Y&D P330-2

NAVY ARCTIC HUT (MARK I)

ENGINEERING TESTS
UNDER CONTROLLED CONDITIONS

Series 1 and 2

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PROVING GROUND
U. S. NAVAL ADVANCED BASE DEPOT
CONSTRUCTION BATTALION CENTER
PORT HUENEME, CALIFORNIA

10 October 1949

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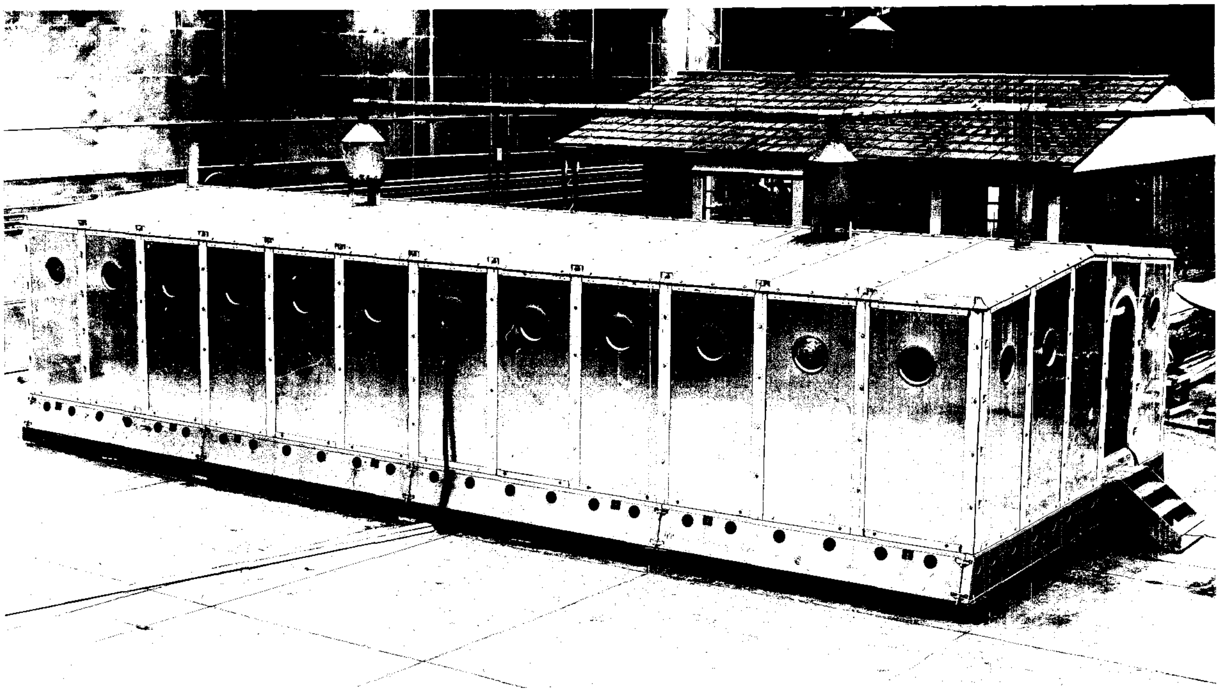
Project No. HA1-000 01A.

Prepared by

Earl H. Moser, Jr.
Head, Structural Division

Proving Ground
U. S. Naval Advanced Base Depot
Construction Battalion Center
Port Hueneme, California

10 October 1949



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NAVY ARCTIC HUT (MARK I)

ENGINEERING TESTS UNDER CONTROLLED CONDITIONS
SERIES 1 AND 2

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PART I - SUMMARY

INTRODUCTION

This report covers a series of tests made as a part of a program to evaluate the suitability of the Navy Arctic Hut (Mark I) for advanced base use as a semi-permanent shelter under cold conditions. The investigation was conducted by the Proving Ground, an activity of the U. S. Naval Advanced Base Depot, Construction Battalion Center, Port Hueneme, California.

Authority

Authority for the tests was issued by the Bureau of Yards and Docks, Washington, D. C. on 16 August 1948 in accordance with the provisions of Proving Ground Order HA1-000 01A, a copy of which is contained in Appendix A.

Physical Description of Hut

The Douglas Aircraft Company, Inc., of Long Beach, California, designed and fabricated the hut under Contract NOy-14943 in compliance with specifications contained in Appendix A.

The hut is a lightweight, prefabricated structure, 20 feet wide, 48 feet long, and 8 feet high, with a low-pitched (1 foot in 10 feet) roof. The floor, walls and roof are made up of panels consisting of a resin-impregnated, honeycombed paper core sandwiched between 0.020-inch aluminum sheets, with plastic laminated fiberglass edges. Ship lap joints are used to join the panels in the same plane, and butt joints for panels in different planes. Felt strips are used to seal all panel joints. Built-up aluminum sections are used to form the built-in, vented foundation beams, and the transverse and ridge beams used to support the peak of the roof. Metal clips with self-contained wedges are used to secure the foundation beams, and aluminum or plastic metal-tipped screw pins or wedged plastic pins are used for all other connections.

The wall panels are 3 inches thick and 4 feet wide, and range from 8 to 10 feet in length. The roof and floor panels are 5 inches thick, 4 feet wide, and 10 feet long. A partition wall 3 inches thick, also made up of panels 4 feet wide, is used to form an entrance vestibule. This partition and the two end walls contain doors fitted with refrigerator-type hardware. The 20-foot, 150-pound transverse roof support beam is the heaviest piece in the hut.

Before acceptance of the prototype by the Navy, a series of structural proof tests (1,pp 49-94) conducted by the manufacturer, confirmed the ability of the hut to withstand the stipulated floor, roof and wind loads under certain conditions.

Purpose

The primary purpose of the Series 1 and 2 tests was to evaluate the hut as a prefabricated structure and as a semi-permanent shelter for human occupancy under cold conditions. Specifically, these tests were conducted under controlled conditions to develop an erection procedure requiring no more than 16 men; to determine the best method of packaging the hut parts for airborne, rail and water shipment; and to determine the ease of erection, the extent of interior comfort, and the structural adequacy of the hut at low ambient temperatures. A secondary purpose was to obtain any test data that would be useful in the general study of housing troops in low temperatures.

Scope

The Series 1 tests, made under ideal conditions at Port Hueneme, California consisted of the development and perfection of an erection and disassembly technique adaptable for erections both on the ground and on pile foundations, the selection of a packaging medium and method of packaging for airborne, rail and water shipment, and an instrumentation study for collection of data in the Series 2 tests. In preparation for the tests under cold conditions, a heating and ventilating system was selected and the specified space heaters were modified for use in this system, an electrical harness was designed and fabricated, and a 12-man team was selected and trained.

The Series 2 tests were made in controlled low temperatures in the Climatic Hangar at the Air Proving Ground, Eglin

Air Force Base, Florida, during the MH1-49 test period. In selected temperatures of 15, 0, -20, -40, and -65 degrees Fahrenheit, erection and disassembly, heating and ventilating, and structural adequacy tests were conducted as detailed in the Memorandum of Test Procedure contained in Appendix A.

LOW TEMPERATURE TEST RESULTS

Based on the tests covered in detail in Part II of this report, a summary has been made of the adequacy of the hut, including the heating and ventilating system, for selected low ambient temperatures.

At -65 degrees Fahrenheit

At an ambient temperature of -65°F with no wind, a trained 12-man erection team can erect the hut on a previously graded area or a pile foundation in 2 hours and 30 minutes. This time will permit two rest periods of 22 minutes each which were found necessary when working at this extreme low temperature. Within 5 hours after the start of erection, using two 50,000-Btu, oil-fired space heaters, the temperature 30 inches above the floor will be 10°F, and within 8-1/2 hours it will reach 70°F. Changing the ventilating air approximately once each hour, the floor surface temperature will be 47°F as will the air around the ankles, the breathing level, the temperature will reach 84°F, and just under the roof, 100°F. Maintaining these temperatures will require 97,000 Btu's of heat input per hour, but by using 4 wall-mounted electric fans to aid circulation of the air, the input requirement will be reduced to 84,000 Btu's per hour. The vertical temperature distribution will become 48°F on the floor surface, 43°F at the ankles, 76°F at the breathing level, and 79°F under the ceiling. In either case only 51,000 Btu's will pass through the structure and the balance will escape through the ventilating air and the combustion productions. The air temperature under the hut will be -65°F.

Caulking the roof panel joints at the eave line and at the 4-corner floor joints down the center of the hut with cotton lampwicking will prevent excessive entry of cold air through the floor joints and loss of heat through the eaves. No other caulking will be necessary at this temperature. However, Minnesota Mining Sealer EC800, recommended by the manufacturer of the hut, could be used in place of the cotton lampwicking, and it can be applied without difficulty with a hand-operated caulking gun.

Sixteen men can live comfortably in the hut, although they would find the air quite dry. This condition can be remedied somewhat by adding 1.18 gallons of water per day to the ventilating air through evaporating pans on the heaters. The additional moisture will create a relative humidity up to 30 per cent, making the hut comfortable for 80 per cent of the occupants, and there will be no condensation.

A fall of snow, loading the roof to a depth of 7-1/2 feet, and a floor loading of 75 pounds per square foot would cause a deflection of 1.66 inches in the center of the transverse roof support beams and lesser deflections in the ridge beams, and the roof and floor panels. However, on removal of these loads, the panels and beams would return to their original shapes. No damage would result from these loads, and a disassembly would be easy, requiring less than 2 hours providing all caulking has been done with cotton lampwicking.

At -20 degrees Fahrenheit

At an ambient temperature of -20°F with a moderate wind, the hut can be erected by a trained 12-man team in 1 hour and 35 minutes, and 2 hours later the temperature of the interior of the hut 30 inches above the floor will be 70°F. Changing the ventilating air once each hour, the floor surface temperature will be 62°F, and the temperature around the ankles will be 56°F. At the breathing level the temperature will be 82°F, and under the ceiling, 99°F. To maintain these temperatures will require 68,000 Btu's of heat input per hour, but by using fans the input requirement will be reduced to 58,000 Btu's per hour. The temperatures will become 55°F on the floor surface, 55°F at the ankles, 73°F at the breathing level, and 75°F under the roof. In either case, 38,000 Btu's at most will pass through the structure, and the balance will escape through the ventilating air and the combustion products. The air temperature under the hut will be -18°F, or 2 degrees warmer than the ambient air. The caulking required will be the same as that required at -65°F.

The addition of 3.54 gallons of water per day to the ventilating air will create a relative humidity up to 40 per cent making the hut comfortable for 90% of the occupants, and there will be no condensation.

Disassembly of the hut will require 45 minutes providing all caulking has been done with cotton lampwicking.

At 15 degrees Fahrenheit

At an ambient temperature of 15°F with a moderate wind, the hut can be erected by a trained 12-man team in 1 hour and 22 minutes, and 1 hour and 20 minutes later the interior temperature of the hut 30 inches above the floor will be 70°F. Changing the ventilating air once each hour, the floor surface temperature will be 74°F, and the temperature around the ankles, 63°F. At the breathing level, the temperature will be 74°F, and under the ceiling, 86°F. To maintain these temperatures will require 40,000 Btu's of heat input per hour, but by using the fans the input requirements will be reduced to 34,000 Btu's per hour. The temperatures will become 68°F on the floor surface, 65°F at the ankles, 70°F at the breathing level, and 71°F under the roof. In either case, 24,000 Btu's at most will pass through the structure, and the balance will escape through the ventilating air and the combustion products. The air temperature under the hut will be 18°F, or 3 degrees warmer than the ambient air.

The caulking will be the same as that required at -65°F. However, if there is a probability of precipitation, it will be necessary to caulk all the outside wall and roof joints with Minnesota Mining EC800 Sealer to waterproof the hut.

The addition of 3.54 gallons of water per day to the ventilating air will create a relative humidity up to 50 per cent, making the hut comfortable for all occupants, and there will be no condensation.

Disassembly of the hut will require only 45 minutes providing only lampwicking is used for caulking.

CONCLUSIONS

The conclusions based on the tests conducted to date on the Navy Arctic Hut (Mark I) are considered preliminary and subject to revision when data is available from the field service and utility tests to be conducted by the U. S. Naval Arctic Test Station at Point Barrow, Alaska.

Merits

The completed tests have proven the hut to have a number of features, both in design and function, which should be considered in the adoption of a standard design for an Arctic Shelter.

Design.

The built-in, vented foundation makes possible the erection of the hut directly on the ground without danger of excessive heat entrapment under the hut and subsequent disturbance of the thermal regime of the permafrost provided the foundation vents are not blocked. Even in relatively still air at ambient temperatures above -20°F, the temperature under the hut will be only a few degrees higher than the ambient air, and below -20°F the temperature under the hut will be the same as the ambient temperature. The foundation is adaptable also to erection on a pile or crib foundation if 1 foot of support is given to each 6 lineal feet of foundation beam.

The lightweight of the individual parts (three men can set the heaviest piece) and the large assembly connectors, single-thread nuts, and easily-cleaned assembly holes make the erection of the hut simple even at very low temperatures. An untrained team of 12 men can erect the hut in less than 4 hours at temperatures above 0°F, and after three successive erections, this time can be reduced to less than 1-1/2 hours. An untrained 6-man team will require about 7 hours for the first erection, and with subsequent erections a comparable reduction in time can be made. At temperatures below 0°F, more erection time will be required by trained or untrained teams; however, an erection by a trained 12-man team will require less than 3 hours even at -65°F.

The hut parts, including the heating and ventilating system, electrical harness, and other accessories can be packaged in 60 boxes for airborne shipment with no package weighing over 400 pounds. Only cardboard cartons reinforced with steel banding are required.

The honeycombed paper sandwich material used for the floor, wall, and roof panels is adequate in strength and for insulation. Further, openings for utilities, ventilation and the like are easily made and the edges readily resealed without impairing the strength of the panel.

Connecting the lap joints between the panels in the same plane and the butt joints between the panels in different planes with the large assembly connectors aids in rapid assembly. Pressing together the felt seals of these joints with the wedged connectors results in a very tight joint;

and by impregnating the felt with a low-temperature grease it is soft and pliable even at -65°F. A heat transmission coefficient of 0.129 Btu/hr/ft^2/°F was established for the hut as a whole, and less than 10 per cent of this coefficient is credited to the losses through the joints.

Functional.

As the design permits erection of the hut in 12-foot sections, a shorter or longer building than the 48-foot pilot model is possible. The partition wall can be erected at any of the three panel joints within these 12-foot sections, allowing considerable latitude in the division of the interior of the structure.

The use of plastic assembly connectors for all inside-to-outside connections eliminates interior frost, and the strength of these connectors permits their use in connecting other objects to the walls and roof. For example, these pins have been used to secure the electrical harness, light fixtures and fans. Other possible uses include supporting bunks, cabinets, wash basins, and so forth.

The felt seals in the panel joints are airtight, but not watertight; however, the Minnesota Mining Sealer recommended by the manufacturer of the hut as a watertight joint sealer should aid materially in remedying this condition.

The hut is adaptable to a variety of heating and ventilating systems, but satisfactory interior temperature distribution both vertically and horizontally can be achieved with space heaters, natural circulation of warm air, and a gravity system of ventilation. The use of oscillating electric fans mounted on the walls in such a manner as to cause circulation in the corners of the living quarters will reduce the vertical temperature difference and make the quarters more comfortable. With a gravity system of ventilation, up to 3 air changes per hour are possible at low outside temperatures even with natural circulation of warm air.

The interior wall and roof surfaces are warm even at low temperatures, and at -65°F they are warm enough to permit a 30 percent relative humidity in the 70° air before causing condensation.

Deficiencies

Deficiencies were observed, both in the design and function of the hut, which require additional study, development, and/or redesign.

Design.

The aluminum skins of the panels are highly susceptible to denting, puncturing and tearing. These ruptures are easily repaired, but the development of a tougher and more pliable skin covering, retaining the strength, lightness and heat retention of the aluminum skins is highly desirable.

The molded panel edges of laminated fiberglass retain their shape and are pliable at low temperatures; however, in warm, moist air these edges tend to warp between the reinforcing blocks.

The tips of both the aluminum and the plastic screw-type connector pins are blunt making it very difficult to start these pins unless the nut receiving the screw tip is in almost perfect alignment. Lengthening these pins with a tapered, threaded joint will permit self-alignment and aid materially in erection. In addition, the plastic screw pin should be strengthened in the joint between the metal tip and the plastic shank. The plastic wedge pin is satisfactory, but could be improved by strengthening the area between the wedge slot and the tip of the pin.

The striker plate of the door hardware does not provide protection for the door jamb. The striker rides on the jamb when opening and closing the door, and, as the jamb is made of laminated fiberglass, it is seriously grooved by this contact. The striker plate should be redesigned to cover and protect the jamb.

Functional.

The space heaters used in these tests proved adequate, but a redesign to reduce the size of the outer jacket, and a study to determine the feasibility of using a mechanical means of reversing the flow of heated air forcing it out at the bottom of the heaters, is desirable to effect higher temperatures near the floor at low outside temperatures. This device should be installed in such a manner that natural flow of heated air could be used in the event of a power failure. The Proving Ground will make a study of the problem before recommending a change in the present design.

Moving objects into the hut which are too large to pass through the doors can be accomplished by removing one or more of the end wall panels. At the present time this can be accomplished without much difficulty; however, if the lap joints on the two door panels were made to face out instead of one out and the other in as is now the case, removal of these panels would be greatly simplified.

RECOMMENDATIONS

It is recommended that:

1. A panel skin be developed that is tougher and less susceptible to denting, puncturing and tearing, yet retaining the light weight and heat retention qualities of the present aluminum skin.

2. The panel edges be redesigned or reinforced to prevent warping when subjected to moisture, yet retaining the temperature characteristics of the present fiberglass edges.

3. The plastic connectors be redesigned to obtain a stronger joint between the plastic shank and the metal tip of the screw connector and a stronger tip on the wedge connector, yet retaining the low heat-transmission characteristics of the present plastic connectors.

4. The screw connectors, both the aluminum type and the plastic type, be made self-aligning by adding a tapered, threaded joint.

5. The striker plate of the door hardware be enlarged to give protection to the inside edge of the door jamb.

6. The panel lap joints on the end wall panels be altered so that both edges of one panel face out in each end wall and the partition wall.

7. The present heating system be studied and redesigned to produce higher temperatures in the level from 2 inches to 30 inches above the floor.

The Proving Ground will make further studies and recommend redesigns on Items 4, 5 and 7.

PART II - TESTS

* * * *

ERECTION AND DISASSEMBLY

Erection and disassembly tests of the Navy Arctic Hut are covered in this part of the report.

The ultimate objective was to ascertain the normal speed and ease of erecting and disassembling the hut at a -65°F outside temperature. Other major objectives were to perfect an erection and disassembly procedure, and train a 12-man erection team; to select packaging for the hut parts to give adequate protection in air shipment, and to simplify the layout of the hut parts around the erection site; and to determine the effect of repeated erections on the hut. Minor objectives included determining ease of installing the heating plant, ventilating system and electrical wiring harness at low temperatures, and the ease of caulking and extent necessary to prevent leakage through the joints.

To perfect the procedure and train the team, erection and disassembly tests were conducted under ideal conditions at Port Hueneme. The trained team was used also for similar tests in the Climatic Hangar. Complete tests were made at ambient temperatures of 70°F, 15°F, -20°F, and -65°F, and a partial test at -40°F.

A brief description of the hut and tabulation of each part with quantities and individual weights is contained in Appendix B.

Erection Equipment and Special Parts

The only tool actually needed for assembly is a useful part of the hut. This is the 7-inch inside door handle, designed to serve as a screwdriver, a wrench, and a mallet for securing the assembly connectors. However, additional tools found useful in the assembly of the hut included wooden mallets, drift pins, mason-type levels and 2-step benches. To install the heating plant and the electrical harness, and to caulk the hut, it was necessary to use pipe wrenches, screwdrivers, caulking irons and caulking guns.

Wooden wedges, 12 inches wide by 24 inches long were used in pairs for leveling the foundation beams, both when the hut was erected on the ground and when erected on a simulated pile foundation. For each foundation condition, care was taken to insure that 1 lineal foot of bearing was obtained for each 6 lineal feet of foundation beam.

Steps were not furnished with the hut, and a set for both outside doors was fabricated in accordance with the details contained in Appendix B. These steps were constructed of aluminum and plywood, and brackets were used to attach them to the hut. The brackets were slotted for adjustment to the required height.

The heating plant and ventilating system also is detailed in Appendix B. Each piece was designed for easy installation even while wearing Arctic mittens. The fuel supply pipes were fitted with unions at the assembly joints, and yokes welded to the female part of these unions eliminated the need for wrenches.

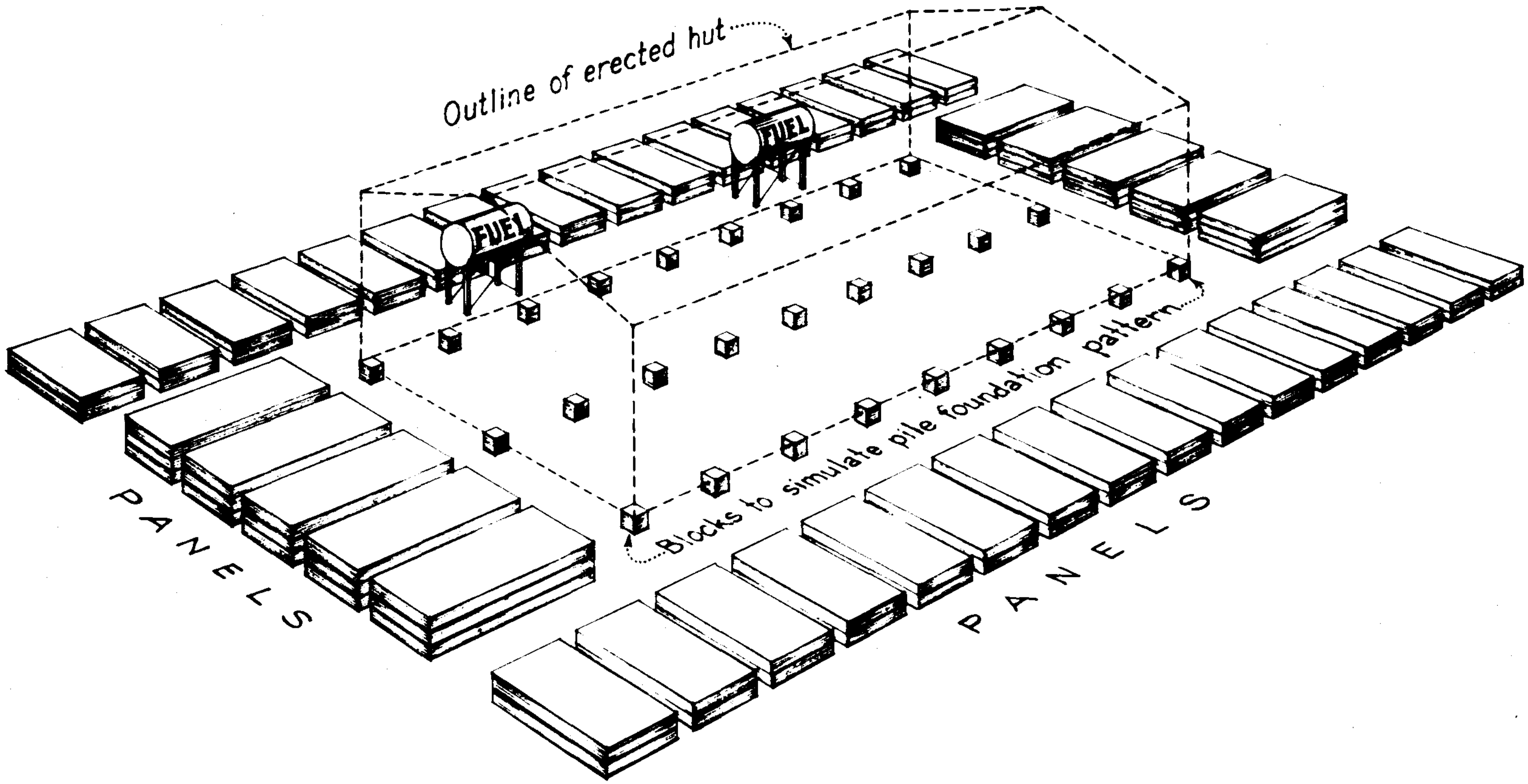


Fig. 5. PATTERN OF PANEL LAYOUT AROUND BUILDING SITE DEVELOPED DURING ERECTION AND DISASSEMBLY TESTS AT PORT HUENEME.

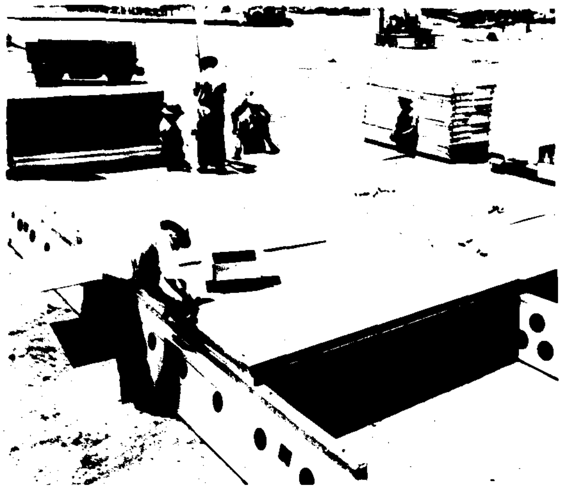


Fig. 1.

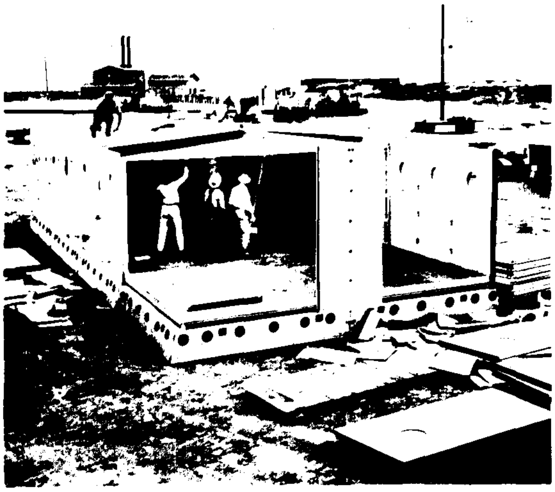


Fig. 2.

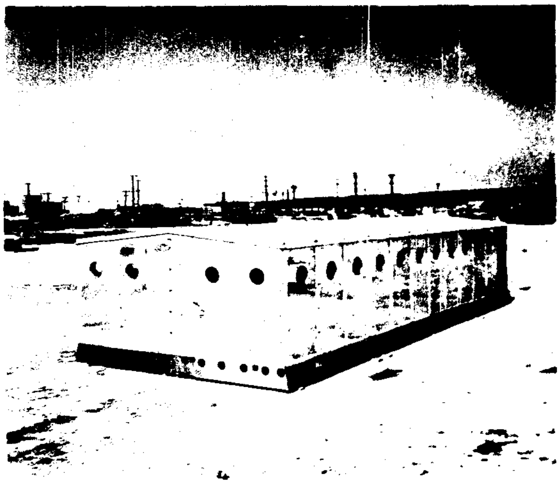


Fig. 3.

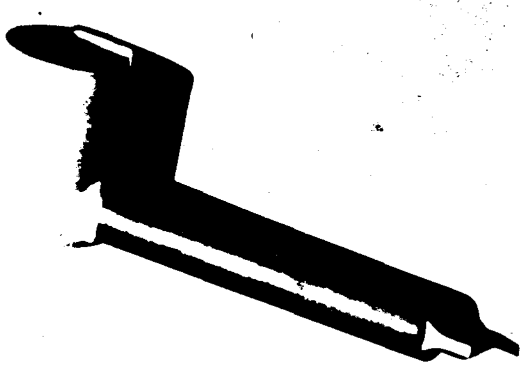


Fig. 4.

Plate 1. The technique for erecting and disassembling the Navy Arctic Hut (Mark I) was perfected in ideal weather at Port Hueneme, California. The foundation beams were placed on a prepared base, and the floor panels and plywood floor surfaces were placed on these beams (Fig. 1). Then the walls and roof were erected simultaneously (Fig. 2) until the hut was completed (Fig. 3). The basic tool used was the 7-inch inside door handle (Fig. 4) serving as a wrench, a screwdriver and a mallet.

The electrical wiring harness, fabricated as detailed in Appendix B, was designed as a 3-wire, self-grounding system. Connection of the various parts of the harness was simplified by using twist-lock plugs. Metal clips, attached to the hut assembly pins, held in place the wires, fixtures, convenience outlets and switches.

Perfection of Erection Procedure Under Ideal Conditions

Before conducting the erection tests under cold conditions, tests were made at Port Hueneme to perfect an erection procedure and train a 12-man Seabee erection team. Figs. 1, 2, and 3 depict a few of the stages of erection, Fig. 4 shows the 7-inch door-handle tool, and Fig. 5 illustrates the layout of the panels around the erection site.

After development of a procedure and perfection of a technique, and the team had become dexterous in handling the parts while wearing Arctic mittens, the final erection under ideal conditions was accomplished in 1 hour and 12 minutes, and the disassembly in 31 minutes as shown in Fig 6. All time observations for erection test-runs started with the placing of the first foundation beam on a previously prepared base and ended with the driving of the last wedge. The disassembly test-runs started with driving free the first wedge and ended with removal of the last foundation beam.

Packaging Manual

In perfecting the erection procedure a layout pattern of the hut parts around the site was established as shown in

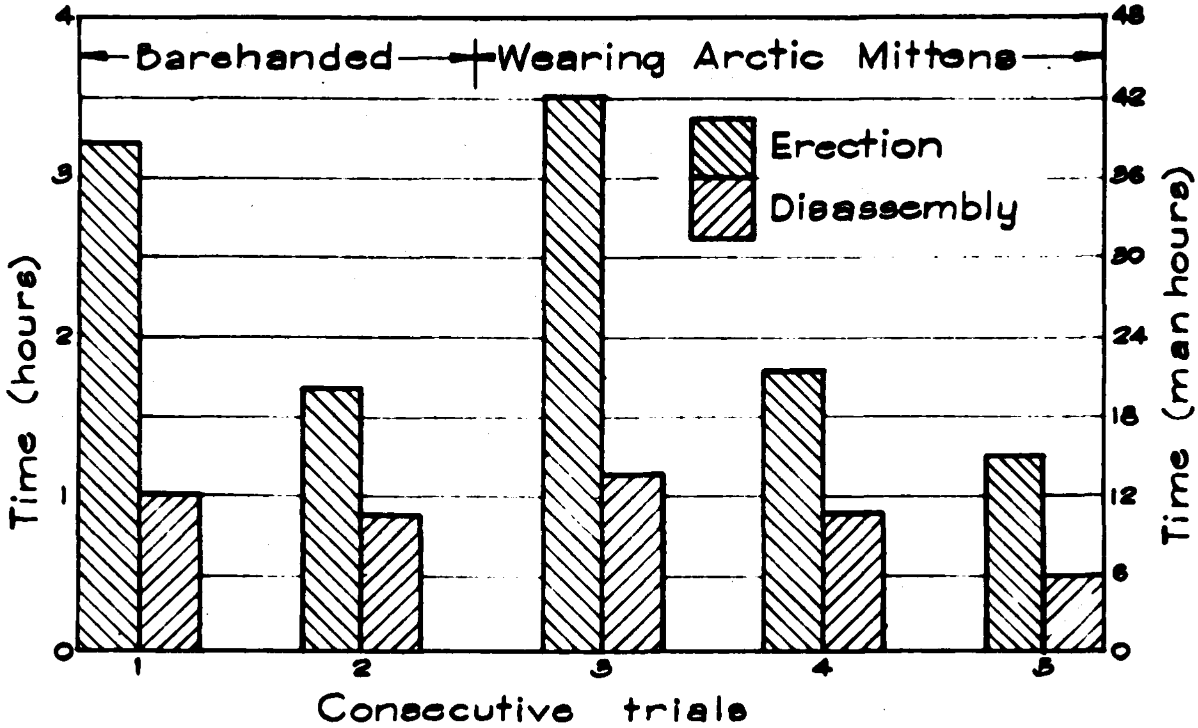


Fig. 6 RELATION OF ERECTION AND DISASSEMBLY TIMES TO CONSECUTIVE TRIALS DURING TRAINING OF 12-MAN SEABEE TEAM IN IDEAL CONDITIONS.

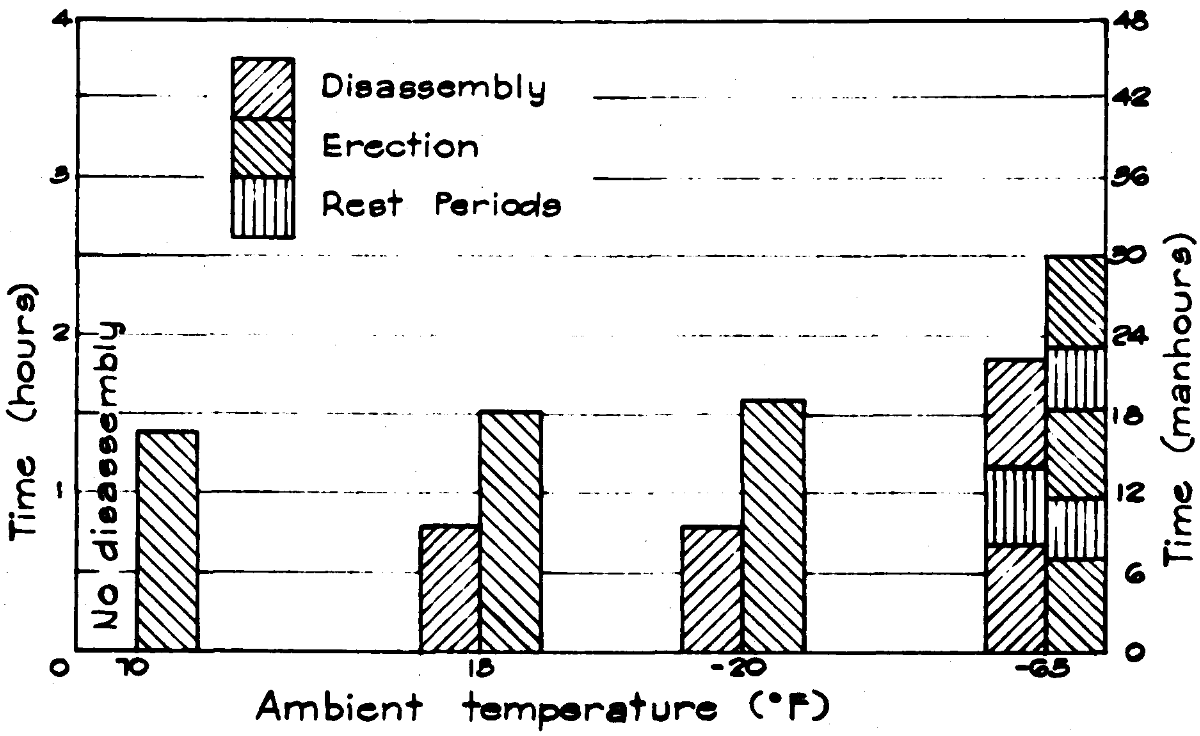


Fig. 7 RELATION OF ERECTION AND DISASSEMBLY TIMES TO VARIOUS AMBIENT TEMPERATURES WITH NO-WIND FOR TRAINED 12-MAN SEABEE TEAM.

Fig. 5. Packaging of the parts for airborne shipment was based on this layout. To protect the pilot model, 1/4-inch plywood was chosen as the packaging medium; however, in the Packaging Manual now in preparation other material is recommended for quantity use.

Erection and Maintenance Manual

Based on the erection procedure developed under ideal conditions and its perfection under cold conditions an Erection Manual is being prepared. In addition to erection and disassembly instructions including personnel assignments, sections have been prepared to cover installation of the heaters, ventilators and electrical harness, and general maintenance of the hut.

Erection and Disassembly Tests Under Cold Conditions

Placing and leveling the blocks to simulate a pile foundation and laying out the hut parts around this site preceded the first erection test in the Climatic Hangar. This was necessary in order to place this test on an equal timing basis with previous and subsequent tests.

The first erection test was made in an ambient temperature of 70°F. Fig. 7 shows the time required for this erection and for those made at 15°F, -20°F, and -65°F, as well as the disassemblies. A study of this data reveals that from 70°F down to -20°F with no wind, the time required for erection increased only 13 minutes, and at -20°F an erection required 1 hour and 35 minutes. Disassembly at -20°F required 45 minutes as compared with 31 minutes at 70°F. Actual erection time at -65°F required only 1 hour and 46 minutes, but rest periods increased the total time to 2 hours and 30 minutes. Partial disassembly and erection at -40°F indicated that both could be accomplished at that temperature without rest periods. The disassembly time at -65°F was recorded as 1 hour and 25 minutes but a rest period increased the total time to 1 hour and 52 minutes. Photographs taken during tests are shown in Figs. 8, 9, 10 and 11.

Beams and Stanchions.

Low temperatures had little or no effect on the size, shape or assembly of the foundation, transverse and ridge beams, and the stanchions. Mismatching of the assembly connector holes by uneven contraction of the parts was not observed. Repeated erections and disassemblies, and uncrated shipment of these parts, resulted in scuffing of the protective covering of paint.

Panels.

The panels fitted into place and matched as well at low temperatures as they had in the erections conducted under ideal conditions. Punctures and tears in the aluminum skins of the panels occurred less often during the low-temperature tests, but were easily repaired with patches held in place by rivets.

Panel Edges: The panel edges, molded from plastic-imprenated fiberglass, had shown a tendency to warp between

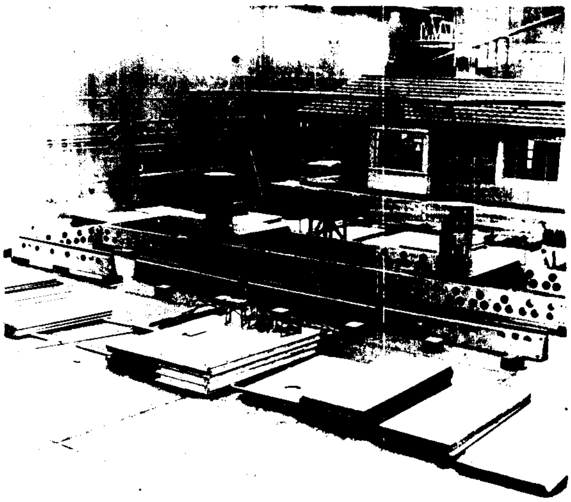
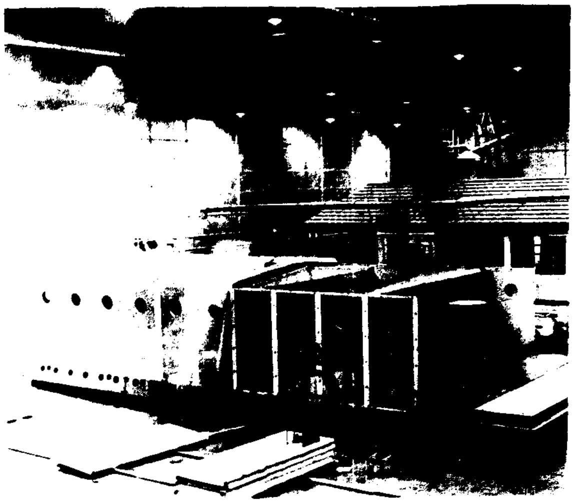
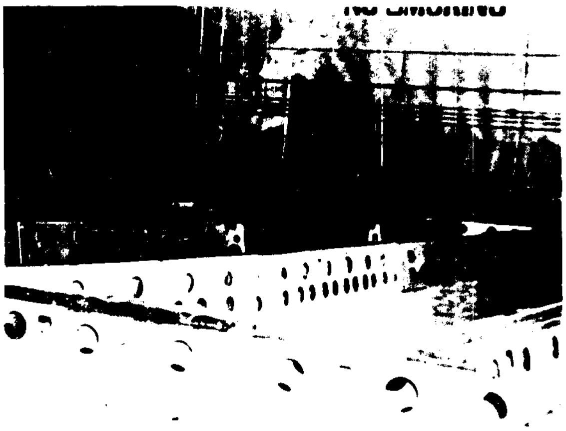


Fig. 8





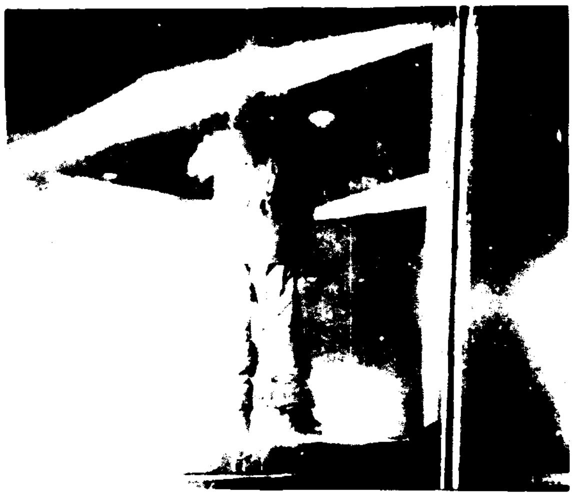


Plate 2. Erection and disassembly of the Navy Arctic Hut (Mark I) in the Climatic Hangar, Eglin Field, Florida. Figs. 8 and 9 show the hut during disassembly and erection at 15°F, and Figs. 10 and 11 during disassembly and erection at -65°F.

the reinforcing blocks during the Port Hueneme tests. This tendency was not experienced during the low-temperature tests, and even at -65°F the edges were straight, square and pliable.

The striker plate provided for each door, illustrated in Fig. 12, covers only the outside face of the door panel. This allows the end of the striker to ride on the panel edge when opening and closing the door unless care is exercised. During the hangar tests constant use of one door cut a deep groove in the panel edge adjacent to the door. A redesigned striker plate to cover the area, as shown in Fig. 13, would prevent this condition.

Felt Seals: The felt seals along the panel lap and butt joints and around the doors were impregnated with ANG-25 grease prior to the low temperature tests. This grease, applied to prevent freezing and subsequent parting of the felt, did not interfere appreciably with the handling of the panels. At each disassembly inspection the felt was found to be intact, pliable, and, with one exception, free from ice. The inspection after the disassembly made at -20°F revealed a very small frost area covering the felt in the joint between a side-wall and end-wall panel. This frost was merely a surface condition and did not penetrate the greased felt.

Assembly Connectors.

Two general types of connectors were used for assembling the hut. Wedged metal clips, which proved satisfactory in all tests, were used to hold together the foundation beams, and

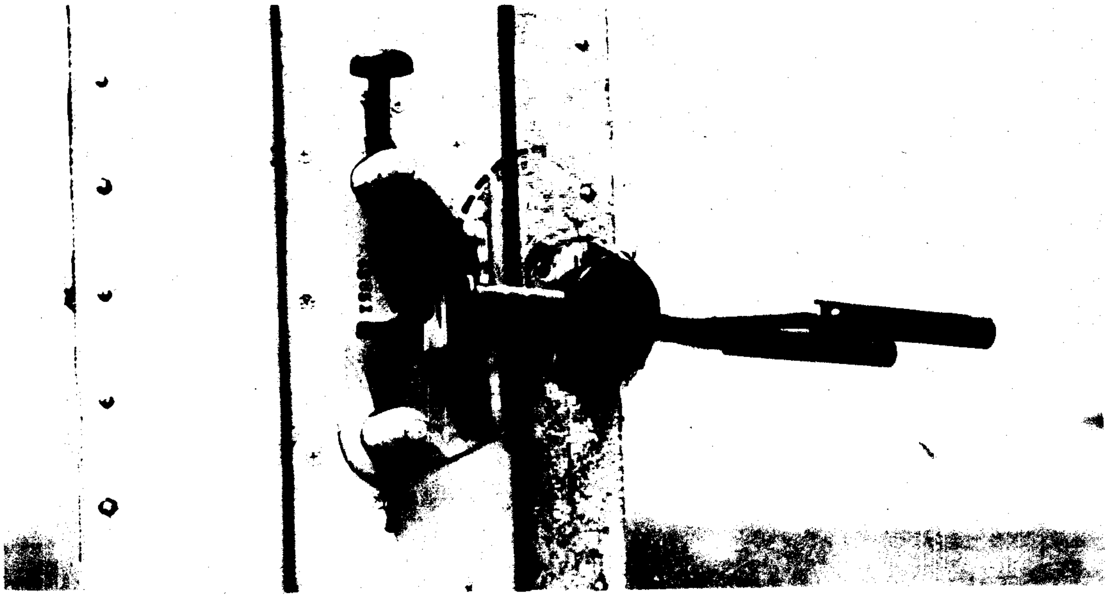


Fig. 12

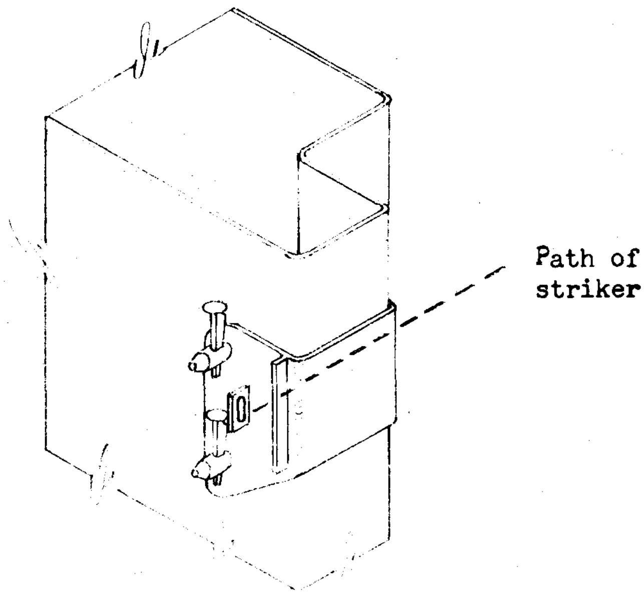


Fig. 13

Plate 3. Hardware for the door of the hut is similar to refrigerator hardware as shown in Fig. 12. As the striker plate covers only the outside face of the laminated fibreglass door jam, the striker rides on the inside edge of the jam and cuts a groove when opening and closing the door. Fig. 13 illustrates a proposed striker plate designed to protect the door jam.

7/8-inch diameter plastic pins fitted either with threaded ends or slotted for wedges were used to secure the floor, wall and roof panels, roof support members, and make all other connections. In general, these plastic connectors proved satisfactory except as discussed below. An attempt at -65°F to break one by hitting it with a hammer proved difficult. Breakage was accomplished little by little as the hammer ate away at the pin.

Metal-Tipped Plastic Screw Pins: During the Port Hueneme tests breakage of the metal-tipped, plastic screw pins averaged 5 for each erection and 4 for each disassembly. These breaks occurred at the riveted joint between the plastic shank and the metal screw tip as shown in Figs. 14 and 15. Substitution of an all aluminum screw pin (Fig. 14) for securing the walls to the foundation, and development of a tapered, threaded drift pin for pre-alignment of the floor-to-foundation assembly holes reduced this breakage to 1 for each erection and 1 for each disassembly under cold conditions. The tapered, threaded drift pin, illustrated in Fig. 16, was made 1-1/2 inches longer than the standard floor-to-foundation pin with the additional length tapered and threaded.

Securing the last two floor panels with attachable clip-mounted nuts and metal-tipped plastic screw pins (Fig. 17) had caused considerable trouble during the Port Hueneme tests. Use of the drift pin for centering the nut prior to inserting the standard pin reduced this trouble considerably.

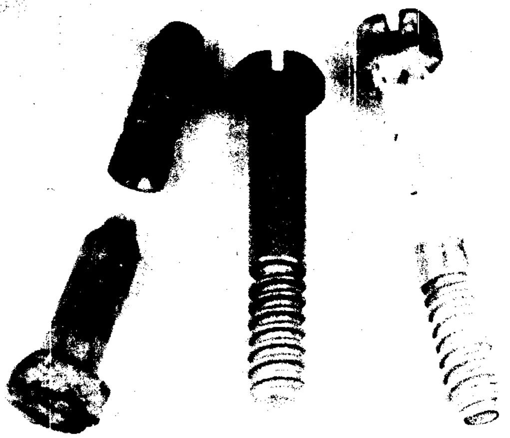


Fig. 14

Fig. 15

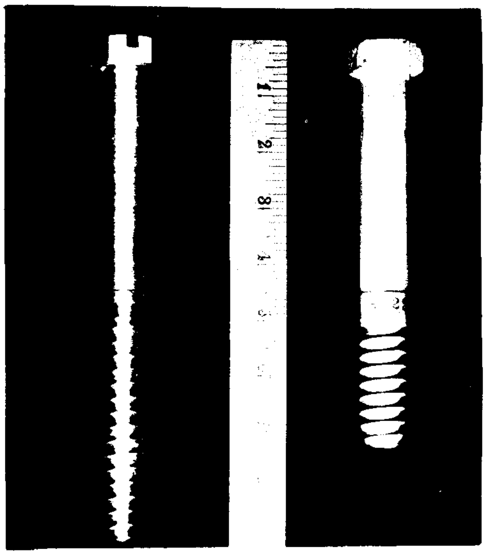


Fig. 16

Fig. 17

Plate 4. Screw-pin connectors were used to secure the wall and floor panels to the foundation beams. Fig. 14 shows two broken wall-to-beam, metal-tipped, plastic screw pins with the replacement all-aluminum pin. In Fig. 15 similar breaks in the floor-to-beam pins are shown. By using the tapered, threaded drift pin shown in Fig. 16, pin breakage was reduced. The drift pin was used also for aligning the clip-mounted nuts when connecting the last two floor panels as illustrated in Fig. 17.

Wedged Plastic Pins: The four lengths of wedged plastic pins are illustrated in Fig. 18. Breakage generally occurred between the wedge slot and the end of the pin as illustrated in Fig. 19, and it became more frequent for each successive erection up through the one conducted at -20°F. A study at that time determined that 75% of the breakage occurred after the pin was driven and alignment for placing the wedges was attempted. To turn the pin when aligning the slot, the practice had been to place a wedge in the slot and drive the pin around with a mallet to the desired position. Tight fits that prevented easy turning often caused splitting as demonstrated in Figs. 19 and 20. In the erection at -65°F, all misaligned pins were backed out, aligned and redriven. As a result, none were broken.

Installation of Heating and Ventilating System.

In the erection at 70°F, the heating and ventilating system was installed after the hut was erected. Using 2 men, this work required 30 minutes, but in subsequent erections no extra time was allotted for this job as it was found these parts could be set in place while erecting the hut with no sacrifice of time.

Installation of Electrical Wiring Harness.

As the temporary electrical wiring harness for the hut, illustrated in Figs. 22, 23 and 24, was fabricated from Romex cable, it could not be installed at temperatures below 0°F without possible damage. This resulted in the installation of

Fig. 18

Fig. 19

Fig. 20

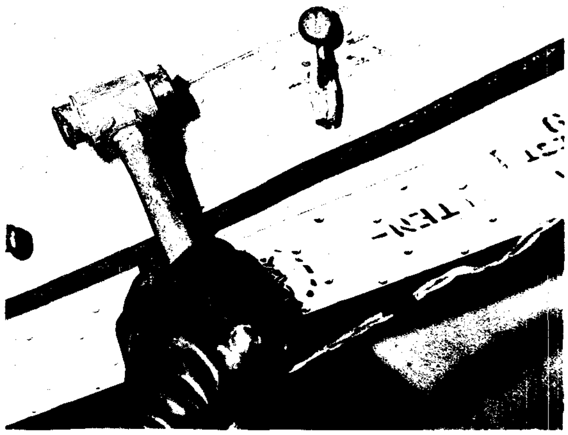


Fig. 21

Plate 5. Wedge-pin connectors were used for all of the panel-to-panel and roof-support-beam connections. Fig. 18 shows the four lengths of connectors required for assembling the hut, and Fig. 19 shows two pins with split tips. The alignment of the wedge hole by force, as illustrated in Figs. 20 and 21, caused 75% of this breakage.

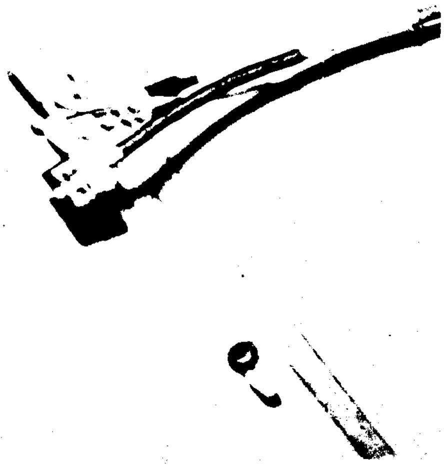


Fig. 22

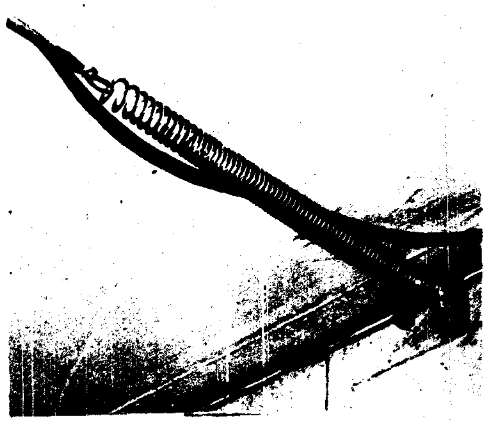


Fig. 23

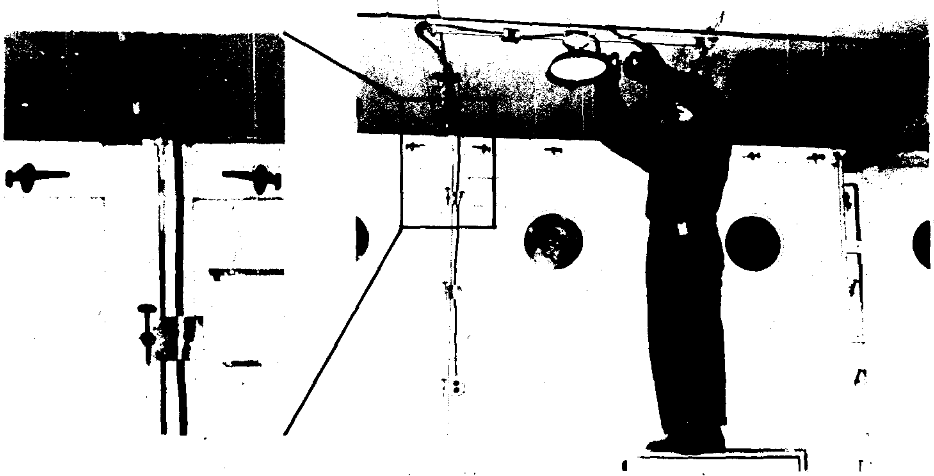


Fig. 24

Plate 6. The wiring harness for distribution of electrical power within the hut consisted of two main feeder lines extending the length of the ceiling, one on each side of the ridge line. Fig. 22 shows the method used to secure the ends of the lines to the wall, and Fig. 23 shows the spring connection used at the service end to obtain a taut line. In Fig. 24 a ceiling fixture is being attached to the main feed line through a 3-pole, twist-lock connector. The branch feeder servicing the convenience outlet is supported by metal clips as illustrated in the enlarged detail.

the harness in the erections at -20°F, -40°F, and -65°F after the interior of the hut was heated above 0°F. The complete installation required approximately 30 minutes.

Caulking.

Caulking the hut, except at -65°F, was limited to packing the roof-panel joints at the eave line as shown in Fig 25. Cotton lamp-wicking was used and tamped in place with a caulking iron as depicted in Fig. 26. This proved satisfactory as inspections at low temperatures failed to reveal icing at any joint on the exterior of the hut due to leakage of heat. Two men caulked all the roof-panel joints in 40 minutes, and at the lower temperatures this job was delayed until after the hut was heated above 0°F.

At an ambient temperature of -65°F a number of exterior roof and side-wall panel joints were easily caulked with Minnesota Mining EC 800 Sealer applied with a hand-operated caulking gun. In addition, this material was also used inside the hut to reduce air leakage between the floor joints down the center of the living quarters. The small frost areas observed at each four-panel floor joint, at an outside temperature of -65°F soon disappeared after caulking. One drawback to using this sealer was found during the -65°F disassembly. The sealer adhered tightly to the fiberglass panel edges and pulled like taffy as the panels were removed. Cleaning the sealer from the edges prior to re-erection proved almost impossible while wearing Arctic mittens.

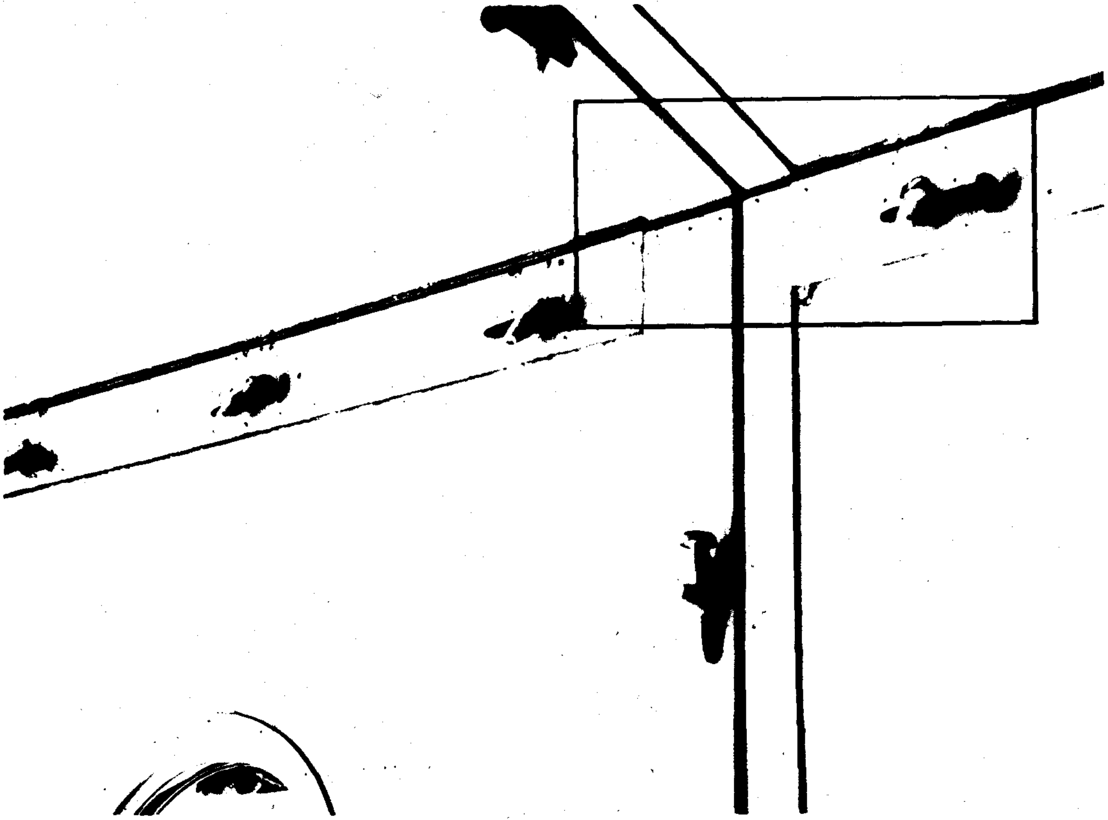


Fig. 25

Fig. 26

Plate 7. The roof-panel and wall-panel joints at the eave line, shown in Fig. 25, were caulked to prevent loss of heat. Cotton lampwicking was tamped into these joints with an iron caulking tool as illustrated in Fig. 26.

Maintenance.

The hut was in continual use for two-week periods between erection and disassembly tests. During these periods other projects being tested in the hangar created winds up to 10 mph and pressure waves of sufficient magnitude to cause considerable vibration of the hut. After each blast of waves, it was necessary to conduct a general inspection and replace 4 to 5 wedges and 1 to 2 foundation beam clamps.

Final Inspection.

Upon completion of all hangar tests the hut parts were moved directly from 20°F hangar air to 80°F outside air. An inspection and trial fitting of various parts 24 hours later indicated all parts to be in good condition and easy to assemble. By then the hut had been assembled 12 times and the painted pieces were badly scuffed. Consequently, after return to Port Hueneme and prior to shipment to Point Barrow, Alaska, for in-service and utility tests, the entire hut was painted. The inside was again painted light green, and the outside, except for selected panels which were waxed, was painted aluminum.

Summary

A 12-man team, trained in the erection and disassembly procedure perfected at Port Hueneme, can erect or disassemble the hut as easily at -65°F as at 70°F, but being encumbered with heavy clothing and working at reduced efficiency the time required will be nearly twice as long. Even so, erection can be completed in less than 3 hours, and disassembly in less than 2 hours.

The layout of the hut parts around the erection site, developed while perfecting the erection procedure, was used as a basis for grouping in making up the airborne packages. Plywood was selected as the packaging medium for the pilot model, but other materials will be selected for quantity packaging.

The hut parts wore well and, except for scuffing of the painted pieces, looked almost the same after 12 erections as when new. All the parts still fitted snuggly at the end of the tests, the molded panel edges were square and straight, and the felt seals were intact, soft and pliable. No failures of the basic parts of the hut occurred, but a tougher panel skin not easily punctured or torn would be desirable. Redesign of the door-lock striker plate to protect the laminated fiberglass jamb from the striker is necessary.

The plastic assembly connectors are easy to handle with mittens and strong enough to secure the hut parts, but breakage during assembly and disassembly of the hut is high. Both the wedged and metal-tipped pins need to be improved before they are entirely satisfactory. As the wedged pin splits between the wedge hole and point, a metal band or cap on the end of the pin will give the additional strength required. The metal-tipped pin breaks in the riveted joint between the metal tip and the plastic shank. The area of the plastic shank is very small at this joint, and a redesign of this pin increasing the size of the plastic section fitting into the metal tip is necessary.

In a redesign of the metal-tipped pin the length should be increased and the added length tapered and threaded. This extra tapered, threaded length should be added also to the all-aluminum threaded pins which are used to secure the floor and walls respectively to the foundation beams. Originally the most difficult part of the erection was centering the assembly holes for starting the pins. The trouble was finally overcome by development and use of a tapered, threaded drift pin which would be unnecessary if the assembly pins were tapered and threaded.

Caulking of the hut to prevent heat loss is necessary only at the roof-panel joints at the eave line and the four corner floor-panel joints down the center of the hut. Satisfactory results can be obtained by tamping cotton lampwicking into the joints with a caulking iron. The Minnesota Mining EC 800 Sealer recommended by the manufacturer for weatherproofing the joints is easily applied even at -65°F with a hand-operated caulking gun, but it is not necessary unless the hut is subjected to precipitation.

The heaters and ventilators can be installed while the hut is being erected with no sacrifice of time and the fire lit as the last panel is placed. No special tools are required as all pipe connections are fitted with yokes for tightening the joints, and the heater stacks and ventilators are attached to the hut with plastic wedged connectors.

The design of the wiring harness is satisfactory. The Romex cable and the twist-lock connectors used in the temporary harness assembly should be substituted with wiring and connectors suitable for low-temperature usage. The substitutions should include cable similar to that known as service drop cable (Harbishaw SBUN) insulated for low temperatures, and connectors similar to E. B. Wiggins Oil Tool Company's N-396 (female) and M-399 (male).

HEATING AND VENTILATING

Adequacy of the Navy Arctic Hut as a suitable shelter for human inhabitance under cold conditions is covered in this part of the report.

The main objective was to ascertain the minimum heat input required at a -65°F outside temperature to maintain an inside temperature of 70°F with one air change per hour. Other objectives included a determination of heat transmission coefficients for the floor, wall and roof panels, and the hut as a whole; the effectiveness of a gravity-type heating plant in maintaining comfortable temperatures; the aid rendered by electrically-driven fans in dissipating vertical temperature differences; the effectiveness of the ventilated foundation in combatting entrapment of heat; and, ascertaining the maximum comfort conditions obtainable for human occupancy.

To obtain the data necessary to evaluate the hut in fulfillment of these objectives, heat tests were conducted at each of the hangar temperatures made available. Detailed heat-test data is contained in Appendix C.

Heating and Ventilating System

The hut was delivered to the Proving Ground without provision for heating and ventilating. The Proving Ground Order stipulated that a heating plant using two 50,000-Btu, oil-fired, space heaters be installed; that a gravity system of ventilation, capable of effecting one air change per hour under the most extreme conditions, be devised; and, that a maximum of floor space be made available for living quarters.

Installation.

The partition wall was placed 4 feet from one end to form the entrance vestibule, allowing an area of 20 feet by 44 feet for living quarters.

In order to preheat the incoming ventilation air and attempt maximum circulation, the heating and ventilating system diagrammed in Fig. 27 was installed. Adopting this system required the design and construction of new jackets and bases for the stoves. To prevent damage from radiant heat, insulated spacer rings were attached to that portion of the heater stacks passing through the roof.

Striving for maximum circulation of the heated air resulted in the adoption of two exhaust ventilators. One was placed in the roof of the vestibule forcing the heated air through this section. The other, located in the roof near the outside end wall of the living quarters, was dropped by ducting to within 12 inches of the floor.

Supply tanks were installed for both inside and outside fuel storage. The supply lines from the outside tanks entered the hut through the air intake ventilators and were connected to the stoves along with the inside tanks through a "T". With this arrangement the source of supply was conveniently controlled by valves.

Details of the exact locations, sizes, and method of sealing the holes cut through the panels to accommodate this heating

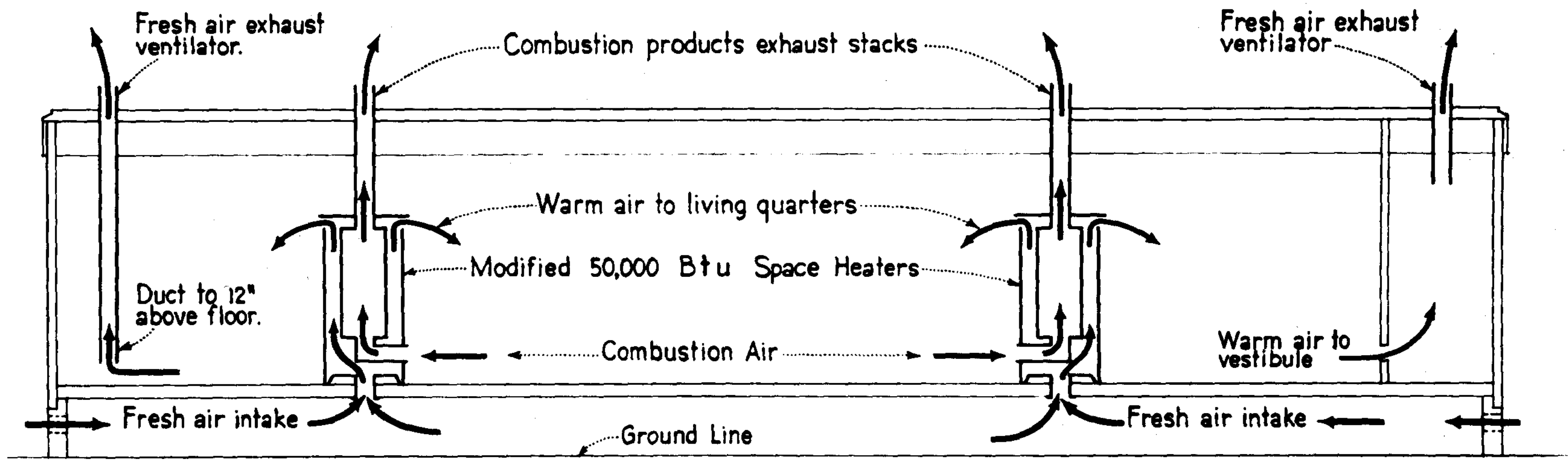


Fig. 27. DIAGRAM OF HEATING AND VENTILATING SYSTEM INSTALLED IN NAVY ARCTIC HUT (Mk-1).

and ventilating system, and details of the stove modifications, ducting, fuel supply lines, and roof jacks are shown in Appendix B.

Removal of Flue Gases from Hangar.

Removal of the space-heater flue gases from the Climatic Hangar was accomplished by placing open hoods over each heater roof jack and joining these through 6-inch-diameter ducting to the floor drainage system of the hangar. Through exhaust fans located at the outlet of this drainage system, the gases were drawn into the hoods and expelled. The ducting was suspended to minimize interference with the erection and disassembly tests.

Test Equipment

To procure data for evaluating both the hut and the heating and ventilating system, use of various instruments and test equipment was necessary.

Heat transmission coefficients for floor, wall and roof panels were measured by fastening a heat meter of the Nichols type to selected panels as shown in Fig. 28. A heat transmission coefficient for the hut as a whole was found by trial heat balances and confirmed with electric heater tests. These coefficients are expressed in Btu/hr/ft^2/$^\circ$F difference in temperature.

Heat balances and air changes were computed from fuel consumption measurements, and quantity and temperature measurements

Fig. 28

Fig. 29

Fig. 30

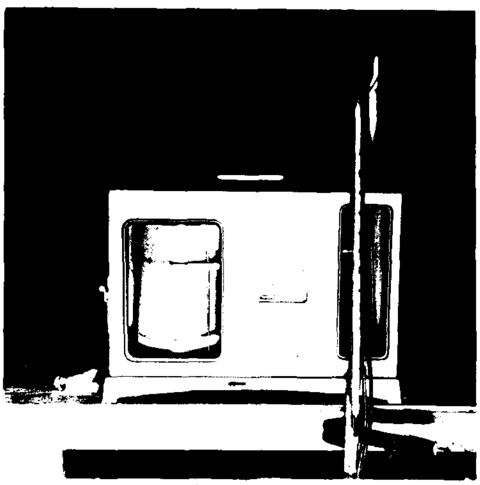


Fig. 31

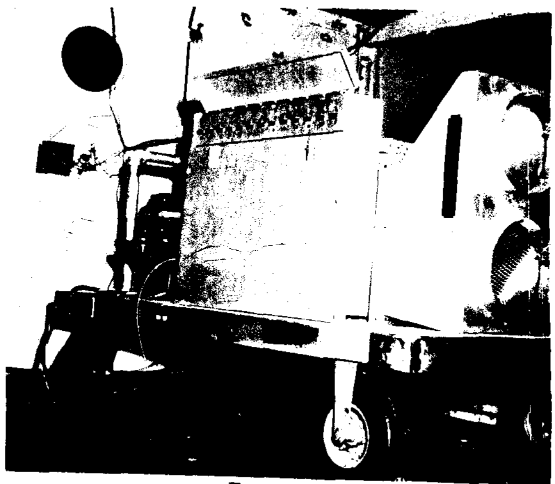


Fig. 32

Plate 8. Test instruments and equipment used inside the hut. Fig. 28 shows the Nichols heat meter mounted on a wall panel. In Fig. 29 the velocity of the ventilating air is being measured with an Anemotherm air meter. Fig. 30 shows the inclined draft gage connected to the pitot tube in the heater stack, and an electric fan can be seen in the background. Both the hygrothermograph and the air thermometer located 30 inches above the floor in the center of the living quarters are shown in Fig. 31. The forced-air electric heater is shown in Fig. 32.

of the gases passing through the heater stacks and ventilators. Storage of the fuel supply at ambient hangar temperatures and volumetric measurements of the amounts burned necessitated establishing a fuel density curve in the range from 68°F to -65°F for determining the Btu's of heat input. Velocity measurements in the heater stacks were made by Pitot tubes and an inclined draft gage (Fig. 30), whereas an Anemotherm hot-wire type air meter was used to obtain flow rates through the outlet ventilators (Fig. 29). Thermocouples were used to determine the temperature of the escaping air and gases.

Thermocouples suspended from the ceiling were used to measure air temperatures in the hut. Five strings of thermocouples were hung in the living quarters, one at the center and one about three-fourths out from the center towards each corner of the room. Each string consisted of 5 thermocouples located at points 2, 30, 60 and 84 inches above the floor and 2 inches below the ceiling. Additional thermocouples were used to determine surface temperatures of the inside and outside floor, wall and roof panels, the air temperature at the 60-inch level in the vestibule, the air temperature 1 foot under the hut, and the surface temperature of the bottom of the foundation beams. A 48-point, precision-indicating potentiometer was used to observe all air temperatures.

A hygrothermograph was used to maintain a continuous record of the temperature and per cent of relative humidity at the center of the living quarters 30 inches above the floor (Fig. 31).

An ordinary air thermometer was attached to the thermocouple string in the center of the room 30 inches above the floor and used as the control point for manual adjustment of the heaters (Fig. 31).

The temperature and barometric pressure within the hangar applicable to these tests were attained from the recorded data of the hangar instruments. No accurate method of recording the relative humidity of the hangar air was available at the time, however, it is accepted that the air was saturated. In general, still-air conditions prevailed but air movement up to 10 mph was observed at times with a three-cup anemometer having an integrating dial for indicating the wind velocity.

Four electrically-driven, 10-inch diameter, oscillating-type, portable fans were mounted on the walls of the living quarters for determining the effect of circulation in the dissipation of temperature differences (Fig. 30).

An Electromode 15-kw, portable air heater containing 12 elements of 1333 watts, each on a separate switch, was used for the electric heat tests (Fig. 32).

Test Procedure

At each selected hangar temperature, the temperature 30 inches above the floor in the center of the living quarters was raised to 70°F in the shortest possible time by burning high fires in the heaters and regulating the exhaust ventilators for minimum air flow. Fig. 33 compares the time required to heat the hut with natural circulation of warm air with the time required using electric fans to aid circulation. Upon reaching 70°F and after a period of stabilization, three tests, each 6 to 8 hours in length, were conducted. During the first test, the exhaust ventilators were dampered to allow an average air flow of 75 fpm; during the second test this flow was increased to 200 fpm; and in the last test the dampers were opened to allow a maximum passage of air.

Upon completion of the maximum air-change test, the heater fires were extinguished and the interior temperature of the hut was reduced to the hangar temperature. The heaters then were relit and the above described tests repeated using electric fans to aid circulation of the warm air.

In addition to the regular scheduled tests, heat tests using the electric heater were conducted at hangar temperatures of -40°F and -65°F. At -65°F, the oil-burning heaters were unable to support a comfortable living temperature with more than a minimum air change. In order to determine the heat input necessary to support a maximum air change, the electric heater was used as an auxiliary.

Temperatures at all thermocouple stations were recorded at 30-minute intervals during each test. Fuel measurements were taken at approximate 2-hour intervals and at the end of each test. Air-flow measurements in both the outlet ventilators

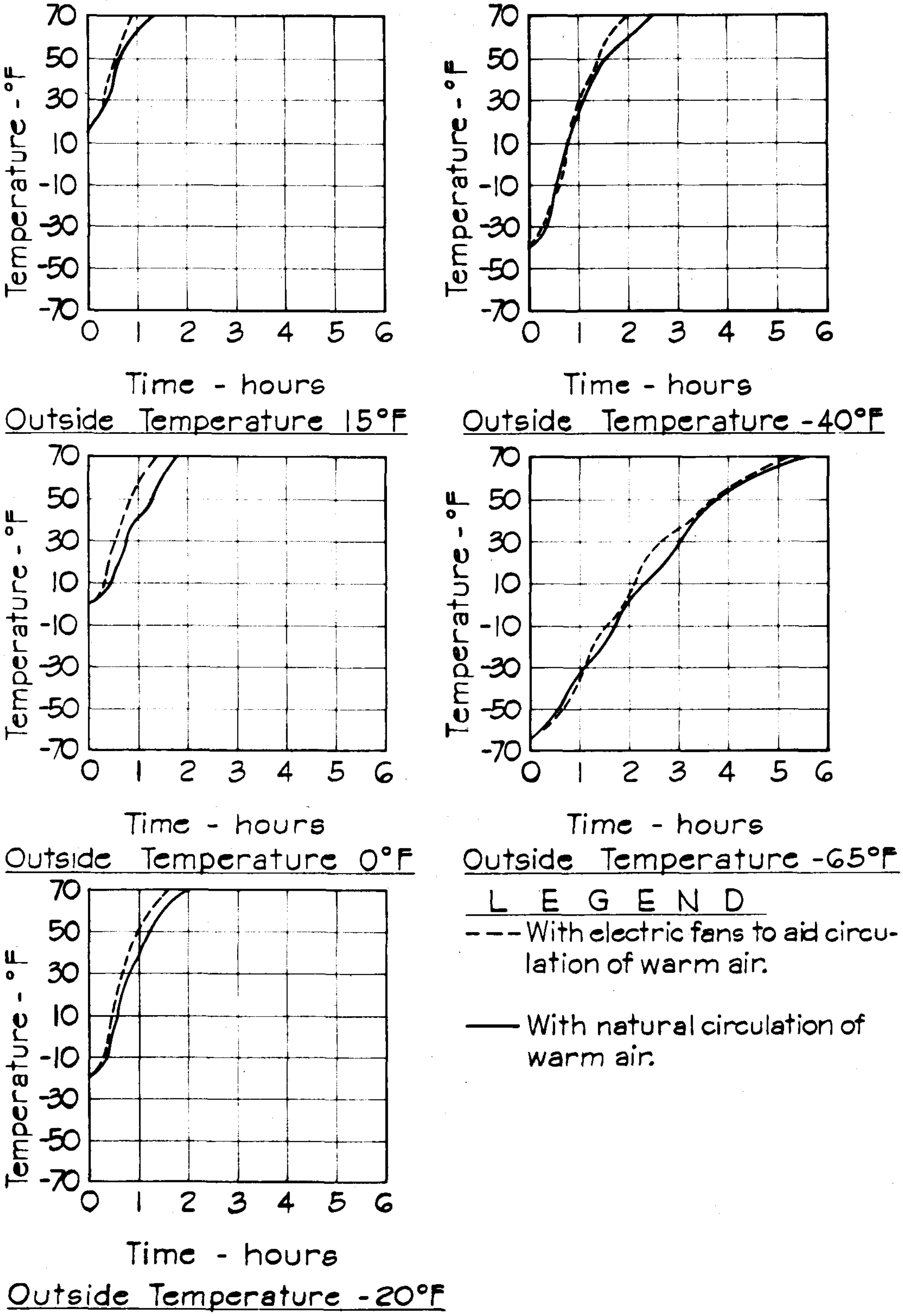


Fig.33. TIME REQUIRED TO RAISE THE INSIDE TEMPERATURE OF THE HUT TO 70°F AT VARIOUS AMBIENT TEMPERATURES WITH ONE AIR CHANGE PER HOUR.

and heater stacks were recorded each hour. Heat transmission coefficients were recorded during the minimum air-change test without fans at each hangar temperature, and also during the electric heat tests at -40°F and -65°F.

Heat Transmission Coefficients

Heat transmission coefficients were established for the floor, wall and roof panels, and the windows of the hut. The heat transmission coefficient for the hut as a whole was established through the nineteen heat balance tests. Coefficients were not established for the heat losses through the floor, wall and roof panel lap and butt joints, the window frames, the plastic pin connectors, the fuel oil and electric supply lines, and the areas around the ventilator and stack openings.

Floor, Wall and Roof Panels, and Windows.

Heat flow observations were made on selected floor, wall and roof panels, and windows in the mid-section of the living quarters. The collected data was combined and an average coefficient determined for each type of panel and the windows. The Douglas Aircraft Company established theoretical coefficients for each type of panel in their original Arctic hut study (2, pp 63 to 65), and these results were used for comparision.

Floor Panels: Heat transmission coefficients were established for two floor conditions--one, where the skin of a panel was used as a wearing surface, and, the other, where a panel was covered with the 3/8-inch plywood covering. A mean heat transmission coefficient of 0.094 was established for the covered panel, and 0.118 for the bare panel. The theoretical coefficient established by Douglas was 0.133.

Based on these studies, the curves in Fig. 34 were developed in such a manner that for a given inside-to-outside temperature difference the heat transfer in Btu/hr/ft^2 of floor panel surface area can be read direct.

Wall Panels: A heat transmission coefficient of 0.164 was established for the wall panels. Douglas established 0.147 as the theoretical coefficient. Fig. 35 presents the results of these studies.

Roof Panels: A mean heat transmission coefficient of 0.097 was established for the roof panels. Douglas established 0.133 as the theoretical coefficient. Fig. 36 presents the results of these studies.

Windows: A mean heat transmission coefficient of 0.332 was established for the windows.

Mean Heat Transmission Coefficient for Total Panel and Window Area.

A mean heat transmission coefficient of 0.121 was computed for the total exposed panel and window area based on the coefficients established above and the total exposed surface area for each.

Mean Heat Transmission Coefficient for Hut as a Whole.

A heat transmission coefficient of 0.129 for the hut as a whole was established as described in Appendix C from the

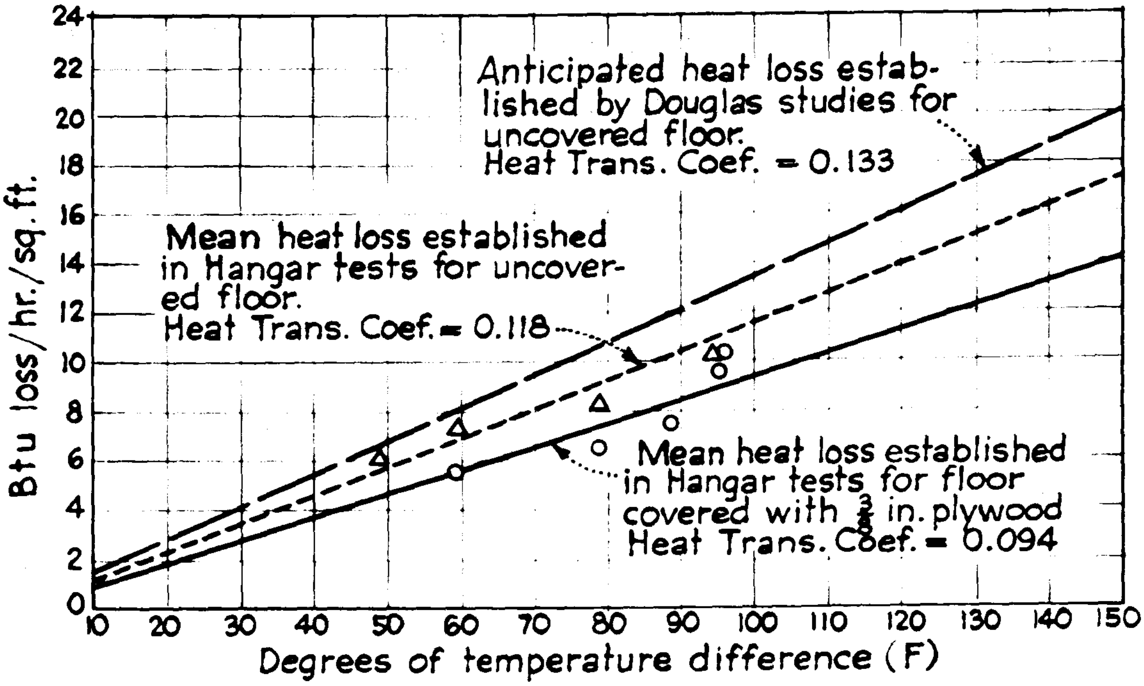


Fig. 34. RELATION OF HEAT LOSS TO TEMPERATURE DIFFERENCE FOR 5 IN. FLOOR PANELS UNDER NO-WIND CONDITIONS ESTABLISHED IN CLIMATIC HANGAR TESTS.

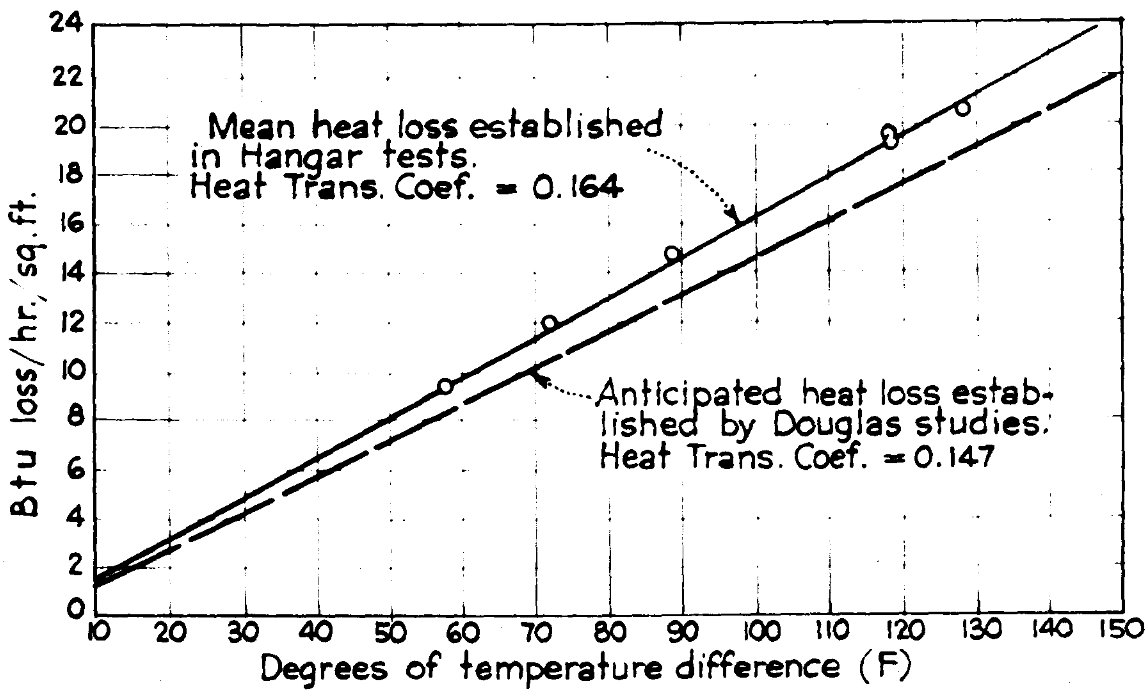


Fig. 35. RELATION OF HEAT LOSS TO TEMPERATURE DIFFERENCE FOR 3 IN. WALL PANELS UNDER NO-WIND CONDITIONS ESTABLISHED IN CLIMATIC HANGAR TESTS.

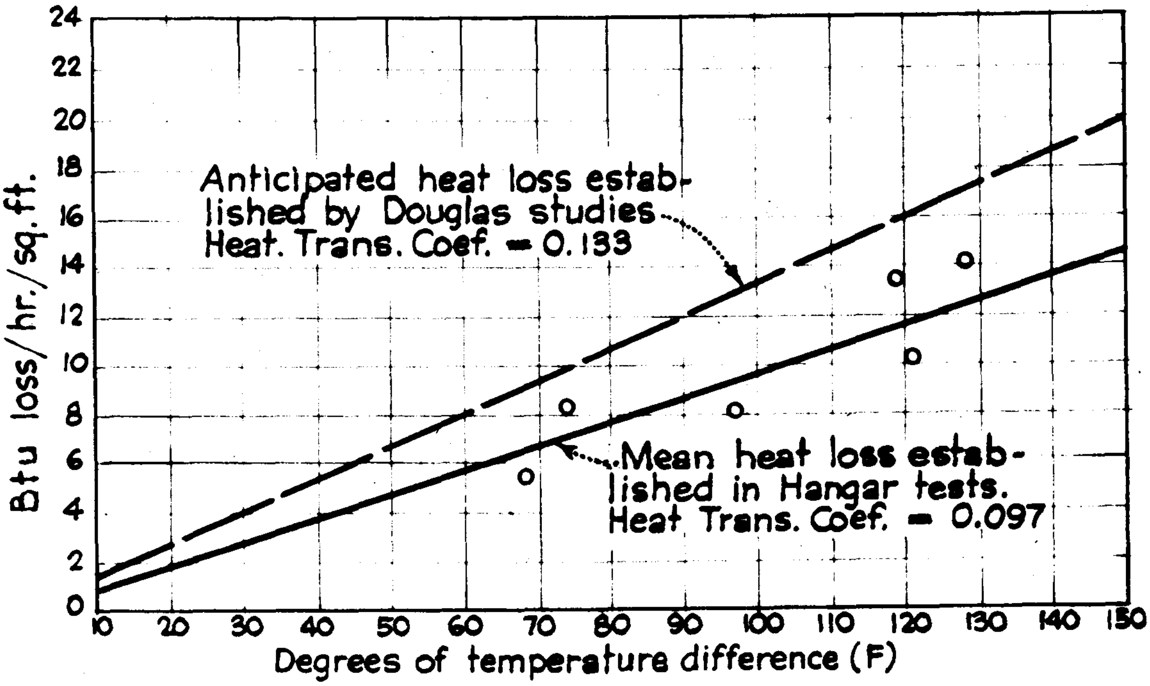


Fig. 36. RELATION OF HEAT LOSS TO TEMPERATURE DIFFERENCE FOR 5 IN. ROOF PANELS UNDER NO-WIND CONDITIONS ESTABLISHED IN CLIMATIC HANGAR TESTS.

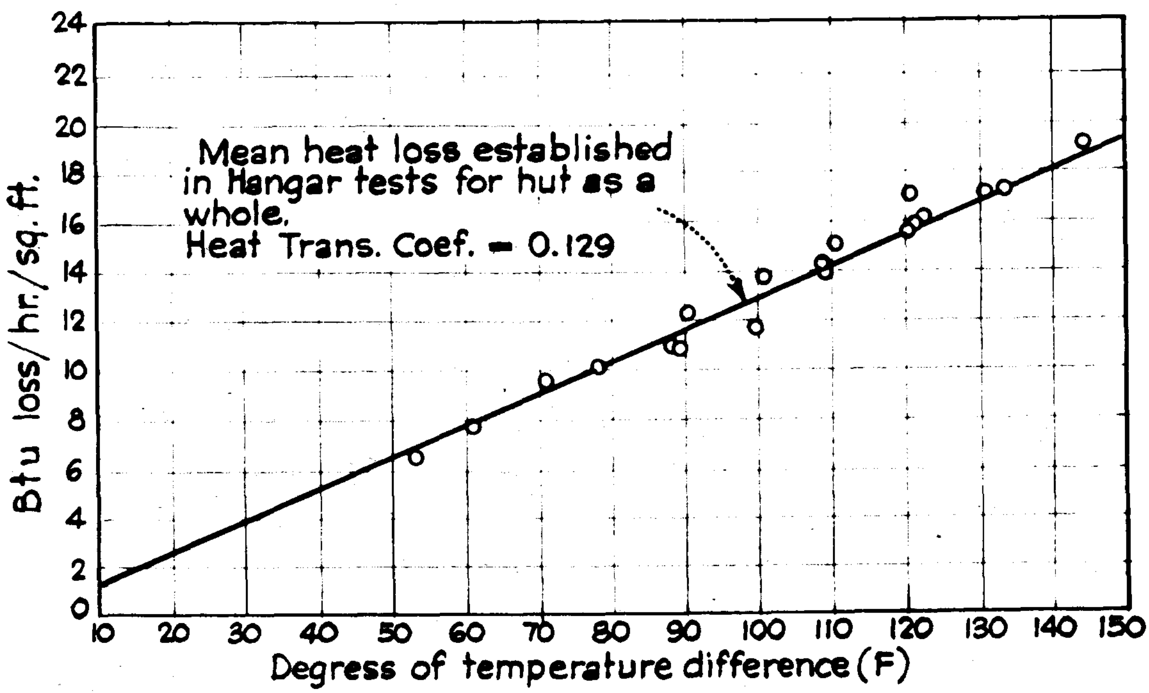


Fig. 37. RELATION OF HEAT LOSS TO TEMPERATURE DIFFERENCE FOR HUT AS A WHOLE UNDER NO-WIND CONDITIONS ESTABLISHED IN CLIMATIC HANGAR TESTS.

nineteen heat balance tests. Fig. 37 presents the results of this study.

Heat Balance Computations

Heat balances were computed for seventeen of the heat tests conducted with the space heaters and for the two electric heat tests. A detailed account of the method of computation employed with selected examples appears in Appendix C. From these computations the total heat input, losses through the heater stacks, outlet ventilators and structure, the number of air changes per hour, and the heat transmission coefficient for the total hut was established for each test. A tabulation of these findings is given in Table 1.

Fuel Requirements.

Fuel storage in temperatures down to -65°F (Fig. 38) necessitated the selection of AN-F-32a Specification, Grade JP-1 fuel for use in the space heaters. A calorimeter test showed this fuel to contain a net value of 18,160 Btu's per pound at 20°C; also, the quantity of fuel burned was measured volumetrically, tests were made to establish the pounds of fuel per gallon for each selected test temperature. The results of these tests are shown below.

Temperature 0°F	Fuel lbs/gal
68	6.830
15	7.066
0	7.111
-20	7.171
-40	7.255
-65	7.285

Table 1. SUMMARY OF DATA ON HEATING AND VENTILATING TESTS OF NAVY ARCTIC HUT (MARK I)

Observations made during Climatic Hangar tests using two 50,000-Btu, oil-fired space heaters, and/or a 15-kw, forced-air electric heater.

Test	Temp. Outside	Test Time	Fuel Qty. Burned	Heat Input	HEAT LOSSES: Through Vent. Air	HEAT LOSSES: Through Heater Stacks	HEAT LOSSES: Through Structure	Ave. Temp. Diff.	Heat Trans. Through Structure	Heat Trans. Coef. (U)	VENTILATION: Volume of Air Passed: Outlet Vents	VENTILATION: Volume of Air Passed: Heater Stacks	VENTILATION: Volume of Air Passed: Total	Volume Rqd. for Combust.	Volume Avail. for Occupants	Air Changes	Circ. of heated air
No.	°F	hrs	lbs/hr	Btu/hr	Btu/hr	Btu/hr	Btu/hr	°F	Btu/hr/ft²	Btu/hr/ft²/°F	ft³/hr	ft³/hr	ft³/hr	ft³/hr	ft³/hr	per hr.	type
2B	15	25.40	2.76	50067	5765	21459	22843	68	7.64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.52	Natural
1C	15	23.92	2.27	41278	5410	16435	19429	54	6.50	0.120	5959	4576	10535	490	10045	1.40	Fans
3B	0	4.13	3.75	68136	5296	32587	30253	79	10.12	0.128	4605	7706	12311	810	11501	1.61	Natural
4B	0	19.92	3.08	55897	4276	23950	27671	71	9.25	0.130	3301	6485	9786	665	9121	1.27	Fans
6C	-20	8.00	5.03	91488	5377	50880	35231	100	11.79	0.118	3530	10434	13964	1087	12877	1.80	Natural
6B	-20	5.00	5.31	96368	11873	43744	40751	101	13.63	0.135	8163	9823	17986	1147	16839	2.35	Natural
5B	-20	27.25	3.88	70400	4583	33050	32777	89	10.95	0.123	3153	7927	11080	840	10240	1.43	Fans
5D	-20	3.42	4.34	78860	8850	37542	32468	90	10.86	0.121	6229	10994	17223	1026	16197	2.26	Fans
6E	-20	8.50	4.75	86260	21593	28215	36452	91	12.20	0.134	15488	6618	22106	998	21108	2.95	Fans
[illegible]	-40	15.50	5.36	97437	7961	38905	50571	121	16.89	0.139	3978	7556	11534	1158	10376	1.45	Natural
9B	-40	19.00	6.27	113900	14396	52003	47501	122	15.89	0.130	7109	10205	17314	1155	15959	2.23	Natural
9E	-40	4.00	7.17	130225	43800	37952	48473	124	16.22	0.131	23473	7197	30670	1549	29121	4.06	Natural
9C	-40	15.30	5.07	92071	11327	39044	41700	109	13.95	0.128	6543	7979	14522	1095	13427	1.87	Fans
9D	-40	6.00	6.66	120809	35392	[illegible]	42136	109	14.10	0.129	[illegible]	8502	29398	1439	27959	3.90	Fans
10C	-40	0.67	Elect.	55346	10502	-	44844	111	15.00	0.135	5392	-	5392	-	5392	0.75	Forced
12B	-65	13.17	6.70	121400	7508	57149	[illegible]	145	19.05	0.131	3193	10510	13703	1447	12256	1.71	Natural
12E	-65	6.42	5.92	107508	6898	48980	51630	134	17.27	0.129	3168	9272	12440	1274	11166	1.56	Fans
12D	-65	3.02	Space & Elect.	138823	50874	37023	50926	131	17.04	0.130	[illegible]	[illegible]	31674	994	30680	4.29	Forced
11C	-65	1.00	Elect.	55877	9441	-	46436	[illegible]	[illegible]	[illegible]	4399	-	4399	-	4399	0.61	Forced

5-A

With this information the field data collected was converted to the actual pounds of fuel required per hour and the resultant Btu's of heat input.

Control of a specified quantity of incoming ventilating air was difficult since accurate measurement at the point of entry was not possible with the available instrument. Conversion of the collected fuel-consumption data, as shown in Table 1, to the quantities required for designated air changes under specific inside and outside conditions is described in Appendix C. From these conversions fuel requirements were computed for maintaining 1, 1-1/2 and 3 air changes per hour, with natural circulation of warm air and using fans to aid circulation. The results of these computations are shown in Fig. 39.

Operating efficiency of the space heaters determined by Orsat Apparatus tests showed that one heater was 53% efficient and the other 67%, with an average efficiency of 60%. Since, under normal conditions, these heaters are designed to operate at a minimum of 70% efficiency (3, pp. 4) the fuel requirements were higher than normal.

<u>Heat Losses.</u>

The heat balance equations were written to compute the heat losses through the heater stacks and outlet ventilators, assuming that the balance of the heat passed through the floor, roof, joints, etc. Since the air changes could not be minutely controlled for like tests at different outside temperatures,

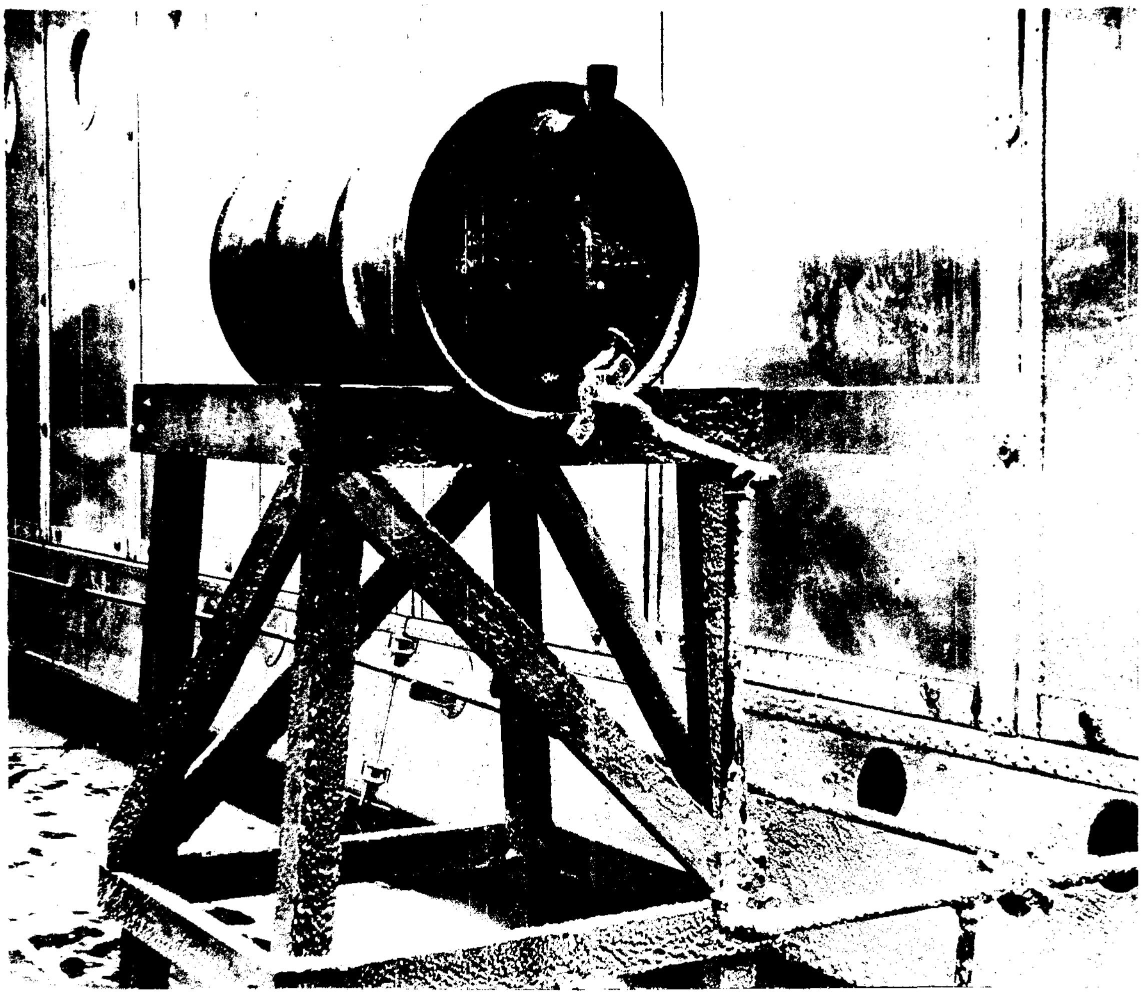


Fig. 38

Plate 9. Fuel for the heaters was stored in two connected tanks outside the hut. Fig. 38 shows the frost accumulated on one of the tanks in a hangar temperature of -65°F.

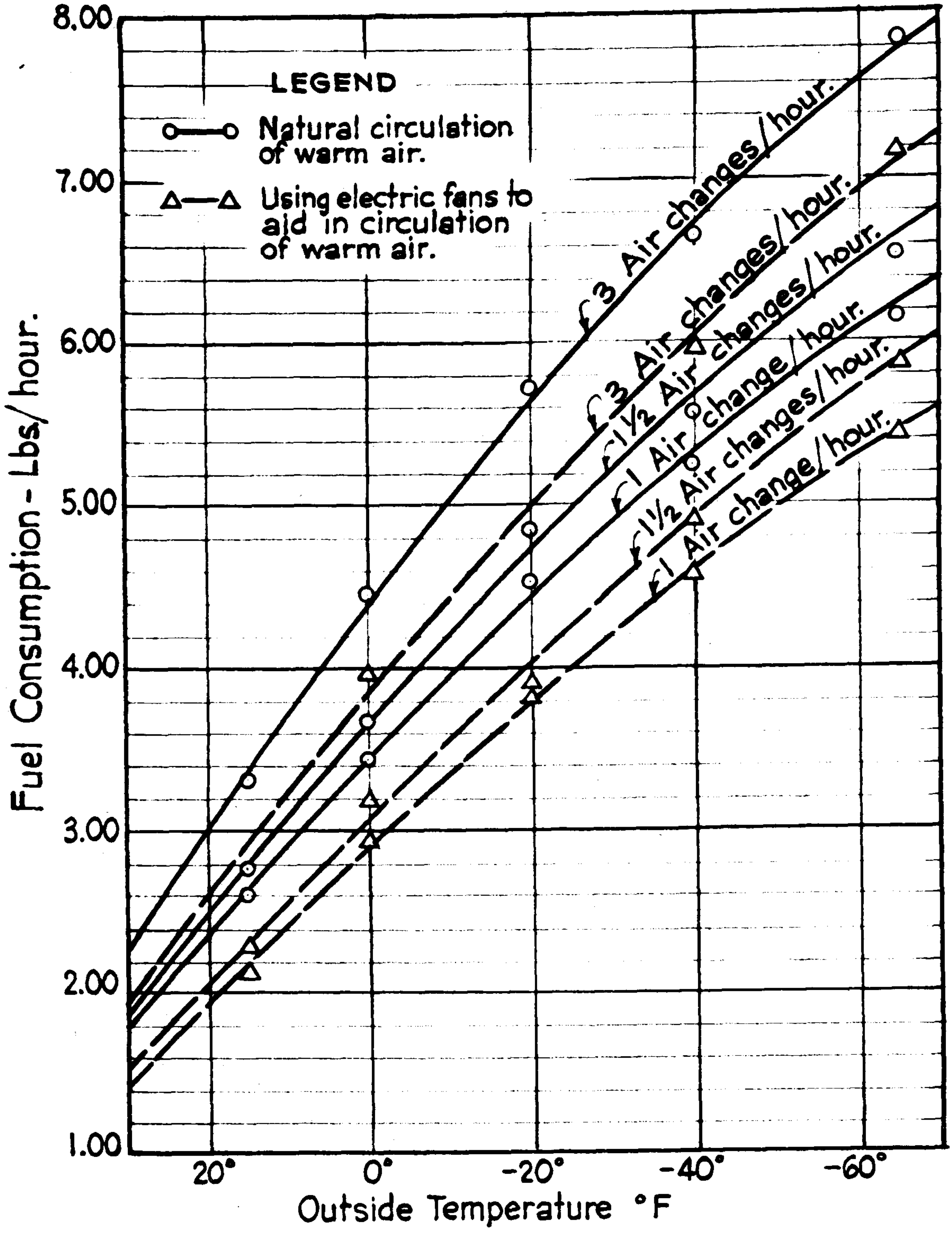


Fig. 39. RELATION OF FUEL CONSUMPTION TO OUTSIDE TEMPERATURE WITH NO WIND AS DEVELOPED FROM CLIMATIC HANGAR TEST DATA USING SPEC. AN-F-32a, GRADE JP-1 FUEL AND HEATERS OPERATING AT 60% EFFIENCY. NORMAL OPERATION REQUIRES A MINIMUM OF 70% HEATER EFFICIENCY.

projection of the recorded data to designated air changes was necessary. Using the projected figures as a basis of comparison, the three major sources of heat loss--through the structure, the heater stacks and the ventilators--could be accumulatively compared. The equations used in these computations are given in Appendix C, and Fig. 40 presents the results of this work for 1 and 2 air changes per hour. Since the tests proved the heaters were performing at only 60% efficiency an additional curve shows the reduction in Btu losses through the flue gases for performance at 70% efficiency.

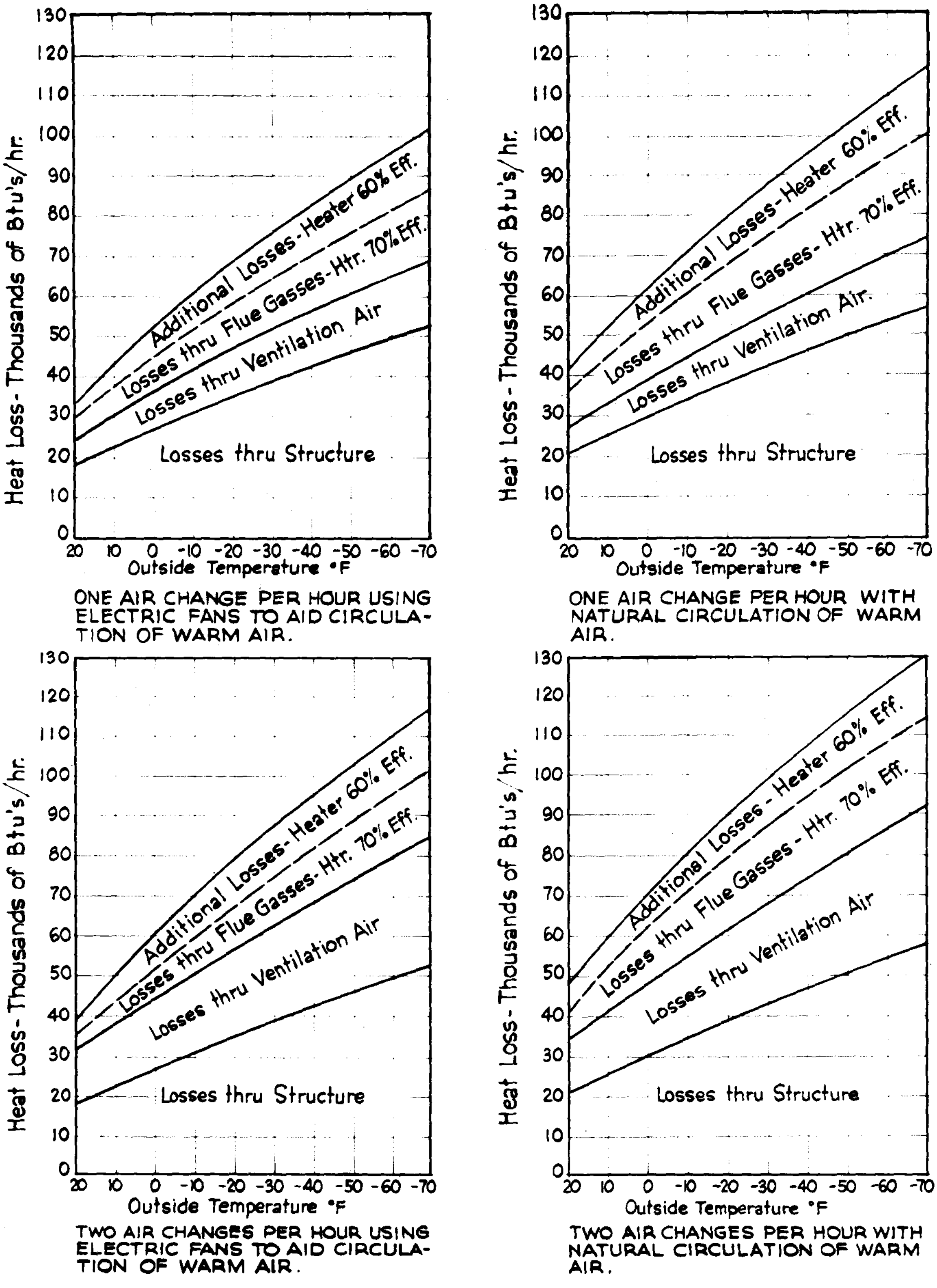
Temperature Distribution

The average temperature obtained at the five levels in the living quarters are presented in tabular form in Table 2 and as isotherms in Fig. 41.

The temperatures presented are those obtained in the tests with a minimum air change in each selected hangar temperature. Inside floor, wall and roof, temperatures, the air temperature under the hut and the surface temperature of the bottom of the foundation beam, have been included. Temperatures recorded under other conditions are presented in Appendix C.

Vertical Temperatures.

The average vertical difference in temperature between the 2-inch level and the 60-inch level above the floor, and the 2-inch level and the 98-inch level, are tabulated



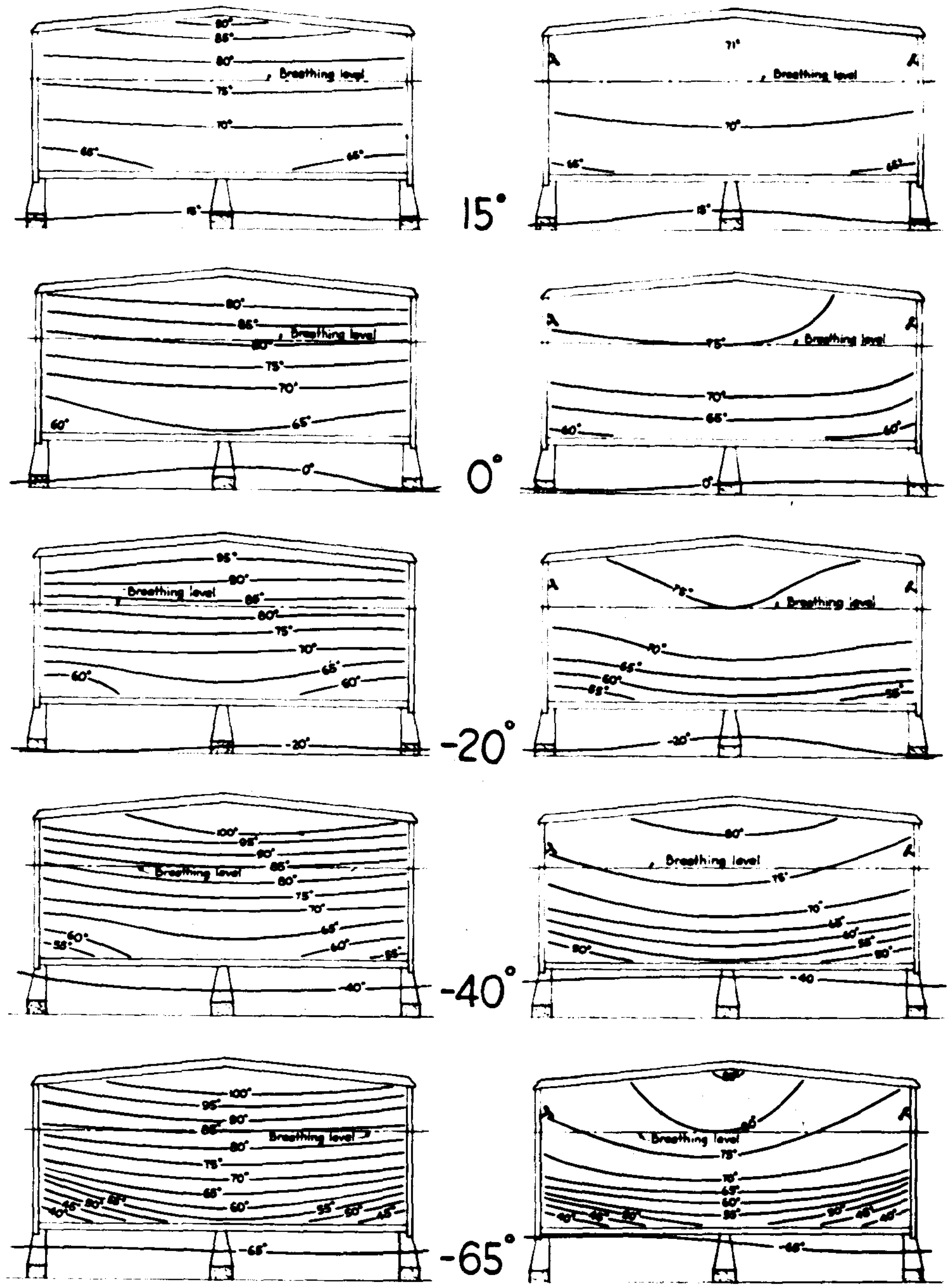
ONE AIR CHANGE PER HOUR USING ELECTRIC FANS TO AID CIRCULATION OF WARM AIR.

ONE AIR CHANGE PER HOUR WITH NATURAL CIRCULATION OF WARM AIR.

TWO AIR CHANGES PER HOUR USING ELECTRIC FANS TO AID CIRCULATION OF WARM AIR.

TWO AIR CHANGES PER HOUR WITH NATURAL CIRCULATION OF WARM AIR.

Fig. 40. SOURCES OF HEAT LOSSES AS RELATED TO OUTSIDE TEMPERATURES FOR ONE AND TWO AIR CHANGES PER HOUR WITH A NO-WIND CONDITION, AS DEVELOPED FROM CLIMATIC HANGAR TEST DATA WITH HEATERS OPERATING AT 60% EFFICIENCY. NORMAL OPERATION REQUIRES A MINIMUM OF 70% EFFICIENCY.



With natural circulation of warm air.

Using electric fans to aid in circulation of warm air.

Fig. 41. ISOTHERMS INSIDE HUT IN 5°F INTERVALS AT VARIOUS AMBIENT HANGAR TEMPERATURES.

for each end and the center of the living quarters. In each case the 98-inch level was 2 inches below the ceiling at the point of observation.

Each table and figure has been so constructed that a direct comparison can be made between the temperature levels obtained with natural circulation of warm air and those achieved using fans. For example, in Table 2 at an outside temperature of 15°F the average temperature difference between the 2-inch to 60-inch level is 11° with natural circulation, whereas, the fans reduced this difference to 5°. At the same outside temperature a difference of 23° between the 2-inch to 98-inch level with natural circulation was reduced to a difference of 6°. A similar comparison at an outside temperature of -65°F shows the average temperature difference between the 2-inch to 60-inch level to be 37° with natural circulation of air, whereas, the fans reduced this difference to 33°; however, between the 2 to 98-inch level, by using the fans a difference of 53° was reduced to 36°. A similar comparison of the effect of the fans at the other outside temperatures indicates that between the 2 to 60-inch level, the fans reduced the average difference about 4°, whereas, for the 2 to 98-inch level this reduction averaged about 17°.

From the standpoint of comfort, the temperatures from the floor to the 60-inch level are the most significant. In the tests with natural circulation of the warm air the observed temperature of 63°F, 2 inches above the floor at a

Table 2. TEMPERATURE DISTRIBUTION IN NAVY ARCTIC HUT (MARK I) AT OUTSIDE TEMPERATURES FROM 15°F TO -65°F.

Observations made during Climatic Hangar tests heating the hut with two 50,000-Btu, oil-fired space heaters and changing the ventilating air approximately 1-1/2 times per hour.

Location	OUTSIDE TEMPERATURE 15°F						OUTSIDE TEMPERATURE 0°F						OUTSIDE TEMPERATURE -20°F					
		Living Quarters						Living Quarters						Living Quarters				
	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F
OBSERVED TEMPERATURES WITH NATURAL CIRCULATION																		
	(1.5 Air Changes Per Hour)						(1.6 Air Changes Per Hour)						(1.8 Air Changes Per Hour)					
2" above floor	--	64	67	63	63	3	--	61	65	62	62	4	--	56	64	59	56	6
30" above floor	--	69	70	69	69	1	--	69	70	70	70	1	--	67	70	70	69	3
60" above floor	58	76	77	76	74	1	53	79	81	79	79	2	50	81	83	82	82	2
84" above floor	--	81	83	86	83	5	--	86	90	94	90	8	--	87	93	102	96	15
98" above floor	68	82	92	88	86	10	63	89	89	97	92	8	60	89	100	106	99	17
Floor surface	--	--	--	--	65	--	--	--	--	--	63	--	--	--	--	--	62	--
Wall surface	--	--	--	--	74	--	--	--	--	--	71	--	--	--	--	--	69	--
Roof surface	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	86	--
Under hut	--	17	--	19	18	--	--	2	--	3	3	--	--	-18	--	-18	-18	--
Foundation beam	--	--	--	--	17	--	--	--	--	--	2	--	--	--	--	--	-18	--
Temperature Differences																		
2" to 60" level	--	12	10	13	11	--	--	18	16	17	17	--	--	25	19	23	26	--
2" to 98" level	--	18	25	25	23	--	--	28	24	35	30	--	--	33	36	47	43	--
OBSERVED TEMPERATURES USING FANS TO AID CIRCULATION																		
	(1.4 Air Changes Per Hour)						(1.3 Air Changes Per Hour)						(1.4 Air Changes Per Hour)					
2" above floor	--	66	67	64	65	3	--	60	61	60	60	1	--	56	58	56	55	2
30" above floor	--	69	70	68	69	2	--	70	71	70	70	1	--	69	71	68	69	3
60" above floor	53	70	71	71	70	1	44	73	75	74	74	2	44	72	75	73	73	3
84" above floor	--	69	71	72	70	3	--	72	77	76	74	5	--	72	78	75	75	6
98" above floor	60	69	71	72	71	3	56	74	78	75	75	4	50	73	78	77	75	5
Floor surface	--	--	--	--	61	--	--	--	--	--	59	--	--	--	--	--	55	--
Wall surface	--	--	--	--	68	--	--	--	--	--	67	--	--	--	--	--	65	--
Roof surface	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	74	--
Under hut	--	17	--	19	18	--	--	4	--	5	4	--	--	-19	--	-16	-18	--
Foundation beam	--	--	--	--	16	--	--	--	--	--	4	--	--	--	--	--	-18	--
Temperature Differences																		
2" to 60" level	--	4	4	7	5	--	--	13	14	14	14	--	--	16	17	17	18	--
2" to 98" level	--	3	4	8	6	--	--	14	17	15	15	--	--	17	20	21	20	--

Table 2. (CONTINUED) TEMPERATURE DISTRIBUTION

Location	OUTSIDE TEMPERATURE -40°F						OUTSIDE TEMPERATURE -65°F						SUMMARY OF AVERAGE TEMPERATURES					
		Living Quarters						Living Quarters					Outside Temperature					Max. Temp. diff. °F
	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	15°F °F	0°F °F	-20°F °F	-40°F °F	-65°F °F	
OBSERVED TEMPERATURES WITH NATURAL CIRCULATION																		
	(1.5 Air Changes Per Hour)						(1.7 Air Changes Per Hour)						(1.5 plus or minus Air Changes Per Hour)					
2" above floor	--	54	62	58	57	8	--	49	54	40	47	14	63	62	56	57	47	16
30" above floor	--	65	69	69	68	4	--	68	71	70	69	3	69	70	69	68	69	2
60" above floor	47	82	85	83	83	3	37	84	86	84	84	2	74	79	82	83	84	10
84" above floor	--	88	102	106	98	14	--	90	100	104	98	14	83	90	96	98	98	15
98" above floor	57	90	101	110	100	20	38	95	103	109	100	14	86	92	99	100	100	14
Floor surface	--	--	--	--	60	--	--	--	--	--	47	--	65	63	62	60	47	--
Wall surface	--	--	--	--	62	--	--	--	--	--	60	--	74	71	69	62	60	--
Roof surface	--	--	--	--	83	--	--	--	--	--	80	--	--	--	86	83	80	--
Under hut	--	-41	--	-40	-40	--	--	-65	--	-65	-65	--	18	3	-18	-40	-65	--
Foundation beam	--	--	--	--	-40	--	--	--	--	--	-65	--	17	2	-18	-40	-65	--
	Temperature Differences																	
2" to 60" level	--	28	23	25	26	--	--	35	32	44	37	--	11	17	26	26	37	26
2" to 98" level	--	36	39	52	43	--	--	46	49	69	53	--	23	30	43	43	53	30
OBSERVED TEMPERATURES USING FANS TO AID CIRCULATION																		
	(1.9 Air Changes Per Hour)						(1.6 Air Changes Per Hour)						(1.5 plus or minus Air Changes Per Hour)					
2" above floor	--	49	55	46	49	9	--	46	52	36	43	16	65	60	55	49	43	22
30" above floor	--	68	70	67	68	3	--	67	70	68	68	3	69	70	69	68	68	2
60" above floor	38	75	78	75	75	3	29	73	80	77	76	7	70	74	73	75	76	6
84" above floor	--	75	80	78	77	5	--	73	82	81	78	9	70	74	75	77	78	8
98" above floor	46	75	80	78	77	5	28	72	86	81	79	14	71	75	75	77	79	8
Floor surface	--	--	--	--	53	--	--	--	--	--	48	--	61	59	55	53	48	--
Wall surface	--	--	--	--	55	--	--	--	--	--	53	--	68	67	65	55	53	--
Roof surface	--	--	--	--	70	--	--	--	--	--	67	--	--	--	74	70	67	--
Under hut	--	-42	--	-41	-42	--	--	-66	--	-65	-65	--	18	4	-18	-42	-65	--
Foundation beam	--	--	--	--	-41	--	--	--	--	--	-65	--	16	4	-18	-41	-65	--
	Temperature Differences																	
2" to 60" level	--	26	23	29	26	--	--	27	28	41	33	--	5	14	18	26	33	28
2" to 98" level	--	26	25	32	28	--	--	26	34	45	36	--	6	15	20	28	36	30

15°F outside temperature, was reduced to 47°F at a -65°F outside temperature, while a 74°F temperature at the 60-inch level was increased to 84°F. With the fans assisting in circulation an observed temperature at 65°F, 2 inches above the floor at a 15°F outside temperature, was reduced to 43°F at a -65°F outside temperature, while a 60-inch level temperature of 70°F increased to only 76°F. This is shown graphically in Fig. 42.

Dill and Achenbach, in their study of temperature distribution with various heating devices in a frame bungalow, uninsulated except for the ceiling (4, pp 4), obtained the following average room temperature at an outside temperature ranging from 12°F to 14°F using an electric warm air heater with the air distributed by natural circulation through a plenum chamber:

Height Above Floor Ins.	Average Temperature °F
2	58
30	66
60	77
78	90
94	105

Temperature Difference	
2" to 60" level	19
2" to 94" level	47

Using the same heater but intermittently distributing the air with a 780-cfm fan at an outside temperature ranging

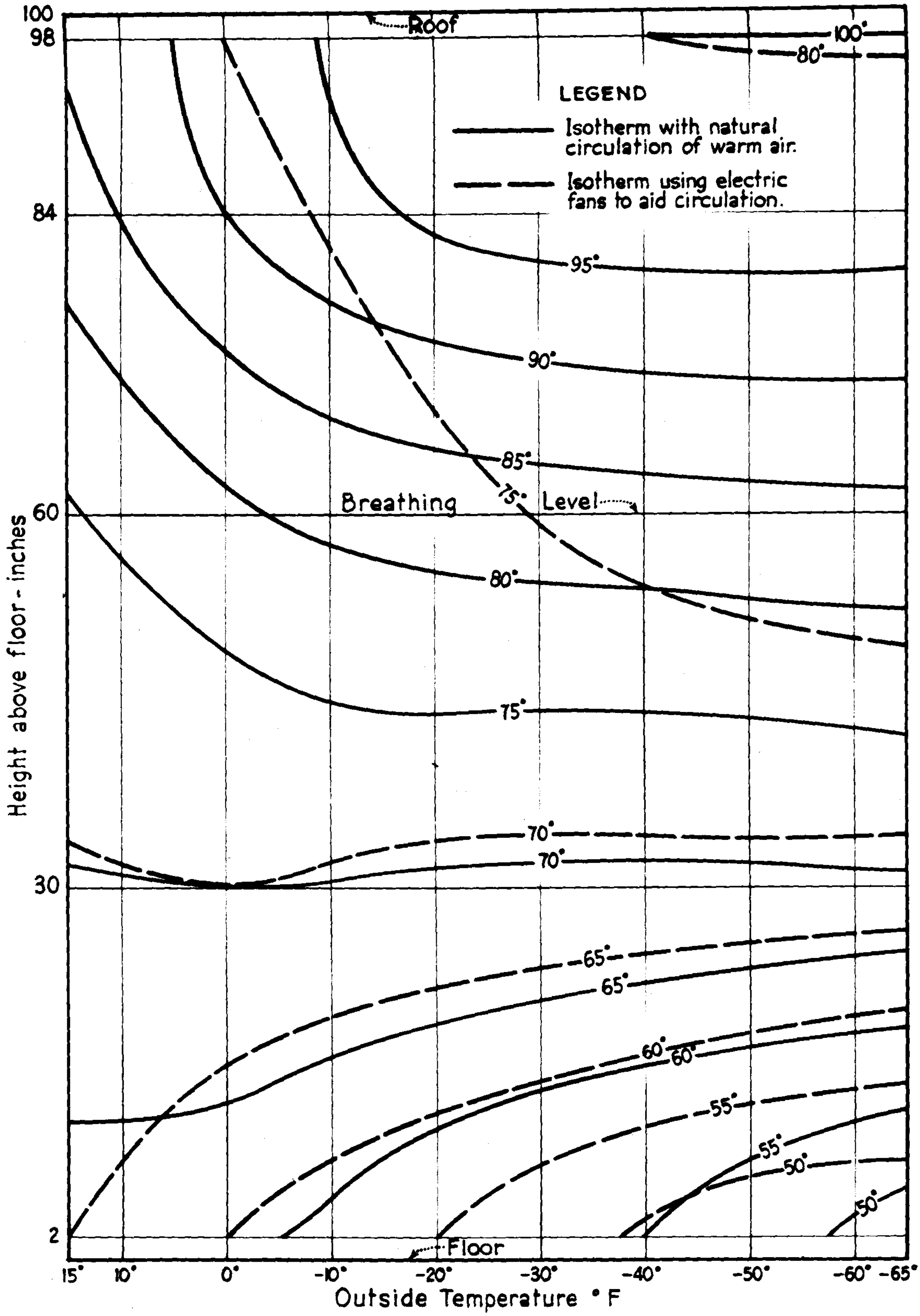


Fig. 42. RELATION OF AVERAGE INSIDE AIR TEMPERATURES TO OUTSIDE TEMPERATURES WITH A NO-WIND CONDITION.

from $8^{O}F$. to $10^{O}F$., these temperatures became:

Height Above Floor Ins.	Average Temperature ^{O}F
2	55
30	70
60	81
78	88
94	94

Temperature Difference	
2" to 60" level	26
2" to 94" level	39

These temperatures when compared with those observed in the hut at an outside temperature of $0^{O}F$ (Table 2) show that with natural circulation of warm air a more even distribution of vertical temperature was obtained in the hut. For example, the hut temperature 2 inches above the floor was 7^{O} warmer even though the bungalow had a basement with a temperature of $35^{O}F$. The temperature under the ceiling of the hut was 2^{O} less, and the 2 to 98-inch level temperature difference was 9^{O} less.

Horizontal Temperatures.

The maximum horizontal temperature differences within the living quarters at each of the five levels are shown in Table 2.

A study of this data revealed no direct relationship between the vertical and horizontal temperature differences. The study did show the entrance end of the living quarters to be somewhat colder. This was accredited to the low efficiency of the heater at this end, 53% as compared to an efficiency of

67% for the other heater, and the entry of outside air when opening the entrance door. Opening this door at outside temperatures below -20°F would cause a 1° drop in temperature 30 inches above the floor at the center of the living quarters.

The data show that the average of the horizontal temperature differences at the 2-inch level at a 15°F. outside temperature was the same for natural circulation as when using fans. On reaching an outside temperature of -20°F this difference was 4° less with the fans, but when an outside temperature of -65°F was reached, the difference was 2° less without the fans. At both the 30-inch and 60-inch level, there was never more than 1° difference until an outside temperature of -65°F was reached, whereupon the difference became 5° greater at the 60-inch level using the fans. Using the fans at the 84-inch level, the difference ranged from 2° to 9° less for all outside temperatures; whereas, at an outside temperature of -40°F, 2 inches below the roof the difference reached 15° less and at -65°F there was no difference. In general, down to an outside temperature of -40°F, the fans assisted in balancing the temperature differences horizontally at the floor and near the ceiling but, at -65°F, the effect of the fans was negative.

Temperatures under the Hut.

The average temperature 1 foot under the hut and in the bottom of the foundation beams is given in Table 2. Down to an outside temperature of -20°F both the air temperature and the bottom of the beams averaged 2°. to 4°. warmer than the ambient hangar air. However, at both -40°F and -65°F there was no difference. The use of fans within the hut had little effect on these temperatures. In Fig. 43 the anticipated air temperature for a given ambient temperature can be read.

Physiological Studies

Observations on factors governing allowable comfort within the hut were made during the hangar tests. These included a recording of the inside floor, wall and roof surface temperatures and the humidity in the 70°F. temperature, 30 inches above the floor for each test condition. Based on these observations a study of occupancy versus allowable comfort has been made.

Inside Surface Temperatures.

Average floor, wall and roof surface temperatures are given in Figs. 44 and 45. Since the rate of air change and the method of warm air circulation affect these temperatures, curves covering both conditions are shown. In outside temperatures down to -65°F, use of the fans lowered the floor temperatures 5° to 7° below those obtained with natural circulation with 1.5 air changes per hour. At -65°F, a floor temperature of 48°F, using the fans was one degree higher than the temperature obtained with natural circulation of air. The wall temperature averaged 5° less for all outside temperatures when the fans were used, and the roof temperatures averaged

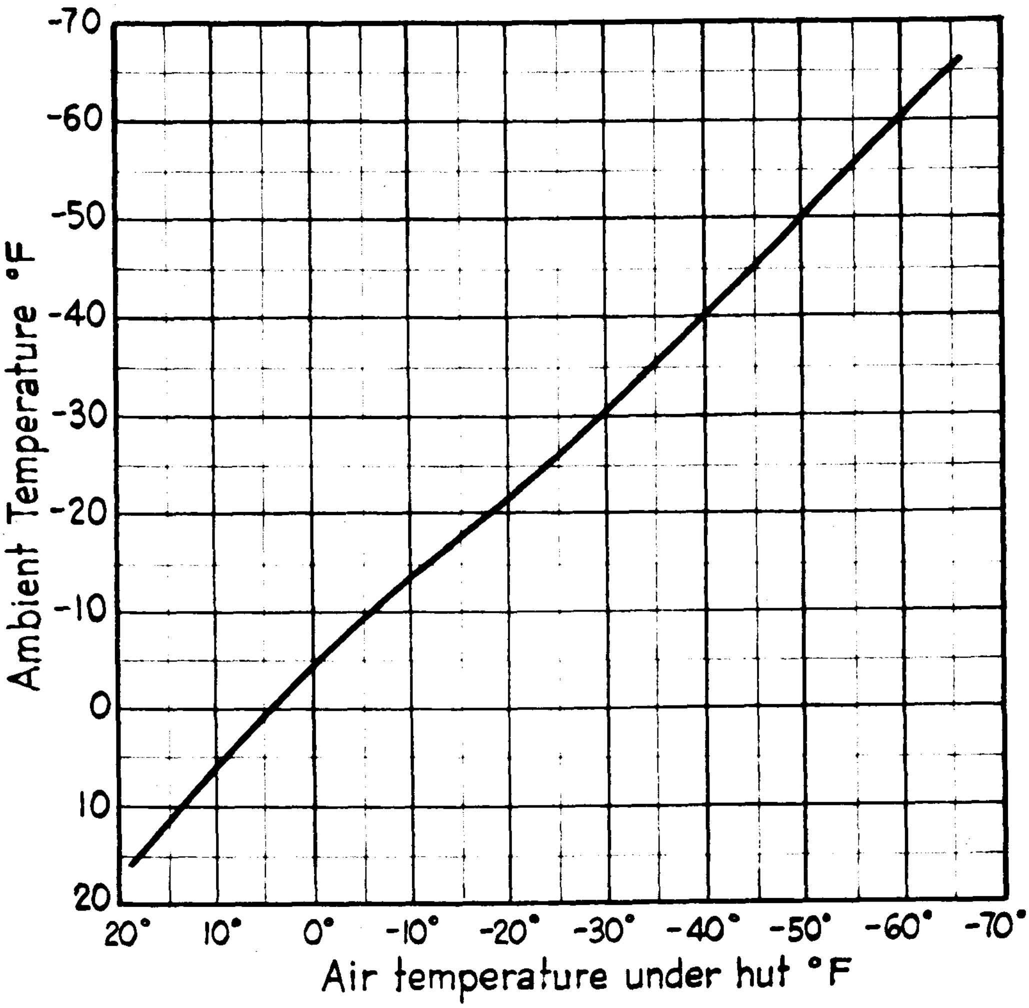


Fig. 43. RELATION OF AIR TEMPERATURE UNDER HUT TO AMBIENT TEMPERATURE WITH NO WIND AS DETERMINED FROM CLIMATIC HANGAR TESTS.

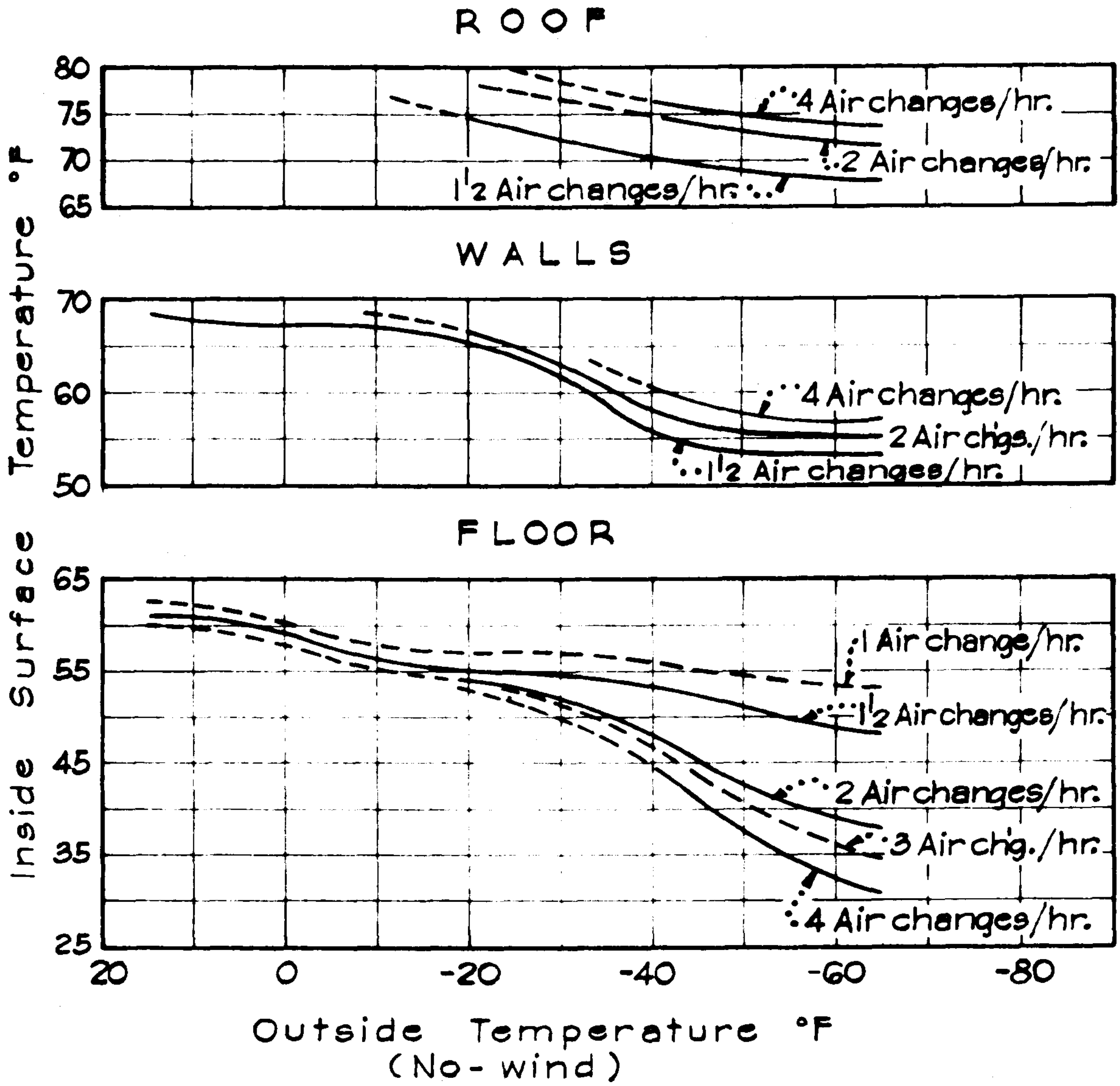


Fig 44. COMPARISON OF INSIDE SURFACE TEMPERATURES TO OUTSIDE TEMPERATURES WITH THE INSIDE TEMPERATURE 70°F AND USING FANS TO AID CIRCULATION OF WARM AIR.

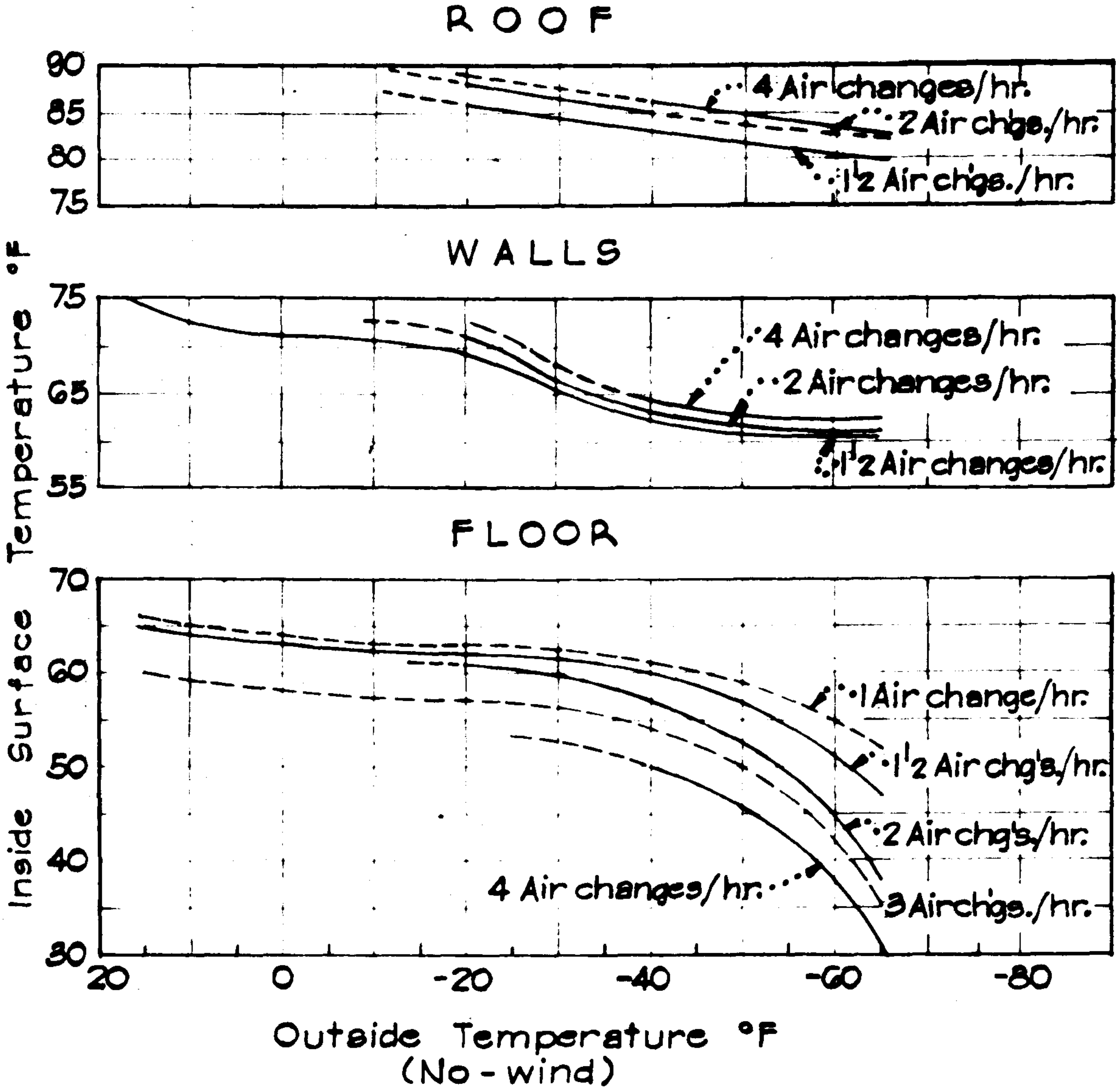


Fig 45. COMPARISON OF INSIDE SURFACE TEMPERATURES TO OUTSIDE TEMPERATURES WITH THE INSIDE TEMPERATURE 70°F AND NATURAL CIRCULATION OF WARM AIR.

10° less. A noticeable drop of several degrees in both the floor and wall temperatures with and without fans occurred between a -20°F and -40°F outside temperature.

Temperatures of the inside window surfaces were not recorded and there was no condensation on the inside surface. All windows were double glazed and icing between the two panes of plexiglass appeared at outside temperatures of -20°F. and below. Complete loss of visibility through any window was not experienced as never more than 20% of the area frosted. A typical frost pattern is shown in Fig. 46.

Relative Humidity.

The maximum relative humidities observed are given in Table 3. These were taken in the center of the living quarters 30 inches above the floor where the air temperature ranged between 68°F. and 72°F. No attempt other than occupancy and making coffee, was made to humidify the hut interior during these tests. With the humidities obtained condensation in the form of water or frost was not observed either in the vestibule or living quarters until the outside temperature reached -65°F. Air leakage through floor panel joints down the center of the living quarters at this temperature resulted in formation of small frost areas, however, by caulking they were soon eliminated.

In addition to the observed relative humidities given in Table 3 the average floor temperatures near the center of the living quarters and the adjacent air temperature two inches a-

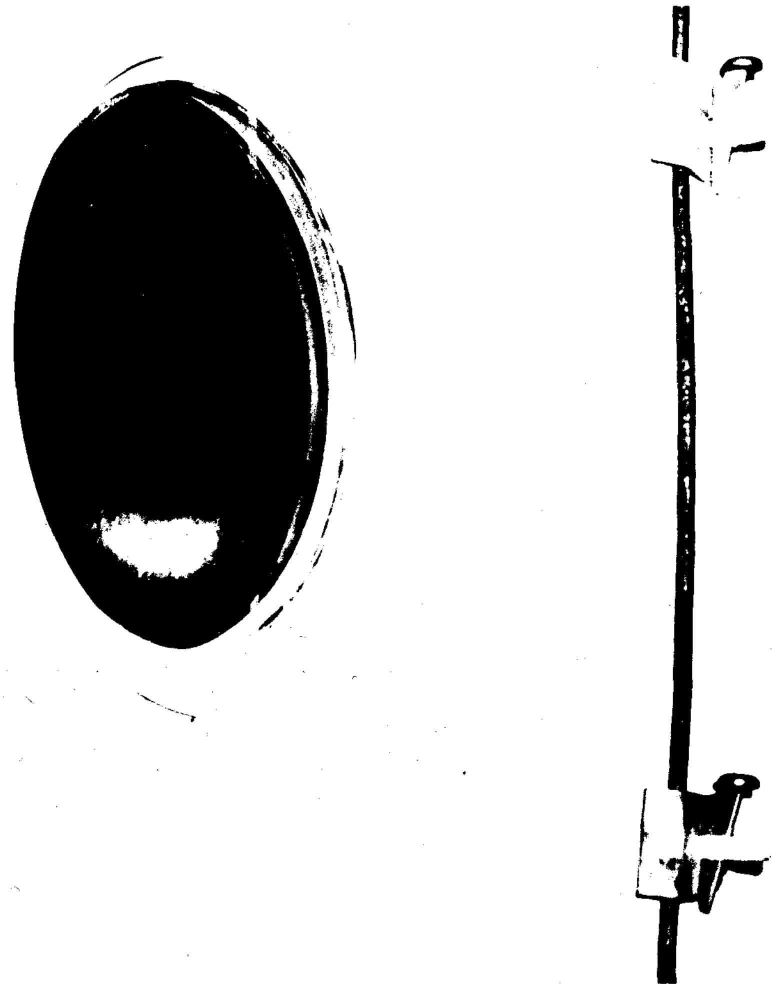


Fig. 46.

Plate 10. Windows in the hut were made of plexiglass and double glazed. Fig. 46 shows a typical frost pattern on the outside of the inside pane which was present in all outside temperatures below $0^{o}F$.

Table 3. RELATIVE HUMIDITY IN NAVY ARCTIC HUT (MARK I) AT VARIOUS OUTSIDE TEMPERATURES

Observations made during Climatic Hangar tests heating the hut with two 50,000-Btu, oil-fired space heaters.

Approx. Air Changes	Average Outside Temperature 15°F				0°F				-20°F				-40°F				-65°F			
	Relative Humidity in 70°F Air 30 in. above floor	Average floor temperature	Average Air Temp. 2 in. above floor	Coldest Air 2 in. above floor	Relative Humidity in 70°F Air 30 in. above floor	Average floor temperature	Average Air Temp. 2 in. above floor	Coldest Air 2 in. above floor	Relative Humidity in 70°F Air 30 in. above floor	Average floor temperature	Average Air Temp. 2 in. above floor	Coldest Air 2 in. above floor	Relative Humidity in 70°F Air 30 in. above floor	Average floor temperature	Average Air Temp. 2 in. above floor	Coldest Air 2 in. above floor	Relative Humidity in 70°F Air 30 in. above floor	Average floor temperature	Average Air Temp. 2 in. above floor	Coldest Air 2 in. above floor
Hrs.	%	°F	°F	°F	%	°F	°F	°F	%	°F	°F	°F	%	°F	°F	°F	%	°F	°F	°F
	WITH NATURAL CIRCULATION OF WARM AIR																			
1-1/2	24	65	67	64	20	63	65	61	11	62	64	56	19	60	62	50	12	47	54	34
2	--	--	--	--	--	--	--	--	17	61	63	57	11	57	60	54	9	38	42	22
4	--	--	--	--	--	--	--	--	--	--	--	--	4	50	56	46	9	31	37	18
	WITH ELECTRIC FANS TO AID CIRCULATION OF WARM AIR																			
1-1/2	20	61	67	64	21	59	61	59	19	55	58	56	6	53	55	45	7	48	52	33
2	--	--	--	--	--	--	--	--	11	54	58	53	6	48	53	45	9	38	38	17
3	--	--	--	--	--	--	--	--	7	54	57	52	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--	--	7	45	49	38	9	31	34	12

bove the floor in the coldest part of the living quarters is also included.

Occupancy.

To evaluate the hut for human inhabitance at low temperatures both a normal and maximum billeting was assumed. A 16-man occupancy using double bunks as shown in Fig. 47 allotted each man 55 square feet of floor space and 448 cubic feet of air space which meets the BuDocks Design Criteria (5), and based on 15 cfm of fresh air per man, 2 air changes per hour are required. However, to remove objectionable body odors only 8 cfm of fresh air (6, pp. 215) are needed, and this quantity can be furnished with 1 air change per hour. Satisfactory interior arrangement for semi-permanent conditions can be obtained by using partitions to form 8 cubicles for sleeping, thus allotting a maximum of space for recreation, washing, and toilet facilities.

A maximum billeting of 28 men was achieved using double bunks as shown in Fig. 48 with space allotted for wash basins and toilets. This arrangement allowed only 30 square feet of floor space and 256 cubic feet of air space per man, which means that 23,000 cubic feet of ventilating air per hour is required based on 15 cfm per man. To provide this quantity of air 3.2 air changes per hour are needed.

Allowable Comfort.

Based on the occupancy requirements and the recorded test data, the charts presented in Figs. 49, 50 and 51 have been

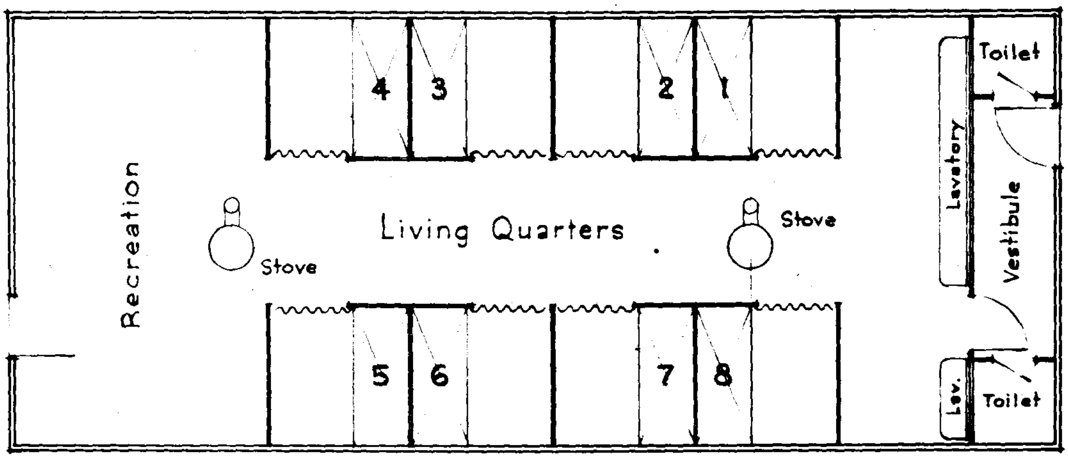


Fig.47. SPACE ALLOCATION STUDY FOR 16 MAN OCCUPANCY.

EIGHT DOUBLE BUNKS ARRANGED TO ALLOW RECREATION AREA AND WASH BASINS IN LIVING QUARTERS WITH TOILET FACILITIES IN ENTRANCE VESTIBULE. LIGHTWEIGHT PARTITIONS AND CURTAINS CAN BE ADDED TO FORM TWO-MAN CUBICLES FOR SEMI-PRIVACY.

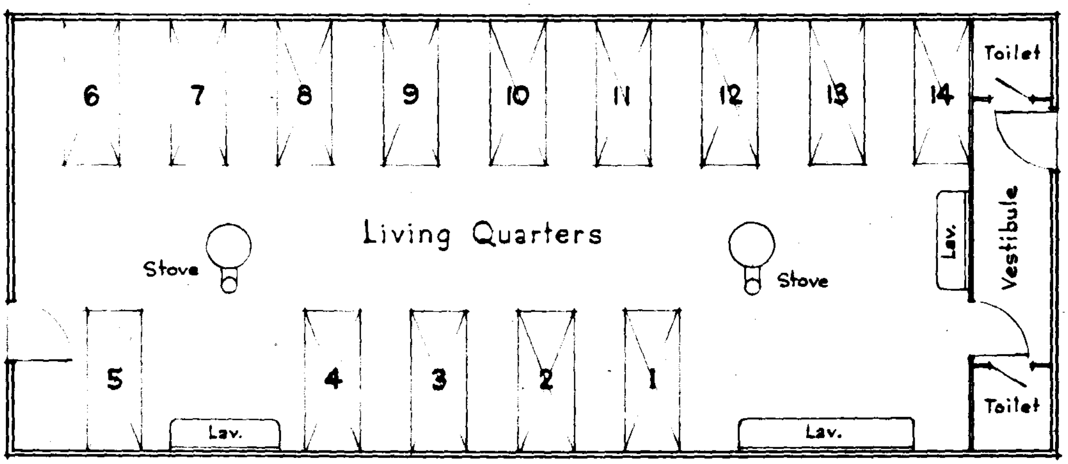
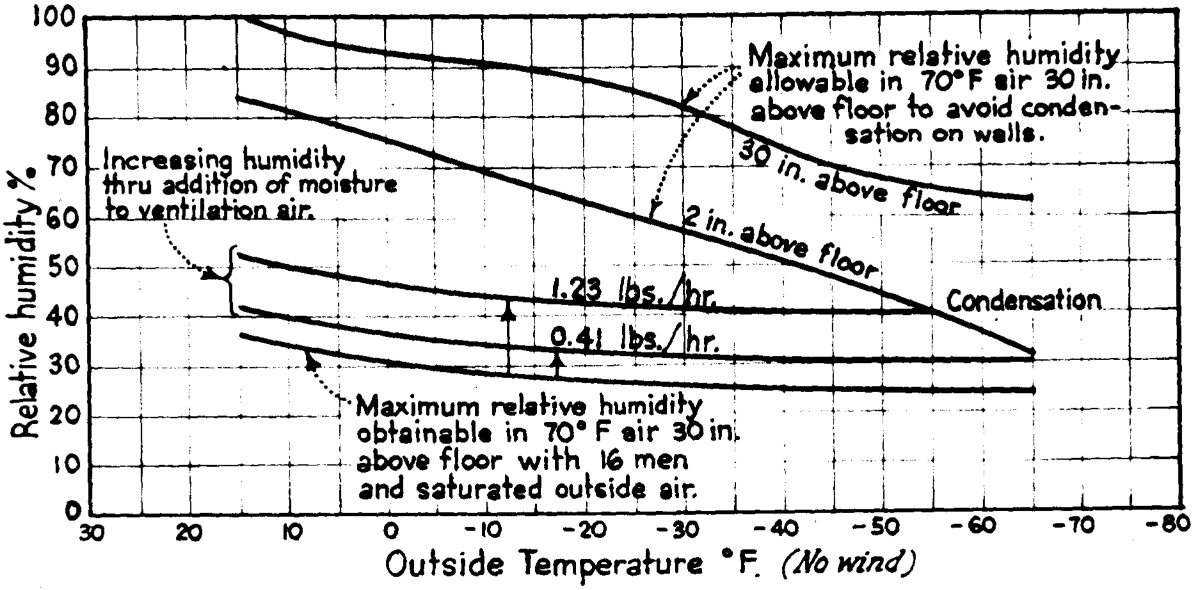
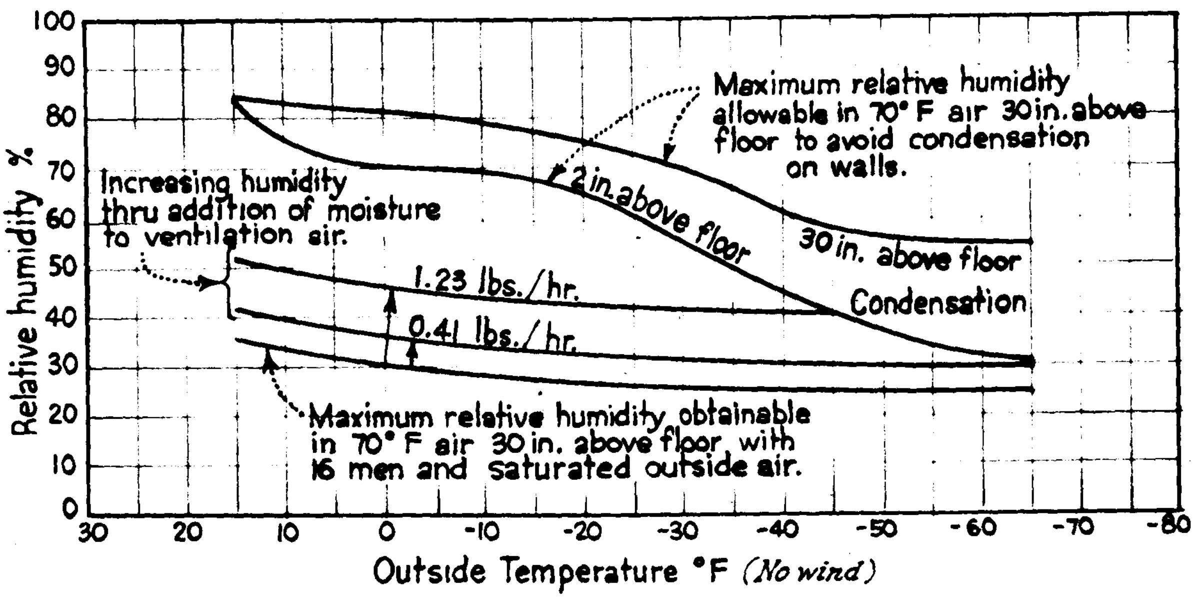


Fig. 48. SPACE ALLOCATION STUDY FOR 28 MAN OCCUPANCY.

FOURTEEN DOUBLE BUNKS ARRANGED TO ALLOW RECREATION AREA AND WASH BASINS IN LIVING QUARTERS WITH TOILET FACILITIES IN ENTRANCE VESTIBULE.

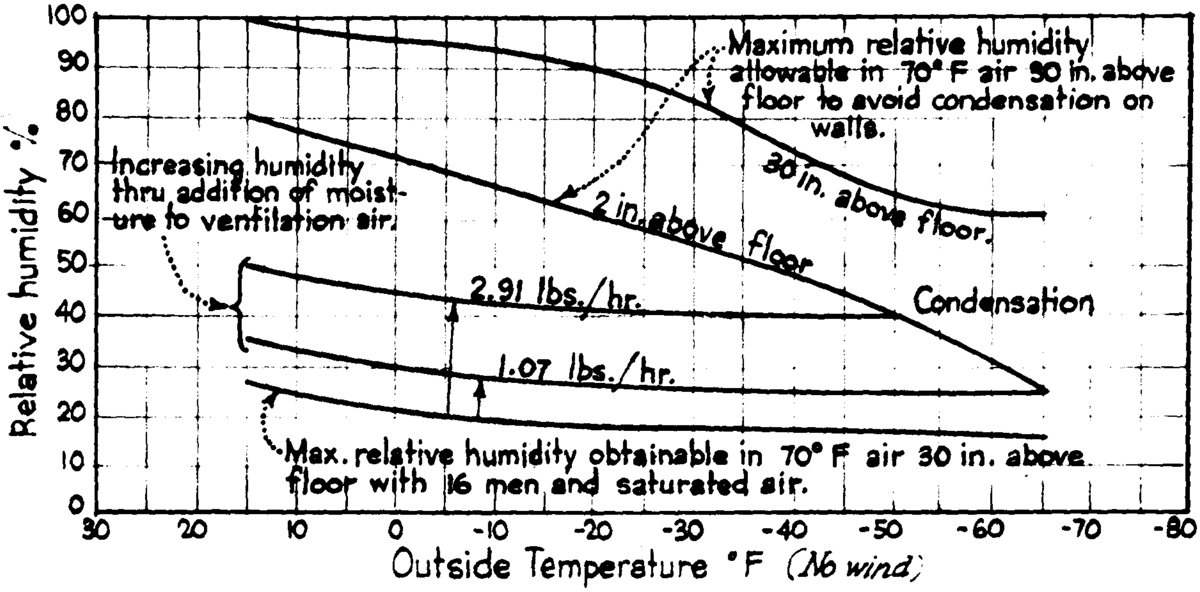


WITH NATURAL CIRCULATION OF WARM AIR

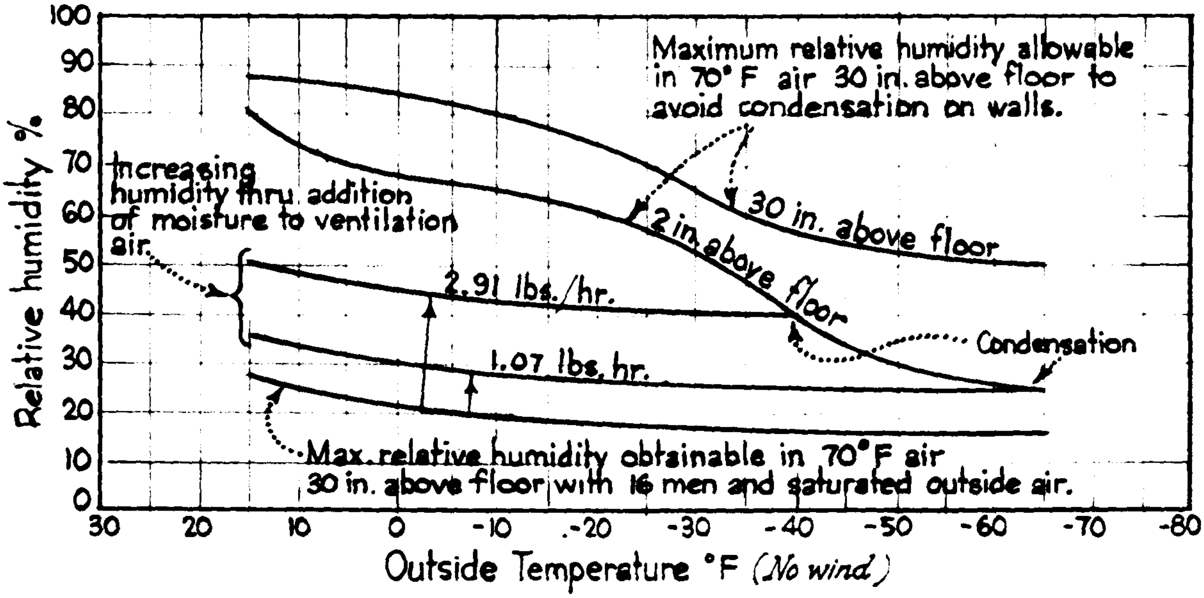


WITH FANS TO AID IN CIRCULATION OF WARM AIR.

Fig. 49. RELATIVE HUMIDITY STUDIES OF ALLOWABLE COMFORT CONDITIONS WITH 16-MAN OCCUPANCY AND 1 AIR CHANGE PER HOUR.

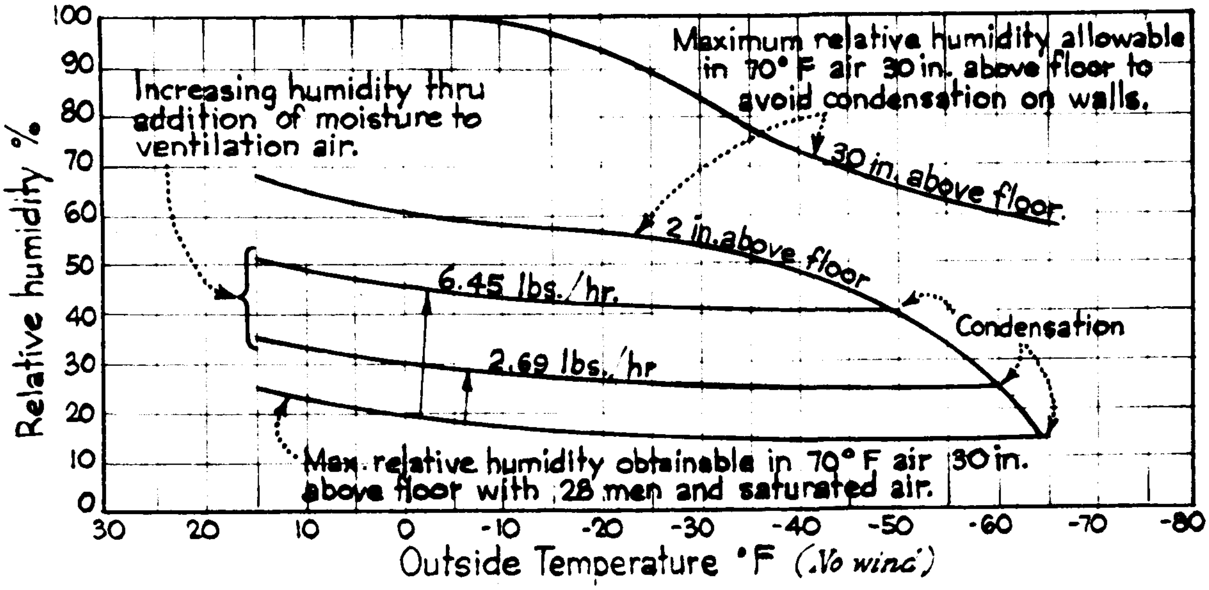


WITH NATURAL CIRCULATION OF WARM AIR

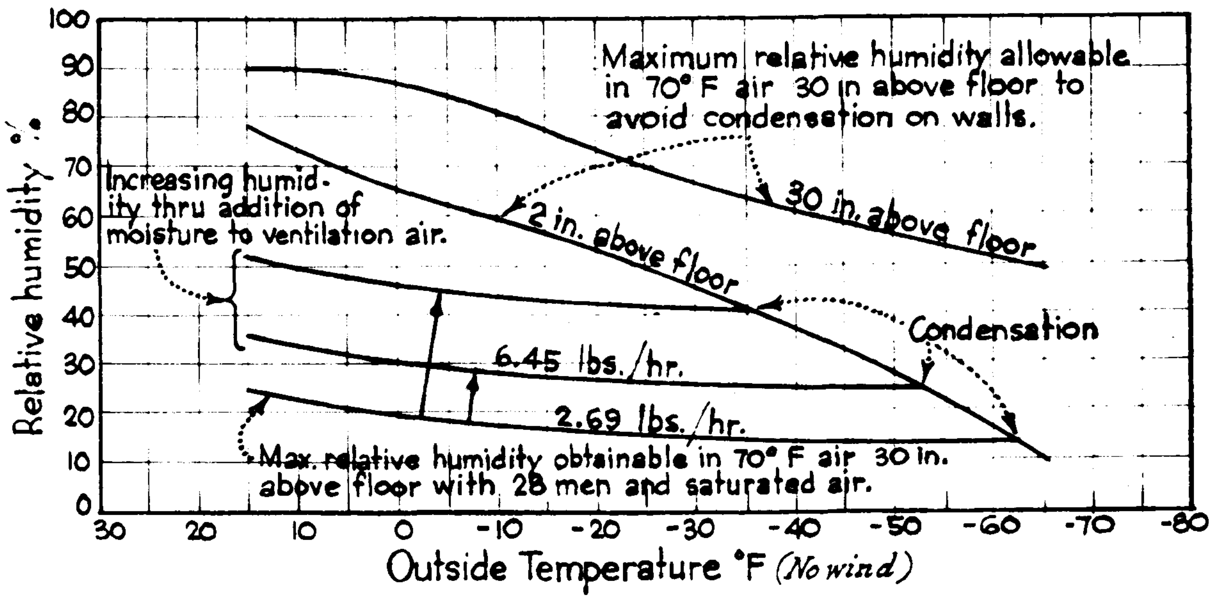


WITH FANS TO AID IN CIRCULATION OF WARM AIR.

Fig. 50. RELATIVE HUMIDITY STUDIES OF ALLOWABLE COMFORT CONDITIONS WITH 16-MAN OCCUPANCY AND 1½ AIR CHANGES PER HOUR.



WITH NATURAL CIRCULATION OF WARM AIR



WITH FANS TO AID IN CIRCULATION OF WARM AIR.

Fig. 51. RELATIVE HUMIDITY STUDIES OF ALLOWABLE COMFORT CONDITIONS WITH 28-MAN OCCUPANCY AND 3 AIR CHANGES PER HOUR.

developed for 1 and 1-1/2 air changes per hour with 16-man occupancy and 3 air changes per hour with 28-man occupancy. The basic data used in the development of these curves appears in Appendix C. For example, in Fig. 49, based on a 16-man occupancy with 1 air change per hour and natural circulation of warm air, one curve gives the maximum allowable relative humidity in the 70°F air 30 inches above the floor to avoid condensation from the coldest anticipated air 2 inches above the floor. Another curve, based on saturated outside air and 16-man occupancy, gives the maximum obtainable relative humidity within the hut in air with a temperature of 70°F.

A comparison of these curves shows that for a 15°F outside temperature, an 83.8% relative humidity is allowable, whereas, only a 36.1% relative humidity is obtainable. For a -65°F outside temperature, the allowable relative humidity is reduced to 31.7% and the obtainable to 25.1%. An effective temperature index of 66°F necessary to create a comfort zone for the maximum number of occupants requires a 50% humidity in the 70°F air (5, pp. 228). This condition could be achieved by introducing additional moisture, but as shown by the maximum allowable relative humidity curve this would cause condensation at an outside temperature of -40°F. A 40% relative humidity which can be achieved by the introduction of 3.85 gallons of water per day to the ventilating air will not cause condensation until the outside temperature reaches -55°F. This percent of relative humidity would give an effective temperature index of 65.5°F thus satisfying approximately 90% of the occupants. At an outside temperature of 10°F, this quantity of extra moisture with saturated outside air and a 16-man occupancy would create a 50% relative humidity. At an outside temperature of -65°F condensation can be avoided with as much as 30% relative humidity. This percentage of humidity can be achieved through the introduction of 1.38 gallons of water per day to the ventilating air creating an effective temperature index of 65°F, thus satisfying approximately 80% of the occupants.

A curve is included giving the allowable relative humidity in the 70°F. air before condensation occurs on the walls 30 inches above the floor.

A comparative study also is shown based on circulation of warm air aided by fans. These curves show that a 30% relative humidity is permissible down to an outside temperature of -65°F without causing condensation, but with 40% humidity condensation will occur at -40°F.

Summary

At an outside temperature of -65°F and operating at a normal efficiency of 70%, the two space heaters used as the heating plant in these tests can maintain a temperature of 70°F, 30 inches above the floor, with a heat input of 97,000 Btu's per hour with one air change per hour. Using four wall-mounted electric fans to aid circulation of the warm air, the heat input requirement will reduce to 84,000 Btu's per hour. In either

case only 57,000 Btu's of this heat will be lost through the structure and the balance will escape through the ventilating air and combustion products. The vertical temperatures of 47°F on the floor and 2 inches above, 84°F at the breathing level, and 100°F under the roof with natural circulation of warm air will become 48°F on the floor, 43°F 2 inches above, 76°F at the breathing level, and 79°F under the roof when the fans are used.

The heat transmission coefficients established during these tests for the floor, walls and roof of the hut were 0.094, 0.164 and 0.097 $Btu/ft^2/^{\circ}F$, respectively, and a computed coefficient for the total exposed panel area was 0.121. From the heat balance tests a coefficient of 0.129 was established for the hut as a whole, indicating that only about 7% of the heat losses through the structure pass through the panel joints, plastic assembly connectors, etc.

Based on the reactions of the personnel used during these tests, the hut temperatures both vertically and horizontally were comfortable but dry in outside temperatures down to -40°F with natural circulation of the warm air, but the comfort conditions improved when using the fans to aid this circulation. At the -65°F hangar temperature, the floor surface and air temperatures below the 30-inch level were considered too cold for comfort and the 60-inch level too hot unless the fans were used. In all outside temperatures the wall surfaces were considered comfortable to the touch.

According to recent tests by the Bureau of Standards (7, pp. 31) the distance between the combustion drum and jacket of the heaters can be reduced from the present 9-inch clearance to 3 inches without materially effecting the temperature distribution. This reduction in jacket size would considerably reduce the floor space now occupied by these heaters. Also, in a redesign, consideration should be given to equipping the heaters with electric fans in a manner similar to the USAF type F-3 heater to reverse the air flow through the jacket and to force the warm air out near the floor. In the event of a power failure, however, normal circulation through the jackets could be resumed.

The vented foundation and the excellent insulation of the floor prevented entrapment of heat under the hut. At an ambient temperature of 15°F, the temperature 1 foot under the floor of the hut in still air averaged only 18°F, and in the bottom of the foundation beam, 17°F. at an ambient temperature of -40°F the air under the hut was also -40°F.

Based on a 16-man occupancy, saturated outside air, and 1-1/ air changes per hour, a relative humidity of 40% can be achieved by adding 8.37 gallons of moisture per day to the ventilating air. This percentage of relative humidity would create a comfortable condition satisfactory to 90% of the occupants, and would not cause condensation on the walls until an outside temperature of -40°F was reached. This amount of extra moisture can be introduced through evaporation by attaching water rings to the jackets of the heaters.

STRUCTURAL ADEQUACY

Determination of the structural adequacy of the Navy Arctic Hut (Mark I) at low temperatures is covered in this part of the report.

The prime objective was to insure the ability of the hut to support the designed floor and roof loads at an outside temperature -65°F. with the inside of the hut heated to 70°F. The loads were stipulated as 75 pounds per square foot for the floor and 60 pounds per square foot for the roof. A secondary objective was to determine the effect of repeated loadings on the heated hut as the outside temperature was reduced.

To obtain the data necessary to evaluate the hut, static loads in increments up to the design limits were placed manually on selected groups of floor and roof panels at outside temperatures of 70°F, 15°F, 0°F, -20°F, and -40°F with the inside temperature of the hut 70°F. At -65°F the entire unoccupied floor area and the middle two-thirds of the roof area were loaded. Only 83.33 percent of the design load was applied to the roof because of the physical inability of the loading crew to place the full load in the time available.

Equipment was not available to determine the ability of the hut to withstand the specified wind load of 135 miles per hour at low temperatures, however, impact loads in the form of pressure waves were present at each test temperature through 20-mm cannon fire in the hangar. The effect of these waves on the hut are included as a matter of general interest.

Test Equipment

Static loads were applied using 10, 20, 30 and 35-pound sand bags and 10 and 25-pound lead shot bags for load material. Various gages and instruments were used to record the deflections and strains created by these loads.

Direct readings of all deflections were made with a surveying level. This necessitated the location of all deflection gages inside the hut where the level could be operated in a 70°F temperature. The gages, made up of scales graduated in 100ths of an inch, were located in the mid-section of the living quarters (Fig. 52), and the surveying level was set up on the floor near the door of the vestibule (Fig. 53). To account for movement of the instrument height through deflection of the floor, two reference gages were located in the opposite end of the hut; one was suspended from the rafters of the hangar and entered the hut through the roof exhaust ventilator (Fig. 54), and the other was located on the hangar deck near the outside door of the hut adjacent to the ventilator. This arrangement placed all the deflection gages between the instrument and reference points. To observe movement in the floor panels, gages were mounted on stands directly over the points under observation, whereas, for the roof supporting beams and roof

Fig. 52

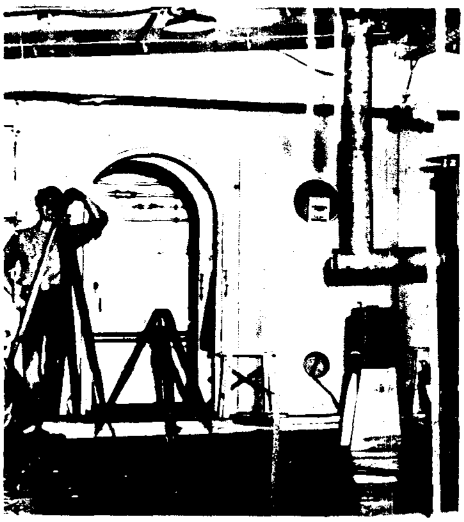


Fig. 53

Fig. 54

Plate 11. Graduated scales attached to selected floor panels and roof members, several of which are shown in Fig. 52, were used to determine deflections. The surveying level used for taking deflection readings is shown in Fig. 53. The reference scales, which were suspended from the hangar rafters, entered the hut through the exhaust ventilator as shown in Fig. 54.

panels the gages were suspended. Figs. 55 and 56 show the location and identifying numbers of the floor and roof gages.

Strains in the surface of selected panels and beams both within and under the hut were observed with SR-4 strain gages. Single-direction gages were used on the beams and three-direction gages (rosettes) on the panels. Temperature compensation gages were mounted adjacent to each strain gage, and observations were made with an SR-4 strain gage indicator. Fig. 57 shows the location and identifying numbers of the strain gages.

The intensity of the pressure waves created by the 20-mm cannon fire within the hangar was recorded by a sound level meter.

Test Procedure

At ambient hangar temperatures of 70°F, 15°F, 0°F, -20°F and -40°F the specified design loads were applied to one-fourth, or 240 square feet, of the roof and floor surface areas (Fig. 58). These areas comprised the six floor and six roof panels located between the second and third transverse roof support beams from the entrance end. This location minimized the influence of support to the roof from either the end walls or the partition wall, and placed full loads on the middle roof and floor panels of each area and on the supporting ridge beam.

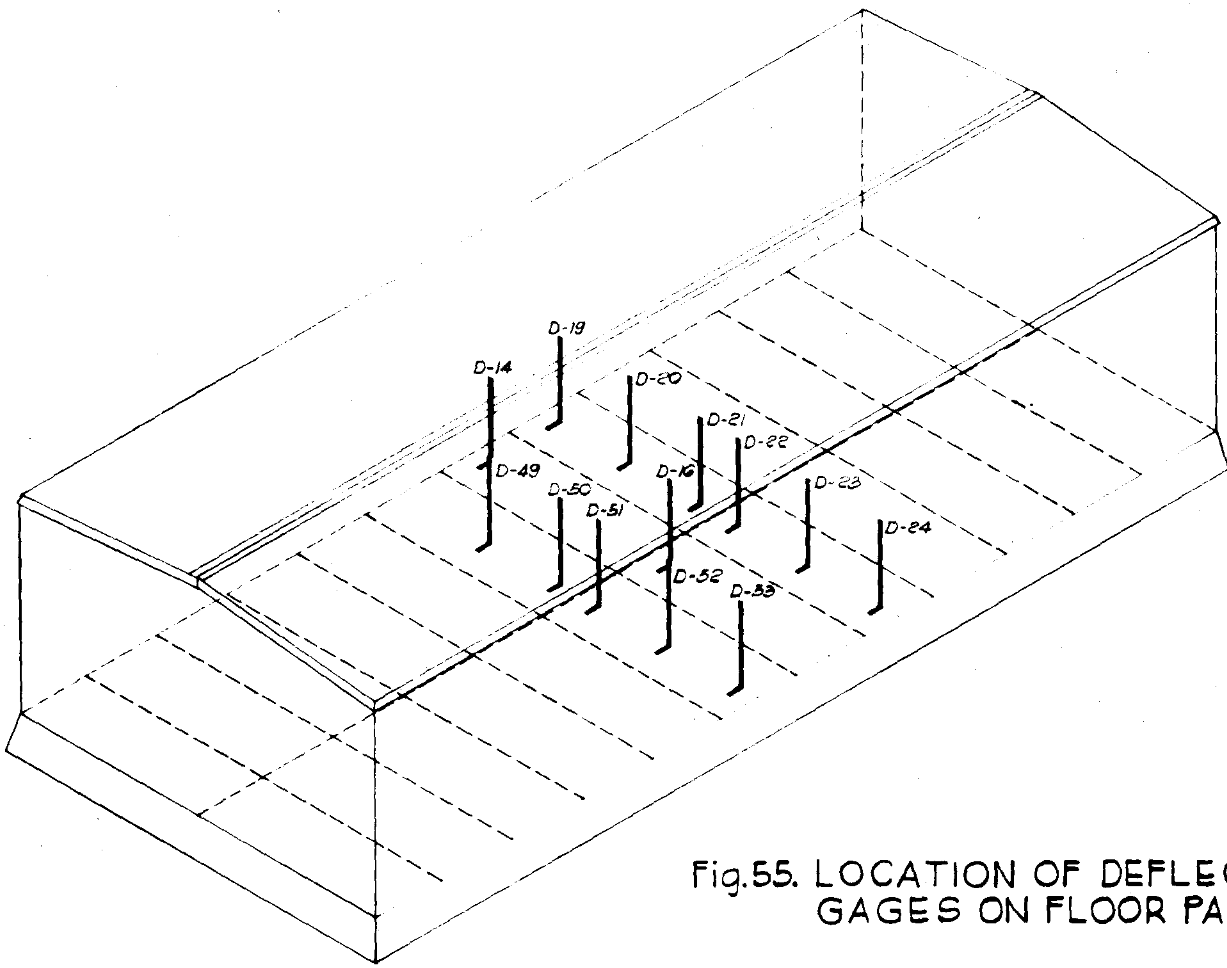


Fig.55. LOCATION OF DEFLECTION GAGES ON FLOOR PANELS.

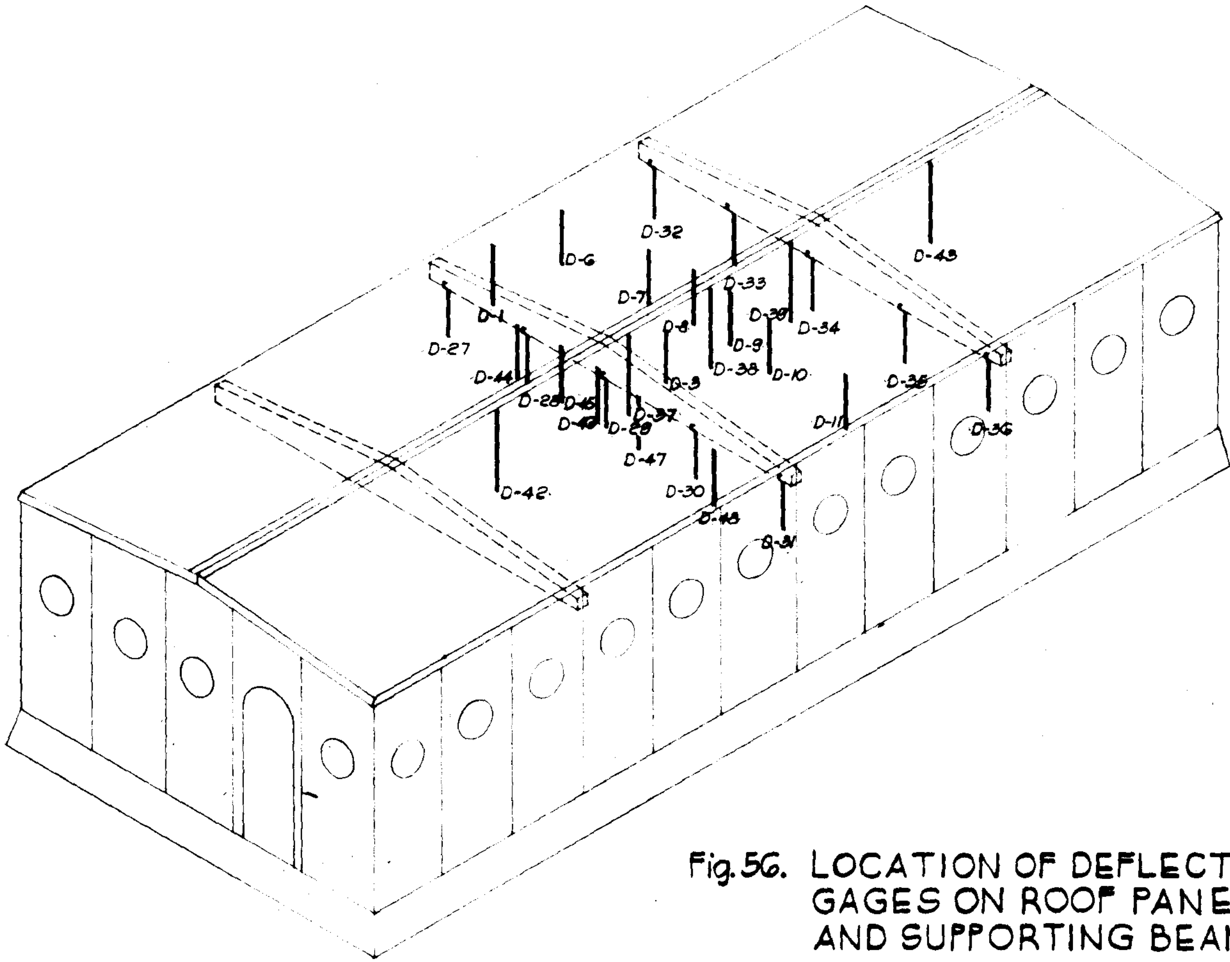


Fig. 56. LOCATION OF DEFLECTION GAGES ON ROOF PANELS AND SUPPORTING BEAMS.

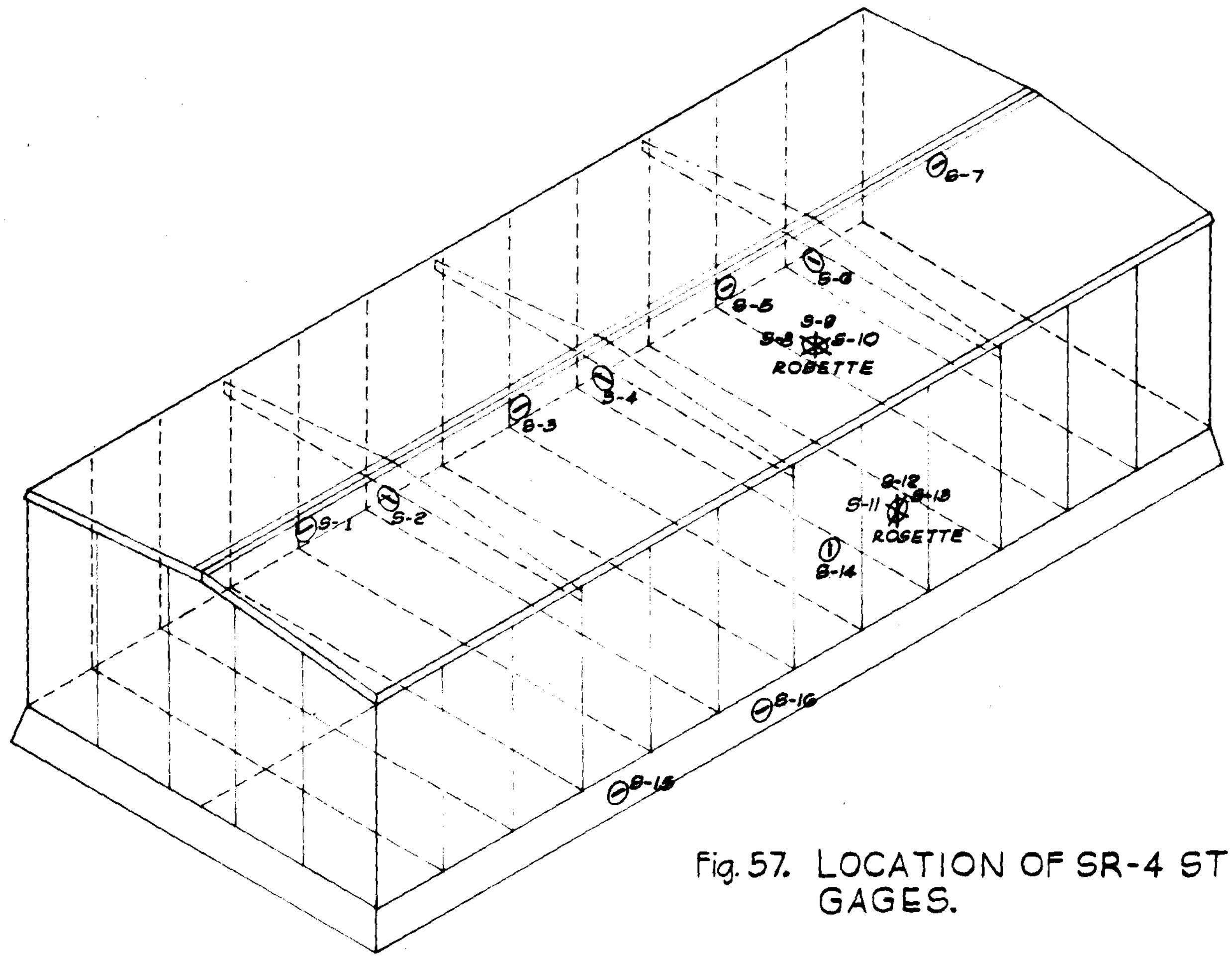


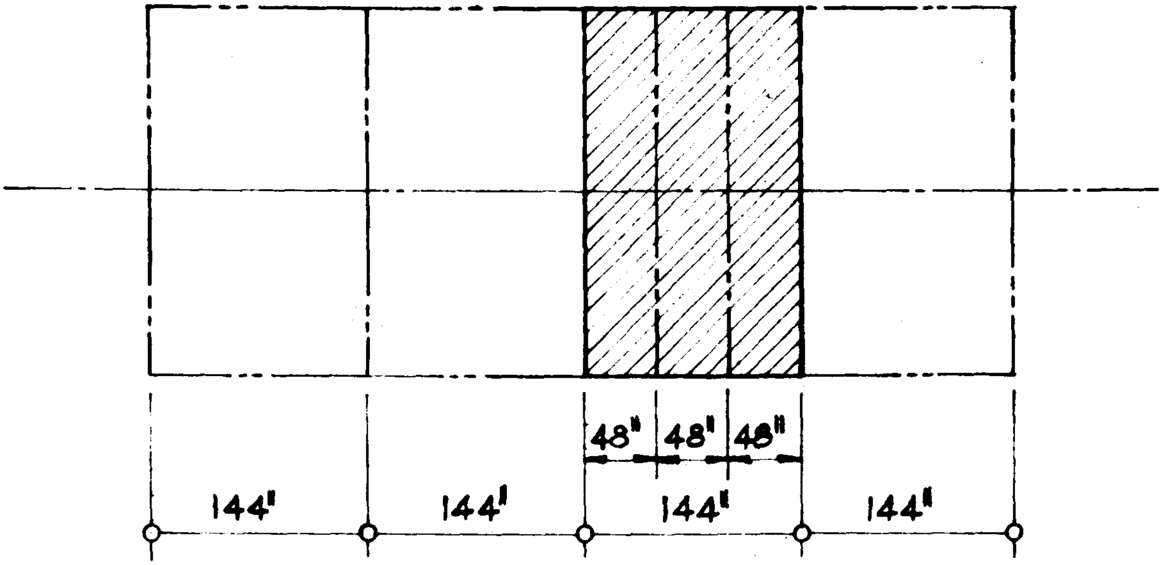
Fig. 57. LOCATION OF SR-4 STRAIN GAGES.

A pre-test load equaling the first load increment was applied to the roof and floor area and removed before the zero-gage readings were observed for the tests. Next, the roof load was applied in increments, and readings of all gages including the reference points were taken between each increment. Then, leaving the roof load in place, the floor load was applied in increments. The roof load was removed first followed by removal of the floor load.

For the test at -65°F the areas of loading for both the floor and roof were increased and the schedule of loading was revised. The floor was loaded first then the roof. The roof load was removed before the floor load. The areas and increments of loading are delineated in Fig. 59.

In all of the load tests, care was exercised to insure that the load material was gently placed. A mobile scaffold which cantilevered out over the roof was used when loading and unloading the roof to avoid superimposing impact loads by men walking over the loaded areas (Figs. 60 and 61); and, when loading the floor, a man was placed in the area being loaded and the material passed to him (Figs. 62 and 63).

Observations on the intensity of the pressure waves created by cannon fire were limited to the 15°F. and 0°F. temperatures due to sensitivity to cold of the microphone used for pick-up of the sound waves. At each temperature, the intensity of the waves was measured 3 feet out from the corner and 5 feet up the side of the hut nearest the point



SECTIONAL LOADING PLAN - FLOOR AND ROOF

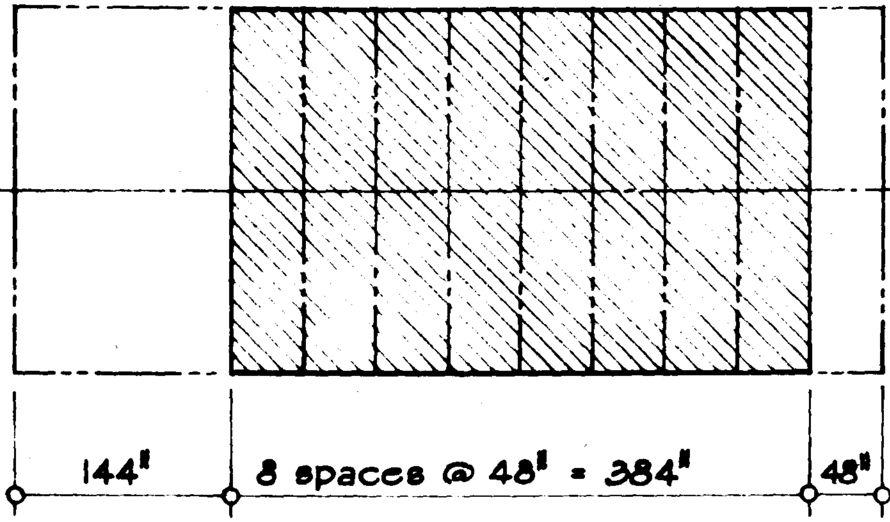
LOAD SCHEDULE

Increment	Bags		Location	Weight	
%	No.	Wt. (Lbs.)	(All loads evenly distributed)	Increment (lbs.)	Total (lbs.)
ROOF - (60 lbs./ft.^{2} design load)					
54.17	312	25	52 per panel	7800	7800
81.25	156	25	26 " "	3900	11700
100.00	270	10	45 " "	2700	14400
FLOOR - (75 lbs./ft.^{2} design load)					
43.33	312	25	52 per panel	7800	7800
86.67	312	25	52 " "	7800	15600
100.00	240	10	40 " "	2400	18000

TEST SCHEDULE

Test Number	1	2	3	4	5
Hangar Temperature	70°F	15°F	0°F	-20°F	-40°F

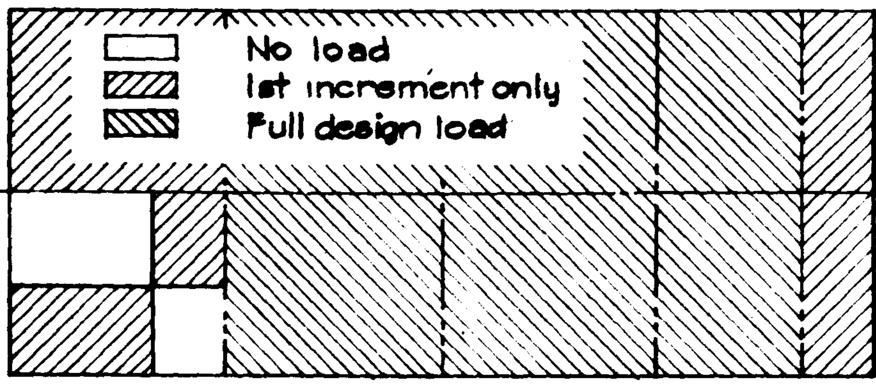
Fig. 58. SECTIONAL LOADING PLAN, LOAD SCHEDULE AND TEST SCHEDULE FOR FLOOR AND ROOF AREAS.



ROOF LOADING PLAN

LOAD SCHEDULE (60 lbs./ft.^{2} design load)

Increment	Bags		Weight	
%	No./panel	Wt./bag (lbs.)	Increment (lbs.)	Total (lbs.)
50.00	40	30	19200	19200
83.33	40	20	12800	32000



FLOOR LOADING PLAN

LOAD SCHEDULE (75 lbs./ft.^{2} design load)

Increment	Bags		Weight	
%	No./panel	Wt./bag (lbs.)	Increment (lbs.)	Total (lbs.)
46.67	40	35	31220	31220
86.67	40	30	19200	50420
100.00	40	10	6400	56820

Fig. 58. LOADING PLAN AND LOAD SCHEDULE FOR FLOOR AND ROOF AREAS. TEST NO. 6 AT -65°F HANGAR TEMPERATURE.

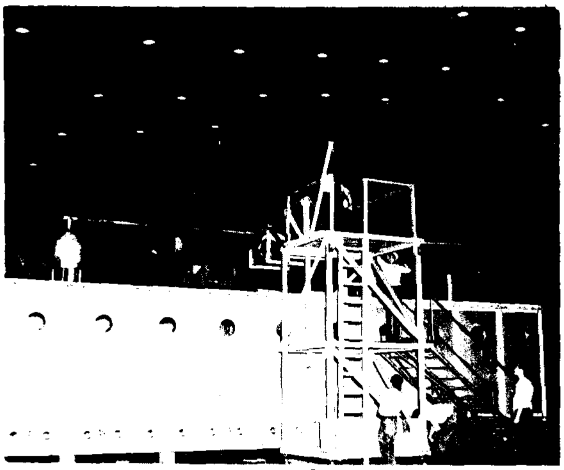


Fig. 60

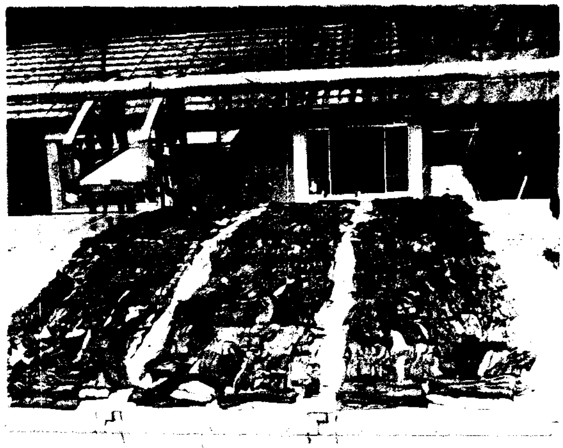


Fig. 61

Fig. 62

Fig. 63

Plate 12. Both the roof and floor test-loads were applied manually. In Fig. 60 the roof-load material is being passed up the scaffolding, and in Fig. 61 the load can be seen in place. In Fig. 62 the floor-load material is being passed into the hut, and in Fig. 63 the load is shown in place.

of fire and out from the corner farthest from the point of fire. The point of fire was 125 feet from the nearest corner of the hut and 200 feet from the nearest hangar wall, which was only 15 feet from the corner of the hut farthest from the point of fire.

Static Loading

Static loads were applied to sections of the floor and roof at each hangar temperature, and deflections and strains were observed. The deflection data collected was grouped into floor and roof studies, since the floor and roof are independently supported by the foundation beams. Appendix D contains the basic data used to develop the graphs appearing in this part of the report.

The strain gage data has been omitted because of the erratic results obtained. These results were due to the lack of a device for calibrating the zero drift of the indicator, the length of the circuits, and the temperature fluctuations around the circuit wires.

Floor.

The floor panels are 4 feet wide and 10 feet long and are supported at each end by the foundation beams. They are secured directly to these beams and interconnected to each other through lap joints. Therefore, three adjacent panels were loaded and the deflections of the center panels used in these studies.

As the outside temperature was reduced, the average total deflection along the longitudinal center line of the panel was consistent, and the deflection at points one foot from each end of the panel was about one-half as much as the center (Fig. 64). Except for a sudden increase in the total deflection in the center of the panel to 0.78 inches, and subsequent set of 0.12 inches on removal of the load at an outside temperature of 40°F, the total average deflection was 0.62 inches and the average set 0.05 inches.

The deflection at the center of the panel was directly proportional to the increment of load down to an outside temperature of 15°F (Fig. 65); whereas, for lower outside temperatures the first 50 per cent of the load caused an increasingly greater percentage of the total deflection until at -65°F a deflection of 0.45 inches was almost three-fourths of the deflection of 0.63 inches obtained under full load. An exception to this trend occurred at -40°F when the relationship of deflection to increment of load was almost a direct proportion.

With the floor panels in place in the heated hut, there was little change in the total deflection or subsequent set of the panels as the outside temperatures were reduced; however, below a 15°F outside temperature the initial deflection under the first 50 per cent of the total load became an increasingly larger percentage of the total deflection. An exception occurred at -40°F when the total deflection and sub-

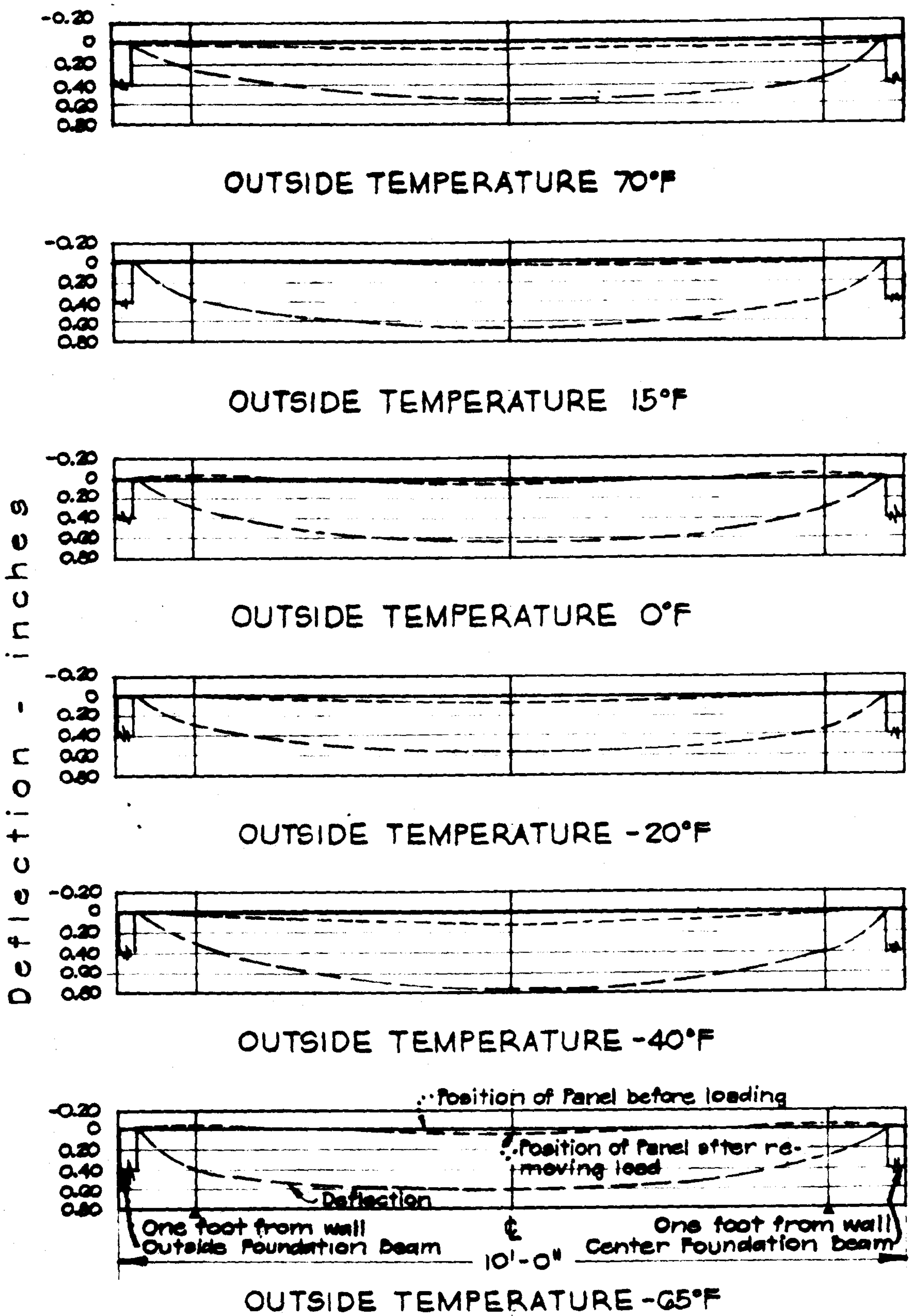


Fig 64. DEFLECTION OF FLOOR PANELS WITH EQUALLY DISTRIBUTED LOAD OF 75 lbs/ft² AT VARIOUS OUTSIDE TEMPERATURES. INSIDE TEMPERATURE OF HUT 70°F FOR ALL OBSERVATIONS.

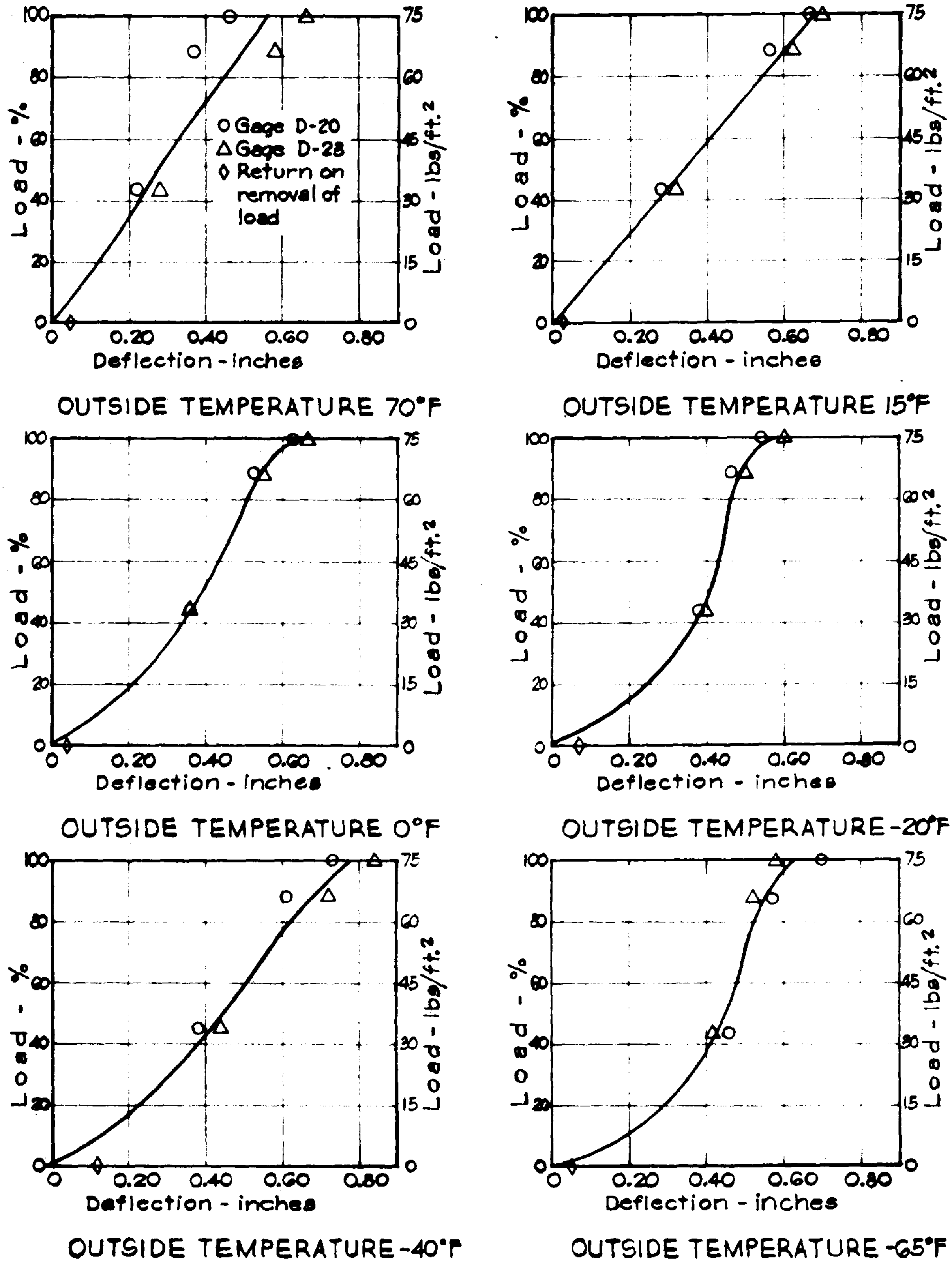


Fig 65. RELATION OF MEAN DEFLECTION TO LOAD AT CENTER OF FLOOR PANELS FOR VARIOUS OUTSIDE TEMPERATURES WITH INSIDE TEMPERATURE OF HUT 70°F. LOAD APPLIED IN INCREMENTS.

sequent set both increased considerably and the initial deflection was only one-half of the total deflection.

Roof.

The roof panels are supported along the sides of the building by the walls and at the center by framing. The framing consists of 20-foot transverse beams at the quarter points and center of the building, supported by stanchions pinned to the side walls and 12-foot ridge beams pinned to the center of the transverse beams and the end walls. As both types of beams are built-up aluminum sections they are subject to rather large deflections under load. Consequently, in the study of the effect of static loadings on the roof it was necessary to consider the effect of these loads, first on the transverse beams, then on the ridge beams, and finally on the roof panels.

Transverse beams: The average total deflection of two transverse beams under a partial roof load down to an outside temperature of -40°F and under a full roof load at -65°F are shown in Fig. 66, and the relation of the mean deflection to the increment of loading at the center of these beams is shown in Figs. 67 and 68.

The average total deflection along the longitudinal axis of the beam under partial load was 0.90 inches and the set on removal of the load 0.05 inches down to -20°F. At -40°F this deflection increased to 1.04 inches and the set to 0.22 inches. Under a full load at -65°F the projected

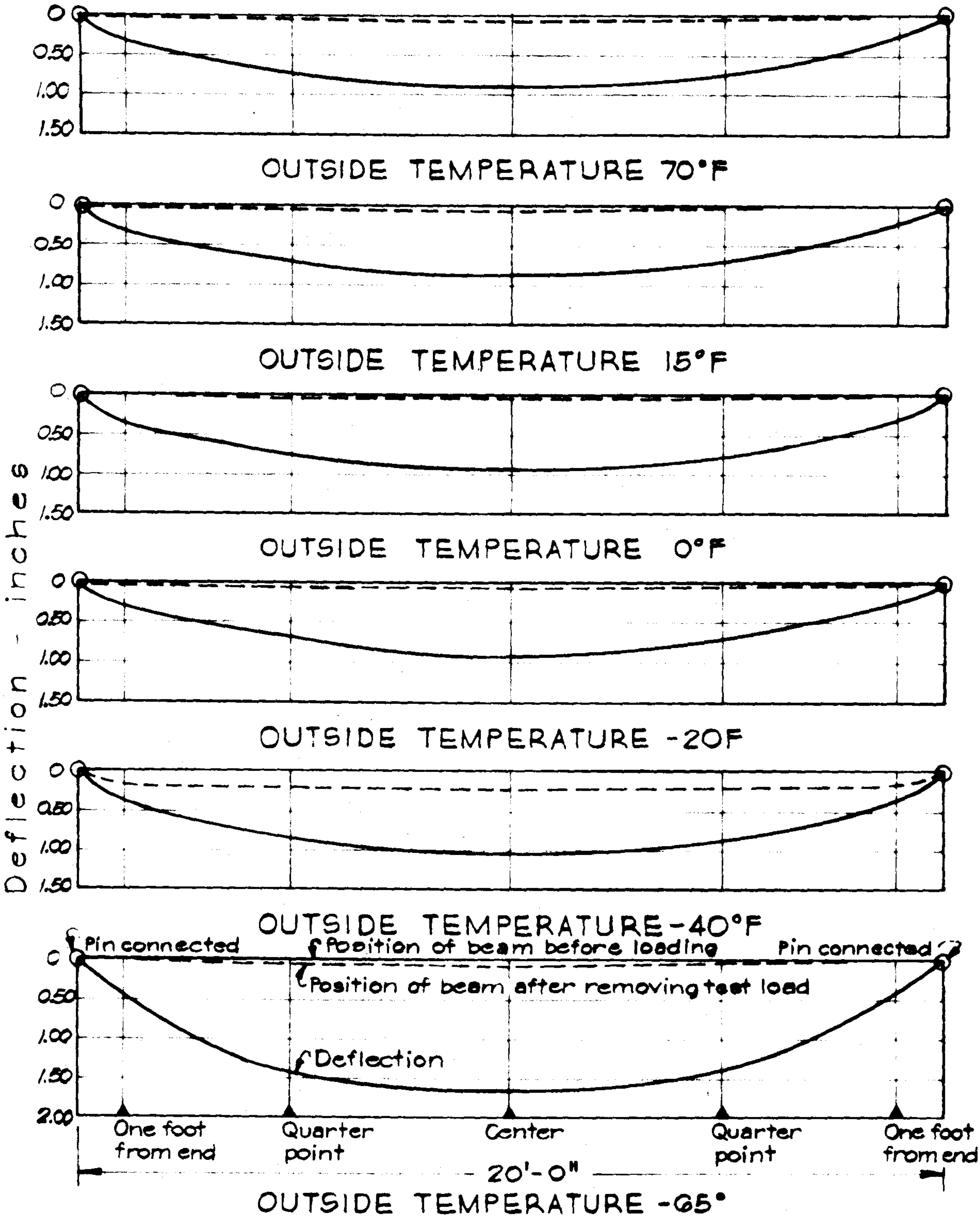


Fig 66. DEFLECTION OF TRANSVERSE ROOF SUPPORT BEAMS AT VARIOUS OUTSIDE TEMPERATURES WITH THE INSIDE TEMPERATURE OF THE HUT 70°F. FROM 70°F TO -40°F THE ROOF AREA BETWEEN THE BEAMS OBSERVED WAS LOADED TO 60 lbs/ft^2 AND AT -65°F THE LOAD AREA WAS INCREASED TO SPAN THESE BEAMS.

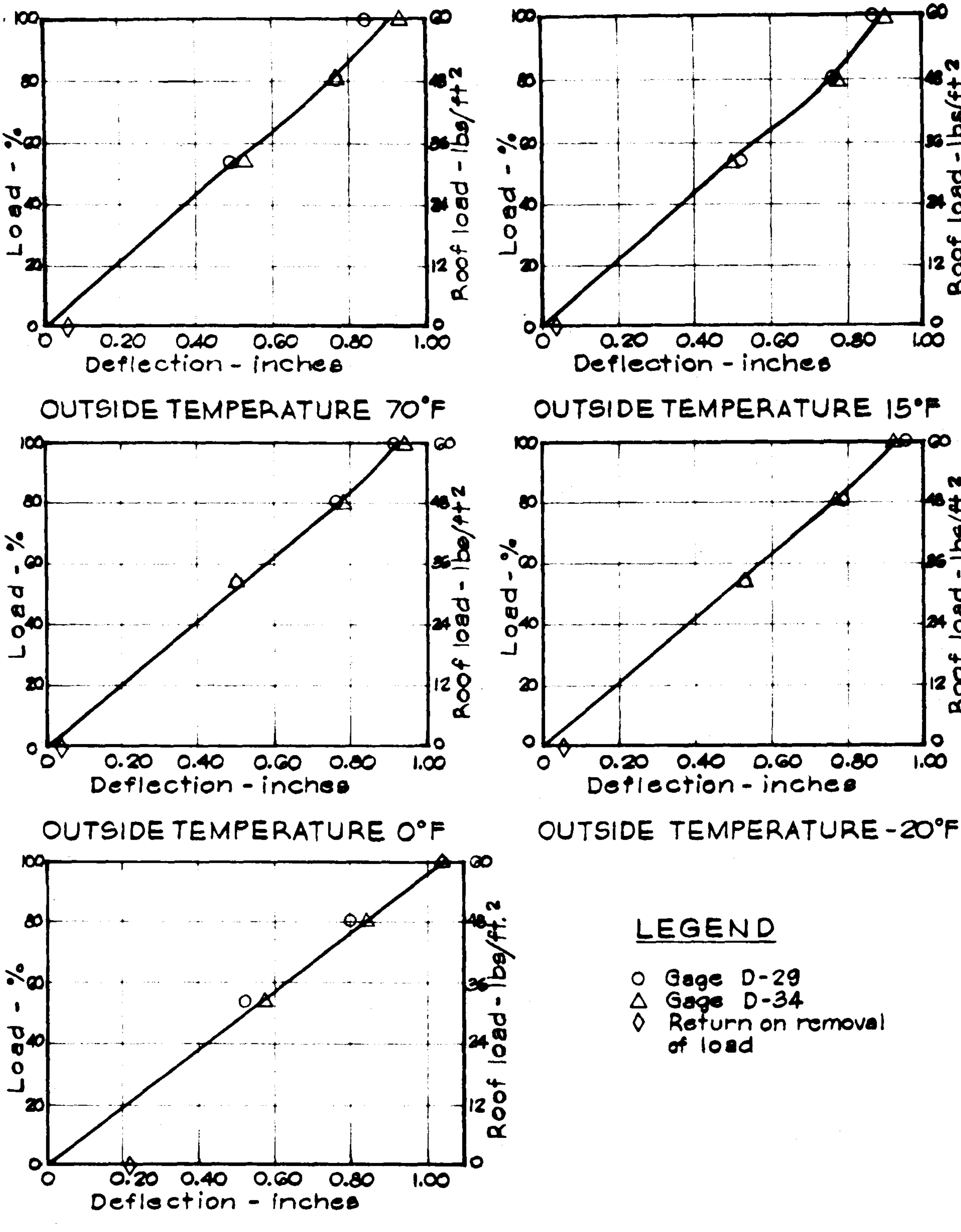


Fig 67. RELATION OF MEAN DEFLECTION TO LOAD AT CENTER OF TRANSVERSE ROOF SUPPORT BEAMS FOR VARIOUS OUTSIDE TEMPERATURES WITH INSIDE TEMPERATURE OF HUT 70°F. LOAD APPLIED IN INCREMENTS TO ROOF AREA BETWEEN BEAMS OBSERVED.

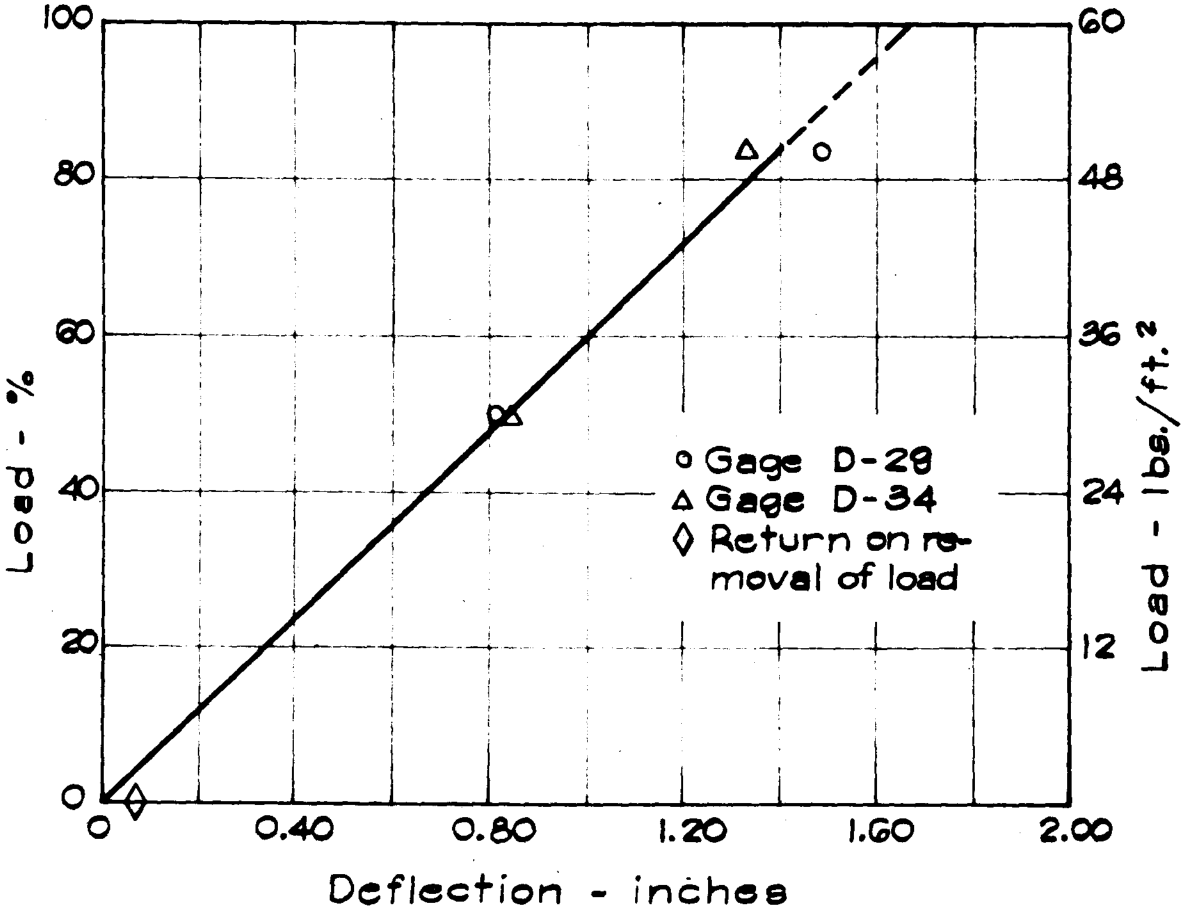


Fig 68. RELATION OF MEAN DEFLECTION TO LOAD AT CENTER OF TRANSVERSE ROOF SUPPORT BEAMS AT AN OUTSIDE TEMPERATURE OF -65°F WITH THE INSIDE TEMPERATURE OF HUT 70°F. LOAD OF 50LBS/FT² APPLIED TO ROOF AREA SPANNING THE BEAMS OBSERVED.

total deflection reached 1.65 inches and the set 0.05 inches. The deflection at the center of the beam was almost directly proportional to the increment of loading in each test.

With these beams pinned in place, repeated loading of the roof appeared to have little effect on the total deflection or in varying the percentage of the deflection of the initial load increment as compared to the total load deflection.

Ridge beams: The ridge beams are supported by the transverse beams; therefore, in determining the net total deflections shown in Fig. 69 deduction of the deflections of the transverse beams was necessary. The relation of the net deflection at the center of the ridge beam to the increment of loading is shown in Fig. 70.

The average total net deflection at the center of the beam decreased from 0.68 inches at an outside temperature of 70°F. to 0.48 inches at -65°F, whereas, the deflection at points one foot from each end of the beam consistently averaged about one-fourth of the total center deflection. Except for an initial set of 0.13 inches at 70°F, on removal of the load the average set was 0.03 inches.

At the center of the panel the initial deflection with a 50 per cent load, equaling two-thirds of the total deflection at 70°F, continually reduced until at -65°F it was less than one-half of the total deflection. The in-

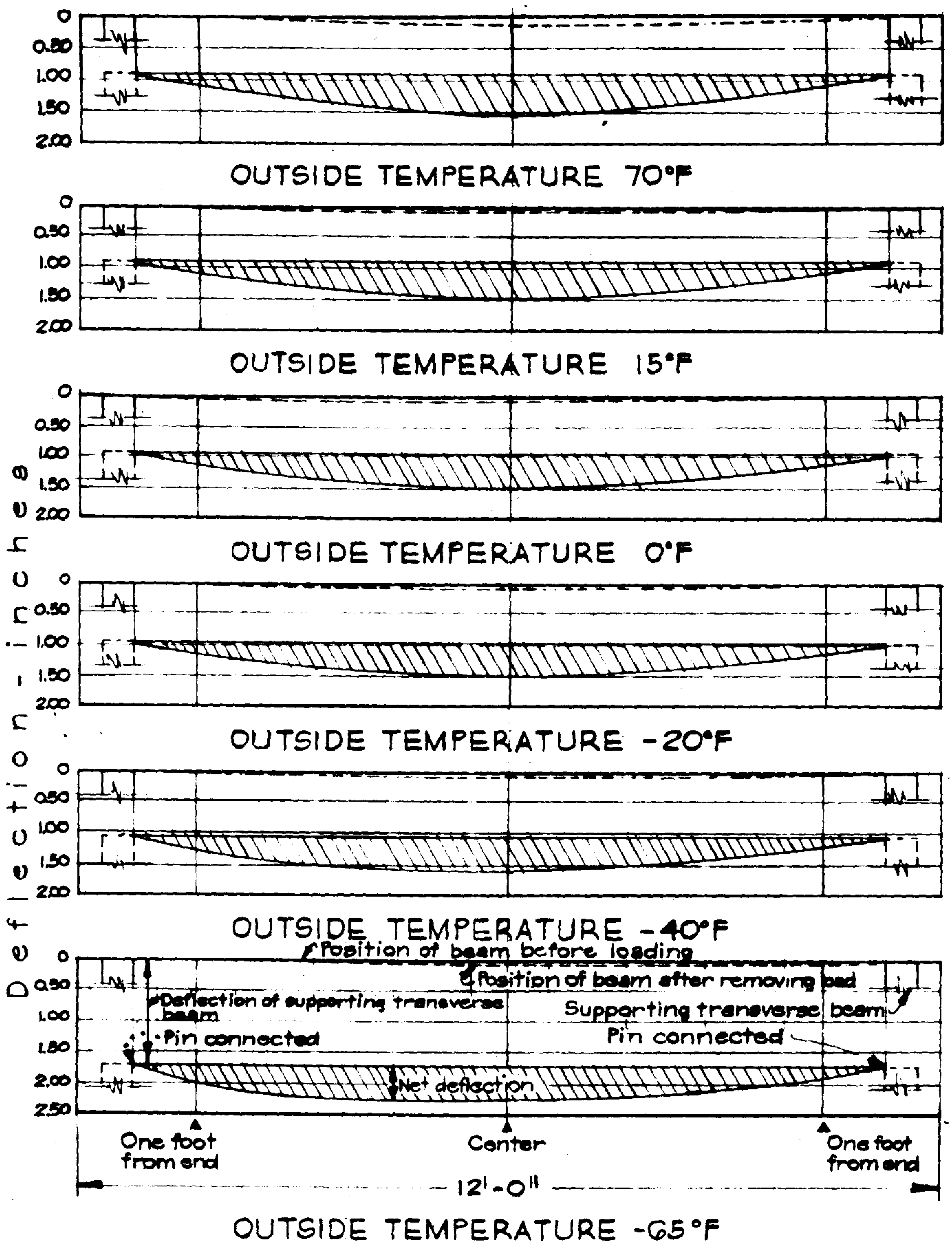


Fig 68. DEFLECTION OF RIDGE ROOF SUPPORT BEAMS AT VARIOUS OUTSIDE TEMPERATURES WITH THE INSIDE TEMPERATURE OF THE HUT 70°F AND THE ROOF AREA OVER THE BEAM OBSERVED LOADED TO 60 lbs/ft².

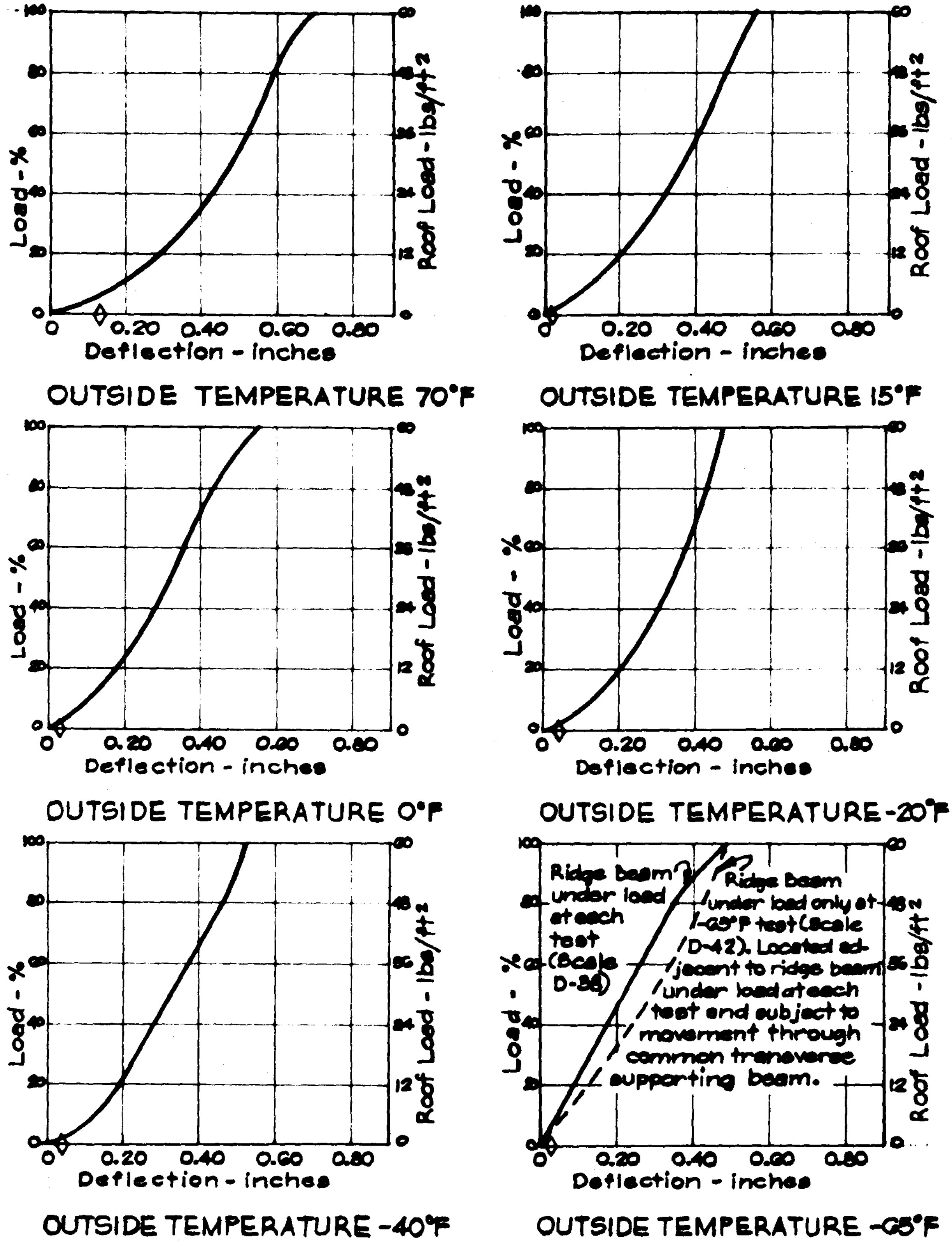


Fig 70. RELATION OF NET DEFLECTION TO LOAD AT CENTER OF RIDGE ROOF SUPPORT BEAMS FOR VARIOUS OUTSIDE TEMPERATURES WITH INSIDE TEMPERATURE OF HUT 70°F. LOAD APPLIED IN INCREMENTS TO ROOF AREA OVER THE BEAM OBSERVED.

creased area of roof loading at -65°F placed a second ridge beam under load. Comparison of the net deflection by increment loading of this beam to the one subjected to repeated loads showed that the proportion of deflection to increment of load to be almost the same and the total deflection identical.

With these beams pinned in place, repeated loading of the roof reduced the total net deflection by one-third, and the percentage of deflection became almost directly proportional to the increment of loading.

Roof panels: The roof panels like the floor panels are 4 feet wide and 10 feet long and interconnected through lap joints, making it necessary to load three adjacent panels and observe the deflection of the center panels. Also, since one end of these panels is supported by the ridge beams, in determining the net total deflections shown in Fig. 71, it was necessary to deduct movement of this beam. The relation of the net deflection at the center of the panel to the increment of loading is shown in Fig. 72.

The average total net deflection at the center of the panel was 0.49 inches regardless of the outside temperature or the number of loadings; whereas, the set on removal of load varied from 0.04 inches above to 0.06 inches below the original position. In the test at 70°F the deflection was almost directly proportional to the increment of load, but in each successive test down to the one at -65°F, the first

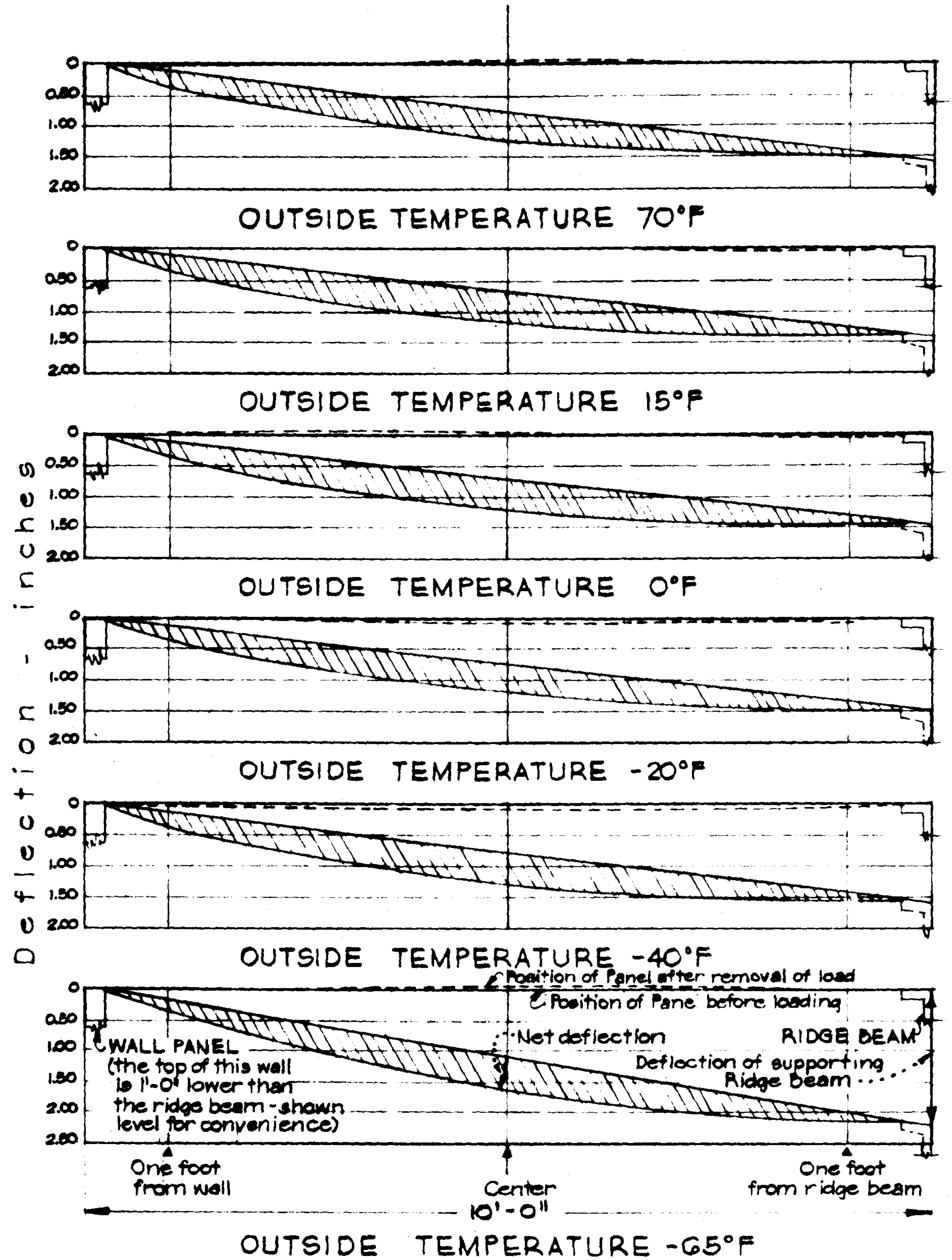


Fig 71. DEFLECTION OF ROOF PANELS AT VARIOUS OUTSIDE TEMPERATURES WITH THE INSIDE TEMPERATURE OF THE HUT 70°F AND THE ROOF AREA SPANNING THE PANELS OBSERVED LOADED TO 60 lbs/ft².

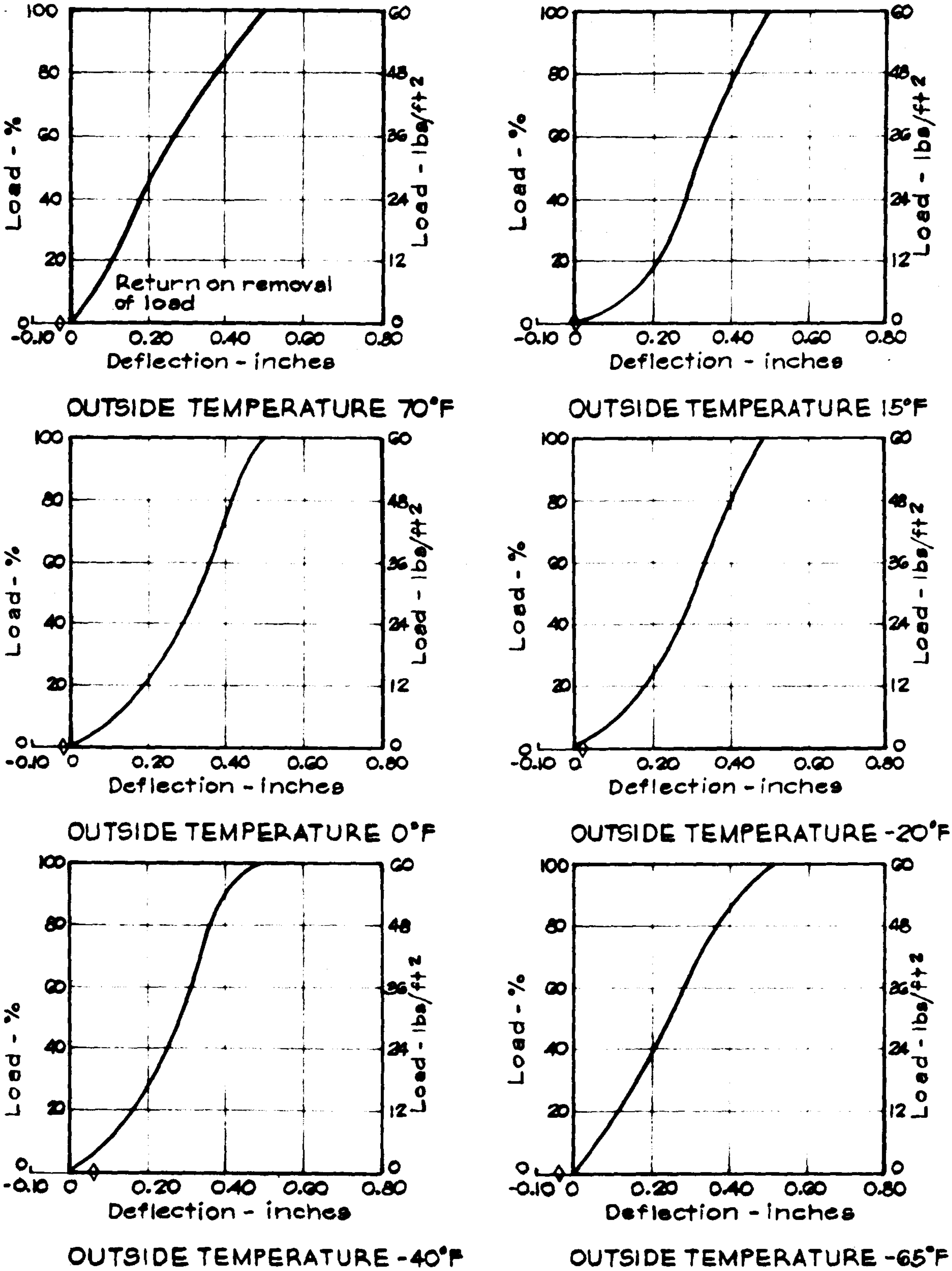


Fig 72. RELATION OF NET DEFLECTION TO LOAD AT CENTER OF ROOF PANELS FOR VARIOUS OUTSIDE TEMPERATURES WITH INSIDE TEMPERATURE OF HUT 70°F. LOAD APPLIED IN INCREMENTS.

50 per cent of the load caused three-fifths of the total deflection. At -65°F the proportion again became almost direct.

With these panels pinned in place repeated loadings appeared to have little effect on the total deflection but they did appear to slightly increase the percentage of the initial deflection under the first load increment.

Dynamic Loading

Dynamic loading to simulate winds up to the 135-mph design load was not applied; however, measurement was made of the level intensity of sound waves caused by cannon fire.

Firing took place twice at each test temperature with the longest bursts lasting about 20 seconds. From measurements taken at 15°F and 0°F, the level intensity of the waves directly hitting the hut was established at 135 decibels and those being returned from the hangar wall as 131 decibels. Converting the decibels to a pressure ratio and computing the pounds per square foot, found that the corner of the hut nearest the point of fire was being subjected to a level pressure wave of 2.36 lbs/ft^2, and that the corner farthest from the point of fire was being subjected to a pressure of 1.48 lbs/ft^2. No determination of the peak pressures, which occurred up to 40 times a second, was made; however, from data previously obtained by the Air Proving Ground, the peak pressures were estimated to be 16 to 20 times greater than the level pressures measured, or equal to maximum pressures of 47.0 lbs/ft^2 and 29.6 lbs/ft^2 respectively.

Converting these peak pressures to approximate wind velocities based on Marvin's formula means that the corner of the hut nearest to the point of fire was being bombarded by pressures equivalent to 108-mph wind gusts and the diagonally opposite corner by pressures equivalent to wind gusts of 85 mph. This difference in pressure caused considerable vibration of the hut, but other than shaking loose a few wedges and foundation beam clamps, which had not been securely tightened, there was no damage.

Summary

In the static load test at -65°F, three-fourths of the floor area was loaded to 75 lbs/ft^2 and two-thirds of the roof area to 50 lbs/ft^2. With the inside temperature of the hut at 70°F these loads remained in place for 40 hours. When the loads were removed, the panels and beams returned to within a few hundredths of an inch of their original positions. There were no failures and no points of stress concentration observed and a subsequent disassembly and erection of the hut was accomplished with ease.

Repeated static loading of selected areas of the floor and roof at various hangar temperatures from 70°F to -40°F caused no damage or excessive permanent set on the hut parts. Except at -40°F where the floor panels and transverse beams

showed 0.20 inches of set, on removal of the load the average set for all parts was less than 0.05 inches.

Accurate strain observation using strain gages in tests of this type requires a device to account for the normal zero drift of the strain gage indicator during the periods between observations. Further, the instrument should be located as close to the gages as possible, preferably within the hut, and dummy circuits should be used to compensate for variable temperature effects on the strain-gage circuits.

PART III - APPENDIXES

* * * * * * * *

APPENDIX A

Specifications, Authority and Plan of Test

Specifications for Development of a Pilot Model Arctic Hut issued by the Bureau of Yards and Docks, Navy Department, dated 21 April 1947.

Proving Ground Order No. HA1-000 01A issued by the Bureau of Yards and Docks, dated 16 August 1948, authorizing tests on the Douglas Arctic Hut.

Memorandum of Procedure issued by the Advanced Base Proving Ground dated 16 December 1948, covering the plan of the tests to be conducted in the Climatic Hangar, Eglin Air Force Base, Florida.

NAVY DEPARTMENT
BUREAU OF YARDS AND DOCKS
WASHINGTON, D. C.

21 April 1947.

SPECIFICATIONS FOR DEVELOPMENT OF PILOT MODEL ARCTIC HUT

A. GENERAL INFORMATION:

The Arctic Hut will be used to house personnel and supplies in frigid zones such as exist in northern Alaska, Greenland, and Antarctica. Due to the remoteness of regions in which the huts are likely to be erected, and the land of overland transportation facilities in such regions, the huts must be of a prefabricated knockdown type suitable for air transport. They will be erected on various types of terrain including soil subject to natural thaw, permanently frozen soil, snow, ice, and rock. The design must take into consideration the fact that transmission of heat from the hut to the frozen ground or cover supporting the hut may adversely affect the stability of its foundation. Erection personnel may be heavily clothed and their efficiency impaired as much as 60%. Their ability to work in close quarters, handle small items such as screws, nails, etc., and make complicated fits and connections under exposed conditions will be materially reduced. (These restrictions would not apply to interior connections and installations which might be completed after installation of heaters within the hut).

Therefore, the hut should be as light as possible in weight, be capable of being compactly crated for shipment, and be easily and quickly assembled and erected in the field with the minimum number of personnel within the minimum of time.

B. GENERAL REQUIREMENTS:

B-1 TYPE-The hut may be of any type, shape, or design consistent with accepted engineering practice and the Detail Requirements in paragraph C below.

B-2 MATERIAL-The materials may be of any type or kind provided (1) they are structurally sound, (2) they are non-inflammable or fire resistant. (3) they meet the generally accepted specifications established by the representative industry, and (4) they are generally available in sufficient quantities to support large scale quantity production of the huts.

C. DETAIL REQUIREMENTS:

C-1 SCOPE OF WORK - Under these specifications the manufacturer shall provide all materials, engineering, development, and fabrication necessary to the furnishing and delivery to the government of a hut, as herein described, complete and ready for field assembly.

C-2 SIZE OF HUT - The floor areas, including a storm entrance, shall be approximately 1000 sq. ft. (plus or minus 10%). The ratio of usable volume to total weight shall be as large as possible consistent with the type of design used. The clear distance between top of finished floor and ceiling (or underside of lowest roof member) shall be 8 ft., although designs which attain this height within approximately 4 ft. from edge of floor will be acceptable. The minimum floor dimensions shall be not less than 20 ft. The design shall be such that the hut may readily be enlarged by the addition of standardized sections plus a minimum of additional construction materials.

C-3 FOUNDATION - Suitable timber caps or sills, and the required sub-support for local conditions will be furnished by the Government to fit the requirements of the hut design. The manufacturer shall provide the necessary floor joists, stringers and anchoring devices for connecting to foundation furnished by the Government and indicate on the drawings the plan of the foundations required. Any special anchoring devices or tie-downs provided to take the wind load and which are anchored outside the foundation for the hut proper shall be furnished by the manufacturer in their entirety.

C-4 INSULATION - The floor, roof, and all exterior walls shall be insulated, based on an assumed maximum 100,000 BTU loss per hour while maintaining an inside temperature of plus 70°F with an outside temperature of minus 60°F, with an air change per hour at maximum temperature difference. (Initial proposals are to assume a total window area of 60 sq. ft.)

C-5 WINDOWS AND VENTILATION OPENINGS - Windows and ventilation openings will depend upon type and shape of hut accepted and will be specified in detail in any final negotiations. Initial designs should take this final requirement into consideration and include the manufacturers suggestions.

C-6 DOORS AND STORM ENTRANCE - A storm entrance of approximately 80 sq. ft. floor area shall be provided entirely within the hutproper. An emergency exit door shall be provided at the opposite end of building. The doors shall be approximately 3' o" x 7' o".

C-7 DESIGN AND FABRICATION - The design and fabrication shall conform to specifications promulgated by the applicable industry for the materials used. The members shall be fabricated to permit nesting and bundling in the most compact manner possible to conserve shipping space. Within this limitation the members shall be shop assembled. The largest member shall not exceed a weight or size which can be easily handled and placed in the structure by 4 men. The hut shall be designed for the following loadings:-

WIND-135 miles per hour (including gusts) SNOW-60 lb. per sq. ft. on the horizontal projection. (Note: Snow load and wind load to be taken separately).

FLOOR LIVE LOAD - 75 lbs. per sq. ft.
DEAD LOAD-Actual weight of structure.

C-8 FASTENERS AND OTHER ACCESSORIES - All fastening, connecting, and anchoring devices and all other accessories necessary for erection of the hut in the field shall be furnished by the manufacturer. (See General Information relative to types desired).

C-9 ELECTRICAL, HEATING, ETC. - All lighting, heating, and plumbing facilities and all interior furnishings will be furnished by the Government. Provisions for their future installations should be considered in designing the hut.

D. MISCELLANEOUS REQUIREMENTS:

D-1 Painting, shop and finished.
D-2 Reproducible Drawings.
 (a) Three sets of shop details prior to commencement of work.
 (b) Ten sets of final approved drawings.

D-3 Erection drawings and instructions - Ten complete sets for file and one complete set to accompany shipment of each hut.

D-4 Erection Tools - One complete set of all hand tools required for the erection of the hut to accompany each hut shipped.

D-5 Packing and Marking - Hut to be packaged for export shipment in boxes or bundles with no box or bundle exceeding approximately 1000 lbs. in weight.

BUREAU OF YARDS AND DOCKS
Proving Ground Order No. HA1-000 01A
Authorized: 16 August 1948

P R I O R I T Y 1

TITLE: Douglas Arctic Hut 20' x 48' - Tests of.

Ref: (a) Specification for Development of Pilot Model Arctic Hut dtd 21 April 1947.
(b) LTN Hdqtrs. U. S. Air Force to BuDocks, dtd 18 Jun 48.

1. The object of this order is to test and evaluate the suitability of subject hut for Advanced Base use in the Arctic. This building was designed and fabricated by the Douglas Aircraft Company, Inc., of Long Beach, California, under Contract NOy-14943, in compliance with Reference (a).

2. The following series of tests for subject hut is to be accomplished under this order:

(a) Series 1 - Proving Ground, Hueneme

(1) Erection Study
(2) Instrumentation Study
(3) Airborne Packaging Study

(b) Series 2 - Climatic Hangar, Eglin Field, Florida

(1) Low Temperature Erection Test (at 40 to 65°F)
(2) Heat Loss Test (By temperature, fuel consumption and humidity observations).
(3) Snow Load and Floor Load Test (Deflection and strain measurements).

(c) Series 3 - Proving Ground, Hueneme

(1) Simulated Wind Load Test (Feasibility to be investigated by the Proving Ground and the Bureau and test undertaken if suitable method can be devised).

(d) Series 4 - Point Barrow

(1) Field Service and Utility Tests

3. In preparation for the test series outlined above, the Proving Ground Officer is requested to provide the following:

(a) Heating System - Two 50,000 BTU Space Heaters, Advanced Base Stock No. 2Q11-9 are to be installed in the hut located approximately 12 feet from either end, flues, exhaust ventilator, etc., are to be designed and fabricated. These should be so designed that they can be quickly installed or removed. Openings are to be cut in the roof panels for the required flues, etc. Suitable insulation is to be provided for chimney flues to prevent damage to roof panels from radiant heat. Gravity air intake ducts are to be provided at each heater and an air exhaust ventilator is to be provided at the center of the hut. The air intake and exhaust are to be provided with suitable dampers. The chimney flues are to be provided with extensions which will permit connection to the flues gas exhaust system in the floor of the Eglin Field climatic hangar.

(b) Foundation - It is considered that two foundation conditions will be encountered:

Case 1 will be in areas of uniform bearing in which a site can be leveled and the foundation beams of the hut will be placed directly on the ground.

Case 2 will be in areas where piling of some other type of column foundation will be required. This type of foundation must provide support at the points shown on enclosure (1). The Proving Ground Officer is requested to provide a foundation system which will simulate Case 2 conditions for use in the Test Series 1, 2 and 3. This foundation should be designed particularly for installation in the climatic hangar, Series 2 Test: Recommendations and suggested designs are requested for a foundation meeting Case 2 requirements for use in Series 4 Tests. This foundation should include a means of anchoring the hut, using the tie down fittings provided in the hut foundation beams.

(c) Temporary Lighting and Power System - Lighting and outlets will be required for the tests. A suitable hole should be cut through the end wall to carry the power to a master panel located in the vestibule near the outside door. It is suggested that two suitable drop type lighting fixtures and two power outlets be provided in each 12 foot bay and in the vestibule. The power outlets should be located on the walls approximately 3 feet above the floor. It is believed a suitable adhesive offers a possible method of fastening the various elements of the electrical system to the walls and ceiling of the hut. The adhesive should be of such a nature that it can be readily removed without damage to the panel faces. Recommendations are requested on methods of installation for fixtures and wiring for adoption in the final hut.

4. The Proving Ground Officer is requested to perform as soon as possible the following series of studies comprising the Series 1 Tests. These studies should be completed in sufficient time to permit delivery to the Air Proving Ground, Eglin Air Force Base, Valpariso, Florida by approximately 20 September 1948 for the Series 2 Tests in the Climatic Hangar:

(a) Erection Study - The object of this study is to determine the best and quickest method of erecting the subject hut using not more than 16 men. The erection procedure developed should include a study of the most advantageous system of placement of stacking of the various hut parts around the previously constructed foundation, and the most efficient use of labor in accomplishing the erection. All personnel engaged in handling the erection should wear Arctic mittens. In the course of this study the hut may be erected as many times as is necessary to perfect the procedure. When the procedure is perfected a final erection run is to be made in which work is to proceed continuously without stopping until the hut is completed. This is to include the building only, not the installation of heaters or electric system. During this run complete records are to be kept of man hours of labor, time, weather, wind velocity, and temperature. The procedure for dismantling the completed hut shall be studied in a manner similar to the method for erection. A manual shall be prepared describing the erection and dismantling procedure developed.

(b) Instrumentation Study - The purpose of this study is to determine nature and extent of measurements and observations required for load tests and heat loss tests to be performed in Series 2 Tests at Eglin Field and to train the test personnel in the installation and use of the required instruments. For load tests it is considered that measurement of deflections of selected panels, columns and beams should be undertaken simultaneously with measurement of strains. A program of such measurements including the determination of the points at which measurements are to be made should be planned. This program should make the most efficient use of available men and instruments. Direct contact should be made with Eglin Field to determine the types and numbers of instruments which they can make available for the Series 2 Tests. For training of personnel, it is suggested that the instruments be installed at a few of the desired points and a series of trial readings made. For this purpose, the roof and floor may be loaded up to the design loads by means of sandbags. The hut was designed for 75 pounds per square foot for the floor and 60 pounds per square foot for the roof (snow load). A set of readings of temperature inside and outside at selected locations should be made over a 48 hour period.

(c) Air Borne Packaging Study - The object of this study is to determine the best method of preparing the subject hut for airborne shipment. The packaging system developed shall be such that it will insure safe transit of the hut materials, and prevent damage in handling. A manual shall be prepared which adequately describes the packaging and the hut shall be packaged for air delivery to Eglin Field. It is intended that the packaging adopted be conservative in order to carefully preserve the pilot model. Experience with this packaging will provide a basis for the packaging of future huts for service use.

5. The Proving Ground Officer is herewith requested to provide all personnel for conduct of the series 2 Tests and to make all necessary arrangements for the Series 2 Tests Directly with the authorities at Eglin Field. Close cooperation will be required in order to get the hut into the Climatic Hangar at the desired temperature. Tentative temperature run down schedule indicates 65°F will be reached on September 20, 1948. Correspondence will be addressed as follows:

Air Proving Ground
Eglin Air Force Base
Valpariso, Florida

Attn: Col. Hedlund

Copies of all correspondence must be sent as follows:

(a) Armament and Equipment Branch
Requirements Division
DC S/O U. S. Air Force
Washington, D. C.

Attn: Col. A. E. Hebert

(b) Chief of the Bureau of Yards and Docks

6. The Proving Ground Officer is requested to investigate the feasibility of shipping the hut to Eglin Field by air and make necessary arrangements if practicable.

7. The Proving Ground Officer is requested to advise the Bureau by dispatch as to the date established for the final erection trial which is to be made in accordance with 4(a) above. This notice should be given at least 10 days in advance of the date set for the trial in order that the Bureau may advise the Corps of Engineers and Quartermaster Corps who have indicated a desire to send representatives.

8. By future correspondence the Bureau will forward further instructions regarding the Series 2, 3 and 4 Tests. Studies for application of designed wind load should be undertaken at once.

9. By reference (b) the Air Forces granted the Bureau permission to use the Eglin Field facilities at a cost of approximately $2,025.00. When exact cost is determined by the Proving Ground Officer, the Bureau will initiate a transfer of funds to the required amount.

10. Photographs and complete reports, both interim and final, with recommendations, should be furnished this office.

Authorized by: J. J. McGaraghan

Encls(h/w) 1. Sketch showing proposed location of supports for foundation beams
2. Copy of Ref (a)
3. Copy of Ref (b)

CC: OinC, ABD, Hueneme (4); DirPacAlDocks; P-332 (JOFile)
P-332 (PGO)

PROVING GROUND
U. S. NAVAL ADVANCED BASE DEPOT
CONSTRUCTION BATTALION CENTER
PORT HUENEME, CALIFORNIA

NT4-59/A1-1
236/bal

16 December 1948

MEMORANDUM OF PROCEDURE NO. HA1-000 01A - SERIES 2 TEST

Subject: Douglas Arctic Hut, Series 2 Tests at Climatic Hangar, Eglin Field, Florida - Job Order No. 4595.

Encls: (A) ABPG Dwg. No. HA1-000 01A - 3 - Thermocouple Layout.
(B) ABPG Dwg. No. HA1-000 01A - 2 - Gage Location Layout
(C) ABPG Dwg. No. HA1-000 01A - 1 - Layout Plan (pre-erection).

1. GENERAL

(a) Project Manager: E. H. Moser.
(b) Field work to start: Approximately 15 January 1949.
(c) Test to start: Approximately 1 February 1949.
(d) Estimated completion date: Approximately 15 March 1949.
(e) Photography: Air Proving Ground will furnish personnel and material for both still and moving pictures desired. The negatives and film of these pictures will be furnished the Advanced Base Proving Ground.
(f) Reports:
(1) Copies of daily test sheets will be forwarded to the Advanced Base Proving Ground.
(2) An interim report will be prepared upon completion of Series 2 Test.

2. MATERIAL AND TEST EQUIPMENT

(A) The following material and equipment will be shipped by the Advanced Base Proving Ground to Eglin Field for use in connection with this test:

(1) Material:
(a) The Douglas Arctic hut and erection tools.
(b) Space heaters and fuel supply system.

(c) Electric fans and ventilating stacks.
(d) Foundation blocks.
(e) Lighting system.
(f) Entrance steps.

(2) Equipment:

(a) Brown Electronik Indicating Potentiometer and necessary thermocouples.
(b) SR-4 portable strain indicator and necessary strain gages.
(c) Deflection gages and stands.
(d) Anemotherm air meter.
(e) Sensitive draft gage.
(f) Nicholls-type heat flow meters (if available).
(g) Sandbags for load test.
(h) Bench mark stand.
(i) Scaffolding for applying roof load material.

(3) Items listed above under paragraphs (A) (1) and (A) (2) will be crated and shipped by rail on 23 December 1948, for arrival at Eglin Field not later than 14 January 1949. The Proving Ground Materials Section will process all papers pertaining to this shipment.

(B) Material and Test Equipment to be furnished by Air Proving Ground, Eglin Field:

(1) Material:

(a) Shot bags totaling up to 30,000 pounds.
(b) Approximately 800 gallons of space heater fuel oil, with a minimum pour point of minus 65°F.
(c) Up to 60 cubic yards of sand for filling sand bags.
(d) Two 5-foot step-ladders for use in erections.
(e) Arctic clothing for approximately sixteen (16) men to wear while working in hangar.

(2) Test Equipment:

(a) Transits and levels for use in reading deflection gages.
(b) Space in portable observation room for location of test instruments.
(c) Simulated winds on hut, if possible.

3. CHRONOLOGICAL ORDER OF SERIES 2 TEST

The chronological order of the Series 2 Test, as outlined in the following paragraphs, is based on the information available concerning the climatic hangar run-down schedule and will be subject to revisions necessary to meet unforeseen changes in this schedule, and to conform with other tests being conducted.

(a) Between 15 January and 1 February:

(1) Due to the number of test erections required, and in order to eliminate extra erections, the erection within the hangar necessary for installation of electrical, test and exhaust equipment will also be conducted for observation by BuDocks representatives.

(2) Sand bags will be filled and load test material stored in available space within hangar.

(b) Cold Soaking Period:

After erecting the hut for installation of instruments, electricity, etc., it will remain erected during the cold soaking period scheduled to start around 1 February 1949, for the starting of testing at plus 20°F.

(c) Plus 20° Test Period:

(1) Heat Loss Test: The eave-line cracks of the hut will be caulked with cotton fiber (lamp wicking) and the space heaters fired as soon as the plus 20° test period starts. For the next 48 hours, the inside temperature of the hut will be maintained at 70° above zero at a point 30 inches above the floor. During this time, hourly recordings of all thermocouples will be logged (for layout see ref (a); and fuel consumption records maintained. Air flow velocities through the intake and exhaust outlets of the ventilation system will be maintained and regulated to obtain one air change per hour for the first 24 hours of test. For the last 24 hours of testing, two, three, and four air changes per hour will be attempted, and test periods of 8 hours each for these air changes conducted, if satisfactory heat comfort is obtained. Air current velocities and directions within the hut will be obtained, and draft records of the space heater exhaust stacks made. If, during this 48-hour test period air stagnation areas are found within the hut, electric fans will be used in an attempt to obtain satisfactory air circulation. Also, if practical, a simulated wind will be applied to the outside of the hut during a part of this test period in order to determine adequacy of caulking and effects on heat losses.

(2) Floor and Roof Load Test: Load test material will be applied to six (6) floor and six (6) roof panels near the center of the hut. These loads will be applied in three increments each until a maximum of 80 pounds per square foot is applied to the roof, and 100 pounds per square foot to the floor. Deflections and strain gage readings will be made during this test (for layout see ref (b).

(3) Erection Test: A disassembly and erection test against time will be made after the completion of 3 (c) (1) and 3 (c) (2), (for layout see ref (c). Upon re-erection, space heaters, lights, instruments, and cotton caulking will be reinstalled and a heat loss test made to determine the time required to bring the hut up to the desired temperature at the comfort zone. Also, if permitted, this heat loss test will continue during reduction of the hangar temperature to the next test period.

(d) Test Period at 0°: If this test period is scheduled for the hangar, the heat loss and floor and roof load tests schedule under paragraph 3 (c) above, will be repeated. No erection tests will be made during this test period.

(e) Test Period at Minus 20°: If this test period is scheduled for the hangar, the heat loss, roof and floor load and erection tests schedule under paragraph 3 (c) above will be repeated.

(f) Test Period for Minus 40°: If this test period is scheduled for the hangar, the heat loss and load tests schedule under paragraph 3(c) will be repeated. However, only a partial disassembly and erection test, to include at least one bay of the hut, will be attempted at this temperature. If an erection is not deemed advisable, all seams will be caulked with Minnesota Mining EC 800 Sealer, and a second 48-hour heat loss test conducted.

(g) Test Period at Minus 65°:

(1) Heat Loss Test: This test will be identical to the test listed under paragraph 3(c) (1) above, except that it will run for only 24 hours, if cotton fiber caulking at the eave line only is used.

(2) Floor and Roof Load Tests: Immediately upon completion of 3(g) (1), a floor and roof load test, similar to the one described under 3(c) (2), will be conducted.

(3) Upon completion of 3(g) (2), and if a partial erection has been made at minus 40°, the building will be completely caulked with Minnesota Mining EC 800 Sealer, and the heat loss test, outlined above, reconducted for another 24-hour period.

(4) Upon completion of 3(g) (3), the roof and floor of the entire building will be completely loaded, applying in increments, 60 pounds per square foot load to the roof, and 75 pounds per square foot load to the floor. Deflections and strains will be read during this load test.

(5) Upon completion of 3 (g) (4), a disassembly and possible erection of the hut will be scheduled.

E. H. MOSER
Structural Division Head

Approved:

Proving Ground Superintendent

Assistant Proving Ground Officer

CC:
DirPacAlDocks
Air Proving Ground, Eglin Field, Fla. (3)
OinC, Arctic Test Station
Proving Ground Personnel

APPENDIX B

Description, Parts List and Details of Modifications and Accessories

Description of Hut

Parts List with Sizes and Weights - Table 4.

ABPG Dwg. No. 810
Pre-Erection Panel Placement of Roof
Plan and Heating Diagram

ABPG Dwg. No. 811
Electrical Wiring Harness and Miscellaneous Details

ABPG Dwg. No. 812
Panel Openings and Details

ABPG Dwg. No. 813
Space Heater

ABPG Dwg. No. 814
Roof Jack Details

ABPG Dwg. No. 815
Fuel Supply System - Miscellaneous Details

DETAILED DESCRIPTION OF NAVY ARCTIC HUT (MARK I)

The Navy Arctic Hut is a prefabricated structure, 20 feet wide, 48 feet long and has an average ceiling height of 8 feet. The largest individual part, a 20 foot, 150 pound transverse roof support beam, can be placed by three men and only two men are required to place any other part.

The floor, walls and roof of the hut are made up of panels. These panels are made of a sandwich type material consisting of a resin-impregnated, honeycombed paper core between two 0.020 inch aluminum skins. The wall panels are 3 inches thick, 4 feet wide and range from 8½ feet to 9½ feet in length. The floor and roof panels are 5 inches thick, 4 feet wide and 10 feet long. The edges of all panels are covered with a plastic laminated fiberglass material which is formed into either shiplap or butt joints as required by the hut design, Felt strips are glued to the matching edges of these joints to form airtight seals, and the panels are held together with wedge type connector pins made of plastic, reinforced with fiberglass.

The roof has a low pitch, dropping 1 foot in the 10 feet from the ridge line to the eave line. The side walls support the outer edges of the roof and the ridge is supported by built-up aluminum H beams. The ridge beams are made up in 12 foot lengths and are supported at each end wall by formed aluminum stanchions and at each 12 foot interval by built-up aluminum transverse beams. The transverse beams are 20 feet long and are supported by stanchions secured to the side walls. All the roof support beams and stanchions are held in place with the wedge type plastic pins.

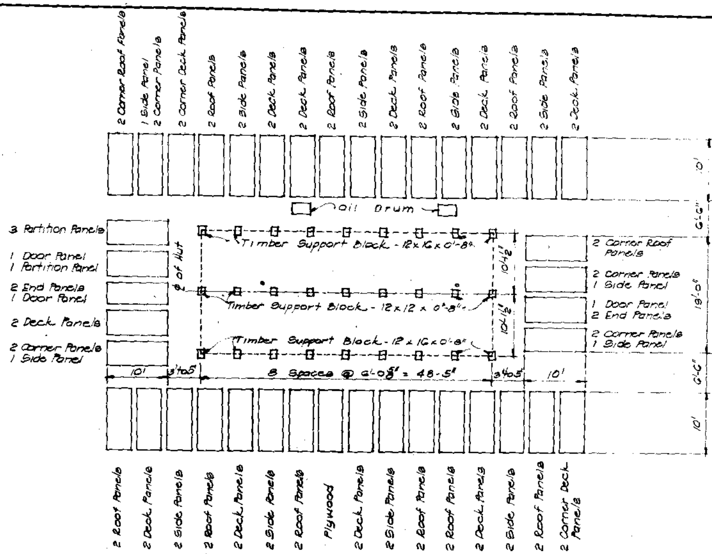
A transverse non-load bearing partition wall is included to form an entrance vestibule. This wall can be located at any of the panel joints along the walls except at those joints where the transverse beams are located. This wall and both end walls include panels containing doors. Each door and wall panel, except the center end wall panels contains a double glazed 14-inch diameter plexiglass window.

The entire building rests on a 2-foot high aluminum foundation. This foundation is made up of beams 12 feet in length and clamps, with self contained wedges, are used to tie the beams to each other. The wall and floor panels are secured to these beams with aluminum and metal-tipped plastic screw pins, respectively.

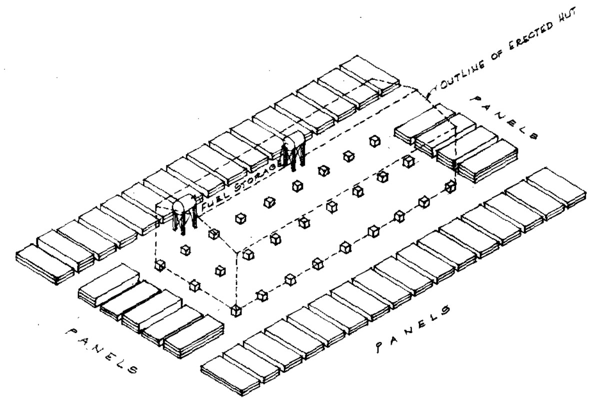
Table 4. **PARTS LIST AND ACCESSORIES FOR NAVY ARCTIC HUT (MARK I)**

Quan.	Description	Weight Each (lbs.)
	DOUGLAS ARCTIC HUT	
4	End foundation beam	73
8	Side foundation beam	103
4	Center foundation beam	90
24	Floor panel	90
24	Floor panel cover (plywood)	29
8	End and side support	14
3	Transverse beam	150
4	Ridge beam	73
4	End wall panel, corner	70
2	End wall panel, intermediate	70
2	End wall panel, center	62
2	End wall panel, door	146
2	Partition wall panel, end	70
1	Partition wall panel, intermediate	65
1	Partition wall panel, center	65
1	Partition wall panel, door	75
4	Side wall panel, corner	70
20	Side wall panel, typical	62
4	Roof panel, corner	97
20	Roof panel, typical	85
3	Door handle assembly	--
16	Wedge connector pin - short (corner wall)	--
181	Wedge connector pin - medium (12 each ridge, transverse and stanchion) (169 ea. wall to wall)	--
270	Wedge connector pin - long (210 ea. roof to roof and roof to wall) (44 ea. floor to floor) (16 ea. heater and ventilator roof jack)	--
86	Wedge connector pin - extra long (72 ea. roof to ridge beam) (14 ea. stanchion to end wall)	--
553	Wedge for connector pin	--
76	Aluminum screw pin connector (wall to foundation)	--

Quan.	Description	Weight Each (lbs.)
	DOUGLAS ARCTIC HUT	
90	Metal tipped plastic screw pin connector (floor to foundation)	--
6	Metal tipped plastic screw pin connector (alternate for floor on last two panels placed)	--
3	Tapered aluminum drift pin, threaded	--
21	Clip angle (for partition wall)	--
6	Nut, clip mounted (floor panel)	--
56	Clamp w/wedge (foundation beam)	--
3	Ridge beam sway brace	--
24	Stake, 1 1/2-inch dia. 24 inch long w/chain (tie down for foundation)	--
	ACCESSORIES	
2	Space heater, oil fired, 50,000 Btu input Advance Base Stock No. 2Q-11-9 (modified)	85
2	Stove base w/fresh air intake duct	15
2	Fuel tank w/stand (5 gal. auxiliary)	15
(set)1	Fuel pipe supply line (for outside storage)	50
2	Stove pipe assembly w/Walker draft regulator	18
2	Roof jack, heater	8
1	Ventilator stack w/damper, 88" long, 4 pieces	10
1	Ventilator stack w/damper, 12" long	2
2	Roof jack, ventilator	6
4	Electric fan, portable, 10" diam., oscillating, 3-speed, 60-cycle, 110 volt	5
1	Electrical wiring harness, 3-wire, self-grounding, complete w/distribution panel, fixtures, switches, convenience outlets and hangar brackets.	155



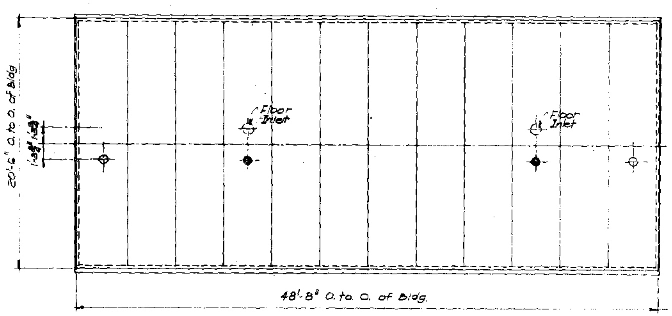
PLAN



ISOMETRIC

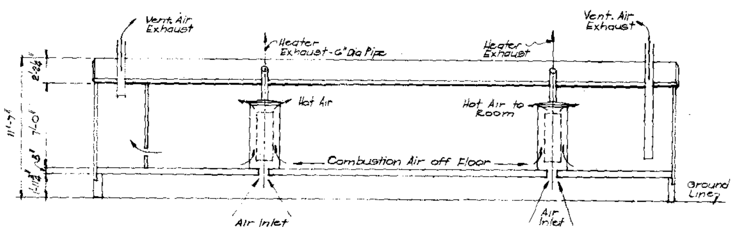
PRE-ERECTION—PANEL PLACEMENT

NOT TO SCALE



ROOF PLAN

Scale: ¼" = 1'-0"



NOTE: All Roof Openings to be 7½" Dia.
" Floor " " " 10" Dia.

HEATING & VENTILATING ARRANGEMENT

Scale: ¼" = 1'-0"

SHEET 1 OF 6 SHEETS

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ADVANCE BASE PROVING GROUND

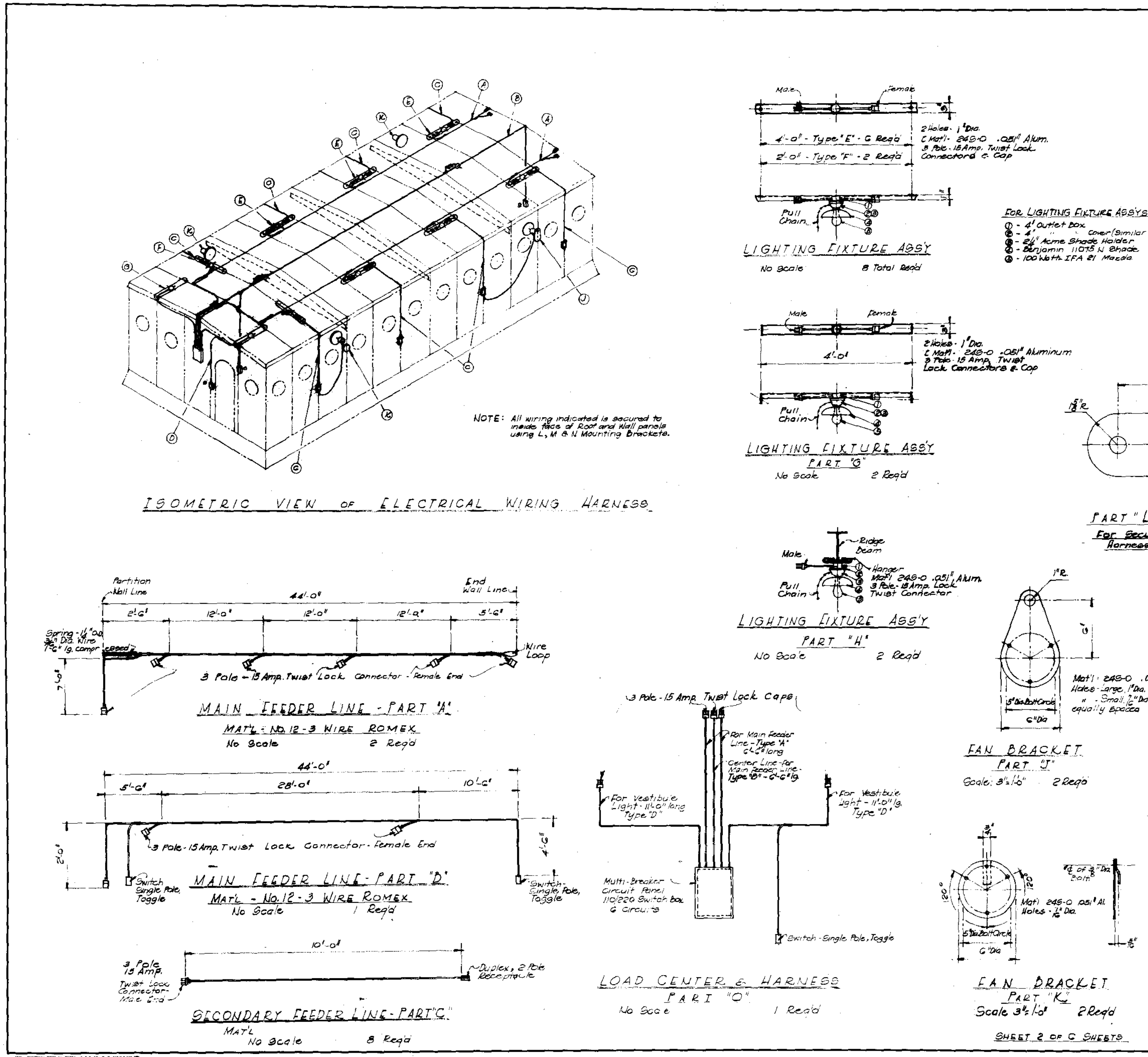
NAVY ARCTIC HUT (MK-1)

PRE-ERECTION PANEL PLACEMENT
ROOF PLAN
& HEATING DIAGRAM

Drawn by: EDDY
Traced by: AUSTIN
Approved: [illegible]
Date: 10/3/49

SCALE: As Noted | P.G.O. HAT-000-0A

810



PARTS LIST			
Part	Q'ty	Description	Material
A	2	Main Feeder Line as detailed	
B	1	" " " "	
C	8	Secondary " " "	
D	2	" " " for Vestibule	
E	6	Lighting Fixture Ass'y, as detailed	
F	2	" " " "	
G	2	" " " "	
H	2	" " " "	
J	2	Fan Bracket, as detailed	Alclad
K	2	" " " "	"
L	16	Clip Bracket, " "	Stnless St.
M	8	" " " "	"
N	1	" " " "	"
O	1	Load Center & Harness	

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ADVANCE BASE PROVING GROUND

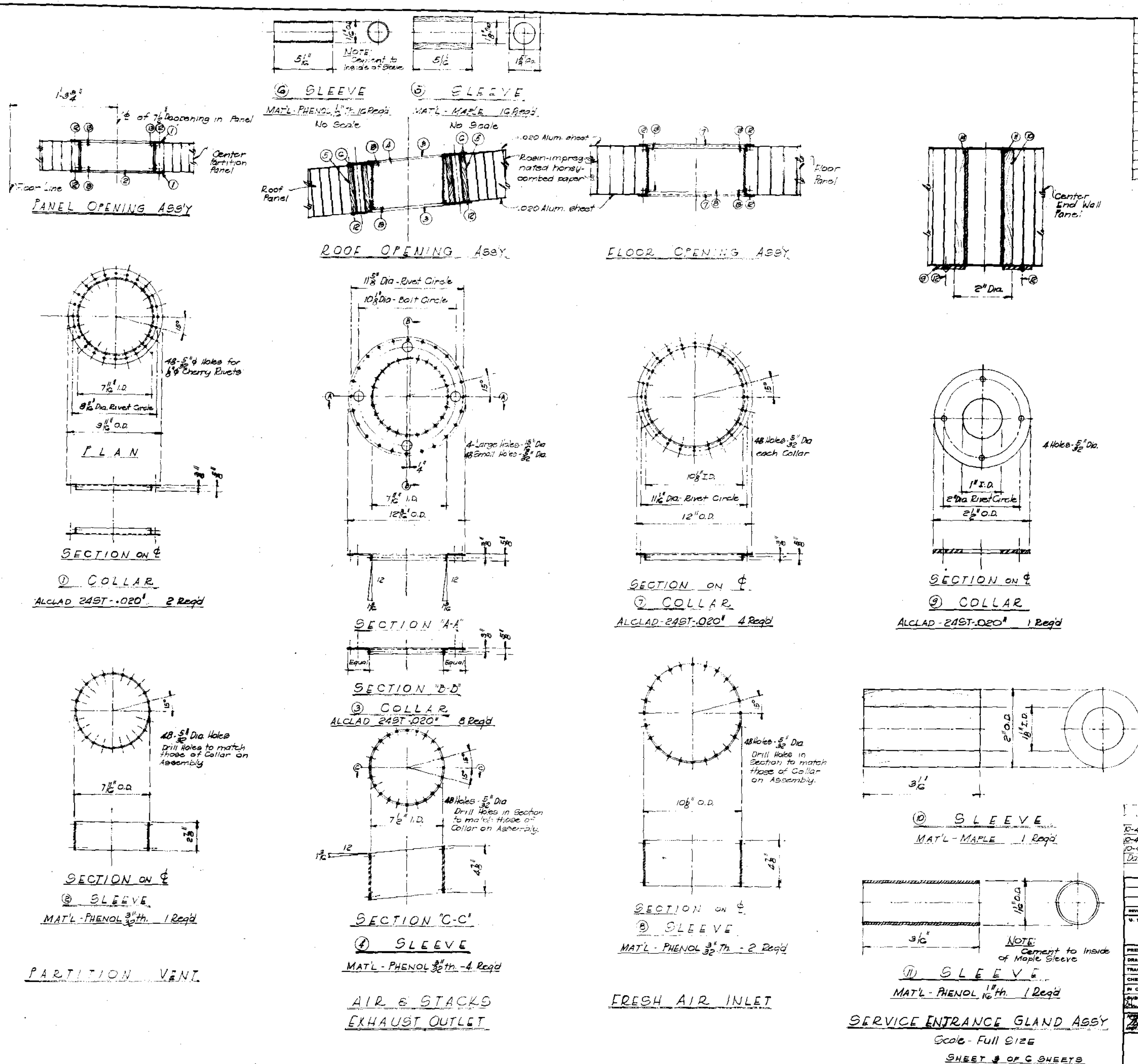
NAVY ARCTIC HUT (Mk-1)

ELECTRICAL WIRING HARNESS & MISCELLANOUS DETAILS

PREPARED BY
DRAWN BY AUSTIN
TRACED BY
CHECKED BY T.E. [signature]
IN CHARGE J.P. [signature]
SUBMITTED: [signature] 9/27/49 SUPERINTENDENT
APPROVED: [signature] ADVANCE PROVING GROUND OFFICER
APPROVED: [signature] PROVING GROUND OFFICER
DATE: 10/3/49

SCALE As Noted | P.G.O. HAI-000-0

A.B.P.G. DRAWING NO. 811



PARTS LIST

Part	Q'ty	Description	Material
1	2	Collar, as detailed	Sh. Alum.
2	1	Sleeve, "	Phenol
3	8	Collar, "	Sh. Alum.
4	4	Sleeve, " "	Phenol
5	16	" " "	Wood
6	16	" " "	Phenol
7	4	Collar, " "	Sh. Alum.
8	2	Sleeve, " "	Phenol
9	1	Collar, " "	Sh. Alum.
10	1	Sleeve, " "	Wood
11	1	" " "	Phenol
12	150	Rivet, Cherry - 1/8"ϕ - CR 162-4-2	Comm.
13	144	" " - 1/8"ϕ - CR 163-4-4	"
14	1 Qt.	Cement Minnesota Mining Co. # EC897	"

GENERAL NOTES:

1. Cherry Rivets No. CR 162-4-2 to be used with Collars & Panels. Cherry Rivets No. CR 163-4-4 to be used with Collars & Phenol Sleeves.

2. Use Minnesota Mining Cement to make joints waterproof or cementing one material to another.

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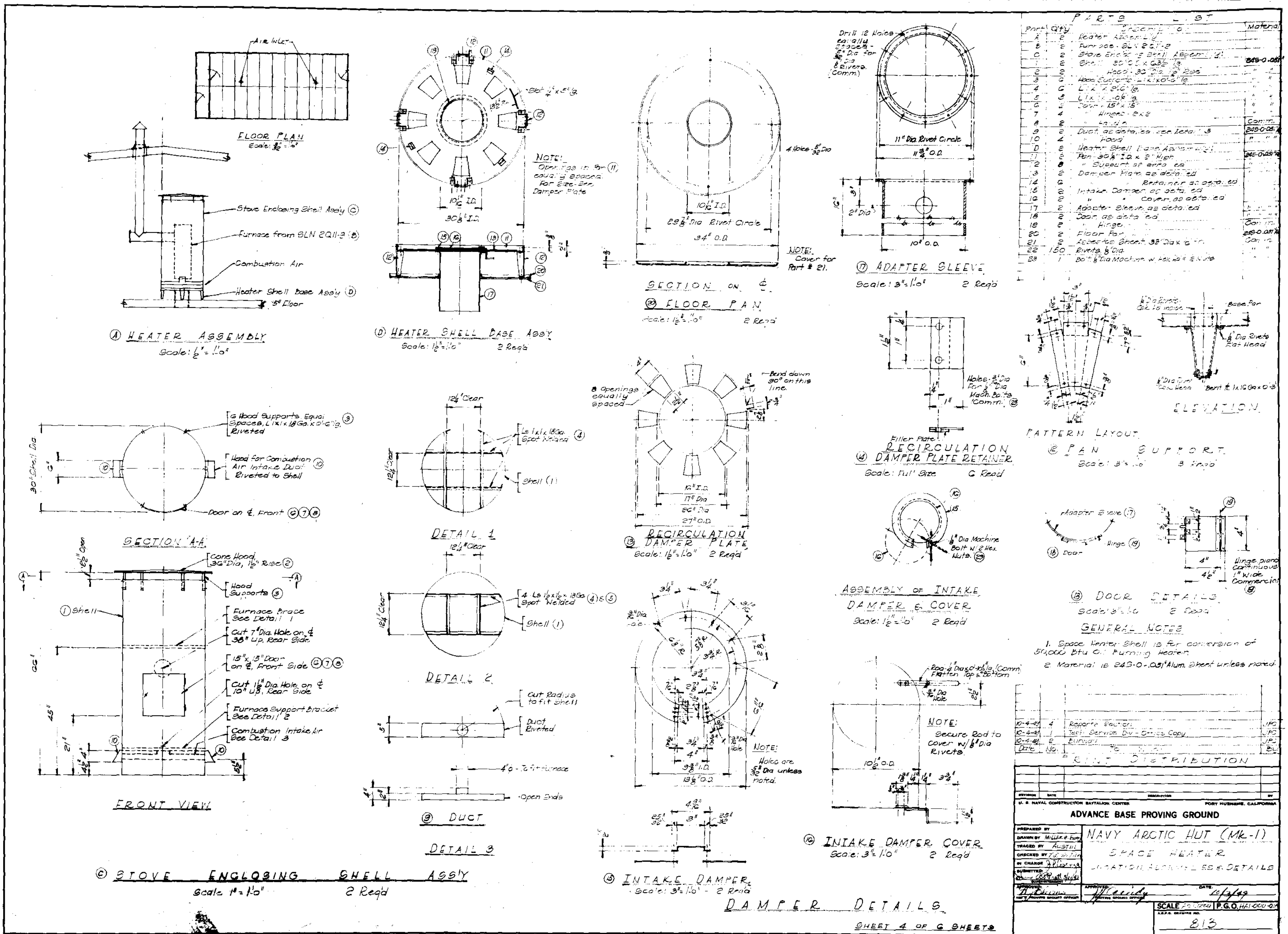
ADVANCE BASE PROVING GROUND

NAVY ARCTIC HUT (Mk.-1)

PANEL OPENINGS & DETAILS

PREPARED BY
DRAWN BY Austin
TRACED BY
CHECKED BY
IN CHARGE J. P. Cosinga
SUBMITTED
SUPERINTENDENT
APPROVED: ASST. PROVING GROUND OFFICER
APPROVED: PROVING GROUND OFFICER
DATE: 11/3/47

SCALE 3" = 1'-0" Unless Noted
P.G.O. AA1-000-016
A.B.P.G. DRAWING NO. 812



PARTS LIST
FLOOR PLAN
Air Inlet
Stove Enclosing Shell Ass'y (C)
Furnace from BLN 2Q11-3 (B)
Combustion Air
Heater Shell Base Ass'y (D)
5" Floor
(A) HEATER ASSEMBLY
Scale: 1/2" = 1'-0"
NOTE: Openings in Part (11) equally spaced. For size see Damper Plate
(D) HEATER SHELL BASE ASS'Y
Scale: 1 1/2" = 1'-0" 2 Req'd
SECTION ON ℄
(20) FLOOR PAN
2 Req'd
NOTE: Cover for Part # 21.
11" Dia Rivet Circle
(17) ADAPTER SLEEVE
Scale: 3" = 1'-0" 2 Req'd
SECTION 'A-A'
Door on ℄, Front (6)(7)(8)
DETAIL 1
DETAIL 2
DETAIL 3
(9) DUCT
Open Ends
8 Openings equally spaced
Bend down 90° on this line.
(13) RECIRCULATION DAMPER PLATE
Scale: 1 1/2" = 1'-0" 2 Req'd
(14) RECIRCULATION DAMPER PLATE RETAINER
Scale: Full Size 6 Req'd
ASSEMBLY OF INTAKE DAMPER & COVER
Scale: 1 1/2" = 1'-0" 2 Req'd
PATTERN LAYOUT
ELEVATION
(E) PAN SUPPORT
3 Req'd
(18) DOOR DETAILS
2 Req'd
GENERAL NOTES
1. Space Heater Shell is for conversion of 50,000 Btu Oil Burning Heater.
2. Material is 243-0-.051" Alum. Sheet unless noted.
FRONT VIEW
(C) STOVE ENCLOSING SHELL ASS'Y
Scale 1" = 1'-0" 2 Req'd
(15) INTAKE DAMPER
Scale: 3" = 1'-0" 2 Req'd
(16) INTAKE DAMPER COVER
Scale: 3" = 1'-0" 2 Req'd
NOTE: Holes are 3/32" Dia unless noted.
NOTE: Secure Rod to Cover w/ 1/8" Dia Rivets
DAMPER DETAILS
SHEET 4 OF 6 SHEETS
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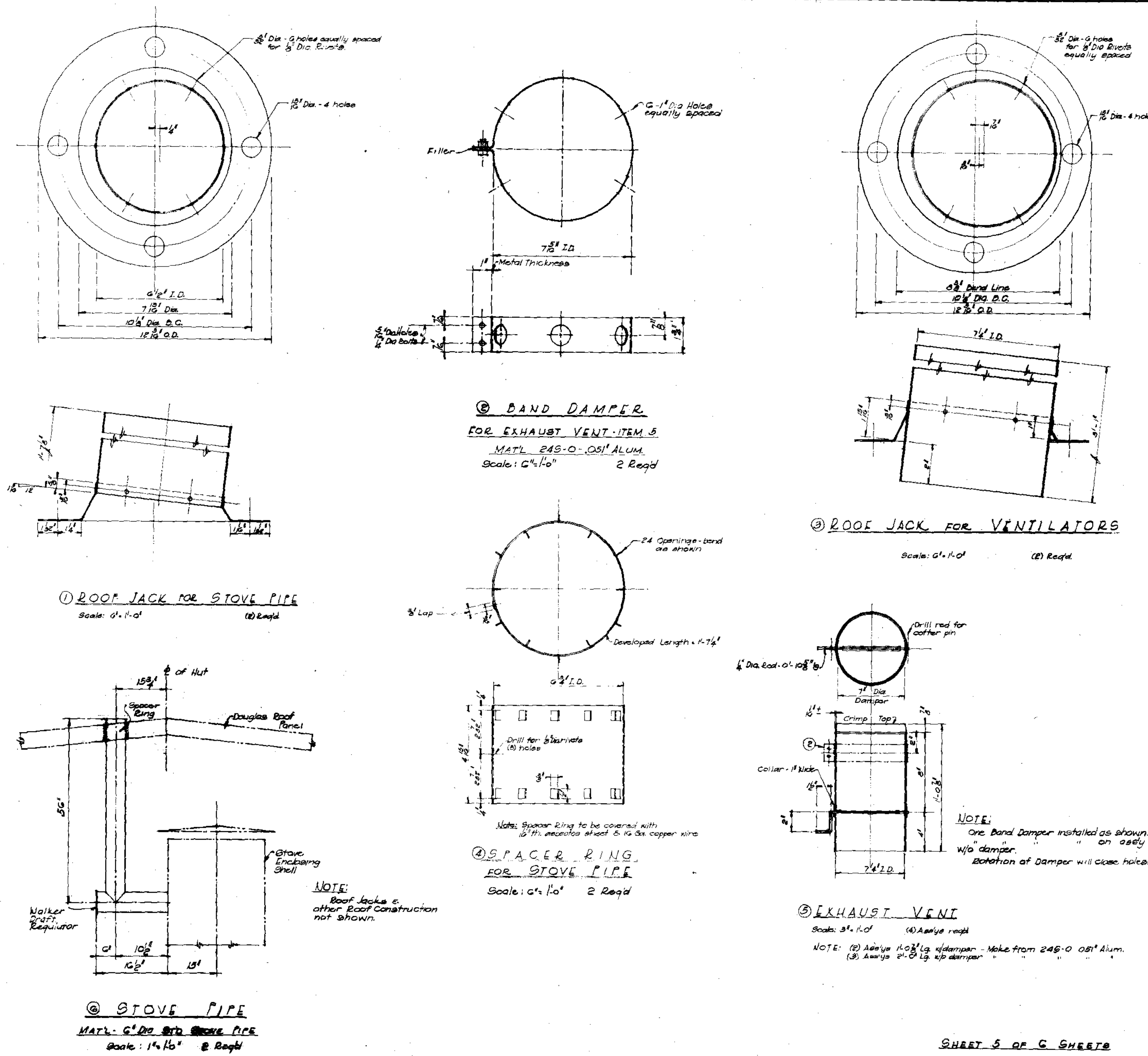
PORT HUENEME, CALIFORNIA
ADVANCE BASE PROVING GROUND
NAVY ARCTIC HUT (MK-1)
SPACE HEATER
LOCATION, ASSEMBLIES & DETAILS
P.G.O. HA1-000-01
813



PARTS LIST			
Item	Q'ty	Description	Material
1	2	Roof Jack, for Stove Pipe, as detailed	Sh. stl. galv.
2	4	Band Damper for item 5 " "	Aluminum
3	2	Roof Jack, as detailed	Sh. stl. galv.
4	2	Spacer Ring, " "	Aluminum
5	4	Exhaust Vent, as detailed	" "
6	2	Stove Pipe, as detailed	Std. stove pipe

GENERAL NOTES:
All material to be 20 Ga. Sheet Steel-Galv. unless noted.

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ADVANCE BASE PROVING GROUND

NAVY ARCTIC HUT (Mk-1)

ROOF JACK DETAILS

Prepared by:
Drawn by: Eddy
Traced by:
Checked by: Donoghue
In charge:
Submitted:
Approved:
Date: 10/3/49

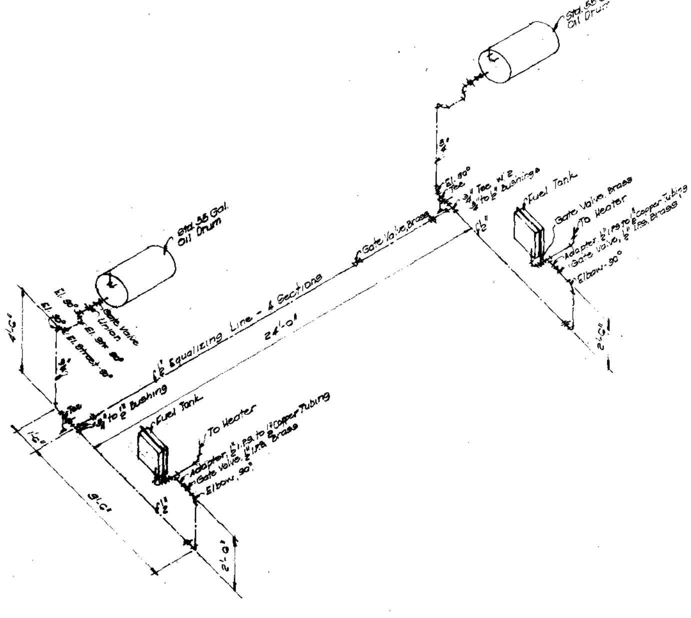
SCALE As Noted
P.G.O. HA1-000-6

A.B.P.G. Drawing No. 814

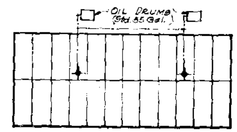
SHEET 5 OF 6 SHEETS

PARTS LIST

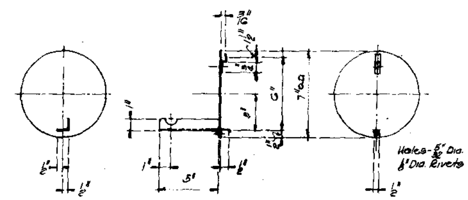
Part No.	Quantity	Name of Part	Material
1	3	Pipe Hanger, as detailed	Aluminum
2	4	Handle for 3/4" IPS Union	Steel
3	4	" " 1/2" " "	"
4	2	Fuel Tank Tank, as detailed	Aluminum
5	2	Steps, Outside, as detailed	Alum. & Wood



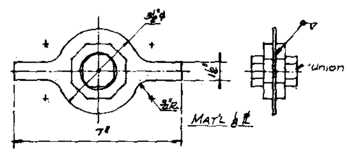
PIPING DIAGRAM
Not to Scale



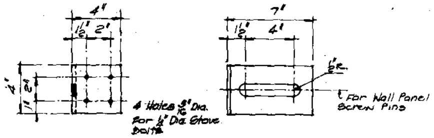
FLOOR PLAN
Scale: 3/32" = 1'-0"



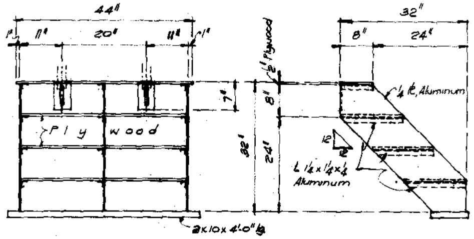
① PIPE HANGER
MAT'L 24S-0-.051" ALUMINUM
Scale: 3" = 1'-0"   3 Req'd



② HANDLE FOR 3/4" I.P.S. UNION - 4 Req'd
③ HANDLE FOR 1/2" I.P.S. UNION - 4 Req'd
Scale: 6" = 1'-0"

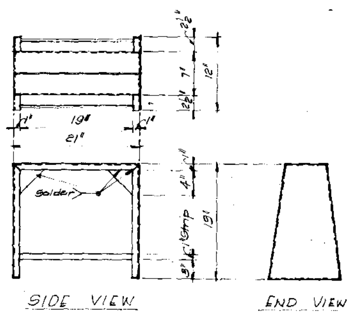


L 7 x 4 x 3/8 x 0'-4"
Scale 3" = 1'-0"   2 Req'd



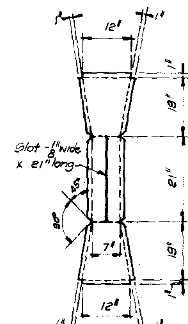
NOTE:
Treads to be 1/2" th. Plywood
Secure Treads to
1/4 Ls w/ 1/4" Dia. Stove Bolts
Secure 1/4 Ls to 1/4 Alum.
Pl. w/ 1/4" Dia. Alum. Rivets

⑤ STEPS
Scale 1" = 1'-0"   2 Req'd



SIDE VIEW   END VIEW

④ FUEL TANK STAND
MAT'L 24S-0 .051" ALUMINUM
Scale: 3" = 1'-0"   2 Req'd



PATTERN LAYOUT
No Scale
SHEET 6 OF 6 SHEETS

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ADVANCE BASE PROVING GROUND

NAVY ARCTIC HUT (MK-1)
FUEL SUPPLY SYSTEM.
MISCELLANOUS DETAILS

PREPARED BY:
DRAWN BY: AUSTIN
TRACED BY:
CHECKED BY: T.E. Miller
IN CHARGE: [signature]
SUBMITTED: [signature]
APPROVED: [signature]
APPROVED: [signature]
DATE: 10/5/49

SCALE As Noted   P.G.O. HAI-000-014
A.B.P.G. DRAWING NO. 815

APPENDIX C

Heating and Ventilating Studies

Development of Equations

Computations

Temperature Distribution

Table 5

Physiological Studies

Table 6

DEVELOPMENT OF EQUATIONS

Heat Balance and Air Change with Space Heaters

Development of heat balance and air change equations for computing heat input; heat losses through combustion products, exhausted ventilation air and exposed surface area of the structure; and, to determine the quantities of ventilating air were based on the following factors:

(A) Use of oil-fired heaters,

(B) Use of a gravity ventilation system,

(C) Inability to accurately measure the volume of incoming ventilating air due to its low temperatures.

Based on these factors and the general arrangement of the heating and ventilation system, the flow diagram in Fig. 73 was constructed for development of the desired equations.

Heat input.

From the flow diagram, the following equation was written:

$$Q = 18160 \times W_F \qquad (1)$$

where Q = Quantity of heat input in Btu's per hour,

18160 = Btu's heat per pound fuel,

W_F = pounds of fuel burned per hour.

For its low freezing point, -76°F., Specification AN-F-32a, Grade JP-1 fuel was used during these tests. A Calire--meter test on a sample from the lot used established a net Btu value of 18,160 per pound. Volumetric measurements were used to determine the quantity of fuel burned per hour. A conversion factor to pounds per hour was established for

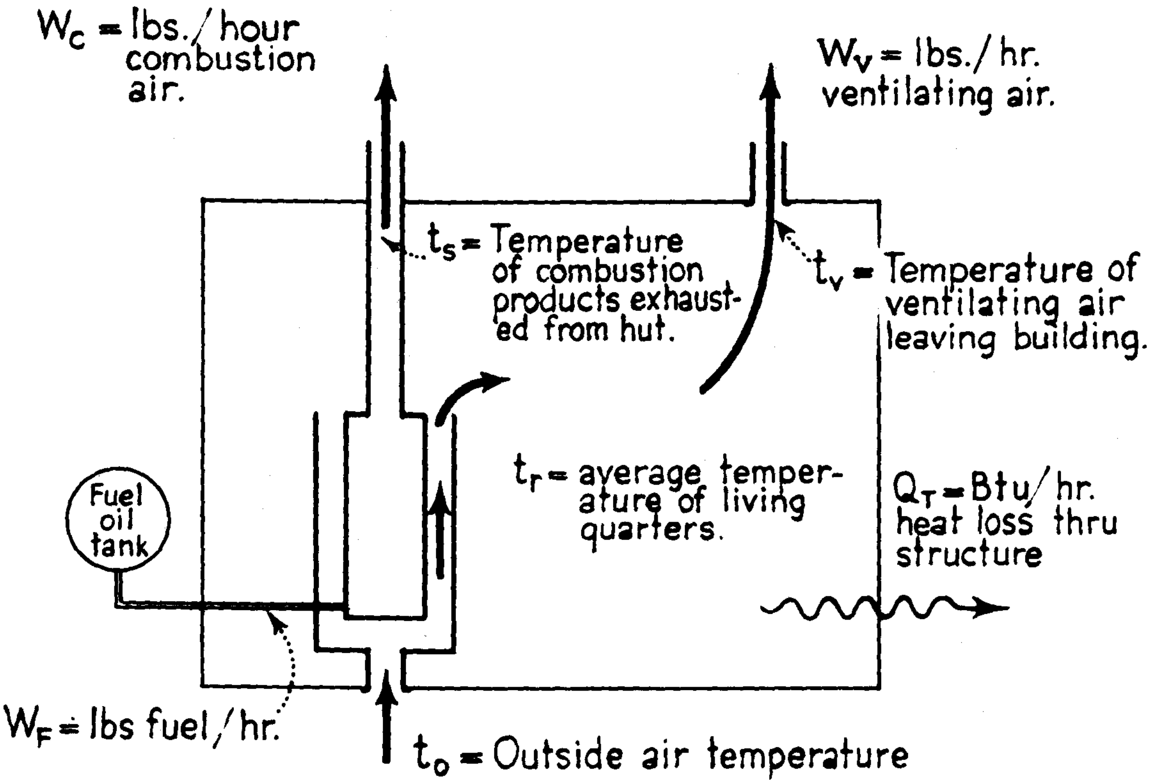

Fig. 73. FLOW DIAGRAM OF HEAT INPUT, HEAT LOSSES, AND VENTILATING AIR FOR NAVY ARCTIC HUT (Mk-1) USING AN OIL-FIRED SPACE HEATER AND A GRAVITY TYPE VENTILATION SYSTEM.

each ambient hangar temperature since the fuel supply was stored outside the hut in the hangar.

Hangar Temperature $^{\circ}$F.	Weight of fuel per liter lbs.
68	1.804
15	1.866
0	1.878
-20	1.894
-40	1.916
-65	1.924

Heat Loss Through Combustion Products.

From the flow diagram the following equation was written

$$Q_C = W_C \times \triangle t \times 0.24 \qquad (2)$$

where

Q_C = quantity of heat loss through combustion products in Btu's per hour,

W_C = pounds of combustion air per hour,

$\triangle t$ = $t_s - t_o$ or temperature difference in $^{\circ}$F. between temperature of combustion products at point of exhausting from hut (t_s) and temperature of outside air (t_o).

Before the tests, the heater stacks were fitted with Pitot tubes and through calibration an Average Air Flow in lbs/hr vs Pitot Tube Head x Density chart constructed. Thus, the Pitot tube head reading, observed in inches of liquid, multiplied by the air density computed by the equation

$$\text{Density} = \frac{1.324 \times \text{in. Hg}}{^{\circ}F + 460}$$

where $^{\circ}F = t_s$

could be found on the chart and the average flow of combustion air in pounds per hour (W_C) read direct.

Heat loss through ventilation air.

From the flow diagram, the following equation was written

$$Q_V = W_V \times \Delta t \times \text{Specific Heat} \qquad (3)$$

where Q_V = quantity of heat loss through ventilation air in Btu's per hour,

W_V = pounds of ventilation air per hour,

Δt = $t_v - t_o$ or temperature difference in ^{o}F. between temperature of ventilating air leaving building (t_v) and temperature of outside air (t_o).

During the tests average air flow rates in feet per minute were observed in the ventilators at a point just below the ceiling using an Anemotherm. The observed flows were substituted in the equation

$$W_V = \text{fpm} \times 0.308\ ft^2 \times 60\ \text{min.} \times \frac{1.324 \times \text{in. Hg}}{^{o}F + 460}$$

where $0.308\ ft^2$ = area of ventilator,

$^{o}F = t_v$

to determine the pounds of ventilation air being exhausted per hour.

Heat loss through structure.

From the flow diagram and equations (1), (2) and (3) the following equation, reasoning that the unaccountable heat losses passed through the structure, was written

$$Q_T = Q - (Q_C + Q_V) \qquad (4)$$

where Q_T = heat losses passing through structure in Btu's per hour,

$Q_C = Q_{CL} + Q_{C2}$ or a summation of the heat losses through the heater stacks,

$Q_V = Q_{V1} + Q_{V2}$ or a summation of the heat losses through the outlet ventilators.

Air change

As the incoming ventilation air was too cold for measurement at the point of entry, the measurements of the quantity of air exhausted through the ventilators and that in excess of the minimum required to support combustion passing out the heater stacks, were combined to obtain an average quantity being passed through the building per hour. Based on this, the following equation was written

$$AC = \frac{V_V + (V_S - V_C)}{7160} \qquad (5)$$

where AC = the number of air changes per hour,

$V_V = \frac{W_{V1}}{d_{v1}} + \frac{W_{V2}}{d_{v2}}$ or a summation of the pounds of air passing through each outlet ventilator divided by its density to obtain the total cubic feet of air passing through the ventilators,

$V_S = \frac{V_{S1}}{d_{s1}} + \frac{V_{S2}}{d_{s2}}$ or a summation of the pounds of air passing through each stack divided by its density to obtain the total cubic feet of air passing out of the building through the stacks,

V_C = the cubic feet per hour of air required to support combustion,

7160 = the cubic feet of air space in the living quarters of the hut with the partition wall located 4 feet from the entrance end.

In determining the cubic feet per hour of air required to support combustion the equation

$$\text{cu ft air reqd/unit fuel} = \frac{\text{Heating Value (Btu/unit)}}{100}$$

was used to arrive at an approximate theoretical air requirement. To this, an excess of 20% was added, based on the quantities of excess air required for best combustion results with fuel oil. Computations established 216 cubic feet of air for each pound of fuel burned per hour as the quantity required.

Heat Losses Through Floor, Walls, Windows and Roof

Delineation of the heat losses for the floor, walls, windows and roof surfaces was accomplished by heat flow studies using a Nichols heat flow meter. Establishment of an average over-all heat transmission coefficient (U) for each surface resulted in development of equations for computing the losses through these surfaces for each heat balance study.

Heat loss through floor.

Two floor conditions were observed, one where the floor was covered with a 3/8-inch plywood wearing surface and the other where the floor was bare. Observations with the heat flow meter were as follows:

Outside Temp. °F	Temperature Diff. Inside to Outside °F	Covered Floor Heat Trans. Coef Btu/hr ft^2°F	Bare Floor Heat Trans. Coef. Btu/hr ft^2°F
15	49		0.128
0	59	0.094	0.123
-20	79	0.083	0.104
-40	95	0.101	0.117
-40	88	0.085	- - -
-65	96	0.109	- - -
Mean	--	0.094	0.118

The plywood floor covering was used throughout the heat tests; therefore, the mean coefficient established for this condition, 0.094, was used for all computations. For determining the total heat loss through the floor the equation was written

$$Q_F = 0.094 \times \Delta t_{fe} \times 80\ ft^2 + 0.094 \times \Delta t_{fq} \times 963\ ft^2 \quad (6)$$

where Q_F = quantity of heat loss through floor in Btu's per hour,

Δt_{fe} = temperature difference in °F BETWEEN AVERAGE inside air temperature over floor in vestibule and average outside air temperature just under floor,

$80\ ft^2$ = area of floor surface in vestibule,

Δt_{fq} = temperature difference in °F between average inside air temperature over floor in living quarters and average outside air temperature just under floor,

$963\ ft^2$ = area of floor surface in living quarters.

Heat loss through walls.

Observations with the heat flow meter resulted in the following:

Outside Temperature °F	Temperature Difference Inside to Outside °F	Heat Trans. Coef. Btu/hr ft^2 °F
15	58	0.163
0	73	0.164
-20	89	0.164
-40	118	0.163
-40	118	0.165
-65	128	0.162
Mean	---	0.164

The mean coefficient established from these observations, 0.164, was used in determining the total heat loss through the walls. The equation was written

$$Q_W = 0.164 \times \Delta t_{we} \times 222\ ft^2 + 0.164 \times \Delta t_{wq} \times 828\ ft^2 \qquad (7)$$

where Q_W = quantity of heat loss through walls in Btu's per hour,

Δt_{we} = temperature difference between the average inside air temperature in the vestibule and the average outside air temperature,

$222\ ft^2$ = area of wall surface in vestibule (this figure does not include the window area),

Δt_{wq} = temperature difference between the average inside air temperature in the living quarters and the average outside air temperature,

$828\ ft^2$ = area of wall surface in living quarters (this figure does not include the window area).

Heat loss through windows.

Observations with the heat flow meter resulted in the following:

Outside Temperature °F	Temperature Difference Inside to Outside °F	Heat Trans. Coef. Btu/hr ft^2 °F
15	--	---
0	73	0.291
-20	89	0.325
-40	118	0.348
-40	118	0.366
-65	128	0.329
Mean	---	0.332

The mean coefficient established from these observations, 0.332, was used in determining the total heat loss through the windows. The equation was written

$$Q_{WW} = 0.332 \times \Delta t_{wwe} \times 1.97\ ft^2 + 0.332 \times \Delta t_{wwq} \times 8.53\ ft^2 \quad (8)$$

where Q_{WW} = quantity of heat loss through the window in Btu's per hour.

Δt_{wwe} = temperature difference between the average inside air temperature in the vestibule and the average outside air temperature,

$1.97\ ft^2$ = area of window surface in vestibule,

Δt_{wwq} = temperature difference between the average inside air temperature in the living quarters and the average outside air temperature,

$8.53\ ft^2$ = area of window surface in living quarters.

Heat loss through roof.

Observations with the heat flow meter resulted in the following:

Outside Temperature °F	Temperature Difference Inside to Outside °F	Heat Trans. Coef. Btu/hr ft² °F
15	68	0.083
0	74	0.109
-20	97	0.083
-40	121	0.085
-40	118	0.114
-65	128	0.109
Mean	---	0.097

The mean coefficient established from these observations, 0.097, was used in computing the total heat loss through the roof. The equation was written

$$Q_R = 0.097 \times \Delta t_{re} \times 80\ ft^2 + 0.097 \times \Delta t_{rq} \times 887\ ft^2 \quad (9)$$

where Q_R = quantity of heat loss through the roof in Btu's per hour,

Δt_{re} = temperature difference between the average inside air temperature just below the ceiling in the vestibule and the average outside air temperature just above the roof,

$80\ ft^2$ = area of roof surface in vestibule,

Δt_{rq} = temperature difference between the average inside air temperature just below the ceiling in the living quarters and the outside air just above the roof,

$887\ ft^2$ = area of roof surface in living quarters.

Summation of losses through floor, walls, windows and roof.

From equation (6), (7), (8) and (9) the following equation was written

$$Q_S = Q_F + Q_W + Q_{WW} + Q_R \tag{10}$$

where Q_S = the total measured heat losses through the floor, walls, windows and roof in Btu's per hour.

Heat Losses Through Joints, Connectors, Etc.

Measurement of heat losses through the joints, connectors, supply lines, etc., of the hut were not attempted during these tests. Sources of such losses include:

264 Lineal feet of wall lap and corner butt joints
221 Lineal feet of roof lap joint
268 Lineal feet of floor lap joint
136 Lineal feet of eave butt joint
48 Lineal feet of ridge butt joint
136 Lineal feet of floor to wall butt joint
32 Lineal feet of door lap joint
110.5 Lineal feet of window frames
616 each inside to outside plastic connectors
1 each electric power inlet
2 each fuel oil supply lines

To determine the probable losses through these sources, the following equation was written

$$Q_M = Q_T - Q_S \tag{11}$$

Thus reasoning that the difference between the total heat loss passing through the structure and the measured losses through the floor, walls, windows and roof passed through the joints, connectors, supply lines, etc. (Q_M).

Heat Transmission Coefficient for Hut as a Whole

To determine a heat transmission coefficient for the hut as a whole, the following equation was written

$$U = \frac{\frac{Q_T}{2989\ ft^2}}{\Delta t} \qquad (12)$$

where U = average heat transmission coefficient for hut as a whole,

$2989\ ft^2$ = total inside floor, wall, window and roof surface area for both entrance vestibule and living quarters (ignoring the area of the partition wall),

Δt = $t_r - t_o$ or temperature difference of $^{\circ}F$ between average inside temperature of living quarters (t_r) and temperature of outside air (t_o).

Heat Balance With Electric Heater

To determine a heat balance using electric heat required consideration of the following conditions:

(A) Lack of heat losses through combustion products

(B) Use of a three-phase electric heater

(C) Measurement of all electric heat input

Base on these factors, equations (1), (2), (3), (4) and (5) were revised.

Heat Input.

The following equation was written

$$Q = W_H + W_L \times 3.4126 \qquad (13)$$

where $W_H = \sqrt{3} \times a \times v$ or the total watt output per hour of the electric heater,

W_L = the total watt output per hour of the electric lights being burned,

3.4126 = the Btu's per watt hour.

Heat loss through ventilation air.

Equation (3) was used to determine the quantity of heat loss in Btu's per hour being passed through both the ventilators and the heater stacks. To make this equation workable for the losses through the heater stacks, air flow rates in feet per minute were observed in the stacks at a point just below the ceiling using an Anemotherm. The observed flows were substituted in the equation

$$W_S = \text{fpm} \times 0.196 \text{ ft}^2 \times 60 \text{ min.} \times \frac{1.324 \times \text{in. Hg}}{{}^{\circ}F + 460}$$

where 0.196 ft^2 = area of stack

${}^{\circ}F = t$

and W_S was substituted for W_V in equation (3).

Heat loss through structure.

The following equation, reasoning that the unaccountable losses passed through the structure, was written

$$Q_T = Q - Q_V \tag{14}$$

where Q_T = heat losses passing through the structure in Btu's per hour,

$Q_V = Q_{V1} + Q_{V2} + Q_{S1} + Q_{S2}$ or a summation of the ventilation air heat losses through the outlet ventilators and the heater stacks.

Air change.

Equation (5) was rewritten to read

$$AC = \frac{V_V}{7160} \tag{15}$$

where $V_V = \frac{W_{V1}}{d_{v1}} + \frac{W_{V2}}{d_{v2}} + \frac{W_{S1}}{d_{s1}} + \frac{W_{S2}}{d_{s2}}$ or a summation of air passing through each outlet divided by its density to obtain the total cubic feet of air passing out of the building.

Fuel Consumption for Specific Air Changes

During the tests, control of the desired quantity of incoming ventilation air was difficult since accurate measurement at the point of entry was not possible with the instruments available. Therefore, for a given set of conditions, the measured air changes as determined by application of equation (5) varied from those desired. However, in order to make comparative fuel consumption studies over the range of outside temperatures made available during the tests, it became necessary to establish a basis of comparison. A study of the collected test data indicated that at each outside temperature, the heat losses through the structure for a given set of inside conditions, i.e. with natural circulation of warm air, were fairly consistent. As the space heaters operating efficiency would also be fairly constant, then the adjusted fuel consumption for a specific air change could be based on the expected losses through the ventilation air passing out of the building. This reasoning resulted in the following equation being written

$$F_{AC} = F_O - \left\{ \frac{\frac{V_V + (V_S - V_C) - AC_D}{V_V} \times Q_V}{18160} \right\} \qquad (16)$$

where F_{AC} = fuel required per hour for a specific air change,

F_O = fuel consumption per hour observed for a given test,

$V_V + (V_S - V_C)$ = total summation of ventilation air in cubic feet for a given test as determined in equation (5),

AC_D = volume of ventilation air in cubic feet required for specific air change,

V_V = summation of ventilation air in cubic feet passing through ventilators for a given test as determined in equation (5),

Q_V = summation of the heat losses in Btu's per hour passing through the ventilators for a given test,

18160 = Btu's in one pound of fuel

Delineation of Heat Losses for Specific Air Changes

As in the establishment of an equation for determining the fuel consumption for a specific air change, it also became necessary to formulate equations for delineation of the heat losses for a specific air change. This was necessary in order to have a basis of comparison for the range of outside temperatures made available during the tests. For a selected air change, the following equations were applied to the results of the test most nearly meeting the desired conditions.

Heat input for desired air change.

The following equation was written

$$Q_{AC} = F_{AC} \times 18160 \tag{17}$$

where Q_{AC} = heat input in Btu's per hour,

F_{AC} = pounds of fuel burned per hour as determined by equation (16),

18160 = Btu's per pound of fuel.

Heat loss through structure for desired air change.

The following equation was written

$$Q_{TAC} = \Delta t \times U \times 2989 \text{ ft}^2 \tag{18}$$

where Q_{TAC} = heat loss through structure in Btu's per hour,

Δt = $t_r - t_o$ or temperature difference in ^oF between average inside temperature of living quarters (t_r) and average temperature of outside air (t_o) as established in the test most nearly meeting the desired conditions,

U = heat transmission coefficient for the hut as a whole as established by the mean for all the tests conducted,

$2989 ft^2$ = total inside floor, wall, window and roof surface area for both entrance vestibule and living quarters (ignoring the area of the partition wall).

Heat losses through ventilation air for desired air change.

The following equation was written

$$Q_{VAC} = \frac{AC_D \times Q_V}{V_V} \tag{19}$$

where Q_{VAC} = heat loss through the ventilation air in Btu's per hour for the desired air change,

AC_D = volume of ventilation air desired in cubic feet,

Q_V = total heat loss through the ventilation air in Btu's per hour as established in the test most nearly meeting the desired conditions and determined by equation (4),

V_V = total volume of air exhausted through the ventilators in cubic feet per hour in the test most nearly meeting the desired conditions and determined by equation (5).

Heat losses through combustion air for desired air change.

The following equation was written

$$Q_{CAC} = Q_{AC} - (Q_{TAC} + Q_{VAC}) \tag{20}$$

where Q_{CAC} = heat loss through combustion air in Btu's per hour for a given air change.

COMPUTATIONS

Heat Balance and Air Change with Space Heaters

Equations (1) through (12) were used in computing the results of all heat tests conducted using the space heaters as a source of heat. To simplify this work, computation sheets based on the equations were developed. Examples of these are shown in Figs. 74, 75 and 76 which also show a complete test computed.

Heat Balance and Air Change with Electric Heater

Equations (6) through (15) were used in computing the results of all heat tests conducted using the electric heaters as a source of heat. To simplify this work, the computation sheets used for the space heater tests were modified. Examples of these are shown in Figs. 77 and 78 which also show a complete test computed.

Fuel Consumption for Specific Air Changes

Equation (16) was used in converting the fuel consumption for an observed air change to the quantity required for a specific air change.

For example, at an outside temperature of -20°F, with natural circulation of warm air within the hut and changing the air 1.43 times per hour, Table 1 shows that 3.88 pounds of fuel per hour were required, 10,240 cubic feet of ventilation air passed through the building per hour of which 3,153 cubic feet passed through the ventilators taking a total of 4,583 Btu's of heat with it. To determine the quantity of fuel required to support one air change per hour,

DOUGLAS ARCTIC HUT - WORK SHEET
PGO HA1-000 01A

Page 1

H. T. No. 5   Test Period: 0350 to 1115 on 15 MAR 1949

Part C   Test Time: 7.417 hours   Outside Temperature -20 °F

Item 1. **Total Heat Input per Hour:**

Column 1 Stoves	Column 2 Total Liters Burned (1)	Column 3 Weight one Liter at -20°F (lbs)	Column 4 Total Weight Fuel Burned (lbs) Col. 2 x 3	Column 5 Test Time (hrs)	Column 6 Fuel Burned Per Hour (lbs) Col. 4 ÷ 5	Column 7 Heat Value Lb of Fuel (Btu's)	Column 8 Heat Input Per Hour (Btu/hr) Col. 6 x 7
1	5.270	1.894	9.981	7.417	1.35	18,160	24,516
2	10.820	1.894	20.493	7.417	2.76	18,160	50,122
Total	16.090	1.894	30.474	7.417	4.11	18,160	74,638

Item 2. **Measured Heat Loss per Hour Through Ventilators and Stacks:** *

Column 1	Column 2 Heat Loss per Hour (Btu/hr)	Column 3 Total Losses (Btu/hr)
Vent No. 1	2381	
Vent No. 2	2760	
Sub Total		5141
Stack No. 1	12649	
Stack No. 2	21293	
Sub Total		33942
Total Heat Loss		39083

Item 3. **Heat Loss through Structure per Hour:**

(a) Heat input/hr (Item No. 1) 74638 Btu/hr

(b) Measured Heat, Loss/hr (Item No. 2) 39083 Btu/hr

(c) Heat loss through Structure 35555 Btu/hr

* See computation sheets on Ventilator and Stack Losses. (See Figs. 75 and 76)

Item 4. **Heat Transferred through Structure per Hour per Square Foot and Average U Factor:**

(a) Exposed surface area of Hut: 2989 square feet.

(b) Outside temperature: -20 °F, Inside Temperature: 69 °F, Δt = 89 °F.

(c) Heat transferred per square foot: $\frac{\text{Btu loss/hr}}{\text{Exposed surface area}}$ equals $\frac{35555}{2989}$ Btu/hr ft^2 = 11.90

(d) Average U factor: $\frac{\text{Btu/hr ft}^2}{\Delta t}$: $\frac{11.90}{89}$ equals 0.134 Btu/hr ft^2 °F.

Item 5. **Fresh Air Changes per Hour:**

(a) Volume of main room: 7160 cubic feet.

(b) Volume of air required for combustion per pound of fuel burned: 261 cubic feet.

(c) Total volume air exhausted per hour. (See computation sheets on Ventilator and Stack Losses) (See Figs. 75 and 76)

Vent No. 1	1797	cu ft/hr
Vent No. 2	1708	cu ft/hr
Stack No. 1	3439	cu ft/hr
Stack No. 2	4760	cu ft/hr
Total	11704	cu ft/hr

(d) Combustion air required: 216 cu ft/lb fuel x 4.11 lbs equals 888 cu ft.

(e) Breathing air supplied: exhausted air minus combustion air equals 11704 minus 888 equals 10816 cu ft/hr.

(f) Air changes per hour: $\frac{\text{breathing air}}{\text{vol. of main room}}$ equals $\frac{10816}{7160}$ equals 1.51 air changes per hour.

Item 6. **Measured Heat Losses as Determined by U Factors Established for Panels:**

Panels	Location	Area	x U factor	=	x Temperature Differential	= Btu/hr	Btu/hr
(a) Wall	Main Room	828	x 0.164	= 135.79	x ~~72 - (-20)~~ or 92	= 12493	
	Vestibule	222	x 0.164	= 36.41	x ~~44 - (-20)~~ or 64	= 2330	Sub Total = 14823
(b) Roof	Main Room	887	x 0.097	= 86.04	x ~~77 - (-20)~~ or 97	= 8346	
	Vestibule	80	x 0.097	= 7.76	x ~~50 - (-20)~~ or 70	= 543	Sub Total = 8889
(c) Floor	Main Room	883	x 0.094	= 83.00	x ~~52 - (-20)~~ or 72	= 5976	
	Vestibule	80	x 0.094	= 7.52	x ~~34 - (-20)~~ or 54	= 406	Sub Total = 6382
(d) Windows	Main Room	8.53	x 0.332	= 2.83	x ~~72 - (-20)~~ or 92	= 260	
	Vestibule	1.97	x 0.332	= 0.65	x ~~44 - (-20)~~ or 64	= 42	Sub Total = 302

Total Measured Heat Loss Transfered through Panels - 30396

Item 7. **Percent of Measured Losses to Total Loss Transfered through structure:**

$\frac{\text{Btu/hr measured losses}}{\text{Btu/hr total losses transfered through structure}}$ x 100 = $\frac{30396}{35555}$ x 100 = 85 %

Fig 74. EXAMPLE OF TRIAL HEAT BALANCE USING SPACE HEATERS.

Page No. 2 | DOUGLAS ARCTIC HUT - WORK SHEET - STACK LOSSES | Date 1 JUNE 1949
H. T. No. 5 | PGO HA1-000 01A | Computer R.D. SCOTT
Part No. C | Stack No. 1 | Checker E.H.M.

Obs. No.	Density	x Velocity Pressure		Lbs. of Air (chart)	x Sp. Ht.	x Temperature Differential	= Btu/hr
1	1.324 x 30.4 / (252 + 460 or 712) = 0.057	x ~~1.74~~ or 0.021	= .0012	= 201	x 0.24	x ~~252 - (-20)~~ or 272	= 13121.
2	1.324 x 30.4 / (237 + 460 or 697) = 0.058	x ~~1.85~~ or 0.024	= .0014	= 217	x 0.24	x ~~237 - (-20)~~ or 257	= 13385.
3	1.324 x 30.5 / (266 + 460 or 726) = 0.056	x ~~2.47~~ or 0.030	= .0017	= 240	x 0.24	x ~~266 - (-20)~~ or 286	= 16473
4	1.324 x 30.6 / (248 + 460 or 708) = 0.057	x ~~1.85~~ or 0.024	= .0014	= 217	x 0.24	x ~~248 - (-20)~~ or 268	= 13957
5	1.324 x 30.6 / (259 + 460 or 719) = 0.056	x ~~1.29~~ or 0.015	= .0008	= 167	x 0.24	x ~~259 - (-20)~~ or 279	= 11182.
6	1.324 x 30.6 / (248 + 460 or 708) = 0.057	x ~~1.31~~ or 0.016	= .0009	= 177	x 0.24	x ~~248 - (-20)~~ or 268	= 11385.
7	1.324 x 30.7 / (223 + 460 or 683) = 0.060	x ~~0.92~~ or 0.011	= .0007	= 155	x 0.24	x ~~222 - (-20)~~ or 243	= 9040.

7/.401 Average .057 | 7/1374 Average 196 | 7/88543 Average 12649

$AIR = \frac{196}{.057} = 3439$ cu. ft./hr

Page No. 3 | DOUGLAS ARCTIC HUT - WORK SHEET - STACK LOSSES | Date 2 JUNE 1949
H. T. No. 5 | PGO HA1-000 01A | Computer SCOTT
Part No. C | Stack No. 2 | Checker EHM

Obs. No.	Density	x Velocity Pressure		Lbs. of Air (chart)	x Sp. Ht.	x Temperature Differential	= Btu/hr
1	1.324 x 30.4 / (374 + 460 or 834) = 0.048	x ~~2.81~~ or 0.034	= .0016	= 233	x 0.24	x ~~374 - (-20)~~ or 394	= 22033
2	1.324 x 30.4 / (338 + 460 or 798) = 0.050	x ~~3.01~~ or 0.036	= .0018	247	x 0.24	x ~~338 - (-20)~~ or 358	21222
3	1.324 x 30.5 / (383 + 460 or 843) = 0.048	x ~~2.12~~ or 0.025	= .0012	= 202	x 0.24	x ~~383 - (-20)~~ or 403	= 19537.
4	1.324 x 30.6 / (370 + 460 or 830) = 0.049	x ~~2.39~~ or 0.029	= .0014	= 218	x 0.24	x ~~370 - (-20)~~ or 390	= 20405
5	1.324 x 30.6 / (369 + 460 or 829) = 0.049	x ~~1.97~~ or 0.024	= .0012	= 202	x 0.24	x ~~369 - (-20)~~ or 389	= 18859
6	1.324 x 30.6 / (302 + 460 or 762) = 0.053	x ~~2.97~~ or 0.036	= .0019	= 254	x 0.24	x ~~302 - (-20)~~ or 322	= 19629
7	1.324 x 30.7 / (349 + 460 or 809) = 0.050	x ~~4.04~~ or 0.055	= .0028	= 309	x 0.24	x ~~349 - (-20)~~ or 369	= 27365

7/.347 Average .050 | 7/1665 Average 238 | 7/149050 Average 21293

$AIR = \frac{238}{.050} = 4760$ cu. ft./hr

Fig 75. COMPUTATIONS OF HEAT LOSSES THROUGH STACKS SUPPORTING COMPUTATIONS CONTAINED IN FIG. 74.

Page No. 4 | **DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES** | Date 2 JUNE, 1949

H. T. No. 5 | PGC HA1-000 01A | Computer R. D. SCOTT

Part No. C | Vent No. 1 | Checker E. H. M.

Obs. No.	Cu ft / Min	x 60 min x area	= cu ft/hr	x Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	92	x 18.42	1695	x 0.078	x ~~50 - (-20)~~ or 70	x 0.24	2221
2	82	x 18.42	1510	x 0.078	x ~~50 - (-20)~~ or 70	x 0.24	1979
3	93	x 18.42	1713	x 0.078	x ~~51 - (-20)~~ or 71	x 0.24	2277
4	96	x 18.42	1768	x 0.078	x ~~50 - (-20)~~ or 70	x 0.24	2317
5	105	x 18.42	1934	x 0.078	x ~~52 - (-20)~~ or 72	x 0.24	2607
6	117	x 18.42	2155	x 0.078	x ~~50 - (-20)~~ or 70	x 0.24	2824
7	98	x 18.42	1805	x 0.078	x ~~52 - (-20)~~ or 72	x 0.24	2440

7) 12580 — Average 1797

7) 16,665 — Average 2381

* Density equals lbs/cu ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{50 + 460}$ equals $\frac{39.72}{510}$ equals 0.078.

Page No. 5 | **DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES** | Date 2 JUNE 1949

H. T. No. 5 | PGC HA1-000 01A | Computer R. D. SCOTT

Part No. C | Vent No. 2 | Checker E. H. M.

Obs. No.	Cu ft / Min	x 60 min x area	= cu ft/hr	x Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	92	x 18.42	1695	x 0.075	x ~~69 - (-20)~~ or 89	x 0.24	2715
2	70	x 18.42	1289	x 0.075	x ~~68 - (-20)~~ or 88	x 0.24	2042
3	97	x 18.42	1787	x 0.075	x ~~72 - (-20)~~ or 92	x 0.24	2959
4	98	x 18.42	1805	x 0.075	x ~~76 - (-20)~~ or 96	x 0.24	3119
5	101	x 18.42	1860	x 0.075	x ~~67 - (-20)~~ or 87	x 0.24	2913
6	94	x 18.42	1731	x 0.075	x ~~66 - (-20)~~ or 86	x 0.24	2680
7	97	x 18.42	1787	x 0.075	x ~~70 - (-20)~~ or 90	x 0.24	2895

7) 11954 — Average 1708

7) 19323 — Average 2760

* Density equals lbs/cu ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{70 + 460}$ equals $\frac{39.72}{530}$ equals 0.075.

Fig 76. COMPUTATIONS OF HEAT LOSSES THROUGH STACKS SUPPORTING COMPUTATIONS CONTAINED IN FIG. 74.

DOUGLAS ARCTIC HUT - WORK SHEET
EGO HA1-000 G1A

Page 1

H. T. No. 10 — Electric Heat Test
Test Period: 1510 to 1550 on 7 APRIL 1949

Part C   Test Time: 10 Minutes   Outside Temperature -40 °F

Item 1. Total Heat Input per Hour:

Column 1 Stoves	Column 2 Total Liters Burned (l)	Column 3 Weight one Liter at ___ °F (lbs)	Column 4 Total Weight Fuel Burned (lbs) Col. 2 x 3	Column 5 Test Time (hrs)	Column 6 Fuel Burned Per Hour (lbs) Col. 4 ÷ 5	Column 7 Heat Value Lb of Fuel (Btu's)	Column 8 Heat Input Per Hour (Btu/hr) Col. 6 x 7
1	Not Applicable						
2	Not Applicable						
Total	Not Applicable						

Item 2. Measured Heat Loss per Hour Through Ventilators and Stacks: *

	Column 1	Column 2 Heat Loss per Hour (Btu/hr)	Column 3 Total Losses (Btu/hr)
	Vent No. 1	1901	
	Vent No. 2	3713	
Sub Total			5614
	Stack No. 1	2444	
	Stack No. 2	2444	
Sub Total			4888
Total Heat Loss			10502

Item 3. Heat Loss through Structure per Hour:

(a) Heat input/hr (Item No. 1) 55346 [1] Btu/hr

(b) Measured Heat, Loss/hr (Item No. 2) 10502 Btu/hr

(c) Heat loss through Structure 44844 Btu/hr

* See computation sheets on Ventilator and Stack Losses.
[1] See Sheet #4   (See Fig. 78)

Item 4. Heat Transferred through Structure per Hour per Square Foot and Average U Factor:

(a) Exposed surface area of Hut: 2989 square feet.

(b) Outside temperature: -40 °F, Inside Temperature: +71 °F, Δt = 111 °F.

(c) Heat transferred per square foot: $\frac{\text{Btu loss/hr}}{\text{Exposed surface area}}$ equals $\frac{44844}{2989}$ Btu/hr ft². = 15.00

(d) Average U factor: $\frac{\text{Btu/hr ft}^2}{\Delta t}$: $\frac{15.00}{111}$ equals 0.135 Btu/hr ft² °F.

Item 5. Fresh Air Changes per Hour:

(a) Volume of main room: 7160 cubic feet.

(b) Volume of air required for combustion per pound of fuel burned: 261 cubic feet.

(c) Total volume air exhausted per hour. (See computation sheets on Ventilator and Stack Losses) (See Fig. 78)

Vent No. 1 1253 cu ft/hr
Vent No. 2 1787 cu ft/hr
Stack No. 1 1176 cu ft/hr
Stack No. 2 1176 cu ft/hr
Total 5392 cu ft/hr

(d) Combustion air required: 216 cu ft/lb fuel x 0 lbs equals 0 cu ft.

(e) Breathing air supplied: exhausted air minus combustion air equals 5392 minus 0 equals 5392 cu ft/hr.

(f) Air changes per hour: $\frac{\text{breathing air}}{\text{vol. of main room}}$ equals $\frac{5392}{7160}$ equals 0.75 air changes per hour.

Item 6. Measured Heat Losses as Determined by U Factors Established for Panels:

Panels	Location	Area	x U factor	=	x Temperature Differential	= Btu/hr	Btu/hr
(a) Wall	Main Room	828	x 0.164	= 135.79	x ~~76 - (-40)~~ or 116	= 15752	
	Vestibule	222	x 0.164	= 36.41	x ~~36 - (-40)~~ or 76	= 2767 Sub Total	= 18519
(b) Roof	Main Room	887	x 0.097	= 86.04	x ~~77 - (-40)~~ or 117	= 10067	
	Vestibule	80	x 0.097	= 7.76	x ~~40 - (-40)~~ or 80	= 621 Sub Total	= 10688
(c) Floor	Main Room	883	x 0.094	= 83.00	x ~~48 - (-40)~~ or 88	= 7304	
	Vestibule	80	x 0.094	= 7.52	x ~~25 - (-40)~~ or 65	= 489 Sub Total	= 7893
(d) Windows	Main Room	8.53	x 0.332	= 2.83	x ~~76 - (-40)~~ or 116	= 328	
	Vestibule	1.97	x 0.332	= 0.65	x ~~36 - (-40)~~ or 76	= 49 Sub Total	= 377

Total Measured Heat Loss Transfered through Panels - - - - - - - - - - - - - - - - 37477

Item 7. Percent of Measured Losses to Total Loss Transfered through structure:

$\frac{\text{Btu/hr measured losses}}{\text{Btu/hr total losses transfered through structure}}$ x 100 = $\frac{37477}{44844}$ x 100 = 84 %

Fig 77. EXAMPLE OF TRIAL HEAT BALANCE USING ELECTRIC HEATERS.

Page 2 DOUGLAS ARCTIC HUT - WORK SHEET (Con't)
FGO HA1-000 01A

H. T. No. 10 Electric Test

Part C

Btu input - .73 x Amps x Volts = Watts x 3.4126 = Btu's

(a) Elec. Heater 1.73 x 19.5 x 460 = 15518.1 x 3.4126 = 52957

(b) Lights --- --- --- 700.0 x 3.4126 = 2389

162181 x 3.4126 = 55346

Page No. 3 DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES
FGO HA1-000 01A

Date 15 JUNE 49

H. T. No. 10 - ELEC. HEATER

Computer EHM

Part No. C

Vent No. 1

Checker CFM

Obs. No.	Cu ft Min	x 60 min x area	= cu ft/hr	Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	68	x 18.42	1253	x 0.079	x ~~40 - (-40)~~ or 80	x 0.24	1901
		Average	1253			Average	1901

* Density equals lbs/sq ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{40 + 460}$ equals $\frac{39.72}{502}$ equals 0.079.

Page No. 4 DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES
FGO HA1-000 01A

Date 15 June 49

H. T. No. 10 ELEC. HEATER

Computer EHM

Part No. C

Vent No. 2

Checker CFM

Obs. No.	Cu ft Min	x 60 min x area	= cu ft/hr	Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	97	x 18.42	1787	x 0.074	x ~~77 - (-40)~~ or 117	x 0.24	3713
		Average	1787			Average	3713

* Density equals lbs/sq ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{77 + 460}$ equals $\frac{39.72}{537}$ equals 0.074.

Page No. 5 DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES
FGO HA1-000 01A

Date 15 June 49

H. T. No. 10 ELEC. HEATER

Computer EHM

Part No. C

STACK No. 1

Checker CFM

Obs. No.	Cu ft Min	x 60 min x area	= cu ft/hr	Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	100	x ~~18.42~~ 11.76	1176	x 0.074	x 77 - (-40) or 117	x 0.24	2444
		Average	1176			Average	2444

* Density equals lbs/sq ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{77 + 460}$ equals $\frac{39.72}{537}$ equals 0.074.

Page No. 6 DOUGLAS ARCTIC HUT - WORK SHEET - VENT LOSSES
FGO HA1-000 01A

Date 15 June 49

H. T. No. 10 ELEC. HEATER

Computer EHM

Part No. C

STACK No. 2

Checker CFM

Obs. No.	Cu ft Min	x 60 min x area	= cu ft/hr	Density *	x Temperature Differential	x Sp. Ht.	= Btu/hr
1	100	x 11.76	1176	x 0.074	x 77 - (-40) or 117	x 0.24	2444
		Average	1176			Average	2444

* Density equals lbs/sq ft equals $\frac{1.324 \times 30}{F + 460}$ equals $\frac{39.72}{77 + 460}$ equals $\frac{39.72}{537}$ equals 0.074.

Fig 78. COMPUTATIONS SUPPORTING TRIAL HEAT BALANCE IN FIG. 77.

7,160 cubic feet of air, the data found in Table 1 was substituted in equation (16) as follows:

$$F_{AC} = 3.88 - \frac{\frac{10240 - 7160}{3153} \times 4583}{18160}$$

$$= 3.88 - 0.25$$

$$= 3.63 \text{ pounds per hour}$$

To check the results of this question, curves, plotting fuel consumption against air changes, were constructed for all the tests conducted at a given outside temperature and the fuel required for a specific air change scaled. Fig, 79 illustrates the curves constructed for an outside temperature of -20°F. Scaling the fuel required to support one air change per hour with natural circulation of warm air gives 3.63 pounds per hour. This result checks that obtained in the computed example above.

Delineation of Heat Losses for Specific Air Changes

Equations (16) through (20) were used to delineate the heat losses for a specific air change.

For example, to determine the losses for one air change per hour, 7160 cubic feet of ventilation air, with natural circulation of the warm air at -20°F the test giving 1.43 air changes per hour was used. From the example above 3.63 pounds of fuel per hour was required and Table 1 shows that a temperature difference between the average inside air and outside air of 89°F was observed while the ventilators were passing 3,153 cubic feet of air per hour and removing 4,583

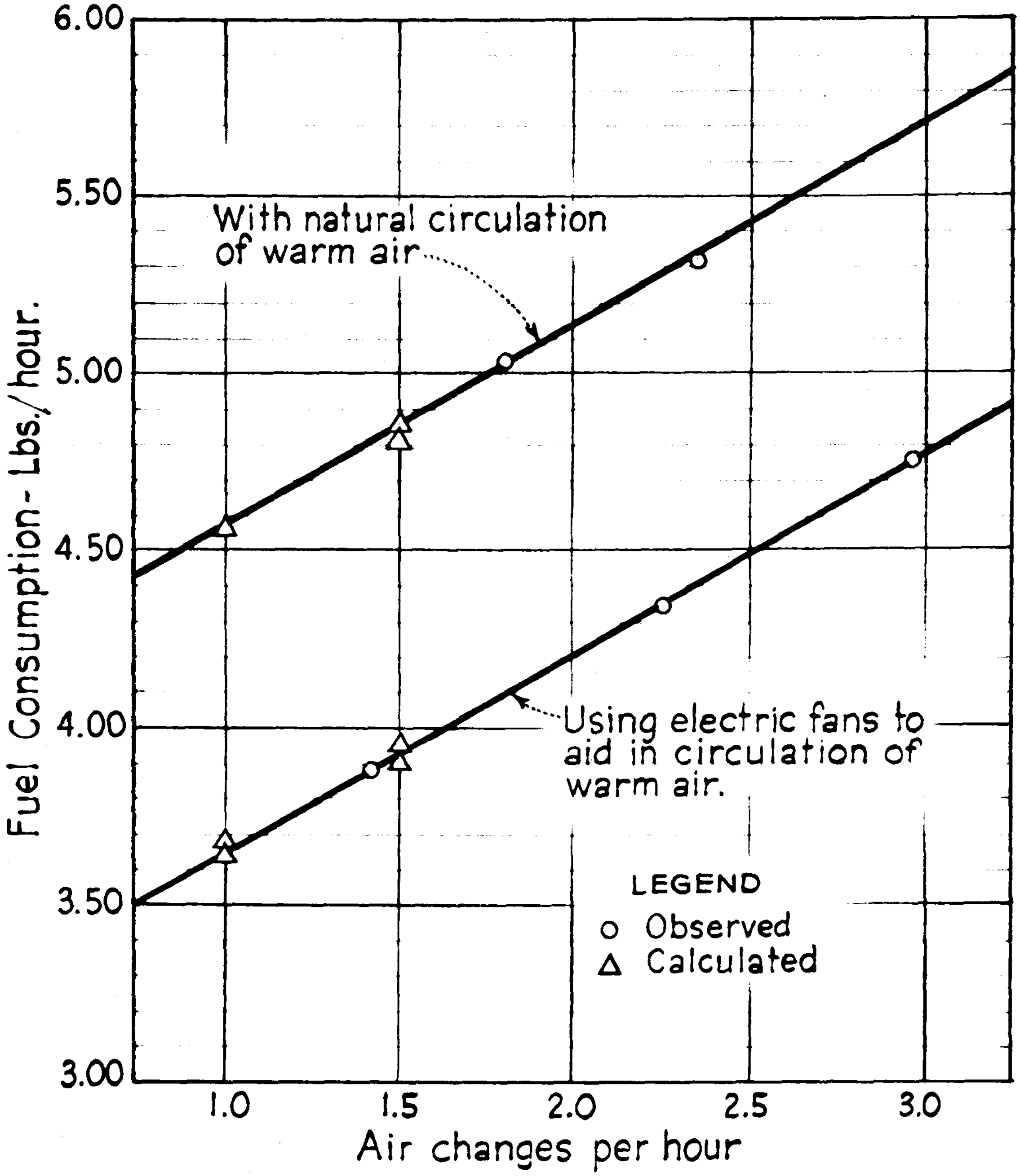

Fig. 79. RELATION OF FUEL CONSUMPTION TO AIR CHANGES PER HOUR AT AN OUTSIDE TEMPERATURE OF −20°F WITH NO WIND. DATA BASED ON HEATERS OPERATING AT 60% EFFIENCY, BURNING SPEC. AN-F-32a, GRADE JP-1 FUEL.

Btu's of heat with it. Fig. 37 shows that a heat transmission coefficient (U) of 0.129 for the hut as a whole was established. Substituting this information in the equations finds the:

<u>Heat input</u> = Q_{AC}

$$Q_{AC} = 3.63 \times 18160 \tag{17}$$

$$= 65921 \text{ Btu's per hour.}$$

<u>Heat loss through structure</u> = Q_{TAC}

$$Q_{TAC} = 89 \times 0.129 \times 2989 \tag{18}$$

$$= 34317 \text{ Btu's per hour.}$$

<u>Heat loss through ventilation air</u> = Q_{VAC}

$$Q_{VAC} = \frac{7160 \times 4583}{3153} \tag{19}$$

$$= 10400 \text{ Btu's per hour.}$$

<u>Heat loss through combustion air</u> = Q_{CAC}

$$Q_{CAC} = 65921 - (34317 + 10400) \tag{20}$$

$$= 21204 \text{ Btu's per hour.}$$

Table 5. TEMPERATURE DISTRIBUTION IN NAVY ARCTIC HUT (MARK I) AT OUTSIDE TEMPERATURES FROM -20°F to -65°F.

Observations made during Climatic Hangar tests heating the hut with two 50,000-Btu, oil-fired space heaters and changing the ventilating air more than twice each hour, and with a 15-kw, forced-air electric heater and changing the air less than once each hour.

Location	OUTSIDE TEMPERATURE -20°F						OUTSIDE TEMPERATURE -40°F						OUTSIDE TEMPERATURE -65°F					
		Living Quarters						Living Quarters						Living Quarters				
	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F
OBSERVED TEMPERATURES WITH NATURAL CIRCULATION	(2.4 Air Changes Per Hour)						(2.2 Air Changes Per Hour)											
2" above floor	--	57	63	60	59	6	--	56	60	57	57	3			NOT OBSERVED			
30" above floor	--	67	71	71	70	4	--	66	70	68	68	4						
60" above floor	42	82	85	85	83	3	48	83	84	84	84	1						
84" above floor	--	89	92	107	97	18	--	92	101	105	99	13						
98" above floor	59	91	105	112	102	21	61	97	100	107	101	10						
Floor surface	--	--	--	--	61	--	--	--	--	--	57	--						
Wall surface	--	--	--	--	71	--	--	--	--	--	63	--						
Roof surface	--	--	--	--	88	--	--	--	--	--	74	--						
Under hut	--	-19	--	-18	-19	--	--	-41	--	-40	-40	--						
Foundation Beam	--	--	--	--	-18	--	--	--	--	--	-41	--						
Temperature Differences																		
2" to 60" level	--	25	22	25	24	--	--	27	24	27	27	--			NOT OBSERVED			
2" to 98" level	--	34	42	52	43	--	--	41	40	50	44	--						
OBSERVED TEMPERATURES USING FANS TO AID CIRCULATION	(2.3 Air Changes Per Hour)																	
2" above floor	--	55	58	55	56	3			NOT OBSERVED						NOT OBSERVED			
30" above floor	--	69	71	69	69	2												
60" above floor	43	72	75	75	74	3												
84" above floor	--	74	78	78	76	4												
98" above floor	51	73	80	79	77	7												
Floor surface	--	--	--	--	54	--												
Wall surface	--	--	--	--	66	--												
Roof surface	--	--	--	--	--	--												
Under hut	--	-20	--	-16	-18	--												
Foundation Beam	--	--	--	--	-17	--												
Temperature Differences																		
2" to 60" level	--	17	17	20	18	--			NOT OBSERVED						NOT OBSERVED			
2" to 98" level	--	18	22	24	21	--												

Table 5. (CONTINUED) TEMPERATURE DISTRIBUTION

Location	OUTSIDE TEMPERATURE -20°F						OUTSIDE TEMPERATURE -40°F						OUTSIDE TEMPERATURE -65°F					
		Living Quarters						Living Quarters						Living Quarters				
	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F
OBSERVED TEMPERATURES WITH NATURAL CIRCULATION (4.1 Air Changes Per Hour)																		
2" above floor	NOT OBSERVED						--	54	56	51	54	5	NOT OBSERVED					
30" above floor							--	67	71	69	69	4						
60" above floor							36	86	91	87	88	5						
84" above floor							--	96	105	110	103	14						
98" above floor							61	102	103	114	107	12						
Floor surface							--	--	--	--	50	--						
Wall surface							--	--	--	--	64	--						
Roof surface							--	--	--	--	86	--						
Under hut							--	-39	--	-38	-39	--						
Foundation Beam							--	--	--	--	-39	--						
Temperature Differences																		
2" to 60" level	NOT OBSERVED						--	32	35	36	34	--	NOT OBSERVED					
2" to 98" level							--	48	47	63	53	--						
OBSERVED TEMPERATURES USING FANS TO AID CIRCULATION	(3.0 Air Changes Per Hour)						(3.9 Air Changes Per Hour)						(4.3 Air Changes Per Hour)					
2" above floor	--	47	57	50	50	10	--	45	49	40	44	9	--	19	34	25	24	15
30" above floor	--	71	72	71	71	1	--	68	71	69	69	3	--	69	72	70	70	3
60" above floor	41	75	78	78	77	3	34	76	79	76	76	3	20	77	79	80	78	3
84" above floor	--	75	81	81	78	6	--	77	81	76	78	5	--	76	80	83	79	7
98" above floor	51	75	83	76	77	8	46	76	81	80	79	5	37	76	79	82	79	6
Floor surface	--	--	--	--	54	--	--	--	--	--	45	--	--	--	--	--	31	--
Wall surface	--	--	--	--	61	--	--	--	--	--	60	--	--	--	--	--	57	--
Roof surface	--	--	--	--	75	--	--	--	--	--	76	--	--	--	--	--	73	--
Under hut	--	-19	--	-18	-19	--	--	-40	--	-40	-40	--	--	-68	--	-66	-67	--
Foundation Beam	--	--	--	--	-19	--	--	--	--	--	-40	--	--	--	--	--	-67	--
Temperature Differences																		
2" to 60" level	--	28	21	28	27	--	--	31	30	36	32	--	--	58	45	55	54	--
2" to 98" level	--	28	26	26	27	--	--	31	32	40	35	--	--	57	45	57	55	--

Table 5. (CONTINUED) TEMPERATURE DISTRIBUTION

Location	OUTSIDE TEMPERATURE -20°F	Living Quarters					OUTSIDE TEMPERATURE -40°F	Living Quarters					OUTSIDE TEMPERATURE -65°F	Living Quarters				
	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F	Vestibule °F	Entr. End °F	Center °F	Far End °F	Average °F	Max. temp. diff. °F
OBSERVED TEMPERATURES WITH NATURAL CIRCULATION																		
2" above floor 30" above floor 60" above floor 84" above floor 98" above floor Floor surface Wall surface Roof surface Under hut Foundation Beam	NOT OBSERVED						NOT OBSERVED						NOT OBSERVED					
Temperature Differences																		
2" to 60" level 2" to 98" level	NOT OBSERVED						NOT OBSERVED						NOT OBSERVED					
OBSERVED TEMPERATURES USING FANS TO AID CIRCULATION							(0.7 Air Changes Per Hour)						(0.6 Air Changes Per Hour					
2" above floor	NOT OBSERVED						--	50	50	45	48	5	--	34	33	28	31	6
30" above floor							--	72	75	73	73	3	--	57	61	59	59	4
60" above floor							36	77	78	79	78	2	21	62	64	64	63	2
84" above floor							--	78	79	80	79	2	--	63	66	66	65	3
98" above floor							40	76	74	80	77	6	20	62	60	66	63	6
Floor surface							--	--	--	--	64	--	--	--	--	--	40	--
Wall surface							--	--	--	--	57	--	--	--	--	--	41	--
Roof surface							--	--	--	--	70	--	--	--	--	--	52	--
Under hut							--	-41	--	-41	-41	--	--	-67	--	-67	-67	--
Foundation Beam							--	--	--	--	-41	--	--	--	--	--	-67	--
Temperature Differences																		
2" to 60" level	NOT OBSERVED						--	27	28	34	30	--	--	28	31	36	32	--
2" to 98" level							--	26	24	35	29	--	--	28	27	38	32	--

TEMPERATURE DISTRIBUTION

Table 5 is included to show the average temperatures obtained at the five levels in the living quarters at air changes greater than the minimums obtained during the tests. Inside floor, wall and roof surface temperatures, the air temperatures under the hut and the surface temperature of the bottom of the foundation beam are also given.

PHYSIOLOGICAL STUDIES

Ventilation Requirements

To determine the ventilation requirements for designated air changes in pounds per hour, establishment of average air densities was made for the air being exhausted through the ventilators. With this data volume of air required per hour for a definite air change could be converted to pounds per hour. From a study of the temperatures of the air being exhausted from the building under observed conditions, densities for 1, 2 and 3 air changes per hour were established for each outside test temperature. Based on these densities, the pounds of ventilation required air per hour for each condition is shown in Table 6.

Maximum Obtainable Relative Humidity

The maximum obtainable relative humidity within the hut for a given set of conditions was based on two factors. The first was the amount of moisture obtainable from the outside air and the second was the amount of moisture each occupant would deliver.

Saturated outside air would deliver the maximum amount of moisture and all studies were based on this condition. The actual quantity of moisture per pound of dry air for each condition studied is given in the following table:

Temperature of Air °F	Moisture Content Per pound of dry air Gr.
70	110.28
15	11.82
0	5.58
-20	1.834
-40	0.569
-65	0.11

The moisture delivered to the air per hour by each man was based on the assumption that each one would give off one gram of moisture per minute (8) or 925.8 grains per hour.

Table 6. QUANTITIES OF VENTILATING AIR REQUIRED FOR DESIGNATED AIR CHANGES BASED ON DENSITIES OF THE VENTILATING AIR MEASURED DURING THE CLIMATIC HANGAR TESTS

Air Changes Per Hour		Outside Temp.	Quantity of Ventilation Air Required	
			Natural Circulation	Using Electrical fans to Aid Circulation
No.	Cu. Ft.	°F	lbs/hr	lbs/hr
1	7160	15	530.56	538.43
2	10740		805.50	810.87
3	21480		1632.48	1632.48
1	7160	0	535.57	540.58
2	10740		810.87	814.09
3	21480		1638.92	1641.07
1	7160	-20	533.42	544.88
2	10740		809.80	820.54
3	21480		1641.07	1649.66
1	7160	-40	527.69	547.02
2	10740		799.06	823.76
3	21480		1615.30	1658.26
1	7160	-65	536.28	553.47
2	10740		811.94	835.50
3	21480		1636.78	1681.88

APPENDIX D

Structural Adequacy Test Data

Table 7. DEFLECTION OF FLOOR PANELS AT VARIOUS OUTSIDE TEMPERATURES

Panels under observation and adjacent panels were loaded in increments to the design load of 75 lbs/ft^2 at various outside temperatures and the deflection was read with the inside of the hut at 70°F. Data from gages on opposite panels were graphically adjusted to obtain the mean deflection. All gages were located on the longitudinal centerline of the panels. Upward movement is prefixed with a minus sign.

ONE FOOT FROM OUTSIDE FOUNDATION BEAM

Load	70°F Outside Temperature			15°F Outside Temperature			0°F Outside Temperature			-20°F Outside Temperature			-40°F Outside Temperature			-65°F Outside Temperature		
	Deflection			Deflection			Deflection			Deflection			Deflection			Deflection		
	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean
	Gage D-19	Gage D-24		Gage D-19	Gage D-24		Gage D-19	Gage D-24		Gage D-19	Gage D-24		Gage D-19	Gage D-24		Gage D-19	Gage D-24	
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.06	--	--	0.08	--	--	0.10	--	--	0.10	--	--	0.10	--	--	0.15
40	--	--	0.12	--	--	0.15	--	--	0.18	--	--	0.18	--	--	0.18	--	--	0.23
43.33	0.15	0.10	--	0.17	0.18	--	0.23	0.16	--	0.18	0.15	--	0.20	0.19	--	0.24	0.25	--
60	--	--	0.17	--	--	0.22	--	--	0.24	--	--	0.22	--	--	0.24	--	--	0.28
80	--	--	0.23	--	--	0.30	--	--	0.28	--	--	0.29	--	--	0.28	--	--	0.30
86.67	0.27	0.24	--	0.28	0.37	--	0.33	0.24	--	0.22	0.35	--	0.28	0.30	--	0.30	0.29	--
100.00	0.30	0.26	0.29	0.32	0.40	0.37	0.37	0.25	0.31	0.26	0.39	0.32	0.36	0.36	0.36	0.43	0.46	0.44
Load Removed	0.03	0.01	0.02	0.01	0.02	0.01	0.01	-0.06	-0.03	-0.02	0.04	0.01	0.04	0.01	0.03	-0.02	-0.02	-0.02

CENTER OF PANEL

Load	70°F Outside Temperature			15°F Outside Temperature			0°F Outside Temperature			-20°F Outside Temperature			-40°F Outside Temperature			-65°F Outside Temperature		
	Deflection			Deflection			Deflection			Deflection			Deflection			Deflection		
	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean
	Gage D-20	Gage D-23		Gage D-20	Gage D-23		Gage D-20	Gage D-23		Gage D-20	Gage D-23		Gage D-20	Gage D-23		Gage D-20	Gage D-23	
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.12	--	--	0.13	--	--	0.22	--	--	0.25	--	--	0.23	--	--	0.30
40	--	--	0.23	--	--	0.27	--	--	0.35	--	--	0.37	--	--	0.39	--	--	0.42
43.33	0.22	0.28	--	0.28	0.32	--	0.36	0.36	--	0.38	0.40	--	0.38	0.44	--	0.46	0.42	--
60	--	--	0.33	--	--	0.41	--	--	0.44	--	--	0.43	--	--	0.52	--	--	0.48
80	--	--	0.45	--	--	0.54	--	--	0.51	--	--	0.46	--	--	0.62	--	--	0.51
86.67	0.37	0.58	--	0.56	0.62	--	0.54	0.53	--	0.46	0.50	--	0.61	0.72	--	0.52	0.46	--
100.00	0.46	0.66	0.56	0.67	0.70	0.68	0.63	0.67	0.64	0.54	0.60	0.57	0.73	0.84	0.78	0.70	0.58	0.63
Load Removed	0.03	0.08	0.05	0.03	0.04	0.03	0.06	0.04	0.05	0.07	0.08	0.07	0.13	0.12	0.12	0.04	0.06	0.05

ONE FOOT FROM CENTER FOUNDATION BEAM

Load	70°F Outside Temperature			15°F Outside Temperature			0°F Outside Temperature			-20°F Outside Temperature			-40°F Outside Temperature			-65°F Outside Temperature		
	Deflection			Deflection			Deflection			Deflection			Deflection			Deflection		
	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean	Observed		Mean
	Gage D-21	Gage D-22		Gage D-21	Gage D-22		Gage D-21	Gage D-22		Gage D-21	Gage D-22		Gage D-21	Gage D-22		Gage D-21	Gage D-22	
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.07	--	--	0.08	--	--	0.10	--	--	0.14	--	--	0.13	--	--	0.10
40	--	--	0.15	--	--	0.16	--	--	0.19	--	--	0.23	--	--	0.22	--	--	0.16
43.33	0.18	0.13	--	0.16	0.21	--	0.22	0.18	--	0.22	0.26	--	0.20	0.24	--	0.16	0.18	--
60	--	--	0.22	--	--	0.24	--	--	0.25	--	--	0.29	--	--	0.28	--	--	0.18
80	--	--	0.30	--	--	0.31	--	--	0.29	--	--	0.33	--	--	0.34	--	--	0.20
86.67	0.36	0.30	--	0.32	0.40	--	0.32	0.24	--	0.30	0.36	--	0.34	0.36	--	0.18	0.20	--
100.00	0.40	0.33	0.37	0.36	0.44	0.39	0.37	0.28	0.32	0.32	0.40	0.35	0.42	0.45	0.43	0.28	0.30	0.28
Load Removed	0.07	0.06	0.06	0.03	0.02	0.02	-0.02	-0.06	-0.04	0.00	0.01	0.01	0.04	0.01	0.02	-0.05	-0.05	-0.05

Table 8. DEFLECTION OF THE TRANSVERSE ROOF SUPPORT BEAMS AT OUTSIDE TEMPERATURES FROM 70°F TO -40°F

The six roof panels between the two beams under observation were loaded in increments to the design load of 60 lbs/ft^2 at various outside temperatures and deflection of the beams was read with the inside of the hut at 70°F. Data from gages on the two beams were graphically adjusted to obtain the mean deflection.

ONE FOOT FROM STANCHION SUPPORT

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed		Net	Observed		Net	Observed		Net	Observed		Net	Observed		Net
Per cent	Gage D-27 Ins.	Gage D-32 Ins.	Ins.	Gage D-27 Ins.	Gage D-32 Ins.	Ins.	Gage D-27 Ins.	Gage D-32 Ins.	Ins.	Gage D-27 Ins.	Gage D-32 Ins.	Ins.	Gage D-27 Ins.	Gage D-32 Ins.	Ins.
20		--	0.08		--	0.08		--	0.07		--	0.08		--	0.07
40		--	0.16		--	0.15		--	0.14		--	0.15		--	0.15
54.17	NOT	0.21	--	NOT	0.20	--	NOT	0.21	--	NOT	0.21	--	NOT	0.20	--
60		--	0.24		--	0.23		--	0.22		--	0.23		--	0.23
80	OBSERVED	--	0.32	OBSERVED	--	0.30	OBSERVED	--	0.30	OBSERVED	--	0.27	OBSERVED	--	0.30
81.25		0.35	--		0.30	--		0.33	--		0.27	--		0.28	--
100.00		0.39	0.39		0.34	0.34		0.38	0.38		0.30	0.30		0.40	0.40
Load Removed		0.03	0.03		0.01	0.01		0.00	0.00		0.03	0.03		0.19	0.19

CENTER

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed		Net	Observed		Net	Observed		Net	Observed		Net	Observed		Net
Per cent	Gage D-29 Ins.	Gage D-34 Ins.	Ins.	Gage D-29 Ins.	Gage D-34 Ins.	Ins.	Gage D-29 Ins.	Gage D-34 Ins.	Ins.	Gage D-29 Ins.	Gage D-34 Ins.	Ins.	Gage D-29 Ins.	Gage D-34 Ins.	Ins.
20	--	--	0.18	--	--	0.18	--	--	0.19	--	--	0.19	--	--	0.20
40	--	--	0.36	--	--	0.37	--	--	0.38	--	--	0.38	--	--	0.41
54.17	0.49	0.52	--	0.52	0.50	--	0.50	0.50	--	0.53	0.53	--	0.52	0.57	--
60	--	--	0.55	--	--	0.54	--	--	0.57	--	--	0.57	--	--	0.62
80	--	--	0.74	--	--	0.76	--	--	0.76	--	--	0.76	--	--	0.82
81.25	0.78	0.79	--	0.76	0.78	--	0.76	0.78	--	0.79	0.78	--	0.80	0.84	--
100.00	0.84	0.93	0.90	0.87	0.90	0.89	0.91	0.94	0.93	0.95	0.92	0.93	1.04	1.04	1.04
Load Removed	0.08	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.08	0.04	0.06	0.24	0.20	0.22

ONE FOOT FROM STANCHION SUPPORT

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed		Net	Observed		Net	Observed		Net	Observed		Net	Observed		Net
Per cent	Gage D-31 Ins.	Gage D-36 Ins.	Ins.	Gage D-31 Ins.	Gage D-36 Ins.	Ins.	Gage D-31 Ins.	Gage D-36 Ins.	Ins.	Gage D-31 Ins.	Gage D-36 Ins.	Ins.	Gage D-31 Ins.	Gage D-36 Ins.	Ins.
20	--	--	0.06	--		0.06	--	--	0.08	--	--	0.10	--	--	0.08
40	--	--	0.12	--		0.11	--	--	0.15	--	--	0.18	--	--	0.15
54.17	0.14	0.17	--	0.12	NOT	--	0.16	0.23	--	0.21	0.18	--	0.19	0.20	--
60	--	--	0.18	--		0.15	--	--	0.23	--	--	0.21	--	--	0.24
80	--	--	0.24	--	OBSERVED	0.19	--	--	0.29	--	--	0.25	--	--	0.31
81.25	0.22	0.28	--	0.21		--	0.25	0.35	--	0.30	0.24	--	0.31	0.33	--
100.00	0.25	0.30	0.29	0.24		0.24	0.26	0.41	0.36	0.34	0.25	0.29	0.40	0.43	0.40
Load Removed	0.06	0.03	0.04	0.03		0.03	0.02	0.03	0.03	0.05	0.03	0.04	0.21	0.17	0.19

Table 9. DEFLECTION OF RIDGE ROOF SUPPORT BEAM AT OUTSIDE TEMPERATURES FROM 70°F TO -40°F

The six roof panels supported by the ridge beam under observation were loaded in increments to the design load of 60 lbs/ft^2 at various outside temperatures, and deflection of the beam was read with the inside of the hut at 70°F. The observed deflection was adjusted graphically and the net deflection was obtained by deducting the movement of the two supporting transverse beams (See Table 8).

ONE FOOT FROM THE LEFT SUPPORTING TRANSVERSE BEAM

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed Gage D-37	Adjusted Gage D-37	Net	Observed Gage D-37	Adjusted Gage D-37	Net	Observed Gage D-37	Adjusted Gage D-37	Net	Observed Gage D-37	Adjusted Gage D-37	Net	Observed Gage D-37	Adjusted Gage D-37	Net
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	0.28	--	--	0.23	--	--	0.28	--	--	0.28	--	--	0.26	--
40	--	0.43	--	--	0.44	--	--	0.45	--	--	0.52	--	--	0.52	--
54.17	0.58	0.58	--	0.62	0.62	--	0.60	0.60	--	0.65	0.65	--	0.67	0.67	--
60	--	0.65	--	--	0.65	--	--	0.68	--	--	0.71	--	--	0.77	--
80	--	0.86	--	--	0.87	--	--	0.92	--	--	0.85	--	--	1.02	--
81.25	0.92	0.92	--	0.94	0.94	--	0.94	0.94	--	0.86	.86	--	1.03	1.03	--
100.00	1.06	1.06	--	1.06	1.06	--	1.14	1.14	--	1.16	1.16	--	1.31	1.31	--
Load Removed	0.04	0.04	--	0.05	0.05	--	0.05	0.05	--	0.08	0.08	--	0.25	0.25	--

CENTER

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed Gage D-38	Adjusted Gage D-38	Net	Observed Gage D-38	Adjusted Gage D-38	Net	Observed Gage D-38	Adjusted Gage D-38	Net	Observed Gage D-38	Adjusted Gage D-38	Net	Observed Gage D-38	Adjusted Gage D-38	Net
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	0.35	0.27	--	0.30	0.19	--	0.29	0.17	--	0.30	0.18	--	0.30	0.19
40	--	0.70	0.42	--	0.62	0.30	--	0.59	0.28	--	0.61	0.30	--	0.62	0.28
54.17	0.93	0.93	--	0.83	0.83	--	0.79	0.79	--	0.84	0.84	--	0.85	0.85	--
60	--	1.04	0.51	--	0.93	0.40	--	0.88	0.35	--	0.92	0.36	--	0.94	0.36
80	--	1.34	0.58	--	1.21	0.47	--	1.18	0.42	--	1.20	0.43	--	1.26	0.46
81.25	1.38	1.38	--	1.26	1.26	--	1.21	1.21	--	1.23	1.23	--	1.27	1.27	--
100.00	1.58	1.58	0.68	1.43	1.43	0.55	1.46	1.46	0.54	1.49	1.49	0.46	1.59	1.59	0.52
Load Removed	0.19	0.19	0.13	0.06	0.06	0.02	0.07	0.07	0.03	0.10	0.10	0.04	0.26	0.26	0.04

ONE FOOT FROM THE RIGHT SUPPORTING TRANSVERSE BEAM

Load	70°F Outside Temperature Deflection			15°F Outside Temperature Deflection			0°F Outside Temperature Deflection			-20°F Outside Temperature Deflection			-40°F Outside Temperature Deflection		
	Observed Gage D-39	Adjusted Gage D-39	Net	Observed Gage D-39	Adjusted Gage D-39	Net	Observed Gage D-39	Adjusted Gage D-39	Net	Observed Gage D-39	Adjusted Gage D-39	Net	Observed Gage D-39	Adjusted Gage D-39	Net
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	0.23	--	--	0.23	--	--	0.23	--	--	0.23	--	--	0.24	--
40	--	0.43	--	--	0.47	--	--	0.46	--	--	0.47	--	--	0.47	--
54.17	0.59	0.59	--	0.62	0.62	--	0.61	0.61	--	0.65	0.65	--	0.64	0.64	--
60	--	0.65	--	--	0.68	--	--	0.68	--	--	0.71	--	--	0.73	--
80	--	0.90	--	--	0.84	--	--	0.90	--	--	0.95	--	--	0.97	--
81.25	0.94	0.94	--	0.85	0.85	--	0.94	0.94	--	0.97	0.97	--	0.98	0.98	--
100.00	1.07	1.07	--	1.07	1.07	--	1.12	1.12	--	1.15	1.15	--	1.23	1.23	--
Load Removed	0.02	0.02	--	0.05	0.05	--	0.06	0.06	--	0.08	0.08	--	0.22	0.22	--

Table 10. **DEFLECTION OF ROOF PANELS AT OUTSIDE TEMPERATURES FROM 70°F TO -40°F**

Panels under observation and adjacent panels were loaded in increments to the design load of 60 lbs/ft^2 at various outside temperatures and the deflection was read with the inside of the hut at 70°F. Data from gages opposite panels were adjusted graphically and the net deflections were obtained by deducting the movement of the supporting ridge and transverse beams. All gages were located on the longitudinal centerline of the panels. Upward movement is prefixed with a minus sign (See Tables 8 and 9).

ONE FOOT FROM WALL

Load	70°F Outside Temperature Deflection				15°F Outside Temperature Deflection				0°F Outside Temperature Deflection				-20°F Outside Temperature Deflection				-40°F Outside Temperature Deflection			
	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net
	Gage D-6	Gage D-11			Gage D-6	Gage D-11			Gage D-6	Gage D-11			Gage D-6	Gage D-11			Gage D-6	Gage D-11		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.09	0.03	--	--	0.08	0.07	--	--	0.12	0.10	--	--	0.09	0.07	--	--	0.08	0.06
40	--	--	0.17	0.05	--	--	0.15	0.13	--	--	0.20	0.14	--	--	0.18	0.14	--	--	0.14	0.10
54.17	0.06	0.26	--	--	0.18	0.26	--	--	0.22	0.26	--	--	0.20	0.26	--	--	0.20	0.26	--	--
60	--	--	0.26	0.09	--	--	0.23	0.16	--	--	0.26	0.17	--	--	0.24	0.19	--	--	0.23	0.14
80	--	--	0.35	0.14	--	--	0.30	0.20	--	--	0.32	0.19	--	--	0.32	0.20	--	--	0.32	0.17
81.25	0.22	0.42	--	--	0.26	0.36	--	--	0.28	0.36	--	--	0.28	0.36	--	--	0.28	0.36	--	--
100.00	0.37	0.47	0.43	0.25	0.30	0.46	0.38	0.22	0.30	0.40	0.37	0.22	0.30	0.40	0.36	0.21	0.30	0.40	0.39	0.21
Load Removed	0.05	0.08	0.06	0.05	0.04	0.04	0.04	0.00	0.02	0.04	0.03	0.00	0.04	0.04	0.04	0.00	0.06	0.10	0.08	0.04

CENTER OF PANEL

Load	70°F Outside Temperature Deflection				15°F Outside Temperature Deflection				0°F Outside Temperature Deflection				-20°F Outside Temperature Deflection				-40°F Outside Temperature Deflection			
	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net
	Gage D-7	Gage D-10			Gage D-7	Gage D-10			Gage D-7	Gage D-10			Gage D-7	Gage D-10			Gage D-7	Gage D-10		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.27	0.10	--	--	0.27	0.21	--	--	0.25	0.19	--	--	0.28	0.18	--	--	0.28	0.14
40	--	--	0.54	0.17	--	--	0.53	0.28	--	--	0.51	0.28	--	--	0.56	0.28	--	--	0.53	0.26
54.17	0.68	0.72	--	--	0.70	0.74	--	--	0.68	0.71	--	--	0.71	0.78	--	--	0.72	0.72	--	--
60	--	--	0.82	0.26	--	--	0.78	0.36	--	--	0.75	0.35	--	--	0.83	0.33	--	--	0.79	0.32
80	--	--	1.09	0.37	--	--	1.04	0.41	--	--	1.00	0.41	--	--	1.05	0.40	--	--	1.03	0.36
81.25	1.07	1.12	--	--	1.03	1.08	--	--	1.01	1.05	--	--	1.04	1.08	--	--	1.02	1.04	--	--
100.00	1.24	1.30	1.28	0.49	1.18	1.24	1.21	0.49	1.20	1.25	1.25	0.49	1.24	1.28	1.26	0.48	1.26	1.28	1.27	0.48
Load Removed	0.11	0.10	0.10	0.00	0.02	0.02	0.02	0.00	0.00	0.02	0.01	0.00	0.06	0.06	0.06	0.02	0.10	0.10	0.10	0.06

ONE FOOT FROM SUPPORTING BEAM

Load	70°F Outside Temperature Deflection				15°F Outside Temperature Deflection				0°F Outside Temperature Deflection				-20°F Outside Temperature Deflection				-40°F Outside Temperature Deflection			
	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net	Observed		Mean	Net
	Gage D-8	Gage D-9			Gage D-8	Gage D-9			Gage D-8	Gage D-9			Gage D-8	Gage D-9			Gage D-8	Gage D-9		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.30	-0.09	--	--	0.31	0.09	--	--	0.30	0.05	--	--	0.30	0.01	--	--	0.32	-0.01
40	--	--	0.61	-0.13	--	--	0.61	0.12	--	--	0.60	0.09	--	--	0.60	0.06	--	--	0.63	0.04
54.17	0.78	0.81	--	--	0.84	0.86	--	--	0.81	0.80	--	--	0.82	0.84	--	--	0.86	0.84	--	--
60	--	--	0.91	-0.02	--	--	0.92	0.10	--	--	0.90	0.11	--	--	0.90	0.08	--	--	0.95	0.05
80	--	--	1.21	-0.01	--	--	1.22	0.08	--	--	1.19	0.12	--	--	1.21	0.09	--	--	1.27	0.05
81.25	1.22	1.25	--	--	1.25	1.24	--	--	1.22	1.22	--	--	1.24	1.24	--	--	1.28	1.26	--	--
100.00	1.42	1.46	1.44	0.03	1.42	1.44	1.43	0.13	1.46	1.46	1.46	0.16	1.46	1.48	1.47	0.14	1.59	1.58	1.58	0.13
Load Removed	0.00	0.00	0.00	0.00	0.05	0.06	0.05	0.03	0.07	0.07	0.07	0.04	0.10	0.10	0.10	0.06	0.14	0.14	0.14	0.09

Table 11. DEFLECTION OF TRANSVERSE BEAMS, RIDGE BEAMS AND ROOF PANELS AT A TEMPERATURE OF -65°F

The roof area spanning the beams and panels under observation was loaded in increments to 50 lbs/ft^2 and the deflections were read with the inside of the hut at 70°F. The observed deflections were graphically adjusted and projected to obtain the expected deflection under the 60 lb/ft^2 design load. Net deflections were obtained by deducting the movement of supporting beams and upward movement is prefixed with a minus sign.

Load	Transverse Beam One foot from end Deflection			Ridge Beam One foot from end Deflection			Roof Panel One foot from end Deflection			
	Observed		Mean	Observed	Adjusted	Net	Observed		Mean	Net
	Gage D-27	Gage D-32		Gage D-37	Gage D-37		Gage D-6	Gage D-11		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20		--	0.05	--	0.40		--	--	0.09	0.04
40		--	0.10	--	0.80		--	--	0.18	0.07
50.00	NOT	0.12	--	0.99	0.99		0.12	0.36	--	--
60		--	0.16	--	1.18		--	--	0.27	0.09
80	OBSERVED	--	0.21	--	1.58		--	--	0.36	0.13
83.33		0.22	--	1.62	1.62		0.20	0.50	--	--
100.00		--	0.32	--	1.97		--	--	0.45	0.15
Load Removed		--	0.00	0.08	0.08		0.02	-0.03	0.00	0.00

Load	Transverse Beam Center Deflection			Ridge Beam Center Deflection			Roof Panel Center Deflection			
	Observed		Mean	Observed	Adjusted	Net	Observed		Mean	Net
	Gage D-29	Gage D-34		Gage D-38	Gage D-38		Gage D-7	Gage D-10		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.34	--	0.44	0.09	--	--	0.30	0.11
40	--	--	0.67	--	0.98	0.18	--	--	0.60	0.20
50.00	0.82	0.84	--	1.10	1.10	--	0.70	0.80	--	--
60	--	--	1.00	--	1.32	0.26	--	--	0.90	0.28
80	--	--	1.33	--	1.75	0.35	--	--	1.25	0.36
83.33	1.49	1.34	--	1.82	1.82	--	1.24	1.36	--	--
100.00	--	--	1.66	--	2.20	0.48	--	--	1.67	0.50
Load Removed	0.08	0.06	0.07	0.10	0.10	0.03	0.04	0.03	0.03	-0.04

Load	Transverse Beam One foot from end Deflection			Ridge Beam One foot from end Deflection			Roof Panel One foot from end Deflection			
	Observed		Mean	Observed	Adjusted	Net	Observed		Mean	Net
	Gage D-31	Gage D-36		Gage D-39	Gage D-39		Gage D-8	Gage D-9		
Per cent	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20	--	--	0.07	--	0.37		--	--	0.43	0.02
40	--	--	0.13	--	0.74		--	--	0.86	0.07
50.00	0.16	0.17	--	0.90	0.90		0.06	0.08	--	--
60	--	--	0.20	--	1.10		--	--	1.29	0.10
80	--	--	0.27	--	1.47		--	--	1.73	0.14
83.33	0.33	0.31	--	1.52	1.52		1.76	1.80	--	--
100.00	--	--	0.34	--	1.83		--	--	2.16	0.17
Load Removed	0.00	0.00	0.00	0.08	0.08		0.00	0.00	0.00	0.00

APPENDIX E

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