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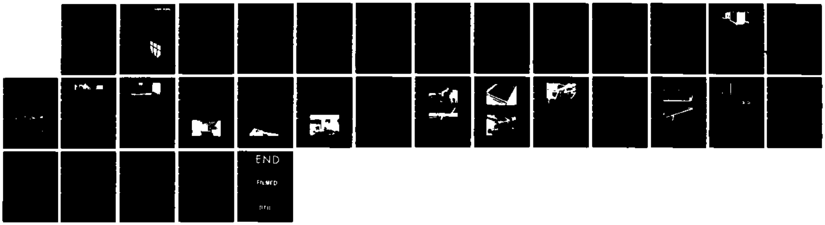

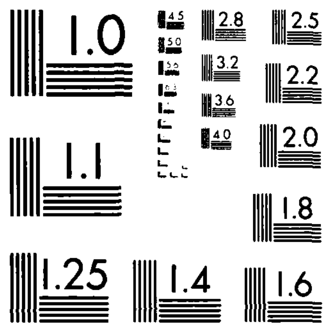

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US Army Corps
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TECHNICAL REPORT M-85/10
April 1985
Rapidly Erectable and Relocatable Lightweight Structures

Field Testing of a Lightweight Relocatable Structure in a Temperate Environment

by
Anthony M. Kao
John S. Carr
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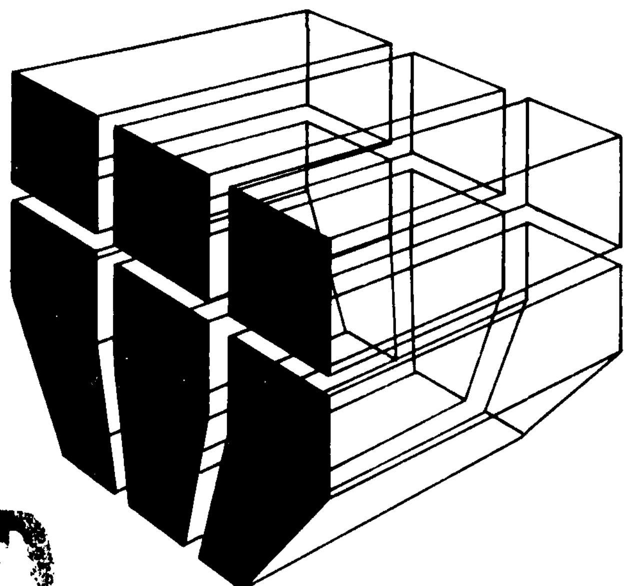
This report describes field tests of a commercially available, off-the-shelf, lightweight relocatable structure (LRS) system selected for possible military use in a theater of operations. A panelized system manufactured by Kelly Klosure, Inc. was selected to determine the constructibility, durability, and habitability of the building system. The first stage tests were conducted in a desert environment (Fort Irwin, CA) and stage II tests were conducted in a temperate environment (Fort Leonard Wood, MO). The results of stage I tests are documented in U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report M-361, *Field Testing of a Lightweight Relocatable Structure in a Desert Environment*, A. M. Kao, et al. (USA-CERL, 1984). This report documents the results of the stage II tests.



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This report describes field tests of a commercially available, off-the-shelf, lightweight relocatable structure (LRS) system selected for possible military use in a theater of operations. A panelized system manufactured by Kelly Klosure, Inc. was selected to determine the constructibility, durability, and habitability of the building system. The first stage tests were conducted in a desert environment (Fort Irwin, CA) and stage II tests were conducted in a temperate environment (Fort Leonard Wood, MO). The results of stage I tests are documented in U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report M-361, *Field*

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Constructibility of the buildings varies, depending on size. The tests confirm that the 20-ft-wide × 8-ft-high buildings can be erected manually by unskilled troop labor using only hand tools. However, for 12-ft-high structures assembled using 4- × 8-ft panels, and for 12-ft-high structures on elevated foundation/baseplates, a crane is needed to help lift assembled components for the erection. Elevated foundation/baseplates greatly increase construction difficulty and construction times.

It took an average of 109 man-hours to assemble and erect a 20- × 8- × 40-ft building on an elevated baseplate, whereas it took only 38 man-hours to assemble and erect an identical building on a standard baseplate in the Fort Irwin tests. The drastic construction time increase was due not only to the elevated baseplates, but also because personnel erecting the structures considered it a training process and thus took a lot of time demonstrating, explaining, and correcting.

Some durability problems were identified which did not occur in the Fort Irwin tests. Fiberboard panels used in the structure had severe weather resistance problems because they wicked in water around the edges and rivets. The galvanized steel panels had no durability problems.

Fiberboard structures are favored for habitability. The environmental tests indicated that fiberboard structures generally stay 3.5 to 5.5°C cooler than identical steel structures on warm days. Adding insulation to a galvanized steel structure decreases the maximum temperatures 4.0 to 7.5°C, and adding insulation to a fiberboard structure decreases the maximum temperatures 2.0 to 3.5°C. Based on environmental performance alone, a fiberboard structure would be a good choice and an insulated fiberboard structure would give even better results.

However, durability problems currently make fiberboard a poor choice for all but extremely arid climates. The moisture wicking delaminates the panels, decreasing their strength and making them susceptible to damage in handling. New and improved methods for weather-proofing fiberboard panels are currently being explored. Therefore, unless the fiberboard moisture problem is corrected, insulated galvanized steel structures would be a better choice in terms of durability and environmental performance.

Additionally, a study has been funded for Fiscal Year 1985 on ways to improve the Kelly Klosure system by eliminating the guy wires. It is recommended that the guyless design modifications be completed, tested, and incorporated into the system design.

FOREWORD

This research was performed for the Office of the Assistant Chief of Engineers (OACE) by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). The work was done under Project 4A162731AT41, "Military Facilities Engineering Technology"; Task Area E, "Military Engineering"; Work Unit 049, "Rapidly Erectable and Relocatable Lightweight Structures." The OACE Technical Monitors were Dr. Clement Meyer, DAEN-ZCM and Mr. Michael Shama, DAEN-ZCM.

Dr. A. Kao was the USA-CERL Principal Investigator. Dr. R. Quattrone is Chief of USA-CERL-EM. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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FIELD TESTING OF A LIGHTWEIGHT RELOCATABLE STRUCTURE IN A TEMPERATE ENVIRONMENT

1 INTRODUCTION

Background

The Army Facilities Component System (AFCS) provides facilities for two different construction standards: initial (0 to 6 months) and temporary (6 to 24 months). Most AFCS systems are designed to meet the temporary requirements and thus are assumed to meet or surpass initial construction standards. Since AFCS does not include many facilities that meet only initial construction standards, there is a need for building types which fulfill these requirements.

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) was asked to identify and evaluate lightweight relocatable structures (LRS) for use in AFCS. USA-CERL has completed a study to identify and evaluate LRS being used by the military and private industry that meet AFCS requirements for initial temporary construction standards.[1] The study concluded that, with some exceptions, the Department of Defense's current inventory of LRS does not meet current theater of operations (TO) needs.

Most of the systems identified were expensive and exceeded military activity requirements. Furthermore, they did not adapt effectively to various climates without the use of mechanical systems. Nevertheless, a commercial off-the-shelf system suitable for military use was found which met the needs of AFCS structures under 60 ft. wide.*

To evaluate the feasibility of the identified system, two-stage field tests were conducted. The first stage of the study, completed in October 1983, field tested the LRS in a desert environment at Fort Irwin, CA.[2] This report documents the results of the second stage of the field tests, in a temperate environment.

Fort Leonard Wood, MO, was chosen for stage II testing because it exhibits temperate climate characteristics with respect to diurnal temperature change, relative humidity, and precipitation.

Objective

The objective of field testing the selected LRS in a temperate environment was to: (1) monitor and evaluate the erection procedures of the selected building system to determine its constructibility, durability, and habitability, (2) study the effect of building modifications and various building configurations on the system's habitability, and (3) confirm and expand on results from the first-stage tests in a desert environment.

Approach

LRS were evaluated according to established military construction criteria, and the system which best met the requirements was chosen for field testing. A site for testing the system in a temperate environment was selected and the system was evaluated in terms of its constructibility, durability, and habitability. The test results were evaluated and modifications were suggested to improve system performance.

Mode of Technology Transfer

It is recommended that the results of this field test be incorporated into Army Technical Manuals 5-301, 5-302, and 5-303.[3]

2 STRUCTURAL SYSTEM DESCRIPTION

AFCS Design Criteria

The major concern in LRS systems development has been their capability to be field-erected in the TO. The system must be easily shipped and erectable in the field as well as capable of being modified to meet climatic or other TO demands. A system to be

[1] Kao, A. M., et al., *Evaluation of Lightweight Relocatable Structures for Use in Theaters of Operations*, Technical Report M-314, ADA117038 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1982).

* Metric conversion factors are found on p. 27.

[2] Kao, A. M., et al., *Field Testing of a Lightweight Relocatable Structure in a Desert Environment*, Technical Report M-361, ADA148841 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1984).

[3] *Army Facilities Component System-Planning*, Technical Manual 5-301 (Headquarters, Department of the Army [HQ, DA], March 1982); *Army Facilities Component System Design*, TM 5-302 (HQ, DA, March 1982); *Army Facilities Component System-Logistics Data and Bills of Materials*, TM 5-303 (HQ, DA, March 1982).

included in AFCS must satisfy the following criteria for construction through standardization:

1. Minimize the time needed to erect building components.
2. Minimize weight and volume logistical requirements.
3. Be container-compatible.
4. Minimize construction costs.
5. Minimize construction skills and required equipment and maximize simplicity of erection components.

Technical objectives of a potential system include:

1. Compatibility with existing AFCS interior design.
2. Easily relocatable.
3. Easily adaptable to different climatic conditions.
4. Adequate shelf life.

Based on its ability to adapt to these AFCS requirements, the system made by Kelly Klosure, Fremont, NE, was chosen as the best commercial off-the-shelf system. This system offers a rapidly erectable structure, along with options for many building configurations. Field tests were done to evaluate the habitability, constructibility and durability of this system as they related to military use.

Kelly Klosure Description

The LRS is a modular panelized system, based on a 1- × 1½- × ⅛-in. steel frame panel. The basic sizes of panels are 4 × 4 ft, 4 × 8 ft, and 4 × 12 ft and they come in galvanized steel, structural fiberboard, and fiberglass. Corrugated galvanized steel and structural fiberboard panels were used for the test.

The galvanized panels are made from 28-gage corrugated steel. The fiberboard panel, manufactured by Simplex, has four 0.043-in. plies of water-resistant recycled paper board. Both outside layers are one ply of 40-lb hard-sized kraft board coated with 1.5 mil of polyethylene. The 4- × 8-ft galvanized steel weighs 61 lb, while the fiberboard weighs 58 lb.

The panel frame, eave angles, corner angles, ridge angles, and chord brackets are all made of M1020 merchants bar steel. Other building components include 2- × 6-in. wood chords, a 2- × 6-in. wood baseplate, lag bolts, guy wire system, and Kelly Klosure keys made of zinc-plated steel. The system is "keyed" together, eliminating most nuts and bolts; this gives quick erection and takedown times (Figure 1). Since all the components interconnect readily, a variety of configurations may be assembled using different size panels. Thus, a large variety of building sizes could be provided in a TO environment in a short period of time. The system is shipped in a storage rack of 24 to 30 panels, with additional components strapped on the top (Figure 2). Table 1 gives material costs for both galvanized steel and fiberboard for typical 20- × 8- × 40-ft and 20- × 12- × 40-ft buildings.

Construction and Erection Procedures

The Kelly Klosure system can be erected directly on unfinished ground, on a concrete slab, or on a suitable raised wood foundation. Details of the construction and erection procedures are in Appendix A of USA-CERL Technical Report M-361.

3 FIELD TEST PROGRAM

Test Method

At Fort Leonard Wood, the LRS system was tested primarily for constructibility and durability although environmental data were gathered also.

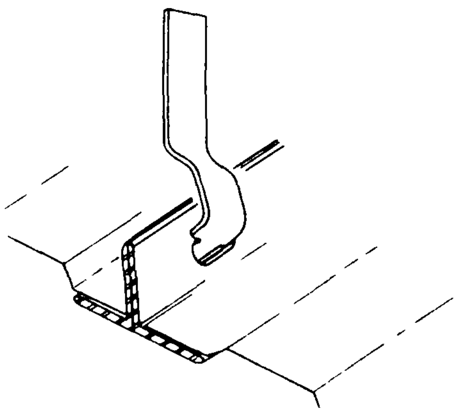


Figure 1. Kelly Klosure key.

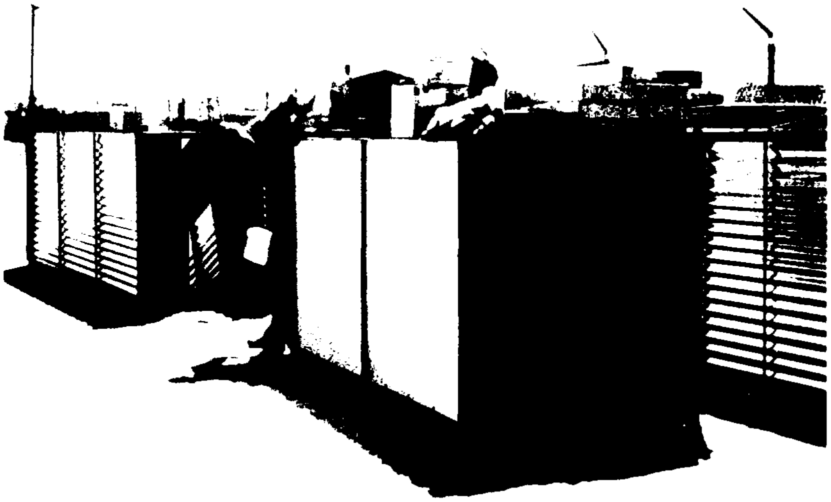


Figure 2. Panel storage rack.

Table 1
Material Costs for Galvanized Steel and Fiberboard Panel Structures

Building Configuration	Panel Insert	Base Cost*
20 × 8 × 40 ft	Galvanized Steel	$5,626.18
20 × 8 × 40 ft	Structural Fiberboard	$4,672.35
20 × 12 × 40 ft	Galvanized Steel	$6,341.13
20 × 12 × 40 ft	Structural Fiberboard	$5,081.90

* The cost (June 1984) includes the 20 percent GSA discount to F.O.B., Fremont, NE, but excludes the cost of the 2- × 6-in. lumber used for the chords and baseplate.

One building was constructed during each cycle. One control building remained in the as-built condition throughout the testing while the other buildings were assembled, disassembled and modified to isolate durability and environmental variables.

The buildings were assembled and disassembled by raw troops who are at Fort Leonard Wood for engineer training school and are rotated out after each test cycle. Thus, all construction times are from new troops with no experience in constructing Kelly Klosure buildings and also include time spent by troop instructors to explain erection procedure details while the students assemble the structures.

A time-tallying schedule was set up to record man-hours required for each task spelled out in the critical path method for the system. A checklist was completed to evaluate each building's performance.

Interior and exterior temperatures and other weather data were also collected with a portable data logger and weather station. The data were compiled and plotted on graphs to evaluate the system's habitability.

Support Systems Tested

Two components devised by USA-CERL were tested in addition to the basic components supplied by the Kelly Klosure system: an insulating system and a ground anchor.

Using an existing 20- × 8- × 40-ft experimental structure, 2 in. of rigid foil-faced, glass-reinforced, polyisocyanurate foam insulation was tested on the walls and ceiling. With a ¾-in. airspace, the insulation has an R-value of 17.2. USA-CERL developed and built a reusable wall panel bracket which incorporated the Kelly Klosure key for connecting insulation to the panels. For the top of the panels, 4- × ¼- × 10-in. steel plate was bent and slotted to match the panel key openings. Two brackets were required to hold the top of each 4- × 8-ft insulation panel to the sidewalls. Wood strips of 1 × 2 in. served as the molding and secured the insulation at the base. Ceiling brackets were designed to fit over the 2- × 6-in. chords. These were made of bent 20-gage galvanized steel metal 4 in. wide.

The standard Kelly Klosure helical screw auger anchor did not work well because it could not penetrate the extremely rocky soil. A straight pipe type anchor developed by USA-CERL, previously used in similar field tests at Fort Irwin, penetrated the ground easily but provided little lateral resistance to pull-out (Figure 3).

Description of Test Program and Test Building Construction

The test was conducted in seven cycles. The buildings tested in these cycles are shown in Table 2.

Some explanation is needed for the construction man-hours (Table 2). The construction of the Kelly Klosure structures at Fort Leonard Wood was supervised primarily by an Army engineering training school instructor and completed by a standard engineering troop training unit (primarily E-1's). At the Fort Irwin stage I field tests, the construction of the Kelly Klosure structures was supervised by USA-CERL and completed by Army personnel from many areas of military training background: [illegible] (E-[illegible] through E-6).

At Fort Leonard Wood, the work progressed slowly with the troops following explicit military training safety rules and lateral *bracing schemes*; this greatly increased overall construction times. At Fort Irwin, both USA-CERL and Fort Irwin military personnel worked at as fast a pace as possible to optimize construction times. To the troops at Fort Leonard Wood, the Kelly Klosure structures were just another type of building to learn to assemble, while at Fort Irwin, the Kelly Klosure structures were a unique building system which allowed the troops to get away from their everyday tasks. However, the construction times in Table 2 do decrease as the tests progress, which seems to indicate an increasing familiarity with the Kelly Klosure system by the troop instructors.

Baseplate/Foundation Construction

Two 20- × 40-ft baseplates were built on separate semi-permanent elevated wood foundations at the start of the test (Figure 4). The foundation consisted of heavy (8- × 8-in.) perimeter beams, 2- × 6-in. flooring supports, and 1- × 12-in. board floors (Figure 5). The foundation was erected on a slight

Table 2
Fort Leonard Wood Test Cycles

Cycle	Building 1	Building 2	Building 2 Total Construction Man-hours
[illegible]	control building 20 × 8 × 40 ft steel	steel and fiberboard 28 × 8 × 32 ft	128
[illegible]	control building 20 × 8 × 40 ft steel	steel 20 × 12 × 40 ft using 4- × 8-ft panels	119
[illegible]	control building 20 × 8 × 40 ft steel	steel using 4- × 12-ft panels 20 × 12 × 32 ft	216
[illegible]	control building 20 × 8 × 40 ft steel	fiberboard 20 × 8 × 40 ft	150
[illegible]	[illegible] building 20 × 8 × 40 ft [illegible]	fiberboard with insulation 20 × 8 × 40 ft	60*
[illegible]	[illegible]	steel 20 × 8 × 40 ft	109
[illegible]	[illegible]	steel with insulation 20 × 8 × 40 ft	[illegible]8*

*[illegible]

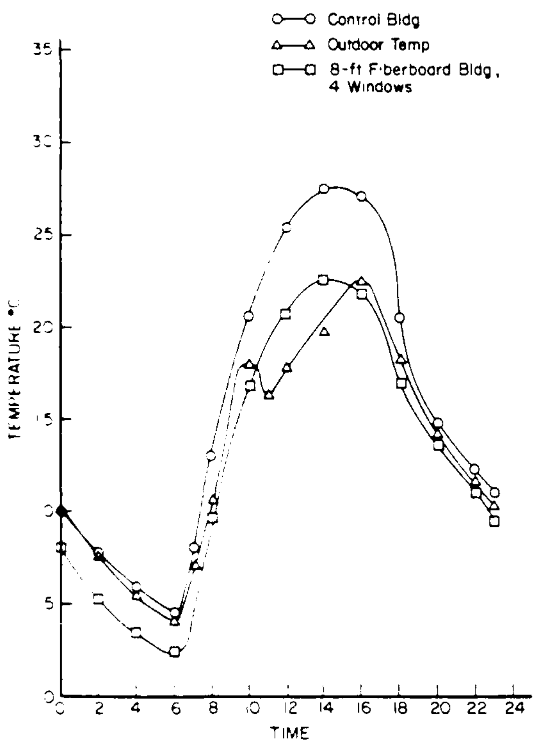


Figure 28. Temperatures at the 6-ft level for the fiberboard and control structures (warm day).

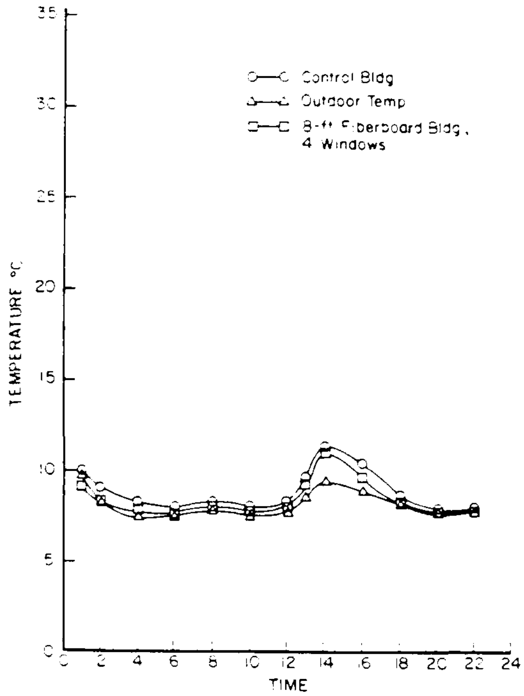


Figure 29. Temperatures at the 6-ft level for the fiberboard and control structures (cool day).

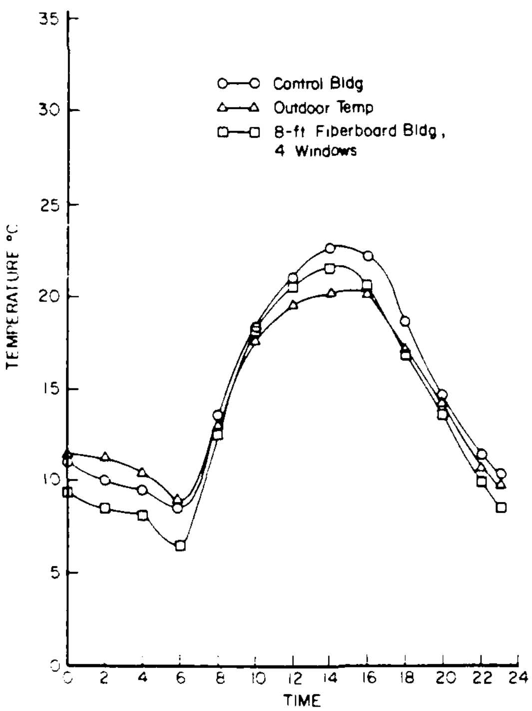


Figure 30. Temperatures at the 6-ft level for the fiberboard and control structures (average day).

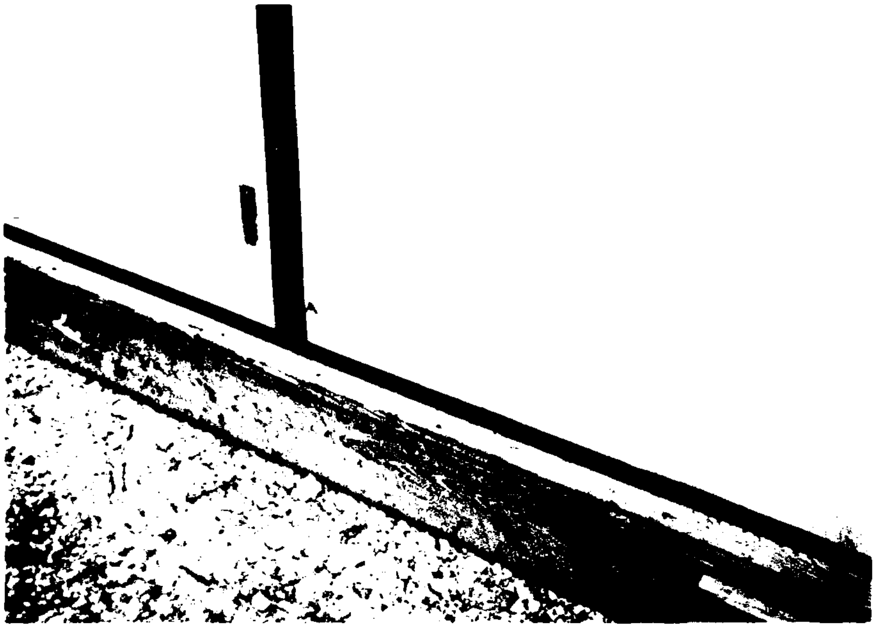


Figure 27. Sidewall moisture damage at panel base.

Effect of Panel Material

The effect of the panel material was evaluated by comparing the 20- × 8- × 40-ft fiberboard structure with the 20- × 8- × 40-ft steel control structure in test cycle 4. The comparison shows the good environmental performance of the fiberboard structure. On hot sunny days, the fiberboard structure's 6-ft temperature closely mirrored the outdoor temperature, consistently staying 3.5 to 5.5°C cooler than the control structure during the daytime (0800 to 1800 hours) (Figure 28). At night, the fiberboard structure's 6-ft level temperature stayed 2.0 to 2.5°C cooler than both the outside and control building temperatures.

On cool days, the fiberboard structure, control structure, and outdoor temperatures remained fairly constant (Figure 29) with the fiberboard structure running 0.5 to 1.0°C cooler than the control structure. On average days (high temperature 20.0°C), the fiberboard structure stayed consistently 1.0 to 2.0°C cooler than the control structure (Figure 30).

Effect of More Window Openings

The effect of more window openings was evaluated by comparing a 20- × 8- × 40-ft galvanized steel structure with 12 window panels to the 20- × 8- × 40-ft galvanized steel control structure with four window panels during test cycle 6. The average temperature difference between the test stucture with extra windows and the control structure was between 0.5 to 1.0°C, which can be considered negligible (Figures 31 and 32).

Effect of Insulation

The effect of insulation was evaluated by comparing the temperature difference between test cycles 4 and 5 and the temperature difference in test cycle 7. The insulation appears to lower the temperature about 2.0 to 3.5°C in the fiberboard structure and 4.0 to 7.5°C in the galvanized steel structure during the daytime (0800 to 1800 hours) of moderately warm to hot days (Figures 33 through 36). During the evening hours of the hottest day, the insulated steel structure stayed 2.5 to 4.0°C warmer than the control structure and the insulated fiberboard structure stayed 1.5 to 2.0°C cooler than the control structure. On the hottest day of test cycle 7, the control structure temperature at the 6-ft level peaked at 33°C, while the temperature at the 6-ft level in the insulated steel structure peaked at 26°C (Figure 35).

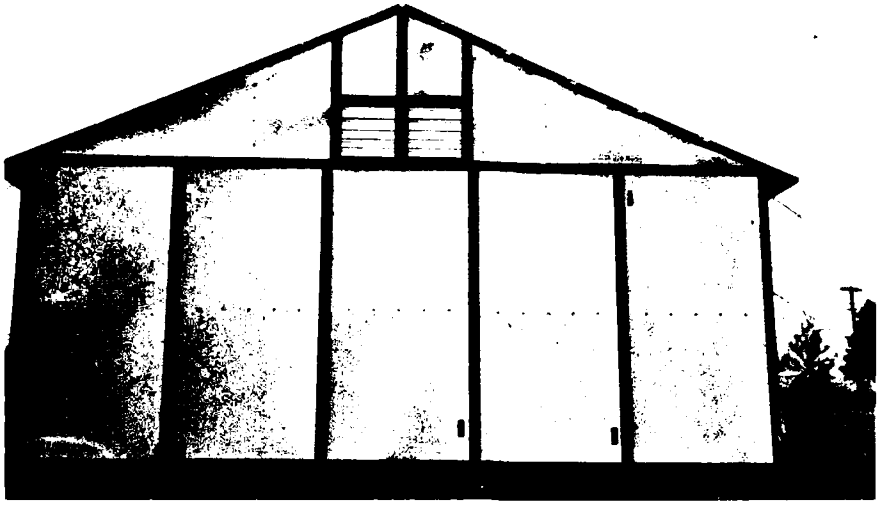


Figure 25. Gable and endwall moisture damage.

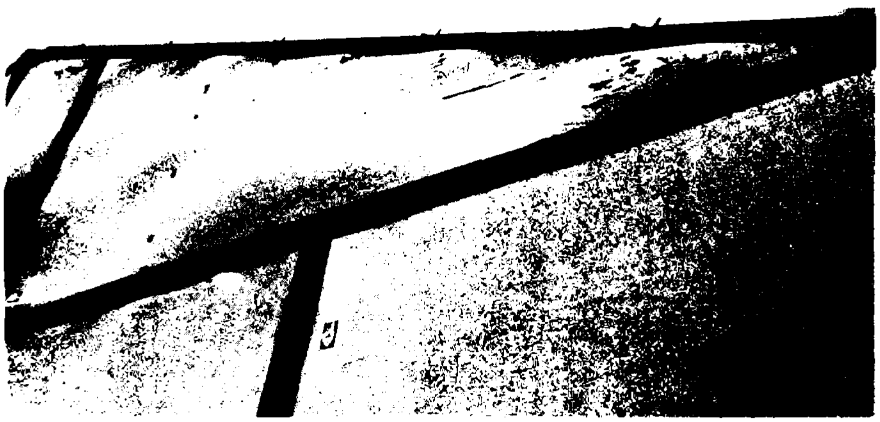


Figure 26. Gable moisture damage: buckling of fiberboard and delamination of surface material.

from Kelly Klosure is a new system and the fiberboard panels used at Fort Leonard Wood were also used in the Fort Irwin field tests and have, thus, been exposed to weather for over 1 year. Improved fiberboard panels, with caulking around all exterior rivets and exterior steel frame edges, are now being tested at Fort Leonard Wood. No noticeable deterioration has been observed on those panels. However, it is apparent that further development work is required.

Habitability Test Results

This section interprets the weather data collected at Fort Leonard Wood. During the test cycles, temperatures were recorded in both the test and control structures and outdoors. The extreme temperatures were recorded from data, and graphs were made for the extreme days. The temperatures at the 6-ft level were chosen for comparison since most occupants will feel the zone around the 4- to 6-ft level.

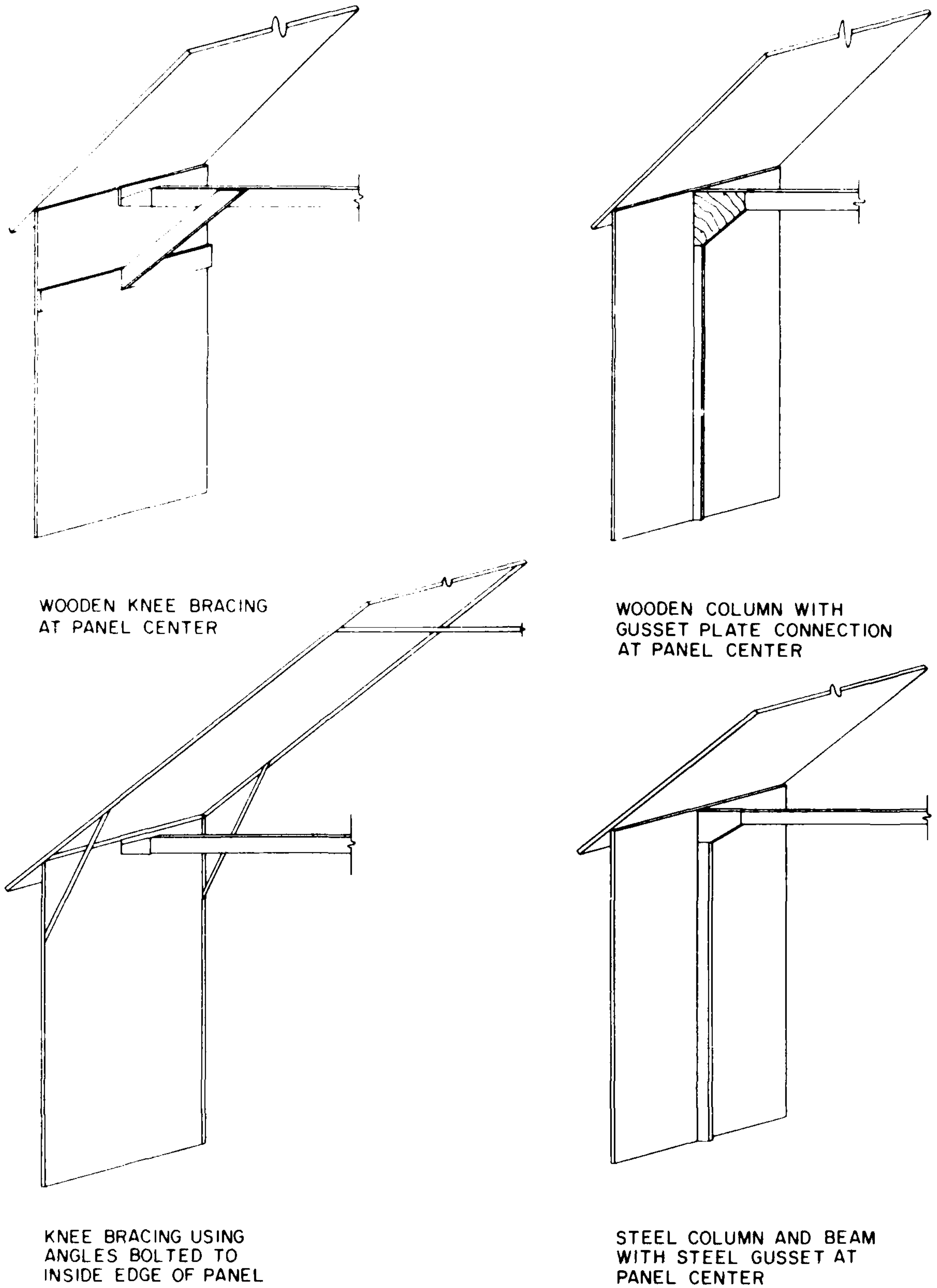


Figure 24. Lateral bracing schemes.

Figure 23. Wood kneebrace attachment to chords and sidewalls.

Guyless Design

Work has been progressing on a guyless design for a 20-ft-wide × 8-ft-high structure. The experimental wooden kneebrace system, used in the 20- × 8- × 40-ft fiberboard test structure at Fort Leonard Wood, is one way resistance to lateral forces could be accomplished. The foundation also needs to be investigated further. A ballast-type foundation needs to be incorporated into the guyless design to resist the uplift on the building. Several other types of lateral bracing systems (Figure 24) were considered by USA-CERL. After consulting with Kelly Klosure and conducting some preliminary independent research, it has been determined that there are two or three possible methods for eliminating guy wires. Further research will be done in FY85 to resolve foundation baseplate details for various soil conditions and to determine the optimum lateral bracing scheme.

Durability Test Results

The galvanized steel panel buildings showed almost no durability problems, more than meeting current AFCS requirements for temporary structures in a TO.

The fiberboard system exhibited several problems not previously noticed in the desert field tests. The fiberboard panels tested at Fort Leonard Wood exhibited extreme weathering problems. Figures 25 and 26 show peeling and delamination of the surface coating (polyethylene) from the fiberboard base material. This problem was most prevalent on the endwall gable sections, but also occurred in other areas.

Another problem first noticed at Fort Leonard Wood was the wicking of moisture by the fiberboard around the panel's perimeter and the interior crossbrace rivet points. The fiberboard panels were not caulked on the outside around the edge of the steel frame. This allowed moisture to seep down between the frame and fiberboard panel base and then up through the layers of fiberboard, causing swelling and delaminating at the panel base (Figure 27). This type of moisture problem was also obvious around the points where rivets attach the fiberboard to the interior cross brace. A perfect circle of swollen, wet, delaminated fiberboard formed around many of the interior crossbrace rivets. In the early, wet spring weather, moisture damage was visually noticeable in 50 percent or more of the fiberboard panels in the 20- × 8- × 40-ft structure.

Although the damaged fiberboard does not, in itself, allow moisture intrusion, it does greatly reduce panel strength and consequently the amount of handling and relocation that can occur without damage. Admittedly, the fiberboard panel system

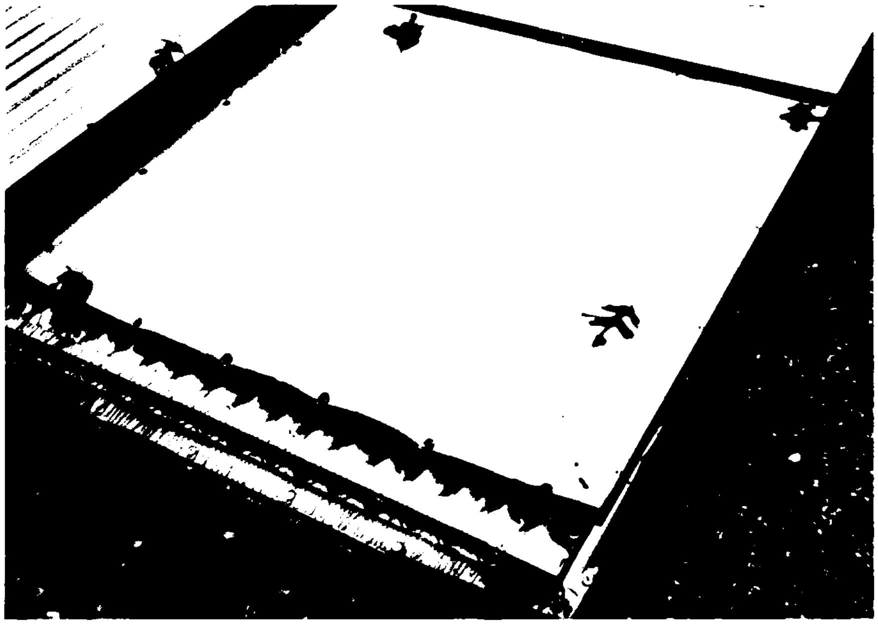


Figure 21. Damaged panel ends.

Figure 22. Wood kneebrace system

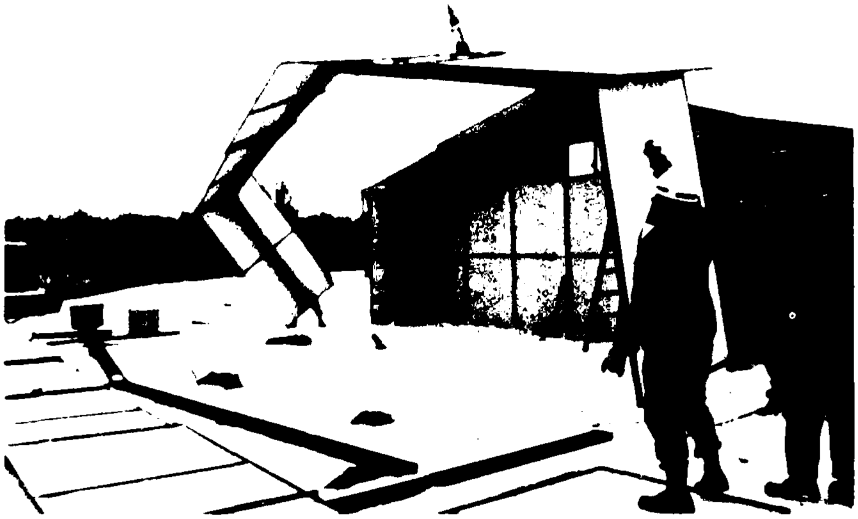


Figure 19. Erection of bay section of 28- × 8- × 32-ft test structure.

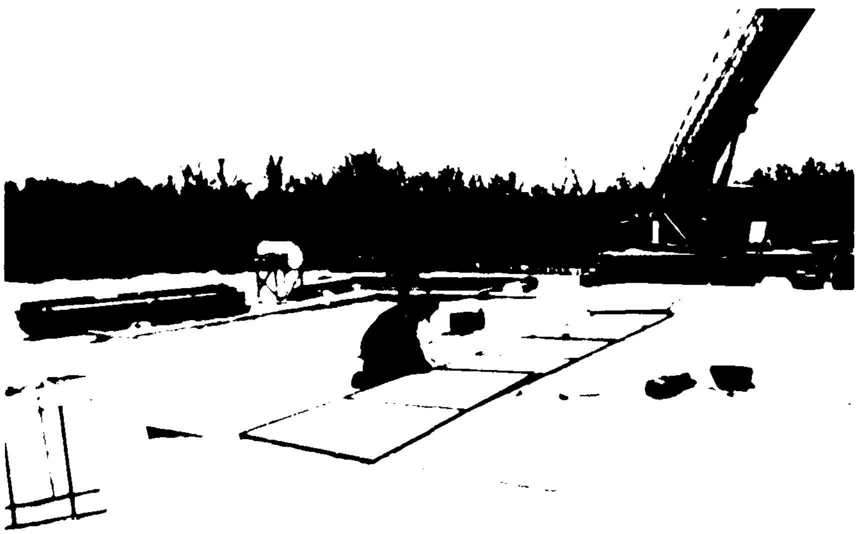


Figure 20. Erection of 28- × 8- × 32-ft test structure.

Weather Sealing

Three types of panel joint weather sealing material were used at Fort Leonard Wood: Kelly Klosure's standard vinyl tape, a standard off-the-shelf silicone caulk, and an elastomeric copolymer caulk (trade name: Magic Seal). These weather sealing materials were applied in temperatures ranging from approximately -9°C to 21°C. In the coldest weather, the tape material did not adhere well to the steel frame. The caulking, both the silicone and elastomeric copolymer, adhered well but did not flow out of the tube easily. After preheating the caulking tubes by holding them above an open fire, the caulking applied easily to the cold steel frame. However, this procedure was done only under emergency conditions and is not recommended. Caulking should be stored at room temperature until it is needed.

the eave angle connection bolt regardless of recommended erection procedures, a new oblong-shaped countersunk bolt will be used by Kelly in the future. It matches the shape of the slot in the roof panel frame and, thus, has more bolt head surface area to bear on the panel's steel frame (Figure 18).

In the third test cycle, a 20- × 12- × 32-ft galvanized steel structure was constructed out of 4- × 12-ft panels. The 32-ft structure length was used because of a lack of 4- × 12-ft galvanized steel panels. (Many of the 4- × 12-ft panels were damaged when used as roof panels on the 28-ft-wide structure.) The use of 4- × 12-ft panels for the sidewalls allows a 12-ft-high building to be erected using a 4-ft-wide bay section. This type of 12-ft-high structure can be manually erected as well as crane erected; however, manual erection is not recommended on an elevated foundation. Using a crane, the 20- × 12- × 32-ft structure was erected in 216 man-hours.

The reason for the extremely large number of man-hours is that the structure was completed by two separate troop crews over a 7-day period. Thus, a duplication of explanation and training greatly slowed the erection process.

28- × 8- × 32-ft Building. The 28-ft-wide structure was erected to further test the flexibility of the panelized building system and to examine the Kelly Klosure erection process which uses a bolted steel structural framework. The 28-ft-wide building was erected on an existing concrete pad foundation onto which a 2- × 8-in. wood baseplate had been attached. The structure was erected on a snowy, cold December day (Figures 19 and 20), in 128 man-hours. A crane was used to lift each bay section into place. During the erection of the first bays, which included the endwall section, several roof panels were damaged by the brackets used to attach the lifting cable. The endwall's extra weight caused the brackets to bend up the steel angle on the 4-ft panel edge (Figure 21). This problem occurred only in the bay sections which included an endwall section. In the future, when erecting end bay sections, troops should include only the gable panels of the endwall. This will alleviate the problem by lightening the end section significantly.

Fiberboard Panel Buildings

Only one size fiberboard panel structure was used: 20 × 8 × 40 ft. In the fourth test cycle, a fiberboard structure identical in size and configuration to the control building was erected in 150 man-hours.

Kelly Klosure structures are difficult to erect on elevated foundation baseplates because of the interior bay section's lateral instability. When erecting an interior bay section, the lack of space for troops to step on outside the baseplate perimeter makes it difficult to counteract any quick lateral shift of the bay section. Fiberboard panel bay sections, being even more flexible than steel panel bay sections, need some type of bracing to facilitate quick erection. Thus, the troops erecting the fiberboard panel structures devised a semi-permanent wood kneebrace type support (Figure 22). The wooden kneebrace was made of standard 2- × 6-in. lumber nailed to the 2- × 6-in. chord member and to each 4- × 8-ft wall section frame (Figure 23). The kneebrace kept the bay secton rigid and prevented all lateral sway during erection.

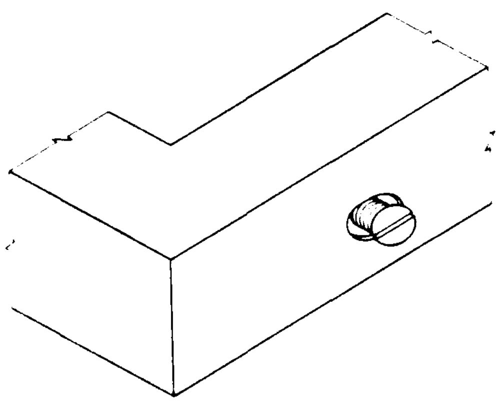


Figure 17. Old style round flat head bolt.

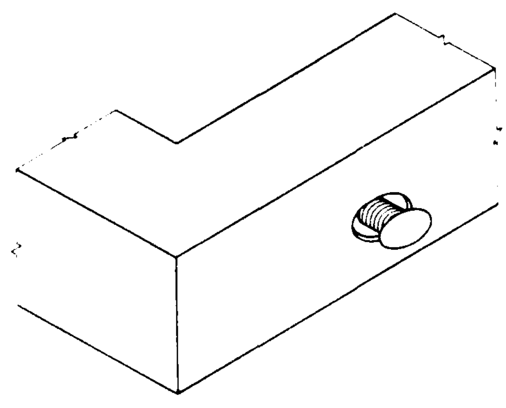


Figure 18. New style oblong flat head bolt.

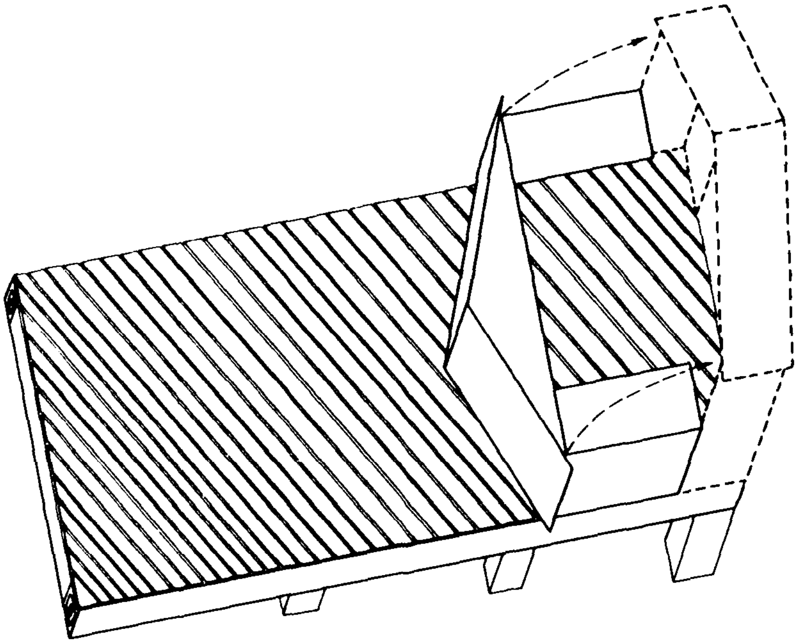


Figure 15. First step of modified erection process.

Figure 16. Interior of the control building.

speed, wind direction, and solar radiation. Thermocouples and or thermistors were mounted at the 1-ft, 4-ft, 6-ft, 8-ft, and 12-ft levels within each building. Relative humidity probes were mounted at the 6-ft level. Wind speed, wind direction, and solar radiation probes were mounted on a steel pipe attached to the control building (Figure 14).

4 FIELD TEST RESULTS

Constructibility Test Results

Galvanized Steel Panel Buildings

Several sizes and configurations of galvanized steel panel structures were used. Following are brief descriptions and explanations of the test results for each steel panel structure configuration.

20- × 8- × 40-ft Building. Since the 20- × 8- × 40-ft galvanized steel control building was the first demonstration of erection procedures and was erected in the rain, detailed construction times were not recorded. USA-CERL personnel assisted in the erection process. The elevated foundation made it difficult to erect the structure because there was no place to stand while erecting the end sections (impossible by standard Kelly Klosure procedures for the highest elevated endwall). The first step of the modified procedure required to erect the highest elevated endwall is shown in Figure 15. Erecting the panels by manually rolling up the 4-ft-wide bay sections was difficult and hazardous on the elevated foundation. (Using a crane is, thus, highly recommended when installing the structures on an elevated foundation.) The interior of the completed control building is shown, with instrumentation in place, in Figure 16.

20- × 12- × 40-ft Building. Several cycles of 20- × 12- × 40-ft structures were assembled to test specific types of panel configurations (Figures 9 and 10). In the second test cycle, a 20- × 12- × 40-ft galvanized steel structure was erected in a total of 119 man-hours, with 4- × 8-ft stiffback panels used to construct the 12-ft sidewalls. In addition, a 12- × 12-ft vehicle door was included in one endwall. A crane was required to erect the 8-ft-wide bay sections.

During the second test cycle, several round countersunk flat head bolts pulled through the slots (Figure 17) which connect the eave angles to the roof panels. It was finally determined that the troops were over-tightening the bolts with a socket wrench (Kelly Klosure's erection guide specifies finger-tight) and consequently, pulling the bolts partially through the roof panel slots. Thus, when the bay sections were erected and the connections stressed, the previously deformed bolt heads pulled through the roof panel slots and the connections failed. Since personnel would probably use some type of wrench on

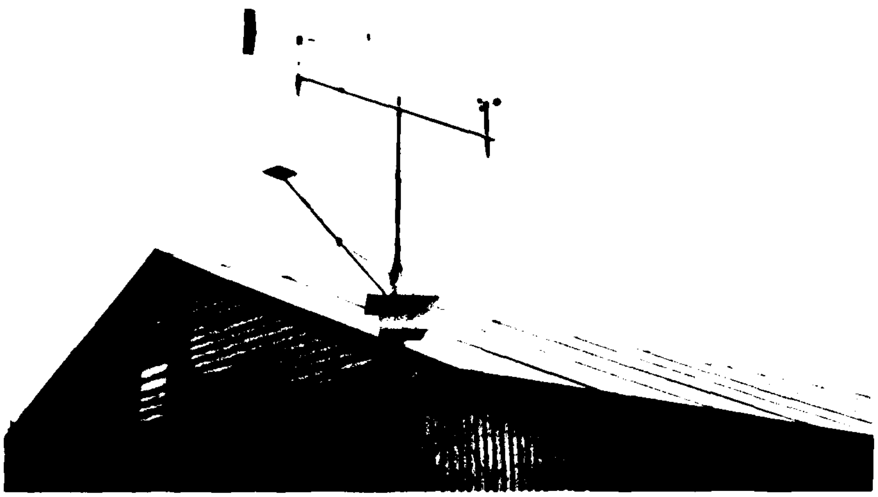


Figure 14. Exterior weather station.

sheets of Thermax foam insulation (manufactured by Celotex) were installed. It took seven people 10 hours to install the installation posts.

Sixth Test Cycle

The sixth test cycle began in mid-May and was finished 2 weeks later, with the construction of a 20- × 40-ft galvanized steel building having 8-ft sidewalls (Figure 12). This test structure was identical to the control structure except that it had 12 window panels instead of the control structure's four.

Seventh Test Cycle

The seventh test cycle began in late May and was finished in early June. In this cycle, 2-in. foam insulation was added to the steel structure used in test cycle six.

Instrumentation

To determine the system's habitability, data from the control building were compared to data obtained from the test structures, using the outdoor conditions as a baseline.

The instrumentation used in the tests was a Campbell Scientific CR7 measurement and control system (Figure 13). The CR7 monitored both temperature and relative humidity inside and outside the buildings. It also recorded the exterior wind

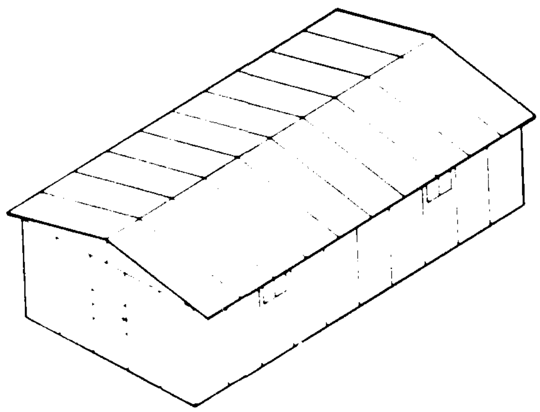


Figure 11. Fiberboard test structure (20 × 8 × 40 ft).

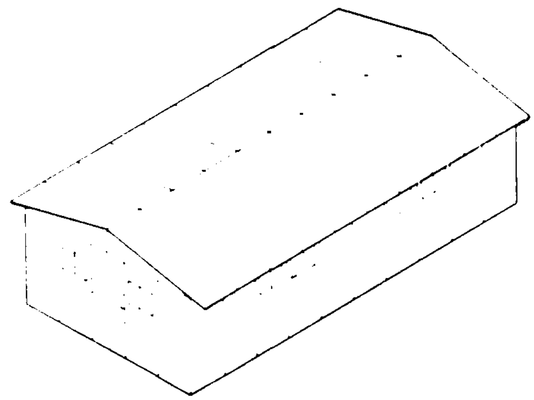


Figure 12. Steel test structure (20 × 8 × 40 ft) with 12 window panels.

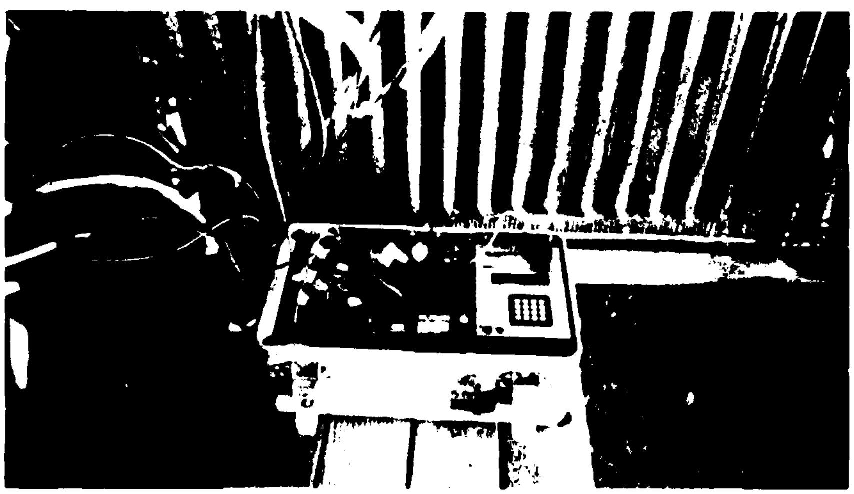


Figure 13. CR7 instrumentation.

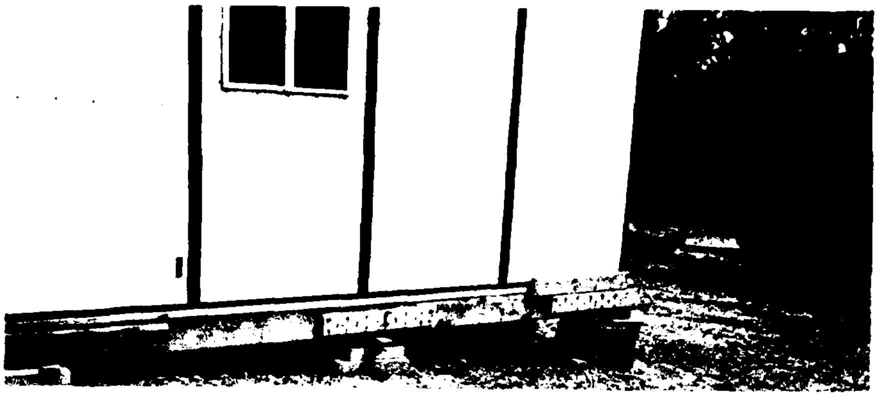


Figure 6. Foundation support blocks.

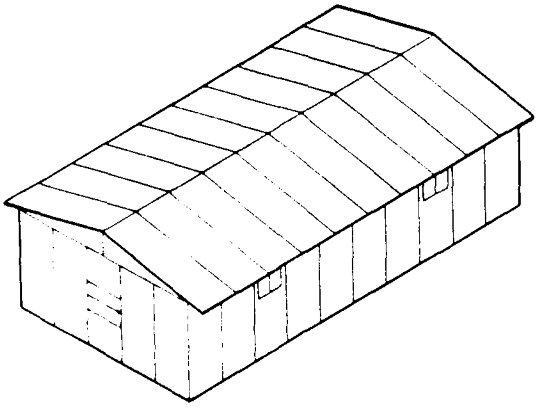


Figure 7. Control structure (20 × 8 × 40 ft).

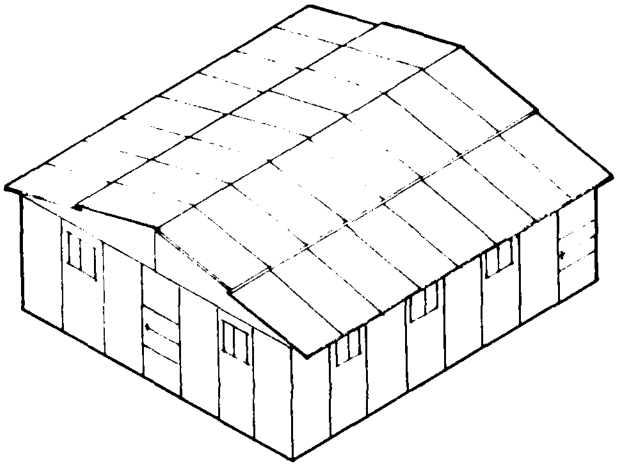


Figure 8. Test structure (28 × 8 × 32 ft).

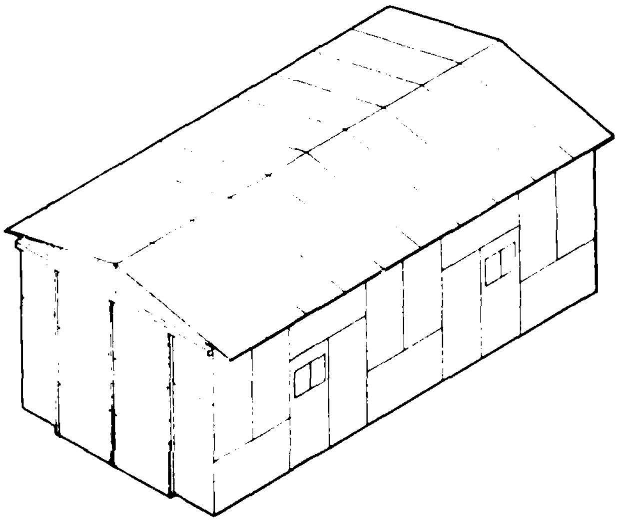


Figure 9. Test structure (20 × 12 × 40 ft) using 4- × 8-ft steel panels with equipment door.

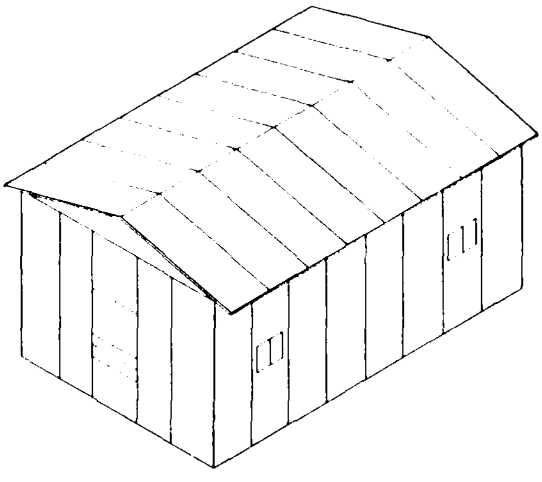


Figure 10. Galvanized steel test structure (20 × 12 × 32 ft).

Figure 4. Test structure and control structure on elevated wood baseplates.

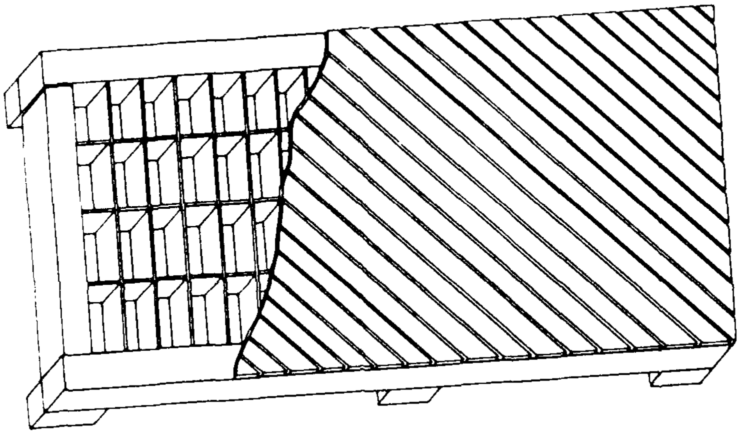


Figure 5. Elevated wood foundation.

grade, which required the use of concrete block and timber shims to level the baseplate (Figure 6).

First Test Cycle

The first test cycle began in early November with the construction of the control building, made of galvanized steel, 20- × 40-ft with 8-ft sidewalls (Figure 7). This building remained up throughout the test cycles. In mid-December, a 28- × 32-ft building with 8-ft sidewalls (Figure 8) was constructed on an existing concrete pad near the control building. This structure used both steel and fiberboard panels and was constructed in 16 hours by an eight-person crew.

Second Test Cycle

The second test cycle began in early February and was completed in mid-February. In this test, a 20- × 40-ft steel building was erected with 12-ft sidewalls. The sidewalls were constructed using 4- × 8-ft panels with 2- × 6- × 12-in. wooden stiffback columns to form 8-ft bays (Figure 9). This building had one personnel door and one vehicle door and was completed in 17 hours by a seven-person crew.

Third Test Cycle

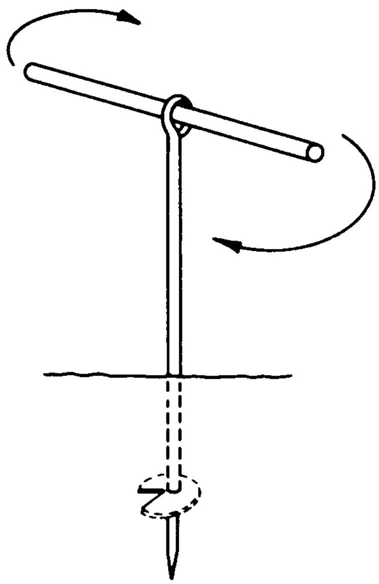
The third test cycle was begun in mid-February and finished in early April. This cycle tested a 20- × 32-ft steel structure with 12-ft sidewalls, built using 4- × 12-ft steel panels (Figure 10). This building, which had two personnel doors, was built in 24 hours by nine people and was disassembled in 8 hours by 10 people.

Fourth Test Cycle

The fourth test cycle ran from early to mid-April. In this cycle, tests were conducted on a 20- × 40-ft fiberboard building with 8-ft sidewalls (Figure 11). This structure was erected with two personnel doors in 15 hours by 10 people.

Fifth Test Cycle

In the fifth test cycle, the same structure was used from the fourth test cycle, but 2-in. thick, 4- × 8-ft



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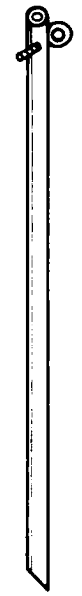

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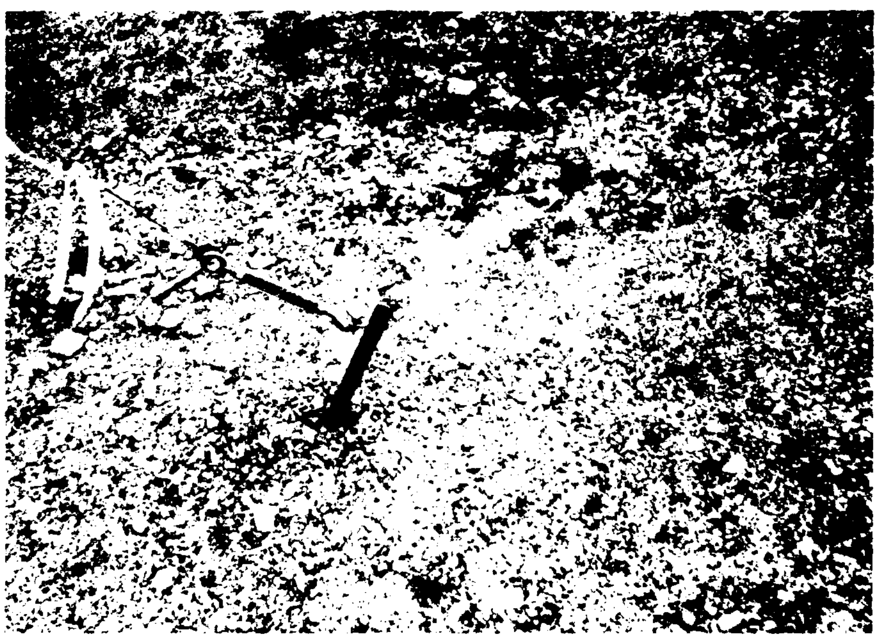

Figure 3. Ground anchors.

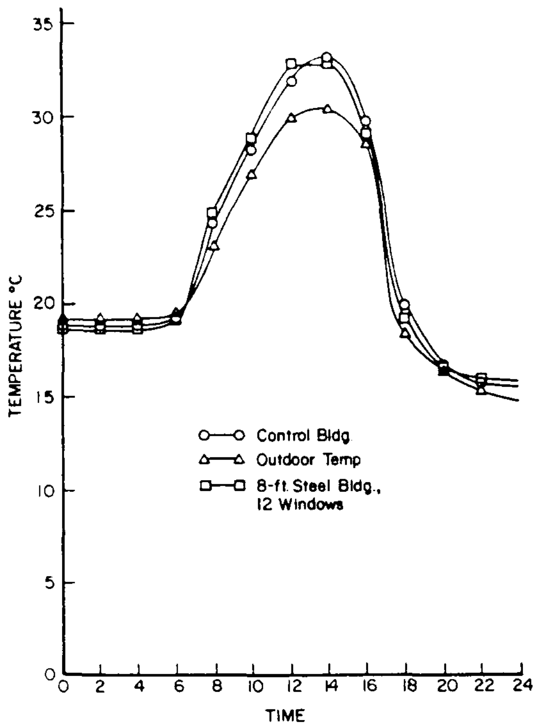

Figure 31. Temperatures at the 6-ft level for the control structure and steel structure with extra windows (warm day).

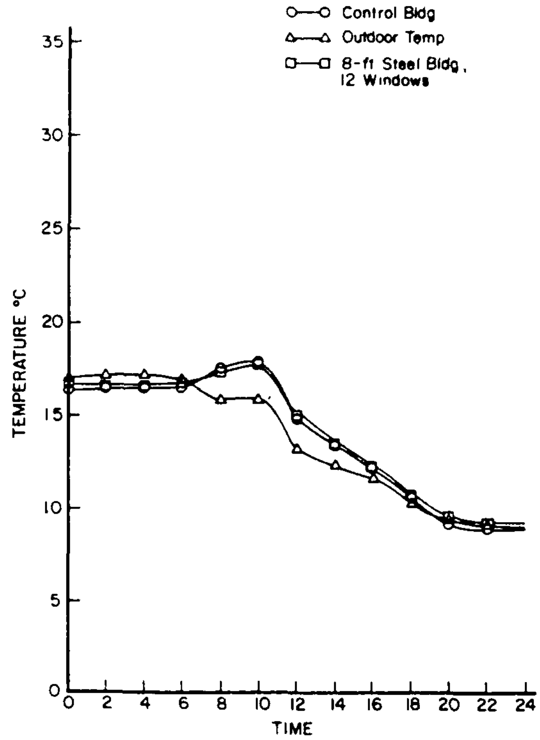

Figure 32. Temperatures at the 6-ft level for the control structure and steel structure with extra windows (cool day).

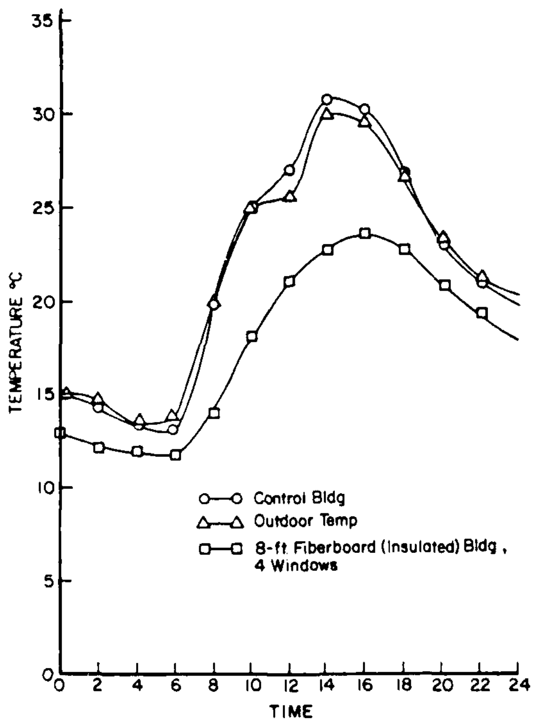

Figure 33. Temperatures at the 6-ft level for the control structure and the insulated fiberboard structure (warm day).

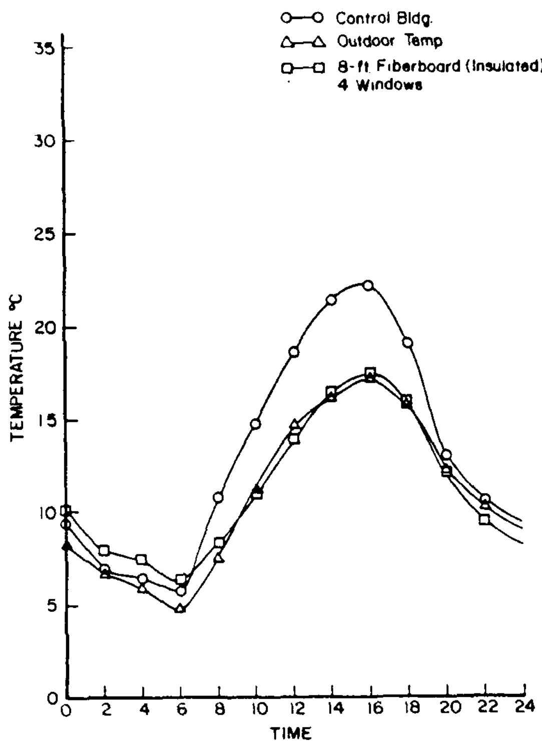

Figure 34. Temperatures at the 6-ft level for the control structure and the insulated fiberboard structure (cool day).

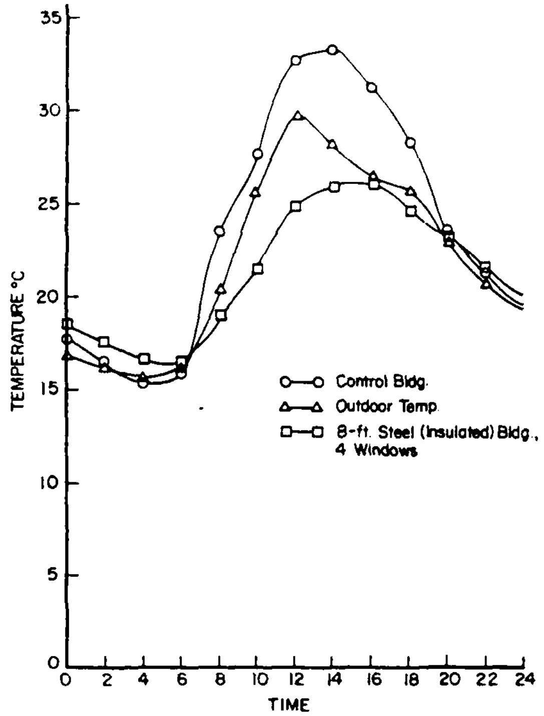

Figure 35. Temperatures at the 6-ft level for the control structure and the insulated steel structure (warm day).

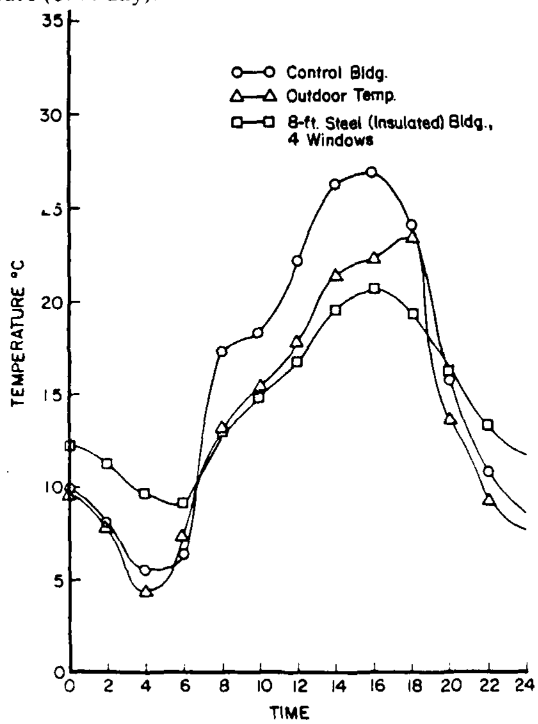

Figure 36. Temperatures at the 6-ft level for the control structure and the insulated steel structure (cool day).

5 CONCLUSIONS AND RECOMMENDATIONS

The stage II tests at Fort Leonard Wood not only confirmed results from stage I tests at Fort Irwin, but also exposed some deficiencies in the fiberboard system which did not occur in a desert environment.

The corrugated steel panel systems satisfy AFCS requirements for both initial and temporary (0 to 24 months) construction, but unless some change is made, the fiberboard panels cannot meet AFCS durability criteria.

In terms of constructibility, the 12-ft-high buildings made of 4- × 8-ft panels were more difficult to erect than 8-ft-high buildings. The 12-ft buildings required a crane to erect the section, which became unstable on the foundation baseplate. The stiffbacks did not help much, so troops devised a temporary knee-brace.

In the area of durability, the galvanized steel building had no problems under the test conditions. It can be expected to perform as well as any galvanized steel skin building currently available.

The fiberboard system showed severe durability problems in moist weather. Damage was noticeable in more than 50 percent of the panels in the 20- × 8- × 40-ft fiberboard test structure. The panel's wicked in moisture around their edges and the interior crossbrace rivet points, causing them to peel and delaminate. This greatly reduces panel strength and the amount of handling and relocatability that can occur without damage. Further tests are being done at Fort Leonard Wood on panels that are caulked around all exterior rivets and exterior edges. The manufacturer is also conducting tests on ways to improve the fiberboard panels.

Neither the Kelly Klosure ground anchor nor the USA-CERL manufactured pipe anchor worked well in the loose, rocky soil at Fort Leonard Wood. The Kelly Klosure auger anchor was almost impossible to get down into the soil and the USA-CERL anchor easily pulled up through the soil. Further research has been funded for FY85 to determine whether a guyless, lateral bracing system can be used. A technical report will be published about that project.

Habitability tests showed that the fiberboard structures are cooler than steel structures. On hot days, the fiberboard structure measured 3.5 to 5.5°C cooler than the steel control structure.

Two building modifications were made in an attempt to affect the structural habitability. More windows were added to a steel building, but their cooling effect was negligible. Modifying the buildings with insulation gave the greatest habitability benefit. Adding insulation to a galvanized steel structure decreased the maximum temperatures 4.0 to 7.5°C, and adding insulation to a fiberboard structure decreased the maximum temperatures 2.0 to 3.5°C. Fiberboard structures are almost as cool as insulated steel structures, but insulated fiberboard buildings are only slightly cooler than insulated steel structures.

Unless the fiberboard moisture problem is corrected, insulated galvanized steel structures would be the better choice, based on durability and habitability.

Metric Conversion Factors

1 in	2.54 cm
1 ft	.3048 m
1 sq yd	.836 m²
1 mil	.0254 mm
1 lb	.453 kg
1 ton	1.016 tonne
°C	(°F − 32)(5/9)

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