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METHODOLOGY INVESTIGATION. MOISTURE AND TEMPERATURE CONDITIONS --ETC(U)

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LEVEL II

METHODOLOGY INVESTIGATION

FINAL REPORT

MOISTURE AND TEMPERATURE CONDITIONS IN STORAGE CONTAINERS IN HUMID ENVIRONMENTS

By

Wilfried H. Portig

December 1978

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UNITED STATES ARMY TROPIC TEST CENTER
APO MIAMI 34004

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

A methodology investigation was initiated by the USATTC in the Canal Zone in February 1976 to provide a further understanding of the basic processes that lead to water damage of material in storage containers, and to enhance knowledge of thermal buildup on surfaces and in the air inside storage containers.

The investigation revealed that moisture conditions inside storage cont

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containers were influenced significantly by the materials inside those containers. With increasing temperature, the materials were found to rapidly release moisture to the container air significantly changing the moisture content (absolute humidity) of the air and increasing the potential for water condensation when radiation cooling of the contents and walls of the container occurred.

To reduce the occurrence of water damage in storage containers, the study recommends that the amount of water initially enclosed in a container be minimized by (1) pre-drying the goods to be stored, (2) pre-drying the materials (e.g., pallets and packing material) associated with the storing of goods and (3) closing the container in a dry ambient environment. Further study of the basics of moisture migration within storage containers is also recommended.

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FOREWORD

This investigation was conducted in the Panama Canal Zone as a methodology investigation of the United States Army Tropic Test Center (USATTC) under the guidance of Dr. D. A. Dobbins, Chief of the Technical Division. The principal investigator, Dr. W. H. Portig, was assisted by all technical branches of USATTC and the Canal Zone Meteorological Team of the Atmospheric Sciences Laboratory, US Army Electronics R&D Command.

SECTION 1. SUMMARY

1.1 BACKGROUND

Experience has shown that materiel may be damaged in the humid tropics through condensation of water inside containers in which items are stored. Condensation may occur directly on water-sensitive contents of a container, or when excessive condensation of water forms on the interior surfaces of the container, water may run or drip onto the contents. The high humidity and presence of free water also provide an ideal habitat for microorganism proliferation. Observations of water accumulation in supposedly sealed containers have led to the advancement of the concept of "breathing" as the mechanism for this formulation. Breathing is defined as a temperature induced phenomenon of exhaling/inhaling of air from/into a container. Exhaling of air from a container occurs when heating of the air in the container causes the volume of air to increase. Inhaling of atmospheric air into a container occurs when cooling of the air in the container causes its volume to decrease. The inhaling of atmospheric air with moisture at a time when the contents and walls of a container are cooling is hypothesized to provide the potential not only for additional water condensation but also for a net gain of moisture in a closed container.

Present technology does not provide the capability to predict the amount of condensation or thermal buildup that may occur in containers exposed to different environmental settings. The use of static-free breathers and desiccants to control moisture buildup is a matter of trial and error. Methodologies for estimating the environmental conditions existing inside containers must be developed in order to design a means of protecting materiel housed in those containers.

1.2 OBJECTIVES

The initial objectives of this investigation were to:

- Develop a procedure to locate, from the outside of the materiel item, those spots that are most likely to produce condensation at night on the inside.

- Develop a mathematical model to assess the probability that the spots, singled out in the preceding objective, will actually become wet.

- Enhance knowledge of thermal buildups on surfaces as well as of the air inside enclosures (shelters, boxes, cases). (NOTE: Surface temperatures up to 180°F and air temperatures inside shelters up to 160°F are known to occur in the Canal Zone.)

The investigation of moisture conditions in storage containers was initiated with the assumption that any moisture migration resulting in changes to the moisture content of the container air came about only through "breathing." However, data obtained early in the investigation showed that the phenomenon of moisture migration in containers depended on more complex factors than breathing. Available resources were not sufficient to address these additional complexities to achieve the first two objectives. Therefore, the first two objectives were dropped and replaced by the following objective:

- Collect data on temperatures, humidities, and moisture conditions inside of storage containers to identify the basic processes that lead to water damage in storage containers.

1.3 SUMMARY OF PROCEDURES

Five containers of varying size and construction were exposed to tropic climatic conditions in both the dry and rainy seasons. Exposure sites were located in open and in jungle areas. The containers were exposed both empty (except for instrumentation) and filled with cardboard boxes. Ambient conditions were measured for wet and dry bulb temperatures, rainfall, and wind velocity. Radiation measurements were obtained at Chiva Chiva Antenna Farm located about 1340 meters from the open area. Surface and air temperatures of the containers were measured by thermocouples at strategic points and recorded at discrete intervals. The relative humidity of the inside air was measured by recording hygrographs using human hair as the sensory element. (NOTE: Other hygrometers were not used because they were known either to degrade in tropic storage or to disturb the environment being measured.) The wetness of the ceiling and floor of the containers was monitored by wetness sensors developed by the US Army Tropic Test Center.

After determining that a source of condensed water was the material in the containers, a recording balance was designed and built. Representative samples of the involved materials were weighed continuously in the containers during several tropic diurnal cycles.

1.4 SUMMARY OF RESULTS

The moisture content of the air in the containers used for the investigation changed substantially in the course of the day. The changes were opposite to those predicted by the "breathing" concept and were much stronger than expected.

Correlation coefficients between changes of absolute humidity and changes of air temperature in the containers ranged from 0.84 to 0.98.

The weight of materials commonly found in containers during storage changed significantly with diurnal changes of the containers' air temperature. Samples of untreated wood and artificial packing fibers, which were placed inside a CONEX container, lost and then regained approximately 4 percent of their weight during the course of a day.

Temperatures on and in containers closely followed solar radiation patterns, i.e., the container temperatures rose or dropped with the presence or absence of solar radiation. Temperature changes occurred almost simultaneously at all levels in the container, but with varying amplitude.

The surface temperatures of the containers fluctuated more often and to a greater degree in the rainy season than in the dry season. Maximum changes observed in surface temperatures (temperature shocks) were a 41°F (23°C) rise in 6 minutes, a 48°F (27°C) drop in 6 minutes, a 15°F (8°C) rise in 90 seconds, and an 18°F (10°C) drop in 90 seconds. The greatest temperature variation was a drop of 100°F (56°C) in 60 minutes, and the highest recorded surface temperature was 181°F (83°C). All maximums occurred on the roof surface of the CONEX container during the rainy season.

In open exposure, the average daily maximum roof surface temperature of the dark-colored noninsulated CONEX container was 33 to 35°F (18 to 19°C) higher than those of white-colored insulated containers. In open exposure, the average maximum temperature of the air inside the CONEX container was 10°F (6°C) higher than that inside the white-colored containers.

1.5 ANALYSIS

Examination of the diurnal changes in air temperature inside containers and the corresponding changes in the relative humidity indicated that the moisture content of the air in containers changed substantially over the course of the day. Increase in moisture content of the air in a container with rise in temperature occurred at a time when movement of air (in accordance with the breathing concept) was from the inside to the outside of the container, indicating that the source of moisture was internal. Weight changes of materials measured as a function of temperature confirmed that materials within the container act as significant sources/sinks for moisture.

1.6 CONCLUSIONS

Moisture conditions inside storage containers are influenced significantly by the materials inside the containers. With increasing temperature, the materials rapidly release moisture to the container air significantly changing the moisture content (absolute humidity) of the air, and increasing the potential for water condensation and subsequent water damage when radiation cooling of the contents and walls of the container occurs.

The phenomenon of moisture migration in containers is complex. When investigating moisture migration in containers, consideration must be given to the type of container, the contents of the container, and the climatic conditions under which the container has been closed. All of these factors play an important role in determining the amount of water enclosed in a container and the subsequent redistribution (and possible condensation) of that water resulting from temperature changes within and on the surfaces of the container.

1.7 RECOMMENDATIONS

- Determine rates of water absorption and desorption for packing materials and materials used in manufacturing materiel components.

- Minimize the amount of water which is enclosed initially in a tightly sealed container by:

  Predrying the goods to be stored.

  Predrying the materials (e.g., pallets and packing materials) associated with the storing of goods.

  Closing the container in a dry ambient environment.

- When camouflage is not a consideration, paint containers with bright, reflective colors to reduce internal thermal buildup, and equip them with ample louvers that protect against rain but allow ventilation to reduce buildup of moisture in the air within the containers.

- Investigate the single and combined effects of temperature, absolute humidity and pressure on moisture migration in closed containers, and establish basic relations required for the development of a mathematical model for predicting moisture phenomenon in containers.

- Initiate development of a model for predicting moisture conditions inside containers, which considers the relative importance of materials, breathing, and ambient conditions.

SECTION 2. DETAILS OF INVESTIGATION

2.1 INTRODUCTORY REMARKS

The investigation was initiated by assuming (a) that condensation occurred at night because of radiation cooling of the surfaces of the containers, and (b) that any change in the moisture content of the enclosed air came about only through "breathing."

Initial data showed that little or no change in relative humidity within the container occurred with large changes in temperature. This indicates that the moisture content of the air, in terms of absolute humidity, changed substantially in the course of the day. After eliminating the possibility of operational errors, it was concluded that matter in the container was a source and sink of water contributing to changes in absolute humidity of the enclosed air.

To demonstrate the exchange of moisture between air and matter inside the container, weight changes of material samples were recorded during several diurnal cycles. Weight of the samples changed with temperature, indicating that moisture was expelled or absorbed with changing temperature.

At that time it was believed that the moisture expelled from porous materials in the containers explained only a part of the change of absolute humidity of the enclosed air. It was hypothesized that the plain, nonporous inner walls of the container were a significant sink/source for moisture with capacity dependent on temperature. An experiment was conducted to examine this phenomenon.

Research into the influences of climate on storage containers also has been conducted recently by the East and West Germans (references 2 and 3 respectively). Reference 2 deals only with climatic influences on goods stored within ships and not exposed to solar radiation; whereas, reference 3 discusses climatic influences on goods stored within containers standing freely exposed to solar radiation on the decks of ships and in freight yards. The primary conclusion of reference 3 was similar to the conclusion in this report, namely, that the potential for water damage in containers occurs when the heat of the solar radiation drives moisture out of goods, shelves, and crates. This moisture then migrates to and settles at places where it is harmful.

2.2 DATA COLLECTION

2.2.1 Containers. Five containers were used in this investigation and are described as follows:

Container A: A camper, painted white, with shallow fiberglass insulation throughout (except the floor and door). All windows and the door were covered with plywood to prevent sunshine from entering. One window was left partially open. The inside dimensions were length 70 inches (178cm), width 46 inches (117cm), and height 79 inches (201cm); the volume was 147 ft^3 ($4.1m^3$).

Container B: A white painted camper with 1-inch (2.5cm) heat insulation. In contrast with container A it was almost airtight. Its dimensions were length 71 inches (180cm), width 45 inches (114cm), and height 56 inches (142cm); the volume was 104 ft^3 ($3.0m^3$).

Container C: A dark-colored shipping container, commonly called a CONEX container, of corrugated steel. Its dimensions were length 97 inches (246cm), width 70 inches (178cm), height 72 inches (183cm); the volume was 283 ft^3 ($8.0m^3$). The container had one door and no windows. It was not insulated and some air exchange was possible through several small cracks.

Container D: A dull black instrument case. In its original configuration it had louvers on two sides, but the louvers were closed by painted aluminum panes that were screwed on from the inside of the box. The lid was on top and had a gasket so that air exchange was greatly impaired. The dimensions of container D were length 21 inches (53cm), width 15 inches (38cm), and height 28 inches (71cm); the volume was 5.1 ft^3 ($0.14m^3$).

Container E: A shiny, whitish-gray instrument case which could be closed to be nearly airtight. It had the following inner dimensions length 24 inches (61cm), width 7 inches (18cm), and height (above the long axis) 6 inches (15cm); the volume was 0.51 ft^3 ($0.014m^3$).

2.2.2 Positioning of the containers.

Containers A, B, and C were positioned on nearly flat unprepared ground and at some points were supported by blocks to level the floors. Container D was positioned on the floor inside Container C. Container E was placed on a pole 59 inches (150cm) above the surface of the ground.

There were two sites where the containers were placed at different times during the study: An open grass area and a forest area. Figure 1 shows the containers positioned at the open site.

2.2.3 Instrumentation.

Ambient conditions were recorded with a wind vane and anemometer, rain gauge, and an aspirated recording psychrometer. Radiation

Figure 1. View of the Containers at Open Exposure Site.

measurements were obtained at Chiva Chiva Antenna Farm* at a distance of 1340 meters.

Surface and air temperatures of the containers were measured by thermocouples and recorded at 6-minute intervals. The relative humidity of the air inside the containers was measured continuously by hygrographs with human hair as the sensory element. (NOTE: The relative humidity inside container E was not measured because the container was too small to house a hygrograph.) The hygrographs were checked at least twice a week and exchanged frequently to confirm previous measurements. Wetness of the container ceiling and floor was monitored

* Hourly data have been published in monthly booklets by Atmospheric Sciences Laboratory, White Sands, New Mexico.

by wetness sensors which were developed by USATTC.

Table 1 lists the location of the container-mounted instruments. In containers A, B, C and D instrumentation arrangement was vertical over the geometric center of the floor. Stands constructed from unfinished wood were employed to position the hygrographs at the different levels in the containers.

Table 1. Location of Instruments

Container	Location	Thermocouple a/	Hygrograph b/	Wetness Sensor b/
A,B,C	roof top	X	-	-
A,B,C	ceiling	X	-	X
A,B,C	12 in (30cm) below ceiling (level 3)	X	X	-
A,B,C	center of air space (level 2)	X	X	-
A,B,C	12 in (30cm) above floor (level 1)	X	X	-
A,B,C	floor	X	-	X
D	ceiling	X	-	X
D	center of air space	X	X	-
D	floor	X	-	X
E	inside	X	-	X
E	outside	X	-	-

a/ recording at 6 min intervals

b/ continuous recording

2.2.4 Observation periods.

The project was divided into eight observation phases which are listed in table 2. Since in the tropics there is a strong tendency for each day to repeat the same diurnal changes that occurred the previous day, the few days of measurement during each observation phase presented a good, low variance sample from which repeatable observations were obtained. During the even numbered phases, containers A, B and C were filled with cardboard boxes (figure 2); otherwise, the containers were empty except for instrumentation. Additional observations were made during the months of July and August 1976, primarily to enhance knowledge of extreme surface temperatures and temperature variability during the rainy season. Also, further experimentation was suggested by the results of these observation phases and is described elsewhere in this section.

Table 2. Observation Periods

Phase	Season	Site	Exposure Period (1976)
I	Dry	Open	9 Feb - 12 Feb
II	Dry	Open	24 Feb - 1 Mar
III	Dry	Forest	26 Mar - 1 Apr
IV	Dry	Forest	2 Apr - 8 Apr
V	Rainy	Forest	14 May - 24 May
VI	Rainy	Forest	25 May - 1 Jun
VII	Rainy	Open	4 Jun - 11 Jun
VIII	Rainy	Open	11 Jun - 17 Jun

2.3 TEMPERATURES

2.3.1 Container Air Temperatures.

Hourly temperature data for containers A, B, C and D are presented in tables B-1 through B-8. The tabulated data are hourly container air temperatures averaged over the several days of an observation phase and, for containers A, B, and C, over the three levels instrumented in those containers.

Maximum and minimum mean hourly temperatures at the three levels measured in empty containers A, B and C are shown in table 3. As indicated, temperature gradients existed within the containers. Maximum temperature gradients occurred at times of maximum temperatures. The maximum temperature gradients were observed in container C in open exposure during the dry season.

The mean maximum air temperature inside the containers was highest in the all-steel container C during each exposure phase. In open exposure, the mean maximum of the air temperature inside container C was 10°F (6°C) higher than that of containers A and B.

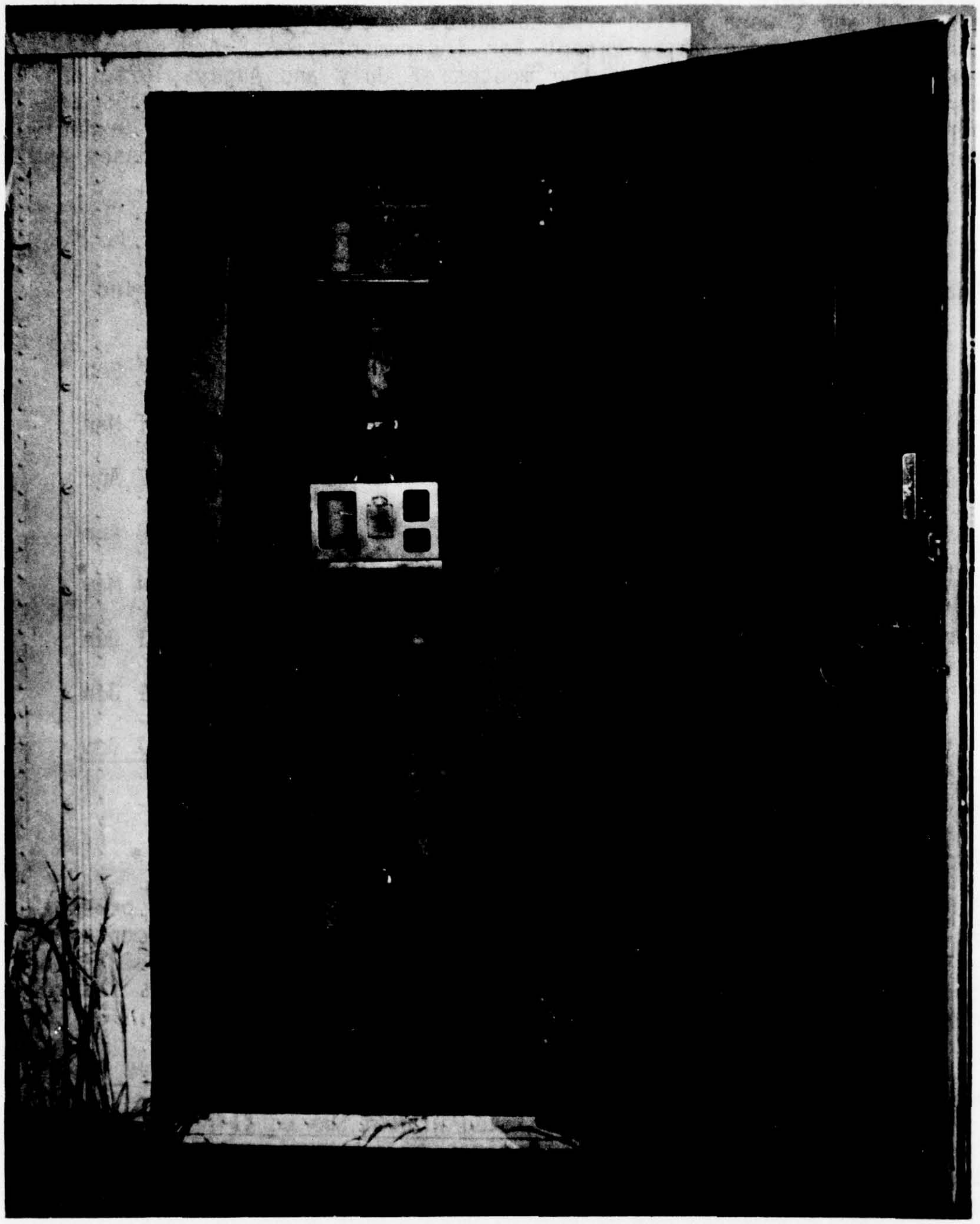


Figure 2. Instrumented Container A Filled with Cardboard Boxes.

Table 3. Maximum and Minimum Mean Hourly Temperatures (^{o}C) of the Air in Empty Containers

		Dry Season						Rainy Season					
		Open Site			Forest Site			Forest Site			Open Site		
		Container			Container			Container			Container		
		A	B	C	A	B	C	A	B	C	A	B	C
MAXIMA	Level 3(30cm below ceiling)	36.4	37.2	46.3	31.9	31.4	33.9	29.3	29.3	30.1	35.1	35.4	41.9
	Level 2(center of air space)	36.3	36.6	41.4	31.4	31.1	33.3	28.7	29.0	29.6	34.1	34.6	39.8
	Level 1(30cm above floor)	34.8	36.3	38.3	29.8	31.1	32.9	27.9	28.9	29.2	30.8	34.0	37.0
MINIMA	Level 3(30cm below ceiling)	19.2	19.4	19.3	21.8	21.6	21.1	22.3	22.4	22.1	23.4	23.4	23.2
	Level 2(center of air space)	19.1	19.1	19.2	21.7	21.4	21.1	22.1	22.4	21.9	23.3	23.6	23.2
	Level 1(30cm above floor)	19.3	19.3	19.4	22.0	21.6	20.9	22.4	22.5	21.9	24.7	23.6	23.2

Temperature maxima of container air occurred earlier in the rainy season than in the dry season. The temperature rise in the forenoon began earlier and was higher in the all-steel container C than in containers A and B.

The daily average air temperature of container C was, under all conditions in open exposure, higher than the average temperature of containers A and B. In open exposure, the average temperature in each container was higher than the average temperature of the ambient air (appendix B).

2.3.2 Surface Temperatures.

Table 4 lists the range of the maximum and minimum roof surface temperatures of the containers during the eight phases of this study. Data for container D are not listed because it was standing inside container C and was not exposed to direct sunlight during the eight scheduled phases.

Table 4. Minimum and Maximum Roof Surface Temperature Ranges of Containers (°C)

	Dry Season				Rainy Season			
	Open Site		Forest Site		Forest Site		Open Site	
Container	Minima	Maxima	Minima	Maxima	Minima	Maxima	Minima	Maxima
A	14-21	48-54	18-24	31-36	20-24	27-41	19-23	38-60
B	14-21	47-53	18-24	31-26	20-24	27-41	19-23	37-63
C	14-21	67-76	18-24	36-47	20-24	28-38	19-23	47-81
E	15-20	48-53	18-23	30-37	21-24	28-42	19-23	35-56

The ranges in maximum surface temperatures for the brightly-colored containers A, B and E were very similar for all test periods and storage modes, whereas the dark-colored container C surface temperatures were much higher than those of the other containers in open storage for both seasons. In open storage, the average daily maximum surface temperature of container C was 35°F (19°C) and 33°F (18°C) higher than that of containers A and B, respectively. The ranges in minimum surface temperatures for all containers were similar.

During August 1976, container D was taken out of container C and placed in the open. An additional thermocouple was glued to the upper side of the lid of container D, and the entire container was covered by a tarpaulin in close proximity to the lid. Table 5 presents the maximum temperatures occurring on 16 August 1976. On this day, the temperature on the surface of container C rose to 181 °F (83°C), the highest temperature recorded during this investigation, and two hours later rose again to 180°F (82°C).

Table 5. Simultaneous Maximum Temperatures

(16 August 1976)

Container	Location	Temperature (°F)	(°C)
D	lid under tarpaulin	164	(73)
D	inner air space	119	(48)
C	upper roof surface	181	(83)
C	ceiling surface (roof underface)	136	(58)
C	inner air space	111	(44)
Ambient Air		88	(31)

Althought the maximum temperatures on other days were lower than those in table 5, the general pattern remained the same. In particular, maximum roof temperatures of container C were always higher than those under the tarpaulin.

2.3.3 Temperature Changes.

Temperatures on and in the containers exposed at the open site closely followed the solar radiation pattern. Figure 3 shows the global radiation recording of 10 July 1976. The roof surface temperatures of container C for the same day are presented in figure 4. The simularity of these two curves provides an example of the high correlation between solar radiation and surface temperatures of containers in open exposure in the tropics. An examination of the curves presented in figure 5, shows that the roof temperature changes are reflected throughout the container. Comparison of many short duration temperature extremes for all thermocouples of any one container shows that these rapid oscillations penetrate the entire container very rapidly, generally in less than 6 minutes. This indicates that it is radiation that transmits the many rapid temperature changes in a container. This statement is supported by the fact that the coincidence of phase at different levels in a container is almost perfect; whereas, the amplitude is greatly reduced with distance from the heat source.

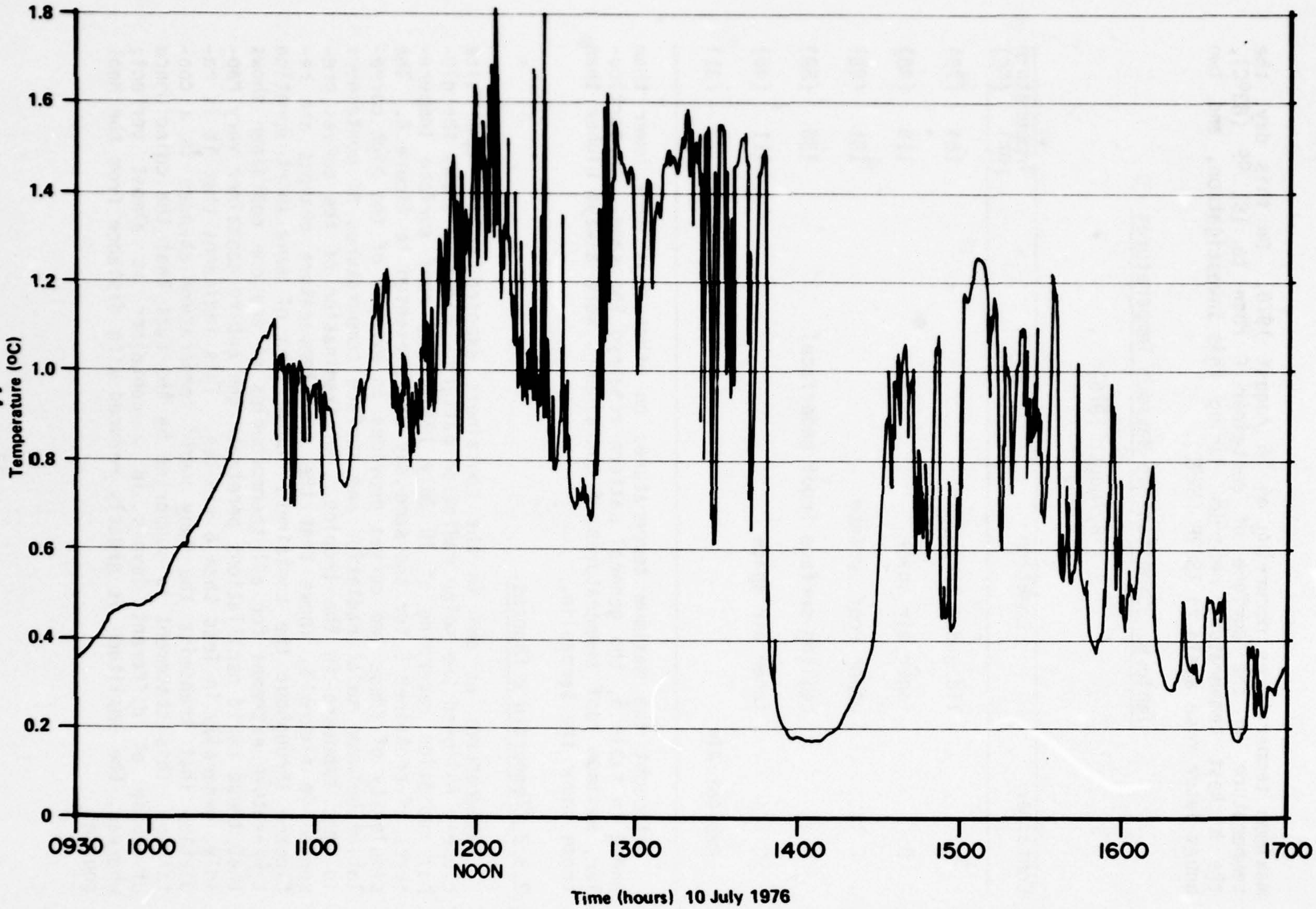


Figure 3. Solar Radiation (Chiva Chiva, Canal Zone--Open Site, Rainy Season.

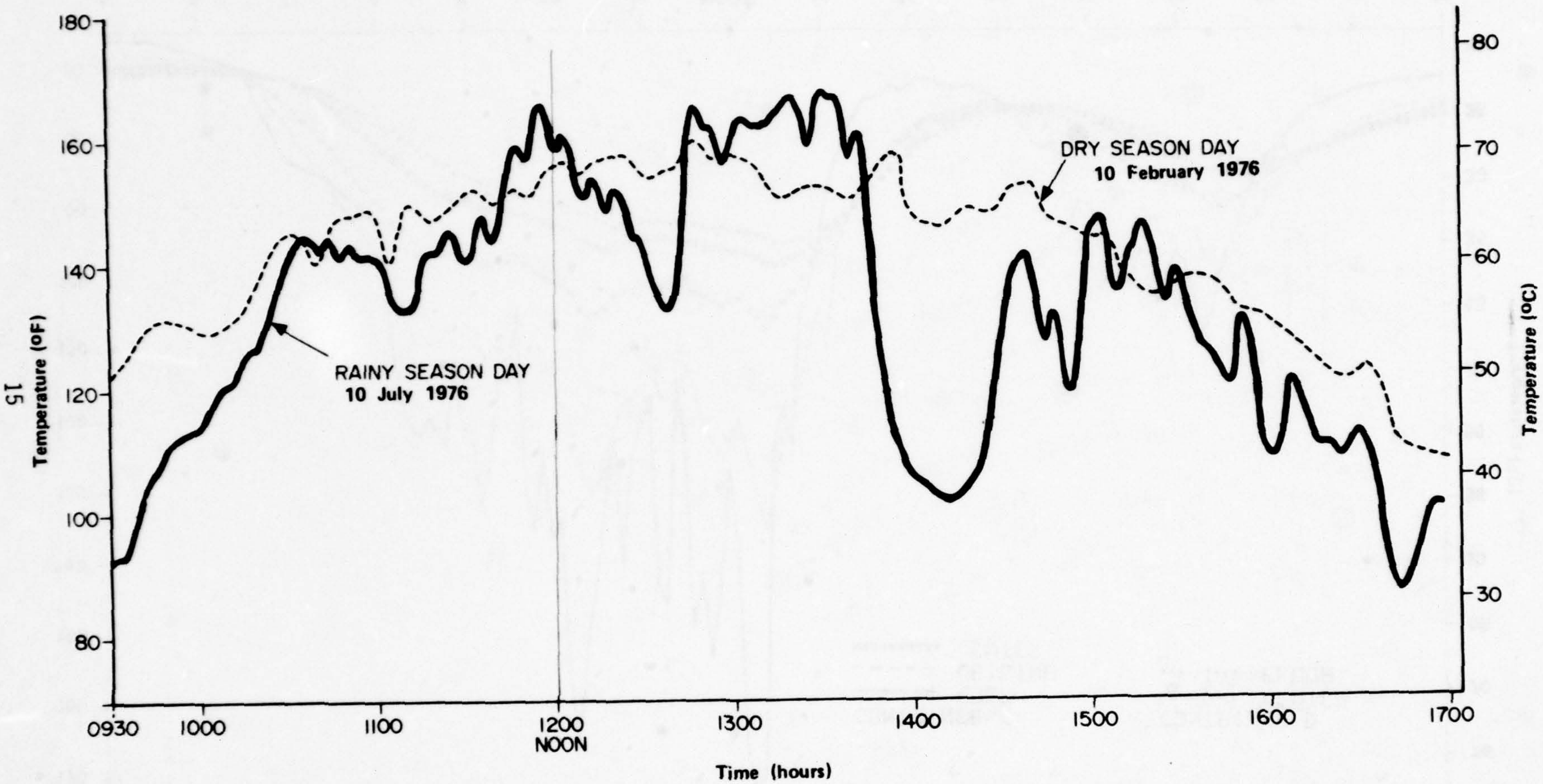


Figure 4. CONEX Container Roof Surface Temperatures (Open Site, Dry and Rainy Seasons).

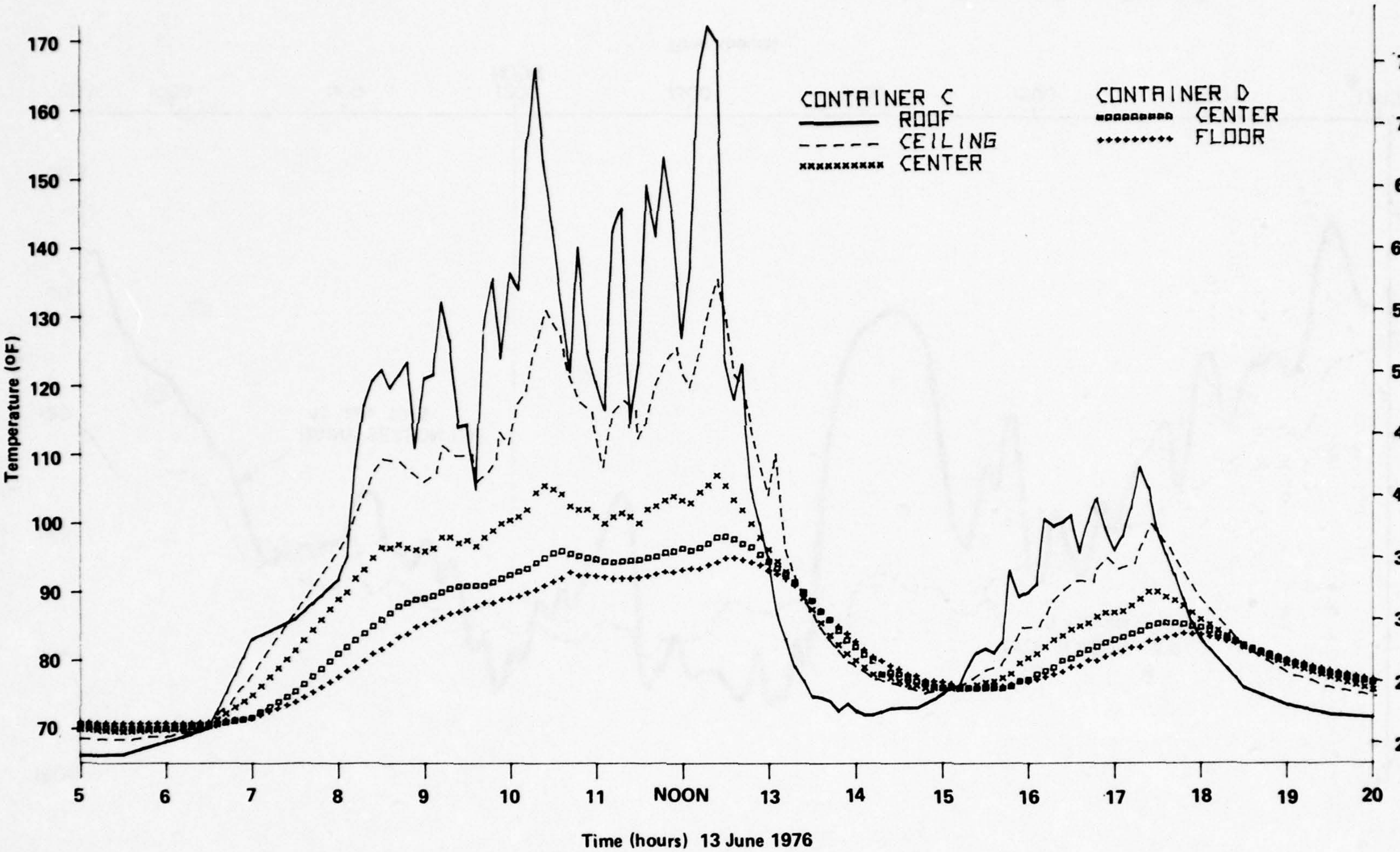


Figure 5. Comparison of Container Roof and Air Temperatures (Open Site, Rainy Season).

The roof surface temperature of containers in open exposure fluctuated more often and to a greater degree in the rainy season than in the dry season. Figure 4 vividly depicts this observation. There are three reasons for the large thermal changes experienced in the rainy season. First, the degree of cloudiness changes rapidly in the rainy season. Second, winds are very light during the rainy season resulting in little opportunity for atmospheric cooling. Third, rains occur frequently resulting in large drops in the temperature. Figure 6 shows such an event occurring shortly after noon.

Table 6 presents a list of the largest changes of container C roof surface temperatures measured at 90-second intervals during the rainy season period, 4-21 July 1976. Table 7 presents hourly frequency distributions of 6-minute, roof-surface temperature changes for the same period. There can be little doubt that greater temperature fluctuations occur regularly since the amount of data available for this investigation was limited and random.

Table 6. Extreme Changes in Surface Temperatures

(CONEX Container)

Temperature Change (°F) From	To	Temperature Differences (°F)	(°C)	Time Required For Change (Minutes)	Rate of Temperature Change (Degrees Per Minute) (°F)	(°C)
176	158	-18	-10	1.5	12.0	6.7
179	149	-30	-17	3.0	10.0	5.6
179	137	-42	-23	4.5	9.3	5.2
179	131	-48	-27	6.0	8.0	4.4
165	116	-49	-27	10.5	4.7	2.6
166	86	-80	-44	18.0	4.4	2.5
124	139	+15	+8	1.5	10.0	5.6
127	154	+27	+15	3.0	9.0	5.0
124	162	+38	+21	4.5	8.4	4.7
124	165	+41	+23	6.0	6.8	3.8
122	169	+47	+26	10.5	4.5	2.5
124	176	+52	+29	12.0	4.3	2.4

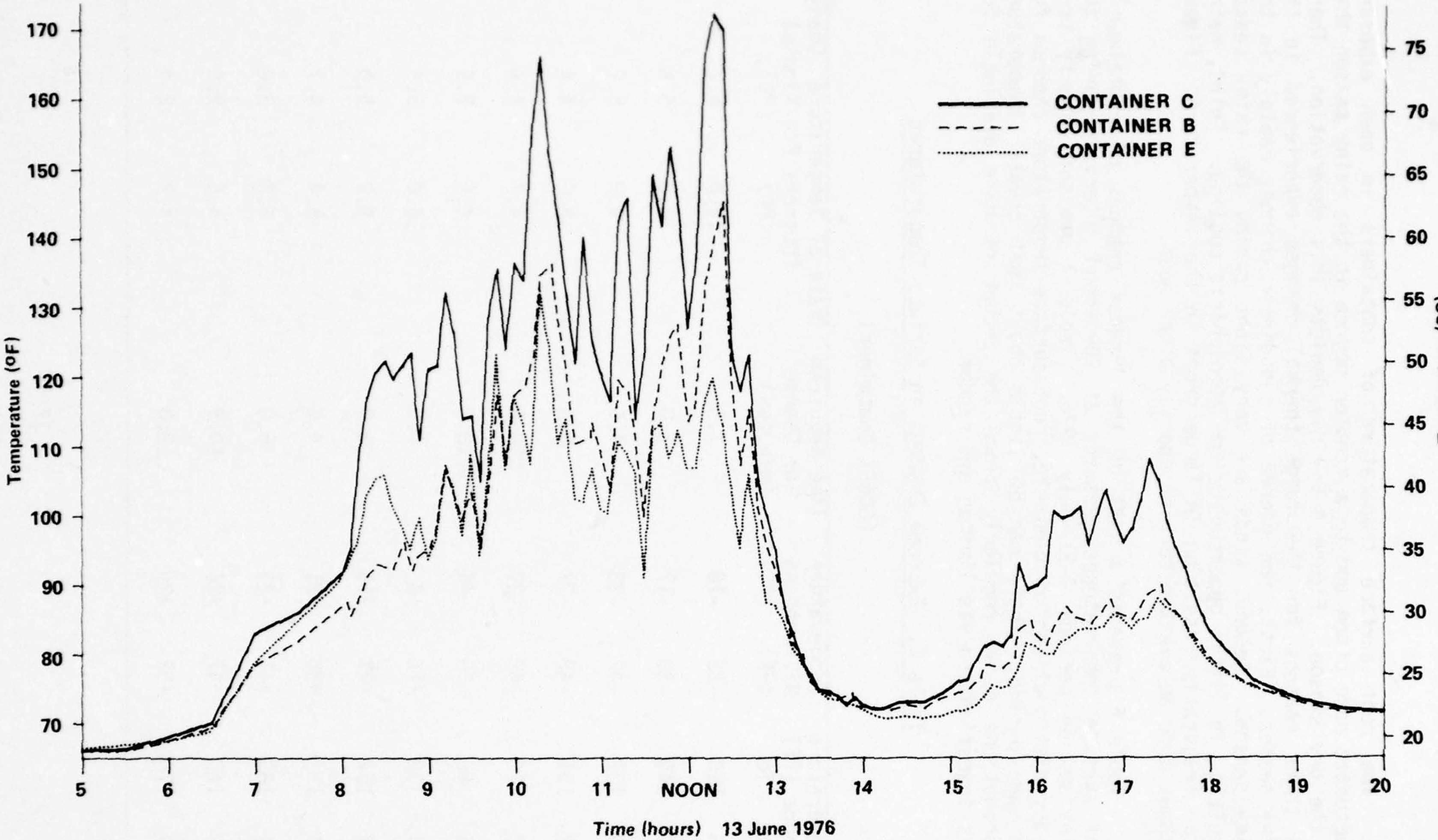


Figure 6. Comparison of Container Roof Surface Temperatures (Open Site, Rainy Season).

Table 7. Hourly Frequency Distributions of 6-Minute Temperature Changes (Percent) (CONEX Container Roof) (4 - 21 July 1976)

Temperature Change (°F)*		TIME FRAMES (EST) 0900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	1600-1700	0900-1700
41-45	rise	-	-	-	0.1	-	-	-	-	0.02
36-40	↑	-	-	0.1	-	-	-	-	-	0.02
31-35		-	-	0.1	0.7	-	0.1	-	-	0.12
26-30		-	0.3	0.3	1.1	0.1	0.1	-	-	0.25
21-25		-	0.4	0.3	0.8	1.1	0.7	0.7	-	0.51
16-20		0.7	0.8	1.9	3.1	3.2	2.1	1.8	0.3	1.75
11-15		2.1	2.2	4.2	6.0	4.0	2.9	2.4	0.7	3.09
6-10		10.9	9.4	13.3	9.4	8.6	7.8	8.1	2.9	8.85
1- 5	rise	53.0	46.3	32.4	22.5	25.3	21.7	24.3	21.2	30.85
0	no change	10.0	8.9	7.6	5.4	8.3	11.1	11.5	16.3	9.84
1- 5	drop	18.6	22.1	22.6	26.3	24.0	38.3	37.9	48.2	29.61
6-10		3.7	6.9	9.2	13.1	9.0	9.6	9.9	6.5	8.50
11-15		1.0	1.4	3.3	6.0	7.1	4.2	2.8	2.9	3.60
16-20		-	0.8	2.4	2.2	2.9	0.7	0.1	0.7	1.25
21-25		-	0.4	1.1	1.7	2.8	0.7	0.3	0.1	0.90
26-30		-	-	0.7	1.1	1.5	-	0.1	-	0.44
31-35		-	-	0.3	0.3	1.1	-	0.1	-	0.23
36-40		-	-	0.1	0.3	0.6	-	-	-	0.12
41-45	↓	-	-	-	-	0.1	-	-	-	0.02
46-50	drop	-	-	-	-	0.1	-	-	-	0.02

* To convert to °C, multiply °F by 5/9.

The deleterious effect of the vacillations of the surface temperatures is enhanced by temperature differences within the roofing material. The upper two curves of figure 5 show the temperatures that were measured on the roof and directly below on the ceiling of the all-steel container C. The differences between these simultaneous measurements ranged from -13°F (-7°C) (ceiling warmer than roof) to 36°F (20°C) (roof warmer than ceiling). The rain that made the roof temperature drop 100°F (56°C) in one hour made the ceiling temperature drop 60°F (33°C) in two hours. Such changes of temperature and such discrepancies between upper and underside of the same layer are typical for daytime hours throughout the rainy season and are strong agents for the deterioration of surface materials exposed in the tropics. Hahin (reference 4) reports that in the Canal Zone the damage to roofs caused in part by thermal expansion and contraction is extensive. He also states that approximately 37 percent of the construction dollar is devoted to controlling corrosion, and that the 193d Infantry Brigade Facilities Engineer allocates approximately 21 percent of his in-house resources to maintain systems damaged by corrosion.

2.4 HUMIDITIES

The amount of water vapor suspended in air can be expressed in several ways. This investigation deals with two of these: Relative humidity (i.e., the ratio of the density of the water vapor at a given temperature to the density of saturated water vapor at the same temperature), and absolute humidity (i.e., the actual weight of water vapor present per unit volume of air, usually expressed as grams per cubic meter (g/m^3)). The two measures are related by the formula $RH = 100\ (AH/AH_x)$ where RH equals relative humidity in percent, AH equals the actual absolute humidity, and AH_x equals the maximum possible absolute humidity.

2.4.1 Relative Humidity

Average hourly relative humidities of the air inside the containers are listed in tables B-9 through B-16. Averaging of the data was performed in the same manner as that for the temperature data presented in Appendix B.

It had been expected that in an empty, sealed container the relative humidity would always decrease in a predictable manner as the container air temperature increased. Assuming a perfectly airtight container, the decrease in relative humidity is easily computed for any given rise in temperature. However, if the container is less than airtight, the phenomenon of "breathing" would cause an additional decrease in relative humidity because of the loss of water vapor as a result of volumetric expansion. These expected results were not realized as the following observations of the relative humidity inside the containers indicate.

The relative humidity dropped most of the time when the temperature rose. However, the amount of change was less than it would have been if there were no moisture sources in the containers. For container D, diurnal changes of relative humidity were extremely small despite sizable temperature variations. As an example, table 8 presents hourly conditions occurring in container D on 16 February 1976. Adjacent to these hourly conditions are the expected relative and absolute humidities assuming (1) an airtight container whose air holds a fixed amount of moisture, and (2) a less than airtight container capable of "breathing" but without internal moisture sources.

Table 8. Actual and Expected Conditions in Container D
16 February 1976

Actual Conditions in Container D					Expected Conditions*			
					Airtight Container		Breathing Container	
Time of Day (EST)	Air Temperature (^{o}F)	Air Temperature (^{o}C)	AH (g/m^3)	RH (%)	AH (g/m^3)	RH (%)	AH (g/m^3)	RH (%)
0700	65	18.3	9.2	59	9.2	59	9.2	59
0800	74	23.3	11.1	53	9.2	44	9.0	43
0900	88	31.1	16.1	50	9.2	28	8.8	27
1000	98	36.7	21.6	50	9.2	21	8.7	20
1100	103	39.4	24.8	50	9.2	19	8.6	17
1200	104	40.0	25.6	50	9.2	18	8.6	17
1300	105	40.6	26.3	50	9.2	17	8.5	16
1400	106	41.1	27.0	50	9.2	17	8.5	15

In insulated container A and B, the relative humidity initially rose along with the container air temperature after sunrise, but eventually dropped while the temperature continued to rise. This rise of relative humidity after sunrise frequently occurred in an "explosive" fashion as shown in figures 7 and 8.

Empty containers experienced larger diurnal changes in relative humidity than filled containers (figures 7 and 8) indicating that diurnal changes in relative humidity are dependent upon the contents of containers.

* Assuming no significant moisture sources within the container.

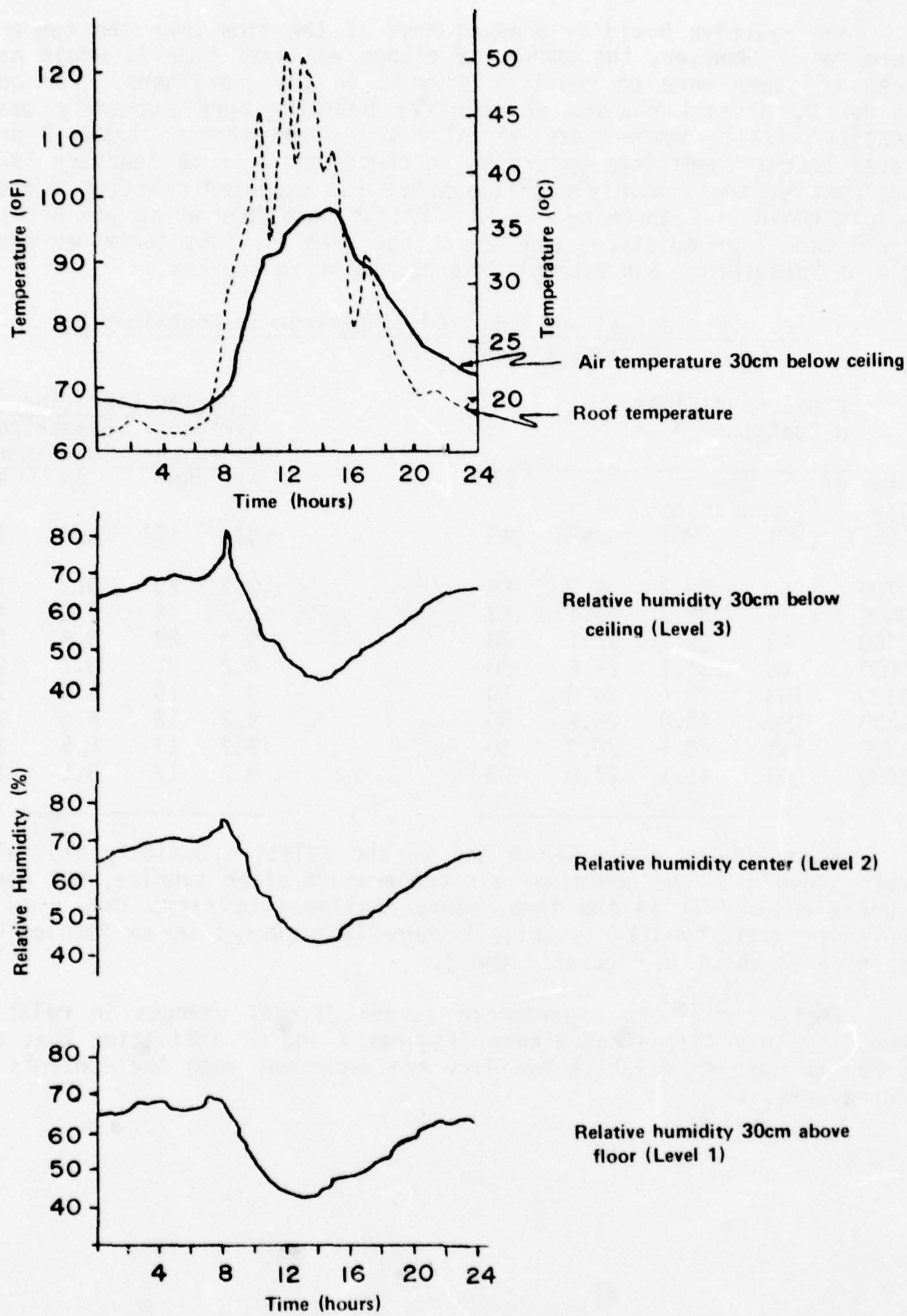


Figure 7. Relative Humidities of Container B on 12 February 1976 - Open Site, Dry Season - Container Empty.

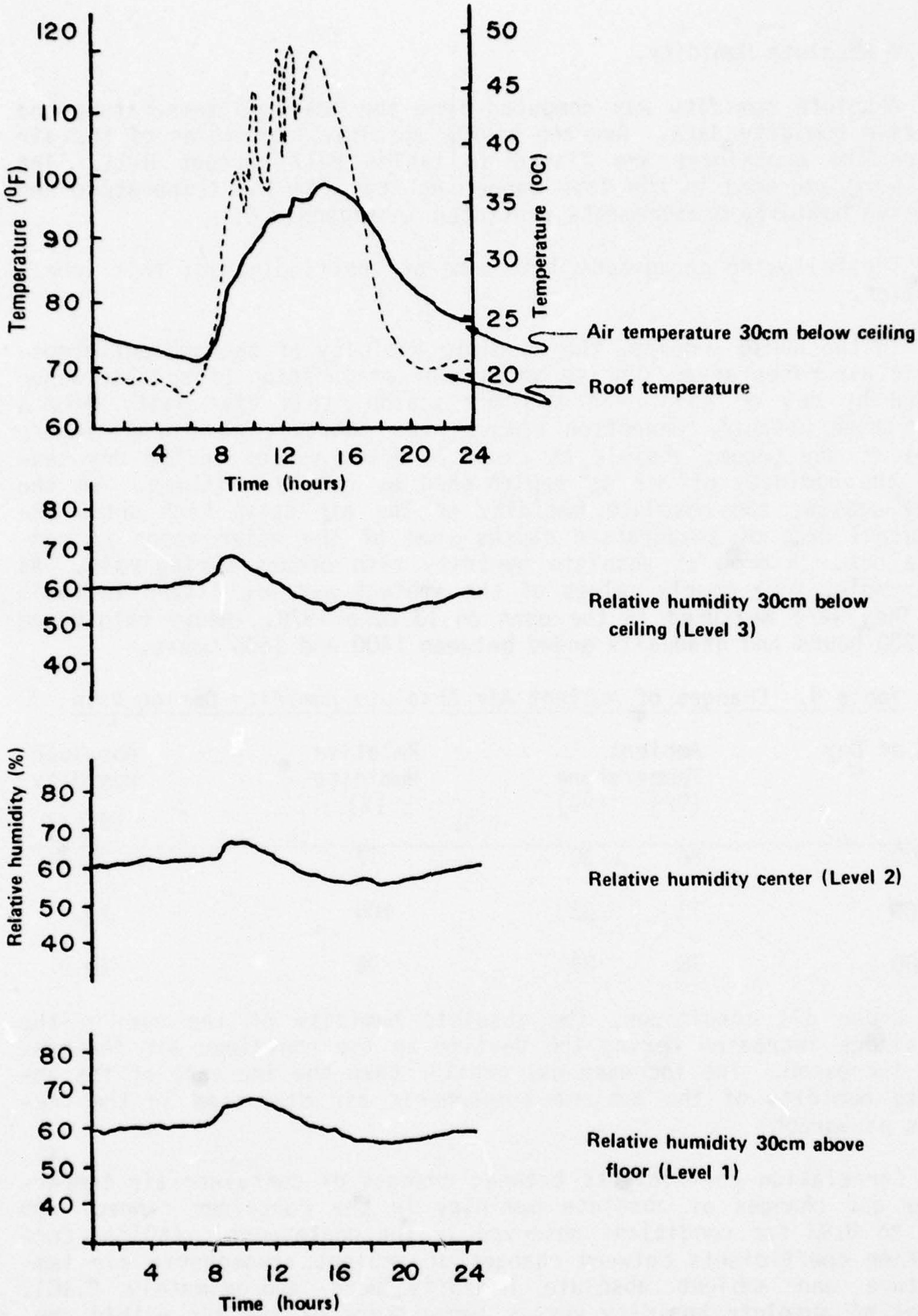


Figure 8. Relative Humidities of Container B on 28 February 1976 - Open Site, Dry Season - Container Filled with Cardboard Boxes.

2.4.2 Absolute Humidity.

Absolute humidity was computed from the measured temperature and relative humidity data. Average hourly absolute humidities of the air inside the containers are listed in tables B-17 through B-24. The data were averaged in the same manner as that for the temperature and relative humidity measurements presented in Appendix B.

The following paragraphs list some of the findings of this investigation.

In the humid tropics, the absolute humidity of the ambient atmospheric air rises after sunrise because of evaporation of surface water formed by dew or rain. In the dry season, this rise lasts only a short time because convection removes the moisture to higher layers where it may become visible as clouds. After sunset in the dry season, the humidity of air is replenished by ground moisture. In the rainy season, the absolute humidity of the air stays high until the nocturnal drop of temperature causes some of the water vapor to condense out. A drop of absolute humidity also occurs during rain. As an example, some hourly values of the ambient air are listed in table 9. They were measured in the open on 13 June 1976. Heavy rain began at 1300 hours and gradually ended between 1400 and 1600 hours.

Table 9. Changes of Ambient Air Absolute Humidity During Rain

Time of Day	Ambient Temperature (^{o}F)	(^{o}C)	Relative Humidity (%)	Absolute Humidity (g/m^3)
1200	86	30	77	23.6
1400	73	23	100	20.4
1600	75	24	96	20.9

Under all conditions, the absolute humidity of the air in the containers increased during the daytime as the container air temperature increased. The increase was greater than the increase of the absolute humidity of the ambient atmospheric air discussed in the previous paragraph.

Correlation coefficients between changes of container air temperature and changes of absolute humidity in the container ranged from 0.84 to 0.98 for conditions observed in the containers. (NOTE: Correlation coefficients between changes of ambient atmospheric air temperature and ambient absolute humidity were approximately 0.10). Curves of absolute humidity versus temperature of the air within container D for different environmental settings are presented in figure 9. Hourly data used in preparing figure 9 are presented in table 10.

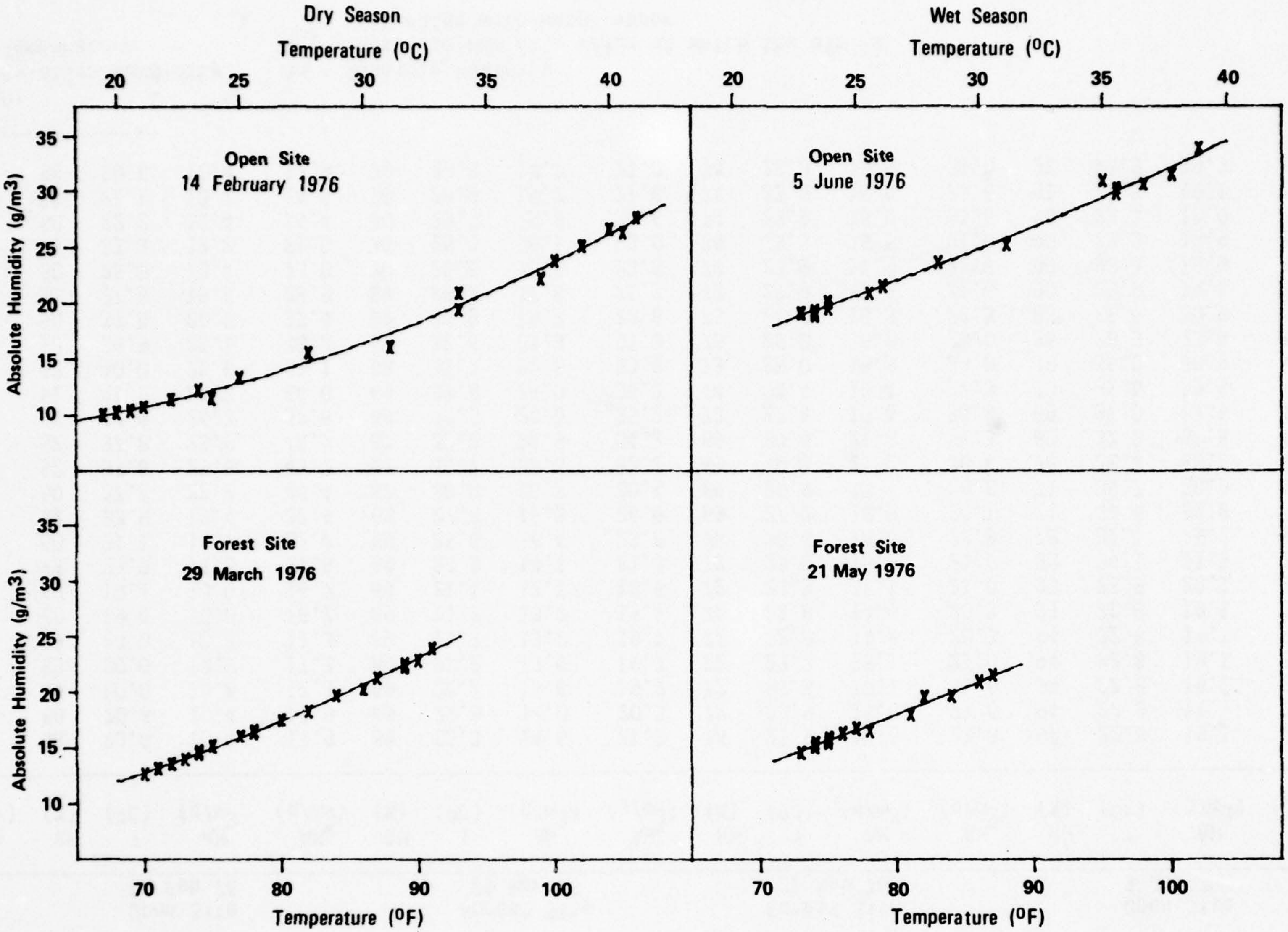


Figure 9. Absolute Humidity Versus Temperature (Conditions Within Container D).

Table 10. Hourly Values of Humidity and Temperature in Container D

	Dry Season								Rainy Season							
	Open Site 14 Feb 76				Forest Site 29 Mar 76				Forest Site 21 May 76				Open Site 5 Jun 76			
Time (hour)	RH (%)	T (°C)	AH (g/m³)	AH_x (g/m³)	RH (%)	T (°C)	AH (g/m³)	AH_x (g/m³)	RH (%)	T (°C)	AH (g/m³)	AH_x (g/m³)	RH (%)	T (°C)	AH (g/m³)	AH_x (g/m³)
01	58	20.6	10.4	17.9	69	23.3	14.5	21.0	76	23.9	15.5	21.6	94	22.8	19.1	20.3
02	58	20.6	10.4	17.9	69	22.8	14.0	20.3	72	23.9	15.5	21.6	94	22.8	19.1	20.3
03	59	20.0	10.2	17.3	69	22.2	13.6	19.7	72	23.3	15.1	21.0	94	22.8	19.1	20.3
04	59	20.0	10.2	17.3	69	22.2	13.6	19.7	72	23.3	15.1	21.0	94	22.8	19.1	20.3
05	59	20.0	10.2	17.3	69	21.7	13.2	19.1	72	22.8	14.6	20.3	94	22.8	19.1	20.3
06	60	19.4	10.0	16.7	69	21.7	13.2	19.1	72	22.8	14.6	20.3	94	22.8	19.1	20.3
07	60	19.4	10.0	16.7	69	21.1	12.7	18.5	72	23.3	15.1	21.0	93	23.9	20.1	21.6
08	53	23.9	11.5	21.6	69	23.3	14.5	21.0	72	23.9	15.6	21.6	88	26.1	21.5	24.4
09	50	31.1	16.1	32.2	69	25.6	16.4	23.8	70	25.6	16.6	23.8	78	31.1	25.2	32.2
10	52	33.9	19.4	37.4	68	27.8	18.3	26.9	69	27.2	18.0	26.1	74	35.6	30.2	40.8
11	50	37.2	22.2	44.4	67	30.0	20.3	30.4	69	28.9	19.7	28.6	71	36.7	30.6	43.2
12	52	37.8	23.8	45.7	67	31.7	22.3	33.2	69	30.0	21.0	30.4	70	38.9	33.8	48.3
13	52	37.8	23.8	45.7	67	32.2	22.9	34.2	69	30.6	21.6	31.3	69	37.8	31.5	45.7
14	50	40.6	26.3	52.6	68	32.8	24.0	35.2	73	27.8	19.6	26.9	69	37.8	31.5	45.7
15	51	41.1	27.6	54.0	68	32.8	24.0	35.2	74	24.4	16.4	22.3	73	35.6	29.8	40.8
16	52	40.0	26.6	51.1	68	31.7	22.6	33.2	73	25.0	16.8	23.0	78	35.0	30.9	39.6
17	52	38.9	25.1	48.3	68	30.6	21.3	31.3	73	25.0	16.8	23.0	85	28.3	23.6	27.7
18	56	33.9	20.9	37.4	69	28.9	19.7	28.6	73	24.4	16.3	22.3	88	25.6	20.9	23.8
19	58	27.8	15.6	26.9	69	26.7	17.5	25.3	73	23.9	15.8	21.6	90	23.9	19.5	21.6
20	58	25.0	13.4	23.0	70	25.6	16.6	23.8	74	23.9	15.9	21.6	90	23.3	18.9	21.0
21	58	23.3	12.2	21.0	70	25.0	16.1	23.0	74	23.3	15.5	21.0	90	23.3	18.9	21.0
22	58	22.2	11.4	19.4	70	23.9	15.2	21.6	74	23.9	15.9	21.6	90	23.3	18.9	21.0
23	58	21.1	10.7	18.5	70	23.9	15.2	21.6	74	23.9	15.9	21.6	91	23.3	19.1	21.0
24	58	20.6	10.4	17.9	70	23.3	14.7	21.0	74	23.3	15.5	21.0	92	23.3	19.3	21.0

LEGEND:
RH - Relative Humdidity
T - Temperature
AH - Absolute Humidity
AH_x - Absolute Humidity value at which the air is saturated with water vapor

During the warm part of the day, the absolute humidity within the containers was generally high above nocturnal saturation values. For example, at 1500 hours on 14 February 1976 (table 10) the absolute humidity within container D was 27.6 g/m^3, and the nocturnal saturation value (AH_x) at 2400 hours was 17.9 g/m^3. Thus, in order for the air not to become supersaturated at 2400 hours, an amount of water must be released from the air between 1500 and 2400 hours to at least decrease the absolute humidity from 27.6 to 17.9 g/m^3. In reality, a larger amount of water migrated from the air to attain the absolute humidity value of 10.4 g/m^3 at 2400 hours (table 10).

Containers filled with cardboard boxes experienced larger diurnal changes in absolute humidity than empty containers, indicating that diurnal changes in absolute humidity are dependent upon the contents of containers.

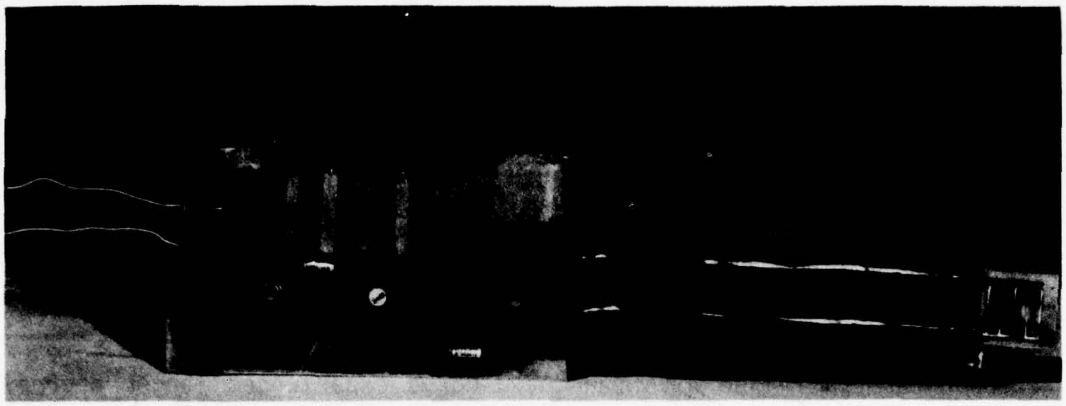
2.5 WETNESS

Wetness of the container ceiling and floor was monitored by wetness sensors (figure 10a).

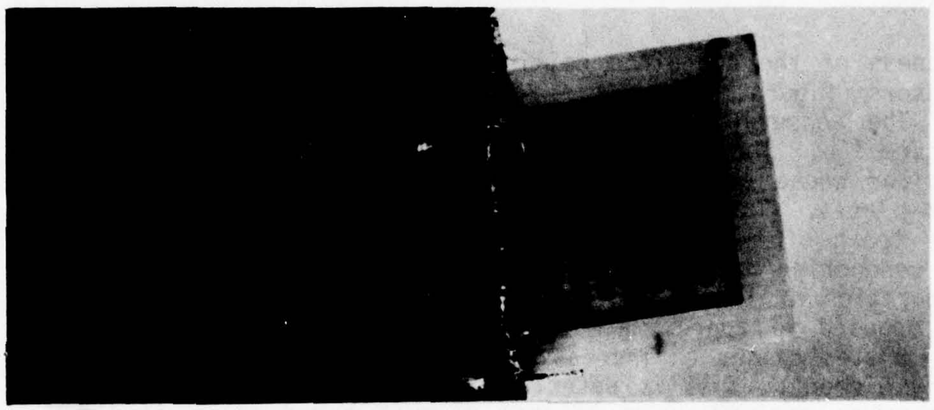
The sensory element of the wetness sensor is shown in figure 10b. The sensory element is basically a variable capacitor whose capacitance depends on the dielectric between its plates. The plates of the sensory element, resembling the teeth of two interlacing combs, are raised thins strips of conducting material deposited on a fiberglass board. The deposition of liquid water (with a dielectric constant of 78 as opposed to approximately unity for ambient air) between the plates causes an increase in the capacitance of the sensory element. This is detected by the wetness sensor electronics contained on a printed circuit board shown in the left half of figure 10a.

A schematic of the wetness sensor is shown in figure 10c. An oscillator produces the driving reference signal, a 1 KHz square wave, for the operation of the wetness sensor. This signal is modified by the capacitance of the sensory element (i.e., a larger capacitance results in a larger circuit time constant) and the modified signal is processed by the wetness sensor electronics producing an output DC signal which is related to the degree of wetness of the sensory element. However, further developmental work is necessary to quantitatively relate the wetness sensor output to the kind and amount of wetness.

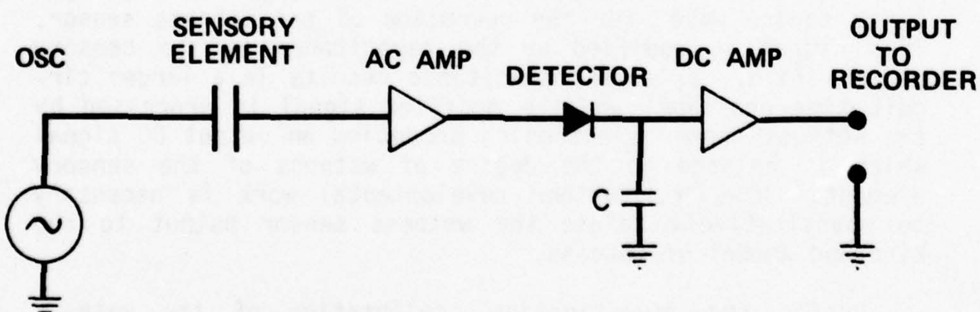
During the investigation, calibration of the wetness sensor was accomplished by spraying the sensor with distilled water for a full scale reading and then drying with a soft cloth for a zero reading.



a. Overall View of the Wetness Sensor



b. Enlargement of Sensory Element



c. Schematic

Figure 10. Wetness Sensor.

The wetness sensor has proven to be extremely sensitive to water deposition; it reacts, for instance, to the moisture deposition of human breath, even though there is no visible sign of wetness. However, the sensor is susceptable to corrosion and to radiated and conducted electromagnetic interference. Additional hardware development is necessary to eliminate or reduce these deficiences.

In its present stage of development, the wetness sensor does not quantitatively measure the amount of water on a surface. However, qualitative results based on the relative changes of wetness are possible, and are presented in the following paragraphs.

The wetness sensor recordings showed repeatable daily patterns of container ceiling and floor wetness which indicated a high degree of association between wetness and the relative humidity of the container air. As an example, figure 11 presents floor wetness and relative humidity data obtained in container B during Phase III. The curves of figure 11 are based on 4-day averages of hourly temperature, relative humidity, and wetness sensor recordings supplemented by data between full hours. The correlation coefficient between the recorded relative humidity and wetness sensor data of figure 11 is 0.952 when the relative humidity is correlated with the floor wetness 60 minutes later. The correlation indicates that an association exists between the amount of water present on the surface of the wetness sensor and the relative humidity of the overlying air*.

Correlation coefficients were computed for all simultaneous recordings of relative humidity and wetness and are summarized in table 11. They were computed for different lags, and only the largest coefficient and the respective lag are listed. Table 11 does not present a complete listing for all phases and containers since the wetness sensor did not always function due to corrosion. In some cases, electromagnetic interference rendered the recordings unusable. Approximately 82 percent of the data were lost as a result of these deficiencies.

Closer inspection of the wetness data indicates that two different processes may cause the ceiling to become wet. In the case of the non-insulated CONEX container, minimum wetness of the ceiling occurred prior to sunset, and maximum wetness occurred at sunrise. This indicates that the wetting was caused through radiation cooling that began at sunset and continued until sunrise. In the case of insulated containers A and B, maximum wetness was observed at mid-morning (figure 11) indicating that the maximum wetting was produced by moisture expelled from the insulation material when it became warmer.

* Changes of the dielectric constant of the air caused by changes in relative humidity are too minute to be detected by the sensor.

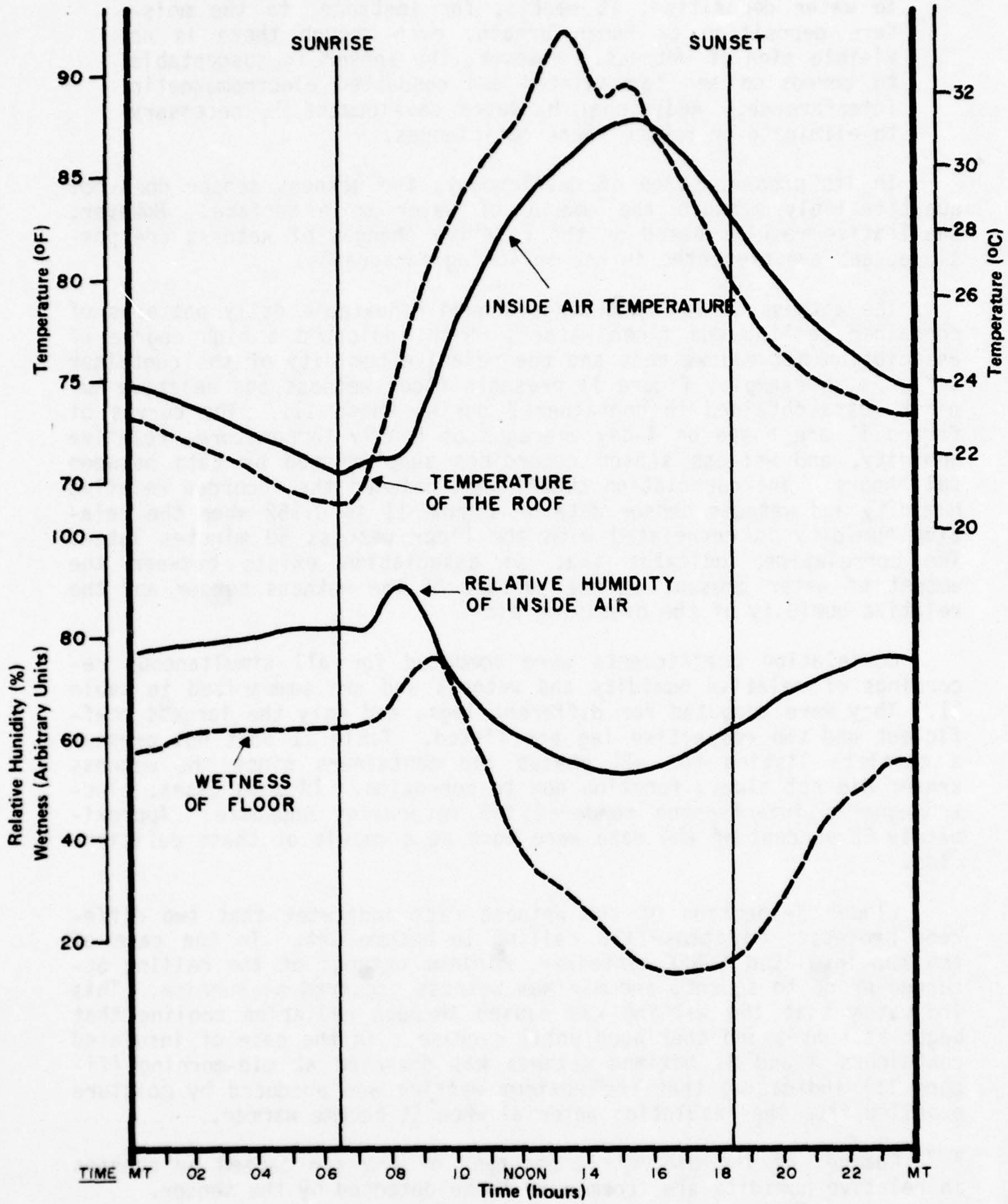


Figure 11. Floor Wetness and Relative Humidity within Container B (Average of 4 Days - Forest Site, Dry Season)

Table 11. Correlation Coefficients (r) Between Wetness Sensor Recordings and Relative Humidity of Contiguous Air

Container	Phase	No. of Days	r	Wetness Lagging/Leading Relative Humidity
A (ceiling)	V	4	.916	zero
B (ceiling)	V	7	.954	leading by 60min
B (ceiling)	VI	4	.656	leading by 90min
B (floor)	III	4	.952	lagging by 60min
B (floor)	IV	6	.901	lagging by 60min
C (ceiling)	I	5	.916	lagging by 30min

2.6 MOISTURE SOURCES/SINKS

The absolute humidity observations discussed in the preceding paragraphs led to an extension of the investigation to substantiate the conjecture that materials within the containers acted as significant sources or sinks for moisture. Lacking a climatic chamber, it was decided to use the steel container (container C) as a chamber that experienced orderly changes in air temperature through solar heating. The amount of water gained or lost by the materials was determined by weighing with a recording balance especially constructed for this investigation. The recording balance was constructed and operated in the following manner:

> A long beam was attached to a solid stand through an elastic U-shaped piece of steel, 2.5 cm wide and 0.24 mm thick. The beam, at one side from the support, had the material to be weighed, a pointer that moved over graduated paper, and a vibration damper consisting of a hanging assembly of several metal plates submerged in a container of brake fluid. At the other side from the support, the beam had a pan for a counterweight to bring the pointer over the graduation. Opposite the pointer was a photographic camera with attached flash, and close to the graduated paper was a small watch. The camera was activated by timer once per hour at which time it photographed the watch and the position of the pointer. The balance was calibrated by attaching and measuring known weights at constant and varying temperatures. A schematic of the recording balance is shown in figure 12.

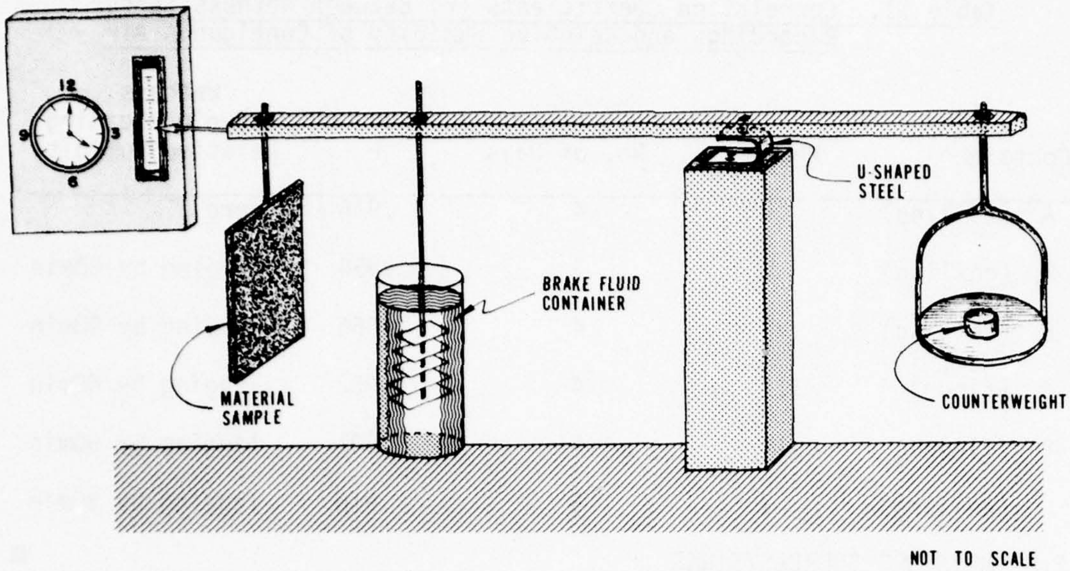


Figure 12. Schematic of Recording Balance.

Five materials were weighted: untreated wood, gray polyurethane foam, green fiber pad, brown fiber pad, and recording paper of the hygrograph. The source for the untreated wood sample was the stand used for positioning of the hygrographs at the different levels in the containers. The fiber pads were taken from packing crates in which TTC had received goods to be tested. The fibers had animal hair and cellulose as a base, coated with phenol-based compounds such as bakelite (brown pad) and latex-based compounds (green pad).

The materials were cut into samples weighing approximately 50 grams (the paper samples weighed approximately 7 grams). During the weighing, the sample hung freely from one end of the recording balance. Container air temperature and humidity were recorded continuously by a hygrothermograph.

Amounts of water released by the samples during daytime heating are shown below. Percentages of material weights lost through desorption of water clearly indicate that the materials are potentially significant sources of water.

Sample	Weight loss (g)	Weight loss (%)
Polyurethane foam	1.0	2
Brown fiber pad	1.9	4
Green fiber pad	2.0	4
Untreated wood	2.3	4
Recording paper	1.1	15

Diurnal curves of material sample weights and of container air temperatures are presented in figures 13 through 17.

The previous wetness and humidity observations also suggested another source/sink of moisture in containers, namely the nonporous inner walls of the containers. It was suspected that the metal inner walls acted as a sink/source for moisture in the form of a water film whose thickness was dependent on temperature. An experiment which investigated this potential source/sink of moisture is described below.

Two new one-gallon tin cans which had inner surface areas of 1608 cm^2 were taken out of relatively dry storage. A small amount of water was poured into can #1 and then as much water as possible was removed from the can without touching the inner surface. Then both cans were weighed. After weighing they were placed in an otherwise empty locker. The cans were open with the lid lying on top. The locker stood in a basement that had temperatures between 75 and 85^{o}F and absolute humidity of 21 g/m^3.

It was assumed that the interior of the cans had come into moisture equilibrium in ten days. At that time the locker was opened, the lids were screwed on their respective cans, and the cans were brought into the rather dry laboratory and weighed. The weighing was repeated after an hour to ensure that the outer surface of the cans would not interfere with the results of weighing. Preliminary experiments had shown that the free surface of metal adapted to the climate near the balance in a very short time.

Then the cans were opened and exposed to heat up to 100^{o}C in an oven to drive out the moisture from the inner walls of the can. The cans were then closed, brought into the lab and weighed again. The weights are listed below:

State of the Cans	Weight in Grams Can #1	Can #2
From dry storage, Can #1 sprinkled inside with water.	383.54	384.74
After 10 days of humid storage.	382.90	384.81
After forced drying	382.61	384.51
Weight loss through oven drying.	0.29	0.30

Since no other volatile substance was identified, the weight losses identified in the above table suggest the existence of a water film covering the inner metal surfaces of the cans.

The results of the above experiment are indicative but not conclusive evidence that such a film could act as a significant source/sink of moisture. Confirmation is left for future studies.

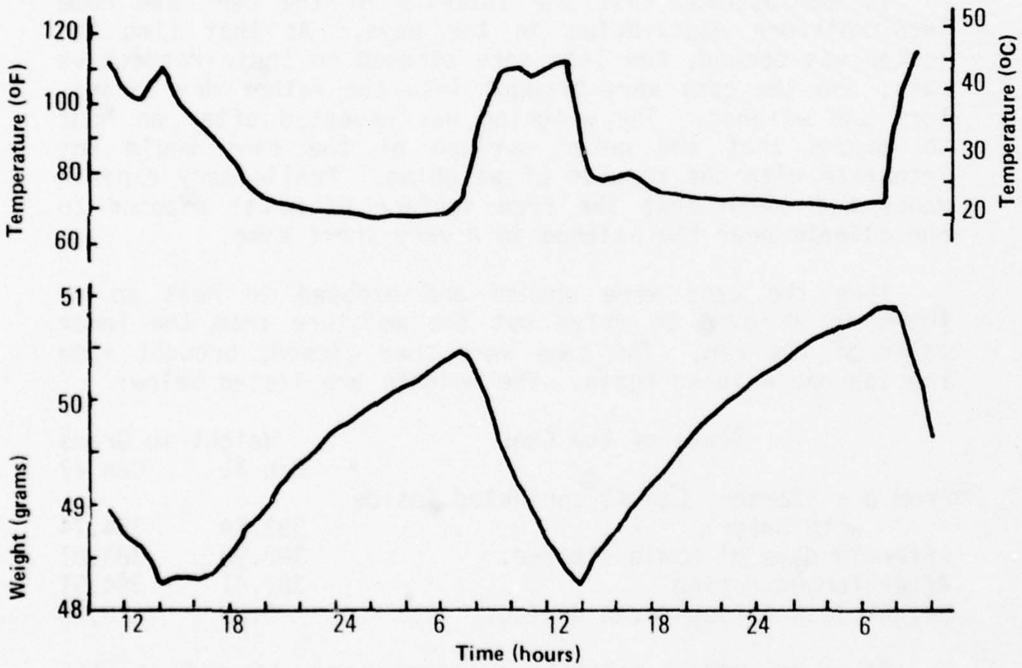


Figure 13. Diurnal Changes in Weight of Untreated Wood and CONEX Container Air Temperature (16-18 November 1976).

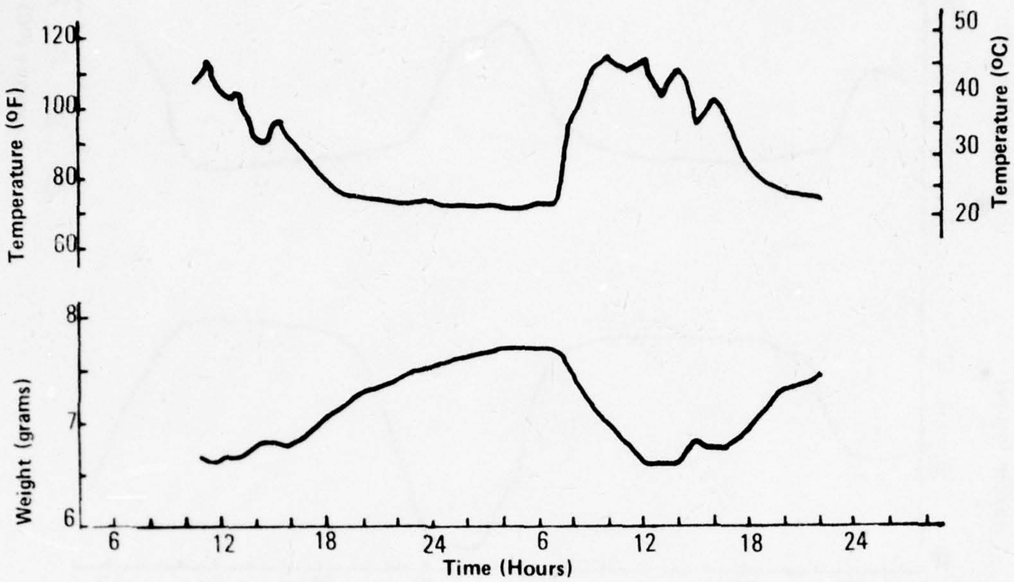


Figure 14. Diurnal Changes in Weight of Hygrograph Recording Paper and CONEX Container Air Temperature (22-23 November 1976)

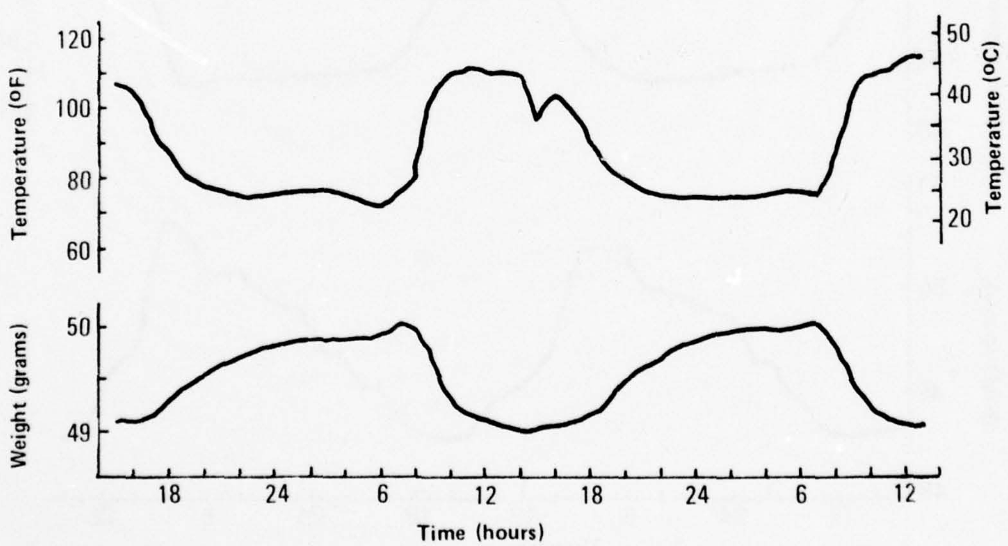


Figure 15. Diurnal Changes in Weight of Polyurethane Foam and CONEX Container Air Temperature (9-11 February 1977).

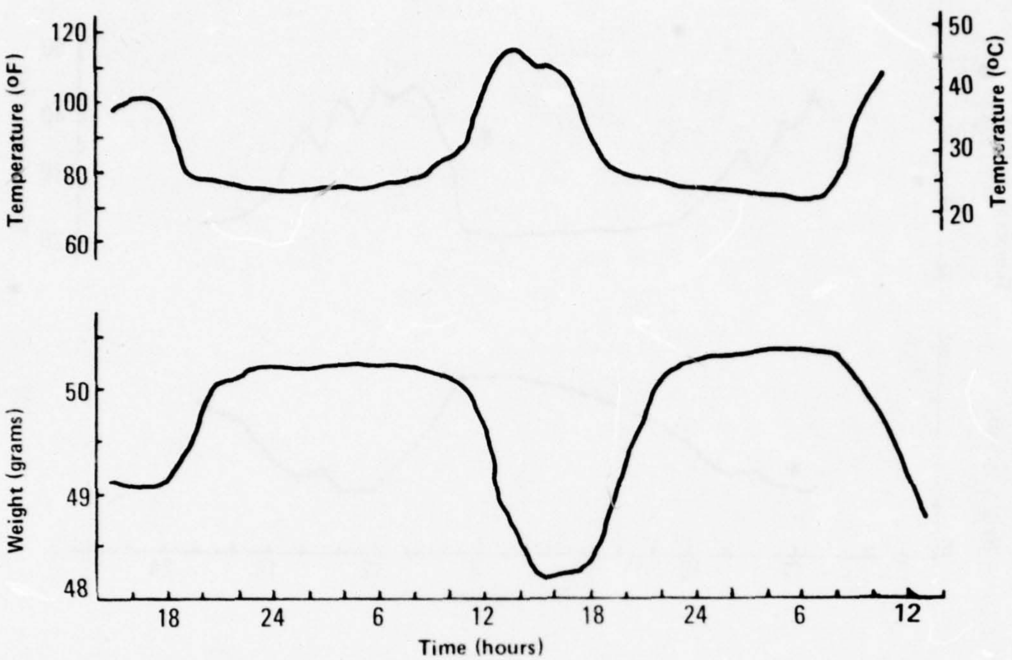


Figure 16 Diurnal Changes in Weight of Green Fiber Pad and CONEX Container Air Temperature (14-16 February 1977).

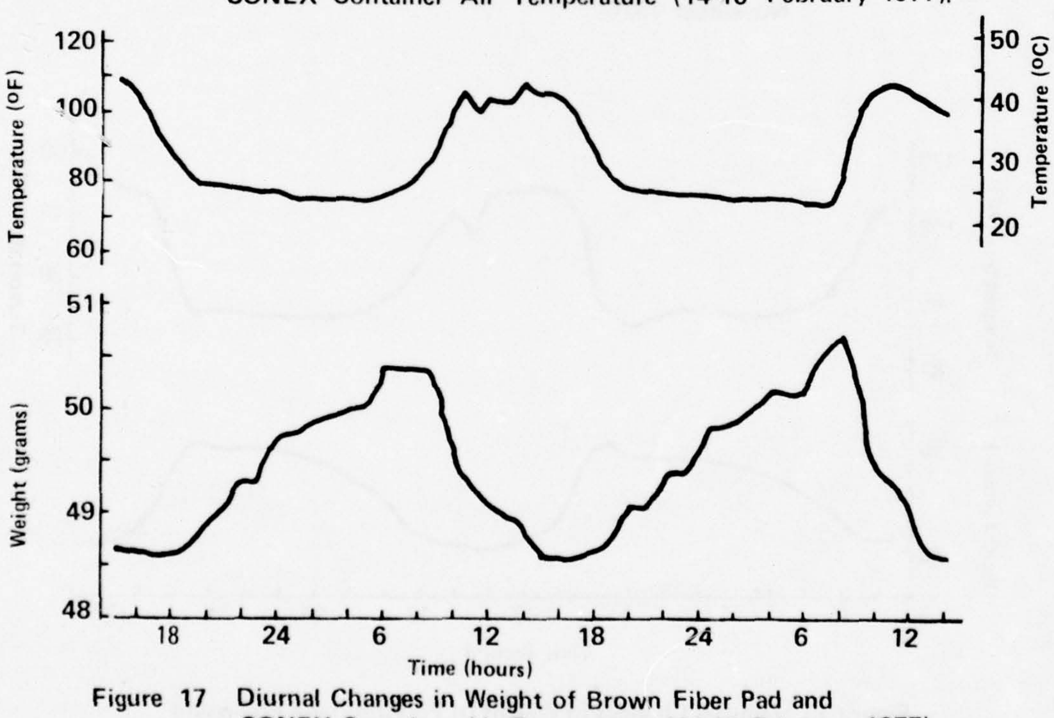


Figure 17 Diurnal Changes in Weight of Brown Fiber Pad and CONEX Container Air Temperature (16-18 February 1977).

2.7 Synopsis

The observations in the preceding paragraphs are summarized below by describing the probable processes and sequence of events influencing changes in moisture conditions in containers. The phenomenon applies to open air storage of a tightly sealed insulated container in a humid environment with ample sunshine. Such conditions can occur outside the tropics during the summertime at places such as the Gulf of Mexico.

Water in containers exists in the form of water vapor in the air within the container materials, and in the air surrounding them. It also may exist in liquid form on nonporous surfaces and in all porous materials within the container. When goods are placed into a container, additional water in and on the surfaces of the goods joins the water that is already in the container. The amount of water trapped after sealing the container depends on the physical properties of the materials and their surfaces, present ambient conditions, and the history of prior ambient conditions. After the container has been closed, the enclosed water begins to migrate to establish a state of equilibrium. This migration process is disturbed by each change in temperature.

In the morning, the container is heated by solar radiation. Initially, water on and in the container walls, especially that in heat insulation layers, begins to evaporate, increasing the absolute humidity of the air in the container. As the internal temperature of the container air increases, the absolute humidity increases as water in and on the surfaces of material and goods located inside the container evaporates. The amount and rate at which water from the contents and surfaces of the container is lost to the air in the container is dependent primarily upon the saturation deficit, i.e., the additional amount of water vapor needed to produce saturation at the current temperature and pressure, expressed in grams per cubic meter. The resulting amount of moisture remaining in the container is dependent upon the air-tightness of the container which controls the amount of air exchange with the ambient environment (the "breathing" phenomenon) during each daily heating and cooling cycle.

The process of moisture movement from container materials into the air during periods of rising temperature cannot be considered to be fully reversible when cooling occurs in mid-afternoon. The excess water of the warm air can be trapped in places other than where it originated. It can condense on surfaces when the temperature drops, or there may be materials in the container that desorb water but cannot readily absorb it.

With the daily repeating of the heating and cooling periods modified by the local weather conditions, harmful moisture accumulation can develop as a result of the daily redistribution of the water in the container. In addition, inhaling (in accordance with the "breathing" phenomenon) may provide additional moisture, which on a single day may be a very small amount but which may accumulate as the days go by.

In summary, temperature causes moisture to migrate from place to place within storage containers, frequently from a place where it is benign to places where it is harmful. Adverse combinations of temperature and moisture exist in containers to the extent that their cyclic changes may produce stresses on materials that can accelerate their rate of degradation. It is not advisable to test for temperature separately from moisture. Rather temperature and moisture should be monitored simultaneously under permanent consideration of their mutual influences on the degree and rate of deterioration of stored materials.

SECTION 3. APPENDIXES

APPENDIX A. METHODOLOGY INVESTIGATION DIRECTIVE AND PROPOSAL

DEPARTMENT OF THE ARMY
Headquarters, U.S. Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland 21005

(COPY)

AMSTE-ME 16 Jul 1975

SUBJECT: Directive, Moisture Conditions in Storage Shelters in Humid Environments, TRMS No. 9-CO-MIP-TR1-004

Commander
USA Tropic Test Center
ATTN: STETC-PD-M
Drawer 942
Fort Clayton, CZ

1. Reference TECOM Regulation 70-12, dated 1 June 1973.

2. This letter and attached STE Forms 1188 and 1189 (Incl 1) constitute a directive for the subject investigation under the TECOM Methodology Improvement Program 1U765602D625.

3. The Methodology Investigation Proposal at Inclosure 2 and the additional guidance provided at Inclosure 3 are the bases for headquarters approval of the subject investigation. Any deviation from the approved scope, procedures, and authorized cost will require approval from this headquarters prior to execution.

4. Special Instruction:

a. All reporting will be in consonance with paragraph 9 of this reference. The final report, when applicable, will be submitted to this headquarters, ATTN: AMSTE-ME, in consonance with Test Event 52, STE Form 1189.

b. Recommendations of new TOPs or revisions to existing TOPs will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.

c. The utilization of the funds provided to support the final investigation is governed by the rules of incremental funding.

d. The addressee will determine whether any classified information is involved and will assure that proper security measures are taken when appropriate.

e. Under the new approved management concept for the methodology program, responsibilities will be delegated as follows:

(1) The Methodology Improvement Directorate will be responsible for management of the methodology programs to include: administration; funding; development, justification and documentation of the programs; and all coordination not specifically designated to other organizations and/or individuals.

(2) The HQ technical responsibility, which include planning, executing and controlling of specific methodology investigations, will be assigned to the most qualified individuals within TECOM using the technical sponsor concept. Although the technical sponsor concept has been approved, the details of implementation have not been finalized as yet. You will be provided with the implementation plan when it becomes available.

f. The responsible individual within the Methodology Directorate is Mr. Albert Crowell, Autovon 283-2575, who is also the technical sponsor.

FOR THE COMMANDER:

/s/ Sidney Wise
/t/ SIDNEY WISE
Dir, Methodology Improvement

3 Incl
as

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(COPY)

March 1975

1. TITLE. Moisture Conditions in Storage Shelters in Humid Environments

2. INSTALLATION. U. S. Army Tropic Test Center
P.O. Drawer 942
Fort Clayton, Canal Zone

3. PRINCIPAL INVESTIGATOR. Wilfried H. Portig
Analysis Division
STETC-AD
313-285-3798

4. BACKGROUND.

a. Tropic service tests of shelters and enclosured items have revealed that current construction and testing technology do not provide the capability to predict the amount of thermal buildup and of damaging condensation. The use of breathers, desiccants and monitoring instrumentation is a matter of trial and error. The following examples demonstrate the need for developing methodologies for predetermining environmental effects inside shelters or enclosed materiel items stored or used in the humid tropics.

(1) Project No. 3EE MPQ 049 034, Forward Area Alert Radar System (FAAR). Extensive electronic and mechanical failures were experienced by the FAAR during brief storage in a humid tropic environment. More than 200 EPRs were submitted on the numerous malfunctions to the FAAR system. Fault analysis revealed that the electronic components were susceptible to moisture damage. The electronic modules were stored in closed shelters to protect them from the ambient environment.

(2) Project No. 3MI 000 HWK 005. This system, like the FAAR, experienced electronic mechanical failures during its brief tropic service test. Moisture problems with the launchers, oscillators, and high failure rate of the electrical components and modules severly reduced the reliability of the entire system. Moisture condensation in the FMTE necessitated a delay in operations until the system was dried, and the condensation resulted in extensive corrosion to the iron cores of the transformers in the oscilloscopes and fungal growth on cables.

(3) Project No. 7IEG 465 000 006, MILVAN. Test results in the Canal Zone show no statistically significant difference of the moisture conditions inside the vans with and without desiccant whereas in the drier conditions of previous tests in CONUS there was such a difference. There is no technology or methodology that explains this and that might have guided the developer.

(4) Project No. 6ES 945 SFB 001, Static Free Breather. Test results show that this item is inadequate for protection of electronic equipment over extended storage periods. As a consequence the developer suspended a large amount of desiccant in nylon sleeves inside the van. This made the shelter dry; however, the amount of desiccant was obviously expensive and space-consuming. Techniques to assess the correct amount were not available.

(5) Project No. 6ES 945 SFB 002, Medium Capacity Assemblages AN/TCC-69 and AN/TCC-117. After five months storage the built-in moisture indicators warned of high humidity or even wetness. The storage phase was interrupted, the assemblage opened, and extreme dryness was found. The humidity indicators had failed. The opening of the assemblages allowed the dry air to escape and to be replaced by humid ambient tropical air.

b. Physical laws predict that under certain conditions the hottest spots during daytime are the coolest spots at night. These conditions are typical for the humid tropics, and therefore investigation of thermal buildup has much in comon with investigation of nocturnal condensation. Moisture condenses out of the air on surfaces when the surface temperature drops below the dew point temperature which is approximately 75^{o}F in the Canal Zone. When the temperature of a surface is slightly above the dew point of the ambient air, it may become damp (depending on the surface characteristics) which may have even more detrimental effects than plain water.

5. <u>STATEMENT OF THE PROBLEM.</u> Testing experience has shown that many materiel items are damaged in the humid tropics through condensation of water on interior walls of enclosures and running or dripping from there onto water-sensitive parts. This occurs often in items with electrical and electronic components. Also considerable heat buildup can occur in enclosures and containers exposed unprotected to ambient, high solar radiation. The physical processes are well understood, but methods to predict these two phenomena are required.

6. <u>GOAL.</u>

a. The investigation will result in a procedure to locate from the outside of the materiel item those spots that are most likely to produce condensation at night on the inside.

b. the investigation will result in a mathematical model that assesses the probability that the spots singled out in the preceding paragraph, will actually become wet.

c. The investigation will enhance knowledge on thermal buildups on surfaces as well as of the air inside enclosures (shelters, boxes, cases, etc.) Surface temperatures up to 180°F and air temperatures inside shelters up to 160°F are known to occur in the Canal Zone.

7. DESCRIPTION OF INVESTIGATION.

a. Temperature measurements with infrared photography and contact sensors will be carried out using several freely exposed items of shelter-like construction. Mathematical modeling wll relate these temperature measurements to constructional characteristics of the item, to the moisture content of the inside air, and in the case of desiccant or a breather--to the changes of moisture content. Wetness of surface will be checked before sunrise, i.e. before evaporation takes place due to rise of temperature.

b. Checks of wetness inside a test item are not appropriate or are even impossible during normal testing procedures because each check is connected with an involuntary exchange of the inside air. This investigation aims at predicting the existence or nonexistence of the possibility that wetness develops through condensation. This prediction may be sufficient to either reduce the testing period or to reduce the number of test phases. It also may lead to recommended constructional alterations such that water will drain away from equipment components and has the opportunity to evaporate without causing damage. Mathematical modeling will indicate how the heat loss of the inner surface can be reduced to decrease the probability of condensation.

8. JUSTIFICATION.

a. Association with mission. A vital area of emphasis in TTC's overview statement is the need for developing accurate and reliable measures to the test microenvironment inside closed storage shelters. Failure to fund this investigation will deny fulfillment of a significant data acquisition requirement in tests conducted in storage shelters.

b. Present capability, limitations, improvement and impact of test if not approved. The present state of the art confines tester and developer to guess if and what damage may occur and then to wait and see what actually happens. This waste of time, and, in the case of damage of material, will continue to be substantial until the guess be replaced by a probability calulation.

Moisture Conditions in Storage Shelters in Humid Environments-Continued

c. Dollar Savings. Savings in future testing will result through elimination of retest of shelters, reduction in equipment failure due to moisture condensation, and man-hours required for monitoring of the visual indicators.

d. Workload. Over the past years TTC has experienced more than 30 of this type. The anticipated future workload is 49. Examples of test items anticipated for testing are:

	FY	76	77	78	79	80
Tank, Collapsible, Fabric, POL		IP	IP	IP	IP	
MILVAN		ED				
Propellants, Prediction of Life		PI	PI	PI	PI	PI
Modular, Collective, Protective		ES				
Tent, Combat				DT		

e. Association with Requirements Documents. This investigation supports all ROC Documents pertaining to enclosure testing in climatic categories 1-8 as defined in AR 70-38.

f. Others. This investigation is being conducted to provide a necessary nonexistent test capability.

9. RESOURCES.

a. Financial.

Dollars (Thousands)

FY 76

	in-house	out of house
Personnel Compensation	11.1	
Travel	1.0	
Contractual Support		10.0
Consultants & Other Svcs		
Materials & Supplies	4.9	
Equipment	7.5	
G&A Cost	9.8	
Subtotals	34.3	10.0
FY Totals	44.3	

b. Explanation of Cost Categories

(1) Personnel Compensation. N/A

(2) Travel. N/A

(3) Contractual Support. Contract support will provide a field operation capability.

(4) Consultant or other Services. N/A

(5) Materials and Supplies. N/A

(6) Equipment.

50 thermocouples with connection	$50 each
Recorders for thermocouples at no cost from U.S. Army Meteorological Team Canal Zone	
Movie Camera, infrared, with accessories	$3000
2 - Instrumented Storage Shelters	$2000

(7) G&A Costs. G&A costs are computed at the rate of $11.50 per direct labor man-hour. This rate, provided by TTC Budget Office, includes overhead and host-tenant agreement cost.

c. Obligation Plan.

	FQ	1	2	3	4	TOTAL
Obligation Rate (Thousands)				37.0	7.3	44.3

d. In-house Personnel

(1)

		FY 76		
		Man Hours		
	Number	Required	Available	Required
Rsch Meteorologist GS-1340	1	400	400	700
Elec Engr GS-0855	1	100	100	175
Mechanical Engr GS-0830	1	250	250	440
OR/SA GS-1515	1	100	100	175
		850	850	1,490

(2) Resolution of non-available personnel. N/A

10. INVESTIGATION SCHEDULE.

	FY 76												FY 77		
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
In-house									-	-	-	-	-	-	R
Contract									A	-	-	-	-	-	

11. ASSOCIATION WITH TOP PROGRAM. None

/s/Arnold M. Sargeant
/t/ARNOLD M. SARGEANT
COL, AR
Commanding

(END COPY)

APPENDIX B. DATA: MEAN HOURLY TEMPERATURES, RELATIVE HUMIDITIES, AND ABSOLUTE HUMIDITIES

Table B-1. Mean Hourly Air Temperatures (°C) in Container A

TIME (EST)	Phase:	Dry Season Open Site I	II*	Forest Site III	IV*	Rainy Season Forest Site V	VI*	Open Site VII	VIII*
01		20.7	24.1	23.4	24.6	23.2	23.3	24.2	23.6
02		20.4	23.9	23.2	24.3	23.1	23.1	24.1	23.5
03		20.1	23.5	22.7	24.0	22.8	23.1	24.1	23.3
04		19.8	23.3	22.6	23.8	22.6	23.0	24.0	23.1
05		19.5	22.9	21.9	23.6	22.3	22.9	23.9	23.0
06		19.2	22.7	21.7	23.5	22.3	22.9	23.8	22.9
07		19.3	22.4	22.5	23.3	22.4	23.0	24.0	23.2
08		21.5	23.7	22.5	23.8	23.0	23.5	25.3	24.7
09		27.4	27.9	23.8	24.7	24.2	24.4	27.5	26.6
10		30.6	30.5	26.5	26.1	25.5	25.4	30.1	28.8
11		33.0	32.0	28.3	27.2	26.6	26.3	32.0	30.8
12		34.3	33.1	29.4	27.8	27.7	27.2	32.4	32.1
13		35.1	33.7	30.0	28.4	28.2	27.5	31.4	33.1
14		35.6	34.5	30.7	28.9	28.4	27.2	31.4	32.4
15		35.8	34.9	31.4	28.7	27.7	26.3	31.0	32.2
16		35.2	34.7	30.8	28.7	27.4	26.1	30.4	31.5
17		34.1	34.1	29.7	28.6	26.9	25.9	28.7	30.6
18		31.7	32.6	28.5	28.2	26.2	25.6	27.5	29.1
19		27.9	29.7	27.2	27.5	25.5	25.3	26.3	27.4
20		25.5	27.8	26.1	26.8	24.9	24.7	25.4	26.0
21		23.7	26.5	25.4	26.0	24.5	24.4	25.1	25.1
22		22.9	25.6	24.8	25.7	24.1	24.2	24.8	24.6
23		21.8	25.0	24.1	25.0	23.8	24.1	24.5	24.0
24		21.1	24.6	23.9	24.8	23.6	23.8	24.4	23.7
Daily Mean		26.5	28.1	25.9	26.0	24.9	24.7	26.9	26.9

* Container was filled with cardboard boxes.

Table B-2. Mean Hourly Air Temperatures (°C) in Container B

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		20.8	24.2	23.5	24.8	23.4	24.0	23.9	23.4
02		20.3	24.0	23.1	24.5	23.3	23.7	23.9	23.3
03		20.1	23.6	22.8	24.2	23.0	23.6	23.7	23.1
04		19.7	23.2	22.3	23.9	22.7	23.6	23.7	22.9
05		19.5	23.0	22.0	23.8	22.6	23.6	23.6	22.8
06		19.3	22.6	21.5	23.6	22.4	23.5	23.5	22.8
07		19.4	22.4	21.6	23.6	22.4	23.4	23.6	22.9
08		20.0	22.7	21.7	23.7	22.9	23.7	24.9	24.1
09		24.9	26.1	23.0	24.4	23.9	24.1	27.3	26.9
10		29.9	29.9	25.4	25.5	25.2	24.7	30.4	29.2
11		33.3	32.1	27.4	26.7	26.6	25.5	32.9	31.1
12		35.1	33.6	28.9	27.8	27.7	26.3	34.0	32.6
13		36.1	34.4	29.8	28.8	28.4	26.8	33.6	33.7
14		36.5	35.0	30.6	29.2	28.8	27.1	33.4	33.7
15		36.7	35.1	31.2	28.9	28.6	26.6	33.3	33.4
16		35.8	34.9	31.0	29.1	28.3	26.6	31.7	32.9
17		34.2	34.1	30.1	29.0	27.7	26.2	29.7	31.9
18		31.8	32.4	28.7	28.5	27.0	26.0	28.1	30.3
19		28.4	30.0	27.6	27.9	26.2	25.6	27.0	28.2
20		25.8	28.0	26.4	27.1	25.5	25.5	25.7	26.7
21		23.8	26.6	25.5	26.4	24.9	25.1	25.0	25.4
22		22.8	25.7	24.8	25.8	24.6	24.7	24.5	24.9
23		21.9	25.0	24.2	25.2	24.0	24.6	24.3	24.1
24		21.2	24.4	23.8	24.9	23.8	24.5	24.1	23.7
Daily Mean		26.6	28.0	25.7	26.1	25.2	25.0	27.3	27.2

* Container was filled with cardboard boxes.

Table B-3. Mean Hourly Air Temperatures (^{o}C) in Container C

TIME (EST) Phase:	Dry Season Open Site I	II*	Forest Site III	IV*	Rainy Season Forest Site V	VI*	Open Site VII	VIII*
01	20.4	23.9	22.9	24.2	23.0	23.2	23.5	23.2
02	19.8	23.7	22.6	23.9	22.9	23.0	23.6	23.2
03	20.0	23.3	22.4	23.8	22.5	22.9	23.7	23.1
04	19.8	23.0	21.8	23.4	22.2	22.8	23.6	22.8
05	19.5	22.7	21.3	23.4	22.1	22.7	23.4	22.8
06	19.4	22.6	21.0	23.2	22.0	22.9	23.3	22.8
07	19.6	22.6	21.7	23.2	22.5	23.0	24.4	23.9
08	28.0	30.1	24.2	24.6	24.1	24.0	29.2	28.3
09	35.9	36.6	26.8	26.4	25.9	25.4	33.6	31.7
10	37.7	38.2	29.0	28.2	27.9	26.6	35.7	35.3
11	40.4	39.2	31.1	29.8	28.9	27.9	38.6	36.6
12	40.9	40.2	31.8	30.7	29.8	28.3	38.0	38.4
13	41.2	40.5	32.2	31.5	29.8	28.1	36.6	39.4
14	41.9	41.3	33.4	32.2	29.6	26.9	37.6	37.7
15	41.8	41.2	33.1	31.2	28.7	25.8	34.9	36.9
16	39.5	40.5	32.2	31.1	28.2	25.9	32.3	35.7
17	37.8	38.6	30.4	30.1	27.1	25.7	29.2	33.3
18	30.9	33.8	28.3	28.8	26.1	25.2	27.3	29.9
19	25.8	28.9	26.4	27.7	25.1	24.7	25.2	27.4
20	23.7	26.9	25.3	26.5	24.6	24.3	24.4	25.1
21	22.7	25.6	24.6	25.7	23.9	24.1	24.2	24.4
22	21.8	24.8	23.9	25.1	23.7	23.8	24.2	24.0
23	21.2	24.5	23.6	24.6	23.5	23.7	23.6	23.6
24	20.9	24.1	23.2	24.4	23.2	23.7	23.5	23.3
Daily Mean	28.8	30.7	26.4	26.8	25.3	24.8	28.4	28.9

* Container was filled with cardboard boxes.

Table B-4. Mean Hourly Air Temperatures (^{o}C) in Container D

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		20.8	24.4	23.1	24.4	23.1	23.5	23.3	22.8
02		20.4	24.0	22.7	24.2	22.9	23.3	23.3	23.3
03		20.0	23.7	22.3	23.9	22.7	23.3	23.4	23.9
04		19.8	23.4	21.9	23.8	22.3	23.2	23.4	23.3
05		19.8	23.1	21.6	23.6	22.1	22.9	23.3	22.8
06		19.7	23.0	21.1	23.5	21.9	23.1	23.2	22.8
07		19.6	22.9	21.7	23.3	22.2	23.2	24.1	23.3
08		23.6	25.1	22.7	23.9	23.2	23.6	28.5	27.2
09		30.7	30.4	24.9	25.1	24.7	24.6	32.6	28.3
10		34.3	33.3	27.1	26.3	26.6	25.6	35.9	28.9
11		37.2	34.8	29.2	28.0	27.8	26.8	36.3	29.4
12		38.3	36.0	30.7	29.2	28.8	27.5	36.5	31.1
13		39.2	36.3	31.6	30.0	29.1	27.7	34.6	33.3
14		39.9	37.2	32.2	30.6	28.8	27.5	35.2	33.9
15		40.1	37.3	32.7	30.2	27.7	26.5	34.8	35.0
16		38.9	37.0	32.2	30.2	27.6	26.1	31.0	34.4
17		37.2	36.0	30.8	30.0	26.6	26.0	28.1	33.1
18		33.1	34.6	29.0	29.0	25.8	25.8	26.6	30.3
19		27.0	30.1	27.0	28.1	24.9	25.3	24.9	27.5
20		24.7	27.6	25.9	27.1	24.4	24.8	24.2	25.3
21		23.4	26.1	25.0	26.2	23.8	24.6	24.2	24.4
22		22.4	25.4	24.2	25.6	23.9	24.3	24.0	24.4
23		21.7	25.0	23.8	25.0	23.6	24.2	23.8	23.9
24		21.2	24.6	23.6	24.7	23.3	24.0	23.6	23.9
Daily Mean		28.0	29.2	25.3	26.5	24.9	24.9	27.9	27.4

* Container C, in which container D was placed, was filled with cardboard boxes.

Table B-5. Seasonal Mean Hourly Air Temperature (°C)

Time (EST)	Dry Season (Phases I-IV) Container A	B	C	D	Ambient Air	Rainy Season (Phases V-VIII) Container A	B	C	D	Ambient Air
01	23.2	23.3	22.9	23.2	22.7	23.6	23.7	23.2	23.2	23.1
02	22.9	23.0	22.5	22.8	22.3	23.5	23.6	23.2	23.2	23.0
03	22.6	22.7	22.4	22.5	22.1	23.3	23.4	23.0	23.3	22.8
04	22.4	22.3	22.0	22.2	21.7	23.2	23.2	22.9	23.1	22.8
05	22.0	22.1	21.7	22.0	21.5	23.0	23.1	22.7	22.8	22.7
06	21.8	21.7	21.6	21.8	21.3	23.0	23.0	22.7	22.7	22.7
07	21.9	21.7	21.8	21.9	21.6	23.2	23.1	23.4	23.2	23.2
08	22.9	22.0	26.7	23.8	24.8	24.1	23.9	26.4	25.6	24.7
09	26.0	24.6	31.4	27.8	27.2	25.7	25.5	29.2	27.6	26.1
10	28.4	27.7	33.3	30.3	29.1	27.4	27.4	31.4	29.2	27.4
11	30.1	29.9	35.1	32.3	30.3	28.9	29.0	33.0	30.1	28.4
12	31.2	31.4	35.9	33.5	31.0	29.9	30.1	33.6	31.0	29.2
13	31.8	32.3	36.4	34.3	31.3	30.0	30.6	33.5	31.2	28.9
14	32.4	32.8	37.2	35.0	31.4	29.9	30.8	32.9	31.3	27.9
15	32.7	33.0	36.9	35.1	31.1	29.3	30.5	31.6	31.0	27.2
16	32.3	32.7	35.8	34.6	30.4	28.9	29.8	30.5	29.8	26.8
17	31.6	31.8	34.2	33.5	29.2	28.0	28.9	28.8	28.4	26.2
18	30.2	30.4	30.5	31.4	27.3	27.1	27.9	27.1	27.1	25.6
19	28.1	28.4	27.2	28.0	25.8	26.1	26.7	25.6	25.6	24.7
20	26.6	26.9	25.6	26.3	24.8	25.2	25.8	24.6	24.7	24.2
21	25.4	25.6	24.6	25.2	24.1	24.8	25.1	24.2	24.2	23.9
22	24.7	24.8	23.9	24.4	23.4	24.4	24.7	23.9	24.2	23.7
23	24.0	24.1	23.5	23.9	23.1	24.1	24.3	23.6	23.8	23.5
24	23.6	23.6	23.1	23.5	22.9	23.9	24.0	23.4	23.7	23.4
Daily Mean	26.6	26.6	28.2	27.5	25.8	25.8	26.2	26.9	26.3	25.1

Table B-6. Mean Hourly Air Temperatures (^{o}C) at Open and Forest Sites

Time (EST)	Open Site (Phases I, II, VII, VIII) Container A	B	C	D	Ambient Air	Forest Site (Phases III-VI) Container A	B	C	D	Ambient Air
01	23.2	23.1	22.8	22.8	22.8	23.6	23.9	23.3	23.5	22.9
02	23.0	22.9	22.6	22.8	22.7	23.4	23.7	23.1	23.3	22.7
03	22.7	22.6	22.5	22.7	22.5	23.1	23.4	22.9	23.1	22.4
04	22.6	22.4	22.3	22.5	22.3	23.0	23.1	22.6	22.8	22.2
05	22.3	22.2	22.1	22.3	22.2	22.7	23.0	22.4	22.5	22.0
06	22.2	22.0	22.0	22.2	22.1	22.6	22.7	22.3	22.4	22.0
07	22.2	22.1	22.6	22.5	22.4	22.8	22.7	22.6	22.6	22.3
08	23.8	23.0	28.9	26.1	25.2	23.2	23.0	24.2	23.3	24.2
09	27.4	26.3	34.5	30.5	27.4	24.3	23.8	26.1	24.8	26.0
10	30.0	29.9	36.7	33.1	28.8	25.9	25.2	27.9	26.4	27.7
11	31.9	32.4	38.7	34.4	29.6	27.1	26.5	29.4	27.9	29.1
12	33.0	33.8	39.4	35.5	30.5	28.0	27.7	30.2	29.0	29.7
13	33.3	34.4	39.5	35.9	30.6	28.5	28.4	30.4	29.6	29.7
14	33.5	34.6	39.6	36.5	30.4	28.8	28.9	30.5	29.8	28.9
15	33.5	34.6	38.7	36.8	29.8	28.5	28.8	29.7	29.2	28.4
16	32.9	33.8	37.0	35.3	29.1	28.3	28.7	29.4	29.0	28.1
17	31.8	32.5	34.7	33.6	28.2	27.8	28.2	28.3	28.3	27.2
18	30.2	30.7	30.5	31.1	26.8	27.1	27.6	27.1	27.4	26.1
19	27.8	28.4	26.8	27.4	25.3	26.4	26.8	26.0	26.3	25.2
20	26.2	26.6	25.0	27.4	24.6	25.6	26.1	25.2	25.6	24.4
21	25.1	25.2	24.2	24.5	24.1	25.1	25.5	24.6	24.9	23.9
22	24.5	24.5	23.7	24.1	23.6	24.7	25.0	24.1	24.5	23.6
23	23.8	23.8	23.2	23.6	23.3	24.2	24.5	23.9	24.1	23.3
24	23.4	23.4	22.9	23.3	23.1	24.0	24.2	23.6	23.9	23.2
Daily Mean	27.1	27.3	29.2	28.1	25.7	25.4	25.5	25.8	25.6	25.2

Table B-7. Mean Hourly Air Temperatures (^{o}C) in Empty and Filled Containers

Time (EST)	Empty (Phases I, III, V, VII) Container A	B	C	D	Ambient Air	Filled with Cartons (Phases II, IV, VI, VIII) Container A	B	C	D*	Ambient Air
01	22.9	22.9	22.5	22.6	22.4	23.9	24.1	23.6	23.8	23.3
02	22.7	22.6	22.2	22.3	22.3	23.7	23.9	23.5	23.7	23.1
03	22.4	22.4	22.1	22.1	22.1	23.5	23.6	23.2	23.7	22.8
04	22.2	22.1	21.8	21.9	21.8	23.3	23.4	23.0	23.4	22.7
05	21.9	21.9	21.6	21.7	21.6	23.1	23.3	22.9	23.1	22.6
06	21.8	21.7	21.4	21.5	21.5	23.0	23.1	22.9	23.1	22.6
07	22.1	21.7	22.0	21.9	21.8	23.0	23.1	23.2	23.2	22.9
08	23.1	22.4	26.4	24.5	24.4	23.9	23.6	26.8	25.0	25.1
09	25.8	24.8	30.6	28.2	26.6	25.9	25.4	30.0	27.1	26.8
10	28.2	27.7	32.6	31.0	28.3	27.7	27.3	32.1	28.5	28.2
11	29.9	30.0	34.7	32.6	29.7	29.1	28.8	33.4	29.7	29.0
12	31.0	31.4	35.1	33.6	30.2	30.1	30.1	34.4	30.9	30.0
13	31.2	31.9	35.1	33.6	30.2	30.7	31.0	34.9	31.8	30.1
14	31.5	32.3	35.6	34.0	30.0	30.7	31.2	34.5	32.3	29.3
15	31.5	32.4	34.6	33.8	29.6	30.5	31.0	33.8	32.2	28.7
16	31.0	31.7	33.0	32.4	28.7	30.2	30.8	33.3	31.9	28.4
17	29.8	30.4	31.1	30.7	27.6	29.8	30.3	31.9	31.3	27.8
18	28.5	28.9	28.2	28.6	26.4	28.9	29.3	29.4	29.9	26.5
19	26.7	27.3	25.6	25.9	25.1	27.5	27.9	27.2	27.7	25.4
20	25.5	25.9	24.5	24.8	24.4	26.3	26.8	25.7	26.2	24.6
21	24.7	24.8	23.9	24.1	23.9	25.5	25.9	25.0	25.2	24.1
22	24.1	24.2	23.4	23.6	23.4	25.0	25.3	24.4	24.9	23.7
23	23.5	23.6	23.0	23.2	23.1	24.5	24.7	24.1	24.5	23.6
24	23.2	23.2	22.7	22.9	22.9	24.2	24.4	23.8	24.3	23.4
Daily Mean	26.0	26.2	27.2	26.7	25.3	26.4	26.6	27.8	27.0	25.6

* Container was always empty. However, container C, in which container D was placed, was filled with cardboard boxes.

Table B-8. Mean Hourly Air Temperatures (^{o}C)
Average of All Eight Phases

Time (EST)	Container A	B	C	D	Ambient Air
01	23.4	23.5	23.0	23.2	22.9
02	23.2	23.3	22.8	23.0	22.7
03	22.9	23.0	22.7	22.9	22.4
04	22.8	22.7	22.4	22.7	22.2
05	22.5	22.6	22.2	22.4	22.1
06	22.4	22.4	22.2	22.3	22.0
07	22.5	22.4	22.6	22.5	22.4
08	23.5	23.0	26.6	24.7	24.7
09	25.8	25.1	30.3	27.7	26.7
10	27.9	27.5	32.3	29.8	28.3
11	29.5	29.4	34.1	31.2	29.4
12	30.5	30.7	34.8	32.3	30.1
13	30.9	31.4	35.0	32.7	30.1
14	31.1	31.8	35.1	33.2	29.7
15	31.0	31.7	34.2	33.0	29.1
16	30.6	31.3	33.2	32.2	28.6
17	29.8	30.4	31.5	31.0	27.7
18	28.7	29.1	28.8	29.3	26.4
19	27.1	27.6	26.4	26.8	25.2
20	25.9	26.4	25.1	25.5	24.5
21	25.1	25.3	24.4	24.7	24.0
22	24.6	24.7	23.9	24.3	23.6
23	24.0	24.2	23.5	23.9	23.3
24	23.7	23.8	23.3	23.6	23.1
Daily Mean	26.2	26.4	27.5	26.9	25.5

Table B-9. Mean Hourly Relative Humidities (%) in Container A

TIME (EST)		Dry Season				Rainy Season			
		Open Site		Forest Site		Forest Site		Open Site	
	Phase:	I	II*	III	IV*	V	VI*	VII	VIII*
01		81.1	60.1	74.2	69.0	90.3	91.1	96.2	79.6
02		82.8	61.5	74.6	69.3	90.6	91.2	96.2	80.4
03		84.8	62.6	75.3	69.7	91.0	91.2	96.5	81.1
04		84.6	63.5	76.2	70.1	91.2	91.3	96.6	81.5
05		85.1	64.2	76.8	70.5	91.5	91.4	96.6	82.6
06		85.8	65.5	77.7	71.2	91.6	91.4	96.5	83.2
07		86.3	67.2	78.7	71.1	91.8	92.0	95.4	84.8
08		79.3	71.1	79.5	71.5	91.6	94.8	91.7	86.7
09		60.8	70.7	75.0	74.1	88.9	96.6	82.4	86.1
10		50.9	57.9	67.5	74.1	84.7	96.5	74.3	84.0
11		43.1	52.6	63.7	73.4	80.5	95.5	68.3	80.2
12		39.8	49.1	57.8	71.6	77.7	93.5	69.0	76.2
13		37.2	46.1	54.9	70.1	76.2	91.1	72.8	71.7
14		36.3	44.9	52.1	68.0	78.0	90.0	71.7	68.9
15		35.9	43.6	51.8	66.2	78.5	89.5	72.1	68.5
16		37.1	42.8	53.2	65.8	79.2	89.5	74.4	68.6
17		39.1	43.0	54.4	65.0	81.4	90.3	79.3	70.5
18		44.0	44.0	58.0	64.8	83.2	90.3	84.2	72.1
19		53.7	47.2	62.2	65.3	85.0	90.7	91.1	72.6
20		61.0	49.9	65.8	66.2	86.6	90.9	93.7	73.4
21		68.4	52.6	69.0	66.7	87.7	90.8	95.3	74.7
22		72.2	54.9	70.7	67.2	88.3	91.1	95.4	75.8
23		76.2	57.1	72.0	68.1	88.8	91.5	96.0	77.0
24		78.9	58.7	73.0	68.5	89.5	91.9	96.3	78.8
Daily Mean		62.7	55.5	67.3	69.1	86.0	91.8	86.8	77.4

* Container was filled with cardboard boxes.

Table B-10. Mean Hourly Relative Humidities (%) in Container B

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		65.9	57.7	78.8	72.4	85.6	83.7	87.2	75.8
02		66.9	58.3	79.4	73.1	85.8	83.8	87.7	76.4
03		67.8	58.7	79.8	73.5	86.3	83.8	88.0	77.1
04		68.4	59.0	80.4	73.7	86.5	83.9	88.2	77.4
05		69.1	59.3	81.5	74.0	87.0	84.2	88.5	78.0
06		69.5	59.4	82.2	74.3	87.1	84.2	88.5	78.5
07		70.4	60.8	83.8	74.3	87.3	84.3	89.1	79.3
08		75.6	62.9	88.5	77.1	87.9	84.4	88.6	80.8
09		67.7	66.8	83.5	78.5	88.6	85.0	84.4	82.7
10		58.6	64.4	73.0	76.0	87.5	85.8	78.8	83.1
11		48.6	61.3	64.6	74.3	83.5	86.4	72.2	81.9
12		44.4	59.1	61.9	72.7	80.2	86.7	69.7	79.9
13		42.1	57.4	57.7	71.0	76.5	86.4	71.5	77.5
14		41.1	56.3	55.5	69.4	74.8	85.4	71.1	74.5
15		40.7	55.1	54.8	69.1	75.1	84.5	70.7	73.2
16		41.8	54.8	55.1	68.8	75.9	84.0	72.5	72.9
17		43.5	54.5	57.6	69.3	77.2	83.7	75.0	72.2
18		46.0	53.6	60.6	69.8	78.6	83.7	78.3	72.5
19		50.8	53.7	65.5	70.2	80.0	83.8	81.0	72.6
20		54.3	54.1	69.0	70.4	81.2	83.8	82.6	73.0
21		57.9	54.8	72.7	71.4	82.3	84.0	84.1	73.6
22		60.3	55.7	75.0	71.7	83.1	84.0	84.9	74.3
23		62.6	56.7	76.0	71.8	83.9	84.1	85.7	74.8
24		64.4	57.2	77.8	71.7	84.6	84.2	86.3	75.3
Daily Mean		57.4	58.0	71.4	72.4	82.8	84.5	81.4	76.6

* Container was filled with cardboard boxes.

Table B-11. Mean Hourly Relative Humidities (%) in Container C

TIME (EST)		Dry Season				Rainy Season			
		Open Site		Forest Site		Forest Site		Open Site	
	Phase:	I	II*	III	IV*	V	VI*	VII	VIII*
01		98.2	61.4	83.7	80.7	95.0	87.4	93.9	80.0
02		98.8	62.8	85.1	81.7	95.2	87.6	93.9	80.0
03		98.8	63.9	86.9	81.9	95.4	87.9	94.0	80.7
04		98.9	64.3	88.1	82.3	95.6	88.6	94.1	81.1
05		99.7	65.4	89.3	83.1	95.8	88.8	94.4	81.8
06		99.6	66.5	89.6	83.3	95.9	88.7	94.4	82.4
07		97.6	69.7	89.2	85.5	96.1	90.9	83.9	80.7
08		70.3	62.1	83.5	85.1	93.5	93.5	66.7	77.3
09		48.0	52.3	68.5	79.0	83.8	91.9	53.3	73.7
10		41.2	46.8	56.3	72.3	75.1	88.9	46.9	69.9
11		33.7	41.5	47.8	67.3	68.9	86.3	44.0	67.8
12		31.9	38.6	45.7	66.2	67.2	84.3	50.6	64.5
13		31.3	35.9	43.7	64.0	65.9	82.3	53.0	60.1
14		31.1	34.5	42.3	62.3	68.7	80.5	50.0	56.7
15		32.0	33.7	42.0	61.4	73.9	81.3	55.9	57.1
16		34.0	33.7	43.9	61.3	74.7	82.5	67.5	58.4
17		39.3	35.0	47.7	63.4	79.2	83.9	77.3	60.9
18		51.3	38.8	53.1	67.0	82.1	84.9	85.7	76.2
19		72.9	45.2	63.1	71.4	86.5	85.6	90.9	70.9
20		84.6	49.1	69.5	73.6	89.1	86.2	91.5	72.9
21		92.8	52.3	75.3	75.5	91.3	86.9	92.9	75.1
22		95.9	54.3	78.6	77.1	92.5	87.3	93.2	76.3
23		97.1	57.4	80.6	78.5	93.6	88.0	93.5	77.3
24		97.7	60.1	82.4	79.7	94.6	88.3	93.8	78.3
Daily Mean		69.9	51.0	68.2	74.3	85.4	86.8	77.3	72.5

* Container was filled with cardboard boxes.

Table B-12. Mean Hourly Relative Humidities (%) in Container D

TIME (EST)	Phase:	Dry Season Open Site I	II*	Forest Site III	IV*	Rainy Season Forest Site V	VI*	Open Site VII	VIII*
01		54.4	50.7	69.8	68.8	67.9	80.9	94.0	89.0
02		54.8	50.7	69.2	68.8	67.9	80.9	94.2	87.0
03		55.1	50.7	69.2	68.8	68.0	80.8	94.2	86.5
04		55.9	50.7	69.2	68.8	68.0	80.8	94.8	86.5
05		55.9	50.7	69.2	68.8	68.0	80.8	94.8	87.0
06		56.1	50.7	69.2	68.8	68.0	80.8	94.8	87.0
07		55.5	50.8	69.2	68.8	68.2	80.8	87.0	86.0
08		51.1	48.8	68.5	68.3	68.0	80.2	82.3	80.0
09		48.7	46.2	67.8	68.1	67.0	79.7	75.3	80.0
10		49.0	46.5	67.5	67.9	66.1	79.0	71.7	79.5
11		47.6	47.2	66.0	67.6	65.8	78.7	75.3	80.0
12		47.6	47.3	66.5	67.7	65.8	79.0	77.3	79.0
13		47.9	47.4	66.2	67.6	65.6	79.2	75.3	75.0
14		47.6	47.7	67.0	67.6	66.2	80.3	75.7	74.5
15		47.8	47.8	68.2	67.7	67.0	80.7	79.3	73.5
16		48.6	48.2	67.8	67.8	67.4	80.9	85.0	74.5
17		49.2	48.6	68.4	67.9	67.7	80.9	88.5	76.0
18		51.9	49.1	68.8	68.2	67.7	81.0	90.5	81.0
19		53.7	50.8	69.2	68.4	67.8	81.1	92.0	85.0
20		53.9	51.0	69.4	68.5	68.0	81.1	92.2	87.5
21		54.0	51.1	69.5	68.8	68.2	81.1	92.5	88.0
22		54.0	51.1	69.5	68.8	68.3	81.1	92.5	86.0
23		54.2	51.0	69.5	68.8	68.7	81.1	93.0	86.5
24		54.3	50.7	69.5	68.8	68.9	81.1	93.8	85.5
Daily Mean		52.0	49.4	68.5	68.3	67.5	80.5	86.9	82.6

* Container C, in which Container D was placed, was filled with cardboard boxes.

Table B-13. Seasonal Mean Hourly Relative Humidities (%)

Time (EST)	Dry Season (Phases I-IV) Container A	B	C	D	Ambient Air	Rainy Season (Phases V-VIII) Container A	B	C	D	Ambient Air
01	71.1	68.7	81.0	60.9	86.3	89.3	83.1	89.1	83.0	96.9
02	72.0	69.4	82.1	60.9	88.2	89.6	83.4	89.2	82.5	96.5
03	72.9	69.9	82.9	61.0	89.6	89.9	83.8	89.5	82.4	97.2
04	73.6	70.4	83.4	61.2	90.4	90.1	84.0	89.8	82.5	97.4
05	74.1	71.0	84.4	61.2	90.9	90.5	84.4	90.2	82.7	97.3
06	75.0	71.4	84.8	61.2	90.8	90.7	84.6	90.3	82.7	97.2
07	75.8	72.3	85.5	61.1	91.3	91.0	85.0	87.9	80.5	97.4
08	75.3	76.0	75.3	59.2	80.2	91.2	85.4	82.7	77.6	93.3
09	70.2	74.1	61.9	57.7	68.9	88.5	85.2	75.7	75.5	87.1
10	62.6	68.0	54.1	57.7	59.0	84.9	83.8	70.2	74.1	81.2
11	58.2	62.2	47.6	57.1	54.1	81.1	81.0	66.7	75.0	77.6
12	54.6	59.5	45.6	57.3	51.0	79.1	79.1	66.6	75.3	75.0
13	52.1	57.0	43.7	57.3	48.8	77.9	78.0	65.3	73.8	75.8
14	50.3	55.6	42.6	57.5	49.4	77.1	76.4	64.0	74.2	79.2
15	49.4	54.9	42.3	57.6	49.6	77.1	75.9	67.0	75.1	82.1
16	49.7	55.1	43.2	58.1	52.0	77.9	76.4	70.7	77.0	84.3
17	50.4	56.2	46.3	58.5	55.9	80.4	77.0	75.3	78.3	85.8
18	52.7	57.5	52.5	59.5	63.4	82.5	78.3	82.2	80.1	88.3
19	57.1	60.0	63.2	60.5	71.6	84.8	79.4	83.5	81.5	91.2
20	60.7	61.9	69.2	60.7	76.4	86.1	80.1	84.9	82.2	93.5
21	64.2	64.2	74.0	60.9	81.5	87.1	81.0	86.5	82.5	94.4
22	66.2	65.7	76.4	60.9	83.4	87.6	81.6	87.3	82.0	95.7
23	68.3	66.8	78.4	60.9	84.8	88.3	82.1	88.1	82.3	96.0
24	69.8	67.8	80.0	60.8	85.8	89.1	82.6	88.7	82.6	96.2
Daily Mean	63.6	64.8	65.8	59.6	72.6	85.5	81.3	80.5	79.4	89.9

Table B-14. Mean Hourly Relative Humidities (%) at Open and Forest Sites

Time (EST)	Open Site (Phases I, II, VII, VIII) Container A	B	C	D	Ambient Air	Forest Site (Phases III-VI) Container A	B	C	D	Ambient Air
01	79.2	71.6	83.4	72.0	94.0	81.1	80.1	86.7	71.9	89.3
02	80.2	72.3	83.9	71.7	94.5	81.4	80.5	87.4	71.7	90.2
03	81.1	72.9	84.3	71.6	95.2	81.8	80.8	88.0	71.7	91.6
04	81.5	73.2	84.6	72.0	95.5	82.2	81.1	88.7	71.7	92.3
05	82.1	73.7	85.3	72.1	95.8	82.5	81.7	89.2	71.7	92.5
06	82.7	74.0	85.7	72.2	96.0	83.0	82.0	89.4	71.7	92.1
07	83.4	74.9	83.0	69.8	96.0	83.4	82.4	90.4	71.8	92.7
08	82.2	77.0	69.1	65.6	86.8	84.3	84.5	88.9	71.3	86.7
09	75.0	75.4	56.8	62.6	76.3	83.6	83.9	80.8	70.7	79.7
10	66.8	71.2	51.2	61.7	70.2	80.7	80.6	73.1	70.1	70.1
11	61.0	66.0	46.7	62.5	67.4	78.3	77.2	67.6	69.5	64.3
12	58.5	63.3	46.4	62.8	64.3	75.1	75.4	65.8	69.8	61.6
13	56.9	62.1	45.1	61.4	63.6	73.1	72.9	64.0	69.7	60.9
14	55.4	60.8	43.1	61.4	64.8	72.0	71.3	63.5	70.3	63.9
15	55.0	59.9	44.7	62.1	66.0	71.5	70.9	64.6	70.7	65.7
16	55.7	60.5	48.4	64.1	68.5	71.9	71.0	65.6	71.0	67.8
17	58.0	61.3	53.1	65.6	70.9	72.8	71.9	68.5	71.2	70.9
18	61.1	62.6	63.0	68.1	76.6	74.1	73.2	71.8	71.4	75.0
19	66.1	64.5	70.0	70.4	83.3	75.8	74.9	76.7	71.6	79.5
20	69.5	66.0	74.5	71.2	86.3	77.4	76.1	79.6	71.8	83.5
21	72.7	67.6	78.2	71.4	89.1	78.6	77.6	82.2	71.9	86.8
22	74.6	68.8	79.9	70.9	91.5	79.3	78.4	83.9	71.9	87.6
23	76.6	70.0	81.3	71.2	92.0	80.1	79.0	85.2	72.0	88.8
24	78.2	70.8	82.5	71.3	92.7	80.7	79.6	86.2	72.1	89.2
Daily Mean	70.6	68.4	67.7	67.7	82.4	78.5	77.8	78.7	71.2	80.1

Table B-15. Mean Hourly Relative Humidities (%) in Empty and Filled Containers

Time (EST)	Empty (Phases I, III, V, VII) Container A	B	C	D	Ambient Air	Filled with Cartons (Phases II, IV, VI, VIII) Container A	B	C	D*	Ambient Air
01	85.4	79.4	92.7	71.5	91.8	74.9	72.4	77.4	72.4	91.4
02	86.0	79.9	93.2	71.5	92.1	75.6	72.9	78.0	71.9	92.6
03	86.7	80.5	93.8	71.6	93.3	76.1	73.3	78.6	71.7	93.5
04	87.1	80.9	94.2	72.0	93.7	76.6	73.5	79.1	71.7	94.2
05	87.5	81.5	94.8	72.0	94.5	77.1	73.9	79.8	71.8	93.7
06	87.9	81.8	94.9	72.0	94.2	77.8	74.1	80.2	71.8	93.9
07	88.0	82.6	91.7	70.0	94.7	78.8	74.7	81.7	71.6	94.0
08	85.5	85.2	78.5	67.5	86.2	81.0	76.3	79.5	69.3	87.3
09	76.8	81.1	63.4	64.7	76.0	81.9	78.2	74.2	68.5	80.0
10	69.4	74.5	54.9	63.6	66.9	78.1	77.3	69.5	68.2	73.4
11	63.9	67.2	48.6	63.7	61.6	75.4	75.9	65.7	68.4	70.1
12	61.1	64.0	48.9	64.3	59.9	72.6	74.6	63.4	68.3	66.0
13	60.3	61.9	48.5	63.8	59.0	69.7	73.1	60.6	67.3	65.5
14	59.5	60.6	48.0	64.1	61.1	67.9	71.4	58.5	67.5	67.6
15	59.6	60.3	50.9	65.3	62.5	66.9	70.5	58.4	67.4	69.2
16	61.0	61.3	55.0	67.2	65.3	66.7	70.1	58.9	67.9	71.0
17	63.5	63.3	60.9	68.5	68.7	67.2	69.9	60.8	68.4	73.1
18	67.4	65.9	68.0	69.7	73.6	67.8	69.9	66.7	69.8	78.0
19	73.0	69.3	78.4	70.7	78.6	69.0	70.1	68.3	71.3	83.9
20	76.7	71.7	83.7	70.9	83.2	70.1	70.3	70.4	72.0	86.6
21	80.1	74.2	88.0	71.1	85.9	71.2	70.9	72.4	72.3	90.0
22	81.6	75.8	90.0	71.1	88.3	72.2	71.4	73.7	71.8	90.8
23	83.3	77.0	91.2	71.4	89.4	73.4	71.9	75.3	71.9	91.4
24	84.4	78.3	92.1	71.6	90.1	74.5	72.1	76.6	71.8	91.9
Daily Mean	75.7	73.3	75.2	68.7	79.6	73.4	72.9	71.2	70.2	82.9

* Container D was always empty. However, container C, in which container D was placed, was filled with carboard boxes.

Table B-16. Mean Hourly Relative Humidities (%)
Average of All Eight Phases

Time (EST)	Container A	B	C	D	Ambient Air
01	80.2	75.9	85.0	71.9	91.6
02	80.8	76.4	85.6	71.7	92.3
03	81.4	76.9	86.2	71.7	93.4
04	81.9	77.2	86.6	71.8	93.9
05	82.3	77.7	87.3	71.9	94.1
06	82.9	78.0	87.6	71.9	94.0
07	83.4	78.7	86.7	70.8	94.3
08	83.3	80.7	79.0	68.4	86.8
09	79.3	79.7	68.8	66.6	78.0
10	73.7	75.9	62.2	65.9	70.1
11	69.6	71.6	57.1	66.0	65.8
12	66.8	69.3	56.1	66.3	63.0
13	65.0	67.5	54.5	65.5	62.3
14	63.7	66.0	53.3	65.8	64.3
15	63.3	65.4	54.6	66.4	65.8
16	63.8	65.7	57.0	67.5	68.1
17	65.4	66.6	60.8	68.4	70.9
18	67.6	67.9	67.4	69.8	75.8
19	71.0	69.7	73.3	71.0	81.4
20	73.4	71.0	77.1	71.5	84.9
21	75.6	72.6	80.2	71.7	87.9
22	76.9	73.6	81.9	71.4	89.5
23	78.3	74.5	83.2	71.6	90.4
24	79.4	75.2	84.4	71.7	91.0
Daily Mean	74.5	73.1	73.2	69.5	81.2

Table B-17. Mean Hourly Absolute Humidities (g/m^3) in Container A

TIME (EST)		Dry Season				Rainy Season			
		Open Site		Forest Site		Forest Site		Open Site	
	Phase:	I	II*	III	IV*	V	VI*	VII	VIII*
01		14.6	13.3	15.7	15.6	18.8	19.2	21.2	16.9
02		14.6	13.5	15.5	15.4	18.8	19.0	21.1	17.0
03		14.6	13.4	15.3	15.4	18.6	19.0	21.1	17.0
04		14.5	13.4	15.2	15.1	18.4	18.9	21.1	16.8
05		14.3	13.2	14.9	15.1	18.1	18.9	20.9	16.9
06		14.2	13.3	15.1	15.2	18.1	18.8	20.9	16.9
07		14.6	13.2	15.2	15.0	18.3	19.0	20.9	17.6
08		15.1	15.2	15.8	15.4	19.0	20.2	21.6	19.7
09		16.0	16.6	15.9	16.9	19.8	21.7	21.7	21.8
10		16.0	18.6	16.5	18.3	20.1	22.8	22.4	23.9
11		15.3	18.3	17.1	19.1	20.4	23.7	22.8	25.5
12		15.0	17.9	16.5	19.4	20.9	24.5	23.5	26.0
13		14.7	17.1	16.5	19.9	21.2	24.1	23.5	25.6
14		14.7	17.2	16.2	19.5	21.9	23.5	23.1	23.9
15		14.7	17.0	16.6	18.9	21.1	22.4	23.0	23.5
16		14.6	16.5	16.8	18.7	21.0	22.0	22.9	22.5
17		14.6	16.1	16.2	18.5	20.9	21.9	22.3	22.0
18		14.7	15.3	16.3	17.9	20.7	21.6	22.3	20.9
19		14.7	14.2	16.3	17.5	20.2	21.3	22.5	19.1
20		14.5	13.5	16.2	17.0	19.9	20.7	22.0	17.8
21		14.8	13.3	16.4	16.4	19.7	20.3	22.0	17.3
22		14.8	13.2	16.1	16.2	19.4	20.2	21.4	17.0
23		14.7	13.2	15.8	15.8	19.1	20.2	21.2	16.8
24		14.7	13.3	15.9	15.6	19.1	19.9	21.2	16.8
Daily Mean		14.8	15.0	16.0	17.0	19.7	21.0	21.9	20.0

* Container was filled with cardboard boxes.

Table B-18. Mean Hourly Absolute Humidities (g/m^3) in Container B

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		12.1	12.8	16.8	16.5	18.0	18.2	18.9	16.0
02		11.9	12.8	16.4	16.4	18.0	18.0	19.0	16.1
03		11.9	12.6	16.2	16.2	17.8	18.0	18.8	16.0
04		11.8	12.4	15.9	16.0	17.5	17.9	18.8	15.9
05		11.8	12.3	15.8	16.0	17.4	18.0	18.8	15.8
06		11.6	12.0	15.5	15.9	17.4	17.9	18.7	16.0
07		12.0	11.9	15.9	15.8	17.4	17.8	19.0	16.2
08		13.1	12.4	17.3	16.6	18.0	18.1	20.4	17.7
09		15.6	16.0	17.2	17.6	19.2	18.3	22.1	20.5
10		17.7	19.4	17.3	18.0	20.4	19.5	24.3	23.5
11		17.6	21.2	17.1	19.0	21.2	20.5	25.5	26.5
12		17.7	22.0	17.8	19.8	21.5	21.6	26.2	27.3
13		17.5	22.0	17.5	20.4	21.3	22.1	25.9	28.5
14		17.5	22.1	17.4	20.4	21.4	22.3	25.6	27.6
15		17.4	21.9	17.9	20.0	21.3	21.5	25.3	26.8
16		17.2	21.4	17.8	20.0	21.1	21.4	24.0	25.9
17		16.5	20.5	17.7	20.1	20.8	20.8	22.4	24.3
18		15.4	18.5	17.3	19.6	20.4	20.6	21.5	22.3
19		14.3	16.3	17.5	19.2	19.8	20.1	20.7	20.0
20		13.2	14.8	17.2	18.4	19.3	20.0	19.6	18.5
21		12.5	13.8	17.4	18.0	18.8	19.7	19.2	17.5
22		12.5	13.6	17.1	17.3	18.8	19.3	19.1	17.0
23		12.3	13.2	16.8	16.8	18.4	19.3	18.9	16.5
24		12.1	12.9	16.8	16.5	18.2	19.1	18.9	16.1
Daily Mean		14.3	16.2	17.0	17.9	19.3	19.6	21.3	20.4

* Container was filled with cardboard boxes.

Table B-19. Mean Hourly Absolute Humidities (g/m^3) in Container C

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		17.4	13.4	17.2	17.8	19.7	18.1	19.9	16.0
02		17.3	13.5	17.2	17.8	19.6	18.2	20.0	16.7
03		17.3	13.4	17.3	17.7	19.2	18.2	20.1	16.7
04		16.9	13.4	17.0	17.4	18.6	18.2	20.0	16.5
05		16.9	13.3	16.6	17.5	18.7	18.0	19.9	16.6
06		16.6	13.4	16.6	17.3	18.6	18.2	19.8	16.7
07		17.0	13.9	16.9	17.8	19.2	19.0	18.7	17.6
08		19.6	18.8	18.4	19.3	20.5	20.8	19.7	21.5
09		20.4	21.4	17.5	19.8	20.4	22.1	20.1	24.1
10		18.6	20.9	16.3	20.0	20.4	22.9	19.9	27.3
11		17.5	19.2	15.5	19.9	19.9	24.0	21.3	28.1
12		16.9	19.0	15.5	20.5	20.3	24.5	22.8	28.9
13		16.7	17.9	15.1	21.2	19.8	23.8	22.6	28.2
14		16.7	17.9	15.6	21.2	20.5	21.5	22.6	24.8
15		17.3	17.3	15.2	20.2	21.1	20.7	22.2	24.0
16		16.4	16.8	15.1	19.9	20.7	20.6	23.2	23.1
17		16.9	16.1	14.9	19.6	20.6	20.8	22.3	21.7
18		16.6	13.7	14.8	19.0	20.3	20.6	22.7	19.9
19		17.4	13.0	15.8	19.2	20.2	20.1	21.2	17.1
20		17.4	12.6	16.3	18.5	20.2	19.5	20.5	16.9
21		18.8	12.6	17.0	18.3	20.0	19.5	20.5	16.8
22		18.4	12.5	17.1	17.8	19.9	19.2	20.5	16.6
23		18.1	13.0	17.3	17.7	19.9	19.3	19.9	16.4
24		17.6	13.3	17.1	17.8	19.9	19.2	19.8	16.4
Daily Mean		17.5	15.4	16.4	18.9	19.9	20.3	20.8	20.4

* Container was filled with cardboard boxes.

Table B-20. Mean Hourly Absolute Humidities (g/m^3) in Container D

TIME (EST)	Phase:	Dry Season Open Site I	Dry Season Open Site II*	Dry Season Forest Site III	Dry Season Forest Site IV*	Rainy Season Forest Site V	Rainy Season Forest Site VI*	Rainy Season Open Site VII	Rainy Season Open Site VIII*
01		10.3	11.5	14.4	15.4	14.1	17.1	19.7	18.1
02		10.0	11.3	14.0	15.2	14.0	17.0	19.8	18.3
03		10.0	11.0	13.8	15.0	13.8	16.9	19.9	18.8
04		9.9	11.0	13.5	14.8	13.5	16.8	20.0	18.2
05		10.0	10.8	13.1	14.6	13.3	16.6	19.9	17.7
06		10.0	10.7	12.8	14.5	13.2	16.7	19.7	17.7
07		9.4	10.4	13.2	14.4	13.5	16.8	19.0	18.0
08		10.8	11.3	13.8	14.7	14.1	17.1	23.1	20.9
09		15.4	14.3	15.5	15.9	15.4	18.0	26.3	22.2
10		18.8	16.8	17.5	16.9	16.6	19.0	29.6	22.8
11		21.0	18.3	19.5	18.4	17.8	20.1	31.6	23.6
12		22.2	19.5	21.2	19.8	18.8	21.0	32.3	25.5
13		23.2	20.2	22.0	20.3	19.2	21.2	28.7	27.2
14		23.8	21.0	23.0	21.3	19.0	21.4	29.6	27.8
15		24.1	21.2	23.7	20.9	18.0	20.6	30.8	29.0
16		23.3	21.0	23.4	21.0	18.0	20.0	27.3	28.6
17		21.8	20.2	21.9	20.9	17.0	19.8	24.3	27.1
18		18.6	19.0	20.0	19.9	16.5	19.6	22.6	25.0
19		13.9	15.5	18.0	18.8	15.6	19.1	21.0	22.5
20		12.4	13.6	16.9	17.8	15.2	18.6	20.3	20.5
21		11.6	12.6	16.1	17.1	14.6	18.4	20.3	19.7
22		11.0	12.2	15.4	16.4	14.9	18.0	20.2	19.3
23		10.6	12.0	15.0	16.0	14.6	17.9	20.0	18.8
24		10.4	11.6	14.8	15.6	14.5	17.8	20.0	18.8
Daily Mean		15.1	14.9	17.2	17.3	15.6	18.4	23.6	21.9

* Container C, in which Container D was placed, was filled with cardboard boxes.

Table B-21. Seasonal Mean Hourly Absolute Humidities (g/m^3)

Time (EST)	Dry Season (Phases I-IV) Container A	B	C	D	Ambient Air	Rainy Season (Phases V-VIII) Container A	B	C	D	Ambient Air
01	14.8	14.5	16.4	12.9	17.5	19.0	17.8	18.6	17.3	20.1
02	14.7	14.4	16.4	12.6	17.5	19.0	17.8	18.6	17.3	19.9
03	14.7	14.2	16.4	12.5	17.5	18.9	17.7	18.6	17.4	19.9
04	14.5	14.0	16.2	12.3	17.3	18.8	17.6	18.4	17.2	19.9
05	14.4	14.0	16.1	12.1	17.2	18.7	17.5	18.3	16.9	19.8
06	14.4	13.8	15.9	12.0	17.0	18.7	17.5	18.3	16.9	19.7
07	14.5	13.9	16.3	12.0	17.3	18.9	17.6	18.6	16.9	20.4
08	15.3	15.0	19.0	12.8	18.3	20.2	18.6	20.6	18.9	21.2
09	16.4	16.7	19.9	15.3	17.9	21.3	20.0	21.7	20.6	21.4
10	17.3	18.1	19.0	17.6	17.0	22.4	21.9	22.6	22.1	21.4
11	17.5	18.6	18.0	19.5	16.5	23.1	23.5	23.3	23.4	21.6
12	17.2	19.4	18.0	20.7	16.2	23.7	24.3	24.1	24.4	21.7
13	17.1	19.4	17.7	21.4	15.7	23.6	24.5	23.6	24.1	21.5
14	16.9	19.4	17.9	22.3	16.0	23.1	24.2	22.4	24.5	21.3
15	16.8	19.3	17.5	22.5	15.7	22.5	23.7	22.0	24.6	21.2
16	16.8	19.1	17.1	22.2	16.0	22.1	23.1	21.9	23.5	21.4
17	16.5	18.7	16.9	21.2	16.2	21.9	22.1	21.4	22.1	21.2
18	16.1	17.7	16.0	19.4	16.7	21.4	21.2	20.9	21.0	21.1
19	15.7	16.8	16.4	16.6	17.3	20.8	20.2	19.7	19.6	20.7
20	15.3	15.9	16.2	15.2	17.5	20.2	19.4	19.3	18.7	20.7
21	15.2	15.4	16.7	14.4	17.9	19.8	18.9	19.2	18.3	20.6
22	15.1	15.1	16.4	13.8	17.7	19.6	18.6	19.1	18.1	20.6
23	14.9	14.8	16.5	13.4	17.7	19.4	18.3	18.9	17.8	20.4
24	14.9	14.6	16.5	13.1	17.6	19.3	18.1	18.9	17.8	20.3
Daily Mean	15.7	16.4	17.2	16.2	17.0	20.7	20.2	20.5	20.0	20.8

Table B-22. Mean Hourly Absolute Humidities (g/m^3) at Open and Forest Sites

Time (EST)	Open Site (Phases I, II, VII, VIII) Container A	B	C	D	Ambient Air	Forest Site (Phases III-VI) Container A	B	C	D	Ambient Air
01	16.5	15.0	16.8	14.9	19.2	17.3	17.4	18.2	15.3	18.4
02	16.6	14.9	16.8	14.9	19.2	17.2	17.2	18.2	15.1	18.3
03	16.5	14.8	16.8	15.0	19.2	17.1	17.1	18.1	14.9	18.3
04	16.4	14.8	16.7	14.8	19.0	16.9	16.8	17.9	14.7	18.2
05	16.4	14.7	16.7	14.6	18.9	16.7	16.8	17.7	14.4	18.1
06	16.4	14.6	16.6	14.6	18.8	16.8	16.7	17.7	14.3	17.9
07	16.5	14.8	16.7	14.2	19.3	16.9	16.7	18.2	14.5	18.4
08	17.9	15.9	19.9	16.5	20.3	17.6	17.5	19.7	14.9	19.2
09	19.0	18.6	21.5	19.7	20.0	18.6	18.1	19.9	16.2	19.3
10	20.2	21.2	21.7	22.0	19.8	19.4	18.8	19.9	17.5	18.6
11	20.5	22.7	21.5	23.7	19.8	20.1	19.4	19.8	19.0	18.4
12	20.6	23.3	21.9	24.9	19.7	20.3	20.2	20.2	20.2	18.1
13	20.3	23.5	21.4	24.8	19.5	20.4	20.3	20.0	20.7	17.7
14	19.8	23.2	20.5	25.6	19.5	20.3	20.4	19.7	21.2	17.8
15	19.6	22.9	20.2	26.3	19.4	19.8	20.2	19.3	20.8	17.6
16	19.1	22.1	19.9	25.1	19.4	19.6	20.1	19.1	20.6	18.0
17	18.8	20.9	19.3	23.4	19.3	19.4	19.8	19.0	19.9	18.1
18	18.4	19.4	18.2	21.3	19.5	19.1	19.5	18.7	19.0	18.2
19	17.7	17.9	17.2	18.3	19.6	18.8	19.1	18.8	17.9	18.4
20	17.1	16.5	16.9	16.7	19.5	18.4	18.7	18.6	17.1	18.6
21	16.9	15.8	17.2	16.1	19.6	18.2	18.5	18.7	16.6	18.9
22	16.7	15.6	17.0	15.7	19.6	18.0	18.1	18.5	16.2	18.7
23	16.5	15.2	16.9	15.4	19.4	17.7	17.8	18.5	15.9	18.7
24	16.6	15.0	16.9	15.2	19.3	17.6	17.6	18.5	15.7	18.6
Daily Mean	18.0	18.2	18.5	19.0	19.4	18.4	18.5	18.9	17.2	18.4

Table B-23. Mean Hourly Absolute Humidities (g/m^3) in Empty and Filled Containers

Time (EST)	Empty (Phases I, III, V, VII) Container A	B	C	D	Ambient Air	Filled with Cartons (Phases II, IV, VI, VIII) Container A	B	C	D*	Ambient Air
01	17.6	16.4	18.5	14.7	18.4	16.2	15.9	16.3	15.5	19.2
02	17.5	16.3	18.5	14.5	18.3	16.2	15.8	16.5	15.5	19.1
03	17.4	16.2	18.5	14.4	18.4	16.2	15.7	16.5	15.4	19.1
04	17.3	16.0	18.2	14.3	18.1	16.0	15.6	16.4	15.2	19.1
05	17.1	16.0	18.0	14.1	18.1	16.0	15.5	16.4	14.9	18.9
06	17.1	15.8	17.9	14.0	17.9	16.1	15.4	16.4	14.9	18.9
07	17.3	16.0	17.9	13.9	18.4	16.2	15.5	17.0	15.0	19.4
08	17.9	17.2	19.5	15.6	19.3	17.6	16.3	20.1	16.1	20.3
09	18.4	18.5	19.6	18.2	19.1	19.3	18.1	21.9	17.7	20.3
10	18.9	20.0	18.8	20.7	18.4	20.8	20.1	22.8	19.0	20.0
11	18.8	20.4	18.6	22.5	18.2	21.7	21.7	22.8	20.2	20.0
12	19.0	20.9	18.9	23.6	18.1	21.9	22.8	23.2	21.5	19.8
13	19.0	20.6	18.6	23.3	17.7	21.7	23.3	22.8	22.2	19.6
14	19.0	20.5	18.9	23.9	18.1	21.1	23.1	21.4	22.9	19.2
15	18.9	20.5	19.0	24.2	18.0	20.5	22.6	20.6	22.9	19.0
16	18.8	20.0	18.9	23.1	18.1	19.9	22.2	20.1	22.8	19.3
17	18.5	19.4	18.7	21.4	18.0	19.6	21.5	19.6	22.1	19.4
18	18.5	18.7	18.6	19.5	18.3	19.0	20.4	18.3	20.9	19.5
19	18.4	18.1	18.7	17.2	18.3	18.1	18.9	17.4	19.0	19.7
20	18.2	17.4	18.6	16.2	18.6	17.3	18.0	16.9	17.6	19.5
21	18.2	17.0	19.1	15.7	18.7	16.8	17.2	16.8	17.0	19.8
22	18.0	16.9	19.0	15.4	18.7	16.6	16.8	16.5	16.5	19.5
23	17.8	16.6	18.8	15.1	18.6	16.5	16.4	16.6	16.2	19.5
24	17.8	16.5	18.7	14.9	18.5	16.4	16.1	16.6	16.0	19.4
Daily Mean	18.1	18.0	18.7	18.0	18.4	18.3	18.6	18.9	18.2	19.5

* Container D was always empty. However, container C, in which container D was placed, was filled with cardboard boxes.

Table B-24. Mean Hourly Absolute Humidities (g/m^3)
Average of all Eight Phases

Time (EST)	Container A	B	C	D	Ambient Air
01	16.9	16.2	17.5	15.1	18.8
02	16.9	16.1	17.5	15.0	18.7
03	16.8	15.9	17.5	14.9	18.7
04	16.7	15.8	17.3	14.7	18.6
05	16.6	15.8	17.2	14.5	18.3
06	16.6	15.6	17.1	14.4	18.4
07	16.7	15.8	17.5	14.4	18.9
08	17.7	16.8	19.8	15.8	19.8
09	18.9	18.3	20.8	17.9	19.7
10	19.8	20.0	20.8	19.8	19.2
11	20.3	21.1	20.7	21.4	19.1
12	20.4	21.8	21.1	22.5	18.9
13	20.4	21.9	20.7	22.9	18.6
14	20.1	21.8	20.1	23.4	18.6
15	19.7	21.5	19.8	23.5	18.5
16	19.5	21.1	19.5	22.8	18.7
17	19.2	20.4	19.1	21.6	18.7
18	18.8	19.5	18.5	20.2	18.9
19	18.3	18.5	18.0	18.1	19.0
20	17.8	17.7	17.7	16.9	19.1
21	17.5	17.1	17.9	16.3	19.2
22	17.3	16.9	17.8	15.9	19.1
23	17.1	16.5	17.7	15.6	19.0
24	17.1	16.3	17.7	15.4	18.9
Daily Mean	18.2	18.3	18.7	18.0	18.9

APPENDIX C. REFERENCES

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