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TECOM PROJECT NO. 9 CO 009 000 016

USATTC REPORT NO. 7502002

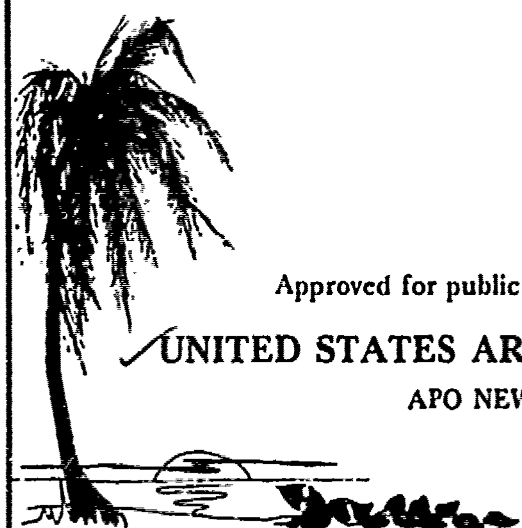
STORAGE AND SURFACE TEMPERATURES IN THE HUMID TROPICS

TECHNICAL NOTE

BY

W. H. PORTIG

FEBRUARY 1975



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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TECOM [redacted] 9-CO-[redacted]-016

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): STORAGE AND SURFACE TEMPERATURES IN THE HUMID TROPICS

5. TYPE OF REPORT & PERIOD COVERED: Technical Note, Sep[redacted]973 [redacted] Apr[redacted]974

6. PERFORMING ORG. REPORT NUMBER: USATTC [redacted] 75[redacted]2002

7. AUTHOR(s): W. H. PORTIG

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
US ARMY TROPIC TEST CENTER
ATTN: STETC-AD
APO NEW YORK 09827

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:

11. CONTROLLING OFFICE NAME AND ADDRESS:
US ARMY TEST AND EVALUATION COMMAND
ATTN: AMSTE-ME
ABERDEEN PROVING GROUND, MD 21005

12. REPORT DATE: FE[redacted]975

13. NUMBER OF PAGES: 44

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Accelerated tests	Humid tropics	Tropic Test Center
Ammunition bunker	Materiel deterioration	Warehouse
Butler building	Methodology	Wet season, tropic
CONEX	Regression analysis	Worst-case storage enclosures
Dry season, tropic	Storage enclosures	Worst-case thermal conditions
Enclosure temperatures	Surface temperatures	
General purpose tent	Thermal buildup	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

The United States Army Tropic Test Center conducted a study of the surface skin and inside temperatures of several typical Army storage enclosures in the humid tropics of the Panama Canal Zone. The study was conducted in the 1974 dry season and the 1973 rainy season. Storage enclosures included a large warehouse, an ammunition bunker, Butler building, a two-man general purpose tent and a CONEX container.

The purpose of the study was to characterize the immediate thermal environment of the stored items of materiel and relate that environment to outside weather conditions. Major conclusions were as follows:

(1) Maximum surface temperatures in the tropics rose as high as 176°F. This is higher than some other geographic areas, including Yuma, Arizona.

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b. (2) Storage enclosures ranged from most thermally severe to least, as follows: General purpose tent, Butler building, CONEX container, concrete warehouse, and concrete ammunition bunker (least).

c. (3) For most enclosures, inside temperatures always exceeded outside temperatures.

d. (4) Outside weather conditions in the humid tropics varied little during the day or the year, but thermal build-ups in and on enclosures were formidable. Attempts to mathematically predict enclosure temperatures from ambient conditions failed.

e. (5) Mean dry season enclosure temperatures were only slightly higher than mean rainy season temperatures. The single highest individual maximum temperatures were found in the rainy season.

It was recommended that tropic storage tests of materiel shift emphasis from ambient weather conditions to enclosure temperatures. It was further recommended that the relative effects of heat-moisture and heat-ultraviolet damage be systematically investigated.

SUMMARY

The United States Army Tropic Test Center conducted a study of the surface skin and inside temperatures of several typical Army storage enclosures in the humid tropics of the Panama Canal Zone. The study was conducted in the 1974 dry season and the 1973 rainy season. Storage enclosures included a large warehouse, an ammunition bunker, Butler building, a two-man general purpose tent and a CONEX container.

The purpose of the study was to characterize the immediate thermal environment of the stored items of materiel and relate that environment to outside weather conditions. Major conclusions were as follows:

a. Maximum surface temperatures in the tropics rose as high as 176°F. This is higher than some other geographic areas, including Yuma, Arizona.

b. Storage enclosures ranged from most thermally severe to least, as follows: General purpose tent, Butler building, CONEX container, concrete warehouse, and concrete ammunition bunker (least).

c. For most enclosures, inside temperatures always exceeded outside temperatures.

d. Outside weather conditions in the humid tropics varied little during the day or the year, but thermal build-ups in and on enclosures were formidable. Attempts to mathematically predict enclosure temperatures from ambient conditions failed.

e. Mean dry season enclosure temperatures were only slightly higher than mean rainy season temperatures. The single highest individual maximum temperatures were found in the rainy season.

It was recommended that tropic storage tests of materiel shift emphasis from ambient weather conditions to enclosure temperatures. It was further recommended that the relative effects of heat-moisture and heat-ultraviolet damage be systematically investigated.

PREFACE

Weather stations have operated for many years in the Canal Zone because of the long United States presence and the vital impact of climate on the operation and maintenance of the Panama Canal. As a result, an impressive bank of climatic data is now available for the ambient conditions of rainfall, temperature, humidity, wind, and radiation. However, the most important data for the storage testing of Army materiel are the microclimatic conditions immediately surrounding the test item. The present report shows that the latter conditions are quite severe and variable, the thermal build-up and consequent severity inside storage enclosures are very dependent on the physical characteristics of the structure.

The present report resulted from a request from Mr. Benjamin Goodwin, Chief Engineer, US Army Test and Evaluation Command, for "worst-case" thermal microenvironments in enclosures for a specific tropic materiel test. The search for an answer revealed clearly the lack of systematic information available. Only scattered and short-term bits of data associated with previous tropic tests were to be found. The present study was designed to partly correct the deficiency. The research was directed by the Chief of the Analysis Division, US Army Tropic Test Center, Dr. D. A. Dobbins.

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SECTION I. STORAGE AND SURFACE TEMPERATURES IN THE HUMID TROPICS

INTRODUCTION

The humid tropics cover 20 percent of the earth's solid surface, and are inhabited by 16 percent of the world's population (Staszewski, 1961).[1] Temperatures and humidities of the humid tropics are characterized by small diurnal and smaller seasonal changes. Table 1 shows an example of some values measured at one location in the Panama Canal Zone (9°N, 80°W) that is typical for wide areas of the humid tropics.

Table 1. An Example of the Small Variation of Outside Air Temperature in the Humid Tropics

Temperatures*	Dry Season (January) °C	(°F)	Rainy Season (June) °C	(°F)
Absolute Maximum	35	(95)	37	(99)
Mean Daily Maximum	30	(86)	30	(87)
Mean of All Hours	26	(79)	26	(79)
Mean Daily Minimum	23	(73)	23	(74)
Absolute minimum	16	(62)	20	(67)

* At Fort Gulick, Canal Zone, from 13 years of records.

The average daily temperature range of only 7°C in the preceding example becomes even smaller when measurements are taken under the canopy of the tropic forest.

These small differences in ambient air temperature are emphasized in many textbooks and have created the erroneous impression that temperature variations of materiel within enclosures in the tropics are also small. The present investigation describes what actually happened on the surface skin and within storage enclosures commonly in military use in the tropics.

Surface Temperatures Obtained in Other Geographical Areas

Kuroari and Schafer (1972)[2] analyzed 80,000 temperature measurements taken near the door at the inner wall of explosive hazard magazines in several climatic regions. The highest temperature, 47°C (117°F), was found in Yuma, Arizona. Bunker temperatures were measured on walls that were not earth-covered.

Porter and Greenwald (1971)[3,4] and Viletto (1973)[5] collected or reported on high surface temperatures obtained mainly at Yuma, Arizona, in a hot, dry climate. Porter and Greenwald pointed to the danger of generalizing the Yuma data: "For a given total solar

1 Staszewski, J., *Petermanns Mitteilungen*, 1961, pp. 133–138.

2 Kurotari, I. S. and H. C. Schafer, *Summary of Selected Worldwide Temperatures in Explosive Hazard Magazines*, Naval Weapons Center, China Lake, CA, 1972.

3 Porter, W. L. and A. Greenwald, *The Analysis of High Temperature Occurrences at Selected Internal and Surface Locations in Food Storage Dumps and Isolated Small Cartons at Yuma, Arizona*, US Army Natick Laboratories, Technical Report 71-59-FL/ES, 1971.

4 Porter, W. L. and A. Greenwald, *Comparison of the Occurrence of High Temperatures in Air and Food in Boxcars in Desert and Humid Subtropical Climates–Yuma, Arizona and Cameron Station, Virginia*, US Army Natick Laboratories, Technical Report 71-55-FL/ES, 1971.

5 Viletto, J. Jr., *Worldwide Distributions of Ambient Temperatures and Temperatures Exposed to Direct Solar Radiation*, US Army Engineer Topographic Laboratories, Ft. Belvoir, VA, 1973.

radiation, air masses with greater moisture content produce higher storage and ambient mean temperatures than dry air masses." The measurements reported below substantiate this statement and are compared with the authors' data in a later section of this report.

Surface Temperatures Obtained in Previous Canal Zone Studies

In the period 20 October through 5 November 1969 hygrothermographs were placed in the middle of each of seven one-man tents by the US Army Tropic Test Center (USATTC). The highest temperatures* were 46°C (114°F) for the coolest tent and 51°C (123°F) for the hottest tent; tent entrances remained closed. The average daily maximum (10 days, seven tents) was 44°C (112°F). This value is exactly the same as that found for the general purpose tent used in the present study.

From 25 February through 1? March 1973 hygrothermographs operated within two two-man tents during testing at USATTC. One of the tents had a woven shade over it to reduce the heat build-up. The highest temperatures recorded were 42°C (107°F) for the unshaded tent, and 39°C (102°F) for the shaded tent. The tent temperatures obtained in this project were lower than those obtained in the study discussed in the preceding paragraph because the entrances were never completely closed. The mean ranges of temperature and humidity were 12°C (21°F) and 44 percent for the unshaded tent, and 9°C (15°F) and 41 percent for the shaded tent.

The maximum roof temperatures of the air-conditioned Truck-Van M292 were measured at several sites by USATTC. Test periods lasted 1 to 3 days and were spread over the entire year of 1970. The highest roof temperature measured was 63°C (146°F). The simultaneous inside temperature was 27°C (81°F), and that of the outside ambient air, 33°C (91°F). During these tests no exceptionally hot or sunny weather was encountered; under such conditions the roof temperature probably would have been higher.

From November 1968 through November 1969, the surface skin temperatures of two M117AE2 bombs were measured by means of recording thermocouples glued on the upper surface of the bombs. The bombs were freely exposed at a Fort Gulick (Atlantic side of the Canal Zone) test site which because of nearness of water and on-shore winds is slightly cooler than other test sites in the Canal Zone. In relatively cool weather the correlation between maximum ambient temperatures and bomb temperatures was good. In warmer weather the correlation worsened as shown in the data of table 2.

Table 2. Maximum Ambient Temperatures and Highest Bomb Surface Temperatures Measured on the Same Day

(November 1968 through November 1969)

Weather	Ambient				Bomb			
	°C	(°F)	°C	(°F)	°C	(°F)	°C	(°F)
Cool	27	(80)			34	(93)		
Warm	31	(87) -	33	(91)	46	(115)-	53	(128)
Hot	33	(92) -	36	(96)	41	(105)-	59	(139)

NOTE: With relatively high ambient temperature (92°F–96°F), the bomb surface heated up to 111°F on 8 percent of the days. On the average, higher air temperatures were associated with higher bomb temperatures, but for individual cases a high air temperature was a poor predictor of skin temperature.

* Taken from continuous strip charts, not discrete readings at the full hour as in the present project.

Purpose and Scope

The purpose of the study was to characterize the immediate thermal environment of various structures typically used by the military for storing materiel items in the tropics, and to relate that environment to outside ambient weather conditions. Surface skin and inside temperature profiles of five different types of storage structures were measured during the dry and wet seasons.

DETAILS OF INVESTIGATION

Five types of structures were selected for the measurements. They are typical of those used for storage by the US Army in the tropics: a large ventilated warehouse, an ammunition bunker, an unventilated Butler building, a general purpose tent, and a transportation (CONEX) container. During the dry season portion of the study, staff personnel of the US Army Frankford Arsenal installed an epoxy plate with internal thermometer sensors for another purpose. Their data are, however, relevant to this study and are reported.

Attempts were made to measure the humidity of the air inside the described structures. Measurements in the bunker made with a hair hygrometer appear to be correct. Measurements in the other structures were made with unaspirated wet thermocouples close to the dry ones. The lack of aspiration resulted in erroneous measurements in the Butler building, the tent, and the CONEX container. The measurements in the warehouse may be correct, but after the experience in the other three structures it was decided not to use them.

Warehouse. The warehouse used was a rectangular building located in Coco Solo (Atlantic side of the Canal Zone), 31 meters long, 18 meters wide, and 10 meters high, without partitions. The walls are concrete with several doors and windows, the roof is corrugated iron, and the ceiling is wood. Three ventilation shafts cross the attic, with air motion in the shafts being natural. The building is bordered on one side by a paved road, and on the other side by trees–some higher than but not covering the roof. During daytime at least one of the doors was open; at nighttime all doors and windows were closed (figure 1).

Thermocouples were glued to the west-southwest slope of the roof and onto the ceiling between two ventilation shafts. Three thermocouples were hanging–one in a ventilation shaft, one below the ceiling thermometer, and one under the ceiling thermometer 2.30 meters above the floor. Hourly recordings were obtained on the days 1 September through 30 November 1973 (rainy season) and 1 February through 31 March 1974 (dry season).

Ammunition Bunker. The ammunition bunker is a concrete structure in Coco Solo (Atlantic side of the Canal Zone) with a steel door on one side and covered with earth and plants on the other sides. The 7.5-meter by 13.5-meter floor is rectangular; the highest point of the semicircular ceiling is 4 meters above the floor and is penetrated by a vent. Hygrothermographs were used to measure in this structure with one located very close to the ceiling halfway between the door and the vent another located directly beneath on the floor, and a third emplaced at approximately eye level between the other two instruments. Hourly data were obtained for the periods 12 September through 12 November 1973, and 1 February through 31 March 1974

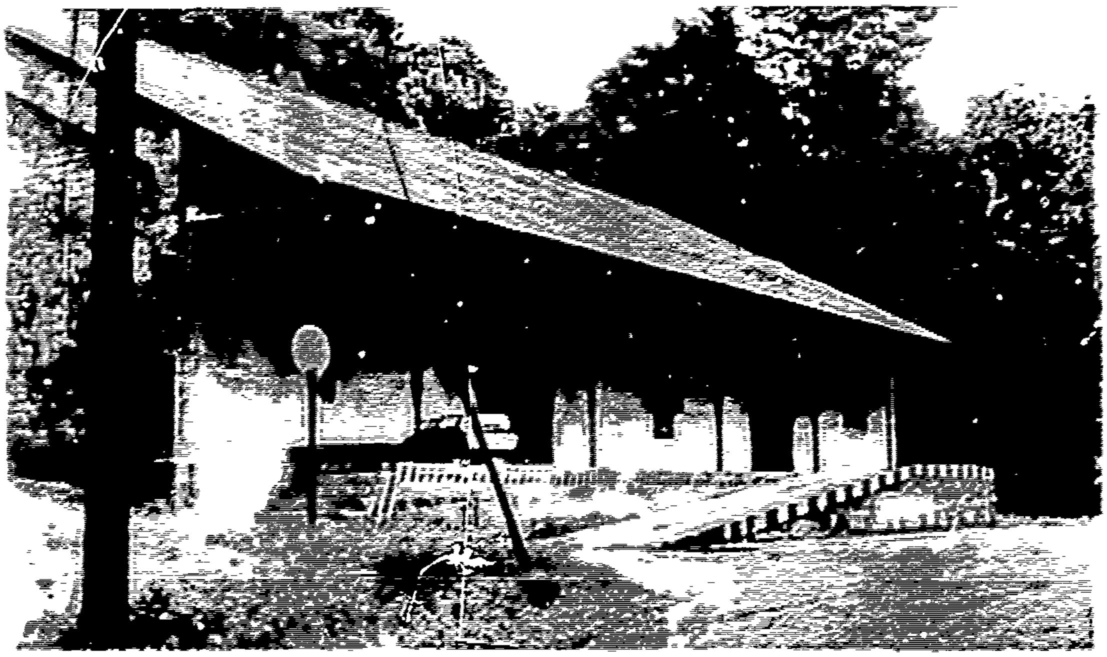

Figure 1. Typical Storage Structure—Warehouse.

Butler Building. The Butler building is an almost empty all-metal structure located at the Chiva Chiva test site (Pacific side of the Canal Zone), 16 meters long, 11 meters wide, and 5 meters high at the ridge. The windows are covered with white Venetian blinds and the doors are almost always closed (figure 2).

Four thermocouples were used to measure in this structure with one glued on the outside of the ridge, one glued on the underside of the roof near the outside temperature sensor, one hanging 1 meter below the ridge, and one hanging 2.4 meters above the floor. Hourly data were obtained for the periods 28 September through 30 November 1973, and 14 February through 15 April 1974.

General Purpose Tent. The general purpose tent,* medium size, was located on the Chiva Chiva Antenna Farm (Pacific side of the Canal Zone). The tents were equipped with three thermocouples, one glued to the slope facing east, one hanging 45 centimeters under the ridge, and one 1 meter above the ground. The entrance of the tent was kept closed. Hourly records were obtained for the periods 12 September through 30 November 1974, and 4 March through 15 April 1974 (figure 3).

* Extent of material deterioration was so great due to the intense solar radiation in the dry season that the first tent disintegrated in February. Its replacement also broke down immediately after termination of data collection in April.

Figure 2. Typical Storage Structure–Butler Building.

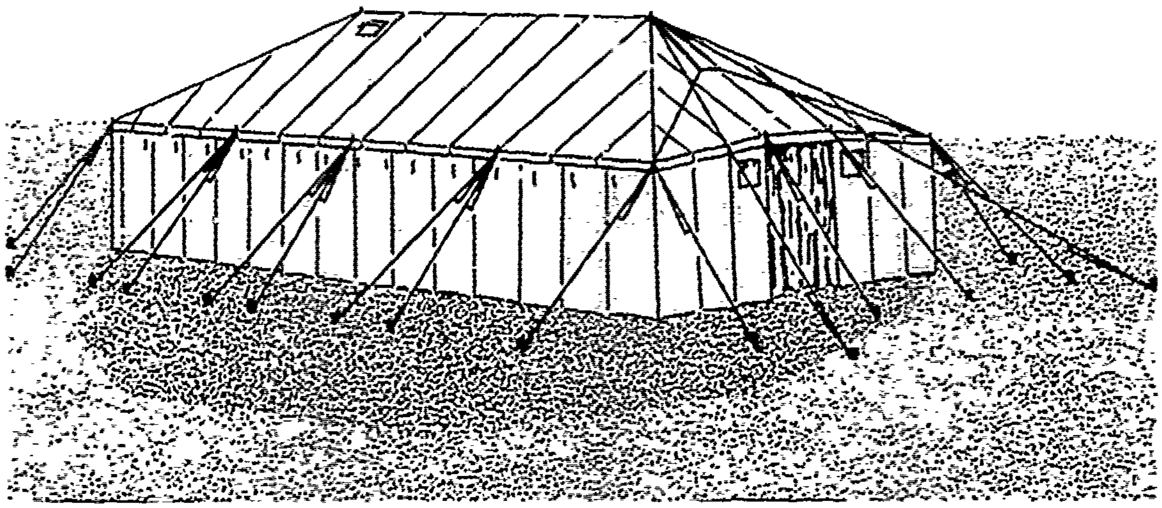

Figure 3. Typical Storage Structure–General Purpose Tent.

CONEX Container. This was a box constructed of corrugated iron, 4 millimeters thick, 2.90 meters long, 2.10 meters wide, and 2.35 meters high. It was emplaced close to the general purpose tent at the Chiva Chiva test site. Thermocouples were glued to the center of the upper surface, glued to the ceiling directly thereunder, and hung in the center of the airspace. Hourly records were obtained for the periods 12 September through 30 November 1973, and 13 February through 15 April 1974 (figure 4).

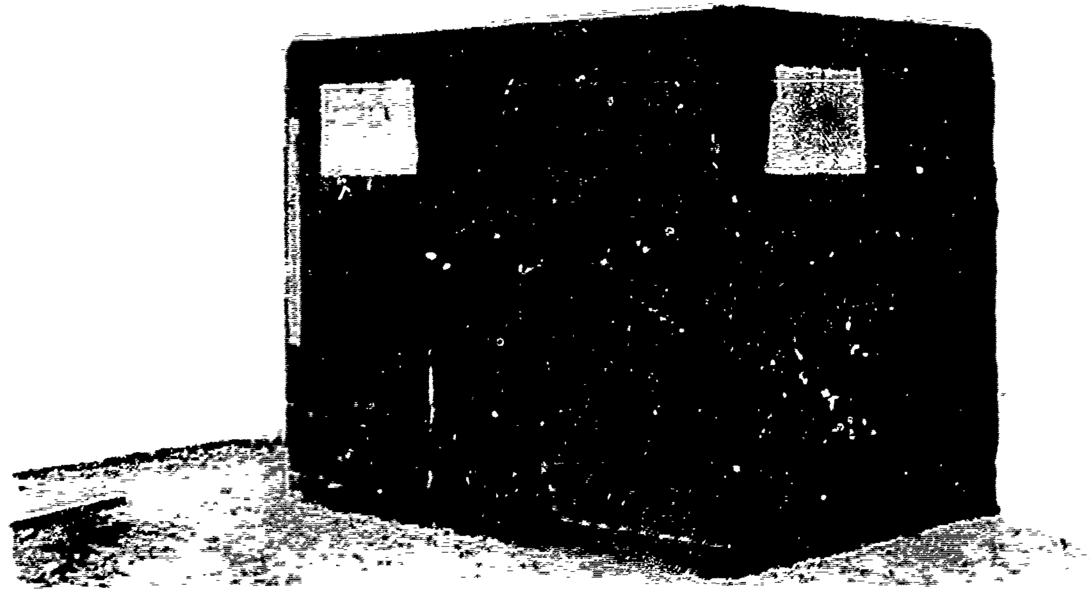

Figure 4. Typical Storage Structure–CONEX Container.

Epoxy Plate. Near the CONEX container a glass fiber-enforced plate of epoxy was emplaced by staff personnel of the US Army Frankford Arsenal on an exposure rack facing south, inclined 45 degrees and 130 centimeters above grass covered soil. The plate measured 33.3 by 28.0 by 0.25 centimeters. Three thermocouples were embedded in the plate, one at its upper end, one at its lower end, and one half-way between. Atmospheric Sciences Laboratory, White Sands, New Mexico, began publication of hourly data on 8 January 1974 (figure 5).

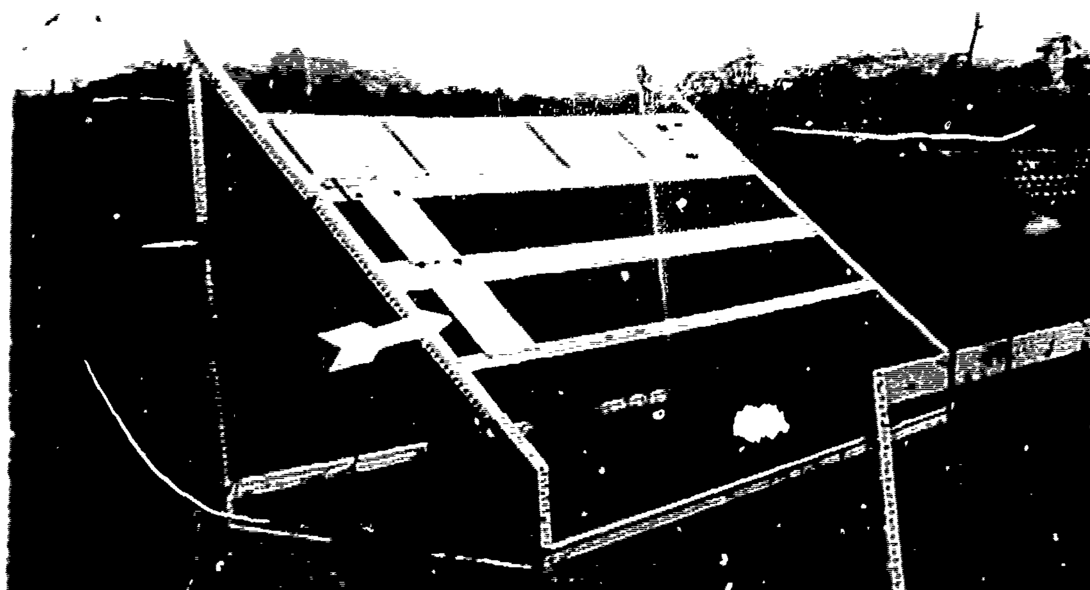

Figure 5. Typical Exposure Rack–Showing (at the left) the Epoxy Plate Discussed in the Text.

ANALYSIS AND RESULTS OBTAINED

Because of redundancy in information, not all of the obtained data series appear to justify their publication Generally the thermometer on the outer side of the structure and the thermometer that measured the air temperature close to the center of the enclosure are discussed here.

In the following discussion, reference to *dry season* means data taken in February, March, or April 1974; *rainy season* means data taken in September, October. or November 1973.

Highest Temperatures. Since these are of special interest, they are presented first (table 3). *Absolute maximum* is the highest value measured in the season. *Mean maximum* is the average of all daily maxima. The absolute maxima are higher than in the subsequent sections because the latter deal only with temperatures at the full hour.

Table 3. Absolute and Mean Maximum Temperatures—Five Storage Structures

	Absolute Maximum				Mean Maximum			
	Dry		Rainy		Dry		Rainy	
	°C	(°F)	°C	(°F)	°C	(°F)	°C	(°F)
Warehouse								
Roof outside	61	(142)	71	(160)	56	(133)	52	(126)
Ceiling	43	(110)	45	(113)	41	(106)	37	(99)
In air current of ventilation shaft	39	(103)	43	(109)	38	(100)	35	(95)
1 meter below ceiling	35	(95)	34	(93)	35	(95)	32	(90)
2.4 meters above floor	34	(94)	34	(94)	33	(92)	32	(90)
Ammunition Bunker								
Near ceiling	28	(83)	27	(80)	27	(80)	26	(78)
At eye level	28	(82)	27	(81)	27	(79)	26	(79)
Near floor	28	(83)	26	(79)	27	(80)	26	(78)
Butler Building								
Roof outside	71	(159)	72	(162)	61	(141)	55	(131)
Roof inside	68	(154)	71	(160)	57	(135)	56	(133)
Air 1 meter below roof ridge	59	(139)	56	(133)	54	(130)	47	(116)
2.4 meters above floor	50	(122)	47	(116)	47	(116)	41	(106)
General Purpose Tent (Medium)								
Fabric outside	74	(166)	80	(176)	64	(147)	62	(143)
Air 45 centimeters below highest point	61	(141)	72	(162)	49	(121)	54	(129)
Center of inner airspace	59	(139)	55	(131)	47	(117)	44	(111)
CONEX Container								
Upper surface	70	(158)	69	(157)	55	(131)	54	(130)
Ceiling	61	(141)	67	(153)	53	(128)	51	(124)
Center of inner airspace	47	(117)	61	(123)	43	(109)	43	(109)

Table 3 shows that the single highest temperature of all surfaces was measured in the rainy season, whereas the mean daily maximum temperature of all surfaces was higher in the dry season.

The highest absolute temperature can develop in the rainy season because lack of wind, greater transparency of the air (in cloud-free spots), and downward reflection of sunlight from towering clouds.

The mean maximum is higher in the dry season because of the daily presence of conditions that produce high surface temperatures; table 4 shows an example. While the roof temperature reached at least 51°C (123°F) every day of the dry season, this temperature was reached on only 71 percent of all days in the rainy season.

Table 4. Absolute Extremes, Quartiles, and Medians of Daily Maximum Temperatures—Roof of Butler Building

	Lowest Maximum		1st Quartile		Median		3rd Quartile		Highest Maximum	
	°C	(°F)	°C	(°F)	°C	(°F)	°C	(°F)	°C	(°F)
Dry Season	51	(123)	55	(133)	59	(139)	63	(146)	71	(159)
Rainy Season	33	(92)	49	(121)	55	(131)	59	(139)	72	(162)

The highest temperatures of each structure were measured at the upper surface of the skin; the lowest* were measured in the inner air space near working level. The latter values did not exceed 59°C (139°F) in the most extreme case, and reached an approximate maximum of 44°C (111°F) daily inside the Butler building, the general purpose tent and the CONEX container.

Whereas the Butler building, general purpose tent, and CONEX container showed very high absolute maxima, mean maxima, and diurnal variability, the bunker showed practically no temperature changes at all. The warehouse showed, through the temperature differences between roof and ceiling, that natural ventilation and an attic very effectively prevent excessive heat build-up.

Based on maximum temperatures one can arrange the structures according to increasing thermal stress: (a) bunker, (b) warehouse, (c) Butler building and CONEX container, and (d) general purpose tent. Data presented in subsequent sections will not change this order.

Figures A-1 through A-19 present highest (symbol v) and lowest (symbol ʌ) temperatures, and the averages of all measurements, for each hour on the hour. The following summary statements with only minor deviations can be derived from the graphs. Statistical support can be found in tables A-1 and A-2. The bunker showed no temperature variations of significance. For the other structures it is practical to distinguish between daytime and nighttime conditions.

During Daytime Hours

- Before noon the surface skin temperatures are generally higher in the rainy season than in the dry season. (Partial exceptions: General purpose tent at afternoon hours, and the Butler building.)

- The single lowest surface temperatures are generally lower in the rainy than in the dry season. This was also true for inside temperatures.

* The *lowest* were still very high in terms of human comfort and well-being.

• The hour with the highest average surface temperature generally occurs sooner in the rainy season than in the dry season. This is true for inside air as well, and for all structures.

During Nighttime Hours

• The averages and minima of most nighttime hours are lower in the dry season than in the rainy season. This was true for all surface temperatures and for the inside temperatures of the smaller enclosures (general purpose tent and CONEX container).

• Mean and extreme temperatures of the epoxy plate (dry season only) are closer to inside air than to surface skin temperatures (table A-1).

Most of the curves, figures A-1 through A-19, show slight irregularities in the afternoon hours because of increased cloudiness. This cloudiness causes substantial temperature drops in individual cases as described in succeeding paragraphs.

Mean Diurnal Variations for the Five Hottest Days. Figures A-20 through A-28 mainly serve the purpose of comparing diurnal variations of the different temperatures within a structure with the ambient outside air, as measured at regular weather stations all over the world. The ambient data of the present study were furnished by the Atmospheric Sciences Laboratory Canal Zone Meteorological Team.

Figures A-20 through A-28 show the following general trends for all enclosures:

• Inside temperatures stayed above the temperature of the ambient air at all hours. (One exception was the CONEX container which was cooler inside than outside at night during the dry season.)

• The outside skin was the warmest place during daytime and the coolest at night. (Afternoon rains interrupt or terminate the heating process.)

• High skin surface temperatures are not predicted by changes in ambient temperatures.

Temperature Drops. Large temperature ranges require large change rates. Although reported changes had to be computed from data taken at the hour on the hour, and therefore are smaller than those that actually occurred, they are important enough to be listed here. See tables 5 through 7, below. The weather records show that there is not always an obvious explanation for the temperature drops. The black globe thermometer of the WBGT (Wet Bulb Globe Temperature) instrumentation showed strong drops at the same times as the thermometers of this project. Hence, one can assume that the measurements are at least qualitatively correct. One or several of the following changes were observed when the data were obtained for tables 5 through 7: decrease of global radiation (i.e., clouds moving in), increase of wind speed, change of wind direction, beginning of rain, no obvious change. None of these factors was in the majority. It is

Table 5. Percentage Frequencies of Days with Extreme Temperature Drops—Measured on Outer Skin

Structure	Rainy Season 20°C (36°F) (%)	Rainy Season 25°C (45°F) (%)	Rainy Season 30°C (54°F) (%)	Dry Season 20°C (36°F) (%)	Dry Season 25°C (45°F) (%)	Dry Season 30°C (54°F) (%)
Warehouse	9.2	5.7	0	1.9	1.9	0
Butler Building	29.0	11.3	6.5	14.3	3.6	1.8
General Purpose Tent	36.7	24.0	13.9	20.9	11.6	9.3
CONEX Container	20.0	10.0	6.7	6.5	1.6	0
Epoxy Plate	*	*	*	3.3	0	0

* Not measured.

Table 6. Percentage Frequencies of Days with Two 20°C (36°F) Temperature Drops—Measured on Outer Skin

Structure	Rainy Season (%)	Dry Season (%)
Warehouse	0	0
Butler Building	1.6	0
General Purpose Tent	8.9	0
CONEX Container	0	0
Epoxy Plate	*	0

* Not measured.

Table 7. Maximum Single Temperature Drop from One Full Hour to the Next—Measured on Outer Skin

Structure	September through November °C	September through November (°F)	February through April °C	February through April (°F)
Warehouse	29	(52)	25	(45)
Butler Building	37	(66)	39	(71)
General Purpose Tent	43	(77)	38	(68)
CONEX Container	33	(59)	26	(47)
Epoxy Plate	no data		22	(40)

possible that an extension of the investigation from full hours to shorter intervals would show a preponderance of one of the reasons; but data available show that the same factor will not be encountered in all cases.

MAXIMUM TEMPERATURES OBTAINED IN THIS STUDY AND IN OTHER AREAS

Table 8 lists the maximum temperatures at the indicated locations, together with the extreme ambient temperatures of the same day. In the Canal Zone data the first line refers to the dry season, the second to the rainy season. Table 8, sections I through III, show that temperatures of storage enclosures are much higher in the Canal Zone than in Cameron Station, Virginia, and only slightly lower than in Yuma, Arizona, in spite of the much higher ambient temperatures at Yuma.

Table 8. Extreme Storage and Surface Temperatures (Extremes of Ambient Temperatures of the Same Day)

Inside Storage Temperatures	Storage		Ambient			
			Minimum		Maximum	
	°C	(°F)	°C	(°F)	°C	(°F)
I Yuma, Arizona						
Air 6 inches below roof of empty, closed boxcar	64	(148)	28	(82)	43	(110)
Air 6 inches above floor of empty, closed boxcar	56	(132)				
II Cameron Station, Virginia						
Air 6 inches below roof of empty, closed boxcar	48	(118)	21	(70)	38	(101)
Air 6 inches above floor of empty, closed boxcar	43	(109)				
III Panama Canal Zone						
Air 1 meter below roof ridge, Butler building	59	(139)	20	(68)	33	(91)
	56	(133)	22	(72)	32	(90)
Center of inner airspace, general purpose tent	59	(139)	21	(71)	33	(91)
	55	(131)	24	(75)	30	(86)
Center of inner airspace, CONEX container	47	(117)	20	(68)	33	(91)
	51	(123)	22	(72)	32	(90)

Surface Skin Temperatures	Surface		Ambient			
			Minimum		Maximum	
	°C	(°F)	°C	(°F)	°C	(°F)
IV Yuma, Arizona						
Thermometer fixed to upper surface of a stack of filled "C ration" cartons	57	(134)	20	(68)	46	(114)
Soil surface ("Desert Pavement")[6]	66	(150)	not known			
Upper seam of a tent	72	(162)	not known			
V Panama Canal Zone						
Upper seam of a tent	74	(166)	21	(69)	32	(90)
	80	(176)	22	(71)	31	(88)
Soil surface, March 1967[7]	64	(148)	20 approximate	(68)	35	(95)

For an explanation of the Canal Zone temperatures which in most cases were higher, it is necessary to take into account the higher moisture of the tropical atmosphere as well as the lower air motion, especially in the rainy season. These factors apparently outweigh the shorter heat[illegible] period caused by the shorter duration of the tropical day. (The typical length of a ho[illegible] Arizona, sunrise to sunset, is 14 hours; the longest day in Canal Zone is 12 hours a[illegible] [illegible]0 minutes.)

REGRESSION ANALYSIS

Six of the data series were submitted to regression analysis in an attempt to get a better insight into the mechanisms of extreme heating. The series were the outer skin temperatures and the temperatures of the inner air spaces of the general purpose tent, the CONEX container, and the Butler building. Only days with very high temperatures were used. The analysis covered the hourly data from 0800 through 1800 hours.

[6] Dodd, A. V. and H. S. McPhillmy, *Yuma Summer Microclimate*, Quartermaster Research and Engineering Center, Natick, MA, Technical Report EP-120, 1959.

[7] *Environmental Data Base for Regional Studies in the Humid Tropics*, Tropic Test Center, Ft. Clayton, CZ, Semiannual Report No. 4, 1958.

The temperatures on and in the three structures were compared with the simultaneous ambient temperature, the total of the global radiation of the preceding 60 minutes, and the mean wind speed of the preceding 10 minutes.

Becaus[illegible]ities in the magnitudes and patterns of the coefficients, only the series fo[illegible] the CONEX container will be reported. Table 9 lists the correlation c[illegible]s which were obtained after combining dry and rainy season data.

Table 9. Correlations for Upper Surface of CONEX Container

(Both Seasons Combined)

Zero o[illegible]der correlation coefficients, r			Multiple correlation coefficients, R	
Between	and	r =	C correlated with	R =
C	E	.854	E^2, E, W	.898
C	T	.681	E, T, W	.895
C	W	.081	E^2, E	.876
E	T	.731	E, W	.873
E	W	.298	E, T	.858
T	W	.539	E^2, W	.777
			T, W	.76[illegible]

LEGEND: C = actual surface temperature
E = accumulated radiation during the last 60 minutes before C
T = ambient temperature, same time as C
W = mean wind speed during the last 10 minutes before C

Replacing the ambient temperature by the square of the solar radiation E^2 increases the multiple correlation coefficient. Although this increase is statistically insignificant, it shows that the ambient temperature does not contribute to the "explanation" of the surface temperatures. This conclusion is supported by the relatively small coefficients of regressions without radiation E. The regression equations associated with the rs or Rs of table 9 are not suitable for predictions for the following three reasons:

- According to the general theory of regressions, the standard error, e, of the prediction is $e = s_C\sqrt{1 - R^2}$, where s_C is the standard deviation of the observed values C, defined as in table 9. For the best R, 0.898, e becomes 44 percent of s_C. In the example, representative of almost all series of this study, s_C = 10.7°C (19.3°F); hence e = 4.7°C (8.5°F).

- The prediction error is not constant over the data range. The mean error of prediction was 7.2°F in our example for surface temperatures between 70°F and 99.9°F, 7.6°F for temperatures between 100°F and 129.9°F, and 15.2°F for temperatures between 130°F and 155°F, i.e., the more relevant and practical the predicted temperature, the greater the prediction error.

- The high correlation (R = .898) is mainly due to the diurnal variation. When the regression computation is based on shorter parts of the day, the correlation coefficient drops considerably, and for data taken only at noon is almost zero.

The poor predictive capabilities of the regression model are independently verified by the fact that the three structures never had their highest temperatures on the same days, even though the ambient conditions were identical. The days with highest temperatures for each structure during the rainy season are listed in table 10.

Table 10. Temperatures When at Least One Outer Surface Had One of Its Five Highest Temperatures*

Day	General Purpose Tent (°F)	Butlar Building (°F)	CONEX Container (°F)
29 Sep 73	168†	143	137
30 Sep 73	174†	159†	139
22 Oct 73	145	154†	129
24 Oct 73	159	130	143†
25 Oct 73	168†	141	139
26 Oct 73	162	152†	155†
28 Oct 73	171†	149	150†
30 Oct 73	15[illegible]	151	141
31 Oct 73	152	148	150†
14 Nov 73	131	154†	115
2[illegible] Nov 73	176†	136	160†

* Temperatures taken at Chiva Chiva during rainy season.
† Five highest temperatures of each structure.

The investigations described in the last paragraphs indicated that extreme surface temperatures cannot be accurately predicted from conventional meteorological measurements. Table 10 makes it appear equally probable that more detailed measurements of the meteorological conditions will not improve such predictions.

SUMMARY AND CONCLUSIONS

- Outside skin temperatures and air spaces within enclosures in the tropics show high variability during the day. This variability sharply contrasts to the small changes in outdoor ambient conditions.

- The single highest surface skin temperatures readings are attained in the rainy season, but the average of daily highs is higher in the dry season.

- Outside skin temperatures went as high as 80°C (176°F). This is higher than measurements made in any other geographic area for which temperature measurements were available.

- Temperatures inside enclosures went as high as 59°C (139°F).

- Temperatures in an earth-covered bunker were low, showed no diurnal variation, and a very small seasonal change.

- Structures ranged in temperature from hottest to coolest as follows: (1) general purpose tent, (2) Butler (metal) building and CONEX container, (3) warehouse (concrete), and (4) ammunition (concrete) bunker.

• With the exception of the bunker and the all-iron CONEX container, the inside temperatures were always higher than the outside temperatures.

• Temperature changes within 1 hour frequently exceeded 25°C (45°F) with a measured maximum of 43°C (77°F).

• Maximum storage temperatures are not accurately predicted by outside weather conditions.

• A material sample weathered in the conventional way (outside on a rack) was subject to all outdoor influences but resulted in measured temperatures as if it were indoors.

• As predicted by Porter and Greenwald (1971), surface temperatures in the humid Canal Zone rose higher than, or as high as dry Yuma, Arizona. It can safely be assumed that the effects of high temperatures at either location should be different because of their coincidence with other relevant factors. Besides temperature and high humidity, in the Canal Zone these factors include presence of many kinds of fungi, high transparency of the atmosphere, low ozone content of the stratosphere (Reynolds)[8] and subsequently high intensities of ultraviolet light, low wind speeds, and great variability of cloudiness (producing great variability of radiative effects).

RECOMMENDATIONS

It is recommended that:

• Tropic storage tests shift emphasis from measurement of ambient meteorological conditions to measurements of the actual conditions in and around the test item.

• The relative effects of the heat-moisture and heat-ultraviolet damage be systematically investigated for three reasons: (1) Design engineers should be provided data to avoid materials and construction features that are foredoomed to failure in the humid tropics, (2) Tropic testers of military materiel need to be able to choose the most likely deteriorative environment for storage, and (3) The specific effects of the combination of climatic and other environmental conditions briefly alluded to in this report, are not known except in their totality (Downs and Lawson, 1973;[9] Sprouse, Neptune and Bryan, 1974;[10] Portig, Bryan, and Dobbins, 1974;[11] Dobbins and Downs, 1973).[12]

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8 Reynolds, R. D., *Ozone: A Synopsis of Its Measurement and Use as an Atmospheric Tracer*, US Army Electronics Command Report No. 5401, 1971.

9 Downs III, G. F. and W. F. Lawson III, *Determination of Optimum Tropic Storage Sites, Report I: Survey of Programs in Tropic Materials Research*, US Army Tropic Test Center, USATTC Report No. 7304001, 1973.

10 Sprouse, J. F., M. D. Neptune, and J. C. Bryan, *Determination of Optimum Tropic Storage and Exposure Sites, Report II: Empirical Data*, US Army Tropic Test Center, USATTC Report No. 7403001, 1974.

11 Portig, W. H., J. C. Bryan, and D. A. Dobbins, *Determination of Optimum Tropic Storage and Exposure Sites, Phase II: Patterns and Predictions of Tropic Materials Deterioration*, US Army Tropic Test Center, USATTC Report No. 7405001, 1974.

12 Dobbins, D. A. And G. F. Downs III, *Laboratory versus Field Tests. A Limited Survey of Materials Deterioration Studies*, US Army Tropic Test Center, USATTC Report No. 7307002, 1973.

APPENDIX A. STATISTICS

The following statistics are applicable under the assumptions that (a) the rainy season represented a typical rainy season, (b) that the dry season represented a typical dry season, and (c) that there are no measurement biases between compared series of data.

Mean and mean maximum temperatures are presented in the following matrix which is actually the combination of two triangular matrices, means being presented above the diagonal and maxima below. Crosses denote that the data that form the cross are not different at the 5-percent level based on Student's t. Temperatures are in Celsius degrees.

Table A-1. Mean and Mean Maximum Temperatures (°C)*

Mean Temperatures

	(R) 29	(R) 29	(D) 29	(R) 29	(R) 29	(D) 30	(D) 30	(D) 30	(R) 30	(R) 31	(D) 31	(R) 31	(R) 31	(D) 32	(D) 34	(D) 35	(D) 35	
Bi (D) 35															x	x	—	64 To (D)
Bo (D) 35															x	—		61 To (R)
To (D) 34															—	x		60 Bo (D)
Wo (D) 32													x	—				55 Wo (D)
Bo (R) 31										x	x	x	—	x				54 Co (D)
To (R) 31									x	x	x	—	x	x				54 Bo (R)
Ci (D) 31									x	x	—	x						52 Wo (R)
Bi (R) 31									x	—	x	x						51 Co (R)
Wo (R) 30							x	x	—									47 E (D)
Ti (D) 30						x	x	—	x									47 Ti (D)
Wi (D) 30					x	x	—	x	x									47 Bi (D)
Co (D) 30					x	—												43 Ti (R)
Co (R) 29			x		—	x												43 Ci (D)
Wi (R) 29	x	x	x	—	x	x												43 Ci (R)
E (D) 29	x	x	—															41 Bi (R)
Ci (R) 29	x	—																33 Wi (D)
Ti (R) 29	—																	31 Wi (R)
	31 Wi (R)	33 Wi (D)	41 Bi (R)	43 Ci (R)	43 Ci (D)	43 Ti (R)	47 Bi (D)	47 Ti (D)	47 E (D)	51 Co (R)	52 Wo (R)	54 Bo (R)	54 Co (D)	55 Wo (D)	60 Ro (D)	61 To (R)	64 To (D)	

Mean Maximum Temperatures

Legend:
- B = Butler building
- C = CONEX container
- T = General purpose tent
- W = Warehouse
- o = Outside skin
- i = Inner air space
- (D) = Dry season
- (R) = Rainy season
- E = Exposure rack (dry season only)

NOTE: X denotes that the temperature difference is not significant at the 5-percent level.

* The data are presented here in full degrees; the t-test was made before rounding off.

Table A-2. Mean Difference, D, of Extreme Temperatures, Rainy Minus Dry Season, for 10 Hours of the Day and Student's t

	Highest Temperatures 08–17 hours		Lowest Temperatures 08–17 hours		Lowest Temperatures 21–06 hours	
	D	t	D	t	D	t
Outer Skin						
General Purpose Tent	−2.2	0.95	−5.6	3.01	+1.1	4.29
CONEX Container	+0.2	0.31	−2.5	1.96	+2.4	6.65
Butler Building	−1.2	0.92	−5.6	3.51	+0.8	3.09
Warehouse	+4.7	2.54	−5.0	3.37	+0.7	2.65
Inner Air Space						
General Purpose Tent	−1.6	2.95	−4.1	4.49	+2.9	22.53
CONEX Container	+2.1	3.33	−2.1	2.08	+2.3	9.03
Butler Building	−3.2	4.18	−5.8	5.00	−1.5	3.05
Warehouse	−0.7	1.22	−2.1	5.01	−1.3	8.33

NOTE The temperature difference is significant at the 1-percent level if $t \geq 2.82$, at the 5-percent level if $t \geq 1.83$.

For example, read the table as follows: At 0800 to 1700 hours, the average of the highest temperatures of the outer skin of the tent, indicated by the symbols v in figure A-14, was 2.2°C lower than the corresponding average of figure A-13 (dry season) with a Student's t of 0.95 (not significant).

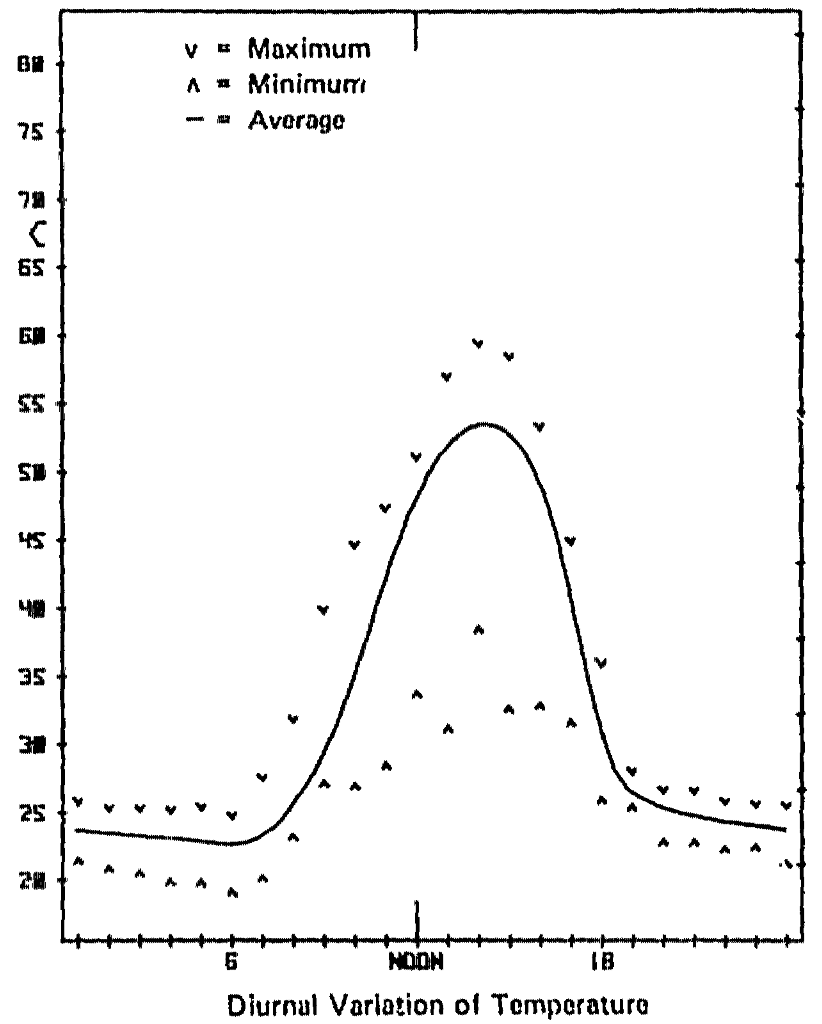


Figure A-1. Warehouse, Roof, Dry Season.

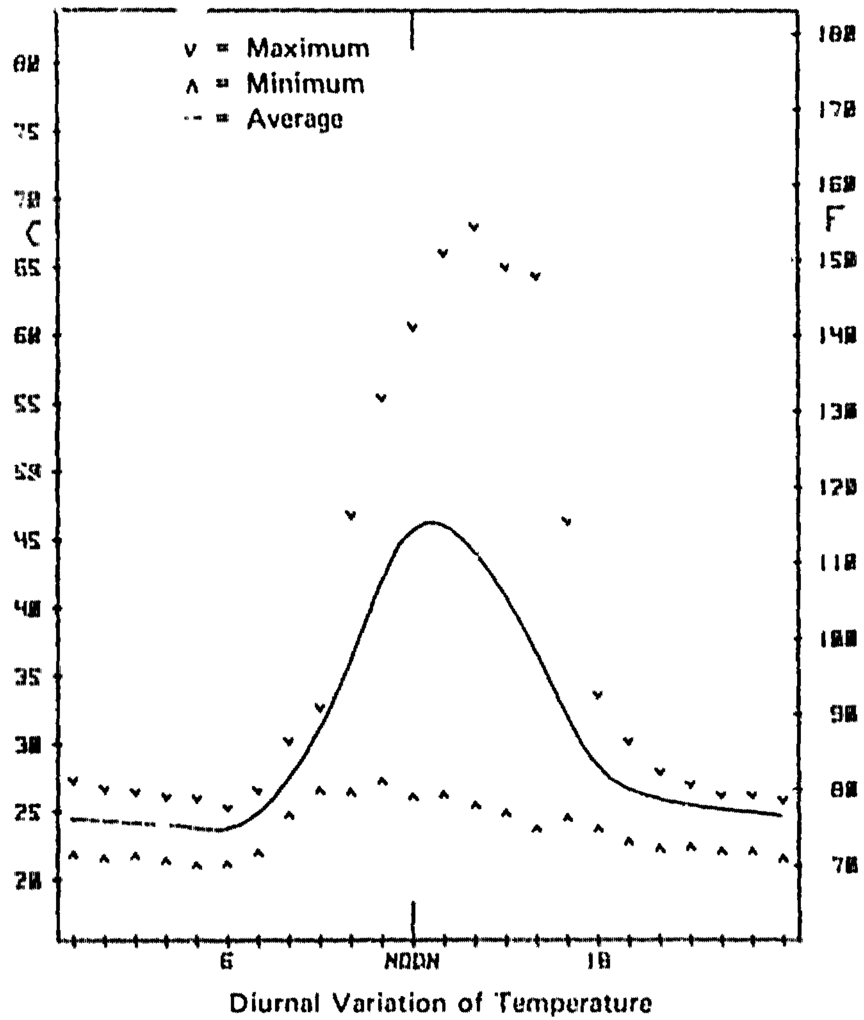


Figure A-2. Warehouse, Roof, Rainy Season.

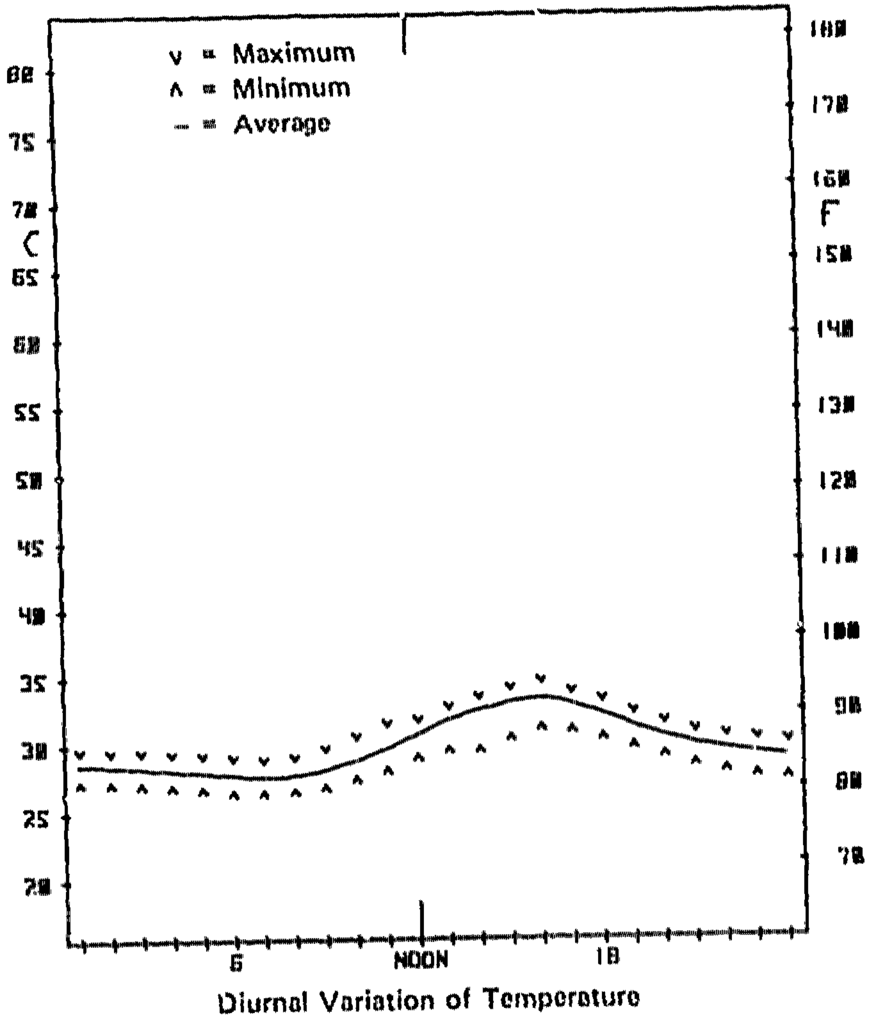


Figure A-3. Warehouse, Air Inside, Dry Season.

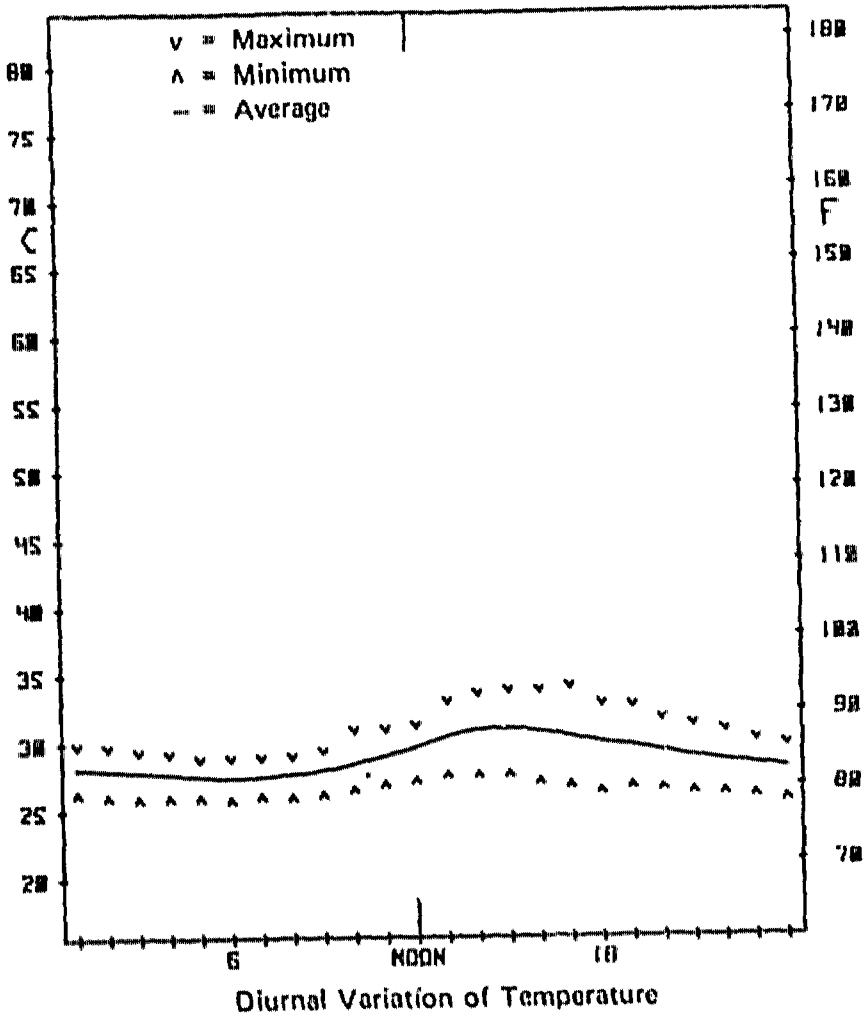


Figure A-4. Warehouse, Air Inside, Rainy Season.

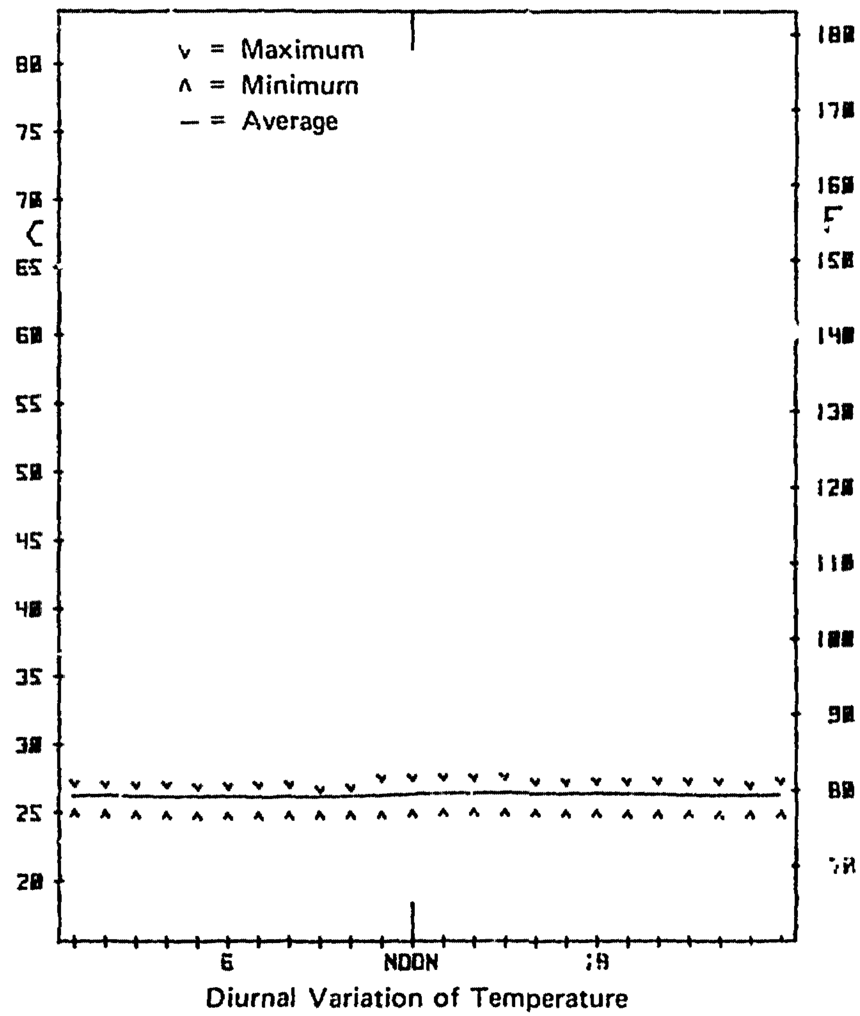


Figure A-5. Bunker, Dry Season.

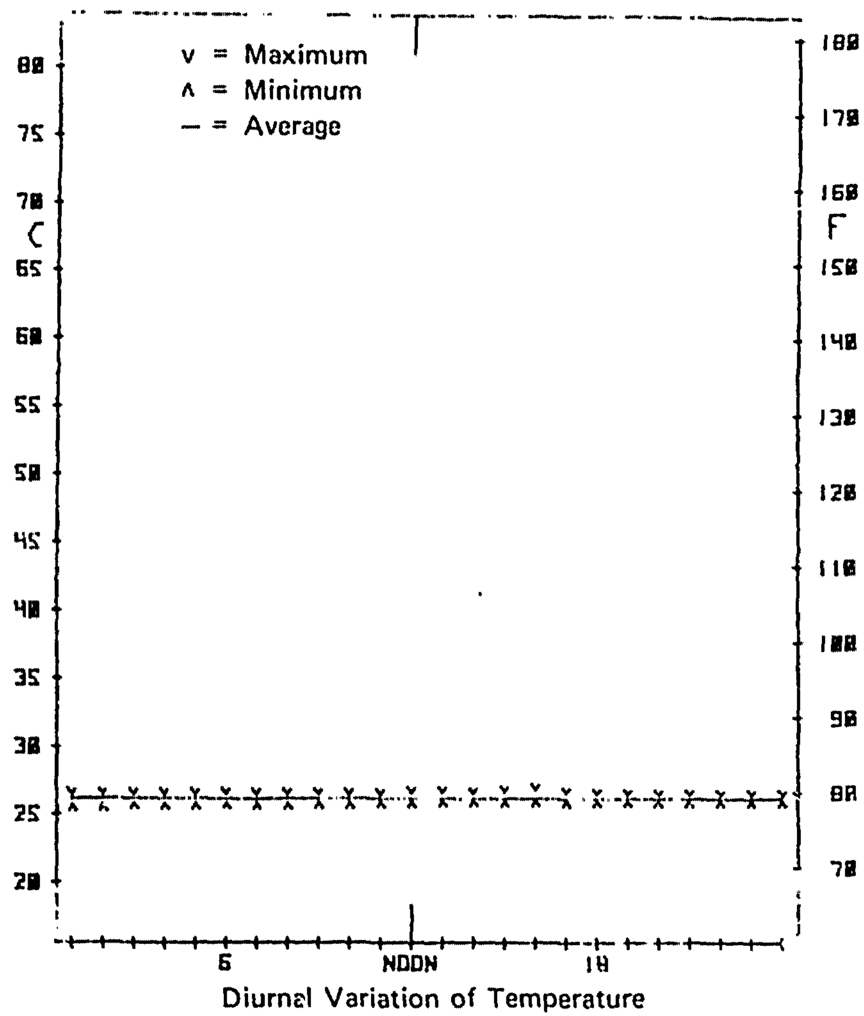


Figure A-6. Bunker, Rainy Season.

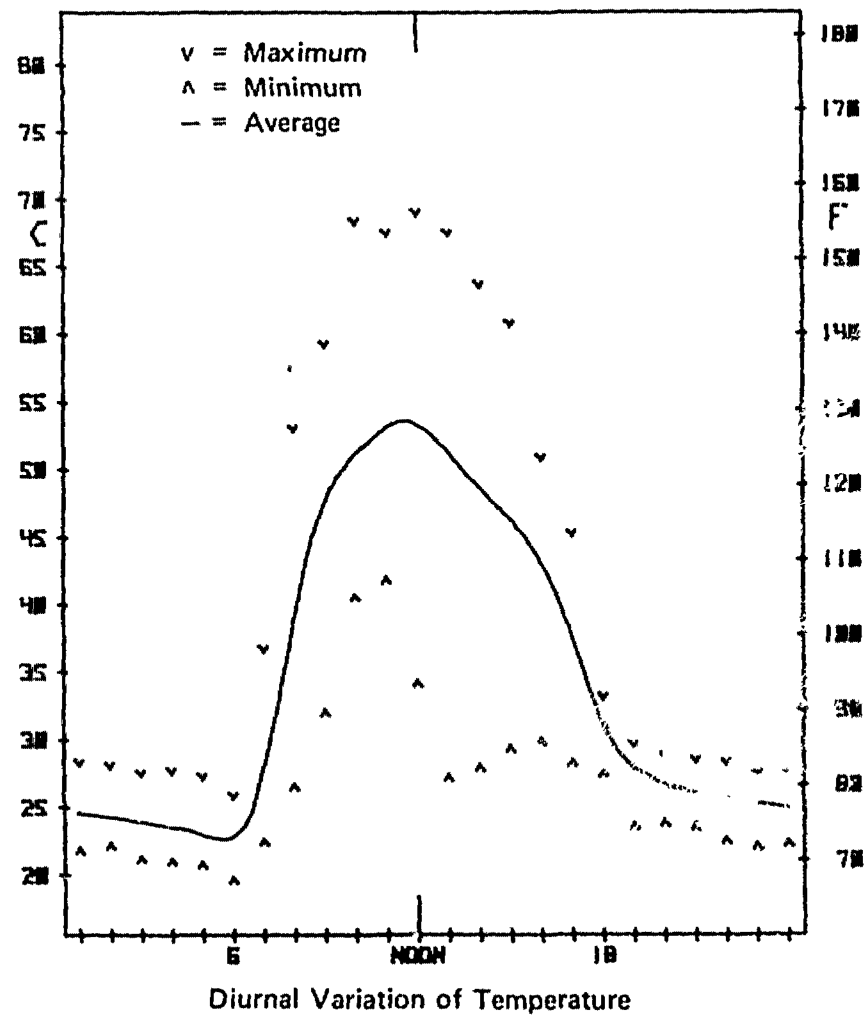


Figure A-7. Butler Building, Roof, Dry Season.

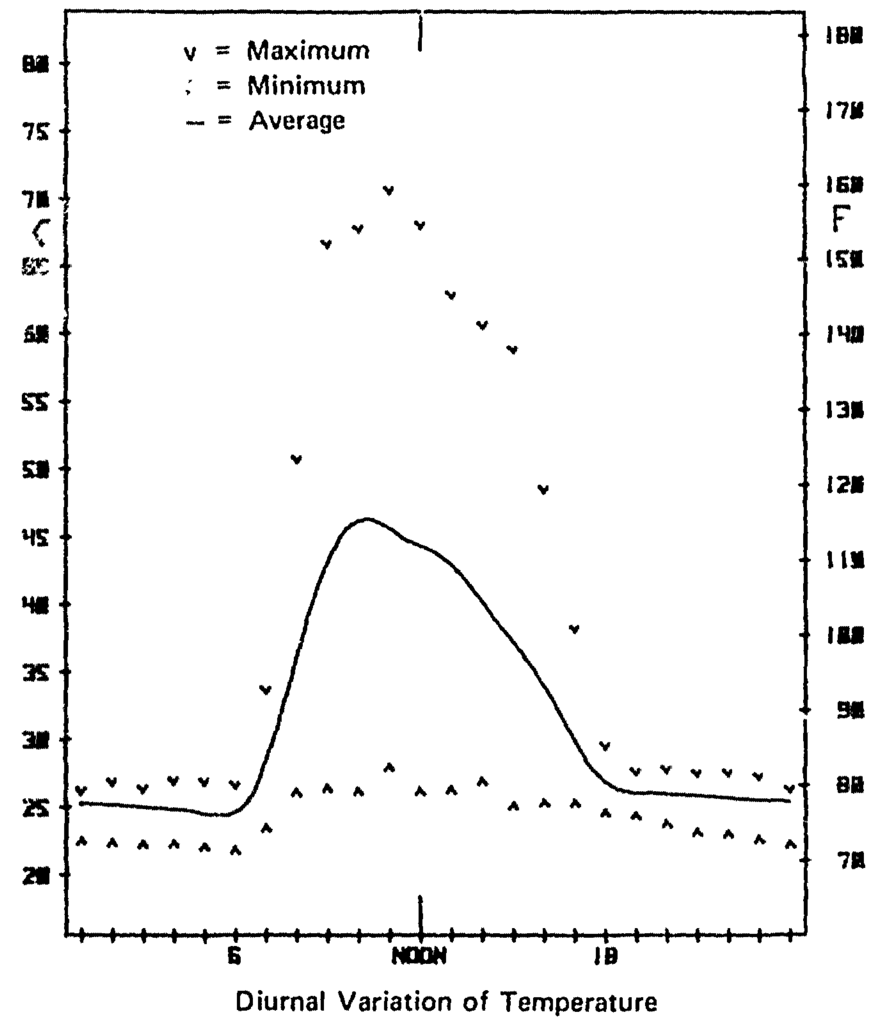


Figure A-8. Butler Building, Roof, Rainy Season.

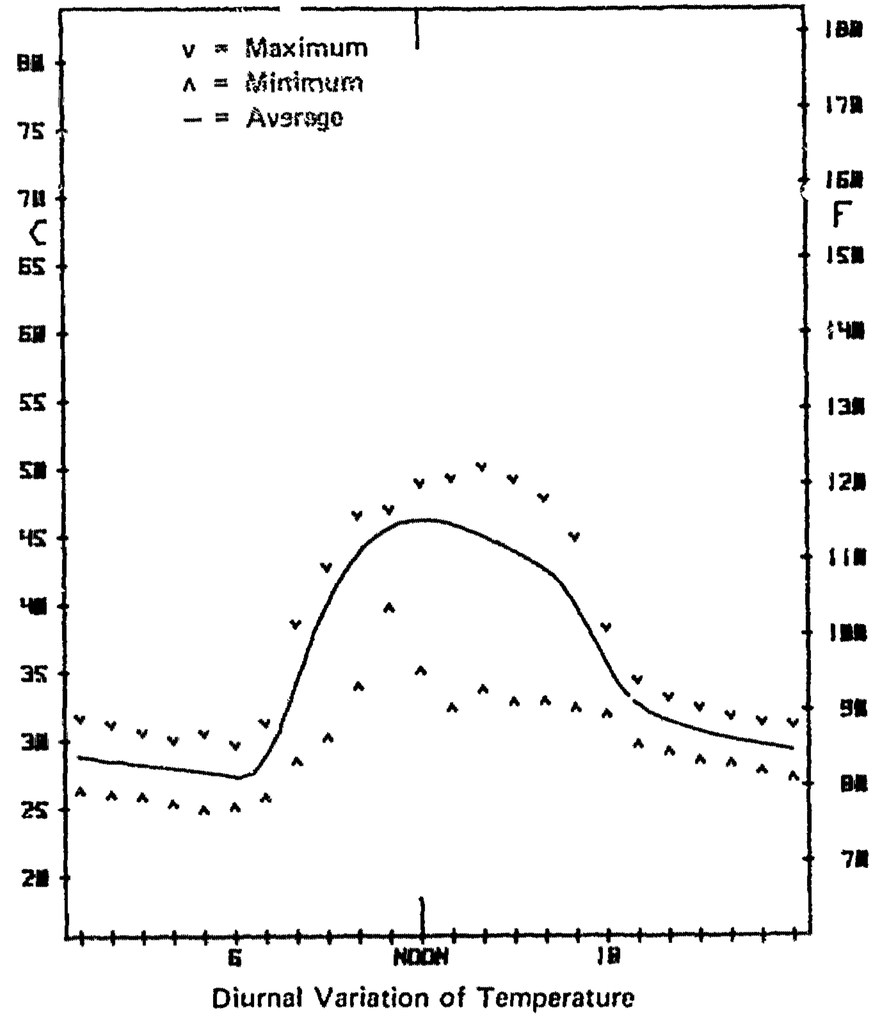


Figure A-9. Butler Building, Air Inside, Dry Season.

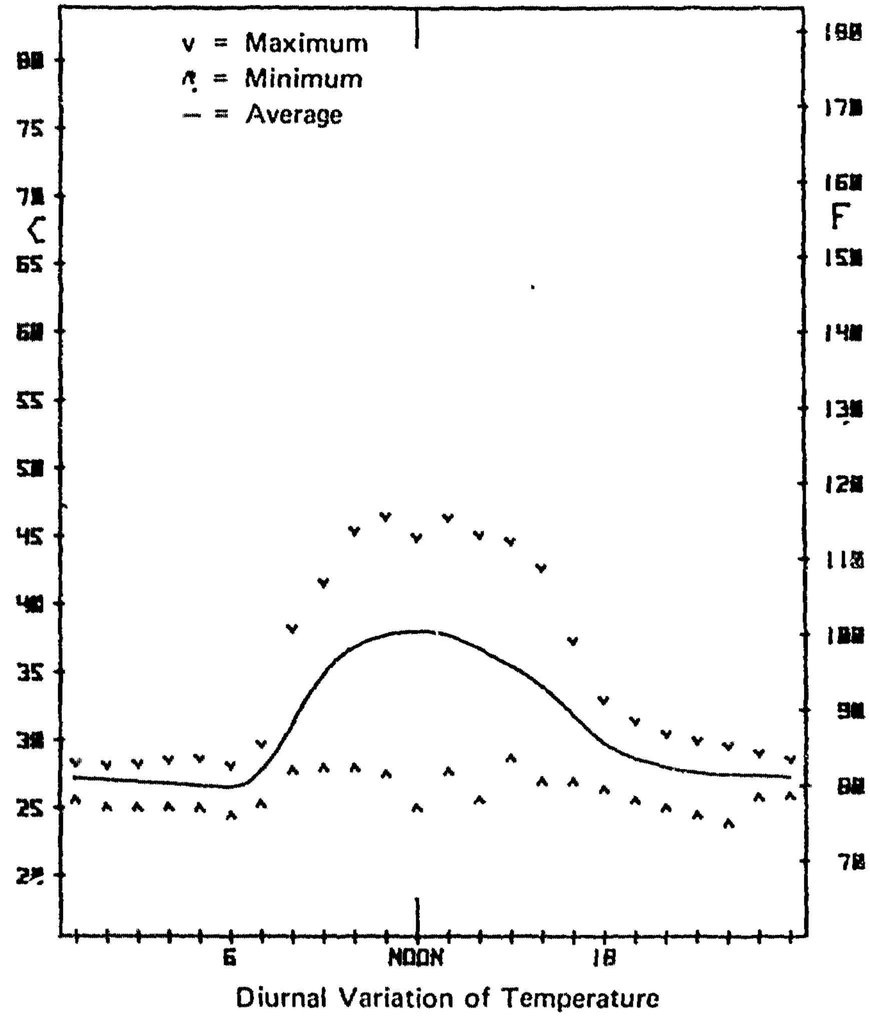


Figure A-10. Butler Building, Air Inside, Rainy Season.

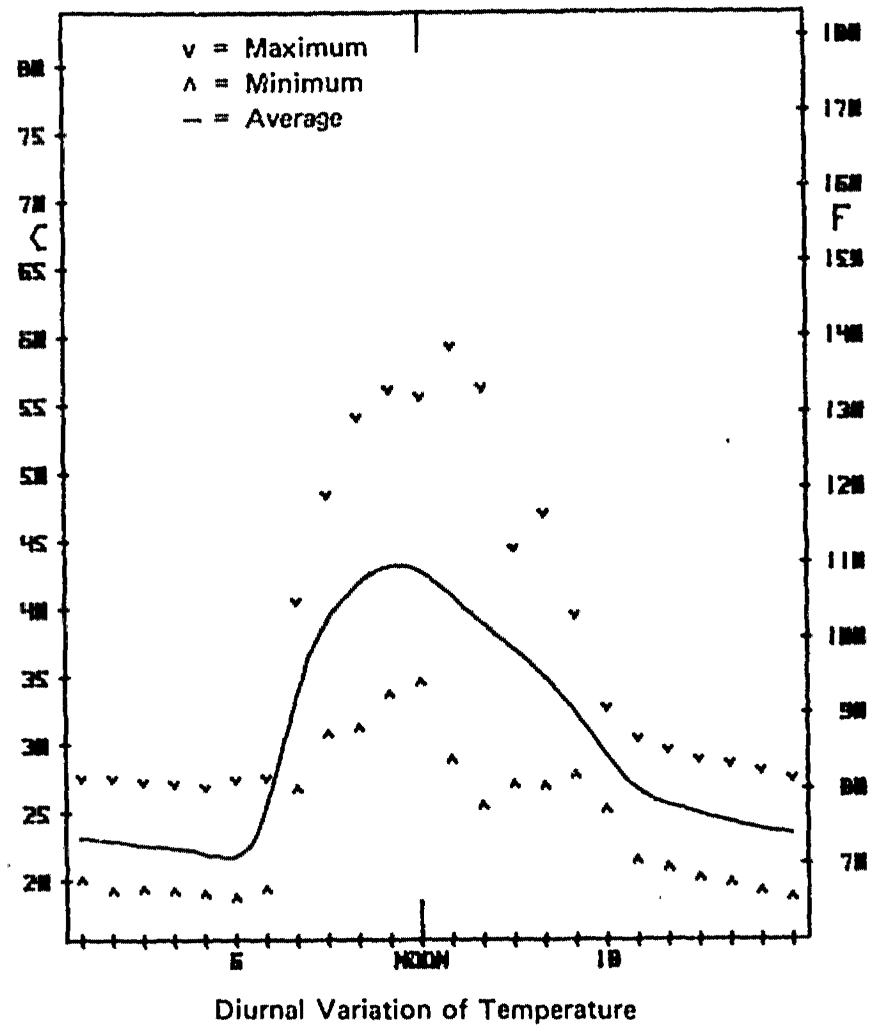


Figure A-11. Tent, Air Inside, Dry Season.

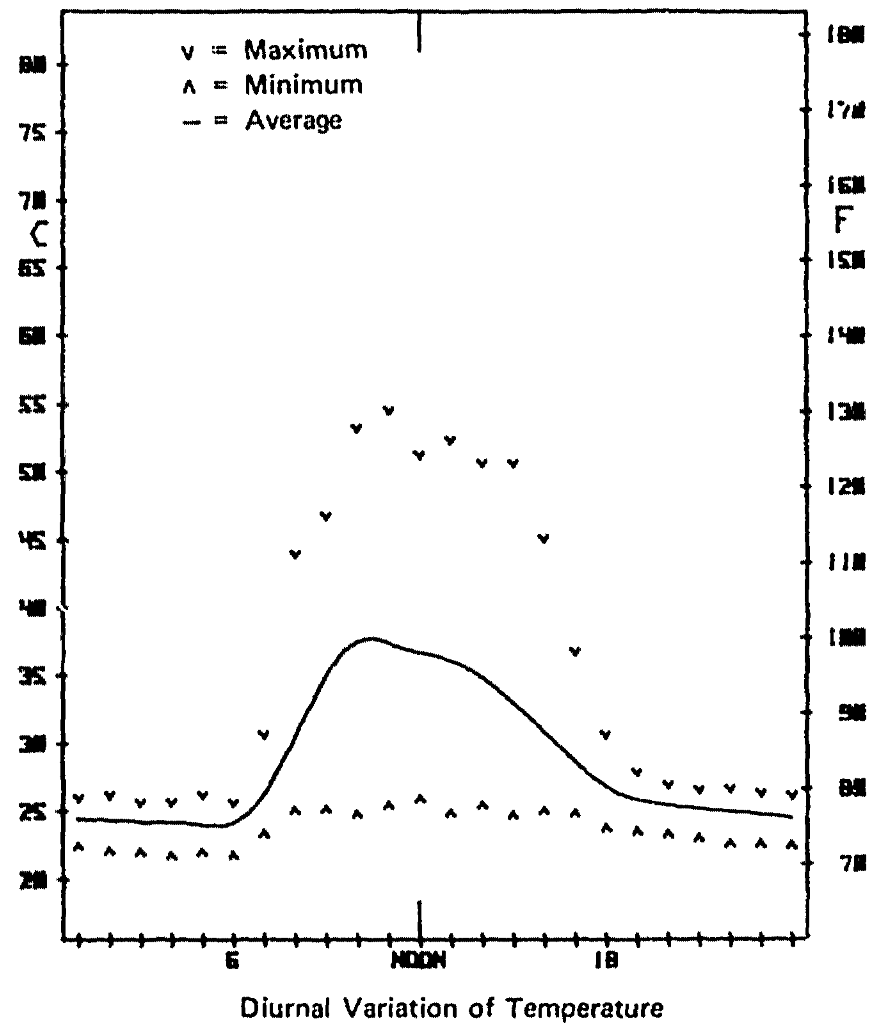


Figure A-12. Tent, Air Inside, Rainy Season.

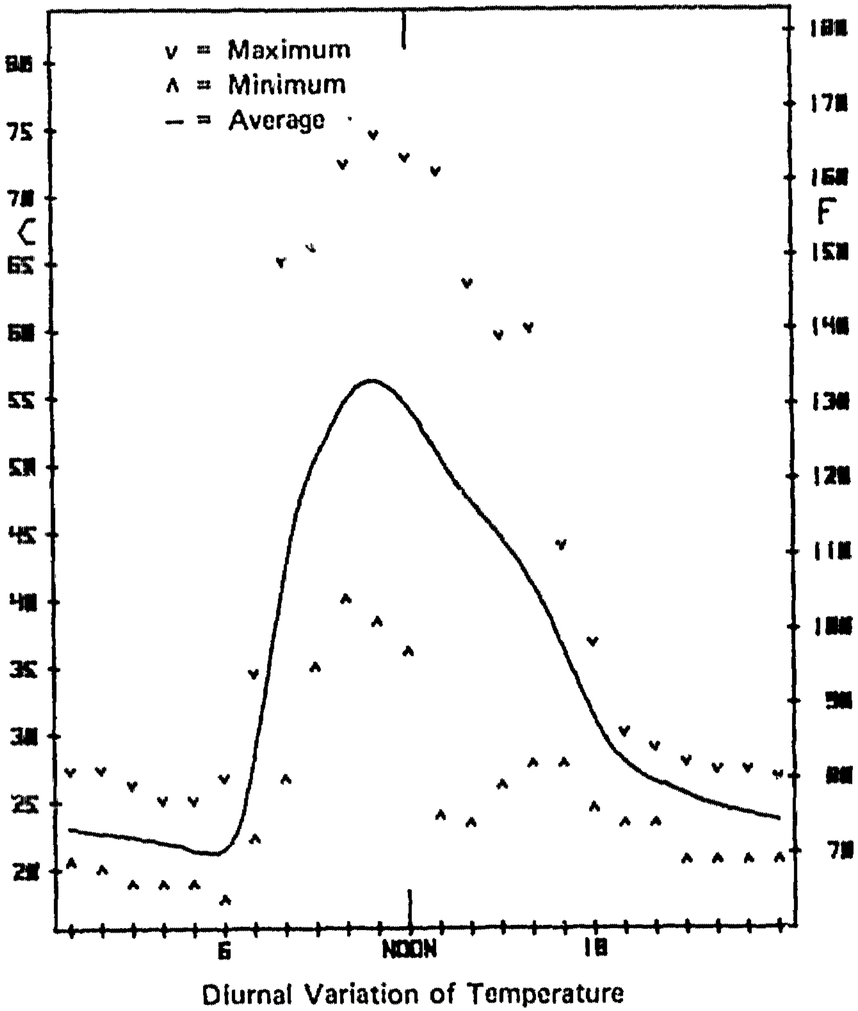


Figure A-13. Tent, Fabric Outside on Top, Dry Season.

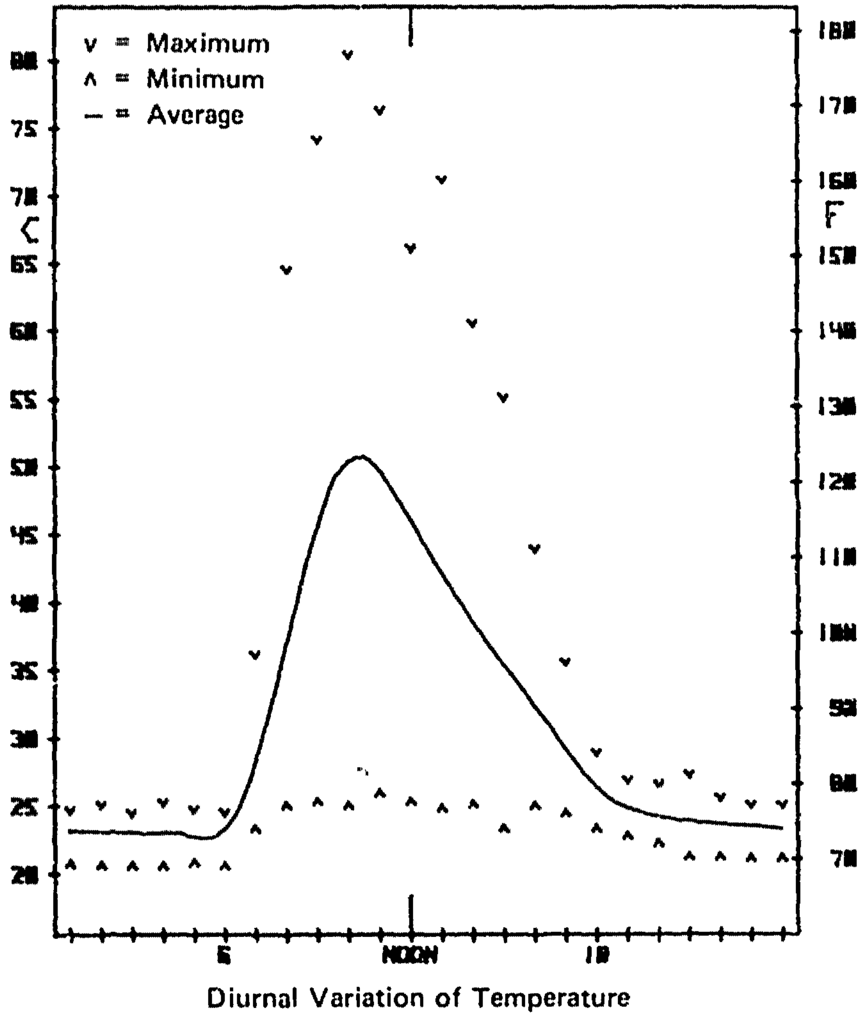


Figure A-14. Tent, Fabric Outside on Top, Rainy Season.

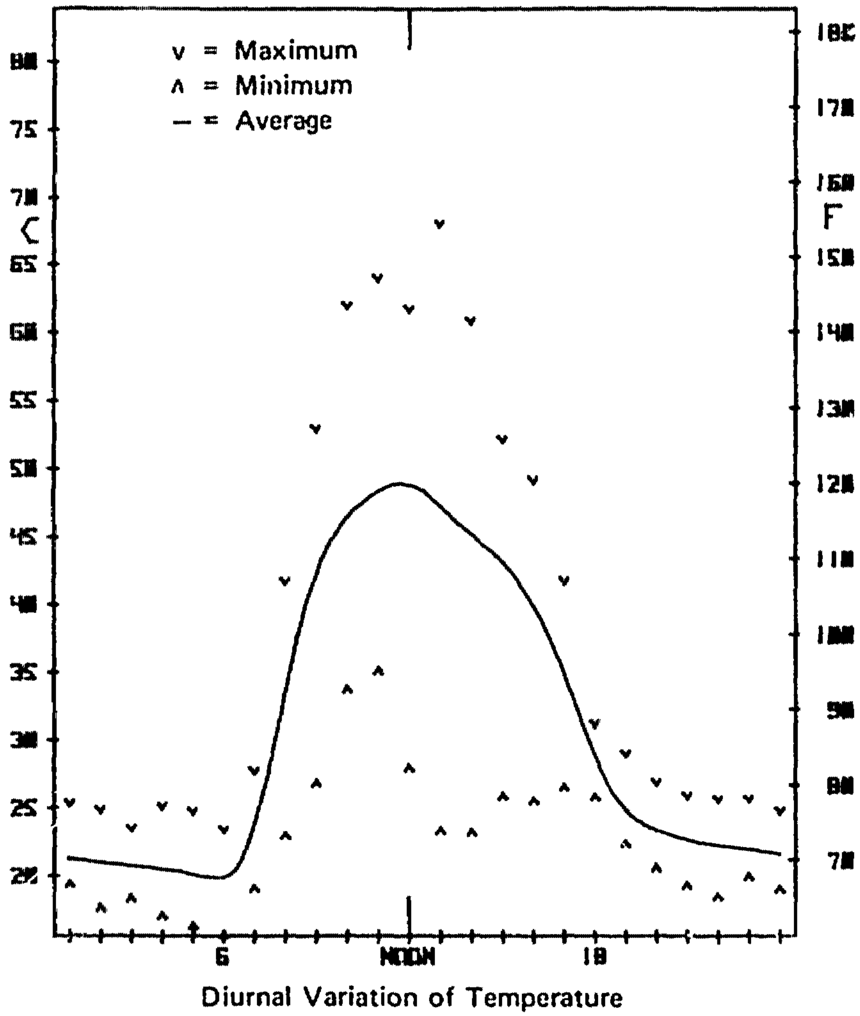


Figure A-15. CONEX Container, on Top, Dry Season.

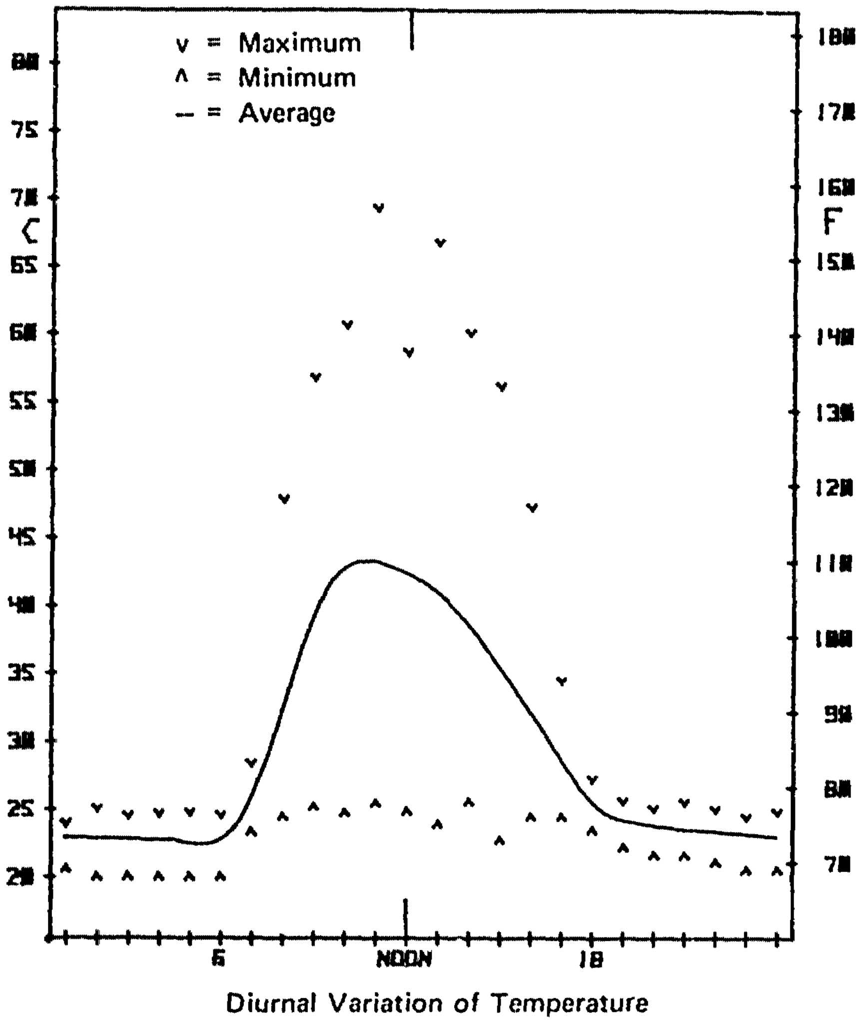


Figure A-16. CONEX Container, on Top, Ra..., Season.

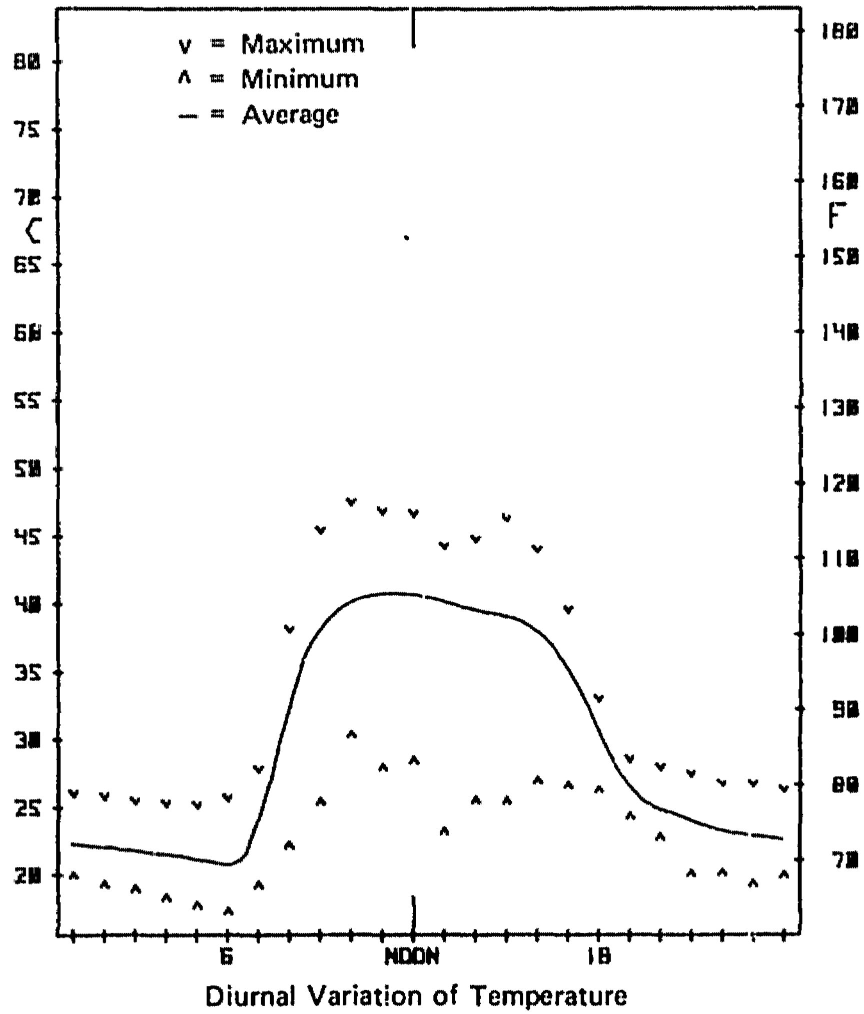


Figure A-17. CONEX Container, Air Inside, Dry Season.

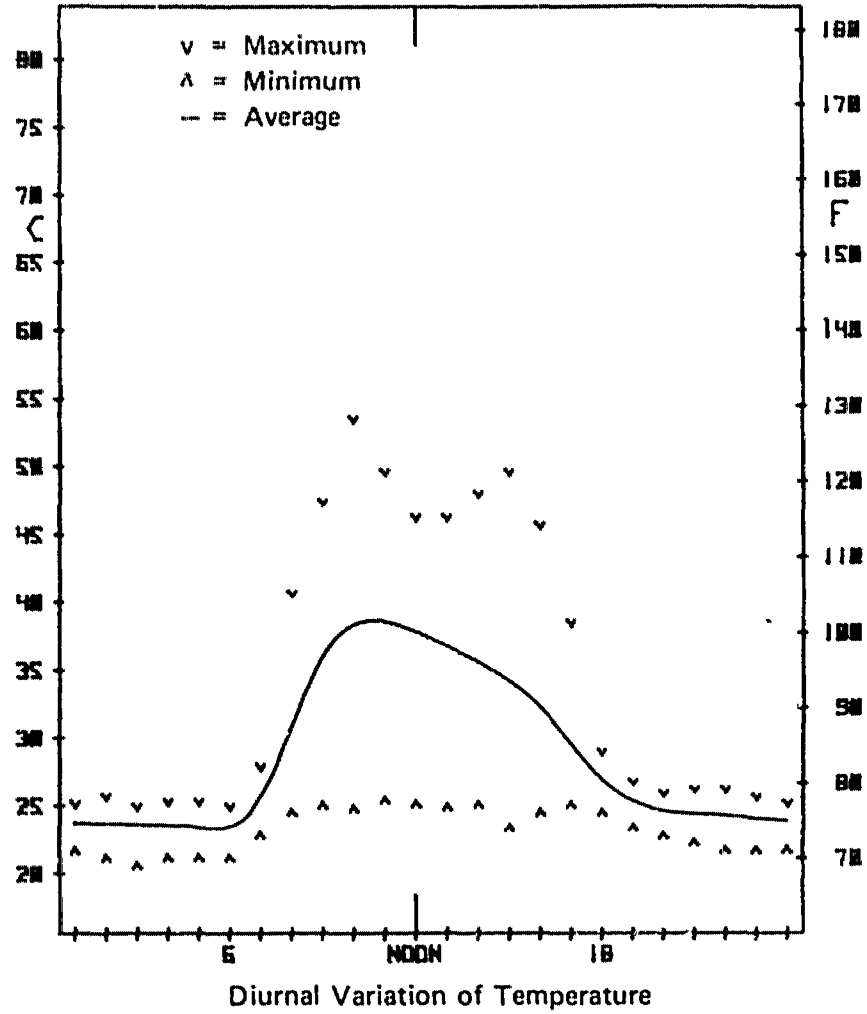


Figure A-18. CONEX Container, Air Inside, Rainy Season.

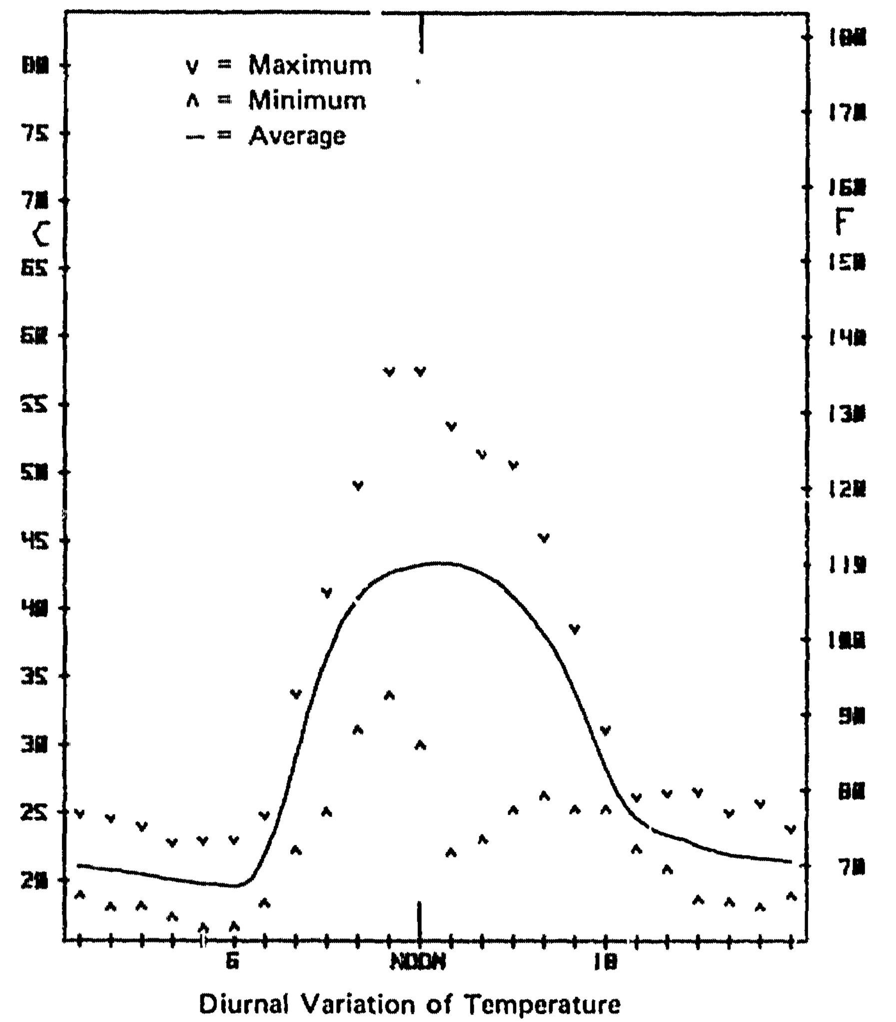


Figure A-19. Epoxy Sample, Dry Season (Only).

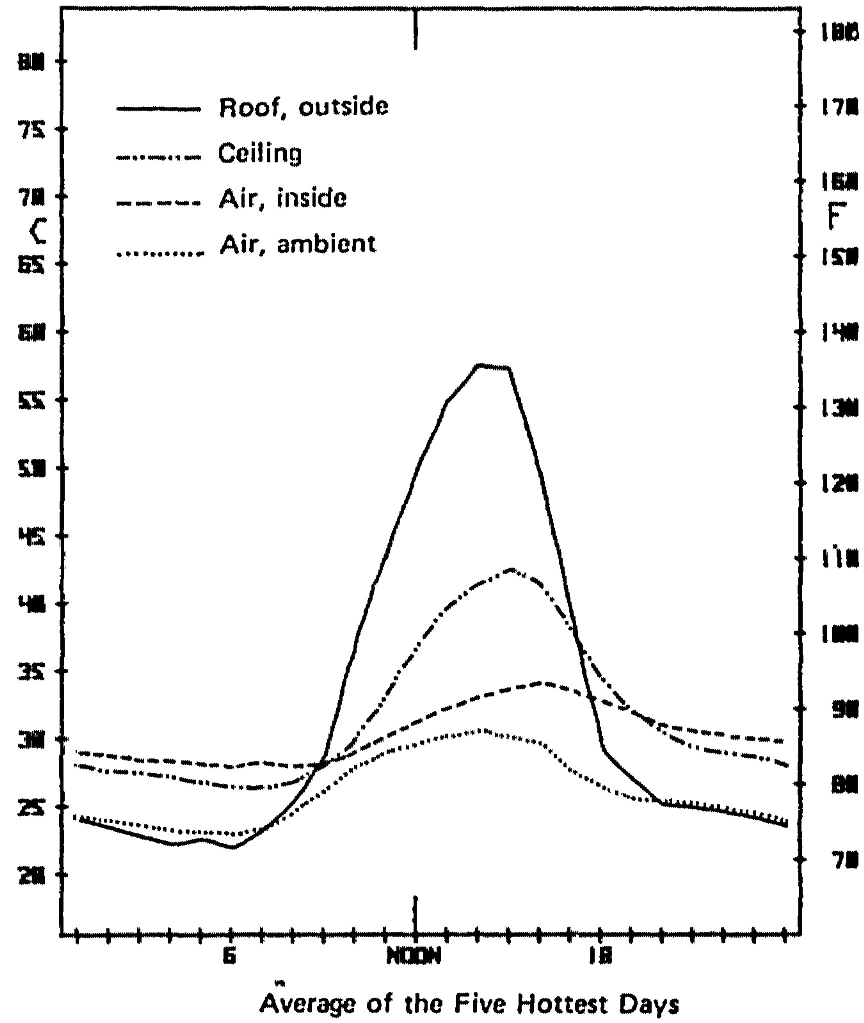


Figure A-20. Warehouse, Dry Season.

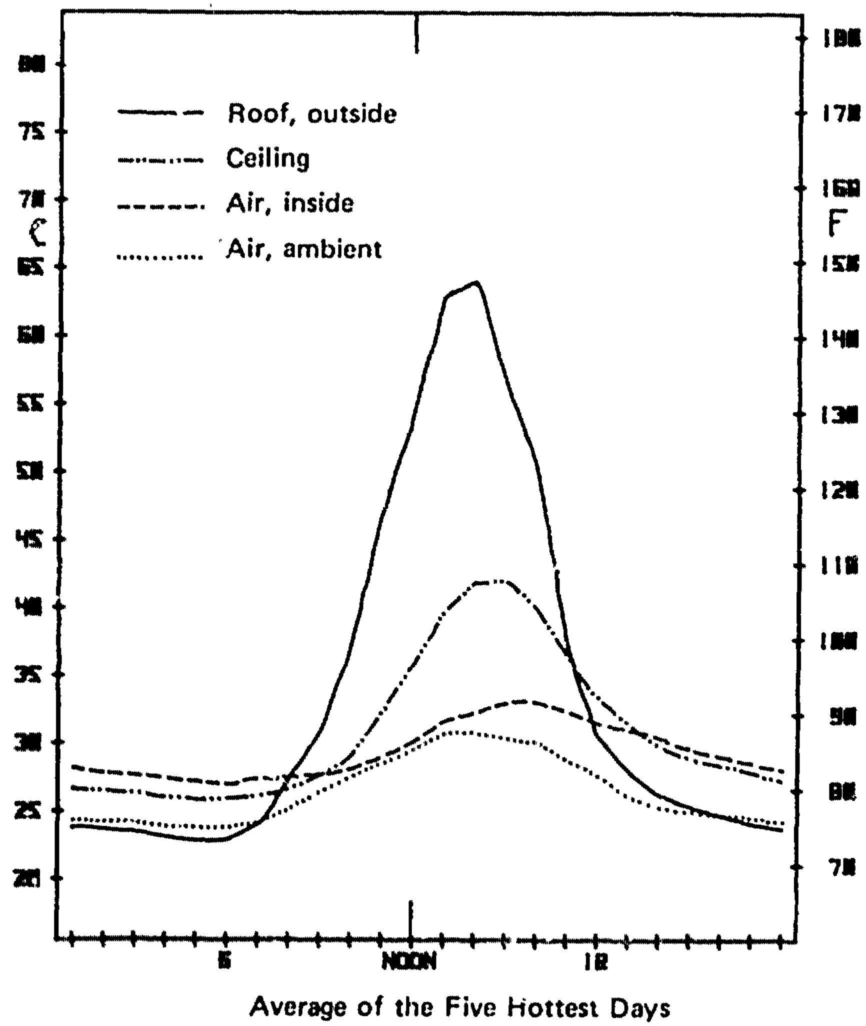


Figure A-21. Warehouse, Rainy Season.

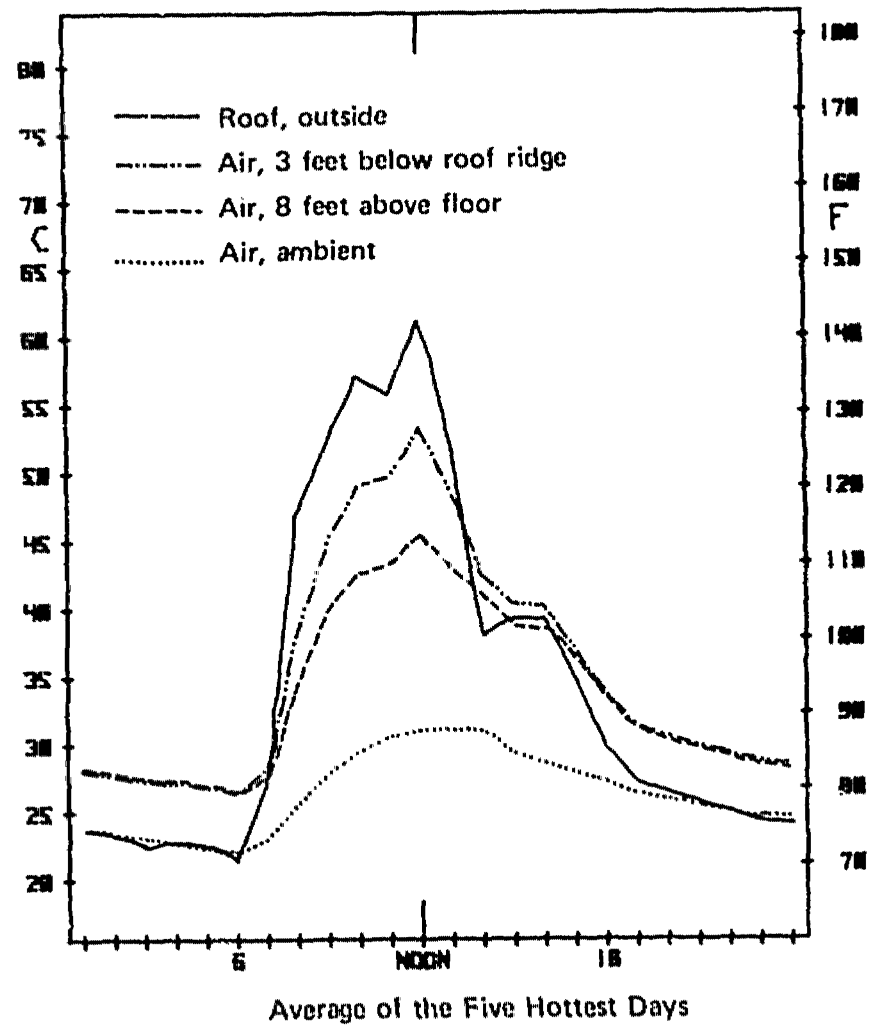


Figure A-22. Butler Building, Dry Season.

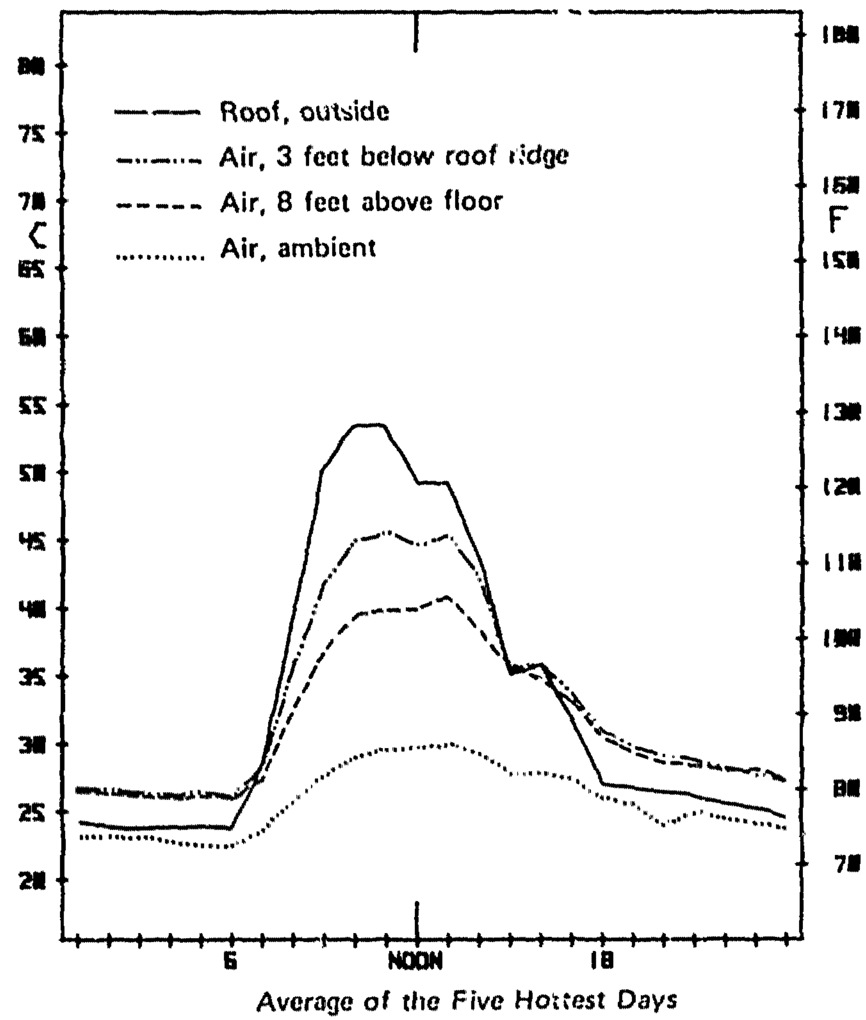
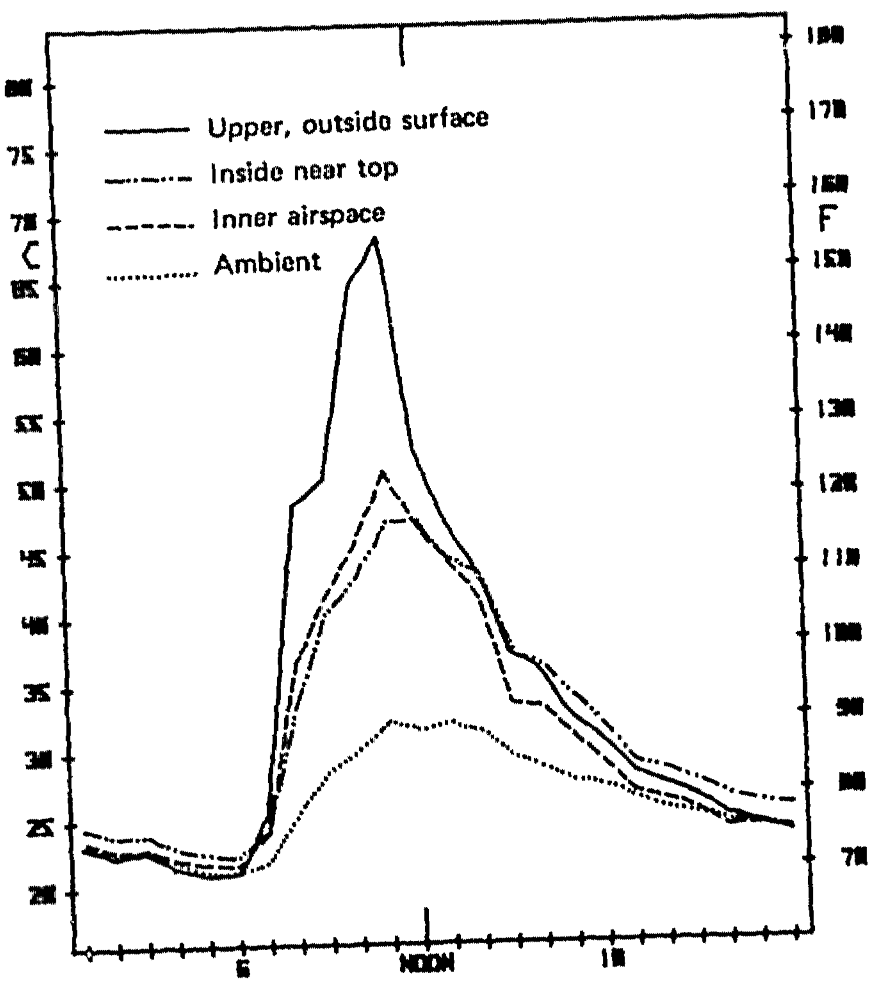
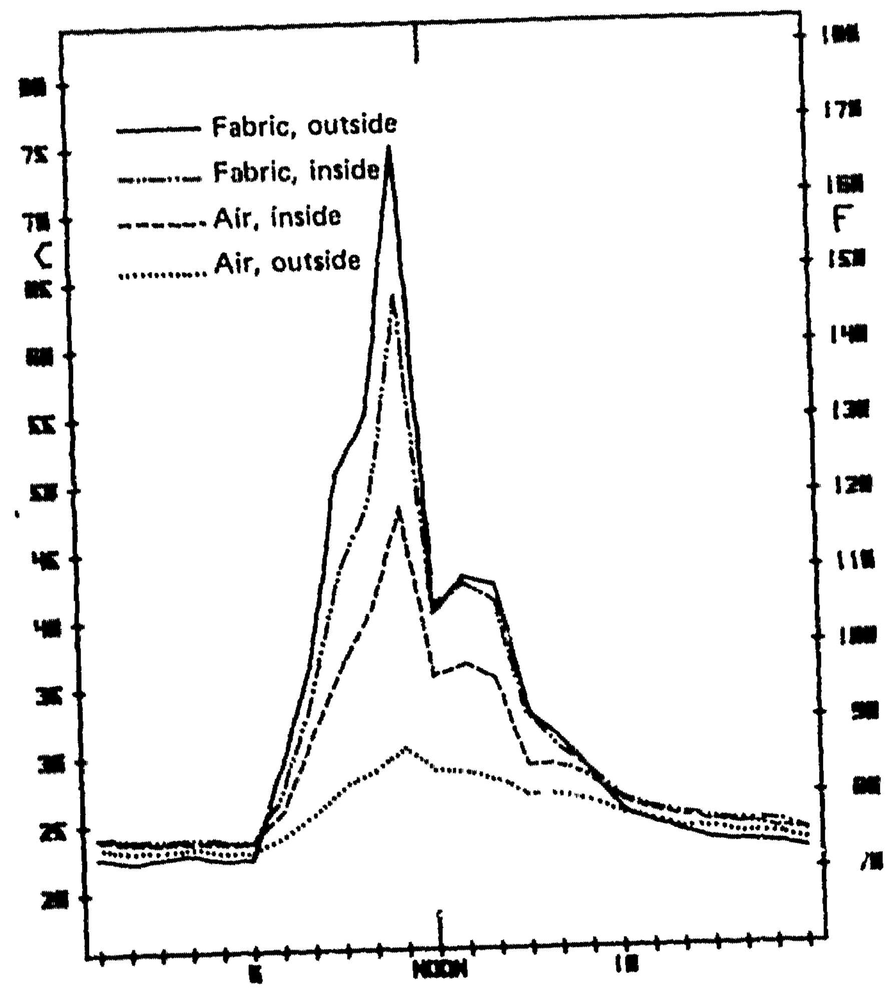


Figure A-23. Butler Building, Rainy Season.



Average of the Five Hottest Days

Figure A-24. Tent, Dry Season.



Average of the Five Hottest Days

Figure A-25. Tent, Rainy Season.

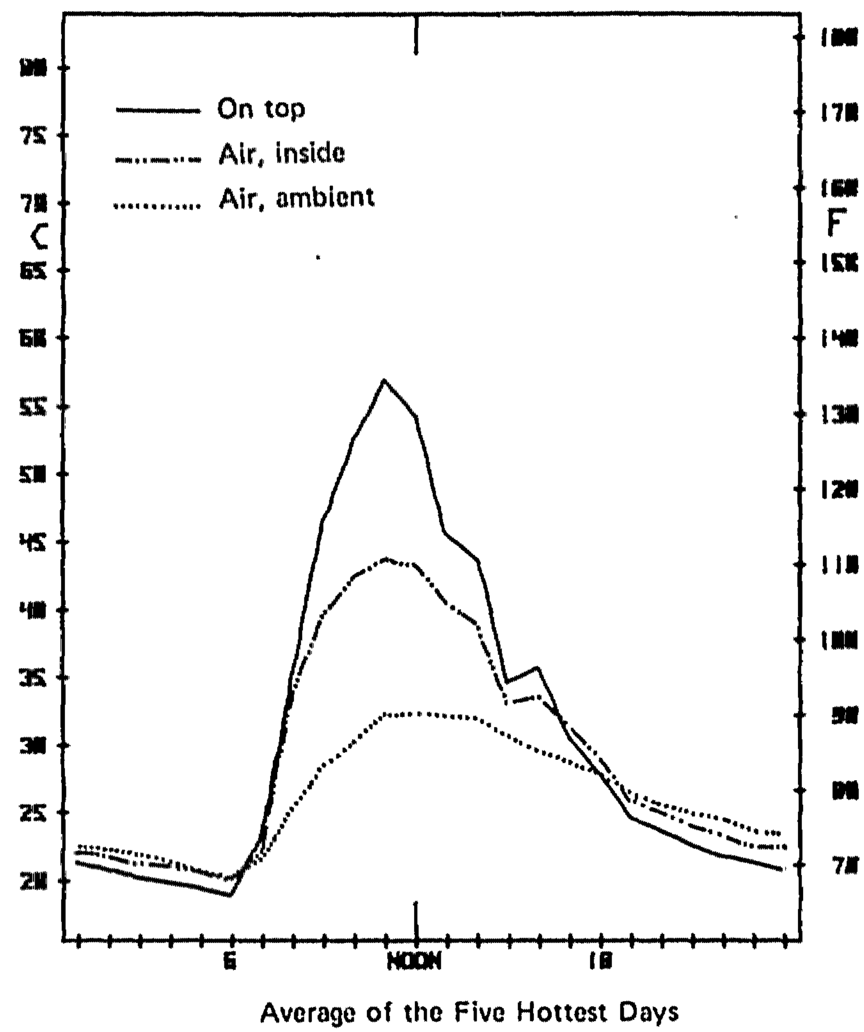


Figure A-26. CONEX Container, Dry Season.

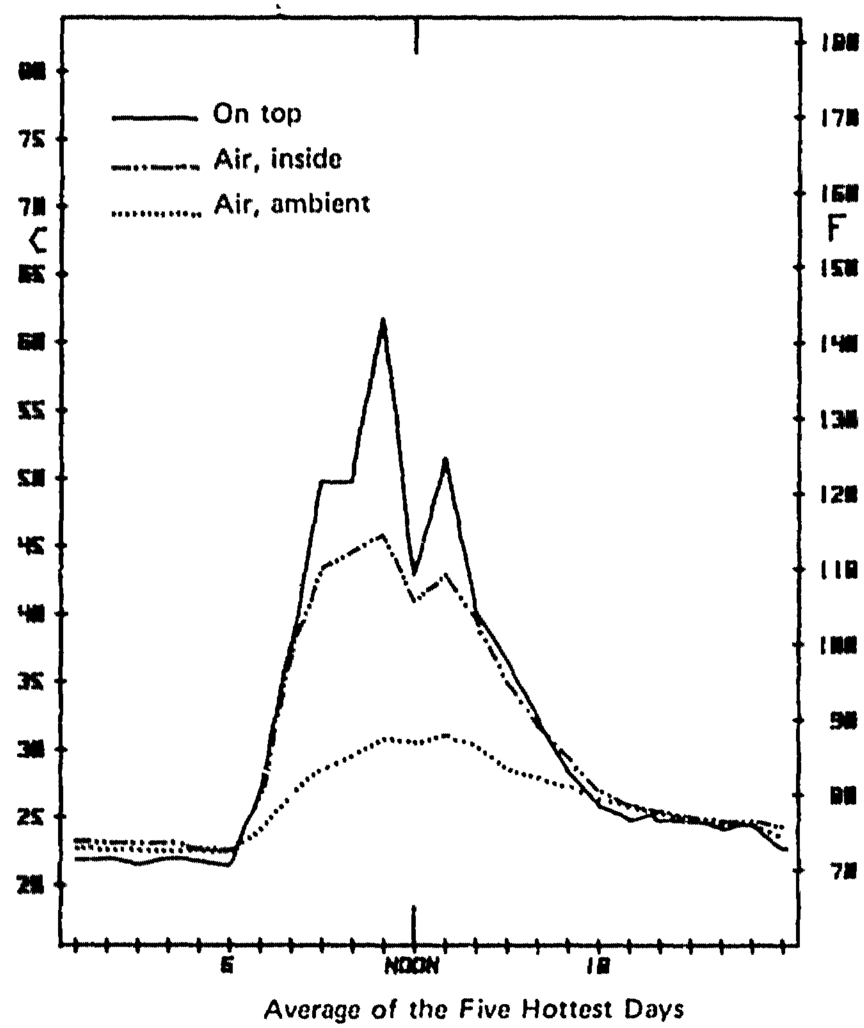


Figure 27. CONEX Container, Rainy Season.

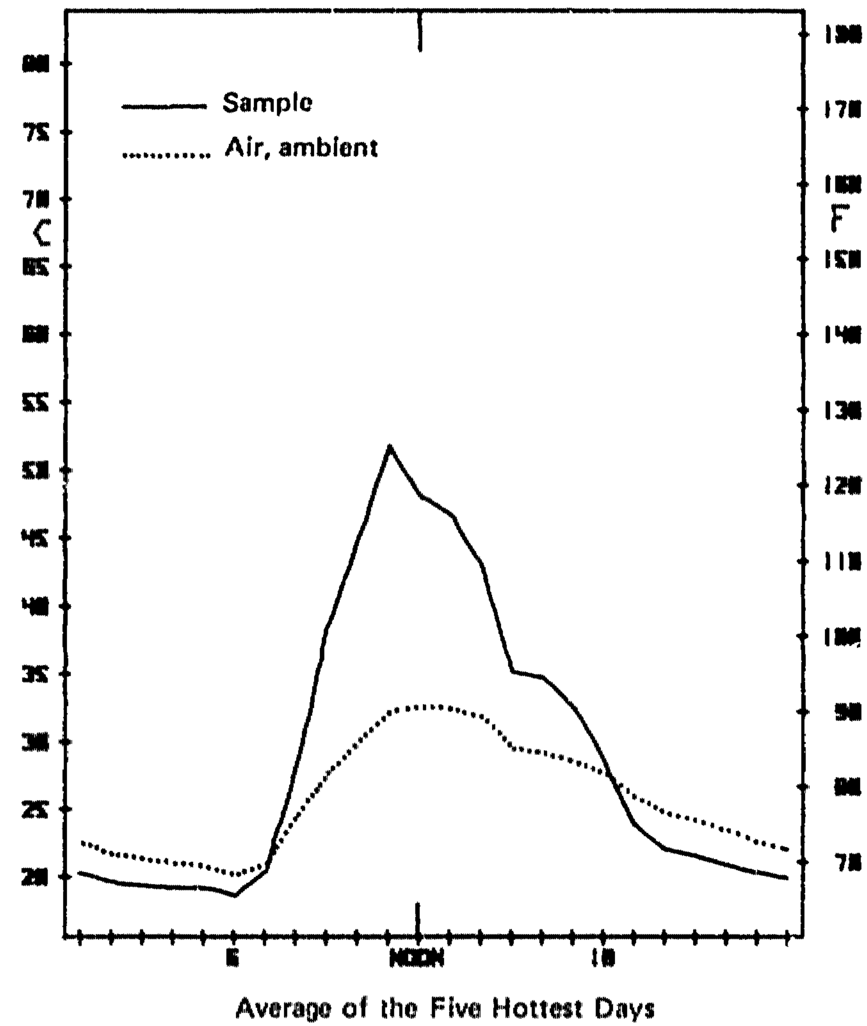


Figure A-28. Epoxy Sample, Dry Season (Only).

APPENDIX B. REFERENCES

1. Staszewski, J., *Petermanns Mitteilungen*, 1961, pp. 133–138.

2. Kurotari, I. S. and H. C. Schafer, *Summary of Selected Worldwide Temperatures in Explosive Hazard Magazines*, Naval Weapons Center, China Lake, CA. 1972.

3. Porter, W. L. and A. Greenwald, *The Analysis of High Temperature Occurrences at Selected Internal and Surface Locations in Food Storage Dumps and Isolated Small Cartons at Yuma, Arizona*, US Army Natick Laboratories, Natick, MA, Technical Report 71-59-FL/ES, 1971.

4. Porter, W. L. and A. Greenwald, *Comparison of the Occurrence of High Temperatures in Air and Food in Boxcars in Desert and Humid Subtropical Climates- Yuma, Arizona and Cameron Station, Virginia*, US Army Natick Laboratories, Natick, MA, Technical Report 71-55-FL/ES, 1971.

5. Viletto, J. Jr., *Worldwide Distributions of Ambient Temperatures and Temperatures Exposed to Direct Solar Radiation*, US Army Engineer Topographic Laboratories, Ft. Belvoir, VA, 1973.

6. Dodd, A. V. and H. S. McPhillmy, *Yuma Summer Microclimate*, Quartermaster Research and Engineering Center, Natick, MA, Technical Report EP-120, 1959.

7. *Environmental Data Base for Regional Studies in the Humid Tropics*, US Army Tropic Test Center, Semiannual Report No. 4, 1958.

8. Reynolds, R. D., *Ozone: A Synopsis of Its Measurement and Use as an Atmospheric Tracer*, US Army Electronics Command, Ft. Monmouth, NJ, ECOM Report No. 5401, 1971.

9. Downs III, G. F. and W. F. Lawson III, *Determination of Optimum Tropic Storage Sites, Report I: Survey of Programs in Tropic Materials Research*, US Army Tropic Test Center, USATTC Report No. 7304001, 1973.

10. Sprouse, J. F., M. D. Neptune, and J. C. Bryan, *Determination of Optimum Tropic Storage and Exposure Sites, Report II: Empirical Data*, US Army Tropic Test Center, USATTC Report No. 7304001, 1973.

11. Portig, W. H., J. C. Bryan, and D. A. Dobbins, *Determination of Optimum Tropic Storage and Exposure Sites, Phase II: Patterns and Predictions of Tropic Materials Deterioration*. US Army Tropic Test Center, USATTC Report No. 7405001, 1974.

12. Dobbins, D. A. and G. F. Downs III, *Laboratory versus Field Tests: A Limited Survey of Materials Deterioration Studies*, US Army Tropic Test Center, USATTC Report No. 7307002, 1973.

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