficiency and then dividing the product into 4540 BTU gives a required collector area of 0.48 square feet for each CFM of ventilation air.

Using the economic analysis present in the ANALYSIS section, the value of energy saved in the first year by the bare-plate collector is

$$P_o = \frac{\left(\frac{27467\ \text{BTU}}{0.48\ \text{ft}^2}\right)(\$1.00/\text{gal})}{90{,}000\ \text{BTU/gal}} = \$0.64/\text{ft}^2$$

and for a 10 year payback and fuel costs exceeding the value of money by five percentage points annually, the installed cost of the bare-plate solar collector should not exceed $8.28 per square foot.

Applying these numbers to a local high school with a student and teacher population of 2000, the ventilation requirements would be 10,000 CFM, assuming 5 CFM per person. The current fuel cost for ventilation, assuming a 70% boiler efficiency and $1.00 per gallon fuel oil would be $4415 this year. A bare-plate solar collector system would save $3052 the first year. The collector system would be 4800 square feet in size and installed, cost $39,744.

Any applications that could utilize the solar energy during the summer months as well as the winter months would appreciably improve the economics of the system. Such applications might include preheating domestic water using an air-to-water heat exchanger, drying a desiccant used for humidity control, preheating air for drying laundry, etc.

FIGURE 1.a. SYSTEM PERFORMANCE

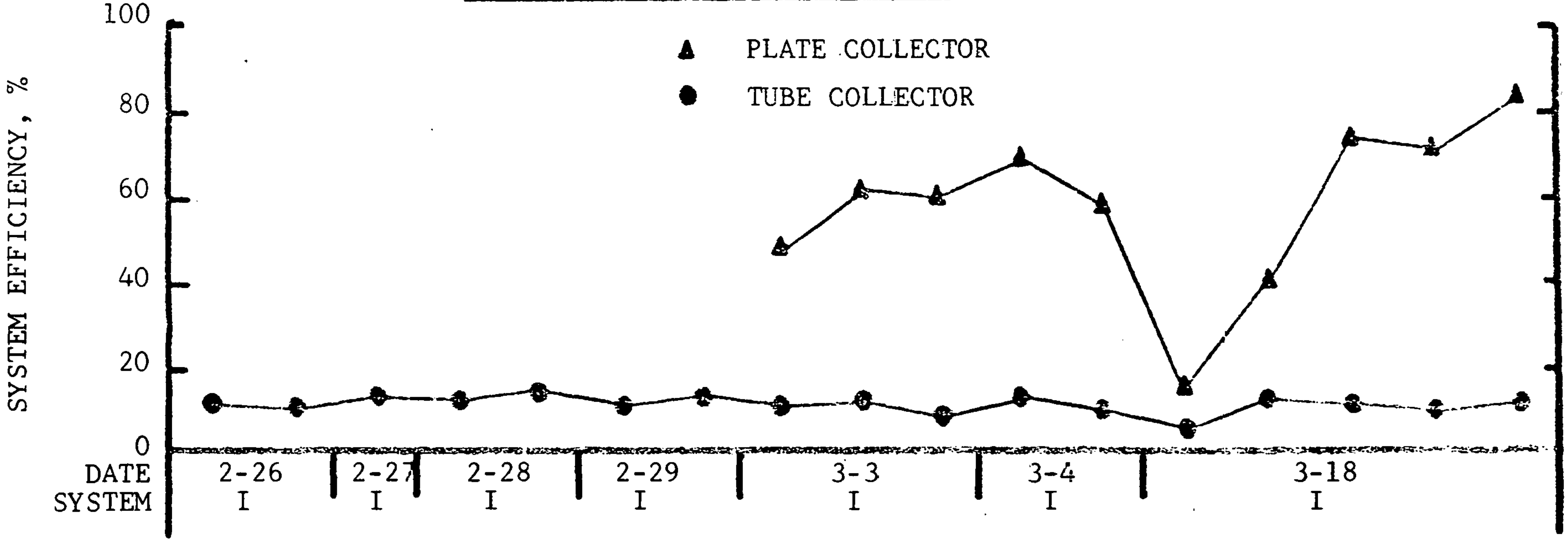


FIGURE 1.b.

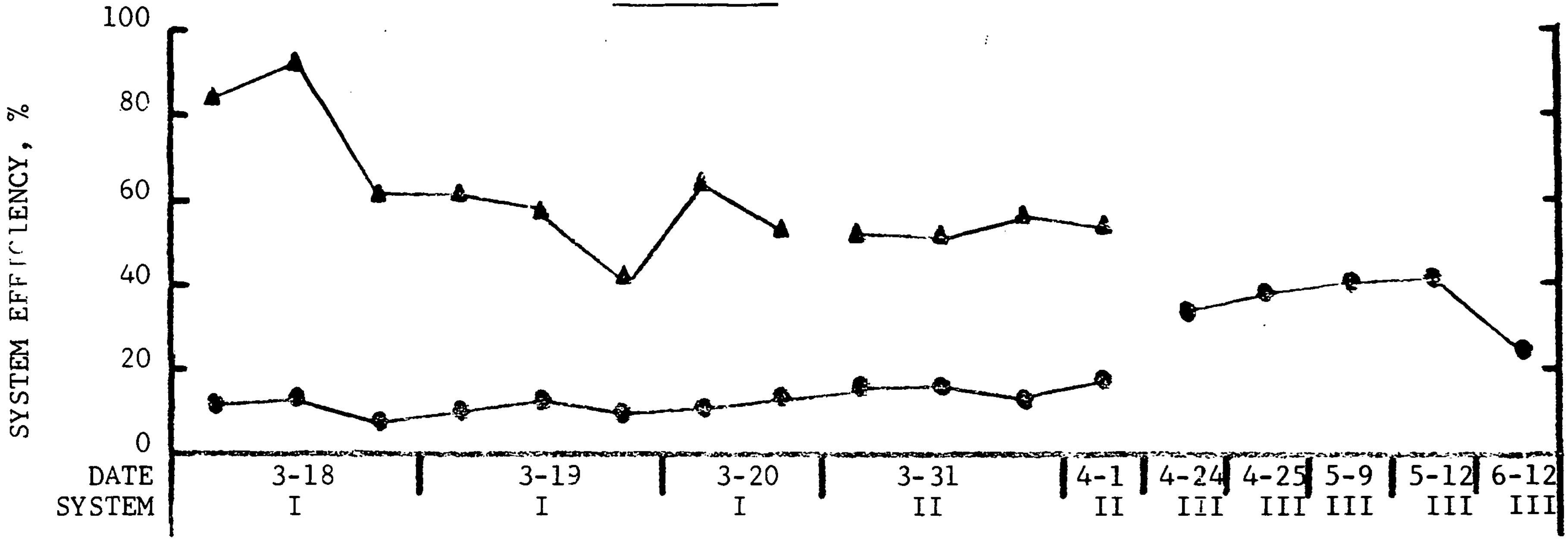


FIGURE 1.c.

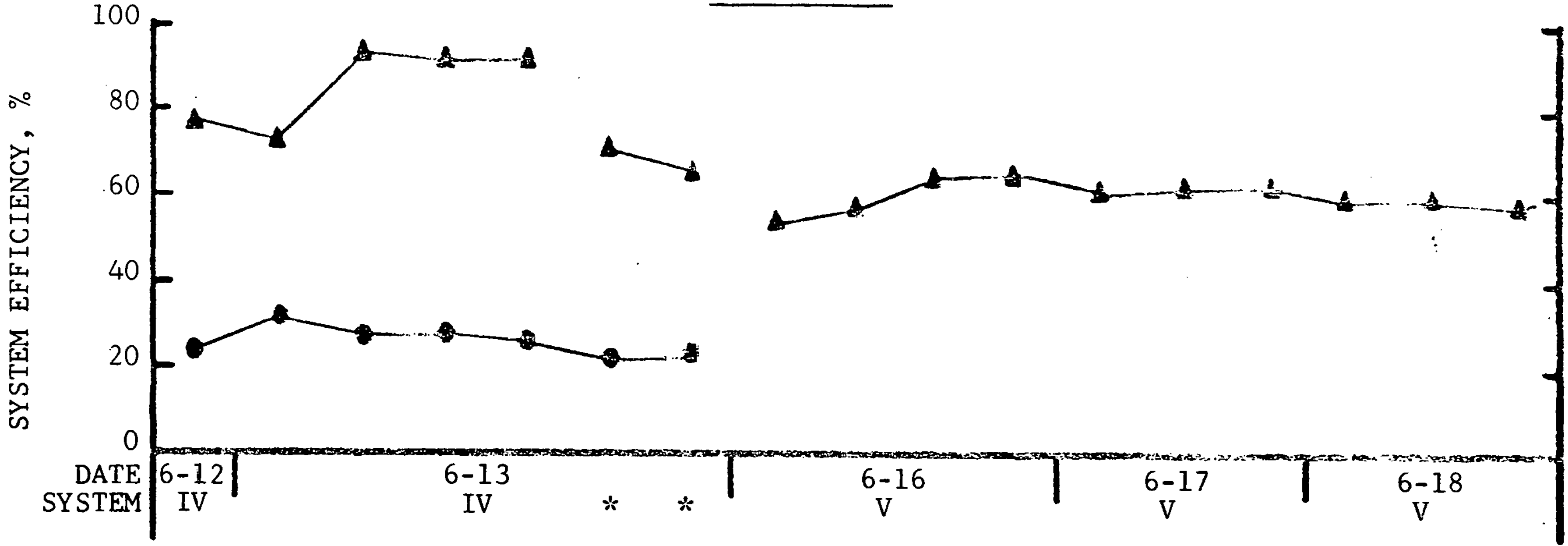
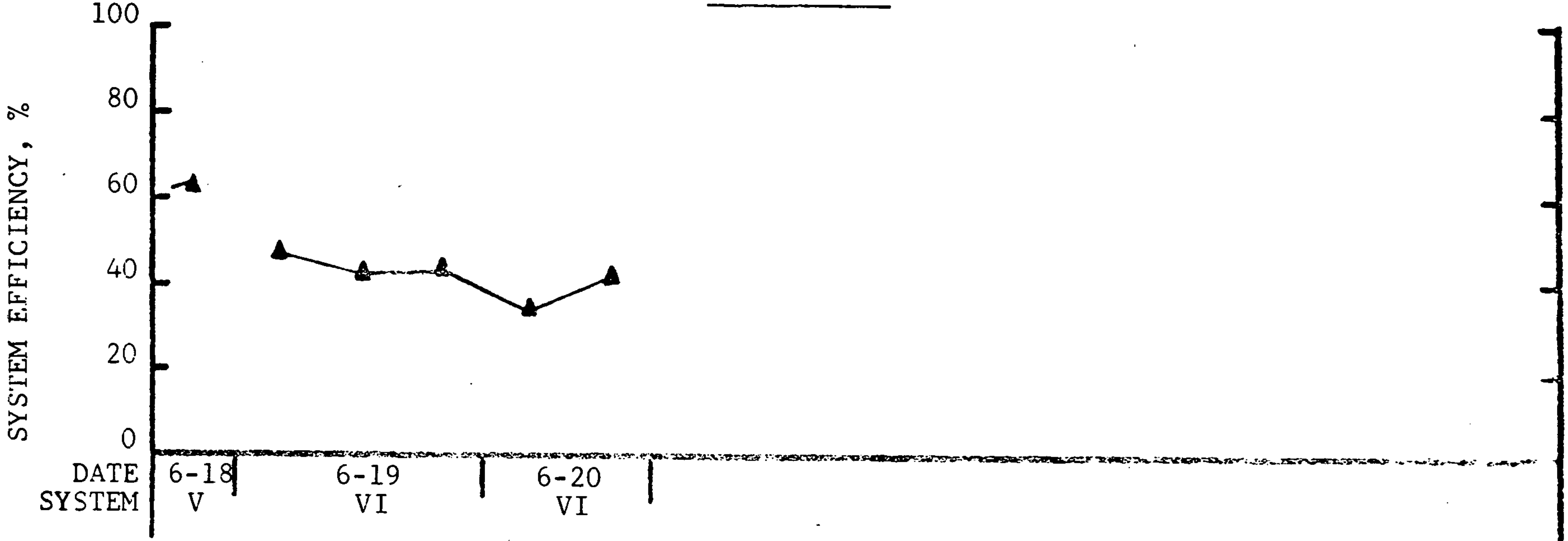


FIGURE 1.d.



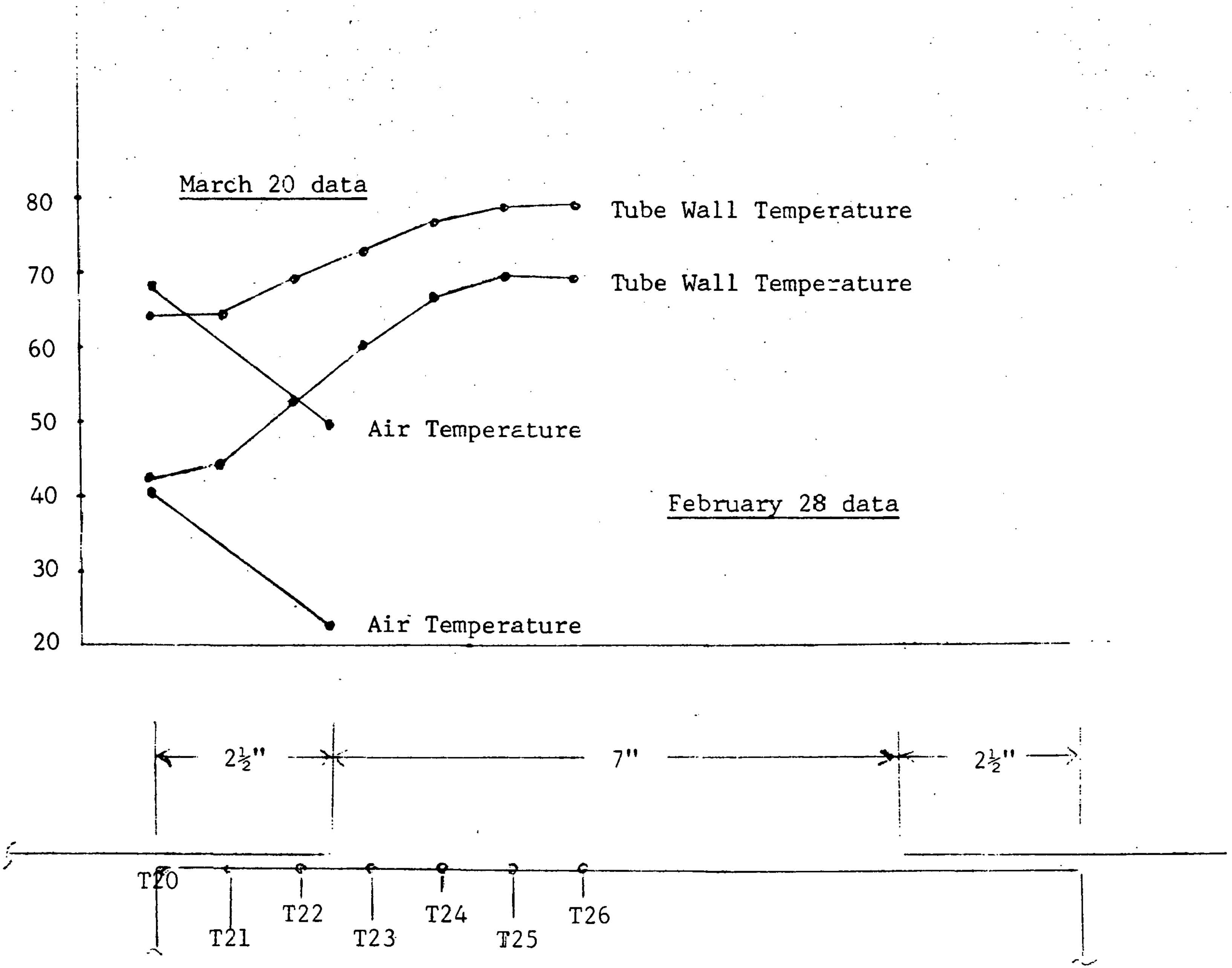


Figure 2 - TUBE SYSTEM, MINIMUM OVERLAP

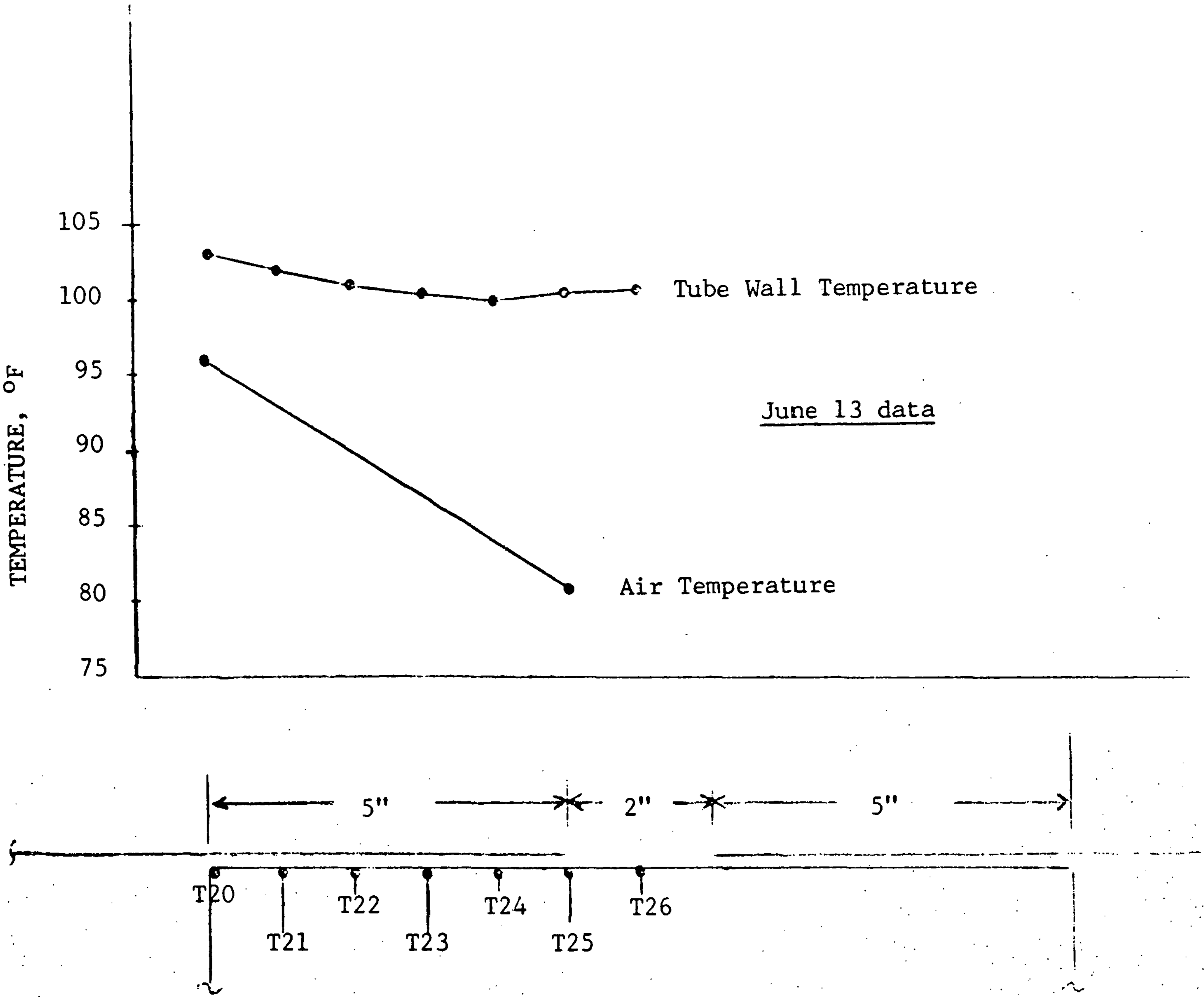


Figure 3 - TUBE SYSTEM, MAXIMUM OVERLAP

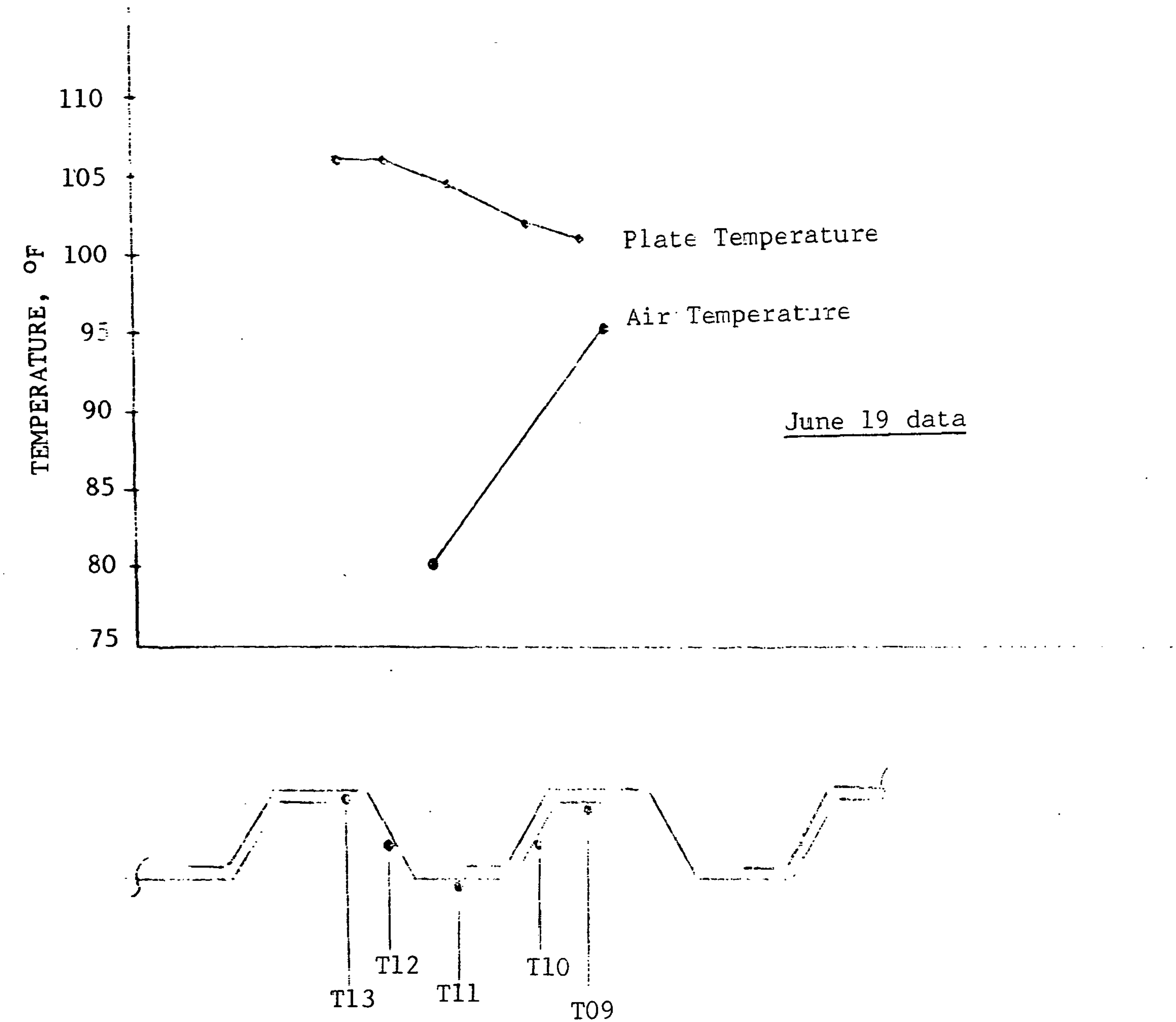


Figure 4 - Plate System

CONCLUDING REMARKS

The purpose of this project was to develop a bare-plate solar collector for preheating ambient air, determine its performance for a variety of climatic conditions, analyze the economics of this type of solar collector and evaluate specific applications.

A bare-plate solar collector was analyzed and designed. Two prototype collectors were fabricated, installed into an instrumented test system and tested for a period of five months.

Results of the tests showed consistent operating efficiencies of 60% or greater with air preheat temperature rises up to 20° F for one of the prototypes. An optimally designed bare-plate solar collector of this design should exhibit performance values that exceed the test results.

The economic analysis indicated that an installed cost of between $5 and $10 per square foot would make this type of solar system economically viable. For the materials of construction and the type of fabrication and installation perceived, these costs are believed to be attainable.

Applications for preheating ventilation air for schools were evaluated and judged economically viable. Any applications, such as drying or water heating, that could utilize the solar system throughout the year would certainly benefit from the energy savings.

FUTURE PLANS

ROM-AIRE Solar Corporation has applied for and will receive a patent covering the design of the bare-plate solar collectors used in this project. Based on the encouraging results of these tests the Company plans to continue the development and commercialization of the bare-plate solar collector system for a variety of applications. Steps toward commercialization would include optimizing the design of the collector, continuation of performance testing, design and installation of a full-scale system that could be monitored, analysis of the market for various applications and development of a marketing plan. The valuable assistance made available through DOE's Midwest Appropriate Technology Small Grants Program has been an important first step toward our goal of commercialization.

APPENDIX A: PHOTOGRAPHS

Photographs of the test apparatus and the equipment used to measure the performance of the bare plate solar systems are presented in this appendix.

Photo 1. Close-up of the flat plate collector showing the overlapping absorber surface and the air flow inlets.

Photo 2. Close-up of the tube collector showing the overlapping absorber surface and air flow passages between the plain tube and the corrugated tube.

Photo 3. The A-frame structure of the flat plate solar collector system.

Photo 4. The tube solar collector system structure.

Photo 5. The air collection header for the tube solar collector system.

Photo 6. Pyronometer used to measure the total solar radiation for the test site.

Photo 7. Wind sensor used to measure the wind direction and speed for the test site.

Photo 8. Junction box, datalogger and computer used to transmit, store and process the test data.

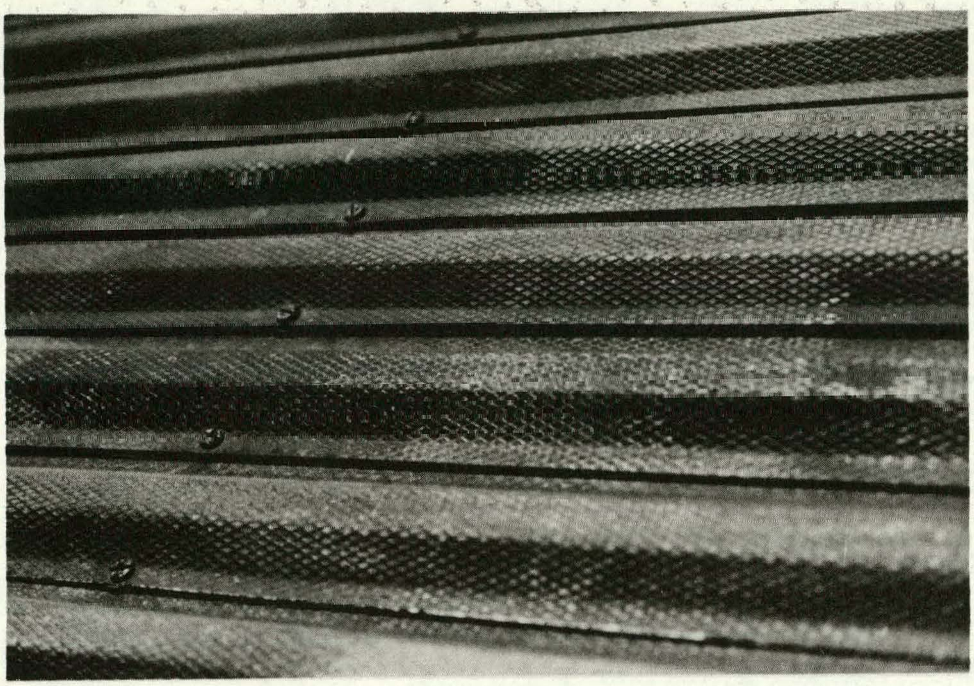
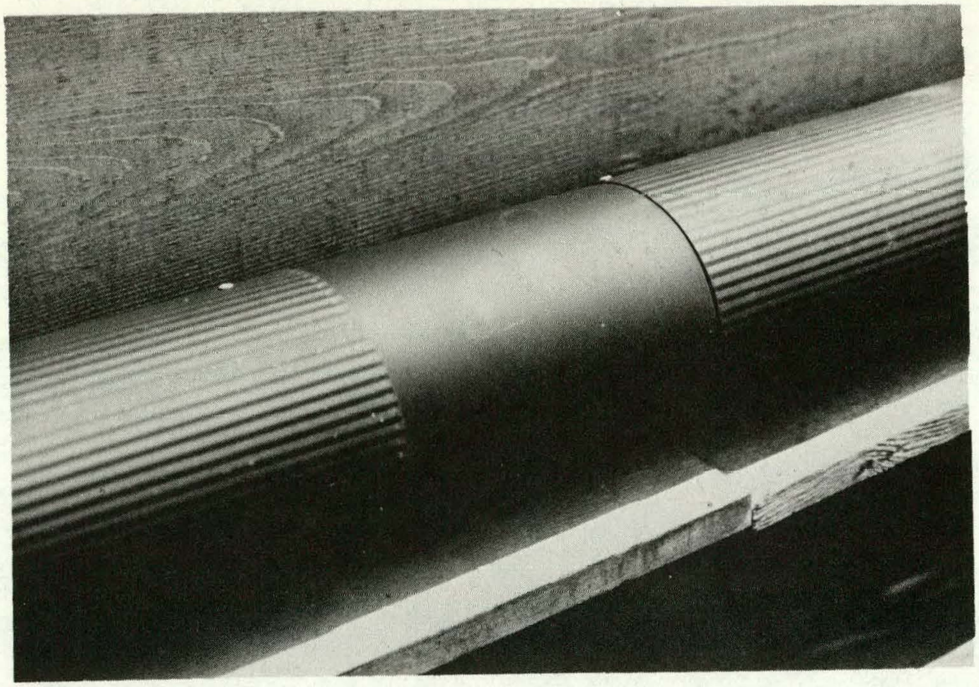


Photo 1.

Plate Collector Structure

Photo 2.

Tube Collector Structure



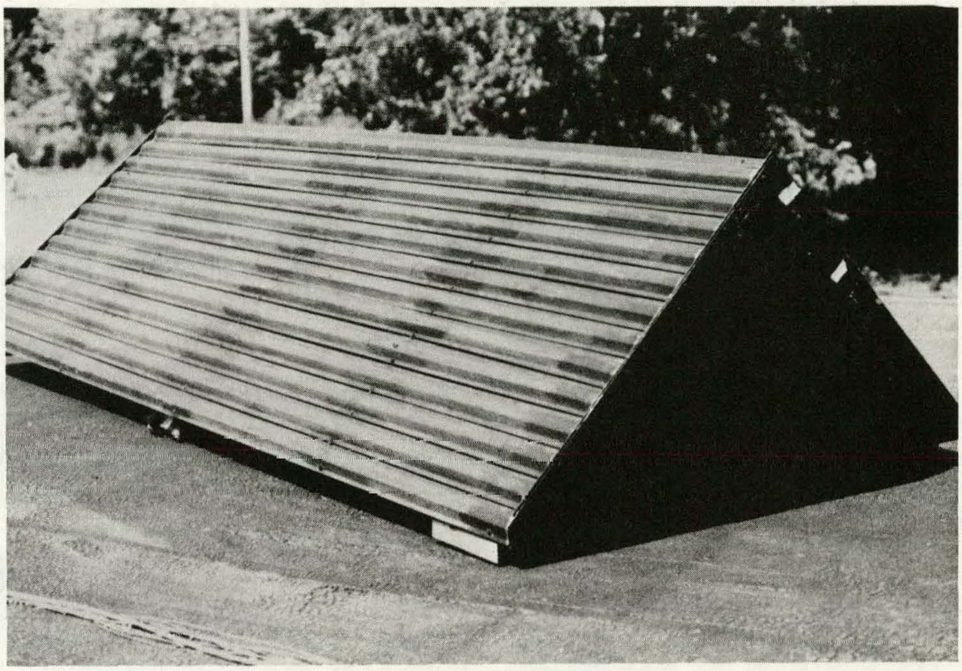


Photo 3.

Plate
Test
Assembly

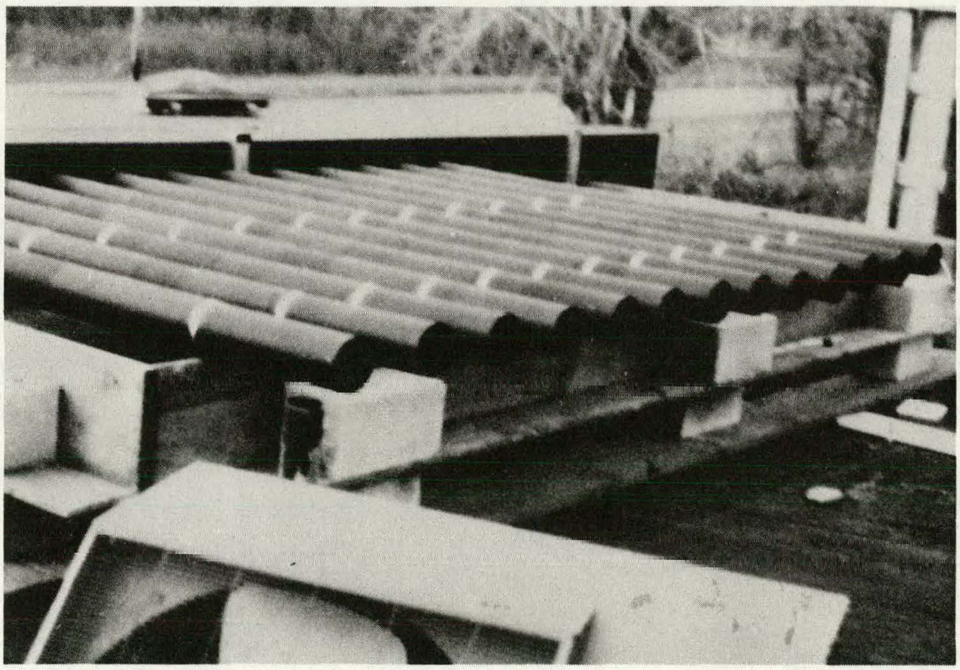
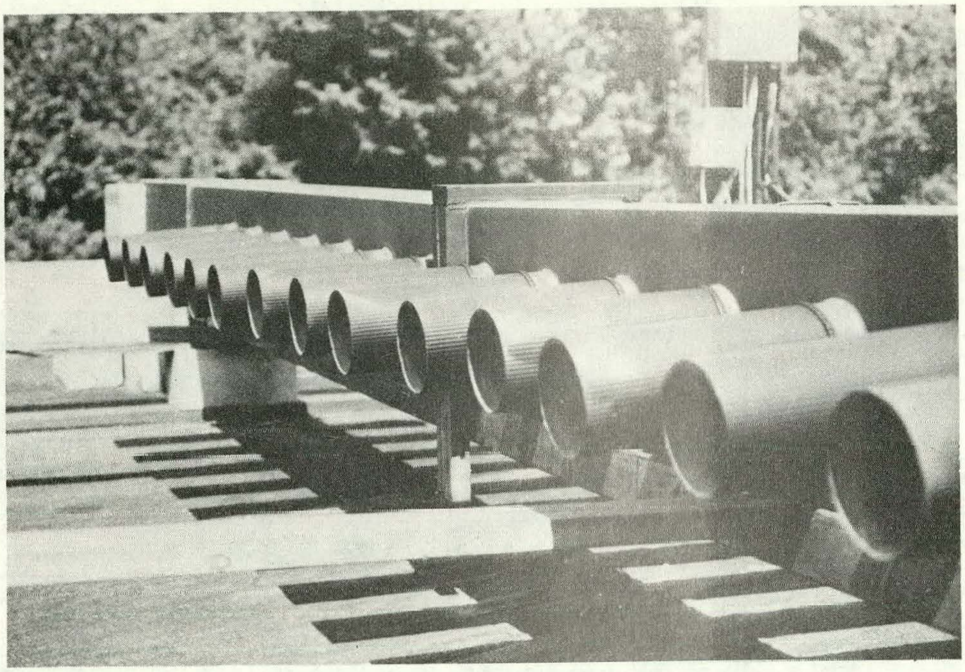


Photo 4.

Tube
Test
Assembly

Photo 5.

Tube
Header



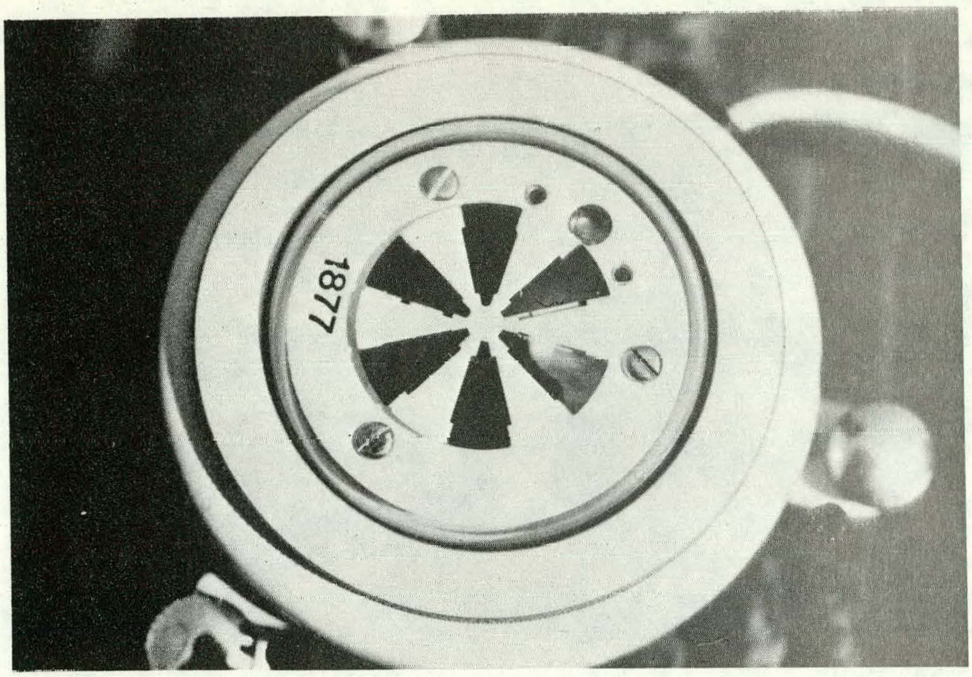


Photo 6.

Pyranometer

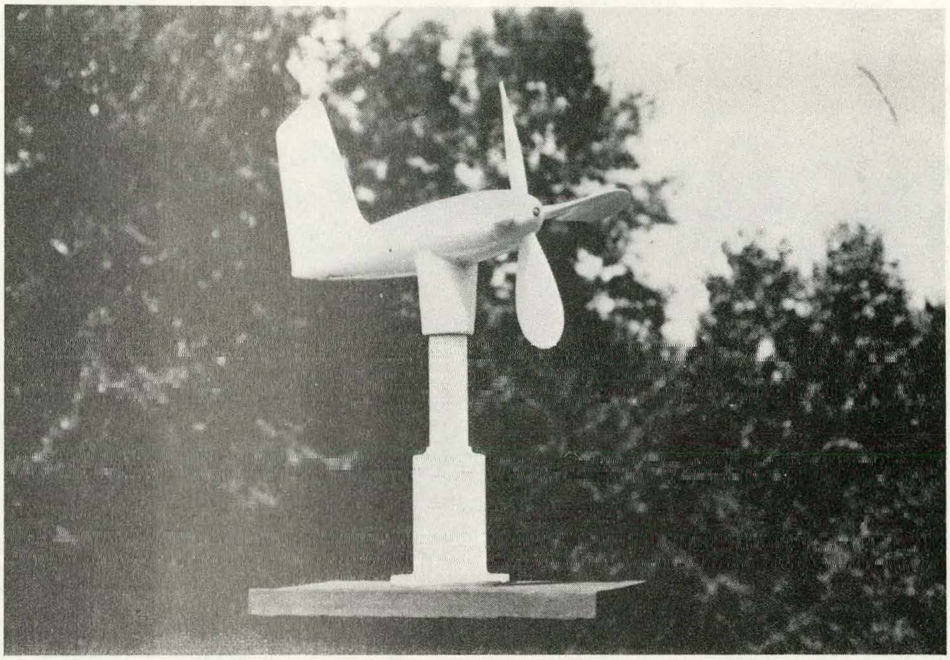


Photo 7.

Wind Meter

Photo 8.

Data Logger Computer

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APPENDIX B: INSTRUMENTATION AND DATA ACQUISITION

The test systems were instrumented to provide the information necessary to evaluate the bare-plate collector performance. The experimental instrumentation consisted of several types of sensors which are monitored by a Digitec "Data Logger 2000" data acquisition system. The types of sensors used include thermocouples, an air velocity probe, a wind sensor, and a pyranometer.

The signals from the sensors enter the data acquisition system through two 20-channel scan cards which plug into the data logger. The scan cards provide programmed scanning of the sensors, conditioning of signals from several different kinds of sensors, and in addition, digitizes the signals for the data logger.

Each scan card is set up to accept inputs from four different kinds of sensors (designated P_1, P_2, P_3, and P_4). The following table describes these inputs:

Designation	Type of Signal	Data Logger Readout
P_1	Copper/Constantan T.C.	°C
P_2	0 - 5 VDC	0 - 100
P_3	0 - 10 MV	BTU/HR/FT^2
P_4	0 - 5 VDC	0 - 1250

The following table shows which channel numbers are used for each type of input:

1st Scan Card		2nd Scan Card	
Channel No.	Type	Channel No.	Type
00 - 14	P_1	20 - 34	P_1
15	P_2	35	P_2
16	P_3	36	P_3
17	P_4	37	P_4
18 - 19	P_1	38 - 39	P_1

The Digitec "Data Logger 2000" is equipped with Input/Output terminals which permit it to be connected to an Apple II Computer terminal. This arrangement permits data to be transferred from the data logger to the computer where a number of things can be done with it:

a. The data can be stored on magnetic discs.
b. The data can be processed and the results stored on magnetic discs.
c. Raw data can be displayed on the cathode ray tube (CRT).
d. Processed information can be displayed on the CRT.
e. Raw data or processed information can be printed out by a printer.

The following figures provide additional information on layout and wiring of the instrumentation:

- Figure B.1 - Instrumentation Sensor Locations
- Figure B.2 - Instrumentation Information Summary
- Figure B.3 - Tube System Thermocouple Locations (Min. Overlap)
- Figure B.4 - Tube System Thermocouple Locations (Max. Overlap)
- Figure B.5 - Plate System Thermocouple Locations
- Figure B.6 - Wind Instrumentation Wiring Schematic
- Figure B.7 - Solar Insolation Instrumentation Wiring Schematic
- Figure B.8 - Thermocouple Wiring Schematic
- Figure B.9 - Air Flow Instrumentation Wiring Schematic

Following the figures the instruments used in this project are described and specified.

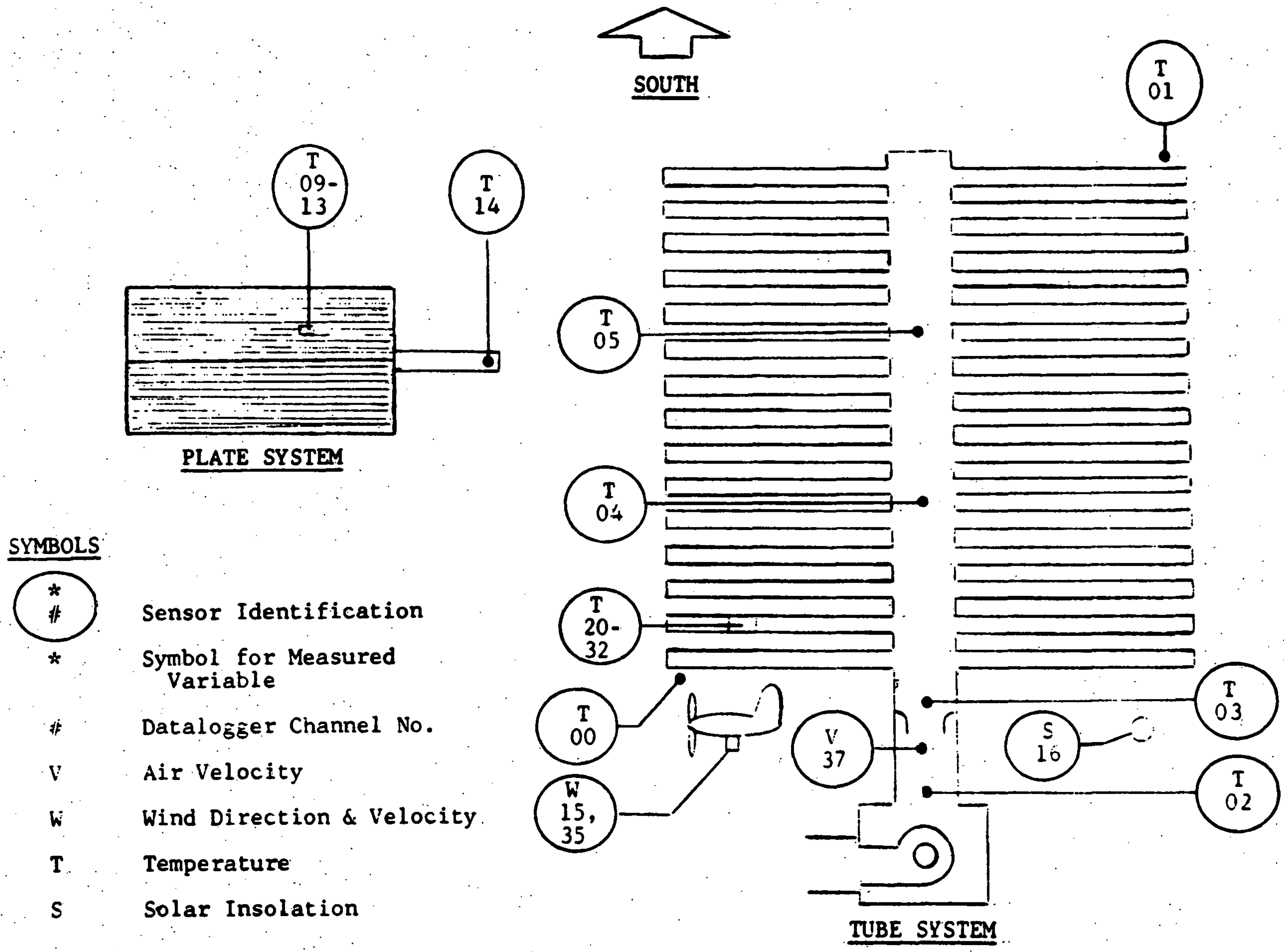

Figure B.1 - INSTRUMENTATION SENSOR LOCATIONS

Figure B.2

INSTRUMENTATION INFORMATION SUMMARY

Channel #	Monitored Variable	Sensor	Type Input
00	Ambient Air Temperature	Cu/Const. T.C.	P_1
01	Ambient Air Temperature	Cu/Const. T.C.	P_1
02	Flow Cone Exit Air Temperature	Cu/Const. T.C.	P_1
03	Air Temperature Exit 15 Rows Tubes	Cu/Const. T.C.	P_1
04	Air Temperature Exit 10 Rows Tubes	Cu/Const. T.C.	P_1
05	Air Temperature Exit 5 Rows Tubes	Cu/Const. T.C.	P_1
09 - 13	Absorber, Plate System	Cu/Const. T.C.	P_1
14	Air Temperature, Exit Plate System	Cu/Const. T.C.	P_1
15	Wind Speed MPH	Sky-Vane	P_2
16	Solar Intensity (Horizontal)	Pyranometer	P_3
20 - 32	Absorber Temperature	Cu/Const. T.C.	P_1
35	Wind Direction	Sky-Vane	P_2
37	Flow Cone Exit Air Velocity	Anemometer	P_4
39	Inlet Air Temperature, Plate System	Cu/Const. T.C.	P_1

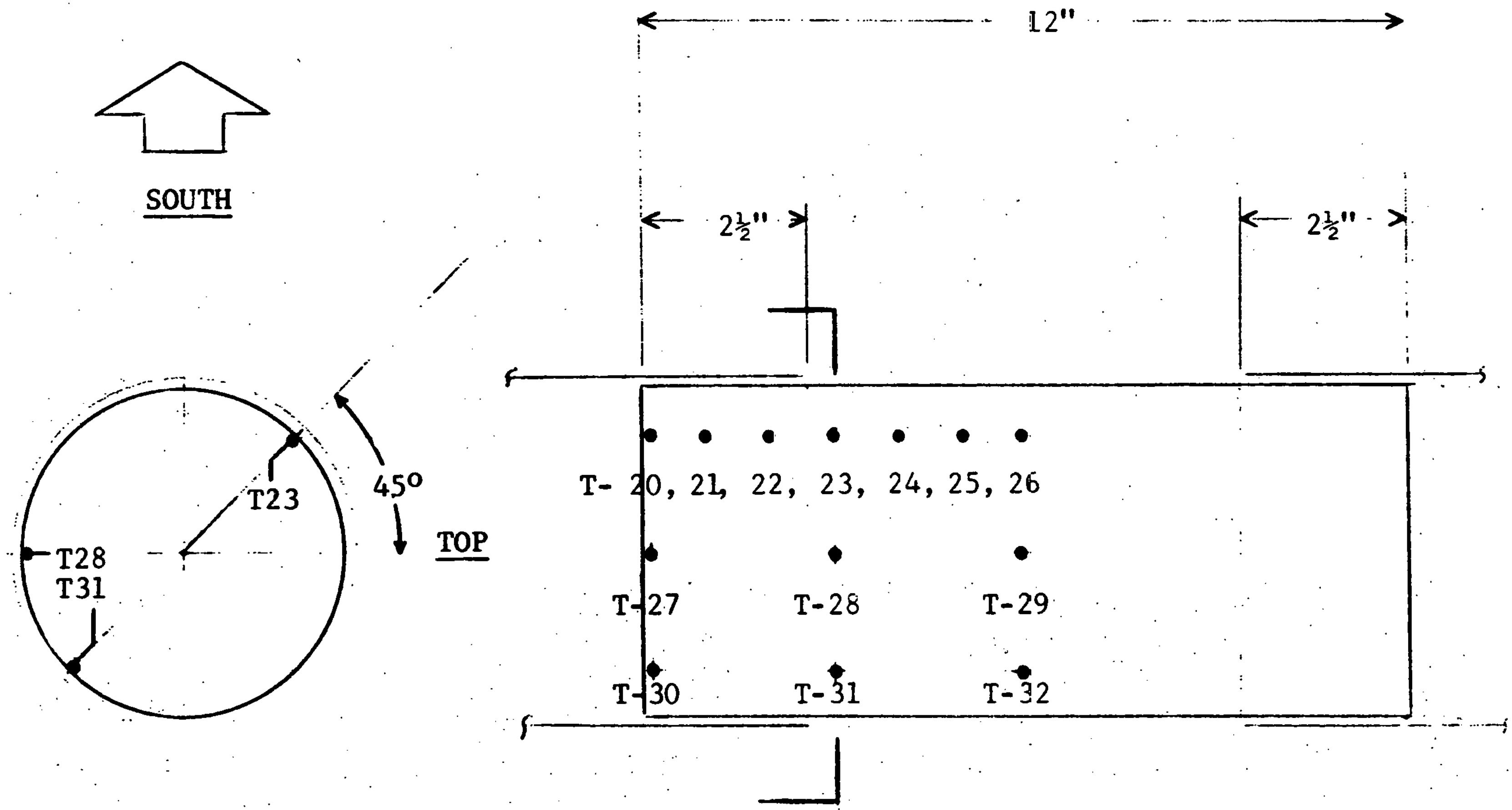

Figure B.3 - TUBE SYSTEM THERMOCOUPLE LOCATIONS (MINIMUM OVERLAP)

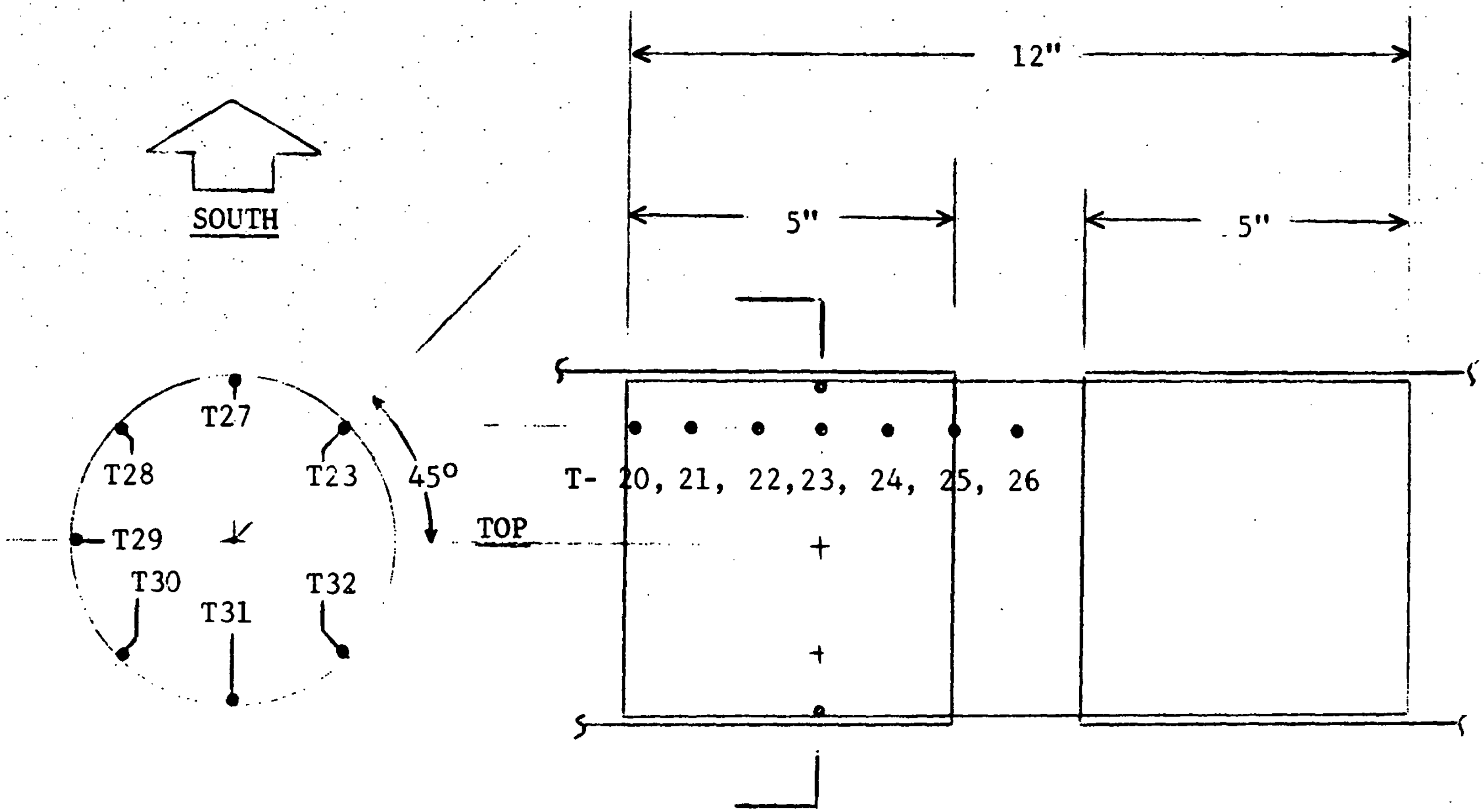

Figure B.4 - TUBE SYSTEM THERMOCOUPLE LOCATIONS (MAXIMUM OVERLAP)

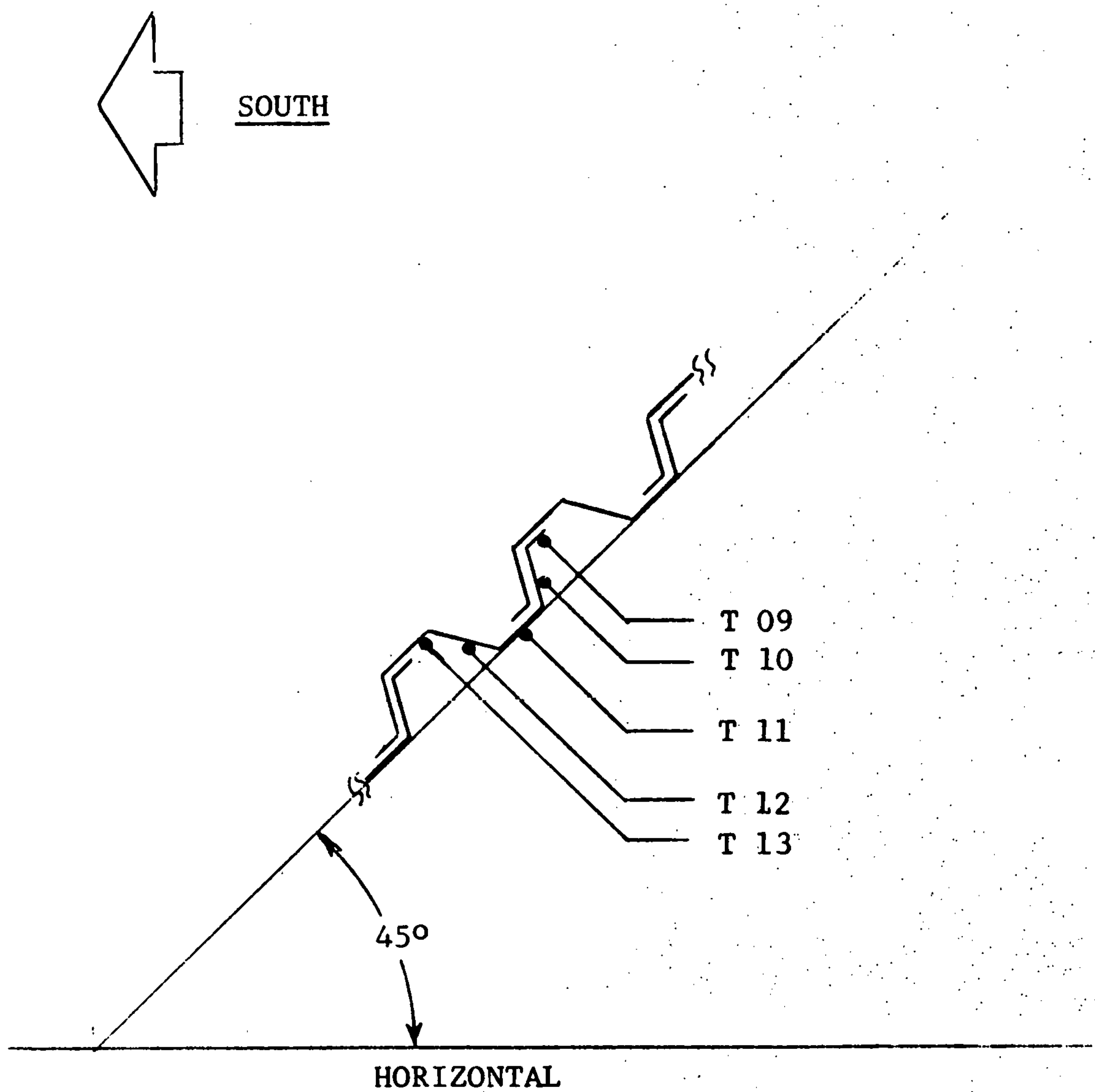

Figure B.5 - PLATE SYSTEM THERMOCOUPLE LOCATIONS

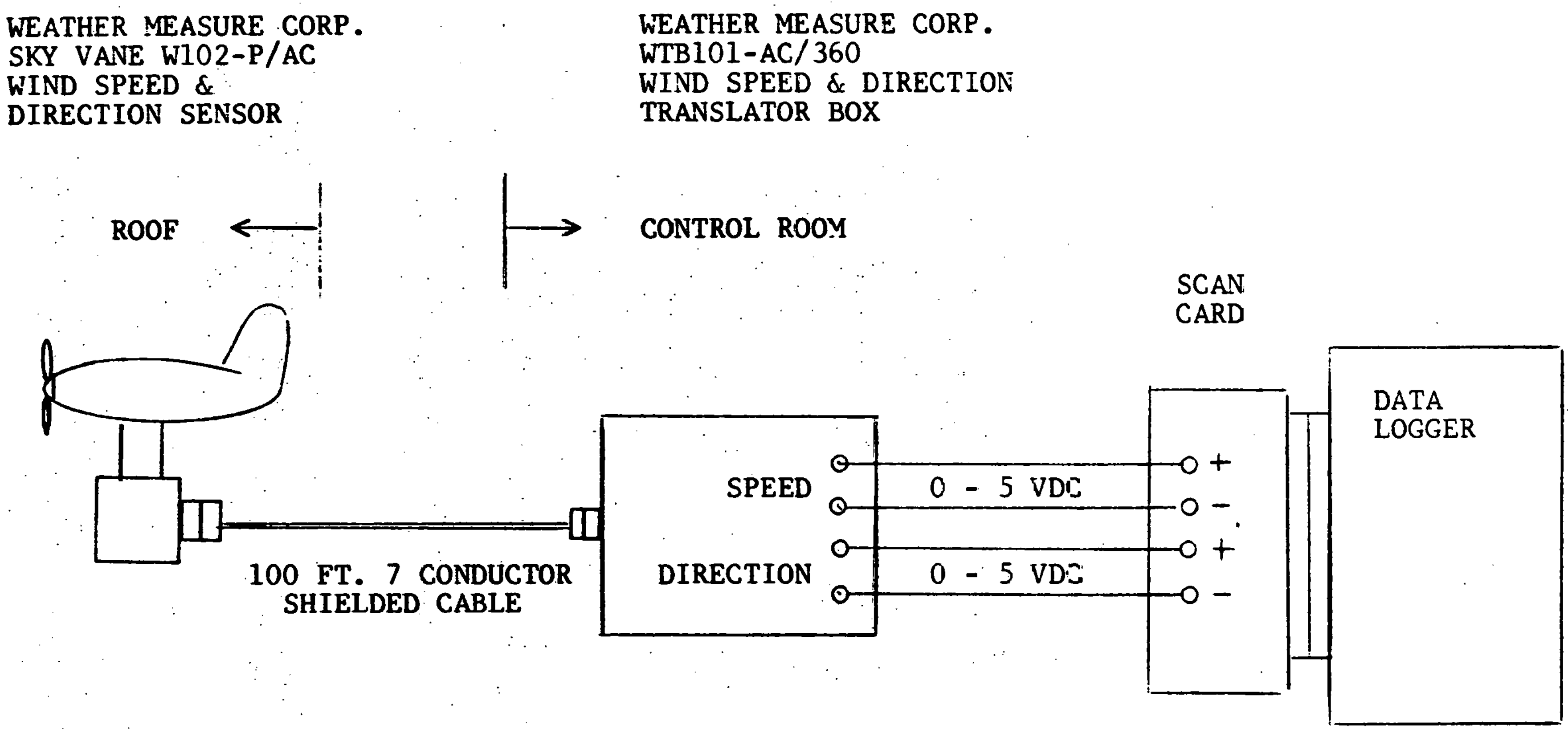

Figure B.6 - WIND INSTRUMENTATION WIRING SCHEMATIC

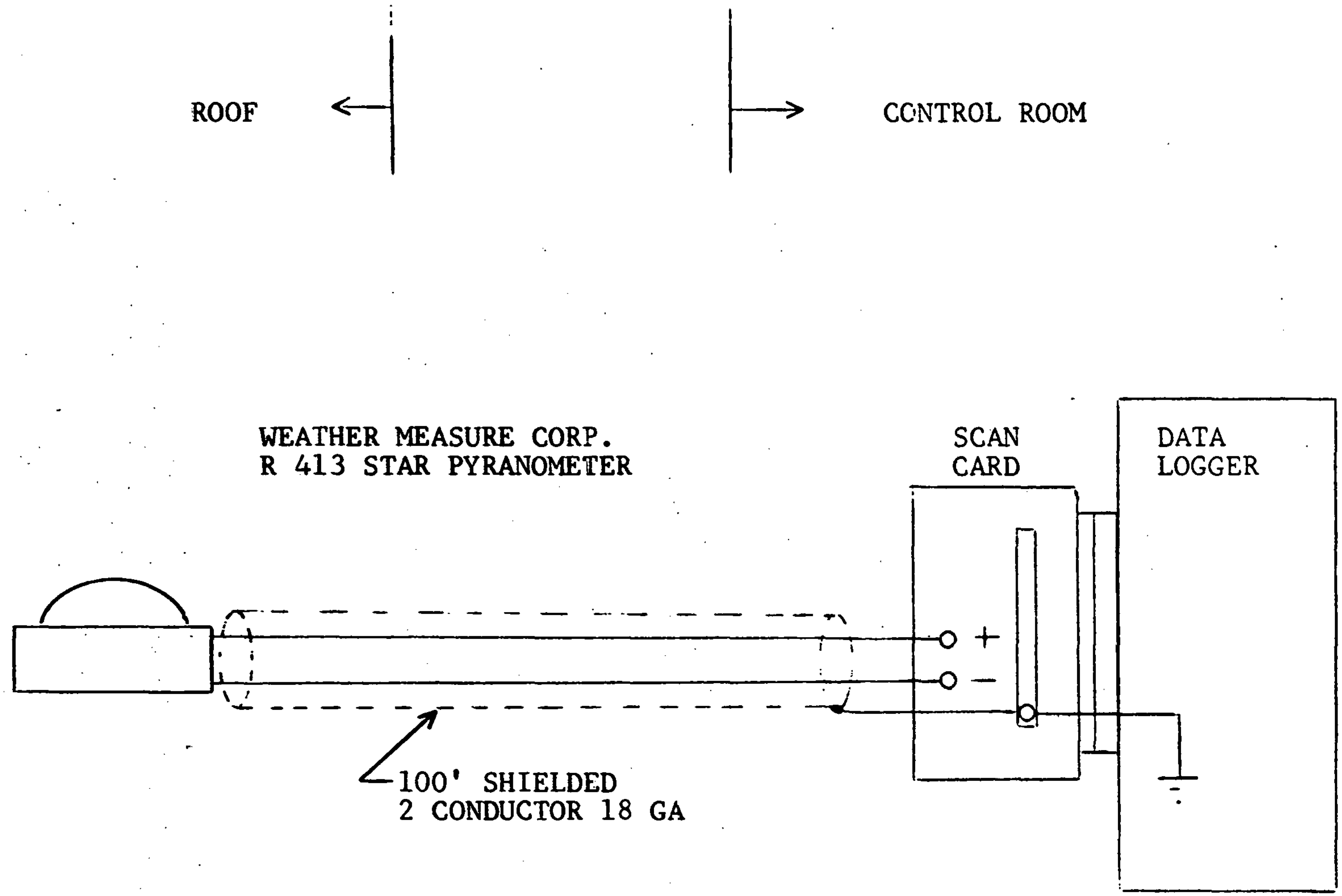

Figure B.7 - SOLAR INSOLATION INSTRUMENTATION WIRING SCHEMATIC

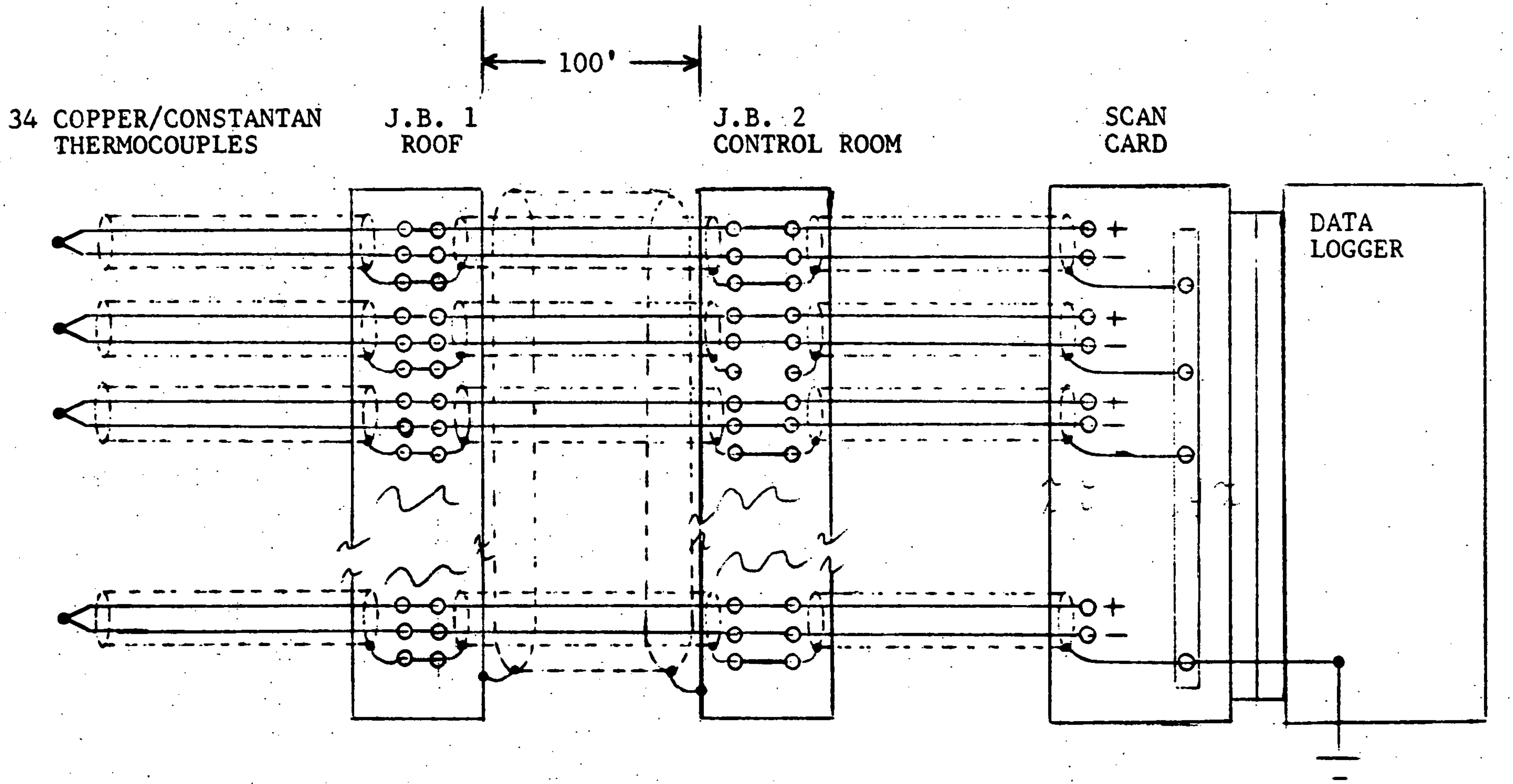

Figure B.8 - THERMOCOUPLE WIRING SCHEMATIC

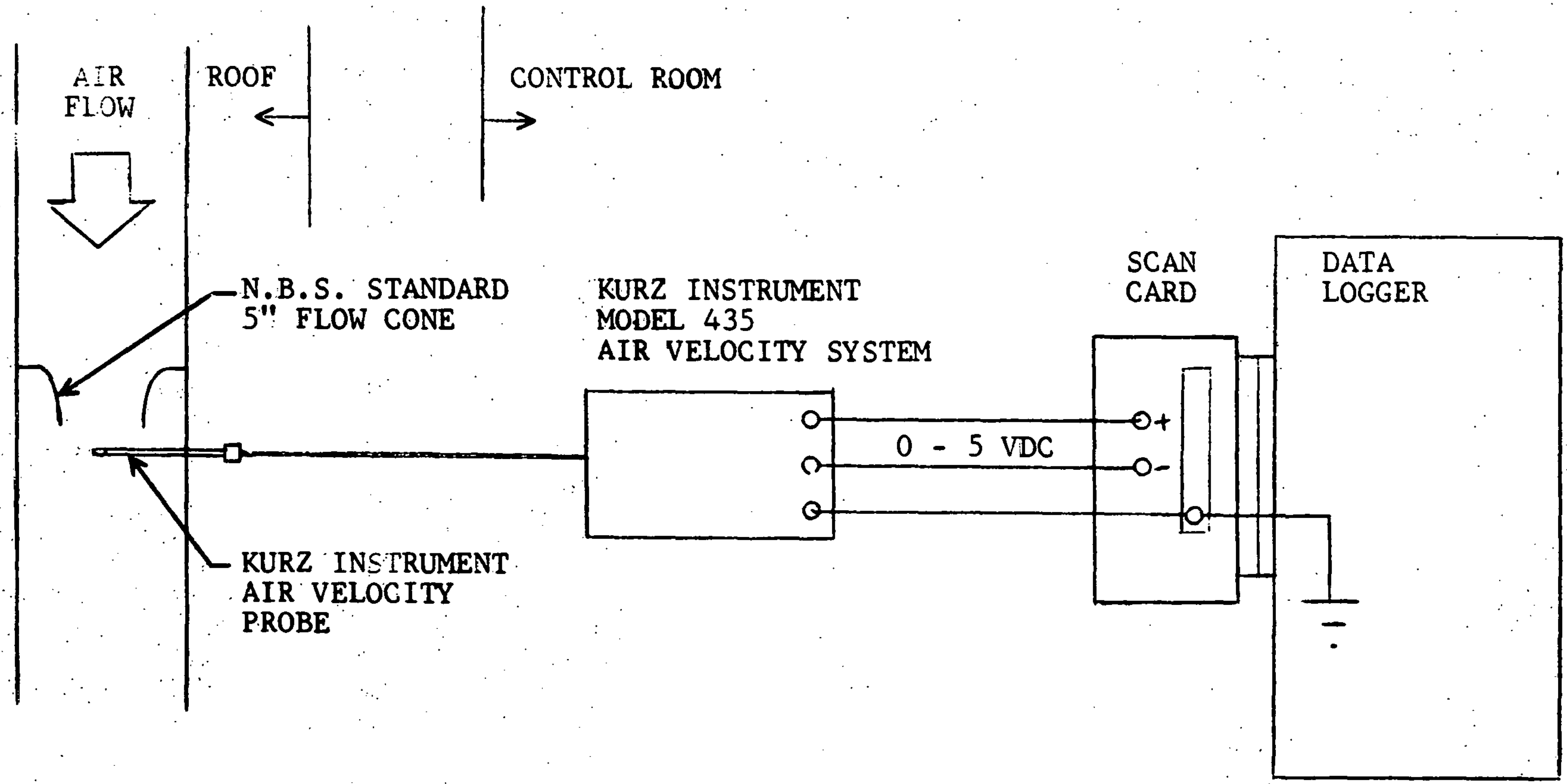

Figure B.9 - AIR FLOW INSTRUMENTATION WIRING SCHEMATIC

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KURZ INSTRUMENT MODEL 435-2 AIR VELOCITY SYSTEM

Description

Kurz Model 435 is a general purpose, bench-top or permanent installation, low-cost velocity and mass flow measurement system operated on line voltage. The output voltage, suitable for recording and other purposes is 0 to 5VDC for several choices of air velocity. The Model 435 has a linear 0-5VDC output voltage suitable for display, recording and totalizing.

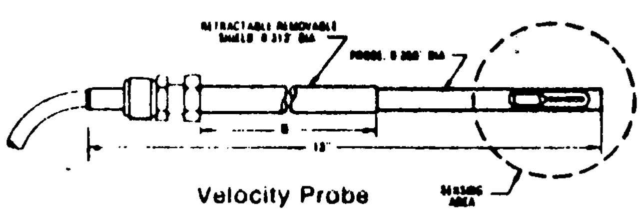
The 435 Air Velocity System comes complete with the unique, rugged "DuraFlo"TM probe, a retractable, removable probe shield, and electronic package housed in a rugged, weather-resistant enameled steel enclosure, 8-foot probe cable, 6-foot power cord, and calibration data. This instrument was ordered with a special 25-foot probe cable.

The Model 435 can be used as an insertion probe in ducts and pipes for the measurement of velocity or total mass flow rate of air flow in a variety of applications.

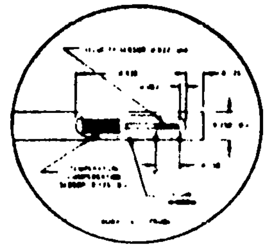
This particular instrument was calibrated beyond the standard 0-1250 fpm range and was found to be both linear and repeatable at velocities up to $\sim$2400 fpm. None of the velocity measurements made during the experiment exceeded 2000 fpm.

SPECIFICATIONS

Model Number (non-linear)	430-1	430-2	430-3	430-4	430-5
Model Number (linear)	435-1	435-2	435-3	435-4	435-5
Velocity ranges (fpm)	0-300	0-1250	0-2500	0-6000	0-12000
Overall accuracy	±2% of full scale over temperature range of 20°C to +60°C. ±5% of full scale over temperature range of 55°C to -20°C and +60°C to +250°C				
Response time	025 second				
Repeatability	±0.25% of full scale				
Output signal	0-5 VDC, 100 OHMS output impedance, barrier strip connections				
Temperature range of probe	-55°C to +125°C standard Model -55°C to +250°C (-HT) Models				
Temperature range Electronics	Operating: 0°C to +50°C Storage: -20°C to +70°C				
Electronic enclosure	Weather resistant enameled steel, 8"L x 6"W x 3.5"H with mounting brackets				
Probe	Nickel-plated brass, ceramic, platinum and epoxy; HT probes are stainless steel, ceramic, platinum and epoxy, 13" long, marked every inch and along axis, probe shield can be used as probe extender to 20"				
Power	115 VAC, 50/60 HZ, 5 watts				
Net weight/Shipping weight	6 lbs. / 8 lbs.				
Metric range option	Add (-M) to Model number and specify 0-1.5, 0-6, 0-15, 0-30 or 0-60mps range				
High temperature option	Add (-HT) to any Model number for operation to 250°C				
Operation at 230 VAC, 50/60 HZ	Add (-X) to any Model number				
Analog readout option (Model 438)	Use with Model 430 (See price list for Description)				
Digital panel meter option (Model 439)	Use with Model 435 (See price list for Description)				
Warranty	1 full year parts and labor				



Velocity Probe



Probe Detail

KURZ INSTRUMENTS INC.

Post Office Box 849 Carmel Valley, Calif. 93924 (408) 659-3421 Telex 337795

W102-P SKYVANE 1 WIND SENSOR

Introduction

The WeatherMeasure Model W102-P Skyvane is a unique wind sensor that combines the features of a rugged instrument coupled with response characteristics not far removed from lightweight cup and vane systems.

The aerodynamic shape of the sensor maintains alignment with the wind direction. A four-bladed low threshold propeller is used to measure the wind velocity.

The propeller of the Skyvane sensor is connected to one of the various rotational velocity transducers, the output of which is fed into the wind speed portion of a translator.

Wind direction is sensed by a potentiometer or a selsyn motor located in the base of the Skyvane, providing a voltage indicative of the sensor direction.

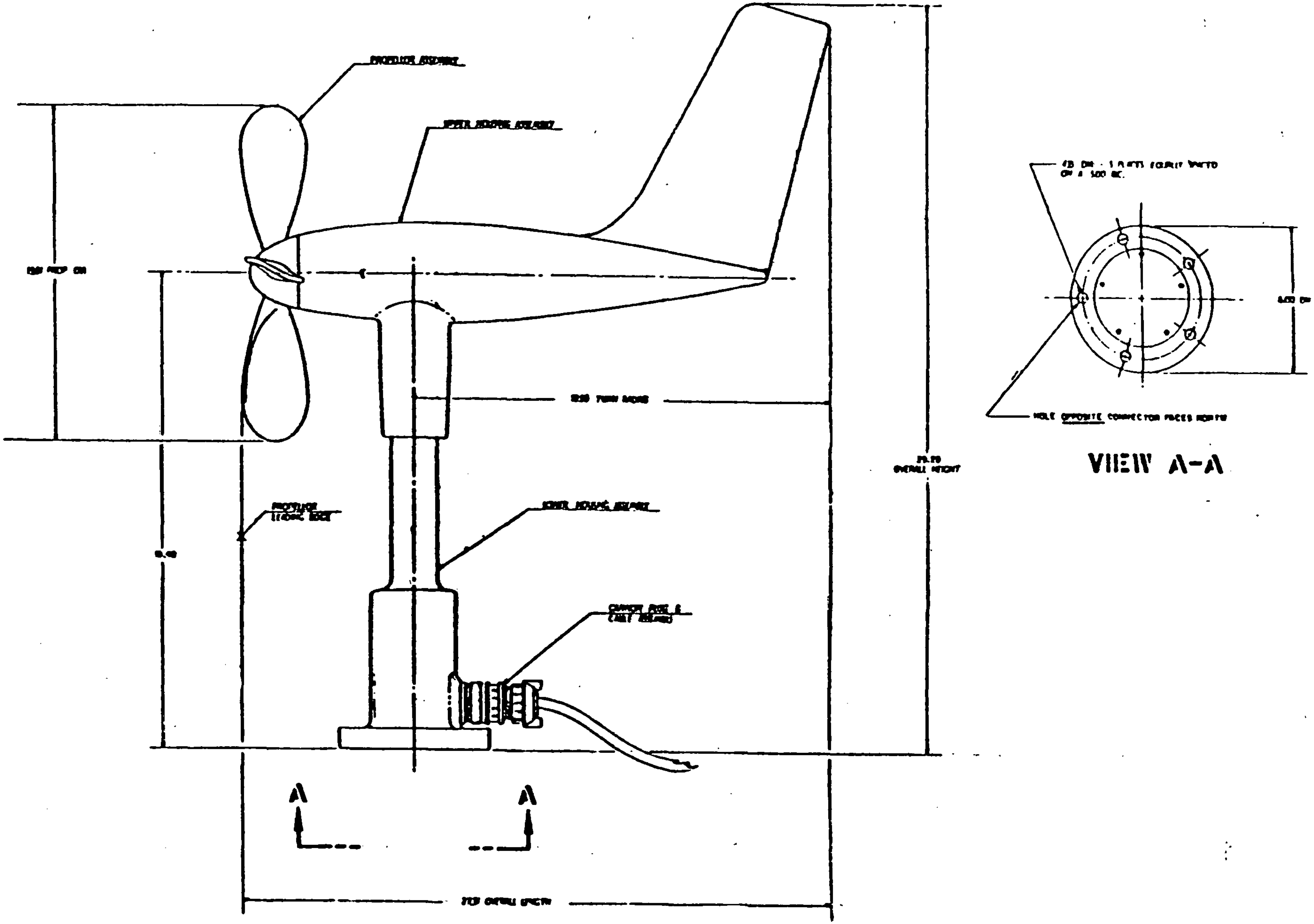
The sensor must be connected to an electronics package (translator) in order to provide necessary voltages and output scaling to permit indication of speed and direction and/or recording of these values.

Description

For general purpose applications, the wind speed transducer most commonly supplied is a permanent magnet type AC generator. Its advantage over the DC generator is that it does not contain brushes and therefore can be expected to operate longer before maintenance is required. The output voltage of this unit is proportioned to wind speed. Slip rings transmit the transducer output voltage to terminals in the base of the sensor. Other transducers which may be supplied are a DC generator or a frictionless high frequency tachometer consisting of a notched disk rotating between an oscillator and receiver. The HF tachometer produces a series of square wave output pulses proportional to wind speed.

The wind direction transducer generally supplied with Skyvane sensors is a circular, dual wiper potentiometer whose input voltage is supplied by an external translator. The output voltages may be recorded as wind direction from 0 to 360° where a single wiper is used. When both wipers are used and connected to an appropriate translator, wind direction may be recorded as 0 to 540° (0-90°-180°-270°-360°-90°-180°). This eliminates painting of strip charts when the wind direction is oscillating about North. Some models use a DC or AC selsyn motor in place of the potentiometer.

Both the propeller shaft and the main body shaft are supported on lubricated stainless steel ball bearings. Labyrinthes are provided to prevent the entry of moisture. The wind sensor is constructe of stainless steel, brass, fiberglass reinforced plastic and other corrosion resistant materials. For most precise results, particularly at low wind speeds, wind tunnel calibrations should be performed at periodical intervals (1 to 2 years) depending upon the environment in which the sensor is used.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WTB102-AC-360
WIND TRANSLATOR

I. General Information

A. Description

The WTB102-AC-360 provides interfacing for wind direction sensor W104-360 and wind speed sensor W102-AC-360. Wind speed has been scaled to 0 - 100 MPH corresponding to an output of 0 - 5VDC.

The input from the wind speed sensor is processed by a tachometer technique and thus is not affected by normal levels of line noise or resistance of long leads. The wind direction circuit is regulated with a zero temperature coefficient zener at the sensor. The high common mode rejection of the input buffers virtually eliminates the effect of noise pickup and resistance variations even in very lone lines.

The output circuit is designed so the user can obtain the standard 0-5 volt output under all conditions and has a choise of auxiliary 0-1 volt or 0-1 ma recorder output. A range switch is provided so that good resolution can be obtained at low wind speeds. An additional front panel switch allows the output to be switched easily between zero and full scale so that the user may conveniently adjust recorder offset and sensitivity. Power may be provided either by an external battery or 115/230 volt battery eliminator.

Specifications

1. Linearity and Accuracy

- WIND DIRECTION (Approximately 0.7 degrees for a 360 degree range)	±0.2% of indicated value, ±0.5F.S.
- WIND SPEED	± 0.3% of indicated value, ±0.1% F.S.

2. Environmental

- SUPPLY VOLTAGE SENSITIVITY (for full scale input)	0.005V/V
- TEMPERATURE SENSITIVITY (total variation over range +35 to +135F)	0.05%
- COMMON MODE REJECTION	CMRR 40Db

3. Outputs

- VOLTAGE (Rsource 1 ohm)*	0-5 volts

- VOLTAGE (Rsource 5K ohm) 0-1 volts

(one of either)

- CURRENT (Rsource = 5K) 0-1ma

*LOW IMPEDANCE VOLTAGE OUTPUT
MAY BE RECALIBRATED TO 0-1 VOLT

4. Power

- BATTERY ELIMINATOR 115V/230V
55/60 Hz

R413 STAR PYRANOMETER

Description

An improved pyranometer; replaces the model R411 Pyranometer. The R413 is a sturdy pyranometer, developed to measure solar and scattered radiation (global radiation) and reflected radiation from the earth's surface (albedo) in the wave range from 0.3-3 The output signal is in mV and can be directly translated into gm-cal/cm^2/min; or mW/cm^2. A thermopile of 72 CrNi-Constantan junctions is in thermal contact with 12 alternately black and white painted Cu-segments. The temperature difference between the highly absorbtive black and the highly reflective white segments creates a thermopower of approximately 8mV per gm-cal/cm^2/min.

The sensitive element, 38mm in diameter, is mounted on a white plate, with a bull's eye level mounted in the same plane as the sensitive plate for exact exposure of the instrument. A ground crystal glass cover of 70mm diameter protects the sensitive plate from influences of the weather. A dessicant container in the housing prevents condensation within the instrument.

Application

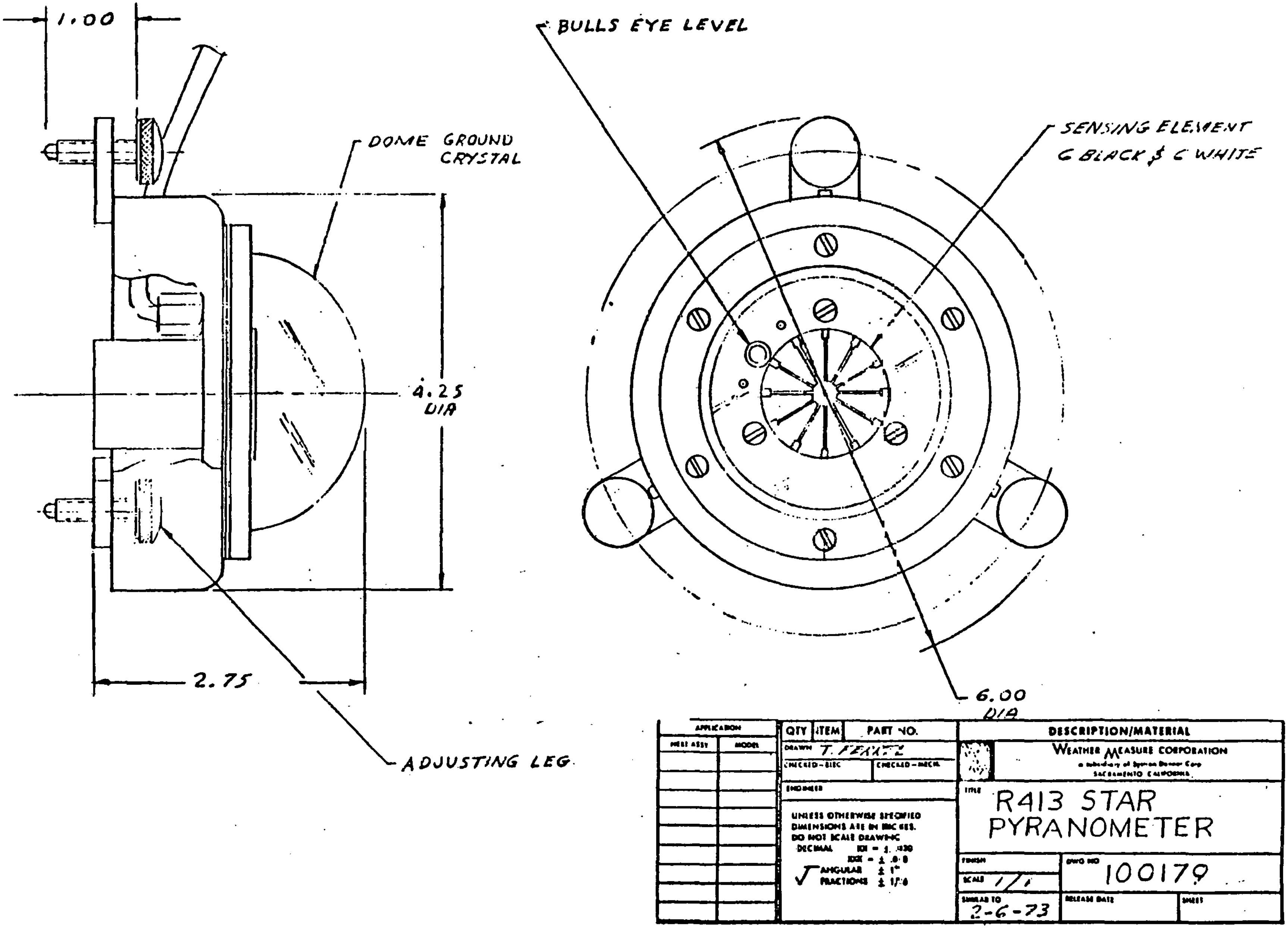
Used for continuous recordings and spot measurements of the solar and scattered radiation and the reflected solar radiation (albedo). This sturdy type instrument makes it particularly useful for measurements in the field. Frequent use in agrometeorology and forest science. Proven also in strictly meterological networks.

Specifications

Sensor

Size	13.5 cm. in diameter, 9 cm. in height
Weight	870 gm. (1.9 lbs.)
Special Response	0.3 ≅ 3 microns
Sensitivity	*1mV per 2.03517 btu/hr/ft^2
Instrument Orientation	Upward, downward or side facing
Impedance	Approximately 35 ohms
Response Time	Approximately 50 sec. full scale
Leveling	Adjusting legs and bull's eye level
Sensing Element	6 black and 6 white segments with thermopile thermal contact
Thermopile	72 junctions CrNi-Constantan
Dome	7 cm (2-3/4") diameter ground crystal glass

* Certified by: Phillip Schenk
Ges. m.b.h. Wien & Co., K.G.
1212 Wien XXI


1.00
DOME GROUND CRYSTAL
4.25 DIA
2.75
ADJUSTING LEG
BULLS EYE LEVEL
SENSING ELEMENT
6 BLACK & 6 WHITE
6.00 DIA
APPLICATION
NEXT ASSY
MODEL
QTY
ITEM
PART NO.
DESCRIPTION/MATERIAL
DRAWN
CHECKED-ELEC
CHECKED-MECH
ENGINEER
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
DO NOT SCALE DRAWING
DECIMAL
ANGULAR
FRACTIONS
WEATHER MEASURE CORPORATION
SACRAMENTO CALIFORNIA
TITLE
R413 STAR PYRANOMETER
FINISH
SCALE 1/1
DWG NO 100179
SIMILAR TO
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RELEASE DATE
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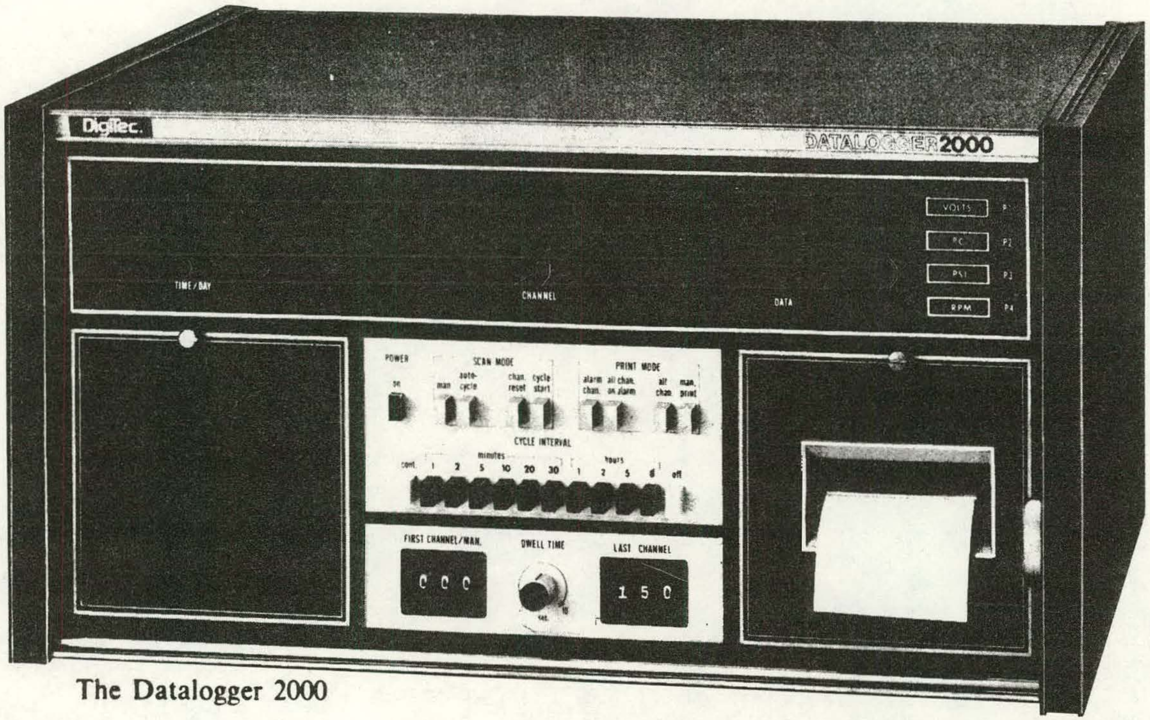

The Datalogger 2000

1.1. GENERAL DESCRIPTION

The Digitec Datalogger 2000 is a powerfully simple data-acquisition system designed with you, the user, in mind. It puts at your fingertips all the performance you need for your application. You can monitor, measure and display up to 1000 channels out of a selection of 32 different parameters (temperature, pressure, etc.) — up to four internally. And you can permanently record this data for future analysis along with time, Julian Date and parameter symbols in engineering units.

We designed the entire instrument around a microprocessor for the power and versatility it affords you. And we added the extra benefit of simple operation. A standard (or custom, as you require), preprogrammed instruction set supervises and controls your system's operation for you. Even the powerful Alarm Option is accessed through a simple, familiar calculator-type keypad. There is no confusing sequence of switches and buttons or complicated programming procedure to master.

The designer-styled enclosure emphasizes the human engineering and quality that is evident throughout the Datalogger 2000. A simple, refined front panel provides easy access to the few controls you need to operate your instrument. These controls are clearly labeled and logically placed for easy understanding and use. The standard case is made of durably-finished, extruded and die-cast aluminum for strong, lightweight protection of your Datalogger. And rear bumpers help protect the instrument and adjacent surfaces from nicks and scratches.

For additional versatility, plug-in circuit boards such as Scan Cards, Signal-Conditioner Cards and Options provide the flexibility necessary to meet the changing demands of Today's applications. So you can easily expand or adapt your Datalogger 2000 as your needs change or grow.

1.2 FEATURES AND BENEFITS

Your Datalogger 2000 is a powerful data-acquisition system that gives you the following outstanding features and benefits:

- 1000 channel capacity, expandable in groups of ten.
- 32 different Signal-Conditioner Cards to choose from to match your requirements exactly.
- Multiple parameter (temperature, pressure, etc.) capability for low-cost, comprehensive monitoring (4 parameters internal, up to 23 total) of your process or test.
- Preprogrammed microprocessor control for simple operation.
- Quiet, alphanumeric printer permanently records your data in your language (letters, numerals and symbols).
- Crystal-controlled Time-Of-Day and Julian Date clock.
- 1360 separate limits, up to four per channel, for alarm monitoring.
- Six-character, English messages (up to 680) to identify alarm status indications.
- Crystal-controlled, Analog-to-Digital conversion (as opposed to power line frequency with transients) for high-accuracy measurements.
- 3-wire (HI, LO, GUARD) input terminations for greatest common mode voltage rejection.
- Input filtering and integrating A/D for high normal mode rejection of noise.
- Skip-channel capability for improved system throughput and concise records.
- 25,000 count LED display of measured data (with BCD input, six full digits without polarity sign or five with polarity sign).
- Optically-isolated, RS-232-C and current loop interfaces for TTYs, modems and computers.
- Optically-isolated BCD data input/output for interfacing with peripheral instruments.

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APPENDIX C: COMPUTER PROGRAMS

For this project an Apple Computer with 32k memory, two floppy disk drives and a video controller were used to process and analyze the test data from the bare plate solar collector systems. Three computer programs, i.e., INSOLATION, DATALOGGER and ANALYSIS, were written for this purpose. The listings are included as part of this appendix.

INSOLATION: This program was used to calculate clear day solar radiation data for the specific location of the test site, which was Cleveland, Ohio. The method of calculation was based on the equations and data presented in Reference 3 . A listing of this program and a list of the variables and their definition is presented in Table C.1.1. The resultant clear day insolation for Cleveland is tabulated in Table C.1.2. This information was used to determine a tilt factor that corrected the measured horizontal insolation value to that for the tilted surface of the frame and tube test collectors. These tilt factors are shown in Figure C.1.3. Although hourly factors were calculated, their values did not differ significantly from the six hour daily average value, so only one value for each test day was used. The tube value differs from the frame value because the tube always shows the maximum surface area to the beam radiation component. Since most test data were obtained for relatively clear conditions the effect of changes in the beam to diffuse radiation components was not considered.

DATALOGGER: A program that provides communication between the Datalogger and the Apple Computer. The program accesses the Datalogger, transmits the information, identified by a channel number, to the computer memory and then stores the information on a disk. A complete scan of data is acquired every two minutes. The typical one-half hour test run contains fifteen complete sets of data. A listing of this program and the variables associated with it and the ANALYSIS program is presented in Table C.2.

ANALYSIS: This program utilizes the raw data acquired by the DATALOGGER program and calculates a heat and material balance for each set of data representing a two minute data scan. From this the efficiency of the system is determined. The program then averages the data for a typical thirty minute test run and presents both the individual results and the summary results. These results are tabulated in Appendix D. A listing of this program is presented in Table C.3.

TABLE C.1.1 - INSOLATION

Variable List

A	Monthly Insolation Value	Btu/hr/ft^2
AL	Local Altitude	ft
B	Atmospheric Coefficient	
C	Diffuse Coefficient	
CO	Cosine of Incidence Angle	
D	Solar Declination	degree
DEg	Latitude	degree
DR	Solar Declination	radian
D$	CTRL D - file manipulation	
H	Hours form Solar Noon	hours
HIa	Horizontal Incidence Angle	radian
HR	Hour Angle from Solar Noon	radian
IDn	Normal Insolation	Btu/hr/ft^2
ITh	Horizontal Insolation	Btu/hr/ft^2
LR	Latitude	radian
M	Air Mass	
MIn	Latitude	minute
MO	Month	
OA$	Disk File Name	
OB$	"	
OC$	"	
OD$	"	
RA$	"	
RB$	"	
RC$	"	
RD$	"	
S1	Sum for Yearly Insolation (Normal)	
S2	" (Horizontal)	
S3	" (Tilt)	
S4	Sum for Daily Insolation (Normal)	
S5	" (Horizontal)	
S6	" (Tilt)	
SA1	Solar Altitude	radian
SD	Solat Altitude	degree
SZz	Solar Azimuth	radian
T	Tilt Angle	degree
TR	Tilt Angle	radian
TTi	Tilt Insolation	Btu/hr/ft^2
ZD	Solar Azimuth	degree
ZZ	Check End of Day	
Z$	Temporary Input	

```
0  REM *** INSOLATION ***********
1  REM
2  REM **************************
10  PRINT  CHR$ (4);"MAXFILES 4"
100  REM ---ESTABLISH FILE VARIABLES
110 OA$ = "OPEN MON INS VAL,S1"
111 RA$ = "READ MON INS VAL"
120 OB$ = "OPEN ATM COF,S2"
121 RB$ = "READ ATM COF"
130 OC$ = "OPEN DIF COF,S3"
131 RC$ = "READ DIF COF"
140 OD$ = "OPEN SOL DEC,S4"
141 RD$ = "READ SOL DEC"
200  REM ---INPUT LOCAL DATA
210  HOME
220  PRINT "LOCAL LATITUDE";: HTAB 20
225  INPUT "DEG  ";DEG
230  HTAB 20: INPUT "MIN  ";MIN
240 LR = (DEG + MIN / 60) * .017453
250  VTAB 5: PRINT "LOCAL ELEVATION";: HTAB 20
255  INPUT "FEET ";AL
260  VTAB 10: PRINT "TILT ANGLE";: HTAB 20
265  INPUT "DEG  ";T
270 TR = T * .017453
400  REM ---OPEN CONSTANT FILES
410 D$ =  CHR$ (4)
420  PRINT D$;"OPEN MON INS VAL"
430  PRINT D$;"OPEN ATM COF"
440  PRINT D$;"OPEN DIF COF"
450  PRINT D$;"OPEN SOL DEC"
460  PRINT D$;"READ MON INS VAL": INPUT Z$: INPUT Z$
465  PRINT D$;"READ ATM COF": INPUT Z$: INPUT Z$
470  PRINT D$;"READ DIF COF": INPUT Z$: INPUT Z$
475  PRINT D$;"READ SOL DEC": INPUT Z$: INPUT Z$
500  REM ---BEGIN LOOP  MO=MONTH
502 S1 = 0:SUM2 = 0:SUM3 = 0: REM   SUM YEARLY INS
505  FOR MO = 1 TO 12
600  REM ---ACCESS CONSTANTS
610  PRINT D$;"READ MON INS VAL"
615  INPUT Z$:A =  VAL (Z$)
620  PRINT D$;"READ ATM COF"
625  INPUT Z$:B =  VAL (Z$)
630  PRINT D$;"READ DIF COF"
640  INPUT Z$:C =  VAL (Z$)
650  PRINT D$;"READ SOL DEC"
655  INPUT Z$:D =  VAL (Z$)
670 DR = D * .017453
680  REM ---BEGIN LOOP  H=HOURS FROM SOLAR NOON
685 S4 = 0:S5 = 0:S6 = 0: REM  SUM DAILY INS
690  FOR H = 7 TO 0 STEP  - 1
695 HR = H * 15 * .017453
700  REM ---CALCULATE SOLAR ALTITUDE (SAL)
710 SAL =  COS (LR) *  COS (DR) *  COS (HR) +  SIN (LR) *  SIN (DR)
720 SAL =  ATN (SAL /  SQR ( - SAL * SAL + 1))
730 SD = SAL / .017453
740  IF SD < 5 THEN 1315: REM  CHECK SUNRISE
750  REM ---CALC AIR MASS
755  REM ---ASSUME DROP 1" PER 1000'
760 M = (29.92 - AL / 1000) / 29.92 /  SIN (SAL)
```

```
800  REM ---CALC SOLAR AZIMUTH (SZZ)
810 SZZ =  COS (DR) *  SIN (HR) /  COS (SAL)
820 SZZ =  ATN (SZZ /  SQR ( - SZZ * SZZ + 1))
830 ZD = SZZ / .01745
850  REM ---CALC NORMAL INSOLATION (IDN)
860 IDN = A /  EXP (B * M)
900  REM ---CALC HORIZONTAL INSOLATION (ITH)
910 HIA = (90 - SD) * .017453
920 ITH = IDN * ( COS (HIA) + C)
950  REM ---CALC TILT INSOLATION (TTI)
955  REM ---ASSUME SOUTH FACING
960 CO =  COS (SAL) *  COS (SZZ) *  SIN (TR) +  SIN (SAL) *  COS (TR)
970 TTI = IDN * (CO + C)
979  REM ---SUM DAILY INS
980 S4 = S4 + IDN:S5 = S5 + ITH:S6 = S6 + TTI
1000  REM ---PRINT RESULTS
1010  HOME
1020  HTAB 15: PRINT "MONTH ";MO
1030  VTAB 3
1033  IF ZZ = 1 THEN  GOSUB 2000
1035  HTAB 4
1040  IF H = 0 THEN  PRINT "     HOUR  12 NOON SOLAR TIME"
1050  IF H <  > 0 THEN  PRINT "HOUR  ";12 - H;" AM   ";H;" PM SOLAR TIME"
1100  VTAB 6
1105  IF ZZ = 1 THEN 1170
1110  PRINT "SOLAR POSITION";
1120  HTAB 20
1130  PRINT "ALT   ";
1132  PRINT  INT (SD * 10 + .5) / 10;
1134  HTAB 32: PRINT "DEG"
1140  HTAB 20
1150  PRINT "AZM   ";
1152  PRINT  INT (ZD * 10 + .5) / 10;
1154  HTAB 32: PRINT "DEG"
1160  PRINT
1170  PRINT "INSOLATION";: HTAB 20
1175  PRINT "NRM   ";
1180  PRINT  INT (IDN + .5)
1190  HTAB 5: PRINT "BTU/HR/SQFT";: HTAB 20
1195  PRINT "HRZ   ";
1200  PRINT  INT (ITH + .5)
1210  HTAB 20: PRINT "TILT  ";
1215  PRINT  INT (TTI + .5)
1300  REM ---PAUSE,CLOSE MONTH LOOP
1305  PRINT D$
1312  INPUT Z$
1313  IF H = 0 AND ZZ = 0 THEN ZZ = 1: GOTO 1000
1315  NEXT H
1317  GOSUB 3000
1320  NEXT MO
13[illegible]  PRINT D$;"CLOSE"
```

```
1400  REM ---PRINT YEARLY SUMMARY
1410  HOME
1420  PRINT "AVERAGE DAILY INSOLATION FOR YEAR"
1425  HTAB 10: PRINT "BTU/DA/SQFT"
1430  VTAB 4: HTAB 10
1440  PRINT "NRM   "; INT (S1 / 12 + .5)
1450  HTAB 10
1460  PRINT "HRZ   "; INT (S2 / 12 + .5)
1470  HTAB 10
1480  PRINT "TILT  "; INT (S3 / 12 + .5)
1490  VTAB 10
1500  PRINT "TOTAL YEARLY INSOLATION"
1502  HTAB 10: PRINT "BTU/YR/SQFT"
1505  VTAB 13
1510  HTAB 10
1520  PRINT "NRM   "; INT (S1 * 365 / 12 + .5)
1530  HTAB 10
1540  PRINT "HRZ   "; INT (S2 * 365 / 12 + .5)
1550  HTAB 10
1560  PRINT "TILT  "; INT (S3 * 365 / 12 + .5)
1600  REM ---RETURN TO MAIN MENU
1610  VTAB 22: HTAB 35
1620  GET A$
1630  PRINT  CHR$ (4);"RUN MENU"
1640  PRINT  CHR$ (4);"RUN MENU"
1999  END
2000  REM ---PRINT HEADING FOR DAILY SUMMARY
2030  HTAB 13
2040  PRINT "DAILY SUMMARY"
2050 IDN = S4 * 2 - IDN
2060 ITH = S5 * 2 - ITH
2070 TTI = S6 * 2 - TTI
2080  RETURN
3000  REM ---SUM YEARLY INS
3010 ZZ = 0: REM ---RESET FLAG FOR DAILY SUM
3020 S1 = S1 + S4
3030 S2 = S2 + S5
3040 S3 = S3 + S6
3050  RETURN
```

TABLE C.1.2

CLEAR DAY INSOLATION

CLEVELAND, OHIO 41°24', 805 FT.

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	SOLAR INSOLATION BTU/HR,FT² NORMAL	HORIZONTAL	45°	VERTICAL
Jan 21	8	4	7.3	55.2	132	25	72	82
	9	3	15.9	43.7	235	78	175	177
	10	2	22.7	30.6	273	121	243	232
	11	1	27.1	15.9	288	148	284	263
	12	12	28.7	0	293	157	298	274
	DAILY TOTALS				2149	901	1846	1782
Feb 21	7	5	4.0	72.1	51	7	17	19
	8	4	14.4	61.5	218	67	123	114
	9	3	23.6	49.3	271	125	207	178
	10	2	31.1	35.0	294	169	270	223
	11	1	36.2	18.4	304	198	309	251
	12	12	38.0	0	307	207	323	261
	DAILY TOTALS				2583	1339	2175	1831
Mar 21	7	5	11.2	80.0	172	46	57	42
	8	4	22.0	69.1	251	112	143	101
	9	3	32.0	56.5	282	170	219	152
	10	2	40.5	41.1	298	214	278	192
	11	1	46.4	22.1	305	243	316	216
	12	12	48.7	0	307	252	328	225
	DAILY TOTALS				2923	1822	2354	1631
Apr 21	6	6	7.8	99.0	100	23	30	0
	7	5	19.0	90.6	210	89	71	23
	8	4	30.2	78.7	254	153	145	68
	9	3	40.9	66.4	276	207	213	110
	10	2	50.5	50.3	287	249	267	144
	11	1	57.7	28.3	293	276	301	166
	12	12	60.5	0	294	285	312	174
	DAILY TOTALS				3134	2279	2366	1196
May 21	5	7	2.7	114.9	6	1	3	0
	6	6	13.3	105.5	152	53	71	0
	7	5	24.3	96.3	220	117	106	0
	8	4	35.5	86.5	252	177	143	43
	9	3	46.6	74.9	269	228	205	81
	10	2	57.0	59.4	279	268	254	111
	11	1	65.4	35.6	284	292	285	130
	12	12	68.9	0	285	301	295	137
	DAILY TOTALS				3209	2573	2432	867

DATE	SOLAR TIME		SOLAR POSITION		SOLAR INSOLATION BTU/HR,FT^2			
	AM	PM	ALT	AZM	NORMAL	HORIZONTAL	45°	VERTICAL
Jun 21	5	7	4.9	117.2	33	7	17	0
	6	6	15.3	108.1	162	64	86	0
	7	5	26.2	99.1	220	126	120	0
	8	4	37.4	89.7	248	184	141	35
	9	3	48.6	78.6	264	234	200	70
	10	2	59.2	63.7	274	272	247	99
	11	1	68.1	39.6	278	295	276	117
	12	12	72.1	0	280	304	287	124
	DAILY TOTALS				3238	2668	2461	766
Jul 21	6	6	13.4	105.7	144	53	70	0
	7	5	24.4	96.5	211	116	106	0
	8	4	35.7	86.7	243	175	142	45
	9	3	46.8	75.2	261	226	202	81
	10	2	57.1	59.7	271	164	250	111
	11	1	65.5	35.8	276	288	280	130
	12	12	69.1	0	277	297	291	137
	DAILY TOTALS				3090	2541	2391	1086
Aug 21	6	6	8	99.1	86	22	28	0
	7	5	19.2	90.6	194	87	70	26
	8	4	30.4	78.9	238	150	142	69
	9	3	41.1	66.5	261	203	208	110
	10	2	50.7	50.5	273	244	260	143
	11	1	57.9	28.4	279	270	293	164
	12	12	60.7	0	280	279	304	171
	DAILY TOTALS				2939	2232	2308	1242
Sep 21	7	5	11.2	80	150	43	53	40
	8	4	22	69.1	231	108	136	97
	9	3	32	56.5	264	164	210	148
	10	2	40.5	41.1	280	208	268	186
	11	1	46.4	22.1	288	235	304	210
	12	12	48.6	0	290	244	316	219
	DAILY TOTALS				2715	1759	2258	1581
Oct 21	8	4	14.2	61.4	201	64	115	108
	9	3	23.5	49.2	256	121	199	172
	10	2	31	35	279	164	261	217
	11	1	36.1	18.3	290	192	299	244
	12	12	37.9	0	293	202	313	253
	DAILY TOTALS				2345	1284	2062	1733
Nov 21	8	4	7.3	55.2	124	24	69	78
	9	3	15.9	43.7	228	77	170	173
	10	2	22.7	30.6	266	119	238	228
	11	1	27.1	15.9	282	146	279	259
	12	12	28.7	0	286	155	293	269
	DAILY TOTALS				2085	887	1806	1744
Dec 21	9	3	12.9	41.7	211	59	154	165
	10	2	19.4	29.1	258	101	226	227
	11	1	23.7	15	277	127	268	261
	12	12	25.2	0	282	136	282	272
	DAILY TOTALS				1774	710	1577	1579

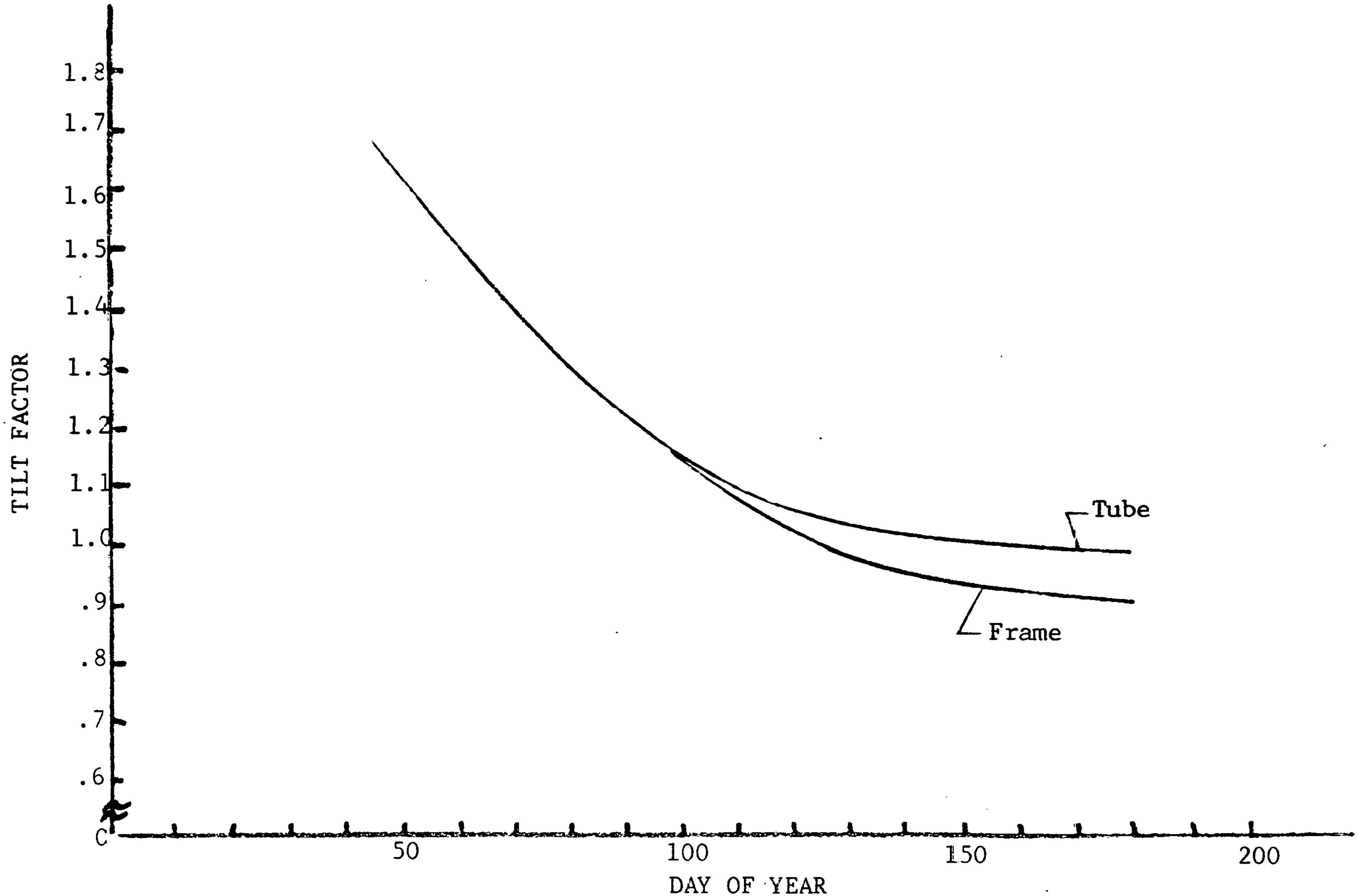

Figure C.1.3 - TILT FACTORS

TABLE C.2

SUMMARIZE DATALOGGER DATA (DAVE8)

Variable List

A45	Area of Frame Collector	ft^2
ACy	Area of Tube Collector	ft^2
A$	Temporary Input	
CA	Flow Cone Exhaust Area	ft^2
DE	Air Density	lb/ft^3
DL	Delay Between Scans	
D$	CTRL D - file manipulation	
DS$	Data Characters	
DT$	Date	
E45	Thermal Efficiency of Frame Array	
ECy	Thermal Efficiency of Tube Array	
E$	Disk File Name	
F45	Tilt Factor for Frame Collector	
FA	Frame Exhaust Area	ft^2
FCy	Tilt Factor for Tube Collector	
F$	Disk File Name	
HC	Air Heat Capacity	Btu/lb/^oF
NC	Number of Channels	
NS	Number of Scans	
QF	Frame Heat Transfer	Btu/hr
QT	Tube Heat Transfer	Btu/hr
T1	Ambient Temperature (ch0)	^oC
T2	Ambient Temperature (ch1)	^oC
TA	Average Ambient Temperature	^oF
TI	Time	
TT	Flow Cone Exit Air Temperature (ch2)	^oF, ^oC
TM$	Time	
S45	Solar Insolation for Frame	$Btu/hr/ft^2$
S	Solar Radiation (ch16)	$Btu/hr/ft^2$
SCy	Solar Insolation for Tubes	$Btu/hr/ft^2$
SUm()	Sums of Measurements	
V	Flow Cone Exit Velocity (ch37)	ft/min
VF	Frame Exit Velocity	ft/min
VL	Value of Data	
WD	Wind Direction (ch35)	1-100
WS	Wind Speed (ch15)	mi/hr
Z	Counter	
ZZ	Counter	
Z$	Temporary Input	

```
0  REM ---LOG DATA
1  REM ---CH SEQ-0-1-2-16-39-15-35-37
2  REM ---MERGED WITH DATA SCAN
10  HOME
20  PRINT "      TIME-BASE DATA SCAN"
30  VTAB 4: INPUT "DATE (MM/DD/YY)";DT$
35 DT$ = DT$ + "-"
40  INPUT "TIME (0000-2400) EST";TM$:TM =  VAL ( LEFT$ (TM$,4))
50  INPUT "SCAN DELAY (MINUTES)";DL
60  INPUT "NUMBER OF DATA SCANS";NS
89  REM ---GOTO INIT ROUTINE---
90  GOTO 5000
99  REM --ESTABLISH CHANNEL/VARIABLE ASSIGNMENT
100 AR(1) = 0:AR(2) = 1
101 AR(5) = 39:AR(6) = 15
102 AR(3) = 2:AR(4) = 16
103 AR(7) = 35:AR(8) = 37
108 NC = 8: REM  NUMBER OF CHANNELS
110 RP = 1: REM  REPEAT COUNT
111 E$ = "OPEN DATA" + DT$ + TM$: PRINT D$;E$
112 F$ = "DELETE DATA" + DT$ + TM$: PRINT D$;E$
113  PRINT D$;E$
114 F$ = "WRITE DATA" + DT$ + TM$: PRINT D$;F$
115  PRINT DT$: PRINT TM$: PRINT DL: PRINT NS
116  FOR SN = 1 TO NS
120  FOR J = 1 TO RP
130  FOR K = 1 TO NC:CH = AR(K)
131 S$ = B$ + "0" +  STR$ (CH)
132  IF CH < 10 THEN S$ = B$ + "00" +  STR$ (CH)
133  IF CH <  > LC THEN  GOSUB 1000
134  IF CH = LC THEN  GOTO 180
135 LC = CH
136  REM
137  REM  NOW LET CHANNEL "SETTLE"
138  REM
139  FOR I = 1 TO ST: NEXT I
150  REM
160  REM  SEND CTRL-Q TO READ DATA
170  REM
180 S$ = Q$
190  GOSUB 2000
191  NEXT K: NEXT J
195  IF SN = NS THEN 240
200  REM ---DELAT BETWEEN READS---
210  REM ---40000=1MIN
218 YY = 2500
219 XX = 20000
220  FOR I = 1 TO XX * DL - YY: NEXT I
230  NEXT SN
240  PRINT D$;"CLOSE"
250  PRINT D$;"RUN MENU"
```

```
1000  REM
1001  REM  SEND STRING IN S$ TO
1002  REM  THE DATALOGGER
1003  REM
1005  PRINT D$;"PR#2"
1010  PRINT S$
1020  PRINT D$;"PR#0"
1030  RETURN
2000  REM
2001  REM GO SEND CTRL-Q (IN S$)
2002  REM  AND THEN READ DATA
2003  REM
2005  GOSUB 1000: PRINT D$;"IN#2"
2010  INPUT "";DT$
2015  PRINT D$;F$: PRINT DT$
2020  PRINT D$;"IN#0"
2027  HTAB 22: PRINT SN;"/";NS;" @ ";DL;" MIN"
2030  RETURN
5000  REM
5001  REM  INITIALIZE CONTROL
5002  REM  CHARACTER STRINGS
5003  REM  AND SETTLE TIME PARAM
5004  REM
5005 B$ = "": REM B$<-10 CTRL-B'S
5006 Q$ = "": REM Q$<-6 CTRL-Q'S
5007 ST = 750: REM  DWELL TIME  20000=30SEC
5008 LC =  - 1: REM  NO "LAST CHL" YET
5009  REM
5010  REM  STANDARD DOS JUNK
5011  REM
5012 D$ = "": REM  D$<- 1 CTRL-D
5013  PRINT D$;"NOMON I,O,C"
5014  REM
5015  REM  SET UP CHANNEL ARRAY
5016  REM
5017  DIM AR(100)
5018  TEXT : CALL  - 936: GOTO 100
```

TABLE C.3

```
1  REM ---ANALYZE EFFICIENCY
2  REM ---NEW CONFIG--6/16/80---
4  HOME : PRINT "ANALYZE WHICH DATA": VTAB 4
5  HTAB 5: INPUT "DATE";DT$
6  HTAB 5: INPUT "EST TIME";TM$
7 F$ = DT$ + "-" + TM$:D$ =  CHR$ (4)
8 E$ = "OPEN DATA" + F$: PRINT D$;E$
9 E$ = "READ DATA" + F$: PRINT D$;E$
10  INPUT DT$: INPUT TM$: INPUT DL: INPUT NS: PRINT D$
11 NC = 8
20 TI =  VAL (TM$)
30  INPUT "<S>UMMARY ONLY OR <E>ACH SCAN";Z$
49  REM ---ACY=AREA OF TUBE COLLECTOR
50 ACY = 24
59  REM ---A45=AREA OF FRAME COL
60 A45 = 24
110 FCY = 1.04: REM  TILT FACTOR CYL
115 F45 = .94: REM  TILT FACTOR FRAME
120  FOR Z = 1 TO NS
130  REM --140-320 INPUT DATA FROM DISK
131  REM --SEE NOTES FOR VARIABLE ASSIGNMENT
140  PRINT D$;E$
150  INPUT DS$: GOSUB 1200:T1 = VL
155  INPUT DS$: GOSUB 1200:T2 = VL
160 TA = ((T1 + T2) / 2) * 1.8 + 32
180  INPUT DS$: GOSUB 1200:TT = VL
190 TT = TT * 1.8 + 32
210  INPUT DS$: GOSUB 1200
211 S = VL
212 S = S * .5888
240  INPUT DS$
260  INPUT DS$: GOSUB 1200
270 WS = VL
290  INPUT DS$: GOSUB 1200:WD = VL
310  INPUT DS$: GOSUB 1200:V = VL
320 VF = 1825: REM  FRAME AIR FLOW
500  REM  CALCULATE TUBE HEAT TRANSFER
510 DE = .0771 - 8.848E - 5 * TT - 3.744E - 8 * TT ^ 2
520 HC = .2382 + 1.39E - 5 * TT + 1.027E - 8 * TT ^ 2
530 CA = .13835
540 QT = V * CA * 60 * DE * HC * (TT - TA)
600  REM  CALCULATE FRAME HEAT TRANSFER
610 DE = .0771 - 8.848E - 5 * TF - 3.744E - 8 * TF ^ 2
620 HC = .2382 + 1.39E - 5 * TF + 1.027E - 8 * TF ^ 2
630 FA = .2097
640 QF = VF * FA * 60 * DE * HC * (TF - TA)
700  REM  CALCULATE TUBE INSOLATION AND EFFICIENCY
710 SCY = S * FCY * ACY
720 ECY = QT / SCY
750  REM  CALCULATE FRAME INSOLATION AND EFFICIENCY
760 S45 = S * F45 * A45
770 E45 = QF / S45
```

```
990  REM --PRINT OUTPUT
1000  HOME : HTAB 15: PRINT "OUTPUT DATA"
1010  PRINT : PRINT "DATE ";DT$,"TIME ";TI + (Z - 1) * DL;" EST": PRINT
1020  PRINT "AMB TEMP","WND VEL","WND DIR"
1030  PRINT TA,WS,WD
1040  PRINT : PRINT "SOLAR RADIATION  ";S: PRINT
1050  PRINT "FRM TEMP","FRM Q","FRM EFF"
1060  PRINT TT, INT (QT), INT (ECY * 100)
1065  PRINT
1070  PRINT "FLOW VELOCITY    ";V
1090  REM ---ACCUMULATE FOR SUMMARY---
1100 SUM(1) = SUM(1) + TA
1101 SUM(2) = SUM(2) + WS
1102 SUM(3) = SUM(3) + WD
1103 SUM(4) = SUM(4) + S
1104 SUM(5) = SUM(5) + TT
1105 SUM(6) = SUM(6) + QT
1106 SUM(7) = SUM(7) + ECY
1107 SUM(8) = SUM(8) + V
1108 SUM(9) = SUM(9) + QF
1109 SUM(10) = SUM(10) + E45
1120  VTAB 20
1124  REM -- AFTER LAST SCAN ZZ=1 TO BRANCH TO SUMMARY
1125  IF ZZ = 1 THEN 2000
1127  IF Z$ = "S" THEN 1140
1130  PRINT D$: GET A$: PRINT D$;"READ BAREDATA"
1140  NEXT Z
1150  PRINT D$;"CLOSE"
1160  GOTO 1300
1200  REM ---GET VALUE FROM DATA STRING
1210 VL =  VAL ( MID$ (DS$,5,7))
1220  RETURN
1300  REM ---DISPLAY SUMMARY DATA---
1310 ZZ = 1
1321 TA = SUM(1) / NS
1322 WS = SUM(2) / NS
1323 WD = SUM(3) / NS
1324 S = SUM(4) / NS
1325 TT = SUM(5) / NS
1326 QT = SUM(6) / NS
1327 ECY = SUM(7) / NS
1328 V = SUM(8) / NS
1329 QF = SUM(9) / NS
1330 E45 = SUM(10) / NS
1340  HOME : PRINT "SUMMARY OF RUN": PRINT
1350  PRINT "DATE ";DT$,"TIME ";TM;" TO ";TM + NS * DL: PRINT "     SCAN E
     ACH ";DL;" MINUTES": PRINT
1360  GOTO 1020
2000  INPUT A$
2010  PRINT D$;"RUN MENU"
```

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APPENDIX D: TEST DATA

The installation of the Bare-Plate solar test systems was completed in February of 1980. The systems became operational on February 26. Test data for this report were compiled from this date through June of 1980. These data are summarized in Table D.1. The summary data represent the average performance of the tube and frame bare solar collector test systems for a thirty minute time period. The eastern standard time is the midpoint time for each set of data. Weather is a visual description of the average weather conditions for the time period, i.e. cloudy, partly cloudy, or clear. A cloudy description might include some sunshine but most of the insolation would be diffuse. The performance or efficiency of the system is calculated by a heat balance for the system as described by the procedures of Appendices B, Instrumentation and Data Processing, and C, Computer Programs.

Variations of both the tube and frame test systems were tested. Those are identified and described by the System Type:

I. Tube array with minimum overlap. Frame array mounted directly on roof with both the north and south sides open.

II. Tube array same as I. Frame array mounted directly on roof with south side open and north side insulated and sealed off with black plastic.

III. Tube array with maximum overlap. Frame array same as II.

IV. Tube array same as III. Frame array same as I.

IV.* Same as IV but air flow through frame array was reduced to approximately the same flow per unit collector area as the tube array.

V. Tube array not active. Frame array mounted 1½ feet above roof with both the north and south sides open.

VI. Same as V but the north side of the frame is insulated and sealed off with black plastic.

Table D.2. is a listing of the raw data that was accessed by the Data Logger. Table D.3. illustrates the raw data output from the Data Logger as printed on the strip chart. This was the source of data that was used to analyze the temperature gradients in the tube and frame solar collector.

TABLE D.1.

TEST DATA FOR BARE PLATE SOLAR SYSTEMS

Date	2/26	2/26	2/27	2/28	2/28	2/29	2/29
Time, EST	11:08	1:54	1:49	12:22	3:50	11:22	12:24
System Type	I	I	I	I	I	I	I
Weather	P.Cldy	P.Cldy	P.Cldy	Clr.	P.Cldy	P.Cldy	Clr.
Ambient Temp., ^oF	17.9	20.4	27.8	24.3	25.3	10.6	15.4
Wind, Direction-MPH	-	-	-	-	-	-	-
Insolation, BTU/HR, ft^2	115.2	205.1	202.8	209.4	134.3	119.9	239.4
Tube Outlet, ^oF	31.2	34.8	45.7	43.0	38.1	19.4	37.2
Tube Efficiency, %	11.8	10.8	13.0	12.8	13.7	11.4	13.1
Frame Outlet, ^oF	-	-	-	-	-	-	-
Frame Efficiency, %	-	-	-	-	-	-	-

Date	3/3	3/3	3/3	3/4	3/4	3/18	3/18
Time, EST	9:40	2:04	4:17	12:11	4:58	11:03	12:03
System Type	I	I	I	I	I	I	I
Weather	P.Cldy	Clr.	Clr.	Clr.	Cldy	Cldy	P.Cldy
Ambient Temp., ^oF	16.3	29.2	30.6	37.3	39.0	29.2	30.4
Wind, Direction-MPH	-	-	-	-	-	SW-6	W-7
Insolation, BTU/HR, ft^2	106.1	211.5	98.1	179.9	54.4	148.8	144.6
Tube Outlet, ^oF	23.9	46.4	37.4	52.3	42.8	35.5	43.8
Tube Efficiency, %	10.6	11.8	9.9	12.5	10.7	5.6	11.8
Frame Outlet, ^oF	20.3	38.5	34.7	46.6	41.4	30.7	34.8
Frame Efficiency, %	47.0	60.8	59.1	69.0	57.2	14.4	39.5

TABLE D.1. - Continued

Date	3/18	3/18	3/18	3/18	3/18	3/18	3/19
Time, EST	1:03	2:03	3:03	4:03	5:03	5:43	9:02
System Type	I	I	I	I	I	I	I
Weather	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.
Ambient Temp., °F	33.3	34.8	36.4	36.9	36.7	35.8	38.6
Wind, Direction-MPH	NW-5	W-10	NW-7	NW-6	W-3	SW-4	SE-2
Insolation, BTU/HR,ft^2	274.8	232.0	197.5	149.3	91.5	40.8	128.2
Tube Outlet, °F	52.6	52.5	52.7	49.7	44.6	38.5	47.2
Tube Efficiency, %	11.1	11.2	12.2	13.0	13.3	9.2	10.1
Frame Outlet, °F	45.6	46.2	47.7	45.5	42.5	37.5	44.0
Frame Efficiency, %	73.4	71.5	83.8	84.3	91.2	60.5	59.7

Date	3/19	3/19	3/20	3/20	3/31	3/31	3/31
Time, EST	11:30	3:30	11:00	3:00	11:02	2:02	4:02
System Type	I	I	I	I	II	II	II
Weather	Clr.	P.Cldy	Clr.	P.Cldy	Cldy	Cldy	Cldy
Ambient Temp., °F	50.1	55.2	53.6	59.7	41.5	43.7	43.2
Wind, Direction-MPH	SE-7	S-5	S-8	S-6	N-1	NW-4	NW-4
Insolation, BTU/HR,ft^2	192.6	101.3	159.8	123.0	48.2	83.6	95.3
Tube Outlet, °F	66.3	61.0	64.6	69.8	46.7	51.8	50.8
Tube Efficiency, %	12.4	10.1	11.2	12.8	16.0	16.2	13.7
Frame Outlet, °F	60.2	57.7	60.6	65.0	43.1	46.8	47.1
Frame Efficiency, %	56.5	42.5	63.8	52.5	50.7	51.4	57.0

TABLE D.1. - Continued

Date	4/1	4/24	4/25	5/9	5/12	6/12	6/12
Time, EST	3:48	1:50	1:59	11:00	11:24	11:25	2:35
System Type	II	III	III	III	III	IV	IV
Weather	P.Cldy	Cldy	P.Cldy	P.Cldy	Cldy	Clr.	Clr.
Ambient Temp., °F	46.0	44.9	52.7	55.6	56.9	71.3	75.2
Wind, Direction-MPH	NE-1	E-5	W-5	NW-5	N-1	W-4	NW-2
Insolation, BTU/HR,ft^2	112.3	78.2	133.9	146.0	66.6	282.4	269.5
Tube Outlet, °F	57.2	51.3	65.6	69.7	64.2	88.5	92.6
Tube Efficiency, %	17.6	34.2	37.0	40.0	40.8	24.0	24.0
Frame Outlet, °F	50.2	-	-	-	-	82.9	87.7
Frame Efficiency, %	53.0	-	-	-	-	60.0	77.0

Date	6/13	6/13	6/13	6/13	6/13	6/13	6/16
Time, EST	8:40	9:30	10:40	11:30	2:45	3:45	12:15
System Type	IV	IV	IV	IV	IV*	IV*	V
Weather	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.	Cldy
Ambient Temp., °F	67.2	74.1	79.0	81.4	80.3	82.6	59.6
Wind, Direction-MPH	S-1	S-2	S-1	S-2	E-2	NE-1	E-2
Insolation, BTU/HR,ft^2	128.8	207.2	233.9	245.6	259.0	206.8	157.0
Tube Outlet, °F	77.3	89.1	96.6	100.1	97.4	96.3	-
Tube Efficiency, %	31.0	27.0	28.0	27.0	23.0	23.0	-
Frame Outlet, °F	72.7	85.5	91.9	94.8	106.9	102.1	77.1
Frame Efficiency, %	72.0	93.0	92.0	91.0	71.0	65.0	54.0

TABLE D.1. - Continued

Date	6/16	6/16	6/16	6/17	6/17	6/17	6/18
Time, EST	1:15	2:08	3:10	12:44	1:58	3:13	10:03
System Type	V	V	V	V	V	V	V
Weather	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.
Ambient Temp., °F	61.8	63.5	63.1	69.5	69.6	70.1	66.5
Wind, Direction-MPH	E-1	E-1	S-2	N-1	N-1	N-2	NW-4
Insolation, BTU/HR,ft^2	306.4	284.2	260.3	301.2	289.2	246.9	235.1
Tube Outlet, °F	-	-	-	-	-	-	-
Tube Efficiency, %	-	-	-	-	-	-	-
Frame Outlet, °F	84.5	86.4	84.5	93.1	92.9	90.4	84.2
Frame Efficiency, %	57.0	63.0	64.0	61.0	62.0	63.0	59.0

Date	6/18	6/18	6/18	6/19	6/19	6/19	6/20	6/20
Time, EST	10:28	1:03	2:48	10:18	11:58	1:03	8:02	9:01
System Type	V	V	V	VI	VI	VI	VI	VI
Weather	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.	Clr.
Ambient Temp., °F	71.0	73.6	75.2	79.5	81.9	83.1	58.9	59.3
Wind, Direction-MPH	W-3	W-3	W-1	S-2	S-3	S-5	W-5	W-5
Insolation, BTU/HR,ft^2	282.9	287.2	250.5	240.6	285.9	289.3	150.9	196.2
Tube Outlet, °F	-	-	-	-	-	-	-	-
Tube Efficiency, %	-	-	-	-	-	-	-	-
Frame Outlet, °F	93.0	95.1	95.9	94.5	98.2	99.6	65.2	69.3
Frame Efficiency, %	59.9	57.0	62.0	47.0	43.0	43.0	33.0	41.0

TABLE D.2: DATA LOGGER CHANNEL ASSIGNMENTS

Channel #	Monitored Variable	Channel #	Monitored Variable
00	Ambient Temp	20	Plate Temps Tube Collector
01	Ambient Temp	21	Plate Temps Tube Collector
02	Flow Cone Exit Air Temp	22	Plate Temps Tube Collector
03	Exit Air Temp 15 Rows of Tubes	23	Plate Temps Tube Collector
		24	Plate Temps Tube Collector
04	Exit Air Temp 10 Rows of Tubes	25	Plate Temps Tube Collector
		26	Plate Temps Tube Collector
05	Exit Air Temp 5 Rows of Tubes	27	Plate Temps Tube Collector
		28	Plate Temps Tube Collector
06	Temp Unused	29	Plate Temps Tube Collector
07	Temp Unused	30	Plate Temps Tube Collector
08	Temp Unused	31	Plate Temps Tube Collector
09	Plate Temps "A" Frame	32	Plate Temps Tube Collector
10	Plate Temps "A" Frame	33	Temp Unused
11	Plate Temps "A: Frame	34	Temp Unused
12	Plate Temps "A" Frame	35	Wind Direction (N=0 & 100, E=25, S=50, W=75)
13	Plate Temps "A" Frame		
14	Exit Air Temp "A" Frame	36	0-10MV Unused
15	Wind Speed MPH	37	Anemometer Ft/Min (Flow Cone Exit Volcity)
16	Solar Intensity (Reading X .5888)= BTU/HR/FT^2		
		38	Temp Unused
17	Anemometer Input Unused	39	Temp Unused
18	Temp Unused		
19	Temp Unused		

TABLE D.3: TYPICAL DATA STRIP CHART

CH.	DATA	PAR
039	+0026.2	C
038	+0031.6	C
037	+01431.	
035	+0080.9	
034	+0067.1	C
033	+0044.8	C
032	+0028.4	C
031	+0029.7	C
030	+0026.4	C
029	+0025.9	C
028	+0026.5	C
027	+0028.4	C
026	+0030.8	C
025	+0030.1	C
024	+0029.6	C
023	+0030.0	C
022	+0030.2	C
021	+0030.5	C
020	+0030.8	C
019	+0056.3	C
018	+0046.6	C
016	+0325.6	
015	+0000.0	
014	+0026.8	C
013	+0027.1	C
012	+0027.5	C
011	+0027.2	C
010	+0026.5	C
009	+0026.2	C
008	+0071.1	C
007	+0057.2	C
006	+0021.7	C
005	+0031.5	C
004	+0030.3	C
003	+0030.3	C
002	+0030.6	C
001	+0022.8	C
000	+0022.8	C

DAY143 TIME09:55

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