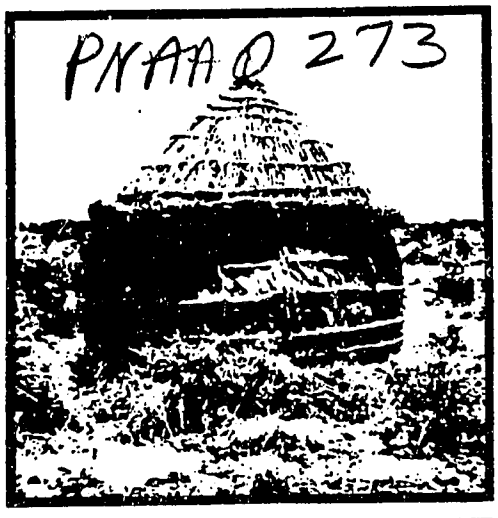

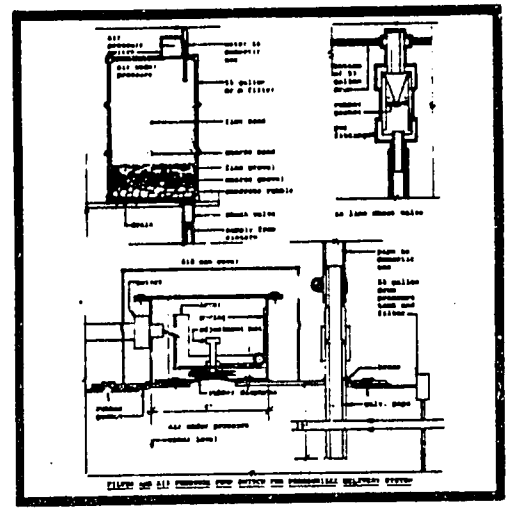

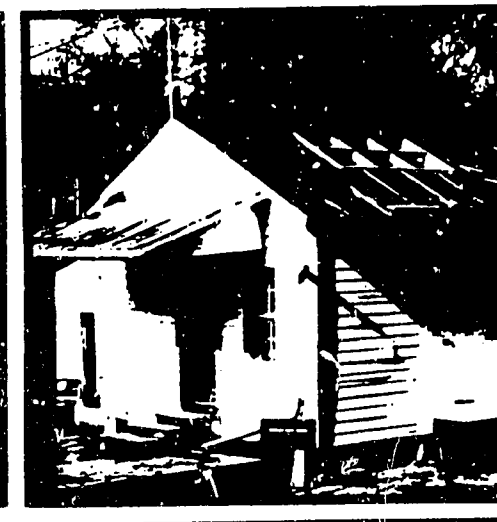

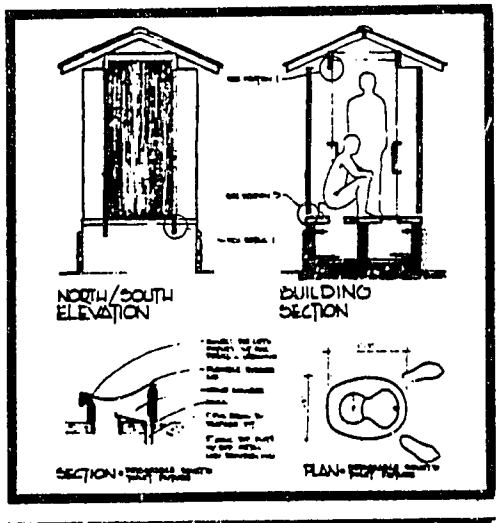

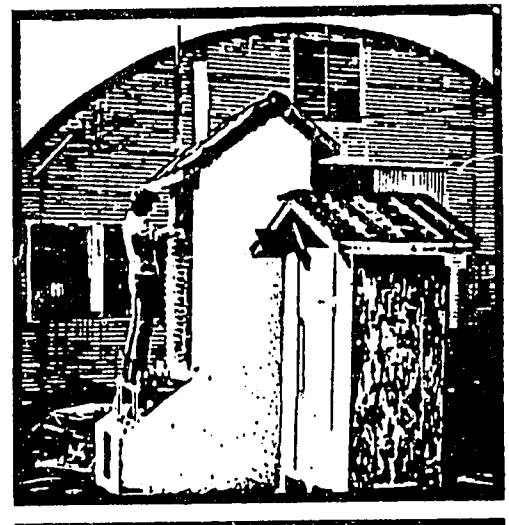

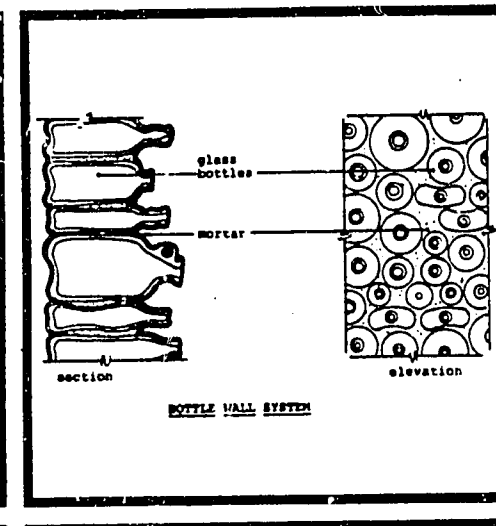

DISASTER SHELTER PROJECT - SUMMARY REPORT

PUBLICATION #10 OCTOBER 1983

EXPERIMENTAL LOW-COST CONSTRUCTION UNIT

FLORIDA A&M UNIVERSITY
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SCHOOL OF ARCHITECTURE

PREPARED FOR:

U.S. DEPARTMENT OF STATE
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FLORIDA A&M UNIVERSITY
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The pictures on the title page and the first page of each chapter are from photographs taken by the authors in El Salvador, Central America (1982) and Colombia, South America (1983) and illustrate the field application of using reinforced plastic sheeting for temporary post-disaster shelter.

TEXT & ILLUSTRATIONS

BLAKELEY BRUCE & LAWRENCE E. BIRCH

DISASTER SHELTER PROJECT - SUMMARY REPORT

PUBLICATION #10 OCTOBER 1983

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Publication #1: Energy Efficient Technologies and Methodologies for Low-Income Rural Housing, 1978.

Publication #2: Training Program in Low-Cost Energy Efficient Technology, 1979.

Publication #3: Construction Training Program for the Kurtunwaare Pilot Housing Project, Kurtunwaare, Somalia, 1981.

Publication #4: Construction Training Manual for the Kurtunwaare Pilot Housing Project, Kurtunwaare, Somalia, 1981.

Publication #5: Alternative Roofing Systems for the Kurtunwaare Pilot Housing Project, Kurtunwaare Somalia, 1981.

Publication #6: Alternative Housing Unit Design for the Kurtunwaare Pilot Housing Project, Kurtunwaare, Somalia, 1981.

Publication #7: Training Program for Low-Cost Housing, Conference paper presented at the International Congress on Housing, Vienna, Austria, 1981

Publication #8: Hybrid Earth Sheltered Structure, 1982.

Publication #9: Sulfur Impregnated Roofing Shingles, 1982.

Publication #10: Disaster Shelter Project, Summary Report, 1983.

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Abstract

BACKGROUND

The work described in this summary report is the continuation of an earlier project (Temporary Systems for Community Space During Disaster Relief and Rehabilitation) which was sponsored by both the Office of Foreign Disaster Assistance and the Office of Housing and Urban Development at the Agency for International Development. That project was coordinated by Mr. Barry Frazier of the Cooperative Housing Foundation and Mr. Lawrence Birch of Florida A&M University.

SCOPE OF WORK

Based on the project described above the Office of Foreign Disaster Assistance contracted with the School of Architecture at Florida A&M University to further develop the use of plastic sheeting as a primary construction material for temporary post-disaster shelter solutions. This project focused on the development of temporary shelter solutions for multi-purpose community spaces and for multi-family housing, which are typically needed during post-disaster relief and reconstruction efforts. The shelter solutions used indigenous materials normally found in disaster prone developing countries for the structural framework and used lightweight reinforced plastic sheeting for the walls and roof covering. The work involved under this contract was divided into five categories, with the majority of the work being done during the summer months of 1982. The work included:

1. Testing the physical strength of the plastic sheeting and various connection details.

2. Building two demonstration structures using plastic sheeting, unskilled labor, and simple construction materials.

3. Writing a multi-lingual field manual intended for distribution along with the plastic sheeting.

4. Monitoring the thermal performance of the two demonstration structures.

5. Monitoring the durability and weatherability of the sheeting over a twelve-month period.

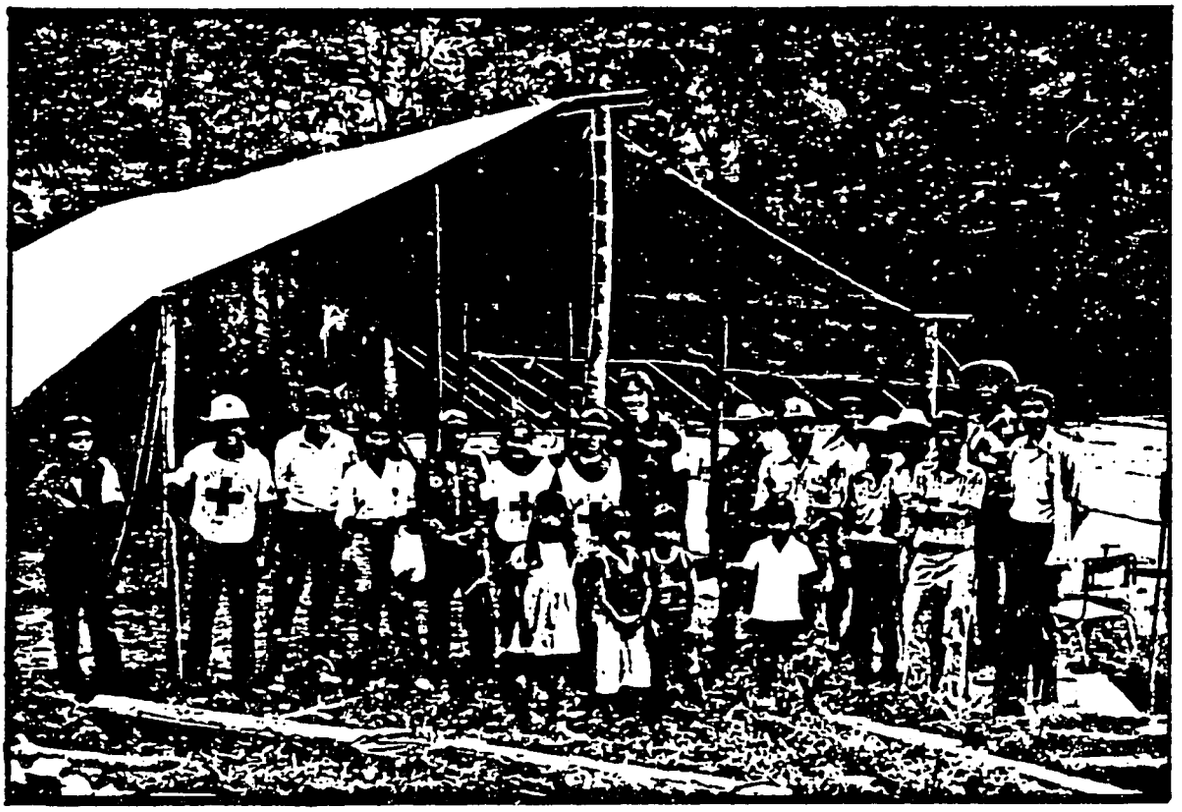
The work described above was conducted by the Experimental Low-Cost Construction Program at the School of Architecture research facility in Tallahassee, Florida.

OBSERVATIONS

If sufficient funds are available to continue all five areas of work as described above, valuable information could be generated in each of the five areas. However, if there is funding to support only one area of work, revision of the field manual would be the most practical.

RECOMMENDATIONS

The most important recommendation is to revise the field manual based on the results of this project and current field experience. At the present time there is no minimum list of steps or set of instructions distributed with the plastic sheeting. It is of critical importance that a basic list of "do's and don'ts" be prepared and enclosed with the sheeting that is to be used under non-structure field conditions (i.e. mass distribution without technical assistance.)



Introduction

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BACKGROUND

In 1982 the Office of Foreign Disaster Assistance of the Agency for International Development commissioned a report titled Temporary Systems for Community Space During Disaster Relief and Rehabilitation. It was prepared by Professor Lawrence Birch of Florida A&M University School of Architecture (FAMU/SOA) working in conjunction with Mr. Barry Frazier of the Cooperative Housing Foundation (CHF).

Upon completion of the work described above, the contract for this project was negotiated between the Office of Foreign Disaster Assistance and the School of Architecture at Florida A&M University. The work described in this report is a continuation of the work begun under the earlier contract.

INTENT

The intent of the project was to: 1) study and evaluate the plastic sheeting; 2) determine the principal characteristics of the material; 3) design and develop a construction system or systems that minimized the negative characteristics and maximized the positive characteristics of the material; and 4) prepare a field manual that described how to efficiently use the plastic sheeting.

The project attempted to evaluate the technical feasibility of using plastic sheeting as a temporary building material —a new and untested use for the material.

SCOPE

This report summarizes the work conducted to determine the technical feasibility of using reinforced plastic sheeting as a primary construction material for temporary structures used during post-disaster relief and rehabilitation efforts. In addition to determining technical feasibility, the project set standards for the efficient utilization of plastic sheeting as a temporary building material.

The work done under this contract is divided into five categories with the majority of the work being done during the summer months of 1982. The work included:

1. Testing the physical strength of the plastic sheeting and various connection details.

2. Building two demonstration structures using plastic sheeting, unskilled labor, and simple construction materials.

3. Writing a multi-lingual field manual intended for

distribution along with the plastic sheeting.

4. Monitoring the thermal performance of the sheeting used on the two demonstration structures.

5. Monitoring the durability and weatherability of the two demonstration structures for twelve months.

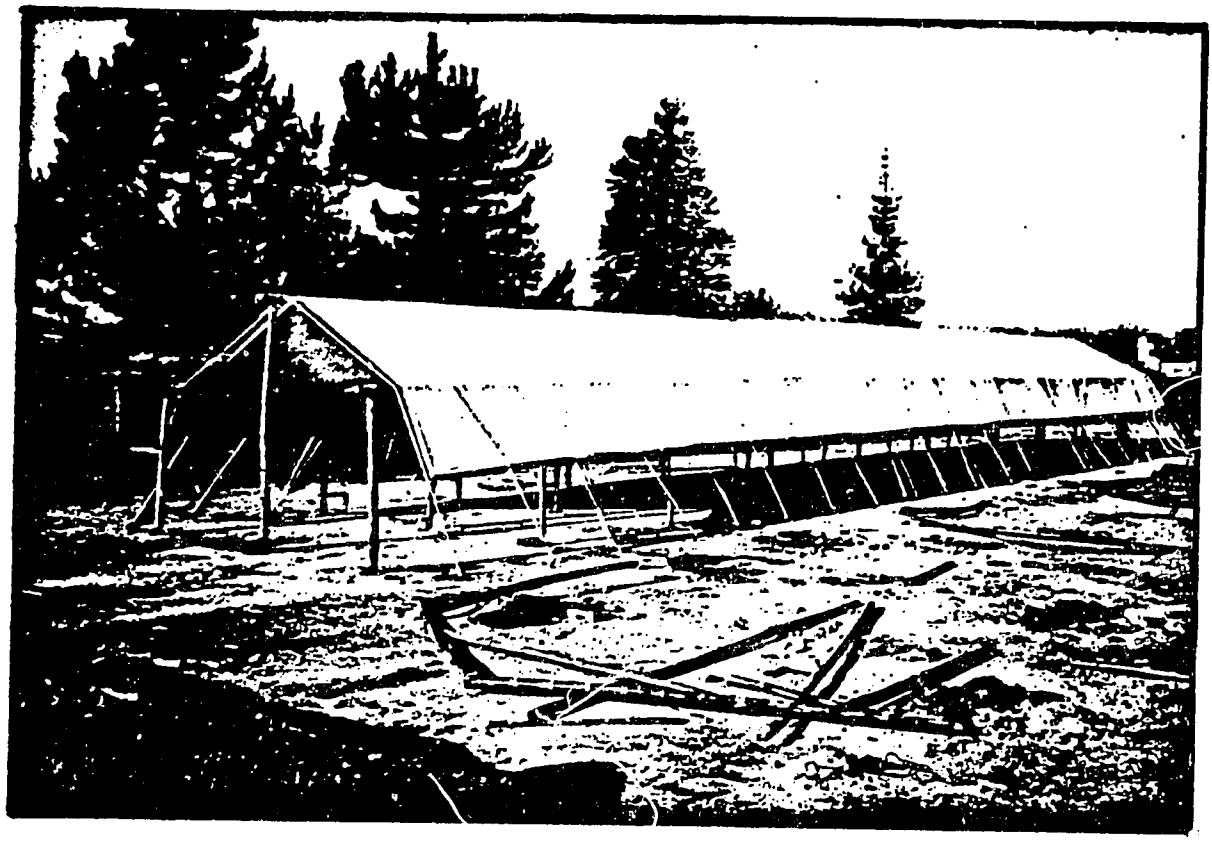
The information and data that was gathered during the testing and building phases (1 & 2) was incorporated into the writing of the field manual (3). The information and data gathered during the two monitoring phases (4 & 5) are included in this document and should be incorporated into a revised field manual.

LIMITATIONS

Given the intent of the work and the financial limitations of the contract the experimentation and monitoring of the plastic sheeting was not designed to be a substitute for American Society for Testing Materials (ASTM) standards or other standardized testing procedures for construction materials. The experiments were carefully designed to provide the project team with only that information needed to successfully complete this project and approximated ASTM procedures and equipment. It should not be assumed that the data contained in this report represents information comparable to manufacturers specifications or other published sources of information concerning the physical characteristics of reinforced plastic sheeting. The experiments were intended to provide qualitative and comparative rather than quantitative results.

PLASTIC SHEETING

The plastic sheeting is a laminate material consisting of a woven or reinforced core with a thin plastic film on both faces and a total thickness of 12 mils. The woven core is constructed from high-density, polyethylene tapes with twelve tapes per inch in both the machine and fill directions. The polyethylene tapes in the core are impregnated with carbon to improve the resistance of the sheeting to ultraviolet deterioration. The woven core is 10 mils thick. The two surface coating films are constructed from low-density polylethylene and have a thickness of 1 mil each. The woven core provides the strength characteristics while the film on both faces provides the water-tight characteristics of the material. The film on one side of the sheeting is white and the film on the other side is a light tan color. Additional manufacturers' specifications and samples of the sheeting are contained in an appendix.



1.0 Strength of Material

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1.6 ANALYSIS 11

1.1 INTENT

The intent of this phase was to test the plastic sheeting in a manner that reflected the way in which it would be used in the field. As stated earlier in the introduction there are published sources of information describing various physical characteristics of reinforced plastic sheeting. The problem is that the characteristics described in the published sources are not appropriate to or applicable to the way in which the plastic is to be used in the field. The purpose of this phase was to test the strength of various methods of attaching the plastic sheeting to other materials and to itself. The information derived from this phase was used to design the connection details that were included in the field manual.

1.2 SCOPE

The tests conducted in this phase fall into five categories:

A. Testing the tensile strength of the new plastic sheeting.

B. Testing the strength of different plastic-to-plastic attachment details.

C. Testing the strength of different plastic-to-rope attachment details.

D. Testing the strength of different plastic-to-timber attachment details.

E. Testing the tensile strength of plastic sheeting that has been in use for twelve months.

Within the five categories, a total of twenty-five elements were tested. Three tests were performed on each element. The twenty-five elements by category are listed below.

A. Testing the tensile strength of new plastic sheeting.

   1. Test samples parallel to the machine direction.

   2. Test samples perpendicular to the machine direction.

   3. Test samples at a 45 degree angle to the machine direction.

B. Testing the strength of different plastic-to-plastic attachment details.

1. Single-sided taped joint with plastic overlap.

2. Double-sided taped joint with plastic overlap.

3. Single-sided taped joint with butt joint.

4. Double-sided taped joint with butt joint.

5. Twine lashed joint with 15 cm between lashings, and one wrap.

6. Twine lashed joint with 15 cm between lashings and three wraps.

7. Bamboo lashed joint with 15 cm between lashings and three wraps.

C. Testing the strength of different plastic-to-rope attachment details.

1. Protective Plastics connectors.

2. Griffolin connectors.

3. Rock-Tie connectors.

4. Lashed connection.

D. Testing the strength of different plastic-to-timber attachment details.

1. 50 mm nails 50 cm o.c. through wood batten

2. 65 mm nails 50 cm o.c. through wood batten

3. 75 mm nails 50 cm o.c. through wood batten

4. 75 mm nails 50 cm o.c. through rope batten

5. 75 mm nails 50 cm o.c. through folded plastic batten

6. 75 mm nails 50 cm o.c. through folded plastic washer

7. 75 mm nails 50 cm o.c. through automobile tire washer

8. 75 mm nails 50 cm o.c. through bottle cap washer

E. Testing the tensile strength of plastic sheeting that is 12 months old.

1. Samples stored and unused.

2. Samples removed from pole tent demonstration structure.

3. Samples removed from BRE Frame demonstration structure.

1.3 EQUIPMENT

Two pieces of test equipment were used during the testing phase of this project. All tests except those for determining the strength of various plastic-to-timber attachment details were done on a Tinius Olsen materials testing machine. Samples being tested were fastened into the Tinius Olsen testing machine using specially designed clamps and followed ASTM specifications. The clamps were designed and built to securely hold the plastic sheeting without contributing to the failure of the plastic by pinching, puncturing, or tearing the plastic while being tested.

The large size of the test samples required for the plastic-to-timber attachment details prohibited the use of the Tinius-Olsen testing machine. A special test device was designed and built that accommodated the larger test samples. The tests were intended to determine the strength of batten and washer type connections that could be used to attach the plastic sheeting to timber framing members.

1.4 PROCEDURES

Tests to determine the tensile strength of new plastic sheeting were conducted for two reasons. One, to compare test results with the figures published in the technical literature. Two, to provide a base figure against which all other test results could be compared. This allowed the strength of the different attachment details to be described in terms of some percentage of the strength of the new plastic sheeting.

All test samples of plastic sheeting were cut-out using a sheet metal template to insure uniformity of the test samples. Three samples were prepared and tested for each of the twenty-five test categories listed in section 1.2. The average test results are described in the following section and the actual test results are contained in the appendix. Each sample was placed in the testing equipment, loaded at a uniform rate and tested until the material or the connection yielded. The results of the tests were incorporated into the field manual where tables were developed to select the most suitable construction details.

1.5 RESULTS

The following results represent the average of three test samples. The results are described in terms of both the kilonewtons (KN) and the equivalent pound-force (lbf.) at the moment of failure. The column on the far right side of the page is a percentage figure that compares the strength of each test sample to the strength of new plastic sheeting.

A. Testing the strength of new plastic sheeting:

1. Parallel to the machine direction	6.5 KN	1460 lbf	100%
2. Parallel to the fill direction	6.4 KN	1440 lbf	99%
3. 45 degrees to the machine direction	2.7 KN	610 lbf	42%

B. Testing the strength of different plastic-to-plastic attachment details:

1. Single-sided taped joint with plastic overlap	1.3 KN	290 lbf	20%
2. Double-sided taped joint with plastic overlap	2.6 KN	590 lbf	45%
3. Single-sided taped joint with butt joint	1.5 KN	340 lbf	23%
4. Double-sided taped joint with butt joint	3.3 KN	740 lbf	51%
5. Twine-lashed joint w/ 15cm between lashings and one wrap.	0.7 KN	106 lbf	11%
6. Twine-lashed joint w/ 15cm between lashings and three wraps	1.0 KN	230 lbf	16%
7. Bamboo lashed joint with 15 cm between lashings & three wraps	1.0 KN	230 lbf	16%

C. Testing the strength of different plastic-to-rope attachment details:

1. Protective Plastic connectors	0.9 KN	200 lbf	14%
2. Griffolin connectors	0.6 KN	140 lbf	9%

3.	Rock-tie connectors	1.1 KN	250 lbf	17%
4.	Lash connection	0.5 KN	115 lbf	8%

D. Testing the strength of different plastic-to-timber attachment details:

1.	50 mm nails 50 cm o.c. through wood battens	1.2 KN	270 lbf	18%
2.	65 mm nails 50 cm o.c. through wood battens	2.4 KN	540 lbf	37%
3.	75 mm nails 50 cm o.c. through wood battens	4.0 KN	900 lbf	62%
4.	75 mm nails 50 cm o.c. through rope battens	4.1 KN	920 lbf	53%
5.	75 mm nails 50 cm o.c. through folded plastic battens	2.8 KN	630 lbf	43%
6.	75 mm nails 50 cm o.c. through folded plastic washers	2.0 KN	450 lbf	31%
7.	75 mm nails 50 cm o.c. through automobile tire washers	4.9 KN	1100 lbf	75%
8.	75 mm nails 50 cm o.c. through bottle cap washers	3.0 KN	670 lbf	46%

E. Testing the tensile strength of plastic sheeting that is 12 months old:

1.	Samples stored and unused	5.8 KN	1310 lbf	89%
2.	Samples removed from BRE frame	4.5 KN	1010 lbf	69%
3.	Samples removed from pole tent	4.1 KN	920 lbf	63%

1.6 ANALYSIS

A. Testing the tensile strength of new plastic sheeting.

The manufacturers' literature indicates that new

sheeting should have a grab tensile strength of 165 lbs/inch (8.1 KN) in both the machine and fill directions. The project figures of 6.4 KN and 6.5 KN are about 20% below the manufacturers' figures. This could be the result of the test samples being from an early production run after the color specifications had been changed from green to tan and white.

The lower strength (2.7KN) of the samples cut at a 45 degree angle to the machine direction is the result of having fewer tapes in the woven reinforcing core to carry a load. With the test samples cut-out at a 45 degree angle, not all the tapes in the sample are connected at both the top and bottom clamps. Those tapes that are not connected at both ends can not carry any load. There were approximately 5 inches (60 tapes) across the width of the test sample that could carry a load. A normal sample cut parallel to either the machine or fill directions is 11.75 inches wide with 12 tapes per inch for a total of 141 tapes capable of carrying a load. The decrease in the number of tapes carrying a load is approximately equal to the decrease in the test results.

B. Testing the strength of different plastic-to-plastic attachment details.

Tests 1-4

The initial test results for the four taped connections appeared to be very good with strengths that averaged from 20 to 51 percent of the strength of new plastic. There are three primary problems with the use of taped connection details.

1. The adhesive backing weakens with heat.

2. The plastic film degrades under exposure to sunlight.

3. The quality of the joint made for the test samples can not be duplicated in the field due to techniques, moisture, etc.

Modifications to the specifications of the tape have been made to help increase the adhesive characteristics of the tape and to reduce its degradation due to UV light. The tape is expensive and of limited use. Consideration should be given to not providing tape with the

sheeting.

Tests 5-7

The results of the twine lashed connections are interesting because they represent the strength of the individual tapes in the core of the sheeting. The attachment details are based on tying two pieces of sheeting together using a piece of string or twine which passes through a hole roughly cut in the plastic sheeting. When the sheeting is pulled tight the string begins to pull against the sheeting at the hole where it passes through the sheeting. As additional loading is applied, one tape at a time reaches its failure point. Once the load is reached, which will cause one tape to fail, the sheeting will slowly tear one tape at a time.

C. Testing the strength of different plastic-to-rope attachment details.

The Protective Plastics connectors tested out approximately 30% stronger than the Griffolin connectors reflecting the higher strength plastic used for the Protective Plastics connectors. The rock-tie connectors were the strongest of the four details, with a strength approximately 17% that of new sheeting. The lash connection was the weakest of the four details at approximately 8% of the strength of the new sheeting. The lash connection was the simplest connection of the four and required only the sheeting and rope.

D. Testing the strength of different plastic-to-timber attachment details.

Tests 1-3

The strenth of any plastic-to-timber detail will be significantly affected by the length of the nails and the strength of the timber to resist the nail from being pulled out. There was a 50% increase in strength achieved by switching from 50 mm to 65 mm nails and an additional 62% increase in strength achieved by switching from 65 mm to 75 mm nails.

Tests 4-8

The highest strength detail was obtained when

using 75 mm nails driven through pieces of automobile tires that were cut into 3" x 3" squares which acted as washers for the nails. The lowest strength detail was obtained when using 75 mm nails driven through pieces of folded-up plastic sheeting which also acted as a washer for the nails.

E. Testing tensile strength of plastic sheeting that is 12 months old.

1. The test samples that were from stored and unused sheeting lost 11% of their original strength. The cause of this is not clear. It could be the result of the sheeting "drying-out" with age or "off-gassing", causing it to become less resilient and weaker.

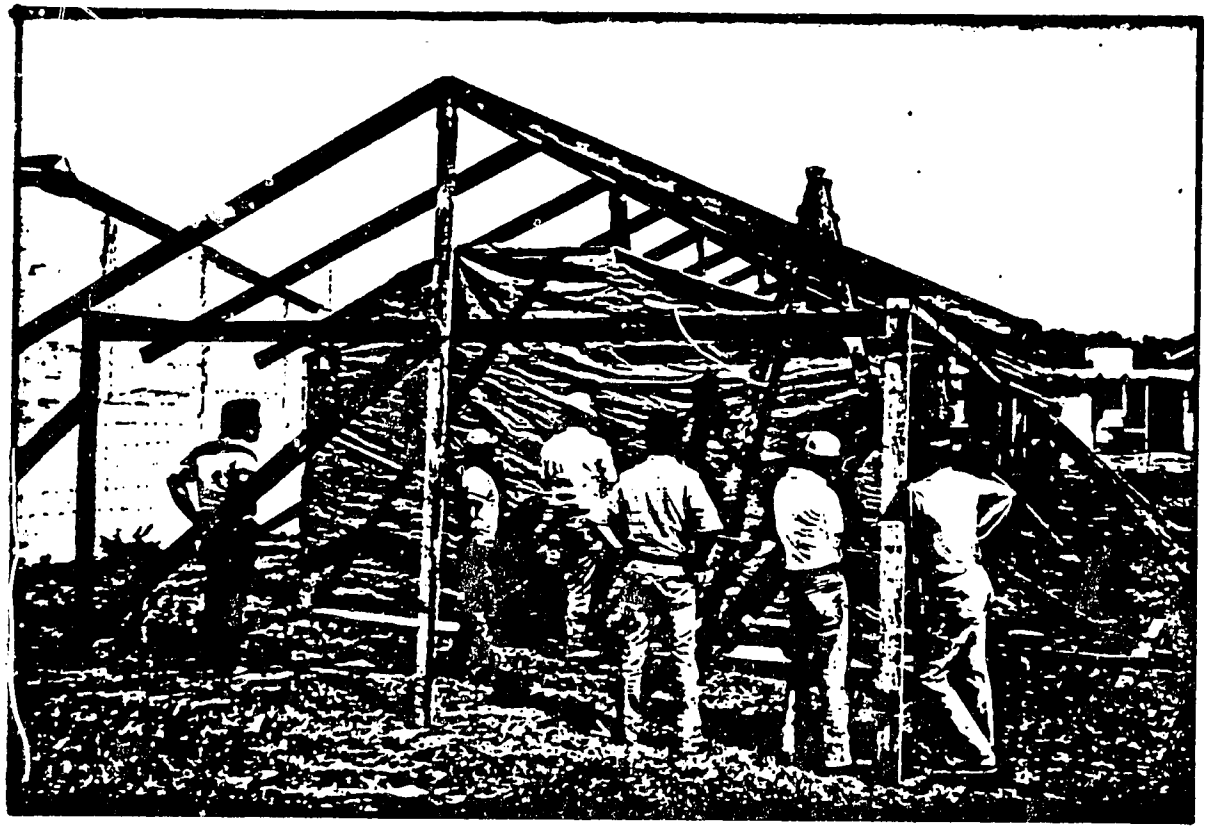
2. The test samples removed from the BRE frame had lost 31% of their initial strength over the 12 month monitoring period.

3. The test samples removed from the pole-tent had lost 37% of their original test strength. The constant flapping and fluttering of the plastic sheeting used on the pole-tent accelerated the deterioration of the sheeting and resulted in the 6% difference in strength between the samples from the two demonstration structures.

The remaining strength of both samples results almost exclusively from the strengths of the tapes in the woven core of sheeting. Much of the plastic film on both sides of the woven core had deteriorated and contributed little to the strength of the material.

The test samples that were cut out of the two demonstration structures did not include areas where the sheeting had been in contact with the building frame. After twelve months of use there were some minor areas of chafing on the BRE frame and a major amount of chafing on the sheeting from the pole tent. These heavily chafed areas affected the strength and integrity of the structure, but were not reflected in the samples tested.

Samples of sheeting removed from the two demonstration structures are contained in the appendix.



2.0 Demonstration Structures

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2.1 INTENT

It was determined during the initial planning of the project that two of the eight frame types described in the field manual should be built as early as possible. The construction and documentation of the construction process was necessary for the following reasons:

1. The building of the two demonstration structures was done while the field manual was in a draft form and the technical lessons learned during this phase were then incorporated into the final draft of the field manual.

2. The building of the two demonstation structures was done in a manner that attempted to reflect the way the manual, plastic sheeting, and construction personnel would most likely function under post-disaster field conditions.

3. The building of the two demonstration structures would provide an opportunity to monitor the thermal performance of the plastic sheeting as well as monitor the durability and weatherability of the two structures over a twelve month period.

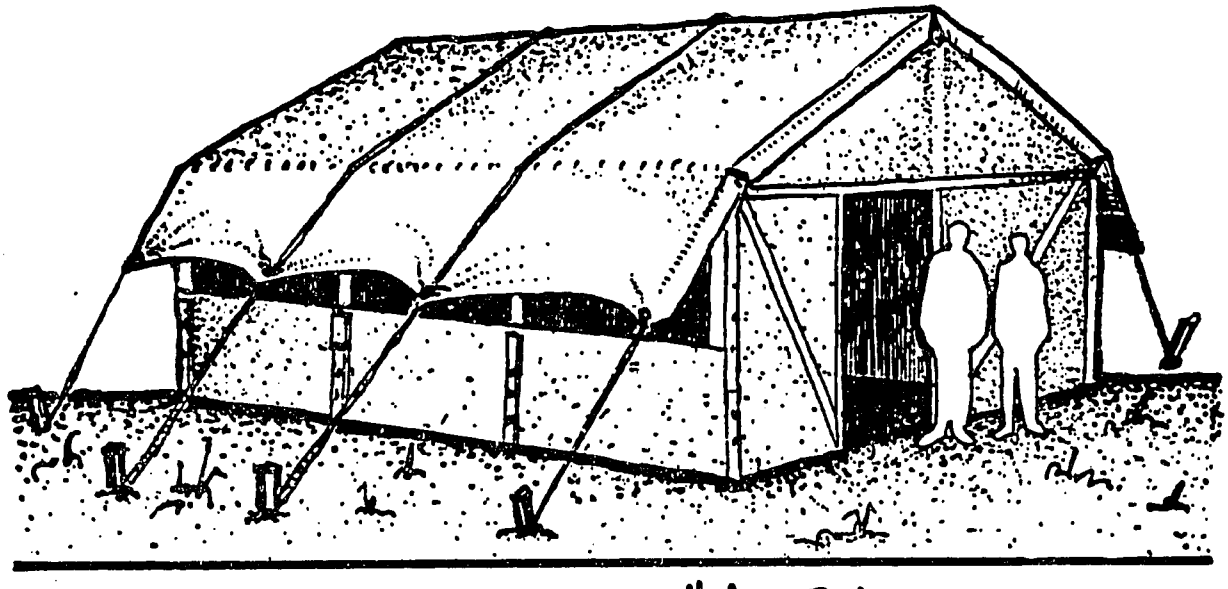
The eight structures described in the field manual can be divided into two groups. One group has rigid frames with the plastic sheeting attached directly to the frame of the structure. The other group has a tent type structure with the plastic sheeting stretched over the frame of the structure and then anchored to the ground.

The eight structures represent a range of complexity and sophistication in terms of the accuracy and level of craftsmanship required to build them. For the purposes of this project it was decided to build one example from each of the two main groups and at opposite levels of complexity. The structures selected were the BRE braced frame, a relatively complex rigid frame, and the pole tent, the simplest and most inexpensive of the eight structures.

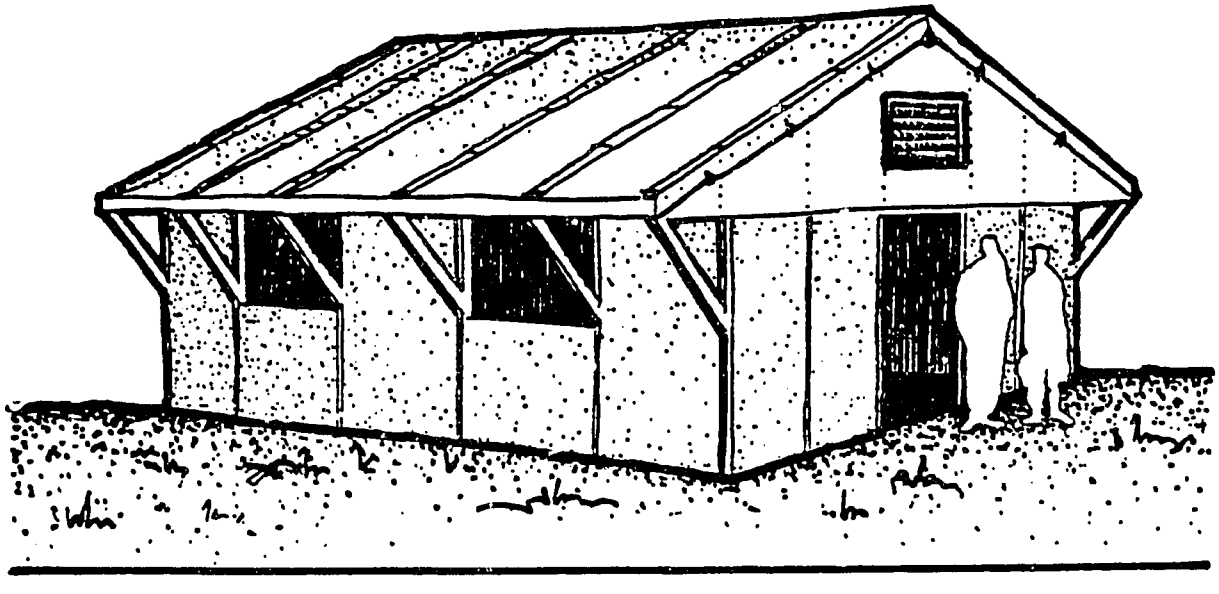
2.2 SITING

Both demonstration structures were built in the research compound at the School of Architecture, Florida A&M University in Tallahassee, Florida. They were built in the research compound for the following reasons:

1. The structures could be easily connected to a computerized data logging device making it possible to record the thermal performance of the plastic sheeting as well as the internal air temperatures.



DEMONSTRATION STRUCTURE # 1 - POLE TENT



DEMONSTRATION STRUCTURE # 2 - BRE FRAME

2. The structures could be conveniently monitored visually by students and faculty allowing minor problems to be observed, recorded, and corrected before any significant damage to the structures occurred.

Typical climate conditions for the Tallahassee/Leon County geographic area during the twelve month monitoring period are listed below:

Average annual temperature..... 67.2 degrees F
Average annual rainfall..... 64.9 inches
Average annual windspeed..... 6.9 MPH
Average annual sky cover. ..... 73.7 %*

*(Percentage of days per year with cloudy or partly cloudly skys)

Maximum daily temperature.....103 degrees F
Maximum daily rainfall ..... 4.7 inches
Maximum daily windspeed ..... 58 MPH
Maximum daily sky cover 26.3%*

* (Percent of days per year with clear skys)

The climate within this region is temperate-to-tropical in nature as the above characteristics indicate. Many of the characteristics are similiar to those in developing countries and building the demonstration structures in this climate should provide a good indication of how the structures will perform and weather under actual field conditions.

The structures were built on leveled and prepared sites. The construction of the two structures did not test the use of those parts of the field manual which describe site selection and preparation.

2.3 PARTICIPANTS

To build the two test structures five individuals were hired for one week. One individual was hired as the team leader, whose job it was to read the manual, assign work responsibilities, monitor the work, and catch mistakes. The other individuals had no extensive construction experience & were not familiar with either the plastic sheeting or the field manual. It should be noted that one of the labor participants was of such limited help that he did not work for the full week. The two structures were essentially built by one supervisor and three workers over a six day period.

The participants were presented with the scenario that their local school building had been destroyed beyond repair and

that they were to build a new temporary classroom. They were then given one copy of the manual, a roll of plastic sheeting, sufficient framing materials, and hand tools to complete the work.

2.4 STRUCTURE #1 - POLE TENT

The system was selected because it represented a relatively simple system that didn't require a large number of structural elements but instead relied heavily on the strength of the plastic sheeting. If the structure described in the field manual could be built and could last for a year, it would be an acceptable, inexpensive easy to build solution.

The pole tent can be made from any linear structural material such as saplings, bamboo, or dimensional lumber. Bamboo was available locally and was chosen for this structure. The participants were given just enough bamboo to construct the most basic frame five meters long and five meters wide. Rope, plastic sheeting and simple hand tools were also provided.

The pole tent consists of a simple post and beam frame that sets in foundation holes. Ropes are stretched over the bamboo frame to stabalize the frame and provide some support for the plastic sheeting. The sheeting is stretched tightly over the rope and frame. The sheeting is then anchored directly to the ground.

2.5 STRUCTURE #2 - BRE BRACED FRAME

The BRE frame was selected for the second demonstration structure because it was a relatively complex structural solution which was designed to provide a more permanent structure. If the more complex construction details could be executed by unskilled individuals using the field manual as a guide then it would provide a strong, relatively maintenance free structure that was more permanent than temporary in nature.

The BRE frame can be built from a variety of materials such as saplings, bamboo, or dimensional lumber. Dimensional lumber was selected for this structure. The participants were given 2" x 4" lumber, nails, and standard carpentry hand tools to build the frame that was five meters long and five meters wide.

The BRE frame consists of a series of rigid frames that are prefabricated and then set into foundation holes. The frames are then connected to one another at the ridge and eave lines and braced diagonally. After the frame is complete the plastic sheeting is stretched over the frame and nailed to the frame. In order to prevent the sheeting

from pulling off (over the nail head) special washers and battens were used to help hold the sheeting down against the building frame. Two types of battens were used (1" x 2" wood and 3/4" diameter rope) and three types of washers were used (automobile tires, flattened beverage cans, and bottle caps.) Each of the batten and washer types were tested for their respective strengths and described in the field manual.

2.6 MONITORING

The project team monitored the construction of the two demonstation structures using both video and 35 mm cameras and by writing a log of activities that documented the progress of work.

The monitoring was interrupted and assistance provided to the construction crew only if:

1. The participants were taking excessive time to complete a particular step which, if given sufficient time, they would have successfully completed.

2. The participants were making a serious error which would either waste the materials provided or cause an injury if allowed to continue.

In either case the reason for the intervention was noted and methods for improving the design of the structures were made in the manual.

2.7 RESULTS

The construction of the pole tent was a complete success. It was the first of the two structures to be built and took two days to build the 25 square meter (270 square feet) structure. The construction team did have some initial difficulty squaring the foundations. They made an attempt to precisely square the foundation rather than approximately square it which was all that was required. The team had little or no trouble building the bamboo structure over which the plastic would be stretched. It was determined that some type of ladder was required for the proper construction of the structure. A ladder was provided and reference to the ladder was included in the manual. The team did have considerable difficulty determining the number and location of the ground anchors needed to fasten the tent like roof to the ground. The Protecting Plastic connectors were rather awkward to attach and took a long time to finish. There was some difficulty getting the connectors to line up with the anchors in the ground.

The BRE frame took four days to build because of its more complex design and because of bad weather. Site layout and

digging the holes went quickly because it was the same process as the pole tent. Building the first rigid frame took a long time and required everyone's participation to both understand the manual and to build. After the first one was completed the remaining five were built very quickly. After the frames were built it took one day to set them in their foundation holes, get everything properly lined-up, and braced in the final position. A variety of batten and washer details were used after the sheeting was stretched over the frame. The team had some difficulty understanding the importance of the spacing between the nails used with either the the battens or the washers.

2.8 ANALYSIS

The construction phase of this project was very successful for the following reasons:

1. The early draft of the field manual worked sufficiently well to allow the timely completion of both structures. There were no major omissions or mistakes in the manual.

2. Both demonstration structures could be built by relatively unskilled individuals, with simple tools, in a short period of time.

3. The deficiencies in the design of the structures or the field manual were spotted and subsequently revised based on the construction experience.

It should be noted that as the building of the structures progressed the construction activities picked up speed. This is the result of an initial slow start-up when the manual is read, interpreted, and work activities assigned. Once the work begins it moves very quickly. The construction of larger buildings should not require the same proportional time as the smaller demonstration structures. In the latter stages of construction the manual was used less and less. The team members freely made modifications to the design and construction of both structures. The manual was primarily being used to gain an understanding of the overall nature of the structure, but not as a reference document for every detail.

The manual leads the user to a basic familiarity with the materials, building design, and construction process, but does not provide a mindless series of step-by-step tasks for the reader.

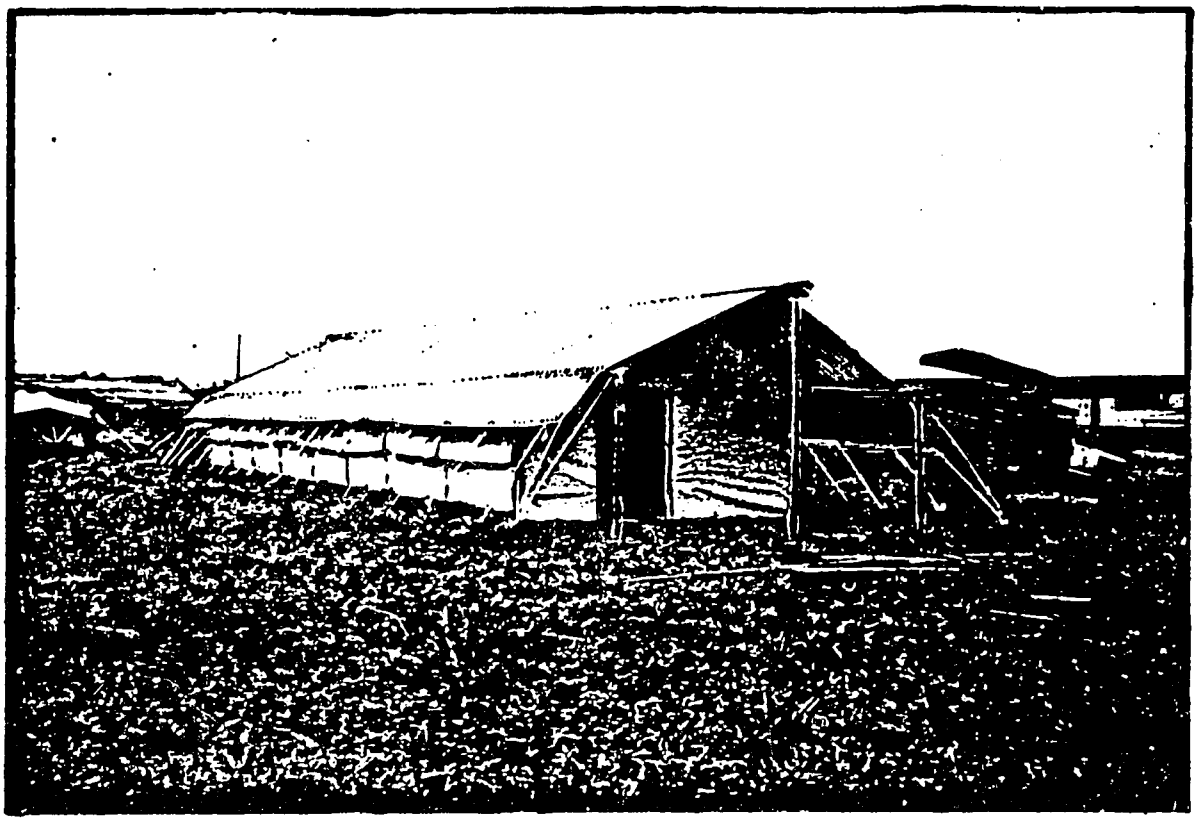
Both demonstration structures looked very professional upon completion. A close inspection revealed many mistakes and variations from the information contained in the manual, yet both were completed and habitable. This same

construction improvisation has been documented from field experience and should be interpreted positively. The construction teams were contributing to the design and construction process.

There were several aspects of the manual that were not tested by the construction of the two demonstration structures.

1. All of the participants were native English speakers and had no foreign language proficiency. The construction phase in no way tested the completeness or usefulness of the field manual for non-English speakers.

2. The manual contained a great deal of information concerning post-disaster site selection, possible framing materials and other vital decisions that need to be made. This project was not designed to test or document these critical areas.



3.0 Field Manual

3.1 INTENT 24

3.2 GRAPHIC VOCABULARY 24

3.3 MULTI-LINGUAL TEXT 24

3.4 PROCEDURES 25

3.5 ORGANIZATION 26

3.6 APPLICATION 26

3.7 ANALYSIS 27

3.1 INTENT

The intent of the field manual was to provide a written document that would be distributed along with the plastic sheeting which would help the person in the field most efficiently utilize the plastic sheeting. The scope of the manual was by definition very large and needed to respond to the following criteria.

1. Multi-Cultural Distribution - the field manual was intended to be distributed in a variety of different cultural areas.

2. Multi-Lingual Distribution - The field manual was intended to be distributed in many different language areas.

3. Multi-Climate Distribution - The field manual was intended to be distributed in many different climatic areas.

4. Multi-Disaster Distribution - The field manual was intended to be distributed in response to many different types of disasters.

The field manual was written as a draft document that was to be reviewed, edited and revised based on documented field experiences.

3.2 GRAPHIC VOCABULARY

A major effort was made to use simple drawings and diagrams to depict the topics that were described in the text of the manual. To effectively do this a graphic vocabulary was designed that would cover the different topic areas and provide a degree of continuity to the drawings. Graphics consultants and multi-lingual, multi-cultural consultants were used to develop the 49 images or diagrams that make up the graphic vocabulary. The extensive use of drawings and illustrations was intended to help the reader understand the technical subjects of the manual without having to completely understand the corresponding text. The illustrations were designed to help those individuals with limited reading abilities.

3.3 MULTI-LINGUAL TEXT

The field manual was written in English and then translated into French, Spanish, and Arabic. The decision to use a single document written in four languages was made to simplify the logistics of distribution during a post-disaster response. The logistical value of having a single document that could be shipped anywhere English, French, Spanish, or Arabic is spoken outweighs the

cumbersome quality of a document translated into four simultaneous languages.

3.4 PROCEDURES

The field manual was developed following the events described below:

1. The basic contents of the manual were developed under an earlier contract and contained in the document titled - Final Report: Temporary Systems for Community Space During Disaster Relief and Rehabilitation. That report was prepared jointly by the Cooperative Housing Foundation and faculty members at the School of Architecture.

2. The document was reviewed by two multi-lingual, multi-cultural consultants.

3. The document was reviewed by two structural consultants, one with extensive experience with tents, tensile structures, and light weight structures.

4. The document was reviewed by a graphics consultant regarding the layout of the manual.

5. Based on the reviews described above the writing and illustration of the field manual was begun.

6. A preliminary early draft of the manual was tested by having five unskilled individuals build two demonstration structures using the manual as a guide.

7. Tests to determine the strength of the different framing systems and construction details contained in the manual were conducted.

8. The preliminary draft of the manual was revised based on the construction experiences and based on the laboratory tests to determine the strength of the attachment details.

9. The text was written in English and all the illustrations completed.

10. Translations into French, Spanish and Arabic were begun.

11. Final editing and typing of the final draft based on review by translators.

The field manual was written in a very rigorous manner with several major reviews and subsequent revisions throughout the process. Little first-hand experience went into the writing of the document. The field manual that was

produced during this project is considered a draft document which needs to be revised based on field experience and on the information gathered during the twelve-month monitoring period.

3.5 ORGANIZATION

The manual is organized in such a way that the user in the field is encouraged to actively participate in making the necessary decisions. The organization of the field manual was divided into the following parts:

1. Introduction - Describes what is contained in the document and how to use it.

2. Design - Describes the characteristics of the sheeting, where to build, and what to build based on available materials, climate and disaster type.

3. Construction - Describes how to build the different components of the community structure (i.e. foundations, walls, roof, door, and windows, etc.)

The field manual is 280 pages long and covers a wide variety of conditions and topics. Because of its broad scope, much of the manual will not be relevent to the actual field conditions where it is being used. For this reason a significant effort was made to write the introduction in such a way that the user would be quickly directed to only those parts of the document relevant to his or her conditions (climate, disaster type, etc.) After the graphic vocabulary and table of contents are covered (pages 1-21) a series of questions are asked relating to the nature of the individuals shelter problem. After the user determines which of the five questions most closely reflects his or her situation a series of steps are provided which directs the user to the relevant sections of the manual.

3.6 APPLICATION

An early draft of the field manual worked very well when the two demonstration structures were built. But currently the final edition of the manual has had limited field application. Before the English text was translated into Spanish the authors were sent to San Salvador, El Salvador to provide technical assistance and field management services for the distribution of plastic sheeting in September 1982. The sheeting was sent in response to flood conditions in the region and was being used for temporary multi-family housing for the displaced and disaster affected population.

Six months later the authors were sent to Popayan, Colombia

in response to an earthquake there. Two-hundred rolls of plastic sheeting were sent to Popayan along with a handfull of field manuals. Project personnel took the manuals and edited them to only the relevant sections while building several training and demonstration structures. The sheeting was primarily used to construct temporary classroom facilities so that the schools could safely re-open. A secondary use of the sheeting was to repair or rebuild (temporarily) damaged residential structures.

3.7 ANALYSIS

Currently the field manual suffers from trying to do too much for too many people. The manual is much too long and broad in scope for a field manual. A serious effort needs to be made to more clearly define who the end-user of the manual will be. This would significantly simplify the necessary contents of the manual.

Consideration should be given to providing the manual in single-language or double-language editions. This would make the manual appear to be more manageable to the user by eliminating the three-languages he or she doesn't speak.

Field experience will go a long way to improving the manual. Based on the limited field experience gained to date the manual could be revised prior to printing a large number of of copies.

4.0 Thermal Performance

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4.2 PROCEDURES 29

4.3 RESULTS 30

4.4 ANALYSIS 32

4.1 INTENT

The intent of monitoring the thermal performance of the two structures was to help determine the effects that different building design features would have on the interior air temperatures. There is a very real potential for building an emergency community structure that is unusable because of excessive interior temperatures. The project team wanted to document the expected heat gain in the two structures to quantify the problem of excessive temperatures and prioritize potential solutions.

4.2 PROCEDURES

Monitoring the thermal performance of the two structures included the following steps.

1. Setting up the Equipment - Each of the demonstration structures was fitted with three electronic thermocouples to measure differences in temperture. A fourth thermocouple recorded the outside ambient air temperature (dry-bulb). The thermocouplers were connected to a data logging device that recorded the temperatures on an hourly basis.

   The first thermocouple was attached to the south facing side of the roof and measured the surface temperature of the plastic sheeting. The tan side of the sheeting was on the outside of both structures. The second thermocouple was located approximately nine feet above the floor line and midway between both ends. This location recorded inside air temperature above head-height. The third thermocouple was located directly below the second one and approximately six feet above the floor line. It recorded the inside air temperature at head-height and this reflected the temperature of the inhabitable section of the structure.

2. Collecting Data - The data logging equipment recorded the temperatures from each thermocouple hourly, twenty-four hours a day. The data was recorded on a continuous tape printout and included the day number (1-365), hour (01:00-24:00), and temperature (oC) for each thermocouple. A sample of the printout is contained in the appendix.

3. Charting the Results - The numeric results contained in the printouts were then charted in order to more clearly understand the relationships between the four temperature readings. The charts illustrated the fluctuations in temperature for each thermocouple over a twenty-four hour cycle. Charts for three days are contained in the appendix.

4. Analysis of the Results - The analysis of the data involved comparing the results from both demonstration structures. Only two of the four thermocouple locations needed to be compared. The surface temperature of both roofs would be approximately the same and the outside ambient air temperatures would be the same. The focus of the analysis was on the comparison of the two structures using the two inside air temperatures.

4.3 RESULTS

The results described here are based on averaging the data from both structures over three discontinuous days. Individual charts for each structure and day are contained in the appendix. The averaged or typical results can best be understood by looking at the chart titled Typical Thermal Performance Data and examining each line separately.

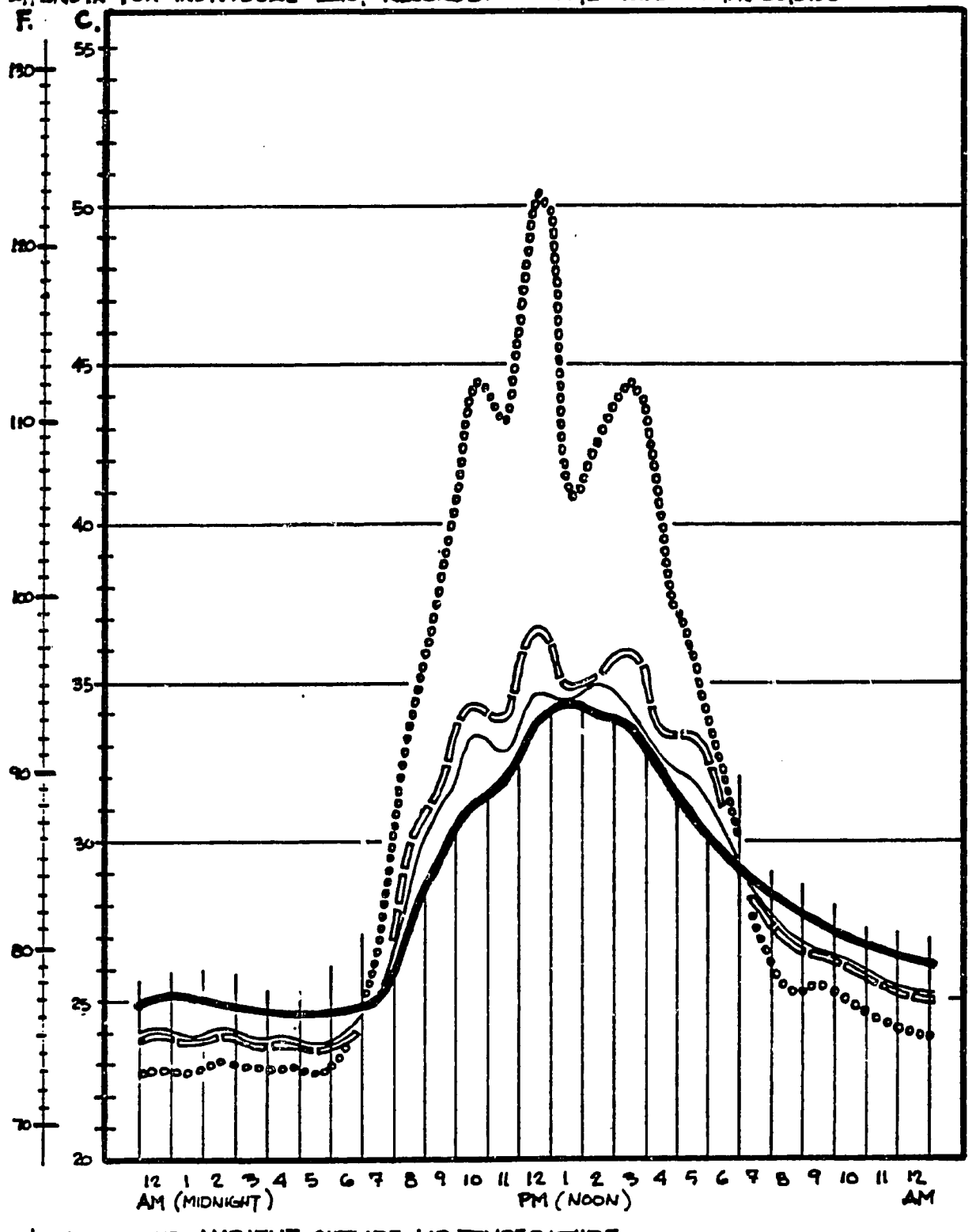
1. Ambient Air Temperature - This is a heavy solid black line on all charts. The ambient air temperature is the most stable line on the chart and fluctuated between 25 and 35 degrees centigrade over the three days.

2. Surface Temperature of the Roof - This is a line composed of small circles on this chart. The surface temperature of the sheeting had the greatest fluctuations of the four lines, and ranged between 23 and 50 degrees centigrade over the three days. The temperature of the roof is colder than the ambient air temperature at night because the roof is radiating or loosing heat to the night sky. During the day the surface temperatures increases very rapidly with averaged temperatures reaching 50 degrees centigrade or 122 degrees Fahrenheit. The hot surface temperatures of the roof began to heat the interior of the structures in two ways. First by radiating heat to other cooler surfaces (people) and secondly, by causing a build-up of the inside air temperature through conduction. It should be noted that the plastic sheeting covering the demonstration structures had the tan side turned out. Lower temperatures would have been recorded if the white side had been turned to the outside. The sheeting was not as white as later production runs of the sheeting. The whiter plastic is expected to reflect more light and subsequently heat up less.

3. Air Temperature Above Head-Height - This is a dashed line on the charts and as expected, corresponded to the fluctuations of the surface temperature of the roof. When the surface temperature of the roof would increase or decrease the air temperature above head-height would also increase or decrease.

TYPICAL THERMAL PERFORMANCE DATA

BASED ON AVERAGING FIGURES FROM BOTH STRUCTURES OVER THREE DAYS. SEE APPENDIX FOR INDIVIDUAL DAILY RECORDS. WHITE INSIDE AND TAN OUTSIDE



1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF *
3. INSIDE AIR TEMPERATURE ABOVE HEAD-HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

* BASED ON AVERAGING DATA FROM BRE STRUCTURE ONLY.

4. Air Temperature at Head-Height - This is a thin solid black line on the charts and is typically the closest line to the ambient air temperature. The air at this height is being heated from above and cooled by ventilation through the doors and windows. The ideal location of this line (for this climate) would be below the ambient air temperature during the heat of the day. This was not the case with the averaged figures, although the air temperature at head-height was seldom more than 2 or 3 degrees above the ambient air temperature.

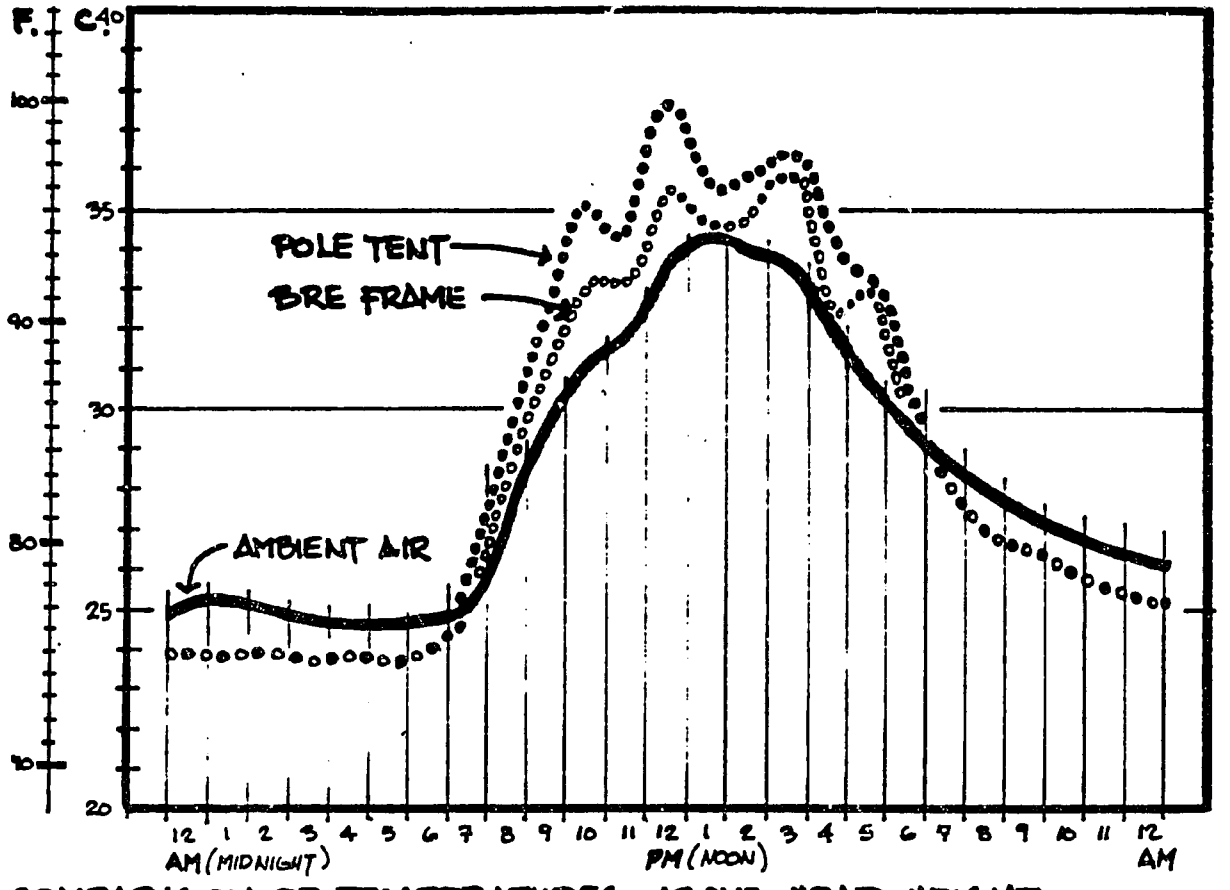
4.4 ANALYSIS

As stated earlier the analysis of the data consisted of a comparison of the interior air tempertures of the two demonstration structures. Two charts titled Comparison of Temperatures Above Head-Height and Comparison of Temperatures At Head-Height are included in this section. On both charts the inside air temperatures were warmer for the pole tent. The average air temperature at head-height for the BRE frame was actually below the ambient air temperature at several points.

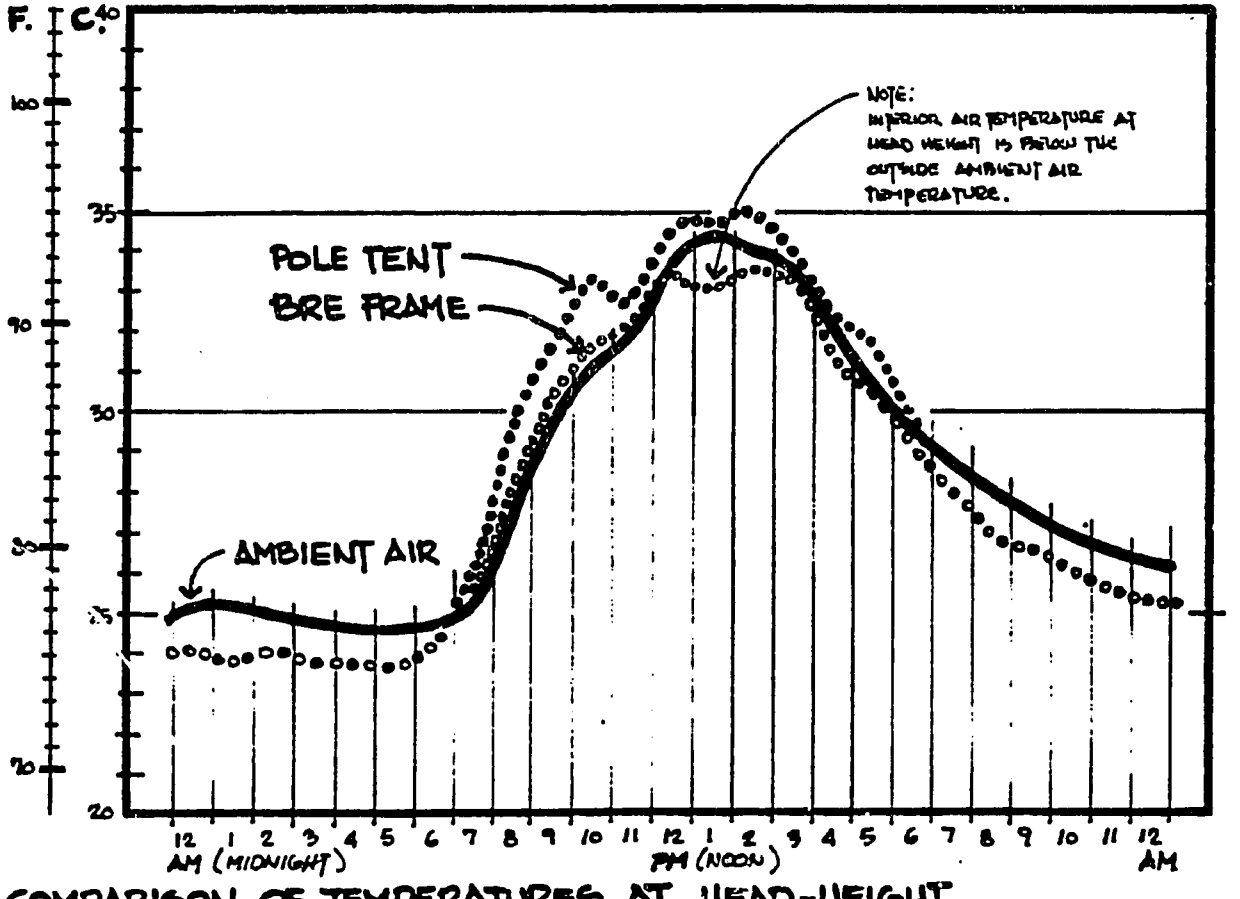
The lower interior air temperatures for the BRE frame structure can be attributed to a single design element, roof vents. There was a vent on both gable ends of the BRE structure while the roof of the pole tent was unvented. The roof vents allowed the super-heated interior air next to the roof to escape without heating up the rest of the air in the structure. It should be noted that the pole tent had considerably more window area than the BRE frame which provided for better interior ventilation of the pole tent at head-height. The increased ventilation through the windows wasn't enough to compensate for the build-up of super- heated air above head-height.

The problem of interior heat build-up in both structures is the result of two forms of heat movement, conduction and radiation. The air (above head-height) that is in contact with the underside of the super-heated roof is heated through conduction or contact with the roof surface (heat source). The use of roof vents or gable end vents adequately resolves this problem. Controlling the radiation of heat from the roof is a separate problem. No data was collected regarding different methods of resolving this problem. There would appear to be two ways of reducing the amount of radiation from the roof surface.

1. Shade the roof from the outside and keep if from heating up. Small tents come with a tent fly designed for this very purpose. This does not seem like a practical solution for community scaled buildings.



COMPARISON OF TEMPERATURES ABOVE HEAD-HEIGHT



COMPARISON OF TEMPERATURES AT HEAD-HEIGHT

2. Shade the interior space from the roof (heat source) by using a ceiling or partial ceiling. This seems to be a very practical solution for community scaled buildings.

5.0 Durability

5.1 INTENT 36

5.2 PROCEDURES 36

5.3 RESULTS 36

5.4 ANALYSIS 38

5.1 INTENT

The tent and frame structures described in the field manual were not intended to be permanent buildings based on conventional construction details and materials. The proposed and untested systems were designed to provide a temporary and minimal solution to the problem of building the needed community spaces during post-disaster relief efforts. The intent of this phase was to document the manner in which the sheeting aged and how the construction details held up over the twelve-month monitoring period. This was the one phase of the project in which the project team had little or no idea of what to expect.

5.2 PROCEDURES

The demonstration structures were built in the research compound at the school of Architecture to facilitate monitoring both their thermal performance and durability. Monitoring was conducted by both students and faculty members of the School and consisted of a bi-weekly inspection of the structures. Periodic photographs were taken to document specific conditions. Active repair or intervention by team members only occurred to prevent the ultimate failure of the structure or to correct what would become a dangerous condition. After the twelve-month monitoring period tests were conducted to determine the tensile strength of samples removed from both structures. The results of the tests are described in an earlier section of this report.

5.3 RESULTS

Both demonstration structures survived the twelve-month monitoring period, but with significant differences between them. Each structure is described separately below.

A. BRE Frame - This structure preformed virtually maintenance free for the entire monitoring period. All walls, windows, roof, and connections were in completely satisfactory condition. The 2" x 4" frame of the structure was strong and the plastic sheeting was still watertight. The BRE structure has been left standing and is expected to easily last another year. The plastic sheeting does show some signs of ultraviolet light degradation of the outside face of the roof, and the samples tested indicated that the sheeting had lost approximately 31% of its original strength.

B. Pole Tent - This structure required constant attention for a variety of reasons. The pole tent was virtually uninhabitable at the end of twelve-months and was subsequently dismantled. The samples of the pole tent indicated that the sheeting had lost approximately 37%

of its original strength. A review of each element of the structure follows.

1. Bamboo Structure - The bamboo structure itself was beginning to loosen-up although it was in satisfactory and usable shape at the end of the monitoring period.

2. Plastic Tape - The tape that was used extensively for many of the connections on the pole tent began to deteriorate within the first month. This was the result of exposure to the ultraviolet light from the sun. The manufacturing specifications for the tape was subsequently revised improving its adhesive characteristics and making it more resistant to ultraviolet light exposure.

3. Plastic Connectors - Within two months the plastic-to-rope connectors provided by Protective Plastics were beginning to fail rather frequently. First on the South side and then on the North side of the roof, the connectors simply crystallized and fell off. The connectors, like the tape, were not designed to withstand constant and direct exposure to ultraviolet light. The manufacturing specifications were revised requiring the use of carbon impregnated plastic, which significantly improved their performance. It should be noted that it is very difficult to re-attach the plastic connectors (for any reason) once the plastic sheeting has been stretched tight.

4. Rope - A sizable amount of rope was used during the construction of the pole tent in order to reduce the amount of structural bamboo necessary to complete the building. An inexpensive brand of plastic rope was used. Like the tape and plastic connectors, the rope began to fail from exposure to ultraviolet light during the second and third months. A more expensive and ultraviolet protected rope was then used to replace all the rope which was exposed to the sunlight.

5. Plastic Sheeting - As stated earlier the strength of the sheeting from both structures was tested after the twelve-month monitoring period. The strength of the samples removed from the pole tent were uniformly weaker than the samples from the BRE structure by an average of six percent. This weakening of the sheeting can be attributed to the slight but constant flapping and fluttering of the roof over the twelve-months. Another and more serious problem resulting from the flapping of the sheeting was the chaffing and abrading action that resulted from the sheeting rubbing against the bamboo structure.

Serious water leakage occured through the abraded openings which was the reason why the structure was uninhabitable after the monitoring period.

5.4 ANALYSIS

As stated earlier in this report the plastic sheeting that was used for both the demonstration structures was from a non-production manufacturing run, used to make a preliminary sample of the white and tan plastic. The durability characteristics of the white and tan sheeting made under the controlled conditions of a production run are expected to be better than the samples tested during this project.

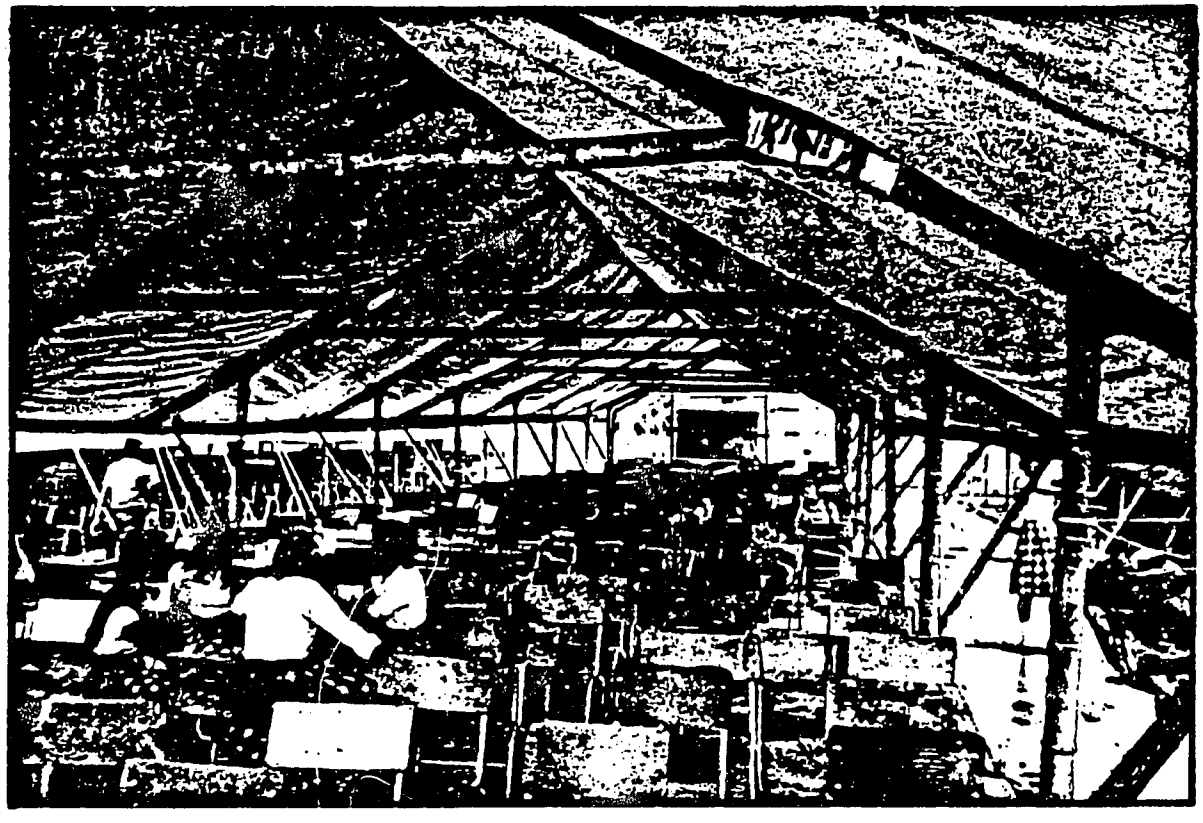
A. BRE Frame

The excellent condition of the BRE frame is the result of: 1) attaching the plastic directly to the building frame and 2) spacing the frames one meter on-center. The spacing of one meter on-center is most likely not feasible except for special and very limited field applications. A spacing of two (2) meters on-center or more would more likely reflect the spacing of the frames in the field.

B. Pole Tent

The corresponding poor durability of the pole tent is partially the result of material failures (tape, plastic connectors and rope) and particially the result of its minimal design. The chaffing of the sheeting resulting from the slight but constant movement of the sheeting against the structure of the tent is the most serious problem. Resolution of the problem can be achieved in two ways. First, by stretching the sheeting as tightly as possible and anchoring it securely to the ground, the magnitude of the flapping will be minimized. Secondly, by increasing the surface area of contact between the bamboo structure and the sheeting, the severity of the chafing will be reduced.

Serious consideration should be given to not providing either the role of tape or the bag of plastic-to-rope connectors which are currently distributed along with the plastic sheeting. Neither products are essential to the successful completion of the structures, and it would eliminate the potential for misuse under minimally supervised or unsupervised construction programs.



Recommendations

OBSERVATIONS 40

RECOMMENDATIONS. 41

OBSERVATIONS

The following observations are based on the five categories of work done for this project.

1. Strength of Material

The plastic sheeting is a very strong material which met manufacturer's published specifications and retained approximately 66% of its original strength over the twelve month monitoring period. The sheeting on both demonstration buildings was structurally sound at the end of the monitoring period. There were no significant rips, tears or holes in the sheeting at the end of the monitoring except for abrasion on the pole tent from the sheeting chafing against the tent frame. Both structures, however, showed a degradation of the surface coating which appeared during the eighth month and progressively worsened. The pole tent, due to its intrinsic flexibility exhibited more severe problems. By the twelvth month the pole tent leaked freely during heavy rain while the BRE frame allowed occasional drips to get through. The strength of the sheeting is illustrated by the fact that during the shipping and transportation of the sheeting and subsequently during construction no damage to the sheeting was observed. This has held true under field conditions as well.

2. Demonstration Structures

The structures and construction details described in the field manual are easy-to build, structurally sound, and represent minimum expense solutions. The organization of the work and the managing of the work by a foreman appears to be the controlling element regarding field application. The demonstration structures were built using one foreman with four laborers. That ratio is not realistic for a large scale project under difficult field conditions.

3. Field Manual

The field manual is a comprehensive multi-lingual document that covers general siting and design information as well as detailed construction information. The comprehensive nature of the document makes it a rather large, cumbersome, and expensive field document.

4. Thermal Performance

The sheeting has no insulating characteristics and quickly heats-up and/or cools-down in response to the radiant heat of the sun. The white and tan color of the sheeting is a significant improvement over the original dark green color

in relation to heat gain. Little can be done to reduce the radiant heat gain of the white and tan sheeting. The radiant heat of the plastic can cause the interior air temperature to rise uncomfortably. The interior air temperature can be controlled by the use of roof or gable end vents.

5. Durability

Both structures lasted the full twelve-months of the monitoring period. The pole tent required more maintenance, particularly the replacement of ropes, than the BRE frame which went untouched over the twelve-months. The plastic sheeting degraded more rapidly on the pole tent because of the constant flapping and fluttering of the material.

Abrasions in the sheeting on the pole tent were a significant problem and resulted from the sheeting constantly rubbing and chafing against the tent frame.

The pole tent was uninhabitable after the monitoring period because water could enter the structure through the abraded sheeting during seasonal rains. The BRE frame was habitable and nearly water tight after twelve months.

RECOMMENDATIONS

The following recommendations are based on the five categories of work done for this project.

1. Strength of Material

   A. The strength of the sheeting is adequate for its intended purpose. No change in the strength of the sheeting would be warranted.

   B. The strength of the attachment details that utilize indigenous materials (rocks, bamboo, etc.) are comparable to the details that utilize specially designed fasteners. Plastic connectors should not be provided.

   C. The strength of taped connections were initially very promising but monitoring the durability of the structures indicated that the tape degraded rather quickly. The specifications for the tape were then modified to improve its strength and to reduce the rate at which it degraded. However, due to its limited value and with regard to problems of distribution, tape should not be provided with the plastic.

2. Demonstration Structures

The use of demonstration structures can play a significant

role at two key points during the implementation of a project:

A. Regional Scale - The use of a demonstration structure is an excellent method of training foremen and other supervisors who can then be sent (or returned to), other regions, where construction of community facilities are likely to be needed.

B. Community Scale - The use of a demonstration structure is an excellent method of training civilians who can then be given plastic sheeting and allowed to build without the use of foremen or supervisors.

The use of the demonstration structures provides the opportunity to select locally acceptable construction details and to reduce the existing field manual to include only the applicable sections. Consideration should be given to adding a section in the field manual on the use of demonstration structures. It is further recommended that regional demonstrations of the system be held in disaster prone areas.

3. Field Manual

A. Consideration should be given to providing a single or double language edition of the manual.

B. Consideration should be given to more clearly define the end-user of the manual and to then tailor the document around that person.

C. Consideration should be given to revising the field manual based on documented field applications.

D. Consideration should be given to expanding the current manual to become a technical reference for disaster planners and technicians.

4. Thermal Performance

A. Consideration should be given to recommending a ceiling liner as part of the standard roof construction providing a thermal buffer and helping to control condensation on the inside surface of the roof.

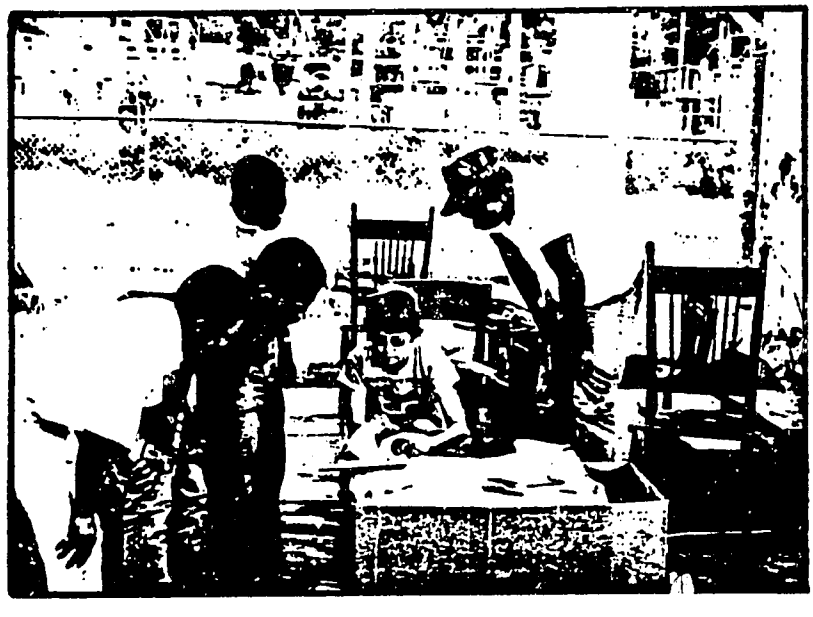
B. Consideration should be given to having the field manual emphasize the use of roof or gable end vents rather than windows to help reduce interior air temperatures.

5. Durability

Consideration should be given to describing the pole tent in the manual as a truly temporary structure with an expected life of twelve months maximum.

Photographs

In addition to the photographs contained here, eighty (80) color slides of the testing and construction phases have been provided earlier.

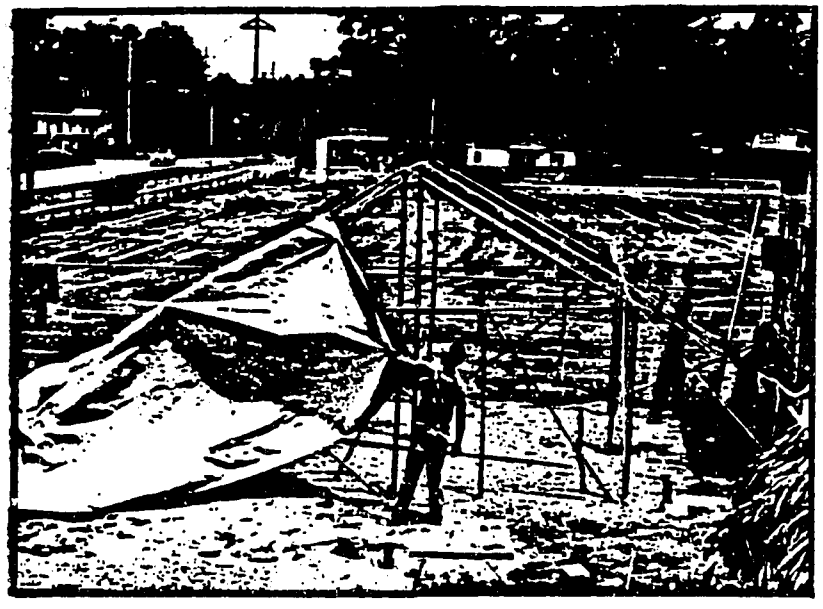


1.

Reviewing the first draft of the field manual prior to constructing demonstration structures.

2.

Laying out and squaring the foundation for the pole tent.



3.

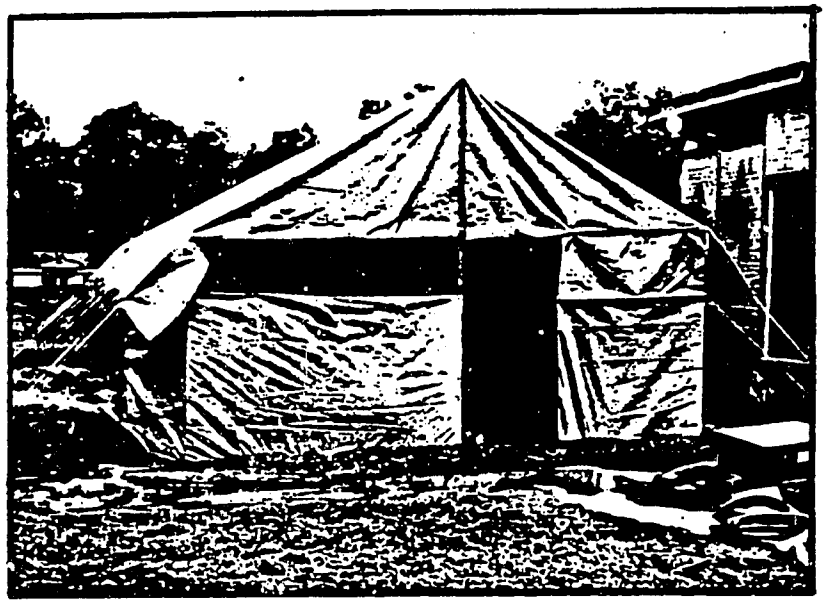
Pulling the plastic sheeting over the pole tent structure.

4.

Checking the location of the sheeting prior to anchoring it to the ground.

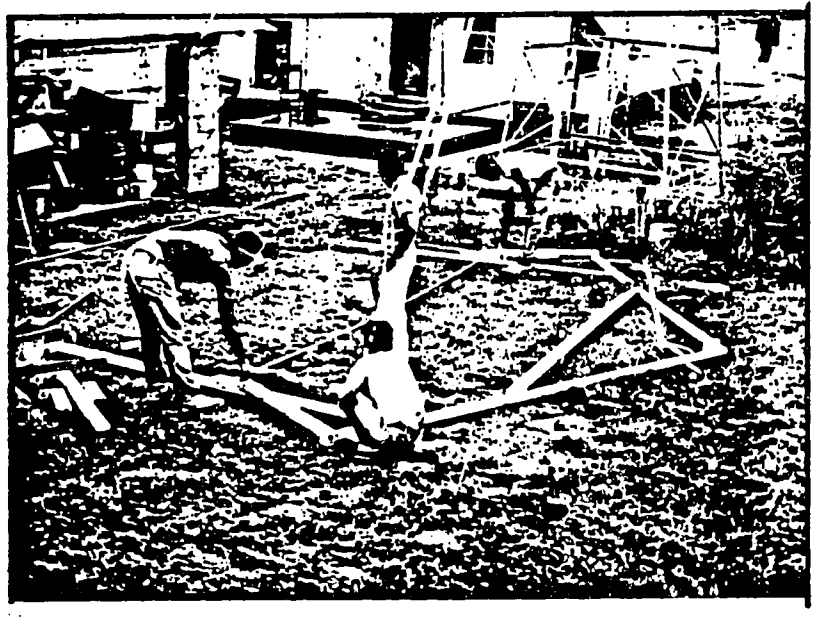
5.

Making a tape connection under field conditions.



6.

Completed pole tent structure.



7.

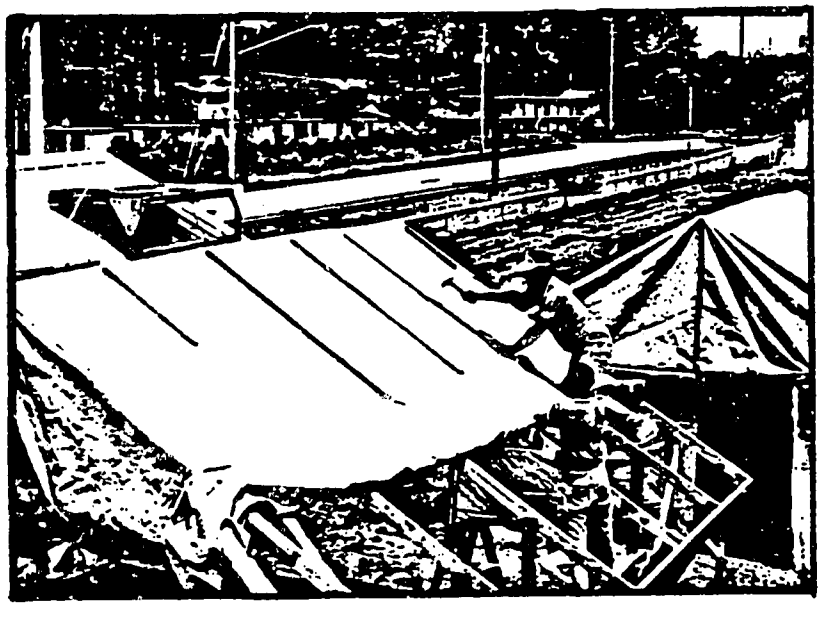
Constructing the BRE rigid frame.

8.

Setting the rigid frames in place.

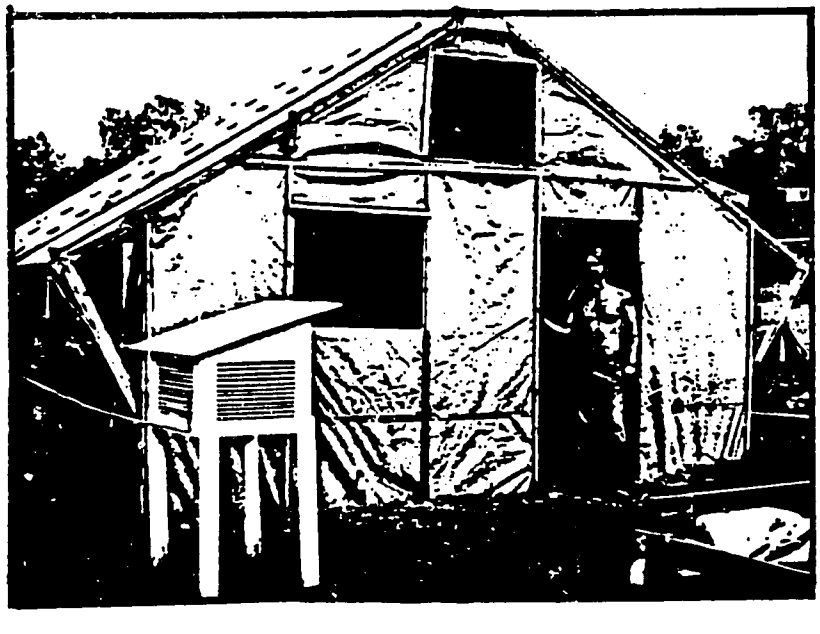
9.

Covering the BRE structure with plastic sheeting.



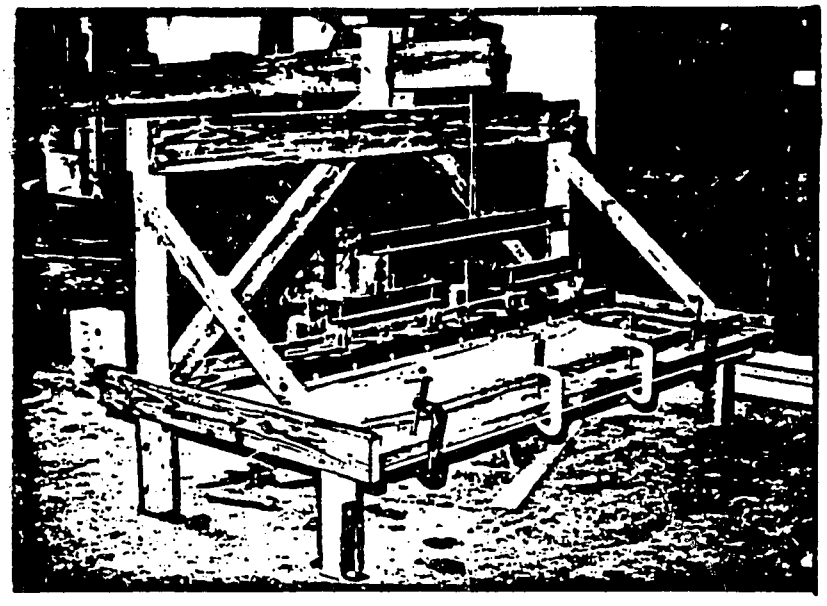
10.

Nailing wooden battens down over the sheeting.



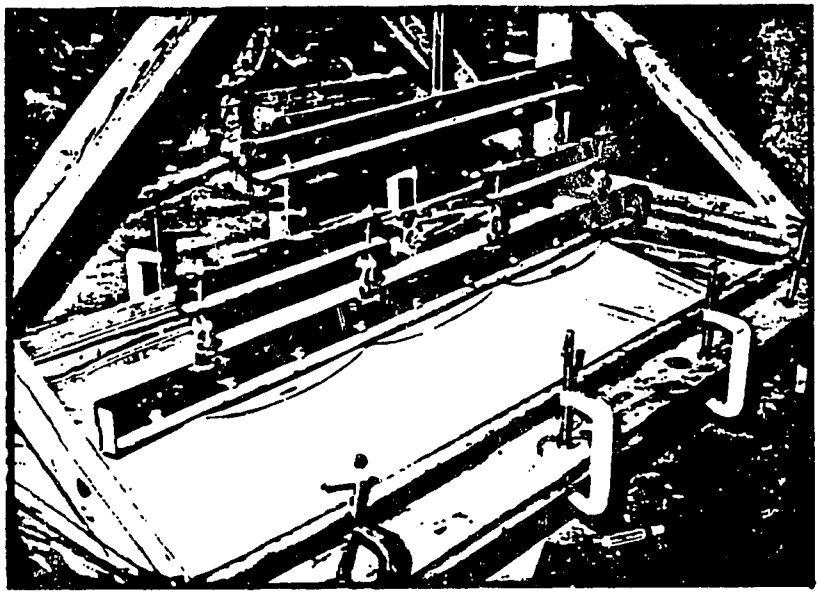
11.

Completed BRE frame.



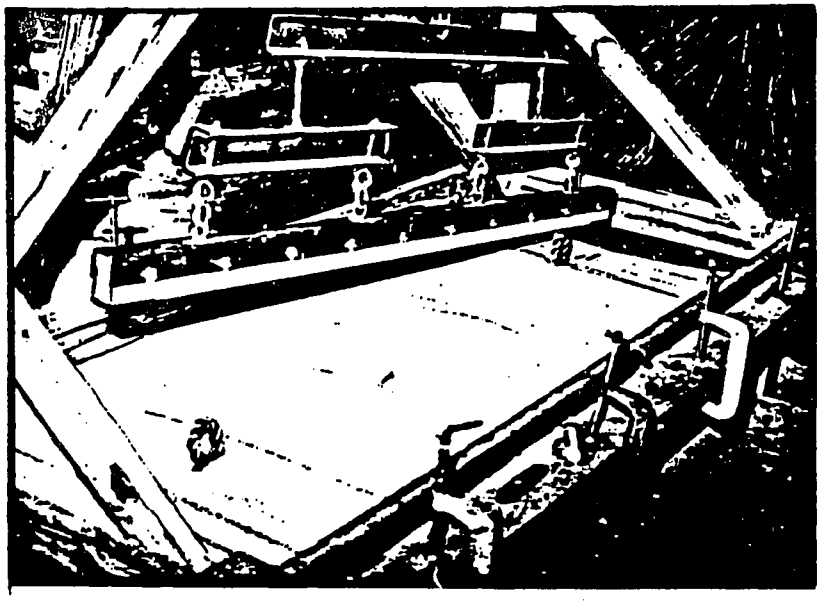
12.

Batten testing device.



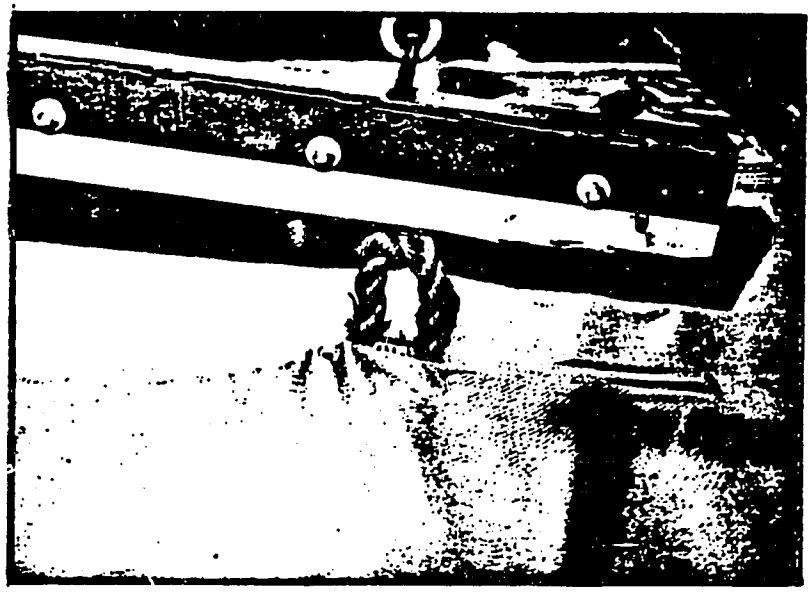
13.

Rope batten connection detail being tested.



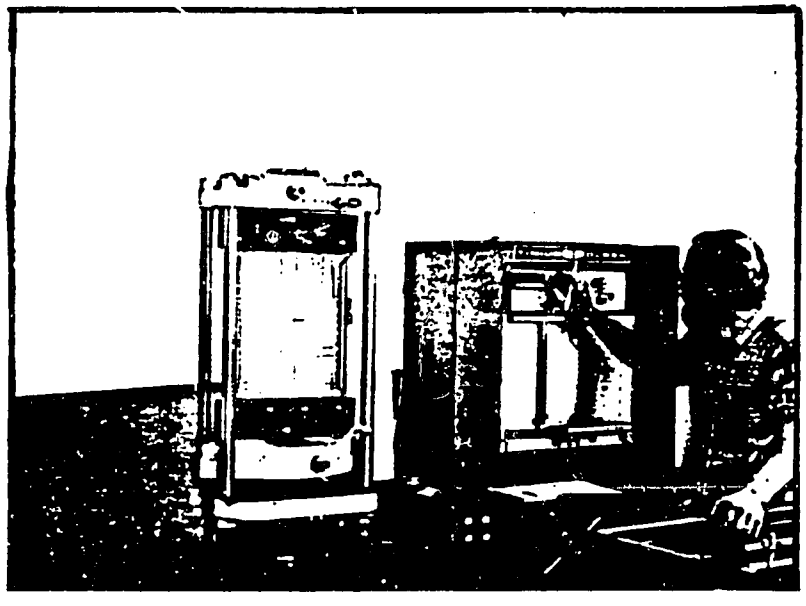
14.

Rope batten detail after failure.



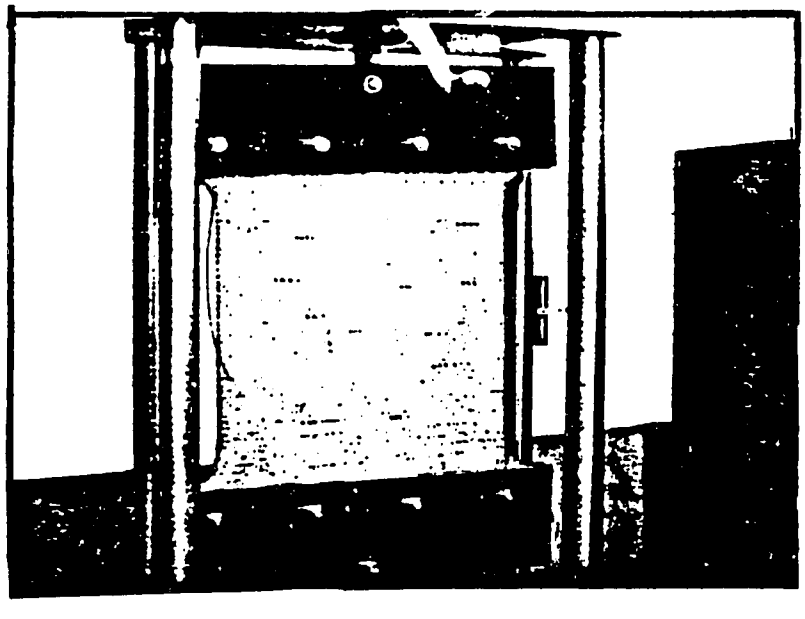
15.

Detail of where the rope pulled through the plastic.



16.

Adjusting the Tinius Olsen machine prior to loading.

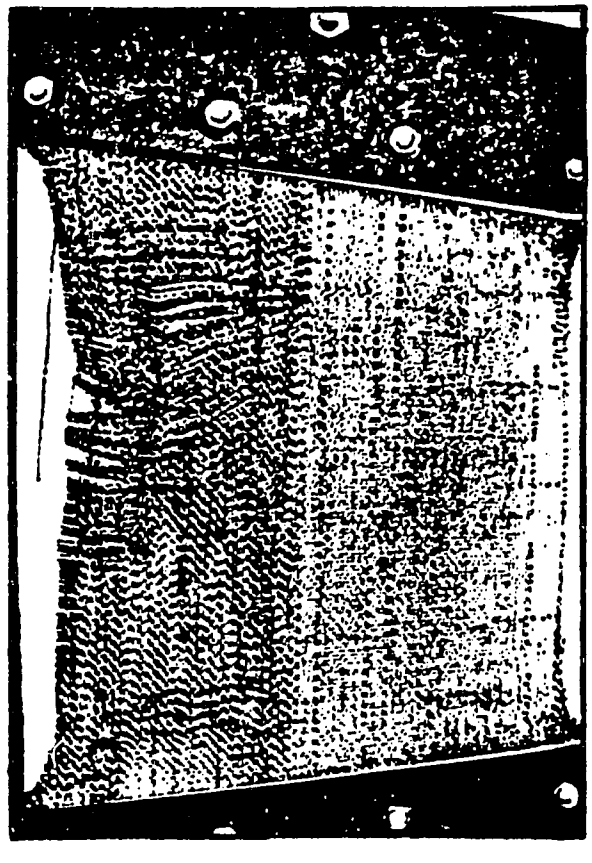


17.

Test sample just prior to failure.

18.

Test sample after failure.



19

Detail of sample after failure.

Appendices

A. Administrative Data 51

B. Plastic Sheeting Data 52

C. Testing Data 53

D. Thermal Performance Data 57

Appendix A: Administrative Data

CONTRACT AMOUNT		$25,000.00
CONTRACT NUMBERS	AID/OFDA FAMU/SOA	PDCV-0029-C-00-2087-00 83-002
PROJECT DATES		June 1982-May 1983

PROJECT PERSONNEL

Director		Lawrence Birch
Research Assistant		Blakeley Bruce
Structural Consultants		Ron Shaeffer Geoffrey Wright
Tensile Structures Consultant		Geoffrey Wright
Graphics Consultant		Earl Morrogh
Cultural Consultants		Trish Delamere Bill Powell
Experimentation & Monitoring		Lawrence Birch Blakeley Bruce Bill Wiencke
Translations of Field Manual		Leona Le Blanc Ramadan Seyam Marie Vivas
Editing		Ann M. Bruce Nancyanne Ropke
Typing	Field Manual Summary Report	Francisco Vivas Marie Hilaman
OFDA Review		George McCloskey Harry Wilkinson George Beauchamp Gudron Huden Weston Emery

OTHER PROJECT DOCUMENTS

Manual for Building Temporary Emergency Shelters: A Multi-Lingual Field Manual. 1982.

Report of Field Test: Popayan Columbia. 1983.

Appendix B: Plastic Sheeting Data

Name of material	Scrimweve TM -1244
Manufacturer	Protective Plastics, Inc. 230 Silver Creek Road Greer, South Carolina 29651 (803) 268-7551
Woven Core	High-density polyethylene woven tapes. Twelve tapes per inch in both directions. Tapes are carbon impregnated to resist ultra-violate light. Thickness 10 mils (.010 inches).
Film Coatings	Low density polyethylene film on each side of the woven core. Thickness 1 mil (.001 inches) each side.
Color	The film on one side of the woven core is tan, the film on the other side is white.
Total Thickness of Sheeting	12 mils (.012 inches)
Finished Weight	6.5 oz/sq.yd. or 117 lbs./roll
Grab Tensile Strength	165 lbs/inch both directions ASTM TEST D 1682-64
Seam Strength	The seam shall be either heat sealed or extrusion sealed. All seams shall be smooth and fully adhered throughout their length and shall be free of puckers and air pockets.
Tongue Tear Strength	60 lbs. both directions ASTM TEST 2261-73
Mullen Burst Strength	350 psi ASTM TEST D 751-73
Hydrostatic Resistance	144 psi
Roll size	7.9 meters (26 ft.) wide 30.5 meters (100 ft.) long DIMENSIONS ARE PLUS OR MINUS 1%
Approximate Cost	$150/1000 sq. ft. or $390/Roll
Flame Retardancy	Sheets shall meet the requirements of CPAI Specification B4 Section 7. CANVAS PRODUCTS ASSOCIATION INTERNATIONAL
Weathering	Fabric shall be ultraviolet stablized such that it will resist UV degradation for a period of at least one year in a high sunlight environment.

Appendix C: Testing Data

The following results are from the tests described in section 1.0 Strength of Materials. Three samples were tested for each of the twenty-five test categories. The three test results and the average are listed here.

A. Testing the Tensile Strength of New Plastic Sheeting

1.	Parallel to the machine direction Average 6.5 KN	6.57 KN 6.54 KN 6.50 KN
2.	Parallel to the fill direction Average 6.4 KN	6.57 KN 6.22 KN 6.43 KN
3.	45 degree to the machine direction Average 2.7 KN	2.78 KN 2.78 KN 2.41 KN

B. Testing the Strength of Different Plastic-to-Plastic Attachment Details

1.	Single sided taped joint with plastic overlap Average 1.3 KN	1.33 KN 1.29 KN 1.31 KN
2.	Double sided taped joint with plastic overlap Average 2.6 KN	2.67 KN 2.58 KN 2.52 KN
3.	Single sided taped joint with no plastic overlap (butt joint) Average 1.5 KN	1.43 KN 1.42 KN 1.50 KN
4.	Double sided taped joint with no plastic overlap (butt joint) Average 3.3 KN	3.38 KN 3.10 KN 3.36 KN
5.	Twine lashed joint with 150 mm between lashings and one wrap Average 0.7 KN	0.73 KN 0.63 KN 0.69 KN
6.	Twine lashed joint with 150 mm between lashings and three wraps Average 1.0 KN	0.96 KN 1.05 KN 1.06 KN
7.	Bamboo lashed joint with 150 mm between Lashings and three wraps Average 1.0 KN	0.94 KN 0.96 KN 1.02 KN

C. Testing the Strength of Different Plastic-to-Rope Attachment Details

1.	Protective Plastics connector Average 0.9 KN	0.86 KN 0.90 KN 0.89 KN
2.	Griffoun connector Average 0.6 KN	0.52 KN 0.80 KN 0.51 KN
3.	Rock-tie connectors Average 1.1 KN	1.13 KN 1.01 KN 1.22 KN
4.	Lash connection Average 0.5 KN	0.54 KN 0.48 KN 0.49 KN

D. Testing the Strength of Different Plastic-to-Timber Attachment Details

1.	50 mm nails placed 50 cm o.c. Through wood battens Average 1.2 KN Failure mode - nail pull out	1.22 KN 1.16 KN 1.16 KN
2.	65 mm nails placed 50 cm o.c. Through wood battens Average 2.4 KN Failure Mode - nail pull out	2.20 KN 2.71 KN 2.22 KN
3.	75mm nails placed 50 cm o.c. Through wood batten Average 4.0 KN Failure Mode - nail pull out	3.78 KN 4.37 KN 3.88 KN
4.	75 mm nails placed 50 cm o.c. Through rope batten Average 4.1 KN Failure Mode - nail pullout and nail pull through	2.99 KN 4.08 KN 5.24 KN
5.	75 mm nails placed 50 cm o.c. Through folded plastic washers (4 ply) Average 2.0 KN Failure Mode - nail pull through	1.59 KN 2.42 KN 2.03 KN 2.03 KN
6.	75 mm nails placed 50 cm o.c. Through folded plastic batten (4 ply) Average 2.8 KN Failure Mode - nail pull through	2.79 KN 2.69 KN 2.89 KN

7. 75 mm nails placed 50 cm o.c. Through automobile tire washers Average 4.9 KN Failure Mode - nail pull out

4.87 KN	
5.04 KN	
4.72 KN	

8. 75 mm nails placed 50 cm o.c. Through bottle cap washers Average 3.0 KN Failure Mode - nail pull through

3.26 KN	
2.69 KN	
3.09 KN	

E. Testing the Tensile Strength of Plastic Sheeting That is 12 Months Old

1. Samples stored and unused Average 5.8 KN

5.67 KN	
5.74 KN	

2. Samples removed from BRE structure Average 4.5 KN

4.45 KN	
4.30 KN	
4.64 KN	

3. Samples removed from pole-tent structure Average 4.1 KN

4.02 KN	
4.05 KN	
4.24 KN	

Conversion Table

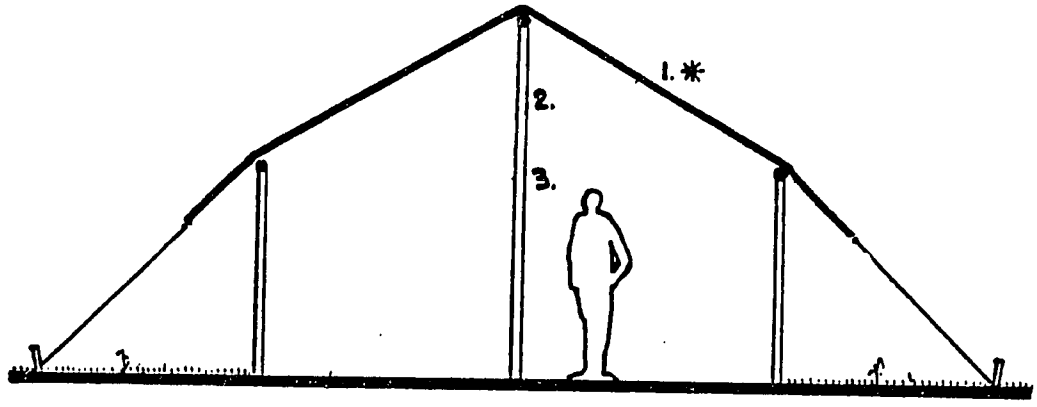
POUND-FORCE TO NEWTONS (1 lbf = 4.448 22 N)

POUND-FORCE	0	1	2	3	4	5	6	7	8	9
	NEWTONS (N)									
0	..	4.45	8.90	13.34	17.79	22.24	26.69	31.14	35.59	40.03
10	44.48	48.93	53.38	57.83	62.28	66.72	71.17	75.62	80.07	84.52
20	88.96	93.41	97.86	102.31	106.76	111.21	115.65	120.10	124.55	129.00
30	133.45	137.89	142.34	146.79	151.24	155.69	160.14	164.58	169.03	173.48
40	177.93	182.38	186.83	191.27	195.72	200.17	204.62	209.07	213.51	217.96
50	222.41	226.86	231.31	235.76	240.20	244.65	249.10	253.55	258.00	262.45
60	266.89	271.34	275.79	280.24	284.69	289.13	293.58	298.03	302.48	306.93
70	311.38	315.82	320.27	324.72	329.17	333.62	336.06	342.51	346.96	351.41
80	355.86	360.31	364.75	369.20	373.65	378.10	382.55	387.00	391.44	395.89
90	400.34	404.79	409.24	413.68	418.13	422.58	427.03	431.48	435.93	440.37
	0	10	20	30	40	50	60	70	80	90
100	444.8	489.3	533.8	578.3	622.8	667.2	711.7	756.2	800.7	845.2
200	889.6	934.1	978.6	1023.1	1067.6	1112.1	1156.5	1201.0	1245.5	1290.0
300	1334.5	1378.9	1423.4	1467.9	1512.4	1556.9	1601.4	1645.8	1690.3	1734.8
400	1779.3	1823.8	1868.3	1912.7	1957.2	2001.7	2046.2	2090.7	2135.1	2179.6
500	2224.1	2268.6	2313.1	2357.6	2402.0	2446.5	2491.0	2535.5	2580.0	2624.5
600	2668.9	2713.4	2757.9	2802.4	2846.9	2891.3	2935.8	2980.3	3024.8	3069.3
700	3113.8	3158.2	3202.7	3247.2	3291.7	3336.2	3380.6	3425.1	3469.6	3514.1
800	3558.6	3603.1	3647.5	3692.0	3736.5	3781.0	3835.5	3870.0	3914.4	3958.9
900	4003.4	4047.9	4092.4	4136.8	4181.3	4225.8	4270.3	4314.8	4359.3	4403.7
1000	4448.2	4492.7	4537.2	4581.7	4626.1	4670.6	4715.1	4759.6	4804.1	4848.6
1100	4893.0	4937.5	4982.0	5026.5	5071.0	5115.5	5159.9	5204.4	5248.9	5293.4
1200	5337.9	5382.3	5426.8	5471.3	5515.8	5560.3	5604.8	5649.2	5693.7	5738.2
1300	5782.7	5827.2	5871.7	5916.1	5960.6	6005.1	6049.6	6094.1	6138.5	6183.0
1400	6227.5	6272.0	6316.5	6361.0	6405.4	6449.9	6494.4	6538.9	6583.4	6627.8
1500	6672.3	6716.8	6761.3	6805.8	6850.3	6894.7	6939.2	6983.7	7028.2	7072.7
1600	7117.2	7161.6	7206.1	7250.6	7295.1	7339.6	7384.0	7428.5	7473.0	7517.5
1700	7562.0	7606.5	7650.9	7695.4	7739.9	7784.4	7828.9	7873.3	7917.8	7962.3
1800	8006.8	8051.3	8095.8	8140.2	8184.7	8229.2	8273.7	8318.2	8362.7	8407.1
1900	8451.6	8496.1	8540.6	8585.1	8629.5	8674.0	8718.5	8763.0	8807.5	8852.0
2000	8896.4									

NOTE: 1000 newtons (N) equal 1 kilonewton (1kN). The lower portion of the table could also have been shown in kilonewtons; for example, 4893.0 N = 4.8930 kN. The table can also be used for the conversion of kips (1000 lbf) to kilonewtons (kN), since a multiplier of 1000 applies to both measurements units.

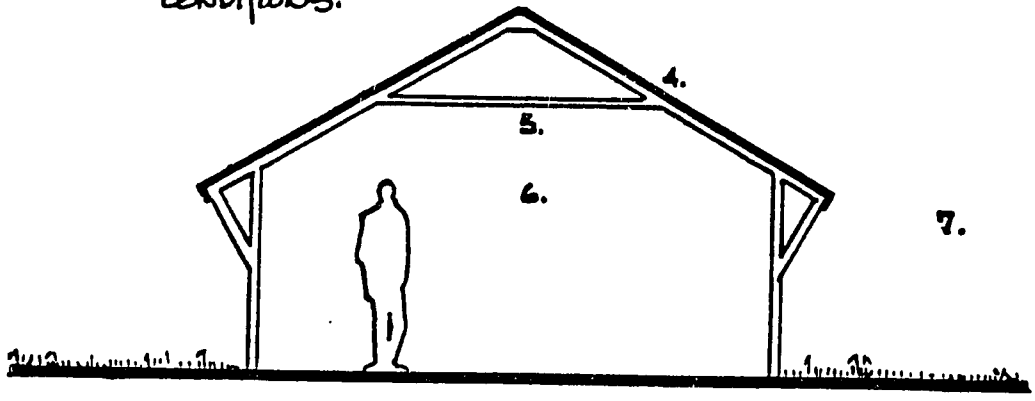
Appendix D: Thermal Peformance Data

LOCATION OF THERMOCOUPLES



NOTE:

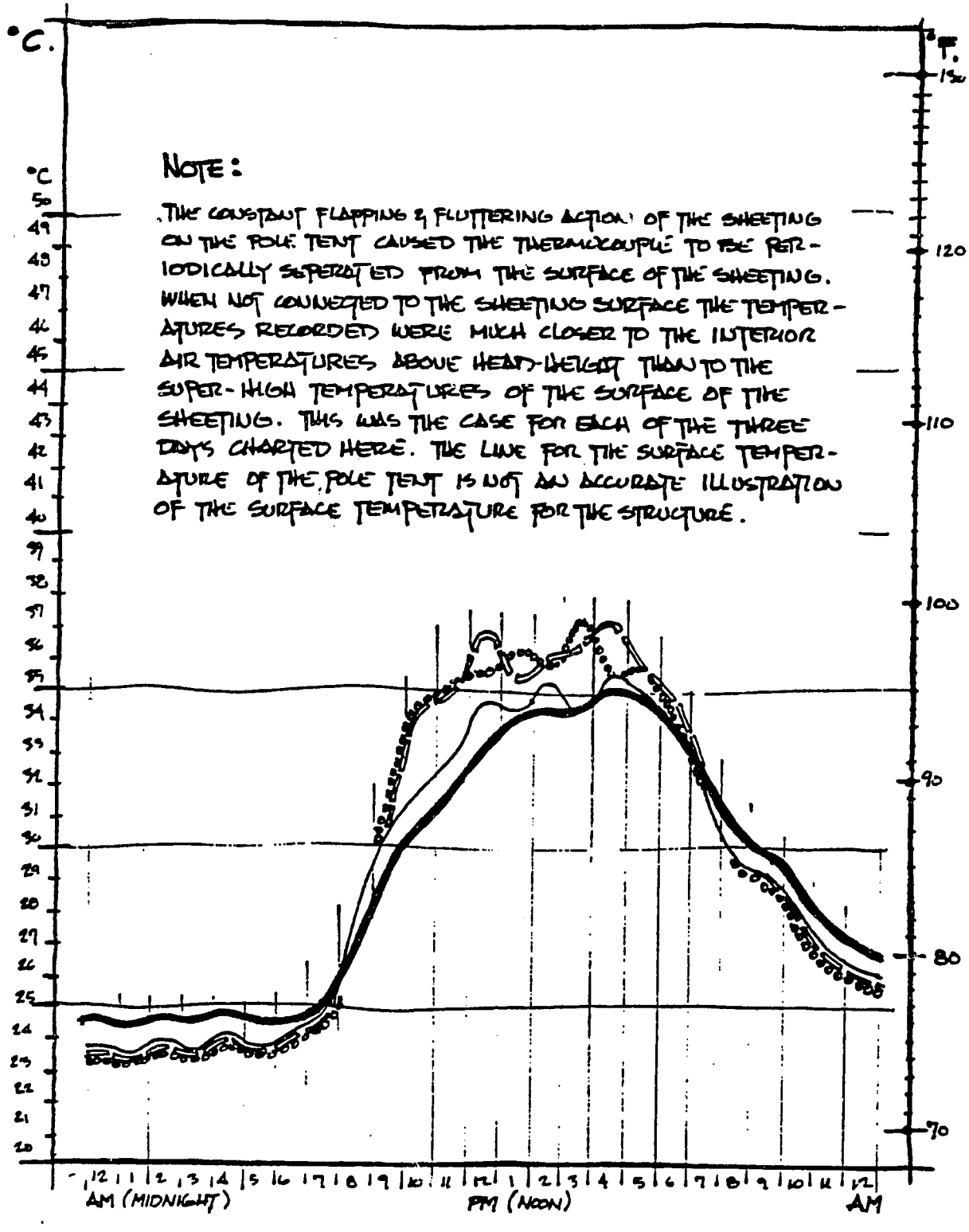
THE PLASTIC SHEETING ON BOTH STRUCTURES HAD THE TAN SIDE FACING OUT AND THE WHITE SIDE FACING IN. THIS PROVIDED AN OPPORTUNITY TO MONITOR THE "WORST POSSIBLE" THERMAL CONDITIONS.



1.	THERMOCOUPLE	# 79 ·	POLE TENT	- SURFACE TEMPERATURE *
2.	"	# 78 ·	"	- AIR TEMPERATURE ABOVE HEAD HEIGHT
3.	"	# 77 ·	"	- AIR TEMPERATURE AT HEAD HEIGHT
4.	"	# 76 ·	BRE FRAME	- SURFACE TEMPERATURE
5.	"	# 75 ·		- AIR TEMPERATURE ABOVE HEAD HEIGHT
6.	"	# 74 ·		- AIR TEMPERATURE AT HEAD HEIGHT
7.	"	# 21 ·	AMBIENT OUTSIDE AIR TEMPERATURE (DRY BULB)	

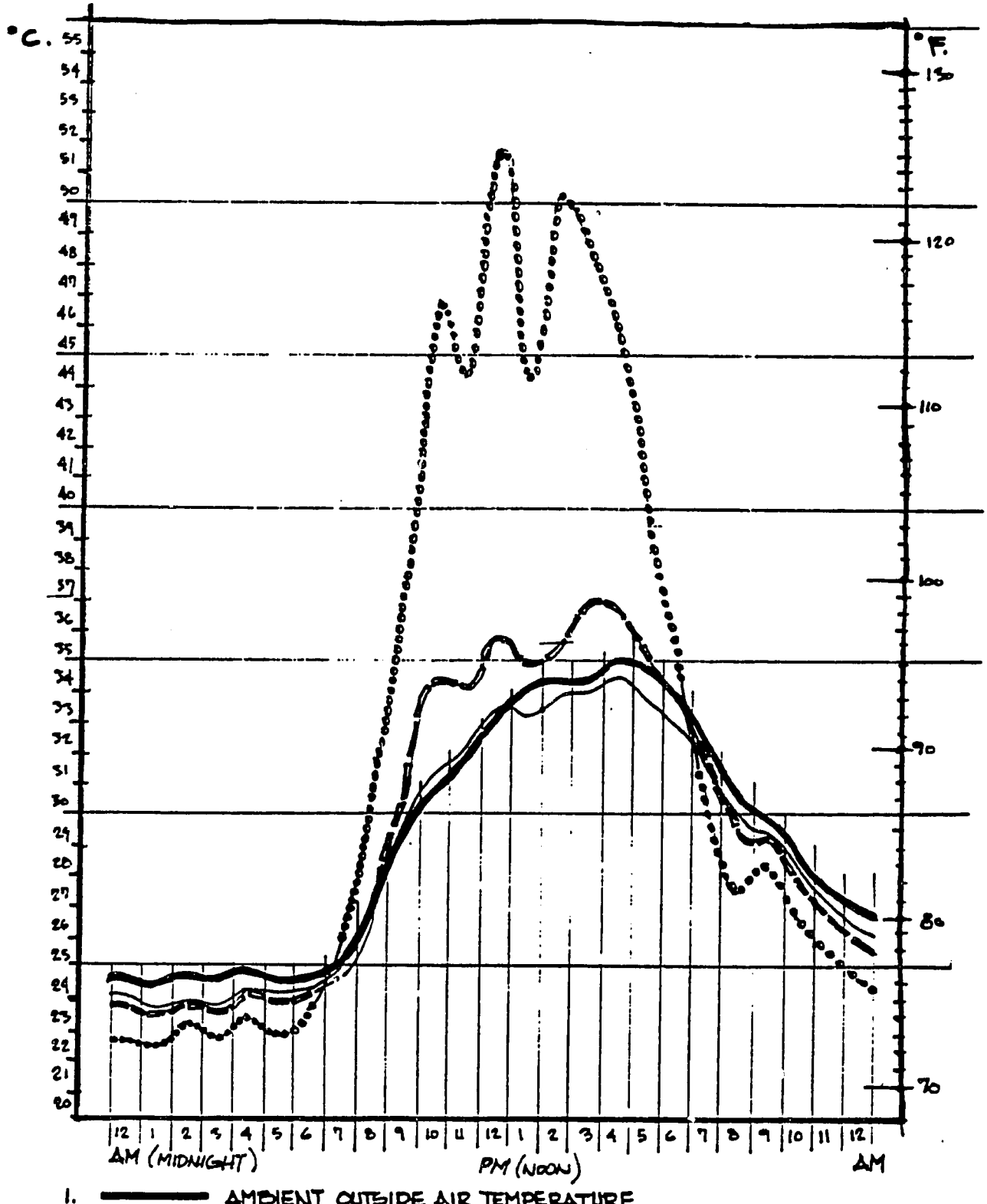
* THIS THERMOCOUPLE HAD BROKEN LOOSE FROM THE SURFACE OF THE SHEETING.

DAY 208 • POLE TENT



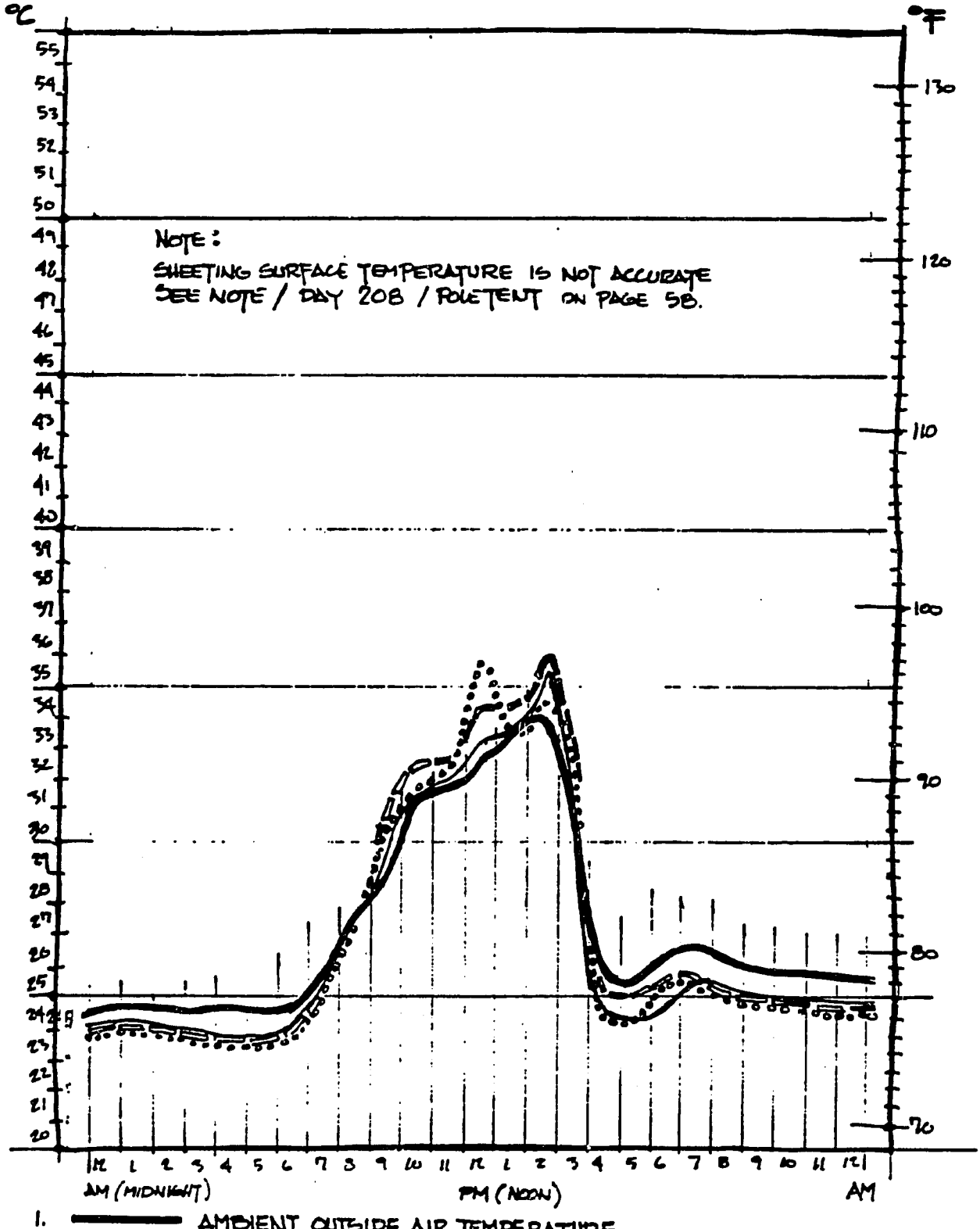
1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD-HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

DAY 208 · BRE FRAME



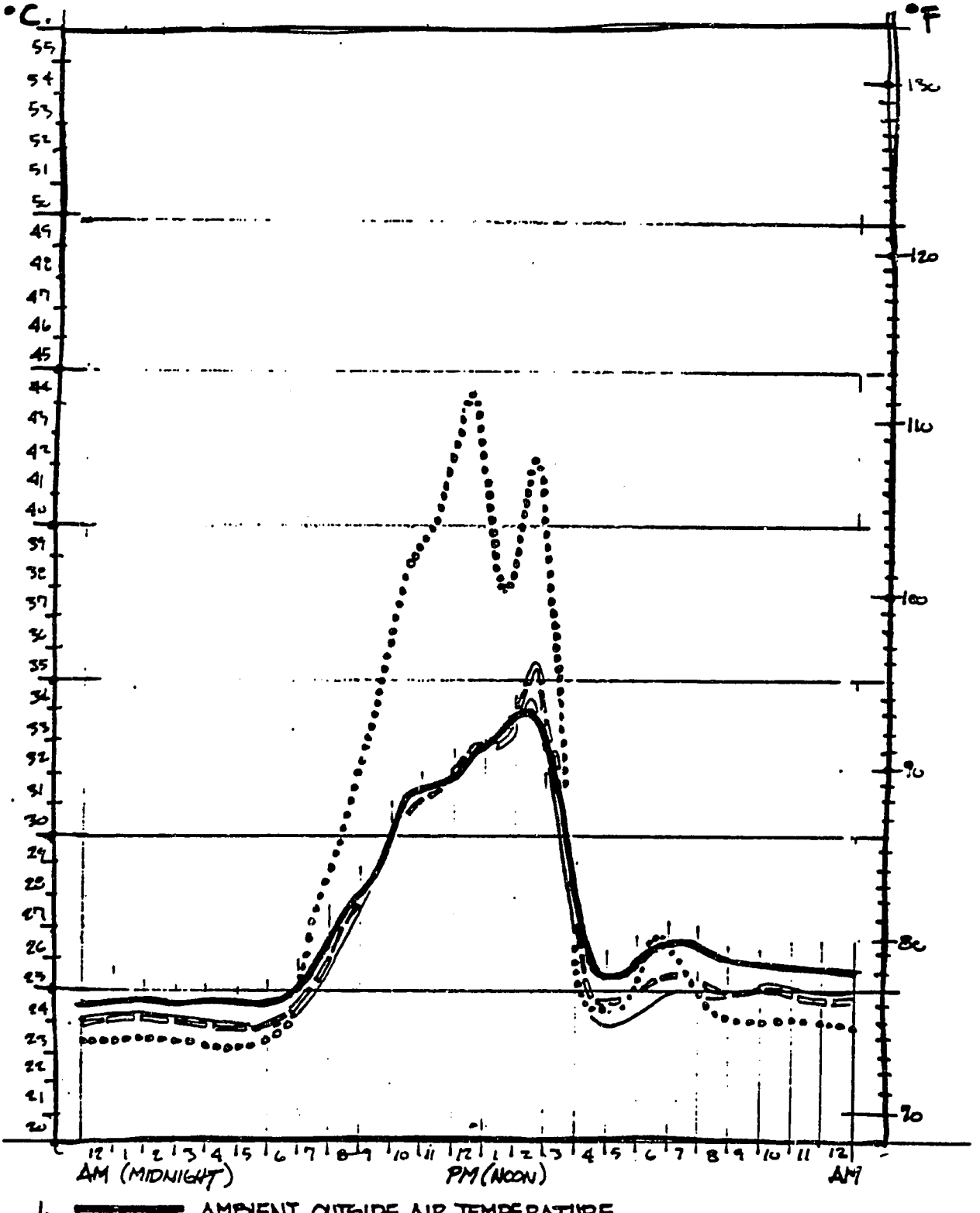
1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD-HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

DAY 212 · POLE TENT



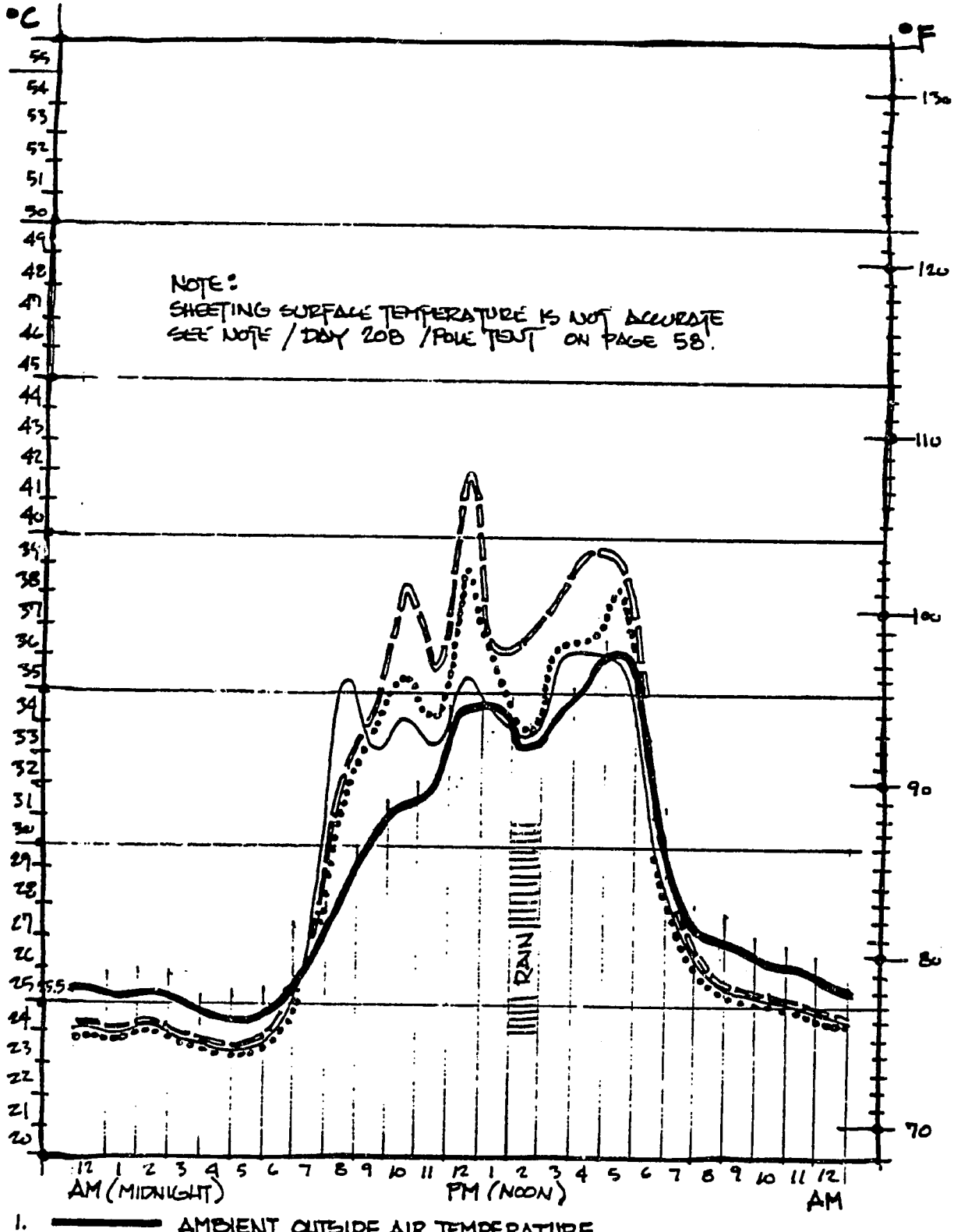
1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

DAY 212 · BRE FRAME



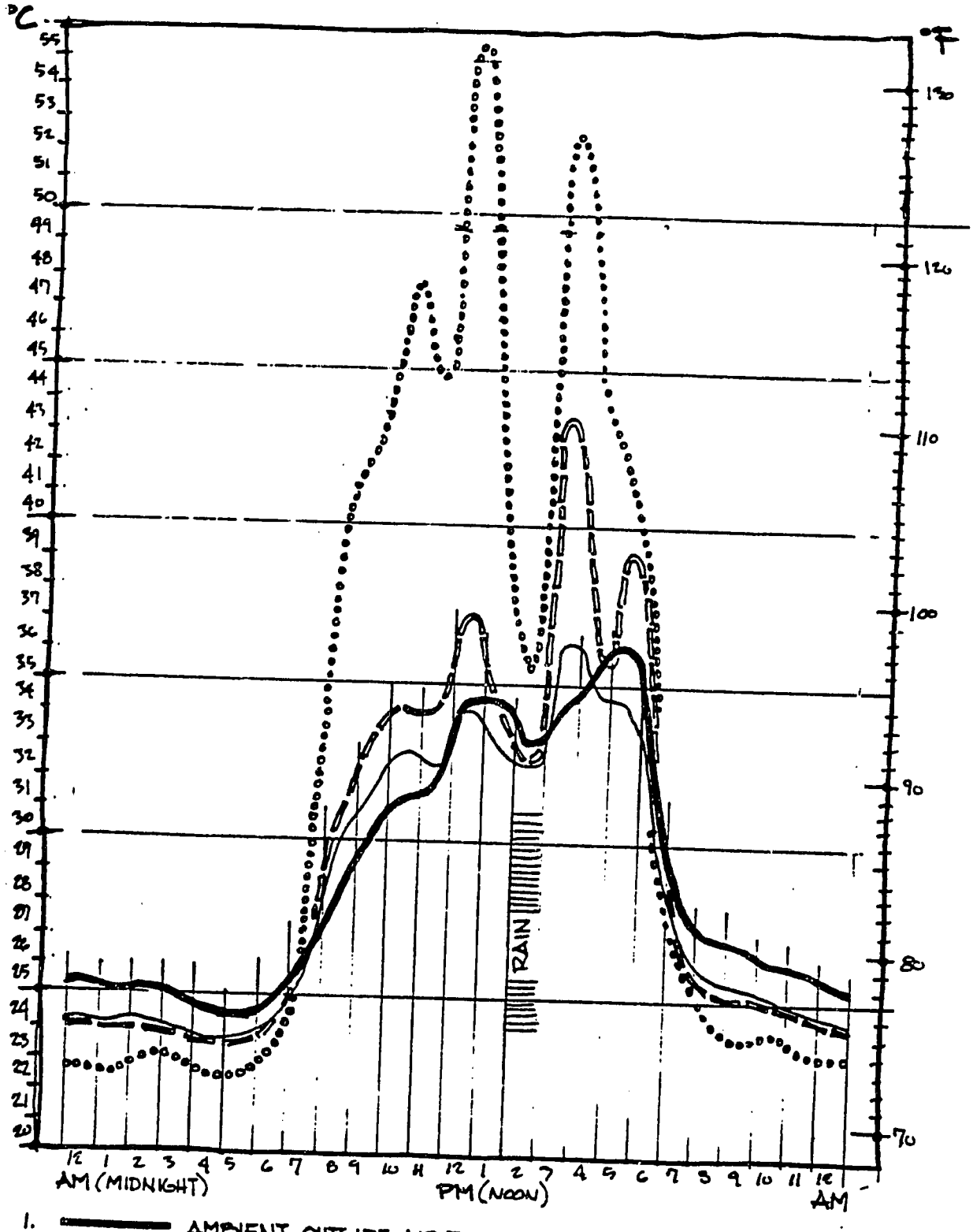
1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD-HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

DAY 217 • POLE TENT



1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD-HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

DAY 217 • BRE FRAME



1. AMBIENT OUTSIDE AIR TEMPERATURE
2. SURFACE TEMPERATURE OF ROOF
3. INSIDE AIR TEMPERATURE ABOVE HEAD HEIGHT
4. INSIDE AIR TEMPERATURE AT HEAD-HEIGHT

TYPICAL DATA-LOGGER PRINTOUT

```
        18    28.8 °C
        17    25.4 °C
        15    24.7 °C
20:00   180

        79    27.8 °C ←—— POLE TENT - SURFACE TEMPERATURE
        78    28.2 °C ←—— POLE TENT - TOP THERMOCOUPLE (ABOVE HEAD-HEIGHT)
        77    27.7 °C ←—— POLE TENT - BOTTOM THERMOCOUPLE (HEAD-HEIGHT)
        76    27.2 °C ←—— BRE FRAME - SURFACE TEMPERATURE
        75    27.7 °C ←—— BRE FRAME - TOP THERMOCOUPLE (ABOVE HEAD-HEIGHT)
        74    27.5 °C ←—— BRE FRAME - BOTTOM THERMOCOUPLE (HEAD-HEIGHT)
        69    25.1 °C
        67    26.1 °C
        66    27.5 °C
        65    25.2 °C
        59    27.7 °C
        53    24.7 °C
        52    28.0 °C
        51    30.9 °C
        50    22.0 °C
        49    23.1 °C
        48    24.0 °C
        44    25.3 °C
        43    26.7 °C
        42    29.3 °C
        41    27.6 °C
        32    36.9 °C
        31    36.1 °C
        30    42.3 °C
        29    45.2 °C
        28    44.4 °C
        27    45.6 °C
        26    38.1 °C
        25    41.8 °C
        24    41.8 °C
        23    41.8 °C
        22    24.7 °C
        21    28.5 °C ←—— AMBIENT AIR TEMPERATURE
        19    28.4 °C
        18    29.9 °C
        17    26.4 °C
        16    24.7 °C
19:00   180 ←———————— TIME OF DAY (7:00 PM) & DAY NUMBER (180)

        79    30.4 °C
        78    31.1 °C
        77    29.5 °C
        75    31.0 °C
        75    31.6 °C
        74    29.3 °C
```

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