TVA 64 (OS 9-65) (OP-WP 7-84)
UNITED STATES GOVERNMENT

PN-ABK-941

Memorandum

TENNESSEE VALLEY AUTHORITY

TO : Paul Weatherly, Bioenergy Systems Technology US Aid
OACD, Arlington Office
FROM : Miguel E. Osores, Supervisor, Admin & Fin Services Section,
310 CUBB-C
DATE : August 19, 1985

SUBJECT: DOMINICAN REPUBLIC SOLAR DRYING FACILITY

Per conversation with Jerry Harper the attached report is our draft report of the evaluation of the solar drying facility we visited last April in the Dominican Republic.

Although we do not expect any major changes, we will be glad to discuss your comments after your trip to the Dominican Republic.

By regular TVA mail we are sending the material requested by some of the contacts we established in the Dominican Republic. Please distribute to the appropriate people during your visit to the Dominican Republic.

MO:VW
Attachments

rec'd BST
8/20/85

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

PN-ABA-921

ISN 76575

SOLAR BAGASSE DRYER

CONSUELO MILL

DOMINICAN REPUBLIC

FIELD EVALUATION

DRAFT REPORT

3

INTRODUCTION

The purpose of this report is to provide the basis of an end of project evaluation of a solar bagasse drying pilot project (AID No. 538-0030) located in the Dominican Republic. The objective of the evaluation is to examine the overall effectiveness of the solar bagasse drying facility constructed at the Consuelo sugar mill and the practicability of applying this technology in larger scale operations.

The field evaluation will examine:

- the design, construction, and installation of the facility;
- the operational test data collected during the initial operation of the facility, including process economics;
- operational and maintenance factors related to the system; and
- the feasibility of using the technology on a larger scale, applying it to other processes and other related energy management opportunities.

4

BACKGROUND

The purpose of this pilot project was to research, test, and demonstrate the use of solar energy to dry bagasse to satisfy process steam and electrical requirements in sugar mills. Since imported fuel oil is used in the sugar mills to satisfy process energy needs when bagasse supplies are insufficient, drying the bagasse will increase its useful heat content, lowering fuel oil costs. Lower fuel oil consumption at the sugar mills will also have a favorable effect on the Dominican Republic's balance of payments by lowering payments for oil importation. Thus, solar bagasse drying has the potential to improve the economics of sugar production and of the nation as a whole.

The principal organizations involved in the solar bagasse drying project were USAID - Dominican Republic, the State Sugar Council of the Dominican Republic (CEA), the Commission on National Energy Policy of the Dominican Republic (COENER), and Trident Engineering Associates, Inc. CEA was responsible for overall project management, while Trident was largely responsible for the design of the facility. The costs for the project were shared equally by the Dominican Republic and the United States The United States incurred approximately US$288,000 in costs (US$186,000 for feasibility studies and design of the facility and US$102,000 in plant construction costs). The Dominican Republic had costs of approximately RD$241,000 (RD$239,000 for plant construction and RD$2,000 miscellaneous expenses). The total outlay for the project was USRD$529,000.

A bibliography of the primary references used in the preparation of this report is in Appendix I. Also, a partial listing of the individuals contacted during the course of the evaluation is given in Appendix II. The expert assistance of Ing. Minerva Pappaterra (CEA) is especially appreciated. Other data presented in the report were collected during the field evaluation of the solar drying facility at the Consuelo sugar mill. The field evaluation was conducted between March 25 and April 2, 1985.

DESIGN AND CONSTRUCTION EVALUATION

General - Figure 1 provides a front and rear view of the solar bagasse dryer. There are three primary components to the solar dryer: a passive solar heating system, an active solar heating system, and the drying plenum. There are 60 passive solar collectors constructed at a 45 degree angle to thermally enhance air flows through the collectors. The active solar heating system consisted of 56 collectors for heating hot water. These collectors were mounted at a 20 degree angle to maximize solar gain during the sugar processing season. The hot water from the active solar system was circulated through four finned heat exchangers. Air was heated by using fans to blow it over the heat exchanger fins and into the drying plenum. The drying plenum contained a 120 foot conveyor system to transport the bagasse. The design called for heated air from the passive and active solar systems to be introduced between the conveyor belts and to pass upward through the moving bed of bagasse. The drying plenum had three large exhaust fans to assist this process. The bagasse throughput (wet basis) was designed to be varied between 4,000 to 10,000 lb/hr. The water removal rate was expected to range between 800 and 1300 lb/hr, depending on the actual performance of the solar collectors.

Passive Collector Performance - Three different aspects of the passive solar system's performance were examined during the field evaluation: air flows through the collector; temperature rise across the passive collector during startup and in steady state operation; and a temperature sensor check on collector 30.

Figure 2 presents the distribution of air flows through the passive collector system as measured by a turbine-flow anemometer. There are two interesting aspects to the data. First, the air flow is highest for the center collectors. Second, backdrafting was observed in the collector nearest the exit. Upon inspection, significant air flows up both the entrance and exit chutes into the drying plenum were measured. The backflow up the exit chute was greatest (approximately 2500 - 3500 CFM). Backflows at these points can explain the air flow distribution pattern observed and account for the reverse flow in collector 60 which was immediately adjacent to the exit chute. The estimated mean air flow for the passive system was at the upper design limits. However, it was evident during the course of the evaluation that the flow was primarily induced through the passive collectors by the drying plenum exhaust fans.

Figure 3 compares input and output temperatures of passive collector 30 and the exhaust temperature of the drying plenum. At 11:15 a.m. the exhaust fans were turned on. The initial temperature differential across the collector (greater than 10 degrees C.) was quickly reduced and the dryer exhaust air temperature reached near equilibrium with the passive collector exit air temperature. The rapid destruction of the passive collector temperature profile during start-up suggests that elevation of the passive collectors to 45 degrees to promote thermal air flow (buoyancy) may not be an effective design concept for solar dryers where forced ventilation is used. Significant cost savings could have been realized if the passive collectors had been mounted on the ground on a 20 percent grade.

No measurable air flows could be observed in collector 30 before the exhaust fans were turned on. Figure 4 compares the performance of the temperature sensors in collector 30 (T7 and T8). The system's sensors recorded temperature readings approximately 10 percent greater than those of the field instruments.

Absorber plate temperatures measured between 60 and 70 degrees C., collector exit temperatures less than 40 degrees C., and an average temperature rise across the passive collector of 4-6 degrees C., which indicate that design improvements are warranted. Reynold's number estimates between 1700 to 2200 suggest primarily laminar air flow through the passive collectors. The sawtooth modification of the passive collector absorber plate depicted in Figure 5 would induce better turbulent flow conditions in the collector, and increase the absorber surface area to collector volume ratio, promoting greater heat transfer.

Active System Performance- Performance of the active solar heating system was evaluated with regard to heat exchanger ventilation, thermal performance of active solar water heating, heat transfer in heat exchanger, and heat exchanger temperature sensors.

Figure 6 illustrates that the heat exchanger fans are operating near design specifications. Initially fans on units 2 and 3 were not operating, but were readily repaired the following day by CEA staff.

The thermal performance curves in Figure 7 demonstrated that temperatures in excess of 50 degrees C. can be realized from the active solar water

heating system. However, degradation of the thermal performance in one of the collector banks was observed. Such a degradation in thermal performance was also noted in Trident's final report. The system was drained and refilled but this only temporarily corrected performance. Possible explanations for this phenomenon include thermal grounding of piping and poor insulation in some of the active collectors.

The effectiveness of heat transfer in the heat exchanger is seen in figure 8. The steady-state temperature of the air exiting the heat exchanger is low. A check of temperature sensors in the collector (Figure 9) shows their readings to be within 10 percent of the field instruments. The higher sensor readings are probably due to their location inside the heat exchanger rather than error.

Dryer Plenum Ventilation - Two aspects of the performance of the dryer plenum were examined: exhaust air flows and the circulation of heated air within the system from the passive and active solar collectors.

Because of the backdrafting observed during the passive collector evaluation, measurements of the exhaust fans' air flow were made under three conditions: (1) all fans on and vents open; (2) heat exchanger fans off, their vents closed and the chute sealed; and (3) all fans on, vents open, and chute sealed. The exit chute was sealed by fastening sugar bags over it. The field air flow data is presented in Figure 10. The highest total flow was observed for the first condition. As may be expected, air flow was the greatest in the exhauset closest to the exit chute. Sealing the exit chute reduced the overall ventilation rate of the dryer plenum by

over 2,000 CFM for both conditions 2 and 3. The air flow pattern for condition 2 resulted in a more uniform flow distribution among the exhausts. Starting the heat exchanger fans and opening their vents increased the flow in the first exhaust relative to the others but not the overall dryer ventilation rate. The air flow through passive collector 30 was also increased by approximately 20 percent.

As was previously mentioned, the air circulation pattern in the dryer plenum was for heated air from the collectors to flow up through the conveyor and the bagasse. Inspection of the system indicated that such an air circulation pattern was probably not obtained. Sheet metal protectors, one foot high, along both sides of the conveyor helped form a channel to circulate the air over the top of the bagasse rather than up through it. Figure 11 illustrates this pattern. The structural framework for the dryer plenum offset the metal protector 3 inches thereby creating a least resistance path for air flow. Even with such short circuiting of the air circulation pattern the operational testing of the system showed that appreciable water removal from the bagasse could occur.

OPERATIONAL TEST DATA

General - Operational testing of the solar bagasse dryer occurred between February and June of 1984. The testing was done by CEA staff. Table 1 summarizes the results of this testing effort. Using the data reported by CEA for these tests the following will be assessed: bagasse moisture content changes; water removal capabilities of the system; incremental energy savings; economics; and system scale-up. June data were not used since only two test runs were performed.

Bagasse Moisture Content - Figure 12 presents the distribution of input and output bagasse moisture contents. The values for this parameter are highly variable. The distribution of individual moisture content changes is given in Figure 13. These data exhibit an even broader and more uniform distribution than was seen in the previous set. Figure 14 presents seasonal averages for these three variables. The primary trend is that the average monthly moisture content change doubles between February and May. The overall average moisture content reduction of 8.7 percent is also much lower than the approximately 12 percent design projection. The system performed above the overall average only in May and the moisture reductions observed during the sugar processing season (February and March) were little more than half the design projection.

Water Removal Capability - The water removal capabilities of the system have been examined relative to the bagasse throughput. Test data on the amount of bagasse loaded into the system for each test run and the conveyor were used to calculate the bagasse throughput. The moisture

content change for each test run was used to estimate the total water removal rate (lb/hr) and the unit water removal rate per ton of bagasse processed.

Figures 15 and 16 compare the bagasse throughput with the water removal rate and the unit water removal rate, respectively. The data were selectively analyzed for the processing season (February and March) and the nonprocessing season (April and May). The February/March data exhibit a characteristic operating curve that identifies an optimal operating range (4,000 to 6,000 lb/hr). The April/May data shows the water removal rate to increase consistently with increasing throughput. The relatively constant unit water removal rate would account for the first relationship. Several factors may contribute to the better performance of the nonprocessing season data. First, the environmental conditions during this period are becoming more favorable for solar heating. Second, because no sugar processing had occurred recently stored bagasse which may have had improved drying properties was used. Third, some recycling of previously dried bagasse may have taken place in the testing. It should be noted that the initial bagasse moisture content does not change much from month to month.

Incremental Energy Gain - as bagasse is dried, water is removed, the energy content of the dried bagasse is increased, and the mass of the bagasse is reduced. Figure 17 reflects these interrelationships. The amount of energy which can be obtained through drying bagasse is determined by the amount of water it contains, and the increase in the energy content of the dried bagasse is not a good measure of this because

of the mass reduction which occurs. For example, reducing the moisture content from 50 percent to 20 percent would result in a net energy gain of approximately 12 percent. This energy savings is roughly equivalent to the energy which would have been required to vaporize the water removed during drying.

Figure 18 presents a curve which relates the effective gain in energy for drying bagasse initially at 50 percent moisture. Using the minimum and the maximum bagasse moisture content reductions, estimates of the incremental energy changes from drying can be made as shown in the figure. Figure 19 uses these estimated energy savings per ton, relates them to bagasse throughput, and expresses them in fuel oil equivalents. Parasitic energy requirements are also given to account for fan and conveyor operation. Using the maximum and the minimum average monthly throughputs, the greatest and smallest hourly fuel oil savings can be determined. These are approximately 9 gallons and 1 gallon, respectively.

Economics - The range of hourly fuel oil savings estimated for the solar drying system span the design estimate for the system. Assuming fuel oil costs from $.80 to $1.00, the saving resulting from 1 to 9 gallons would probably not cover labor costs and replacement parts for the system. Process economics for the system appear to have been marginal from its outset.

Scale-up Considerations - the main factors concerning scale-up are the unit's prospective size and associated storage facilities which may be

required. During the processing season, sugar mills operate 24 hours a day and generate about 2000 tons of bagasse a day. A solar dryer would operate efficiently about 8 hours a day and would have to be scaled-up to handle the plant's entire 24 hour output to have maximum savings assured. The scaled-up unit would have to dry 250 tons/hour of bagasse to satisfy this requirement. It would be 50 times larger than the current unit. Also, storage and material handling facilities would have to be developed to store and transport 1500 tons of wet and dried bagasse per day. Scale-up to fully utilize a sugar mill's production does not appear to be feasible.

OPERATION AND MAINTENANCE

Site Operations - At the time of the field evaluation the system appeared well maintained and only one minor problem with two fans was encountered and was readily corrected. However, the system had not been operated since the operational testing was done in 1984. The reason for this was the dryer location, which was far removed from the sugar mill's bagasse handling and storage facilities. This was the most significant oversight in the project's implementation. At a minimum the system should have had greatly facilitated bagasse handling for transport to other sugar mills. Loading of trucks for bagasse transportation is now done by hand.

APPLICATIONS AND RECOMMENDATIONS

Sugar Industry/Solar Bagasse Drying - The use of solar bagasse dryers in the sugar industry is not recommended. The following reasons are given: marginal energy savings, scale-up requirements to handle 24 hour a day mill production, and seasonal utilization.

Sugar Industry/Solar Sugar Drying - Solar drying may have a potential application in the sugar industry in the drying of white sugar. White sugar refining is often done throughout the year and bagasse is typically not available during the nonprocessing season. If economically feasible, solar drying could encourage more white sugar refining, thus increasing the value of sugar exports.

Flue Gas Particulate Removal - Much of the energy in bagasse goes up the boiler's smokestack as carbonized bagasse particulates. These particulates are large and could be readily removed by a cyclone and reinjected into the boiler. Deposition of this material is evident in the areas surrounding the mill site and is a major source of local pollution. Removal of these particulates and their reburning may prove to be a cost effective method of energy recovery and enhancement of local environmental quality.

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APPENDIX II - INDIVIDUALS CONTACTED

Jose Ramon Acosta, Comision Energetica

Rodolphe H. Ellert-Beck, U.S. Agency for International Development

Ing. Mamoru Hidaka, Indotec

Mitchell A. Kapland, Trident Engineering Associates, Inc.

Agustin Leon, Comision Energetica

Walter Aviel Henry Matthew, Consejo Estatal Del Azucar

Atim Eneida Ogunba, Vice Consul, U.S. Embassy

Ing. Minerva Pappaterra M., Consejo Estatal Del Azucar

Ing. Leo Perez-Minaya, U.S. Agency for International Development

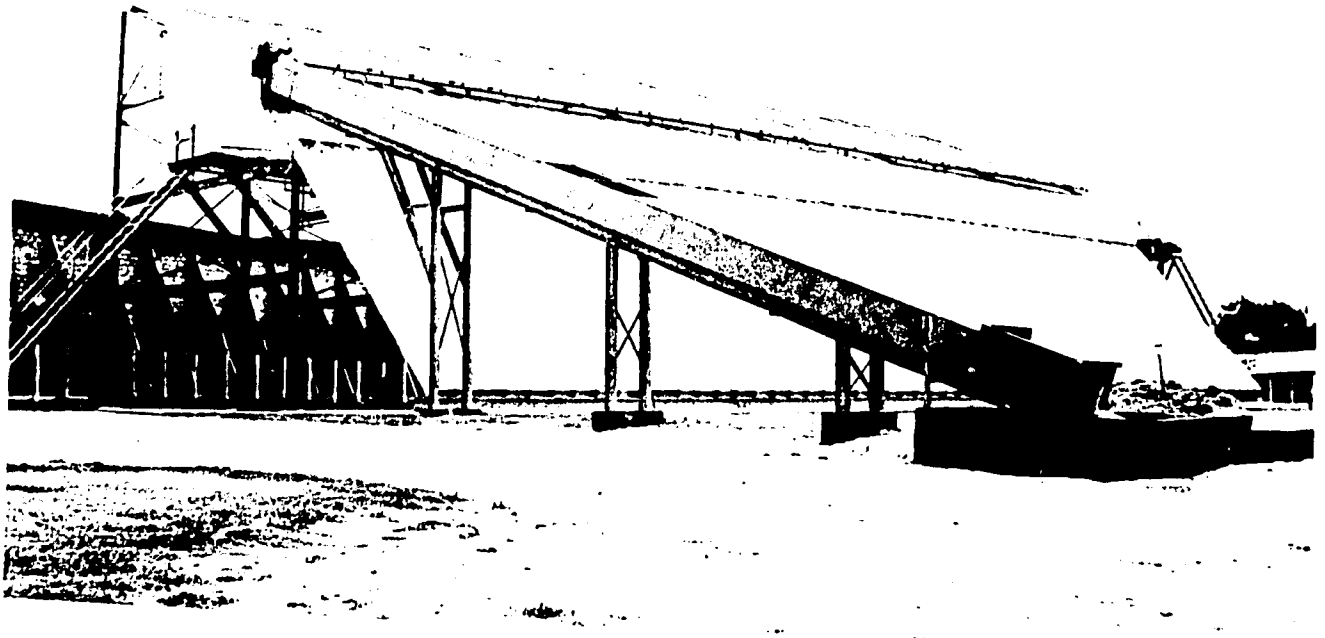
Ing. Ramon Pichardo, Comision Energetica

Ing. Cesar Sanchez, Corporacion Dominicana De Electricidad

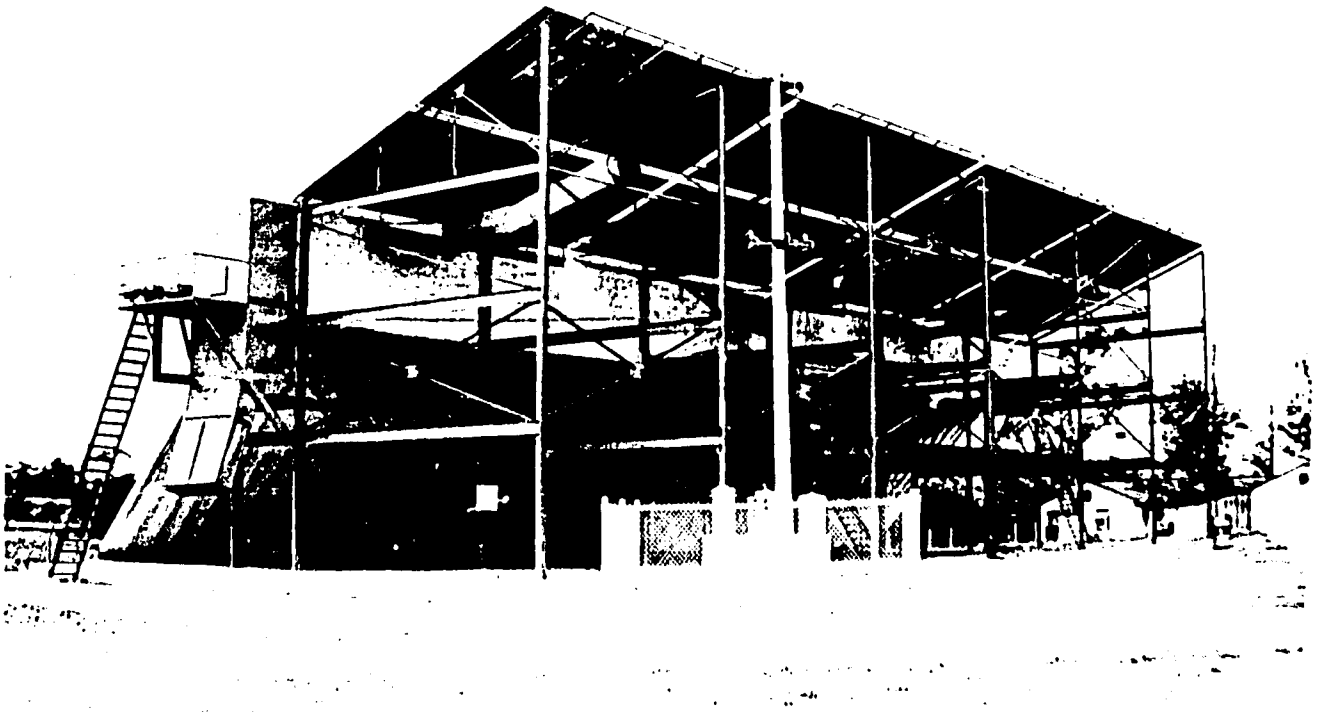
Guillermo H. Smith, U.S. Agency for International Development

Ing. Belen del Toro, Consejo Estatal Del Azucar

FIGURE I



VISTA FRONTAL
SECADOR SOLAR INGENIO CONSUELO



VISTA POSTERIOR

SOLAR DRYING FACILITY
PASSIVE SOLAR COLLECTOR PERFORMANCE

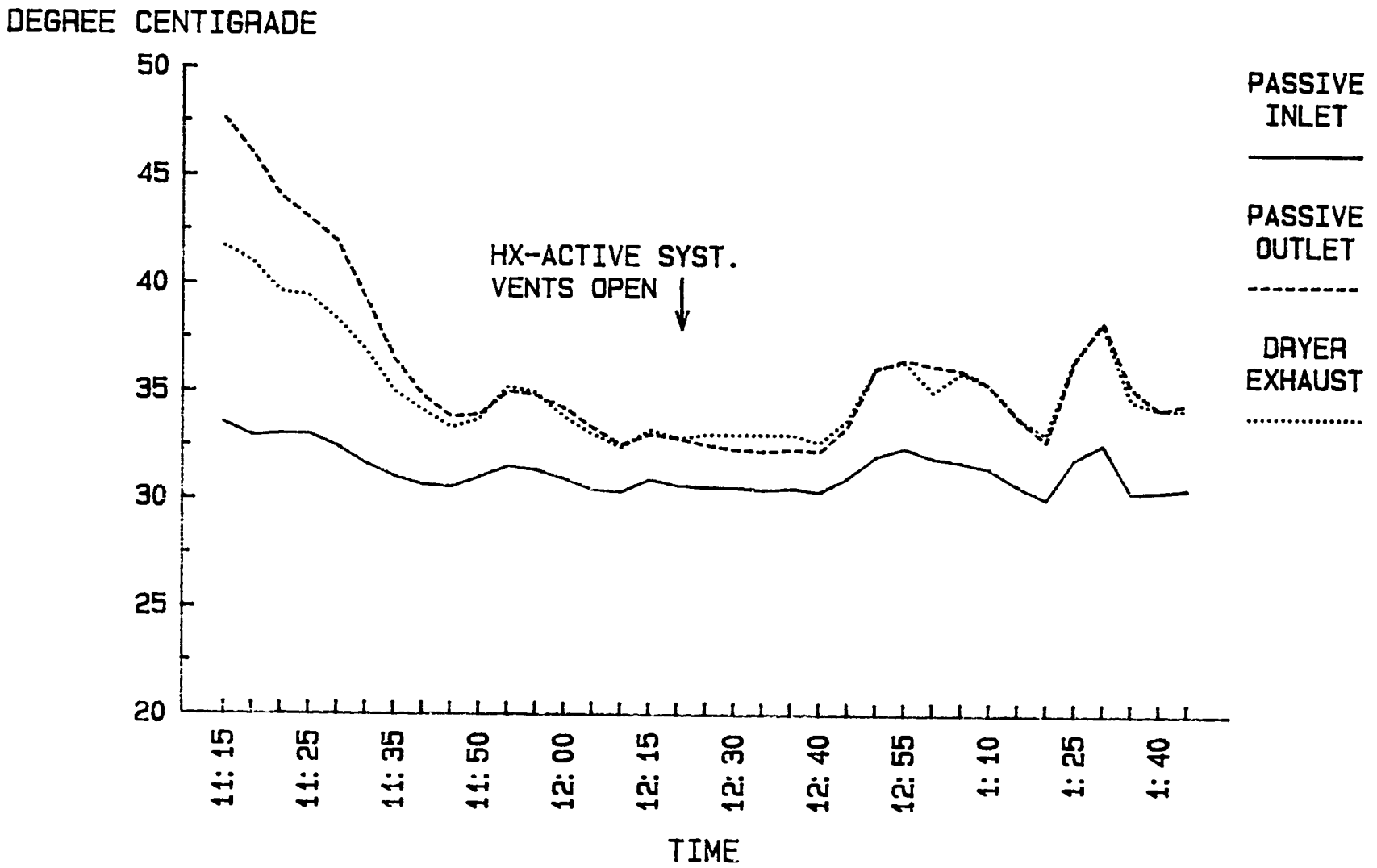


FIGURE 2

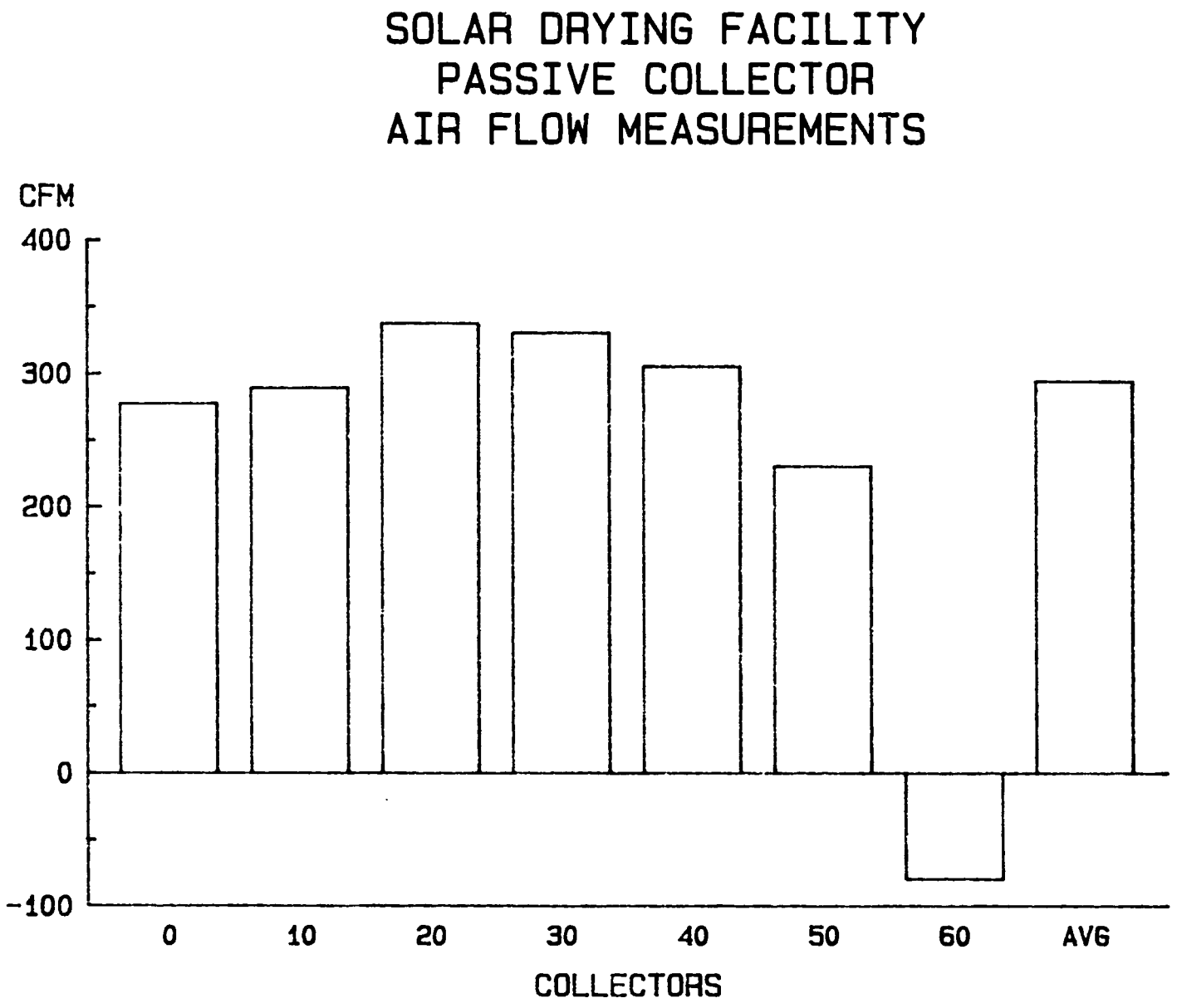

SOLAR DRYING FACILITY
PASSIVE COLLECTOR
AIR FLOW MEASUREMENTS
CFM
400
300
200
100
0
-100
0
10
20
30
40
50
60
AVG
COLLECTORS

FIGURE 3

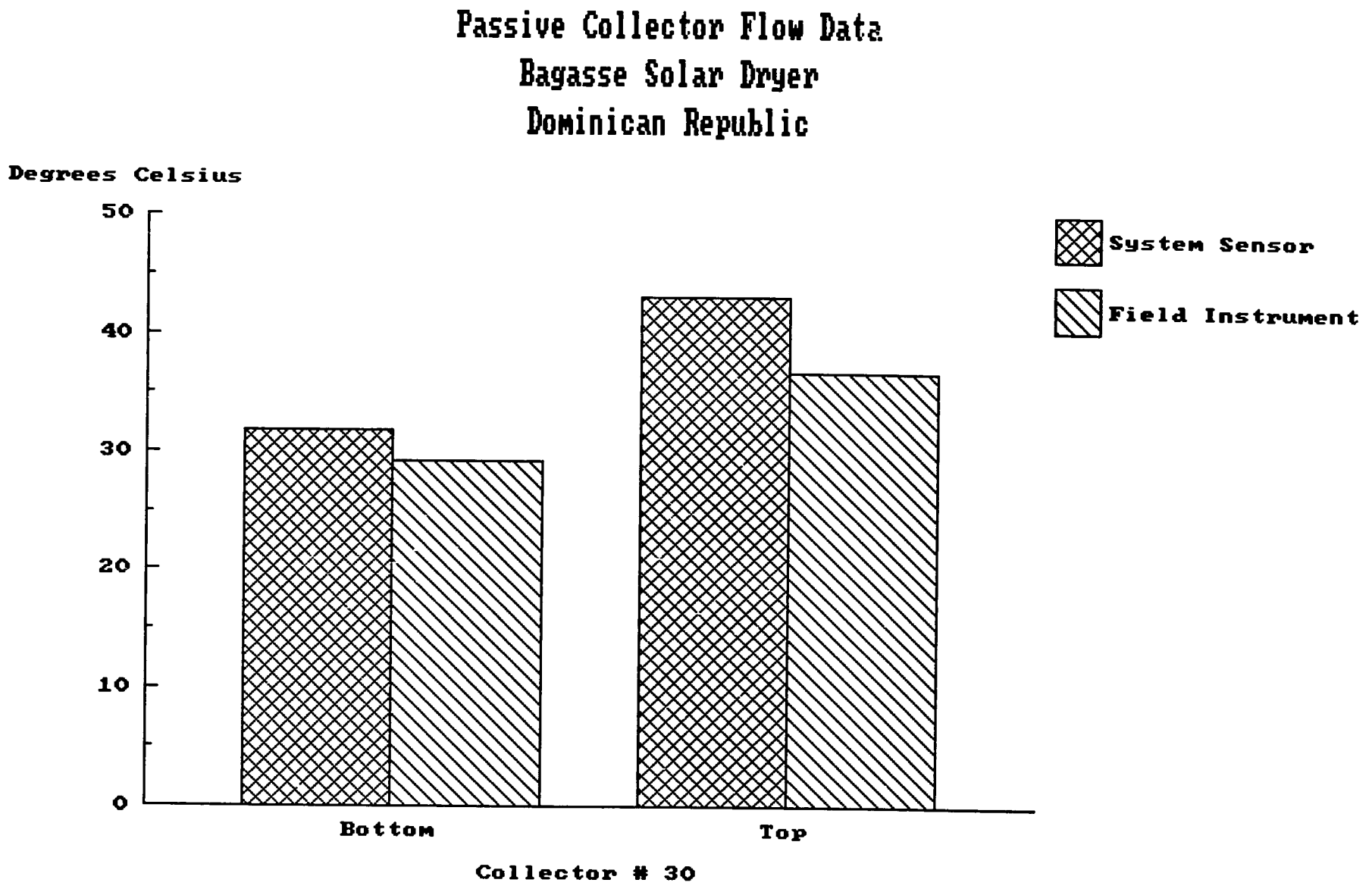
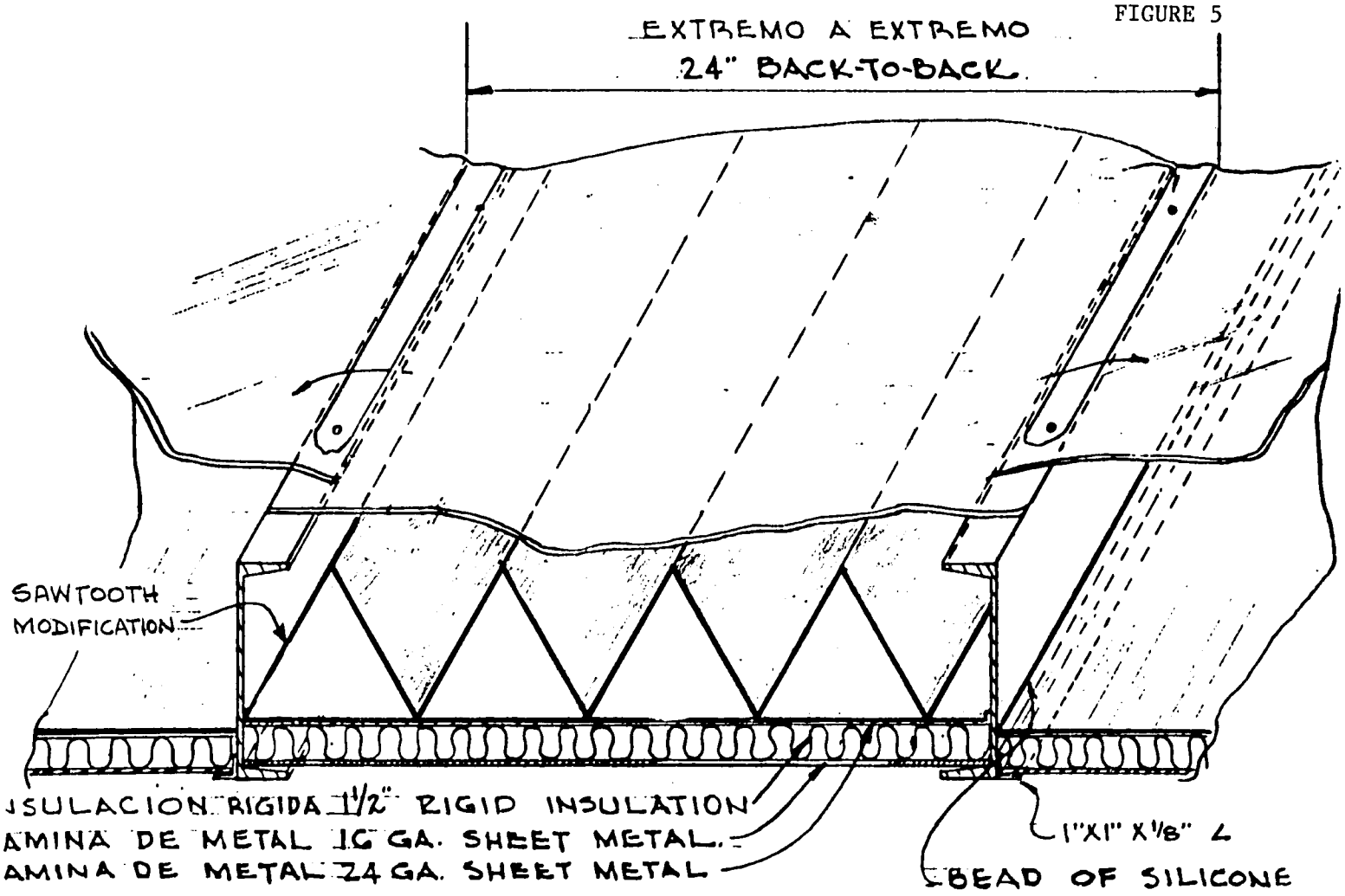

Passive Collector Flow Data
Bagasse Solar Dryer
Dominican Republic
Degrees Celsius
50
40
30
20
10
0
System Sensor
Field Instrument
Bottom
Top
Collector # 30

FIGURE 4



SECTION THRU
TYPICAL COLLECTOR TROUGH

CORTE TRANSVERSAL
TIPICA COLECTOR DE CUBETA

TYPICAL CELL DETAILS
PASSIVE COLLECTOR

DETALLES DE UNA CELDA TIPICA
COLECTOR

FIGURE 5
FIGURA 5

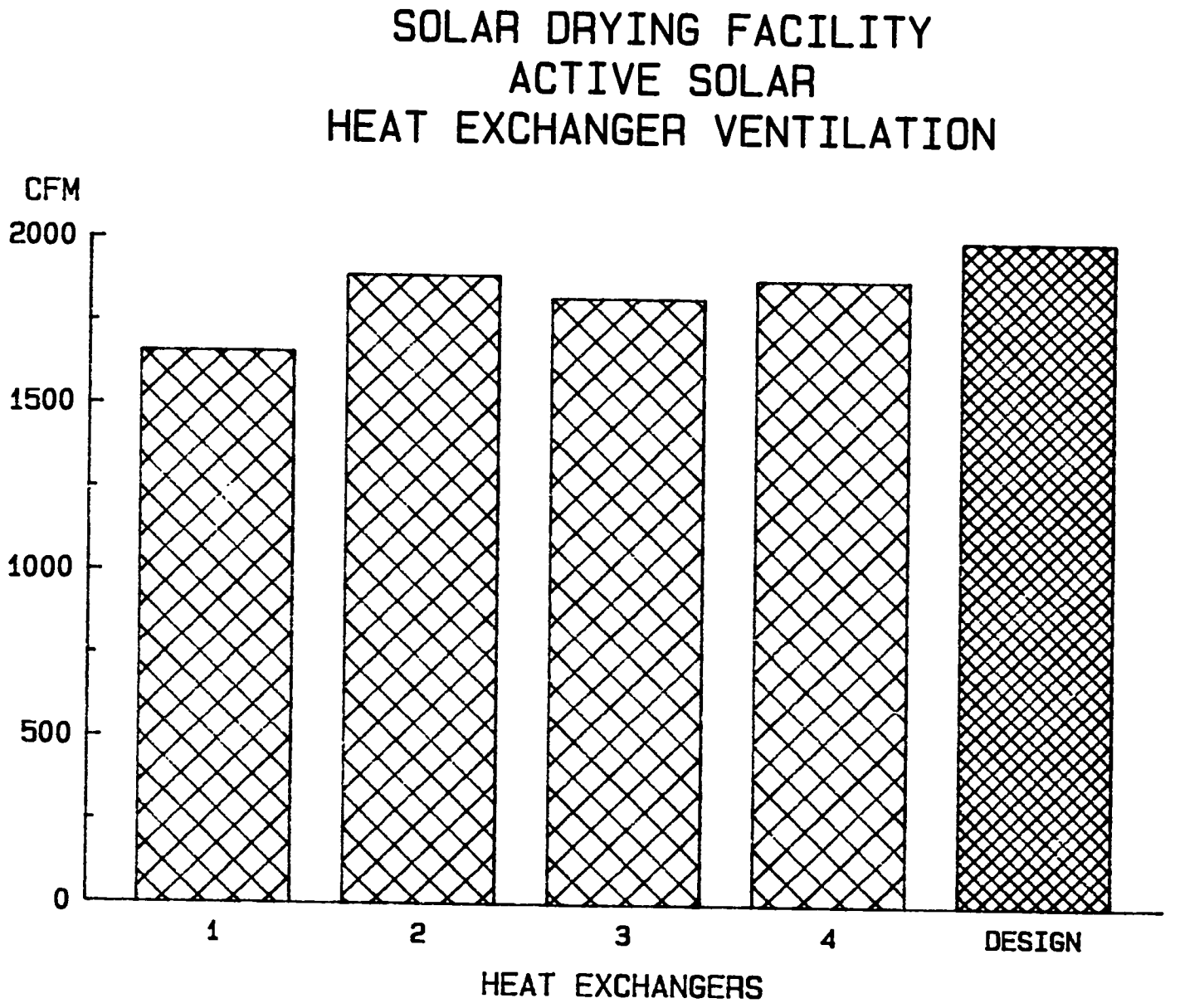

SOLAR DRYING FACILITY
ACTIVE SOLAR
HEAT EXCHANGER VENTILATION
CFM
2000
1500
1000
500
0
1
2
3
4
DESIGN
HEAT EXCHANGERS

FIGURE 6

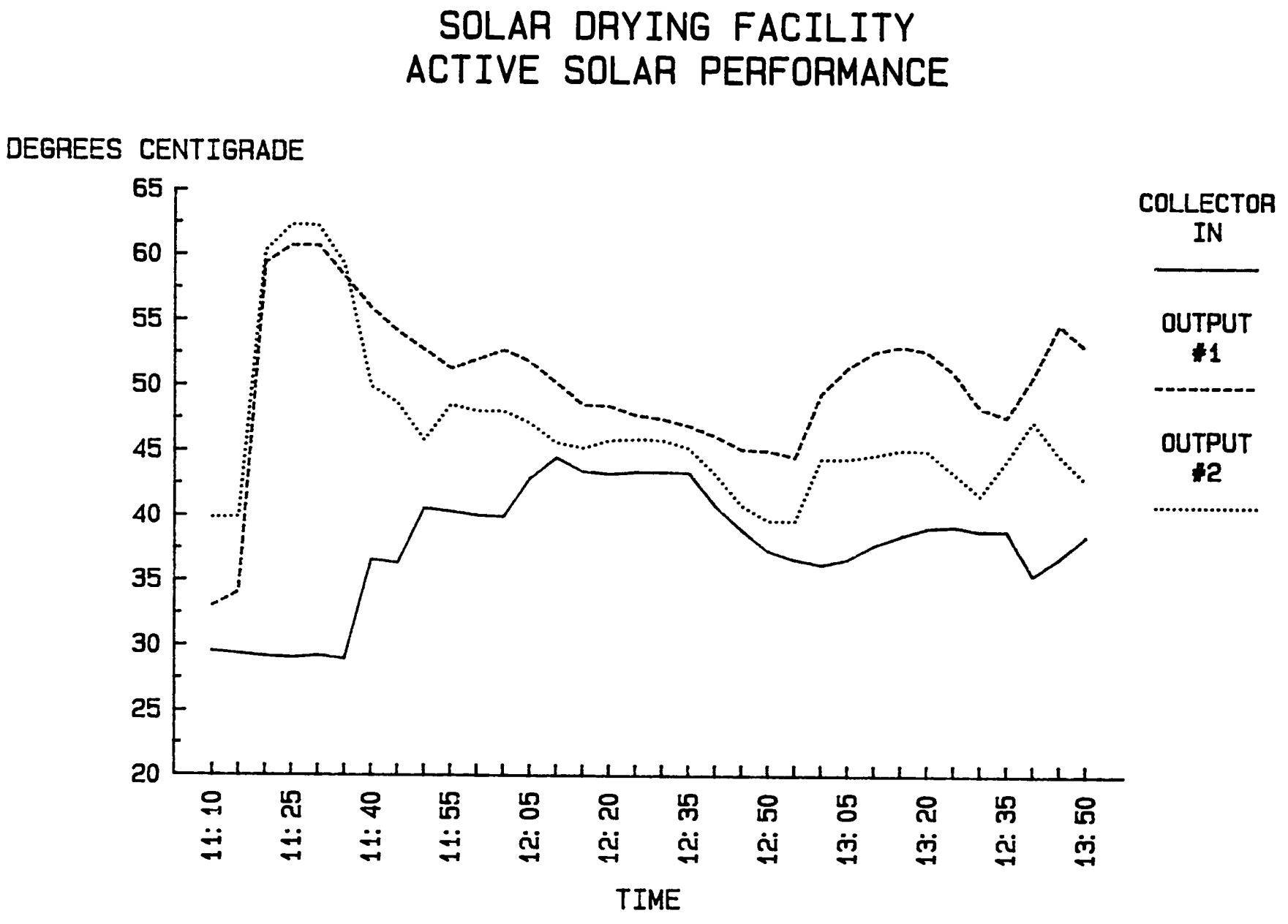

SOLAR DRYING FACILITY
ACTIVE SOLAR PERFORMANCE
DEGREES CENTIGRADE
65
60
55
50
45
40
35
30
25
20
11: 10
11: 25
11: 40
11: 55
12: 05
12: 20
12: 35
12: 50
13: 05
13: 20
12: 35
13: 50
TIME
COLLECTOR IN
OUTPUT #1
OUTPUT #2

FIGURE 7

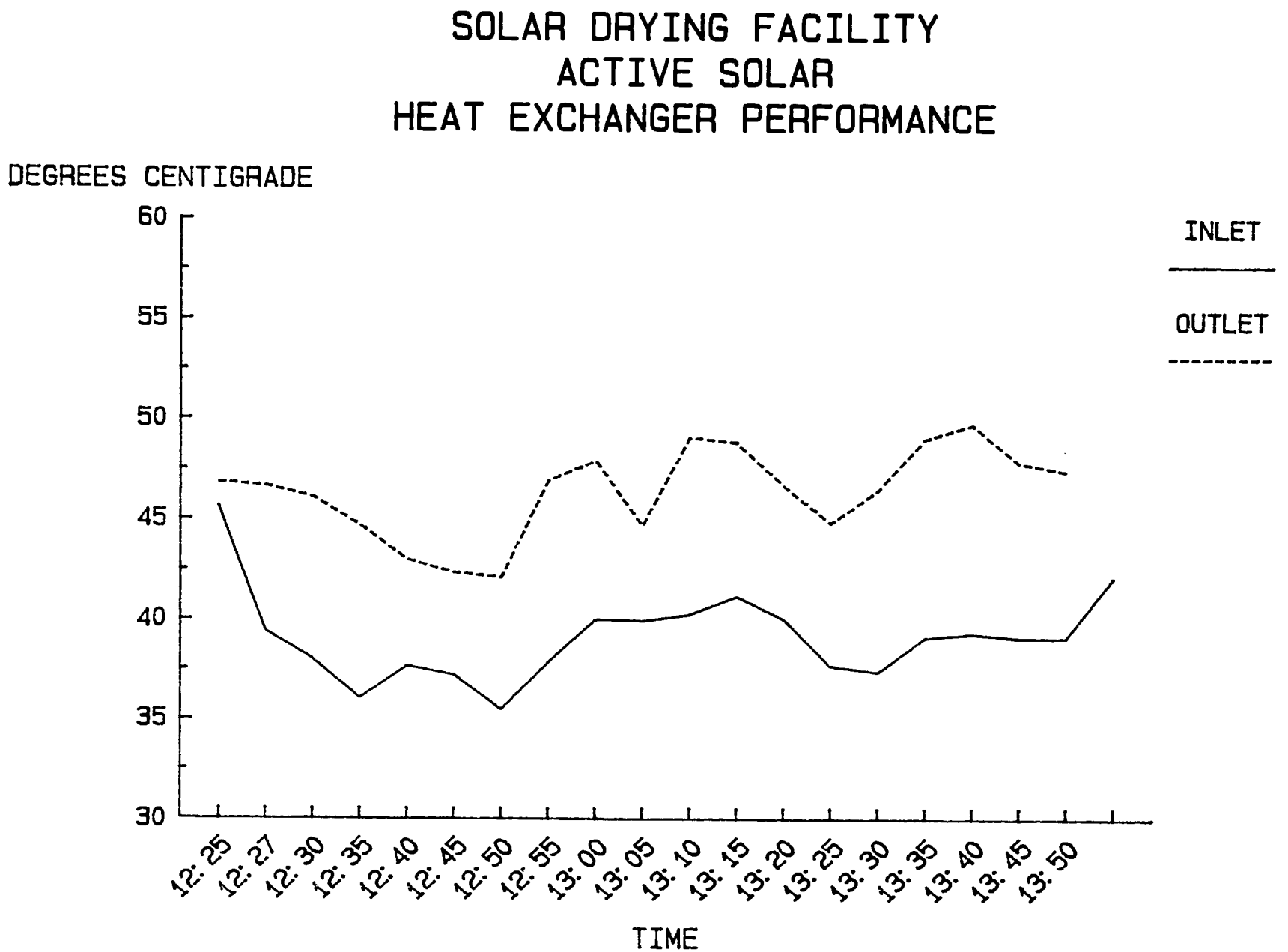

SOLAR DRYING FACILITY
ACTIVE SOLAR
HEAT EXCHANGER PERFORMANCE
DEGREES CENTIGRADE
60
55
50
45
40
35
30
INLET
OUTLET
12:25
12:27
12:30
12:35
12:40
12:45
12:50
12:55
13:00
13:05
13:10
13:15
13:20
13:25
13:30
13:35
13:40
13:45
13:50
TIME

FIGURE 8

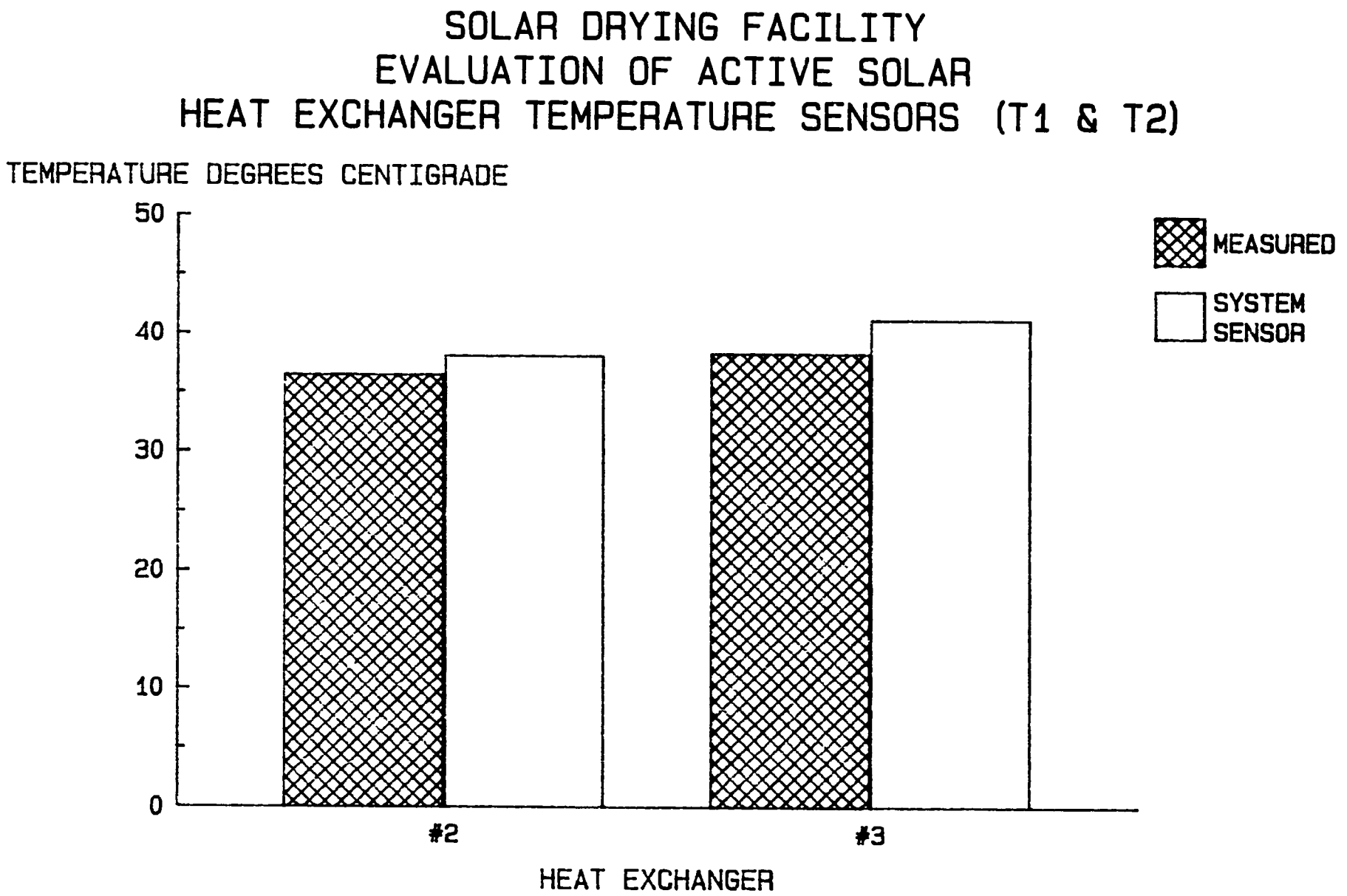

SOLAR DRYING FACILITY
EVALUATION OF ACTIVE SOLAR
HEAT EXCHANGER TEMPERATURE SENSORS (T1 & T2)
TEMPERATURE DEGREES CENTIGRADE
50
40
30
20
10
0
MEASURED
SYSTEM SENSOR
#2
#3
HEAT EXCHANGER

FIGURE 9

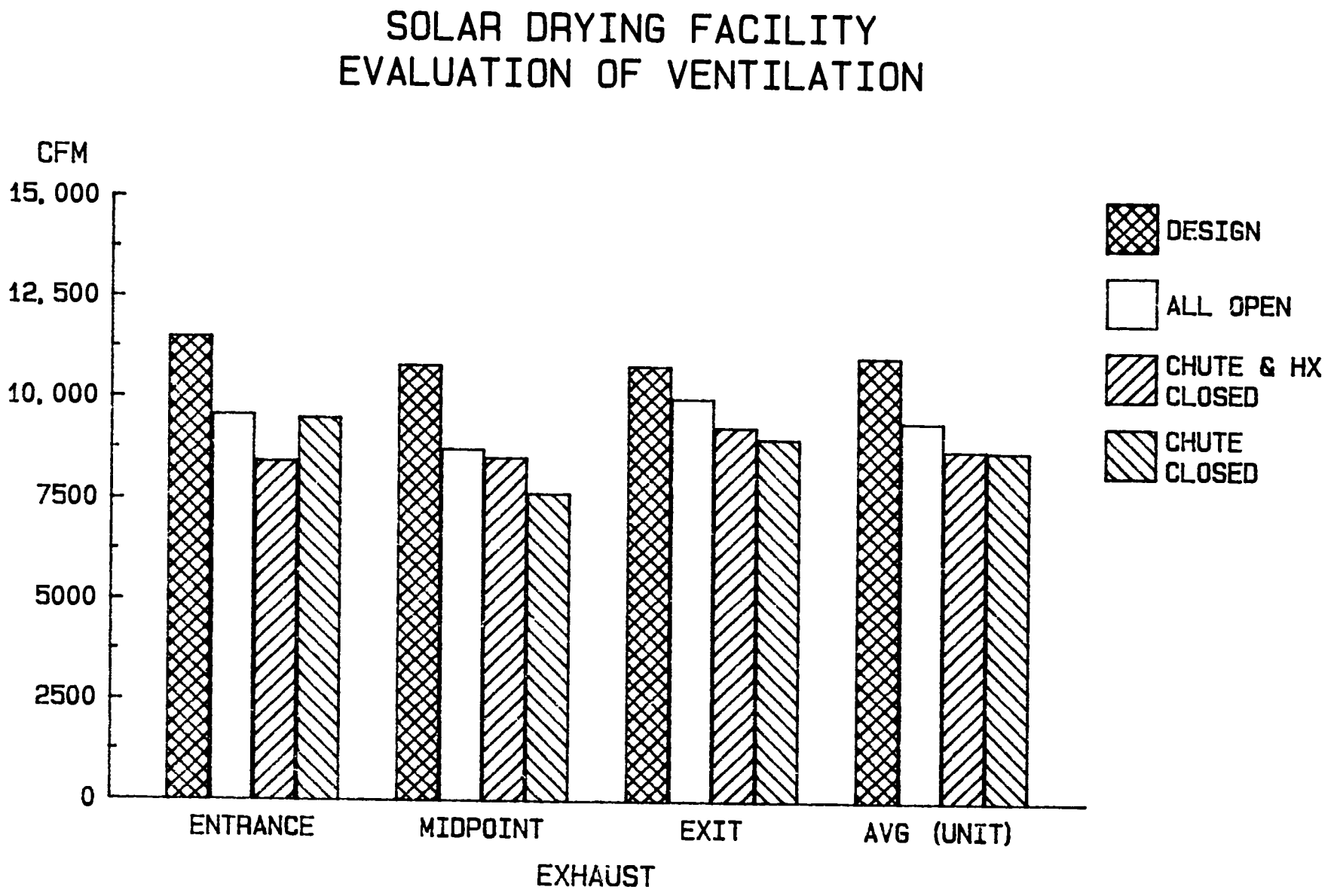
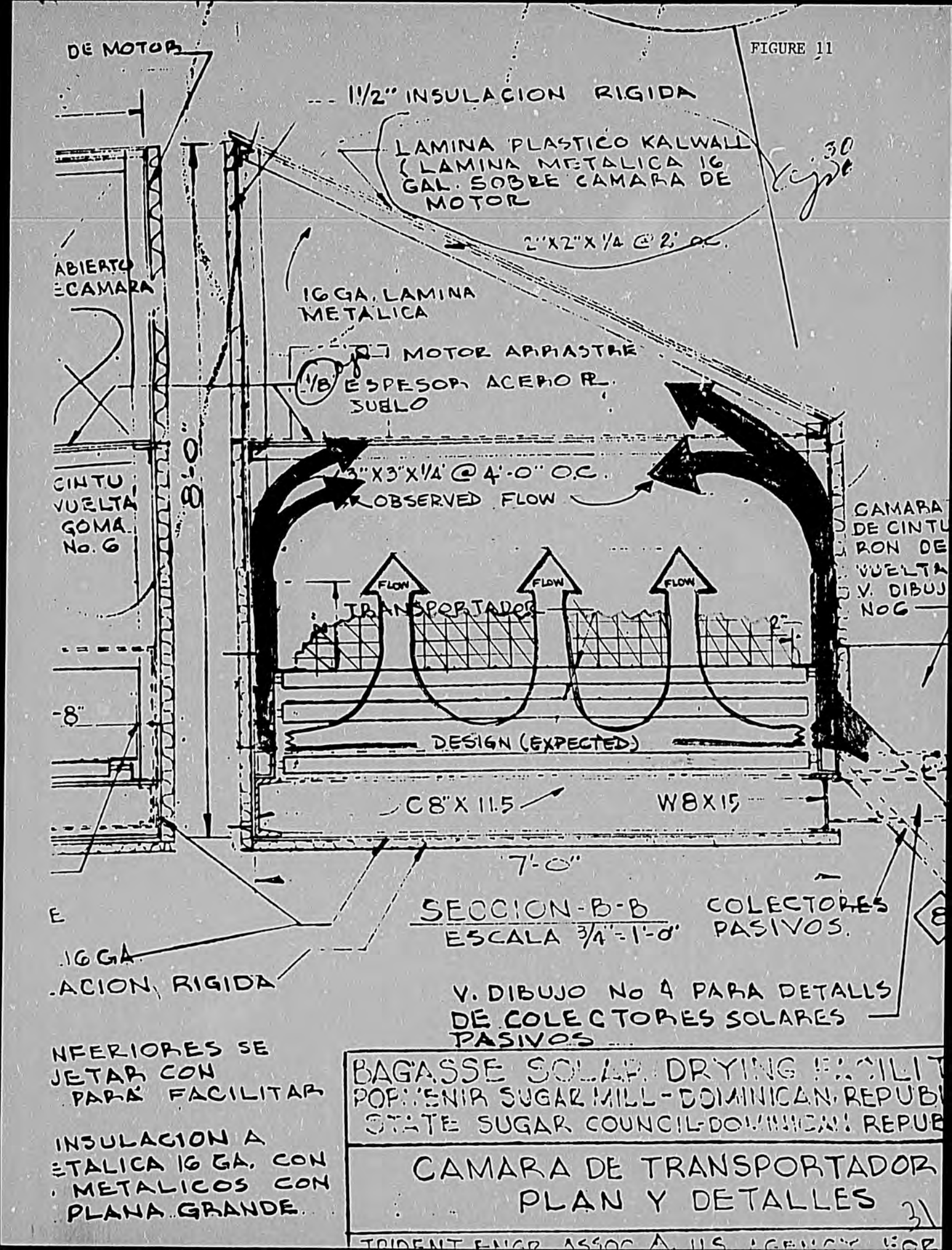

SOLAR DRYING FACILITY
EVALUATION OF VENTILATION
CFM
15,000
12,500
10,000
7500
5000
2500
0
ENTRANCE
MIDPOINT
EXIT
AVG (UNIT)
EXHAUST
DESIGN
ALL OPEN
CHUTE & HX CLOSED
CHUTE CLOSED

FIGURE 10

FIGURE 11


DE MOTOR
1 1/2" INSULACION RIGIDA
LAMINA PLASTICO KALWALL
(LAMINA METALICA 16 GAL. SOBRE CAMARA DE MOTOR
2"X2"X1/4 @ 2' O.C.
ABIERTO
CAMARA
16 GA. LAMINA METALICA
MOTOR APRIASTRE
1/8 ESPESOR ACERO PR. SUELO
8'-0"
CINTU
VUELTA
GOMA
No. 6
3"X3"X1/4 @ 4'-0" O.C.
OBSERVED FLOW
CAMARA
DE CINTU
RON DE
VUELTA
V. DIBUJ
NO 6
FLOW
FLOW
FLOW
TRANSPORTADOR
2"
-8"
DESIGN (EXPECTED)
C8"X 11.5
W8X15
7'-0"
SECCION-B-B
ESCALA 3/4"=1'-0"
COLECTORES PASIVOS.
16 GA.
ACION RIGIDA
V. DIBUJO No 4 PARA DETALLS DE COLECTORES SOLARES PASIVOS
NFERIORES SE
JETAR CON
PARA FACILITAR
INSULACION A
ETALICA 16 GA. CON
METALICOS CON
PLANA GRANDE.
BAGASSE SOLAR DRYING FACILIT
POR: ENIR SUGAR MILL - DOMINICAN REPUB
STATE SUGAR COUNCIL-DOMINICAN REPUB
CAMARA DE TRANSPORTADOR
PLAN Y DETALLES
31
TRIDENT ENGR. ASSOC. A. US. AGENCY FOR

SOLAR DRYING FACILITY
DISTRIBUTION OF INPUT AND OUTPUT
BAGASSE MOISTURE CONTENT

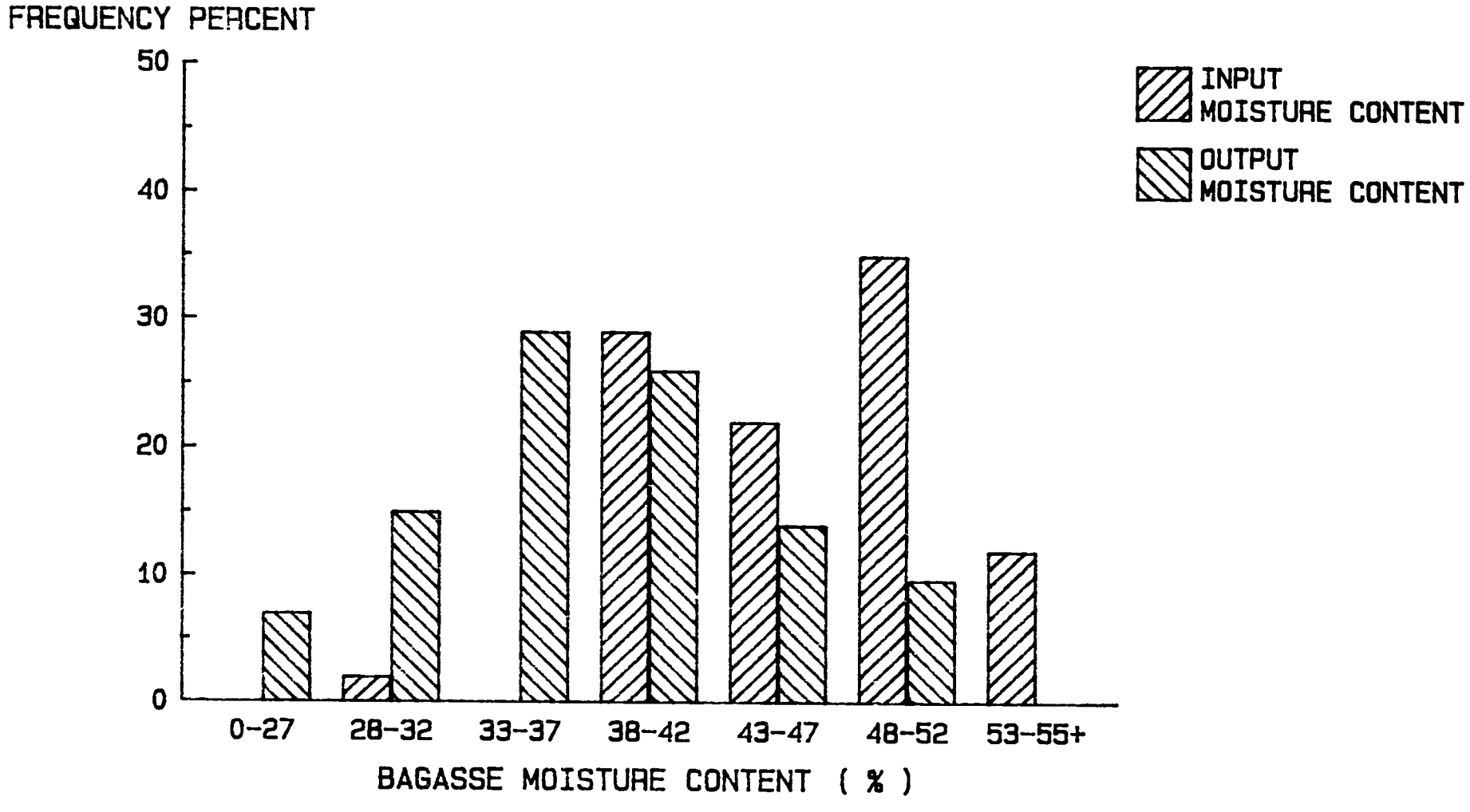


FIGURE 12

SOLAR DRYING FACILITY
DISTRIBUTION OF BAGASSE MOISTURE CONTENT CHANGE

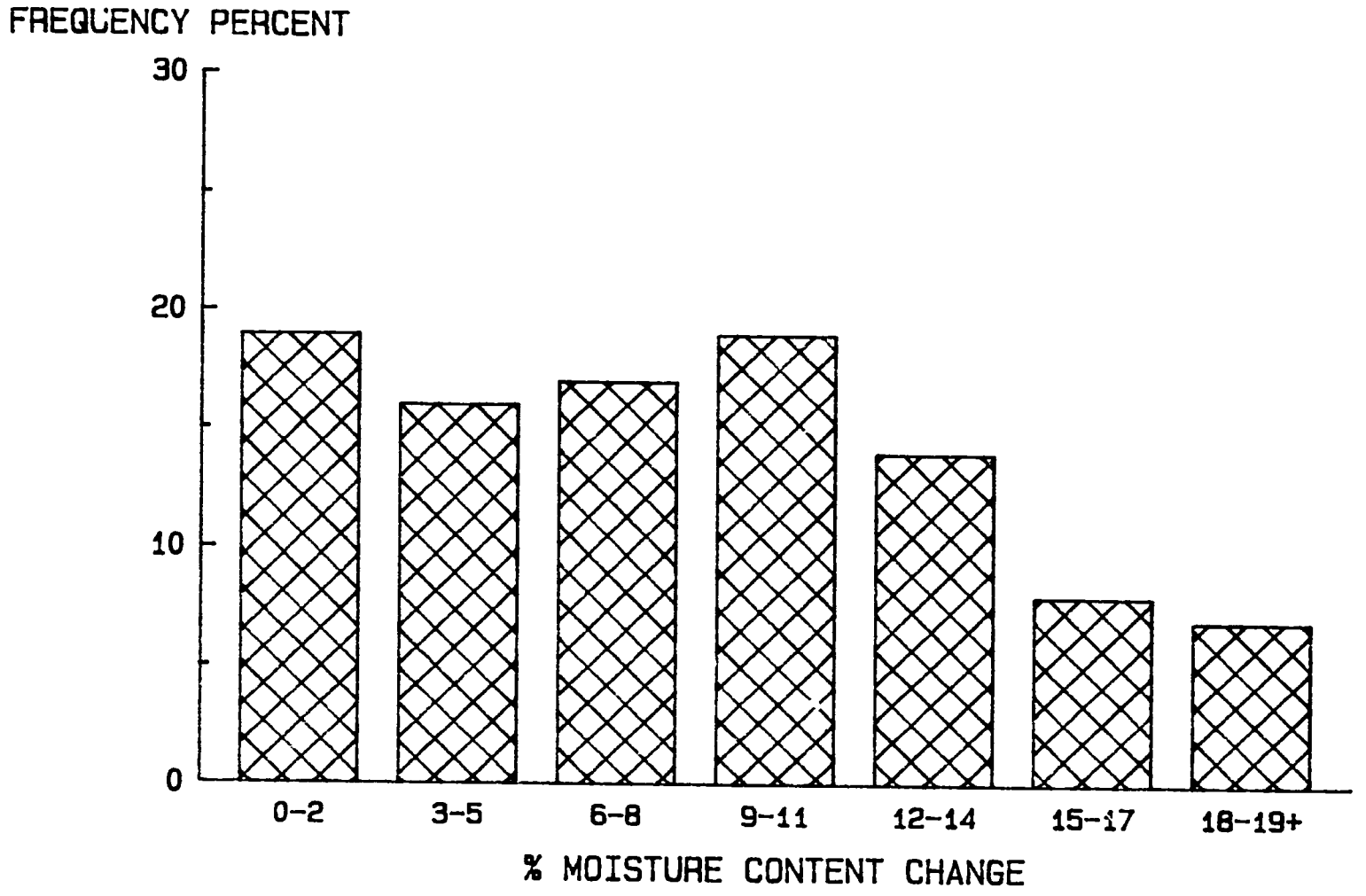


FIGURE 13

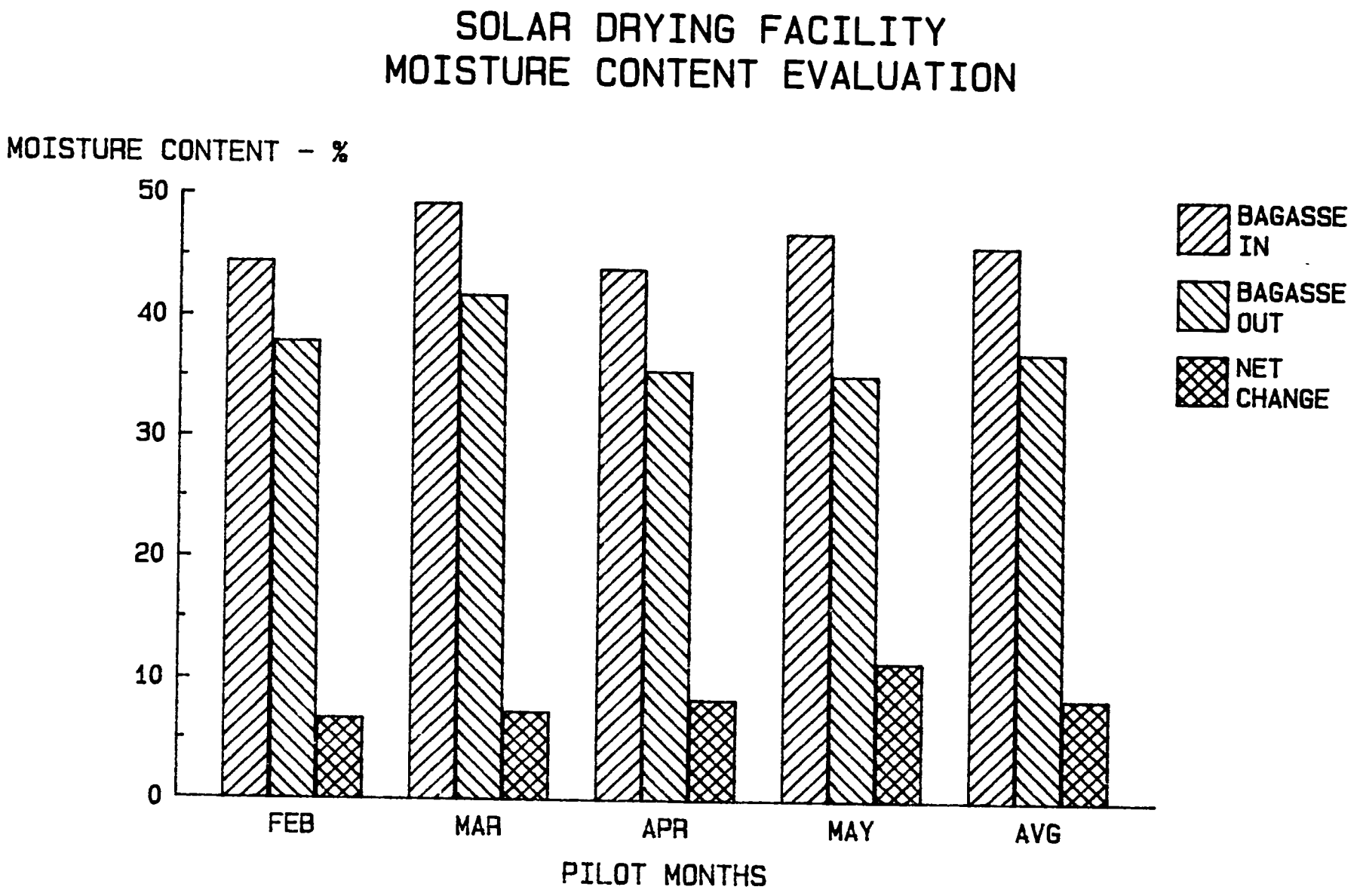

SOLAR DRYING FACILITY
MOISTURE CONTENT EVALUATION
MOISTURE CONTENT - %
50
40
30
20
10
0
FEB
MAR
APR
MAY
AVG
PILOT MONTHS
BAGASSE IN
BAGASSE OUT
NET CHANGE

FIGURE 14

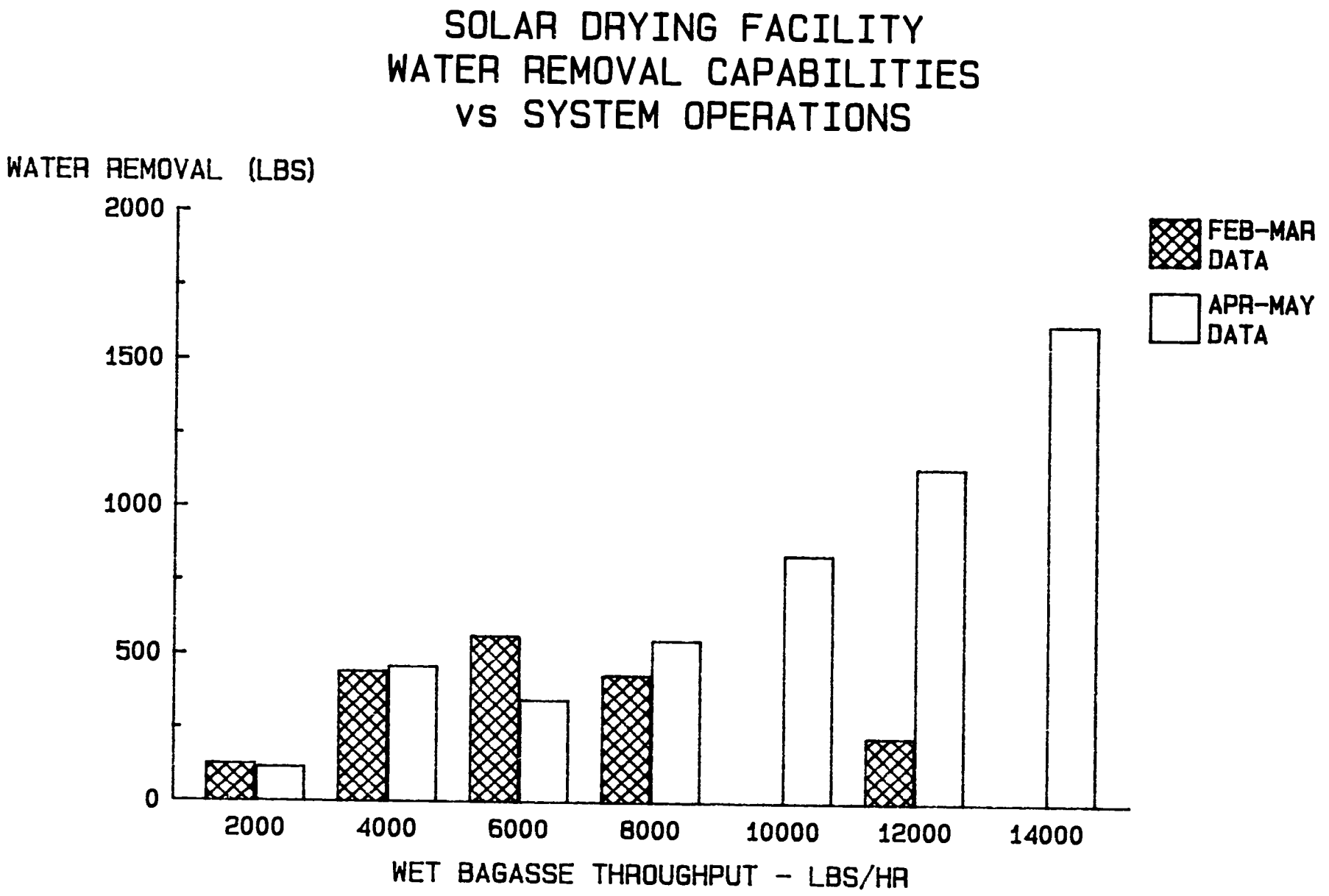

SOLAR DRYING FACILITY
WATER REMOVAL CAPABILITIES
vs SYSTEM OPERATIONS
WATER REMOVAL (LBS)
2000
1500
1000
500
0
2000
4000
6000
8000
10000
12000
14000
WET BAGASSE THROUGHPUT - LBS/HR
FEB-MAR DATA
APR-MAY DATA

FIGURE 15

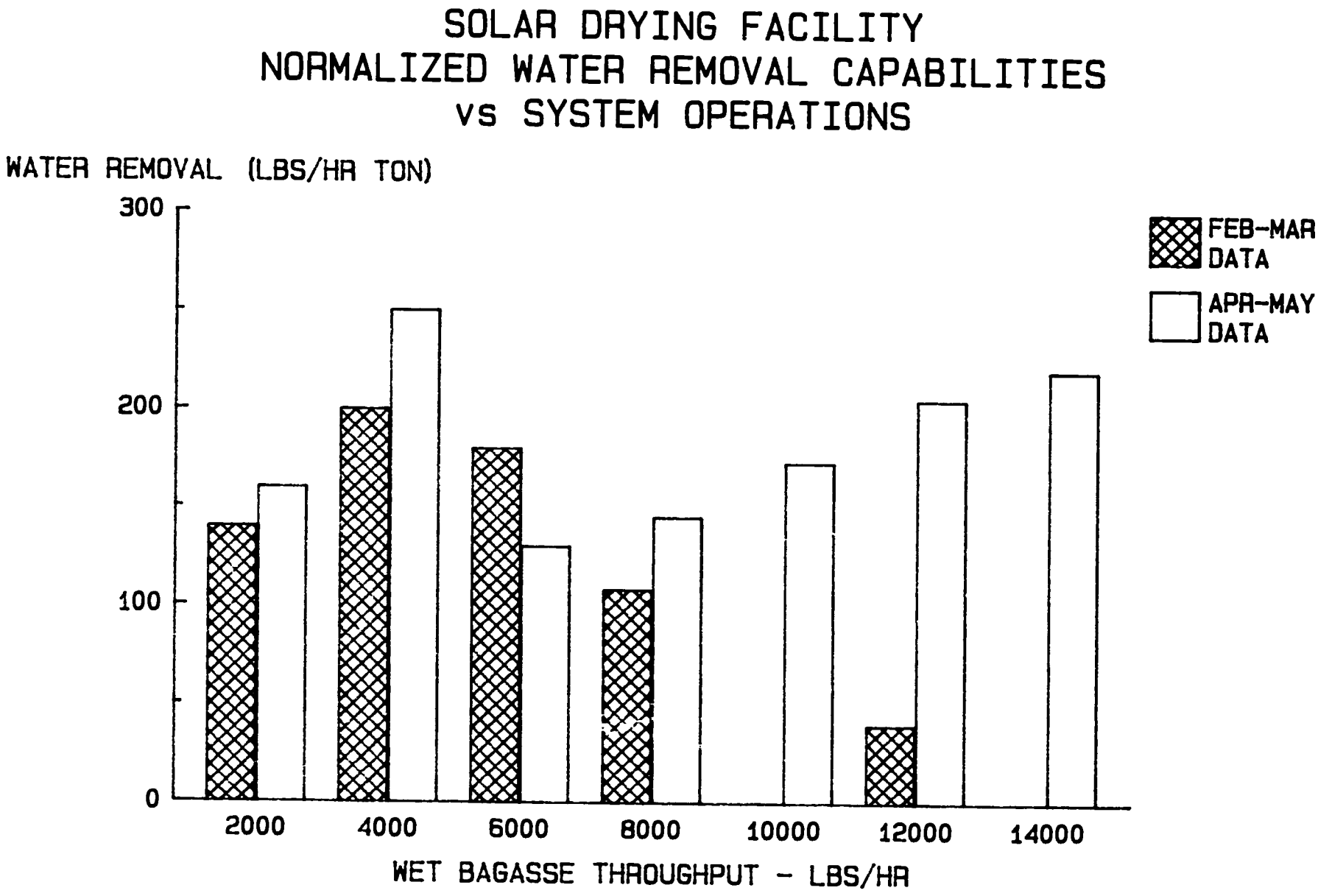
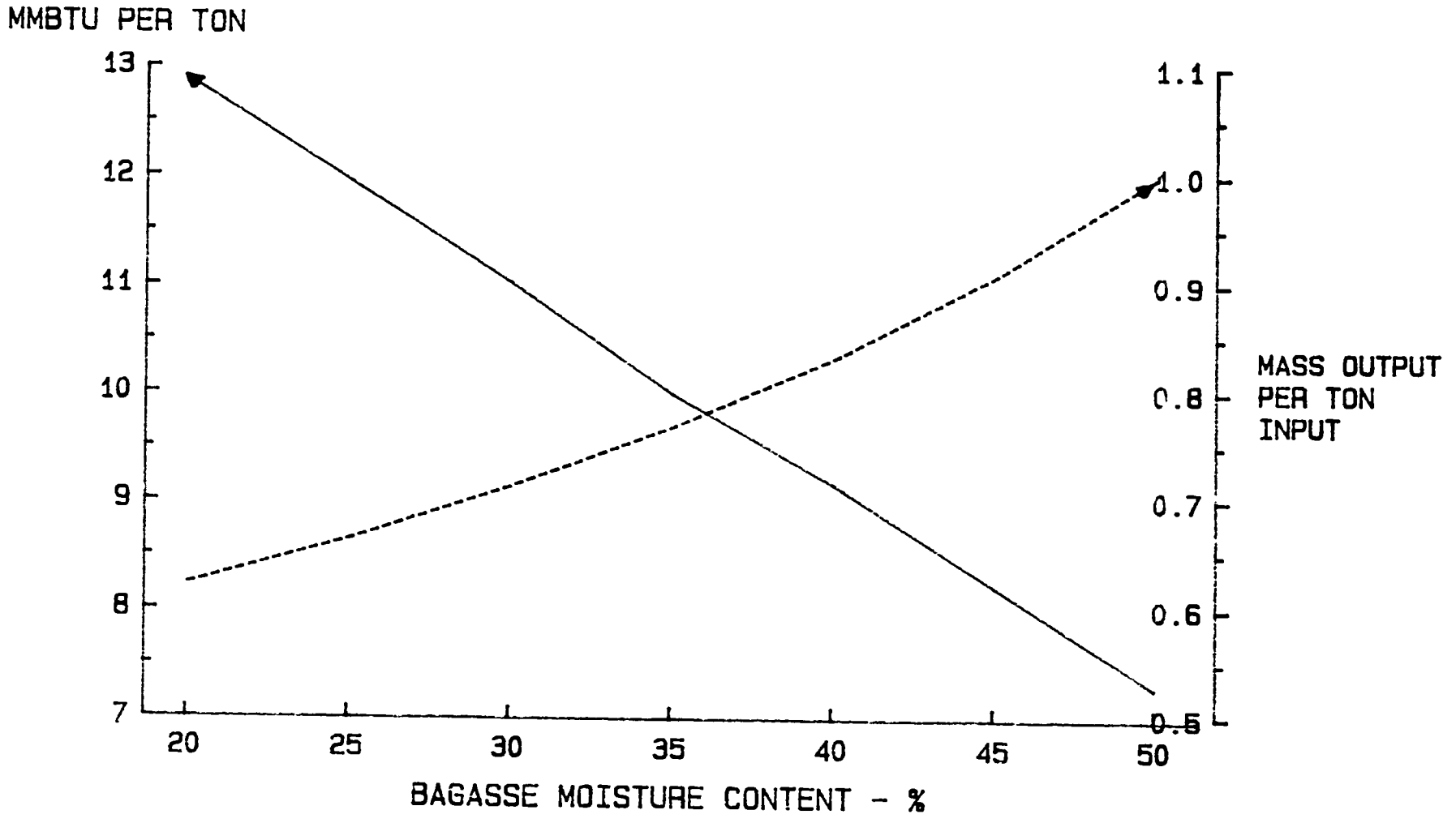

SOLAR DRYING FACILITY
NORMALIZED WATER REMOVAL CAPABILITIES
vs SYSTEM OPERATIONS
WATER REMOVAL (LBS/HR TON)
300
200
100
0
2000
4000
6000
8000
10000
12000
14000
WET BAGASSE THROUGHPUT - LBS/HR
FEB-MAR DATA
APR-MAY DATA

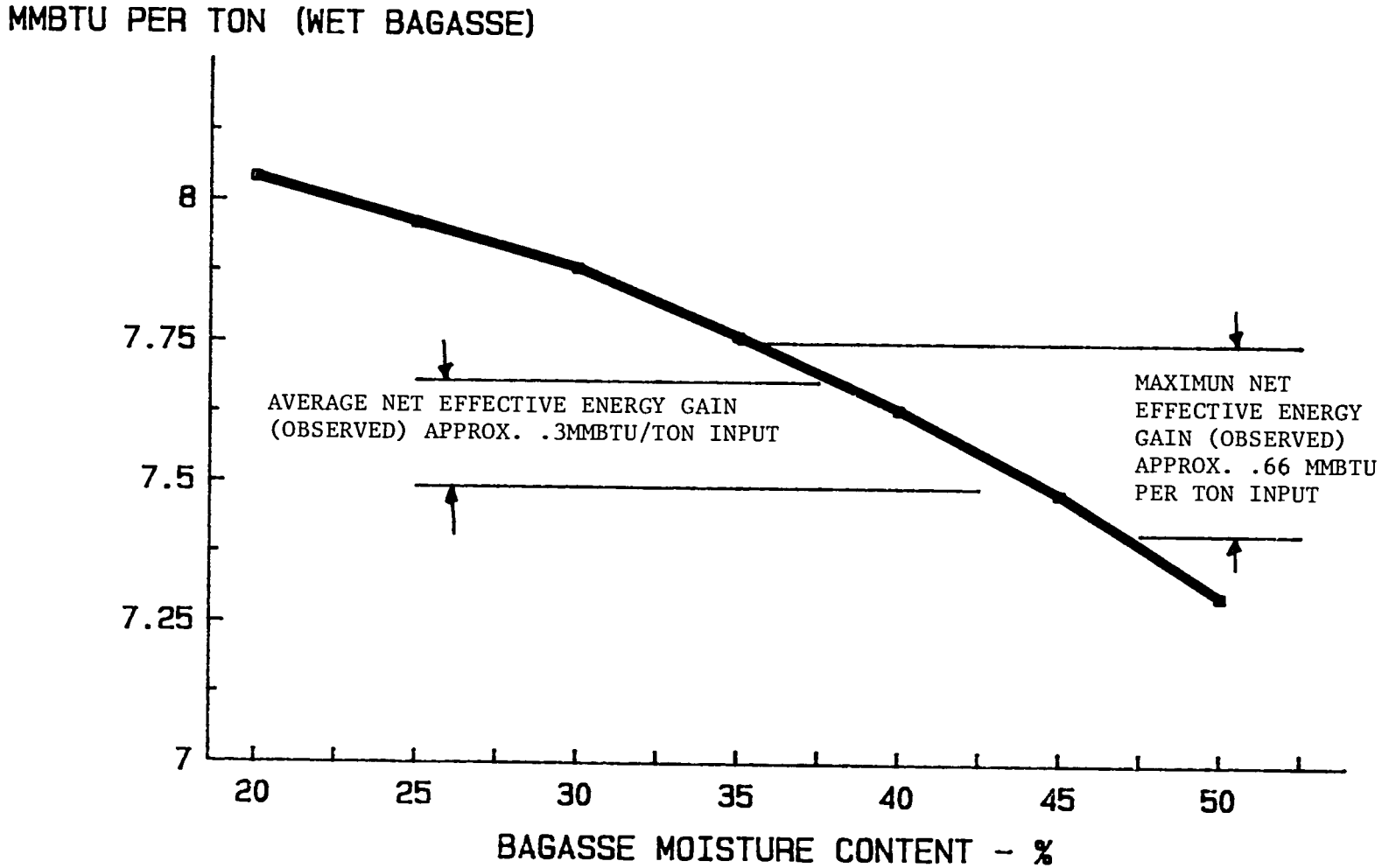
FIGURE 16

FIGURE 17

SOLAR DRYING FACILITY
EVALUATION OF ENERGY CONTENT
AND MASS OUTPUT VS MOISTURE CONTENT



SOLAR DRYING FACILITY
EFFECTIVE ENERGY GAIN



MAX. BASED ON 11.6% MOIST. CONT. REDUCTION
MIN. BASED ON 8.8% MOIST. CONT. REDUCTION

FIGURE 18

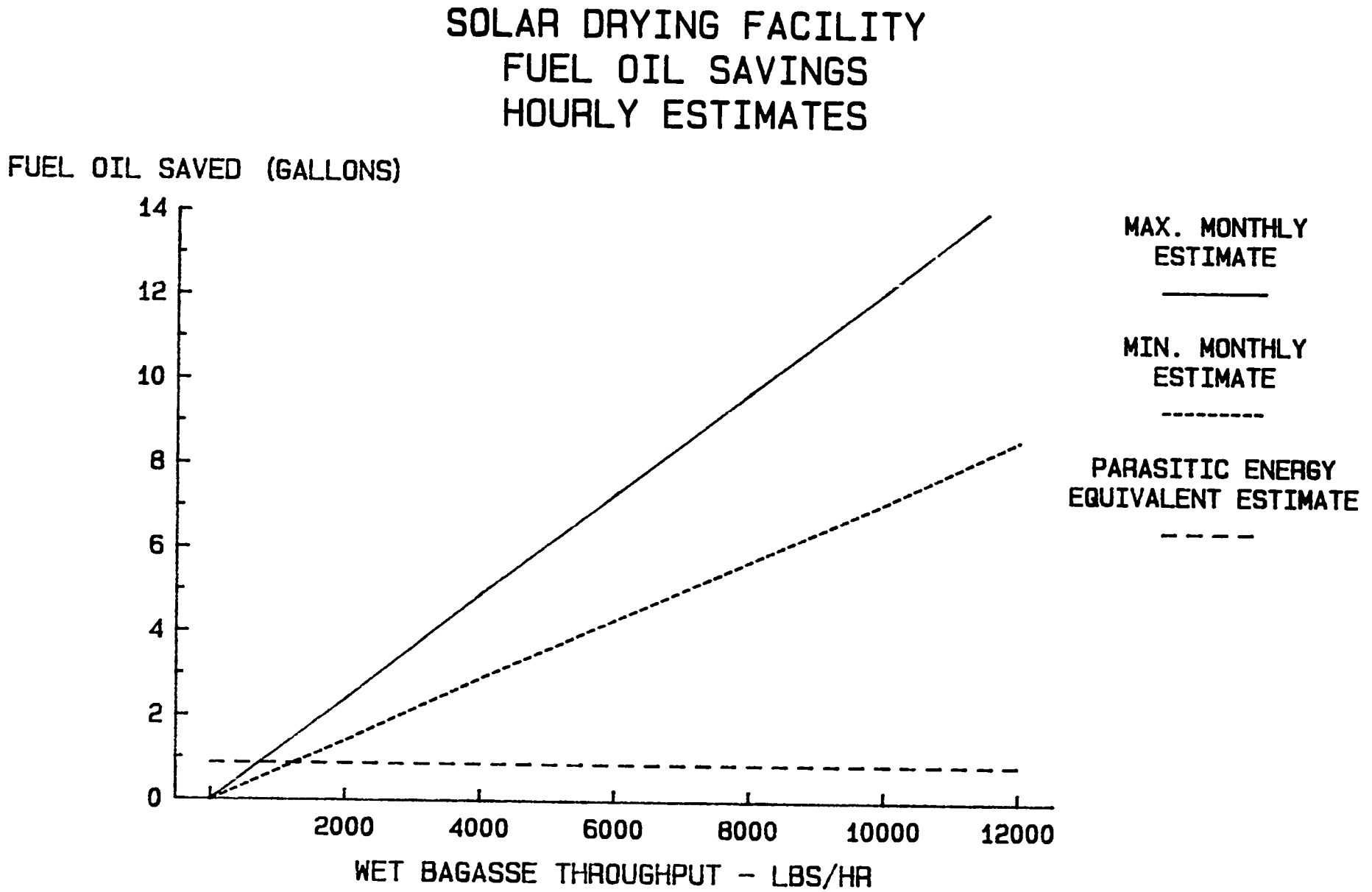

SOLAR DRYING FACILITY
FUEL OIL SAVINGS
HOURLY ESTIMATES
FUEL OIL SAVED (GALLONS)
14
12
10
8
6
4
2
0
2000
4000
6000
8000
10000
12000
WET BAGASSE THROUGHPUT - LBS/HR
MAX. MONTHLY ESTIMATE
MIN. MONTHLY ESTIMATE
PARASITIC ENERGY EQUIVALENT ESTIMATE

FIGURE 19

TEMPERATURAS OPERACION

PLANTA SECADO DE BAGAZO CON ENERGIA SOLAR
(FEBRERO/JUNIO 1984)

PROMEDIO MENSUAL	AIRE SALIDA INTERCAMBIADOR DE CALOR T_1 °C	AIRE SALIDA INTERCAMBIADOR DE CALOR T_2 °C	AGUA ENTRADA A LA BOMBA T_3 °C	AGUA ENTRADA A LOS COLECTORES T_4 °C	AGUA SALIDA DE LOS COLECTORES T_5 °C	AGUA SALIDA DE LOS COLECTORES T_6 °C	AIRE ENTRADA COLECTOR PASIVO T_7 °C	AIRE SALIDA COLECTOR PASIVO T_8 °C	TEMPERATURA AIRE DE ESCAPE T_9 °C.
FEBRERO	59.50	55.97	57.84	56.37	60.37	61.40	32.19	46.80	41.80
MARZO	54.61	47.71	51.31	47.10	59.64	57.23	31.91	40.12	38.53
ABRIL	55.69	48.51	52.24	47.67	64.88	59.35	33.11	39.24	38.12
MAYO	49.97	45.74	47.86	47.16	51.99	52.61	32.37	36.42	35.57
JUNIO*	54.00	49.84	50.81	52.56	56.55	54.16	32.21	36.72	36.00
PROMEDIO GENERAL	54.75	49.55	52.01	50.17	58.69	56.95	32.36	39.86	38.00

*Una semana de operación.

PLANTA SECADO DE BAGAZO CON ENERGIA SOLAR

(FEBRERO/JUNIO 1984)

PROMEDIO MENSUAL	RADIACION SOLAR ($WATTS/M^2$)	VELOCIDAD DEL AIRE (PIE/MIN)	FLUJO DE BAGAZO (LIBRAS/HR)	HUMEDAD DE ENTRADA DE BAGAZO	HUMEDAD DE SALIDA DE BAGAZO (%)	TEMPERATURA AMBIENTE (° C)*	TEMPERATURA PUNTO DE ROCIO (°C)	HUMEDAD RELATIVA (%)
FEBRERO	429.71	330.67	4560.71	44.33	37.29	29.80	36.92	53.80
MARZO	580.48	489.39	7732.14	45.79	34.82	28.65	30.10	58.78
ABRIL	607.78	489.39	5144.38	49.25	41.83	30.26	29.42	56.35
MAYO	544.31	525.30	7396.15	45.67	35.03	29.02	28.03	63.45
JUNIO*	410.09	493.87	3700.00	50.00	29.00	29.65	28.36	71.36
PROMEDIO GENERAL	514.47	465.72	5706.68	47.01	35.59	29.48	30.49	60.75

UNA SEMANA DE OPERACION