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NO. 122

# HEAT-RETENTION PROPERTIES OF TENT LINERS

QUARTERMASTER RESEARCH & ENGINEERING CENTER
CLOTHING & ORGANIC MATERIALS DIVISION

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# HEAT-RETENTION PROPERTIES OF TENT LINERS

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# FOREWORD

Since World War II, efforts of the Quartermaster Corps to reduce the cost of heating temporary shelters and to make them more habitable and durable have led to the adoption of specific design and construction features in the Army's general purpose, medium size tents. Studies had shown that these new features would improve the heat-retention characteristics of tents. However, the wide range of test results suggested that heat retention was influenced by certain other factors, such as the environment, the construction of the tent, and the fabric of the liner. These factors had not been adequately analyzed.

The present two-part study was made in order to obtain quantitative data on the effects of environment, tent construction, and liner fabric properties on the heating requirements of Army tents. It covers work accomplished during two testing seasons, February and March 1959, and February and March 1960. Although the Tent, General Purpose, Medium, was selected for this study, it was felt that the results could be applied also to other Army tents of similar construction.

The authors wish to express their appreciation for the support given to the program by Miss Agnes M. Galligan, Dr. Peveril Meigs, Mr. Jack V. Chambers, and Dr. Ivan V. Bennett of the Earth Sciences Division; Dr. Alan H. Woodcock of the Army Research Institute of Environmental Medicine; Lieuts. G. H. Lane and A. L. Handman and the enlisted personnel of the Signal Corps Meteorological Team of this Command; and Mr. C. W. Weikert of the Mechanical Engineering Division.

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# ABSTRACT

This study presents quantitative measurements of the heating requirements of Tents, General Purpose, Medium, under a wide range of windspeeds, nighttime radiation, and outdoor ambient temperatures. It discusses the relation of liner fabric thickness, air permeability, and surface reflectivity to the heating requirements of tents.

While all the liners effected heat savings, it was found that their insulating ability was influenced by windspeed, environmental radiation, and temperature differential. It was also found that a low-ceilinged tent requires less heat than a high-ceilinged tent.

The most practical liner from the standpoint of manufacture and use, and the liner showing the greatest amount of heat savings while maintaining comfort within the tent under all the environmental conditions encountered in this test, was constructed from a lightweight, thick-napped, modacrylic fabric. In this study, approximately 38 percent of heat input, or 4.79 gallons of fuel per tent per day, was saved by the use of this liner.

Although the results suggest that a reflective surface would improve the heat-retention properties of tent liner fabrics, additional research is necessary before a sufficiently durable and practical reflective surface can be provided for Army tents.

Layout of Tents in Phase I Test Area

# HEAT-RETENTION PROPERTIES OF TENT LINERS

## 1. Previous Studies

The maintenance of habitable temperatures in temporary field shelters is important in planning winter military operations. Previous studies (2,3,33,34) have shown that shelter temperatures of 65° to 70°F are the most conducive to a man's well-being, health, and morale. The same studies have shown that, while men can adapt themselves in a few days to shelter temperatures as low as 50°F without ill effects, the increased cost of feeding and clothing men at these lower temperatures may exceed the savings in heating costs.

Military agencies have recognized the need for providing habitable temperatures in tents at a minimum expenditure of fuel and facilities. Studies conducted under their auspices have reported a wide range of heat savings (from 25 to 64%) by the use of a single-fabric liner. Dr. Barnes, of the University of Louisville, showed (6,7) that maintaining habitable conditions within tents during moderate- or cold-climate winter operations requires a considerable amount of fuel and even then it is frequently impossible to maintain these conditions, additional insulation is needed besides that afforded by the tent structure itself. Extensive laboratory and field tests by Dr. Barnes showed that tent liners consisting of a single fabric layer could reduce the heat loss from an unlined tent by from 38 to 64 percent under certain conditions (7); a 2-fabric liner could reduce heat loss by as much as 51 percent, and a 1/2-inch glass-fiber batt liner could reduce heat loss by as much as 70 percent. Studies conducted by Dr. Yaglou (Harvard School of Public Health), under contract with the Office of The Surgeon General (33), showed that a liner in the 5-man pyramidal tent could reduce heat loss by 47 percent. On the other hand, field tests by the Quartermaster Field Evaluation Agency at Fort Lee, Virginia, showed that fabric liners in medium- or large-size tents could reduce heat requirements by amounts ranging from 25 to 45 percent (23-26,29,30), which is less than either Dr. Barnes or Dr. Yaglou had found.

Dr. Barnes found that the effectiveness of a liner in reducing heat loss was not influenced by the type of its material alone. Under certain conditions a thin, porous fabric proved to be as effective as a thick, heavy fabric or an impermeable coated fabric (7). While Dr. Barnes stated that a reflective inner surface of a liner theoretically should reduce heat loss, he could not prove this experimentally because of the lack of a suitable coating material to give the fabrics sufficiently high surface reflectance.

Dr. Herrington, of the John B. Pierce Foundation, in his study "Comfort Conditioning of Tents" (13), discussed the value of a reflective type of insulation. He stressed its effect, in a standard Jamesway Shelter, on comfort rather than on the reduction of heat required to maintain habitable conditions (12, 13). He found that one of the factors influencing comfort was the maintenance of a uniform temperature. Dr. Herrington suggested that the comfort and heating efficiency of the standard frame-type shelter might be improved by two modifications involving the principle of reflection: adding polished aluminum foil to the inner shell of a batt-type blanket liner, and suspending a convex reflector above the stove.

A field test of the heating requirements of a frame-type, 16- by 32-foot tent was conducted by the Quartermaster Field Evaluation Agency (24) using convex reflectors lined with a polyester film coated on both sides with highly reflective aluminum. While this test failed to show any savings in heat, it did show that the best nonrigid tent and fabric liner combination was less effective for heat retention than a 1-inch glass-fiber batt liner in a semirigid standard Jamesway Shelter.

Other studies were conducted by the Quartermaster Field Evaluation Agency (1,19,24-26) and by the Quartermaster Corps under contract with the Harris Research Laboratories, Washington, D. C. (35), to determine the influence of solar heat buildup on the durability of deck fabrics*. During these studies, a carefully kept record of the diurnal temperature variations within the unheated tents showed that an unlined, 6-panel, roofwall tent could be heated by the sun to from 10° to 12°F above the soil temperature. This finding was later confirmed at the University of Louisville.

From this brief review of earlier studies of heat loss in tents and tent-type structures, the following conclusions may be drawn:

1. There are indications that a fabric liner substantially reduces the heat required to maintain a habitable temperature within a tent.

2. A ½-inch glass-fiber batt liner in a frame-type, semirigid shelter appears to be more efficient in reducing heat loss during cold weather than fabric liners in nonrigid shelters.

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*"Deck fabric" refers to the fabric used for the roof of the tent as distinguished from the fabric used for the side walls.

3. Liners with reflective surfaces appear to be effective in improving comfort because of their radiative properties, and in helping to maintain a relatively uniform temperature within the tent structure, although there is no conclusive evidence that such liners would reduce heat requirements.

4. Solar radiation is a significant factor in the daytime heating of tents.

## 2. Scope of This Study

The present study has made further inquiries into the insulating properties of fabric tent liners to determine:

1. By how much a fabric liner can reduce the heat requirements of a tent during the winter to maintain an internal temperature of between 65° and 75°F.

2. What the comparative heat losses are for the same tent, lined and unlined.

3. What properties a liner fabric should possess to enhance its effectiveness as a conserver of heat.

4. What variables other than type of liner fabric affect the heat requirements of a tent.

This report discusses the findings from two separate heat-retention studies conducted on lined and unlined tents at the Quartermaster Research and Engineering Center at Natick, Massachusetts. The first study, Phase I, was conducted during February and March 1959; the second study, Phase II, was conducted during February and March 1960. These studies were designed not only to determine quantitatively the insulating characteristics of the fabric liners but also to determine the influence, if any, of certain controllable variables (liner fabric properties, tent position, and tent and liner construction) and certain uncontrollable variables (environmental temperature, windspeed, and radiation).

The findings of Phase I are discussed in detail in Appendix A, and those of Phase II are discussed in Appendix B.

The planning behind both phases, a description of the test equipment and procedure, and a summary of the effect of the environmental, constructional, and fabric variables studied are included in the body of the report.

## 3. Test Planning

The wide range of results previously reported had suggested that the earlier studies of the heating requirements of tents might have been influenced by certain variables (of liner fabric, of environment, of tent and liner construction) that had not been studied simultaneously or had been discounted. In other words, the results were inconclusive as to the magnitude of heat savings that could be achieved by the use of an insulating tent liner.

The present study was initially designed to evaluate, separately, the effect on fuel consumption of three liner-fabric variables: thickness, air permeability, and surface reflectance or emissivity, each of which conceivably could influence the heat requirements of a tent (21). It was proposed to hold as constant as possible two of these variables and to change the remaining variable in each of four test tasks. A plan was drawn up describing each task and, in order for the results to be analyzed statistically, it was determined to require from 15 to 18 runs per task.

Before the initial plan could be carried out, however, it was found advisable to supplement the three fabric variables with three environmental and three constructional variables. The test plan was therefore revised to include environmental radiation, windspeed, and temperature, and the constructional features of open/closed ventilators, tent volume, and tent location. No attempt was made to evaluate any one of these variables singly; each test included all the variables, hence only their gross effect was evaluated. Variables that could be controlled (those having to do with fabric or construction) were included in a balanced though random fashion. Variables that could not be controlled (those of the environment) were carefully recorded during each test run. All test results were compared to one heat input value: the amount of heat necessary to maintain a predetermined temperature (65-70°F) inside the tent, as measured in the center and 4 feet above the ground. Measurements at the 4-foot level were used for the comparisons in this report because Phase I pre-test temperatures taken at various distances from the floor had shown that those at 4 feet represent a good average (see next page). Pre-test measurements also showed that the temperature gradient from the floor to the ceiling is steep, averaging 5.1°F per foot.

|  | Temperature (°F) in Center of Tent |  |  |  |  |  | Vertical Gradient |
|---|---|---|---|---|---|---|---|
| Distance above floor | 1/2 in | 2 ft | 4 ft | 6 ft | 9-1/2 ft | Avg | (°F/ft) |
| No liner | 41 | 53 | 65 | 72 | 97 | 66 | 5.9 |
| Standard sheeting liner | 42 | 55 | 65 | 88 | 92 | 68 | 5.3 |
| Cotton sateen liner | 51 | 60 | 68 | 80 | 94 | 70 | 4.5 |
| Nylon liner: |  |  |  |  |  |  |  |
| Chloroprene-coated | 38 | 49 | 65 | 88 | 95 | 67 | 6.0 |
| " | 40 | 54 | 65 | 83 | 96 | 67 | 5.9 |
| CSP*- & chloroprene-coated | 42 | 51 | 66 | 86 | 94 | 68 | 5.5 |
| " | 44 | 53 | 65 | 86 | 92 | 68 | 5.0 |
| Aluminized & chloroprene-coated | 48 | 62 | 68 | 83 | 87 | 69 | 4.1 |
| " | 50 | 60 | 66 | 80 | 91 | 69 | 4.3 |
| Avg. temperature & gradient | 44 | 55 | 66 | 83 | 93 | 68 | 5.1 |

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* CSP = chlorosulphonated polyethylene

a. Liner Fabric Variables

Both test phases included liner fabrics varying in thickness (which, though it may not be related to heat loss, is directly related to insulation), air permeability (which is the ability of a fabric to resist wind penetration) (12), and surface emissivity (which Dr. Herrington had related to increased comfort). The Phase II liners extended the range of liner thickness and surface emissivity.

b. Environmental Variables

1) Radiation. During the day, a liner with good insulating properties may increase fuel requirements by preventing the interior of the tent from being heated by solar radiation. At night, however, a good insulating liner may decrease fuel requirements by conserving the heat within the tent and reducing heat loss due to wind infiltration, conduction through the fabrics, and radiation from the outside tent deck to the sky. Nighttime radiation becomes important during the winter and in locations where nights are long. Daytime and nighttime heating

requirements were compared during a pre-test, with results as given below:

| | Unlined Tent | Tent Lined with 9-oz Sateen | Percent Difference |
|---|---|---|---|
| | (BTU/hr °F)* | | |
| Daytime requirements | 102 | 171 | + 40 |
| Nighttime requirements | 1536 | 1230 | - 25 |

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*British thermal units per hour degree Fahrenheit is calculated as follows:

$$\frac{KWH \times 3.413}{H \times {}^{\circ}F}$$

where: 3.413 = conversion constant
H = lapsed time of test, in hours
°F = difference between the temperature inside the tent at the 4-ft level and the outside ambient temperature.

Early work by the Quartermaster Field Evaluation Agency (1,19,26) showed that, during the month of February, there is a minimum amount of solar radiation between 1800 and 0800 hours, and that daytime shelter temperatures increase with increased solar radiation, with a time lag, and decrease with decreased solar radiation (Fig. 1).

The time-temperature findings of Sissenwine were corroborated by a University of Louisville study (7) on the effect of solar radiation on all types of lined and unlined tents. The greatest variation (the greatest effect of solar radiation) was found in the unlined tents, and the least variation in the tents having a good insulating liner, such as one made from a 1/2-inch glass-fiber material. With constant heat input during the day, the time-temperature curves inside both the lined and unlined tents followed the solar radiation curve of an unheated tent, although at a higher level, with the unlined tents gaining heat faster during sunlight hours and losing heat faster after sundown. As a result of these findings, the University of Louisville study recommended that adjustable liners be constructed so that portions of the liners could be folded back to let in solar heat during the day but that these be replaced in the afternoon to conserve heat during the night.

Although these tests were planned to take advantage of minimum solar radiation, its effect could not be totally eliminated without restraining the running time each night to an impractically short period (7). Because it was considered advisable to run the tests for as many hours as possible, each run usually started at 1630 hours and ended at 0800 hours the following day.

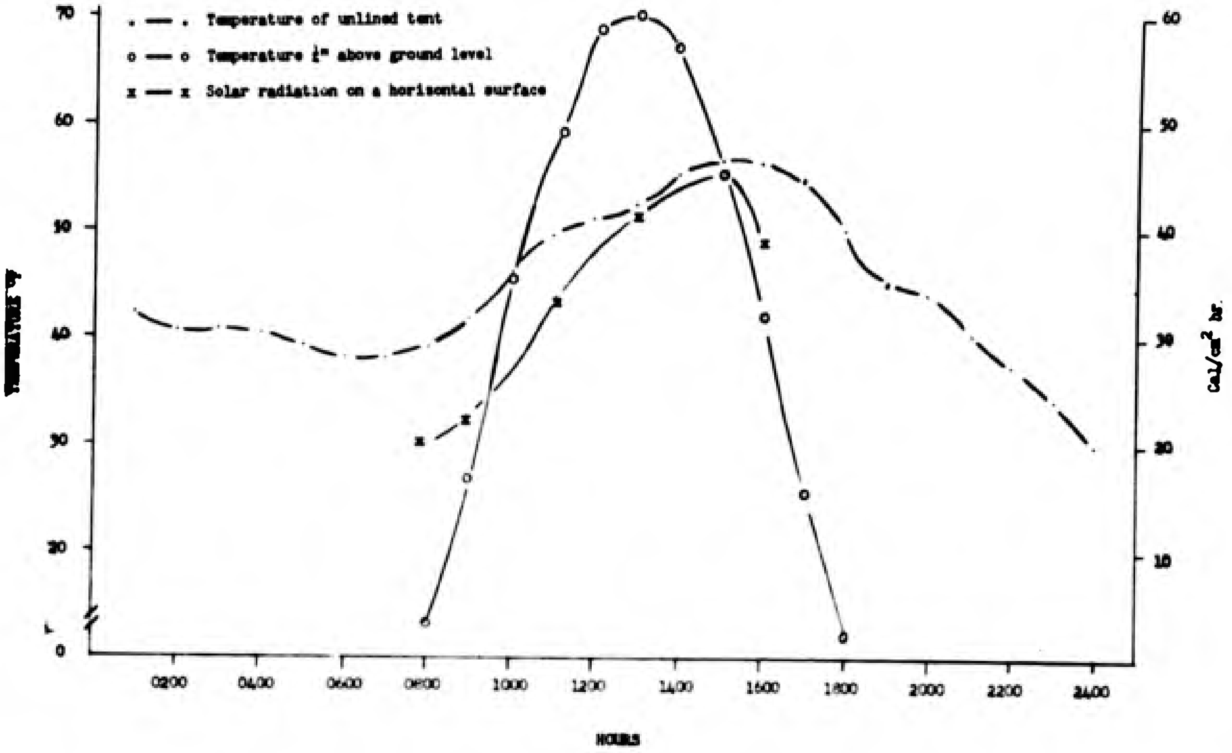

Figure 1. Sissenwine's Time-Temperature Curves in an Unlined Tent Heated Only by Solar Radiation (Reference 27)

2) Windspeed and temperature. Two other environmental variables were considered in the overall plan of the test: windspeed and temperature. During Phase I, data on windspeed and wind direction were limited (11,31) because of an embankment extending along the south and east sides of the test area and the presence of other large tents and truck trailers undergoing test (see frontispiece). During Phase II, therefore, the tents were placed in a slightly more exposed location.

### c. Tent and Liner Construction Variables

1) Ventilators. Previous studies had frequently referred to heat loss through holes and other openings that are part of the tent structure. This type of heat loss varies from tent to tent. Unlike environmental variables, construction variables can be controlled. Ventilating ports are required for ventilation when gasoline stoves are used. These ports, or vents, are placed near the roof of the liners.

When the ports are open, a considerable amount of heated air escapes through them, thus increasing the heat requirements. In Phase I, the tents were tested with the liner vents open and also with the liner vents closed. Only closed vents were used in Phase II because of the greater heat savings they realized.

2) Volume. The volume of air enclosed within each tent liner was calculated from the dimensions of the tent. The sagging of the heavier liners lowered the ceiling and resulted in less total interior volume (Figure 7 in Appendix A).

3) Position. When more than one tent is used, their relative position must be considered to ensure that the results will not be influenced by any environmental advantage or disadvantage due to a particular position or to the position of one tent with respect to the others. In Phase I, three tents, erected with their ridgepoles parallel and oriented in a north-south direction, were placed in an east-west relationship to each other and their relative positions rotated. In Phase II, two tents, with ridgepoles running in an east-west direction, were placed in a north-south relationship to each other.

## 4. Test Equipment and Procedure

### a. Tents.

Three Standard, Medium, General Purpose Tents, 16 by 32 feet, conforming to Specification MIL-T-1712E (Tent, GP, Medium, FWWMR, Olive Drab, Complete) and with two ventilating ports each (16,17), were drawn from stock. All three tents were used in Phase I; only two tents were used in Phase II.

An unlined tent and tents lined with standard sheeting or with one of eight experimental liners were compared according to a predetermined daily rotation plan. The liners were made in accordance with Specification MIL-L-12919, 27 July 1953 (Liner, Tent, FWWMR, GP, Medium) (18).

The tents were coded as follows:

Phase I:
- a. unlined tent (control)
- b. 3.8-oz standard cotton sheeting liner (control)
- c. 9-oz cotton sateen liner
- d. 4.5-oz nylon liner, chloroprene-coated on one side

e. 8.5-oz nylon liner, chlorosulphonated polyethylene-coated on one side and chloroprene-coated on the other side

f. 4.5-oz nylon liner, aluminized on one side and chloroprene-coated on the other side

g. 2.1-oz nylon liner (low-twist yarns)

Phase II: a. unlined tent (control)

b. 3.8-oz standard cotton sheeting liner (control)

h. 7.2-oz modacrylic liner, napped on one side

i. 8.1-oz cotton poplin liner, laminated with 1-mil 1-oz/sq yd aluminized polyester film on one side

j. 12-oz cotton poplin liner, laminated with 1-mil 1-oz/sq yd aluminized polyester film on one side, and with 0.5-mil aluminum foil cemented to the other side

b. Equipment

Special heating facilities were improvised by mounting electric heaters within the shells of modified M-1941 tent stoves. Each heater contained heating elements totaling 15 kilowatts, with toggle switches that permitted the output to be controlled in steps of 5 kilowatts. The stoves were metered individually to measure kilowatt-hours and were controlled automatically to maintain the desired inside temperature of 65° to 70°F 4 feet above the floor in the center of the tent. Two heaters were installed in each tent 8 feet from either end in a manner normal under typical field conditions except that stove pipes were not used.

In Phase I, 6 thermographs were used to record temperature variations at both the 2-foot and the 4-foot levels in the center of the tent (Fig. 2). Thermographs were not used in Phase II.

In Phase I, a 12-point Brown recording thermometer was used (center tent only) for 12 copper-constantan thermocouples (5 in the center tent, 3 in each of the two side tents, and 1 outside the west tent), and in Phase II, 2 Brown recording thermometers were used (1 in each of the two tents). The recording thermometers were placed in a wooden box with insulating material around the sides and back to minimize the effect of heat coming from the instrument. In addition,

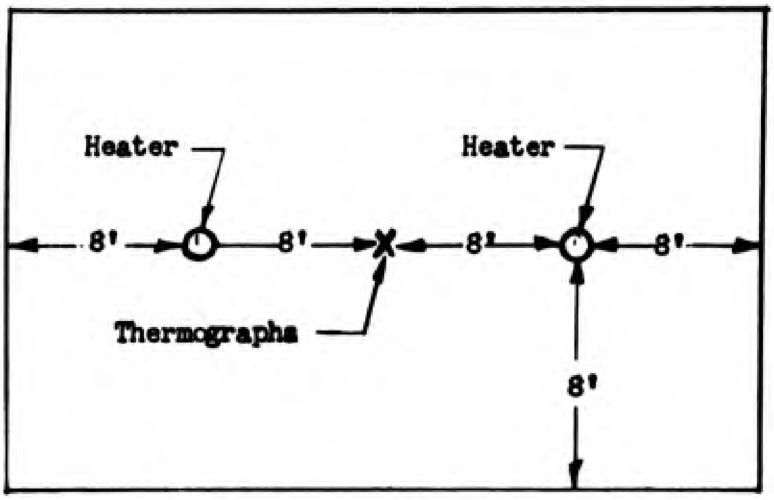

Figure 2. Location in Tents of Heaters and Thermographs

a glass thermometer measured the temperature at the center of the tent at the 4-foot level.

A thermocouple for the deck fabric was located 6 feet above the ground; thermocouples for the space between the deck fabric and the liner and thermocouples for the liner fabric were located on an imaginary line extending on either side inward from the deck fabric and perpendicular to the slant of the canvas deck (Fig. 3).

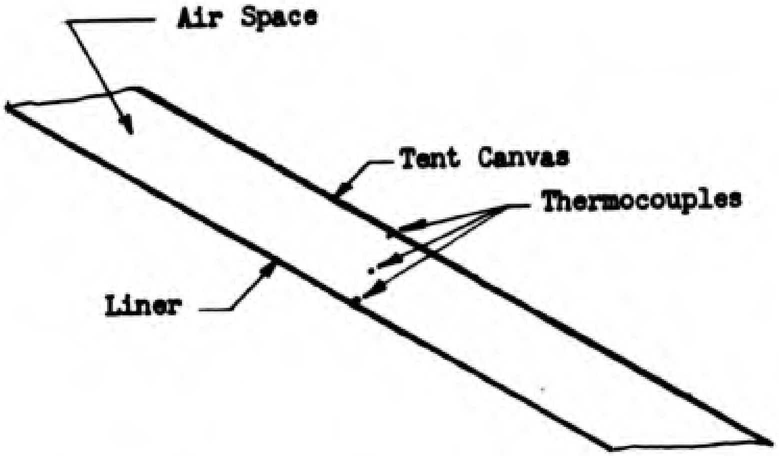

Figure 3. Tent Section Showing Locations of Thermocouples

A net-exchange radiometer measured radiation inside the tent and radiation outside from the tent deck to the sky.

A meteorological team from the Earth Sciences Division and the Signal Corps stationed at the Quartermaster Research and Engineering Center provided an anemometer and supervised the installation of the net-exchange radiometer.

### c. Operating Procedure

After a number of trial runs (to insure the proper functioning of the equipment) the tents, liners, stoves, and measuring equipment were ready for the test runs. The standard procedure of operation was as follows: 1) in the afternoon the heaters were turned on in each tent and the tents were allowed to reach an equilibrium temperature of 65°F at the 4-foot level; 2) the main switch was then turned off, the meters were read, and the doors of the tents were closed; 3) the main switch was turned on and the test was continued until the following morning; and 4), on the following morning, the main switch was turned off and the meters were again read.

On nights when it was necessary to enter the tents to measure radiation, care was taken to treat each tent in the same manner; that is, the doors were opened and closed the same number of times and the lights were switched on and the tents were occupied for the same length of time to minimize the effects of entry, if any, on the heat requirements. The recording thermometer was serviced during the day so that the servicing would not interfere with the test runs.

Temperature, relative humidity, radiation, wind direction, and windspeed were recorded at the main weather station of the Center; temperature and relative humidity were also recorded in the test area to provide a cross-check and ensure the accuracy of the hygrothermographs. Generally, both test sites were a few degrees colder than the main weather station, therefore only those temperatures recorded at the test site were used. On the other hand, the humidity data obtained at the test site were erratic; consequently only the main weather station humidity data were used.

## 5. Test Results

The results of Phases I and II, together with liner fabric and tent volume data, are summarized in Table I. Milder weather during

Phase II required that these test results be adjusted by a correlating factor of 1.16 in order for the data to be comparable.

The Phase I raw data may be found in Appendix A, Tables IV and V; Phase II raw data may be found in Appendix B, Tables XVII and XVIII.

## TABLE I

### Summary of Heat Requirements and Savings by Use of Liners with Closed Vents
(also some liner fabric properties and the volume of air in each tent)

| Liner (code) | Liner Thickness (mils @0.01) | Air Permeability of Liner (ft$^3$/min/ft$^2$) | Radiant Heat Loss* (BTU/hr ft$^2$) | Volume of Air (ft$^3$) | Avg Heat Requirement (BTU/hr °F) | Average Heat Saved (BTU/hr °F) | Average Heat Saved (%) |
|---|---|---|---|---|---|---|---|
| a | -- | --- | -- | 3610 | 1251 | 0 | -- |
| b | 31 | 186 | 57 | 2815 | 1115 | 136 | 11 |
| c | 53 | 5 | 57 | 2515 | 808 | 443 | 35 |
| d | 9 | 0 | 61 | 2805 | 956 | 295 | 24 |
| e | 18 | 0 | 45 | 2775 | 933 | 318 | 25 |
| f | 11 | 0 | 43 | 2745 | 921 | 330 | 26 |
| g | 7 | 57 | 62 | 2700 | 1081 | 170 | 14 |
| h | 86 | 55 | 55 | 2755 | 778** | 473 | 38 |
| i | 35*** | 0 | 50 | 2838 | 845** | 406 | 32 |
| j | 45*** | 0 | 31 | 2850 | 574** | 677 | 54 |

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**Code**
a. unlined tent (control)
b. 3.8-oz standard sheeting liner (control)
c. 9-oz cotton sateen liner
d. 4.5-oz nylon liner, chloroprene-coated on one side
e. 8.5-oz nylon liner, chlorosulphonated polyethylene-coated on one side, chloroprene-coated on other side
f. 4.5-oz nylon liner, aluminized on one side, chloroprene-coated on other side
g. 2.1-oz nylon liner (low-twist yarns)
h. 7.2-oz modacrylic liner, napped on one side
i. 8.1-oz cotton poplin liner, aluminized polyester film on one side
j. 12-oz cotton poplin liner, aluminized polyester film on one side, aluminum foil on other side

* As measured by a radiometer.

** Because of the milder temperatures of Phase II, values for "h" through "j" are adjusted by a factor of 1.16.

*** Thickness @ 1.0 psi, due to wrinkling. (At 0.01 psi, thickness would be 75 and 95 mils for "i" and "j" respectively.)

### a. Effect of Environment

1) Windspeed. In Phase I, gusts of up to 10 knots were noted but the wind never exceeded a 3-4 Beaufort scale value (32). The average and sustained winds were, of course, even lower than this. During this phase, heat savings in a lined tent as compared to an unlined tent were found to increase as windspeed increased up to 7 knots, when 29 percent heat savings were realized. In Phase II, with daily windspeeds averaging from 0.8 to 16.7 knots and with gusts of up to 27 knots, the lined tents showed increased heat savings, to an average of 40 percent, with increased windspeeds of up to 5.6 knots. At greater windspeeds, the heat savings from use of a liner gradually decreased.

2) Temperature. The fabric and space temperature measurements of these tests proved to be in agreement with those previously reported at Fort Lee and at the University of Louisville. Sissenwine made a thorough analysis of temperature rise in the deck fabrics of heated and unheated unlined tents at Fort Lee (27), and Barnes studied the temperature rise in the deck fabrics of lined and unlined tents at the University of Louisville (7). In general, they found that the lower the outside temperature, the greater was the difference in heat requirements between the lined and unlined tents, hence the greater the heat savings by the use of a liner.

In this study, the microclimate of the tents was somewhat modified by the sheltered test site of Phase I; in Phase II, the tents, while more exposed to the north and west, were under the modifying influence of buildings to the east and of the solar furnace about 100 feet to the south. As stated above, the milder weather conditions during Phase II required that these values be adjusted by a factor of 1.16.

3) Radiation. On clear cold nights, radiant heat loss from the tents to the sky, and consequently the heat requirements of the tents, increased as expected. However, in Phase I, the increase was small, amounting to a maximum average difference of only 9 percent for the extremes of radiation encountered on the days the unlined tent was tested. During Phase II, in which reflective liner surfaces were used, it was found that the most reflective surface, that of liner "j", was the most effective in reducing nighttime radiant heat loss.

### b. Effect of Construction

1) Position. The average heat requirements for each position in Phase I were found to be remarkably uniform. In Phase II, the more sheltered north position required 6.8 percent less heat, therefore the position 2 values were adjusted by a factor of 1.068.

2) Ventilators. In Phase I, the percentage of heat saved in the lined tents with the vents open averaged about one-half of that in the tents with the vents closed (12% versus 22% heat savings). In Phase II, the vents of all liners were kept closed for maximum heat savings.

3) Volume. The volume of air encompassed by the tent liners of Phase I and Phase II is plotted, in relation to the amount of heat saved, in Figure 4. These data can be correlated at four levels. At the top level is the aluminum foil liner "j". This liner, which permitted the greatest amount of heat saving, is the heaviest and most reflective liner but also the liner enclosing the greatest volume. At the second highest level are the napped modacrylic liner "h" and the cotton poplin liner with aluminized polyester film "i", both of medium weight. The high efficiency of these liners is due primarily to their greater thickness and also, possibly, to the limited reflective properties of the aluminized polyester. The third group, containing the second heaviest cotton liner and the liner enclosing the smallest volume, the cotton sateen "c", and the three chloroprene-coated nylon liners ("d", "e", and "f"), shows the greatest spread in volume and includes the liner enclosing the smallest area. At the lowest heat-saving level are the low-twist nylon "g" and the standard sheeting liner "b", the two lightest liners. The poor capabilities of "b" and "g" are due primarily to their lesser thickness and their relatively high air permeability. It will be noted that, at each level, the greater the volume of air to be heated the lower was the heat-saving capability of the liner.

### c. Effect of Liner Fabric Properties

1) Thickness. Using the fabric thickness and heat-saving values in Table I, a curve was drawn (Fig. 5) to illustrate the effect of liner fabric thickness on heat savings. This curve shows a general relationship between thickness and heat saved, with only two values falling outside the curve. (This high value above the curve is that of the aluminum foil reflective surfaced "j", while the low value below the curve is that of the highly permeable 3.8-oz sheeting fabric "b".) The most rapid gains in heat saving are noted for the

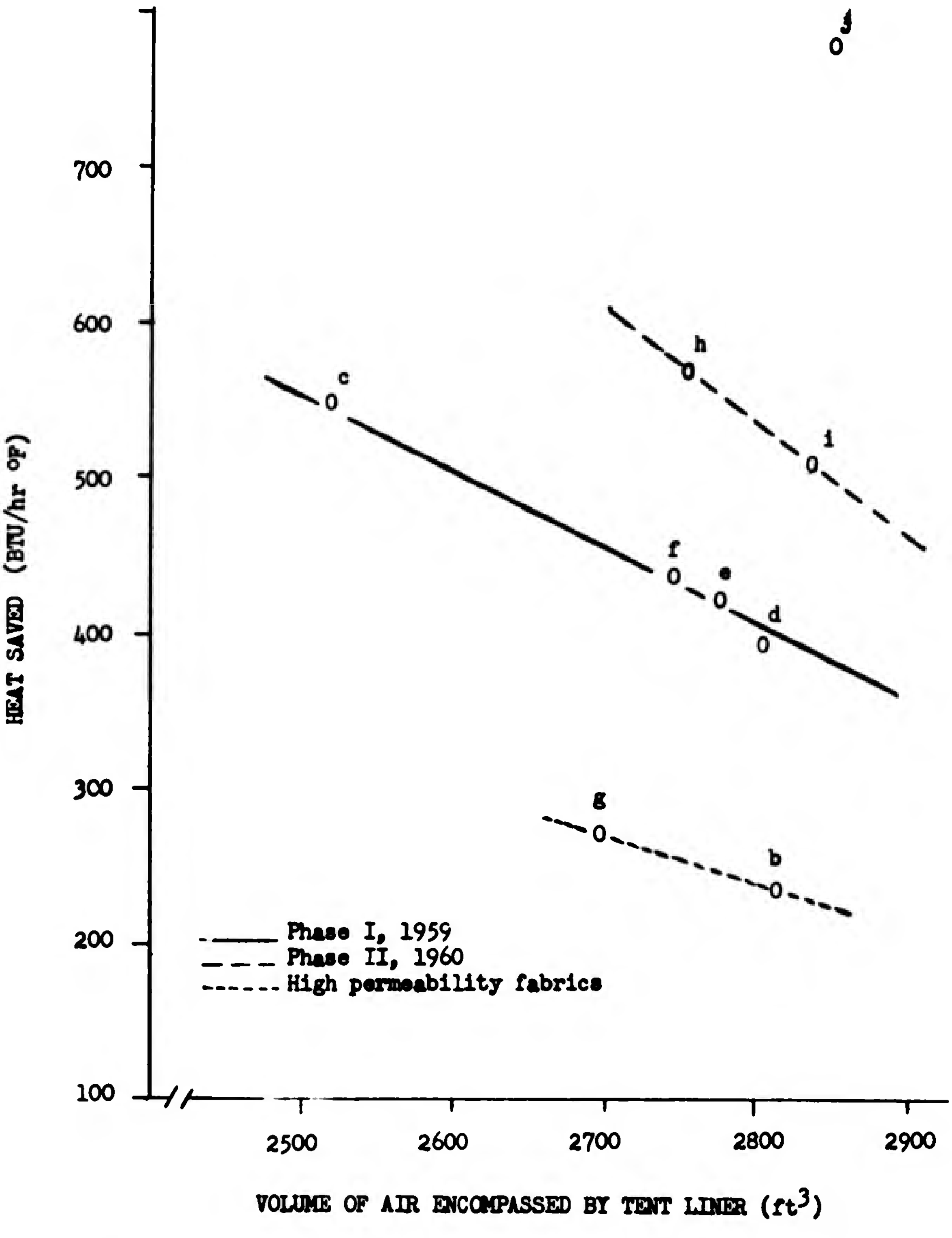


Figure 4. Relation of Volume of Encompassed Air to Heat Savings

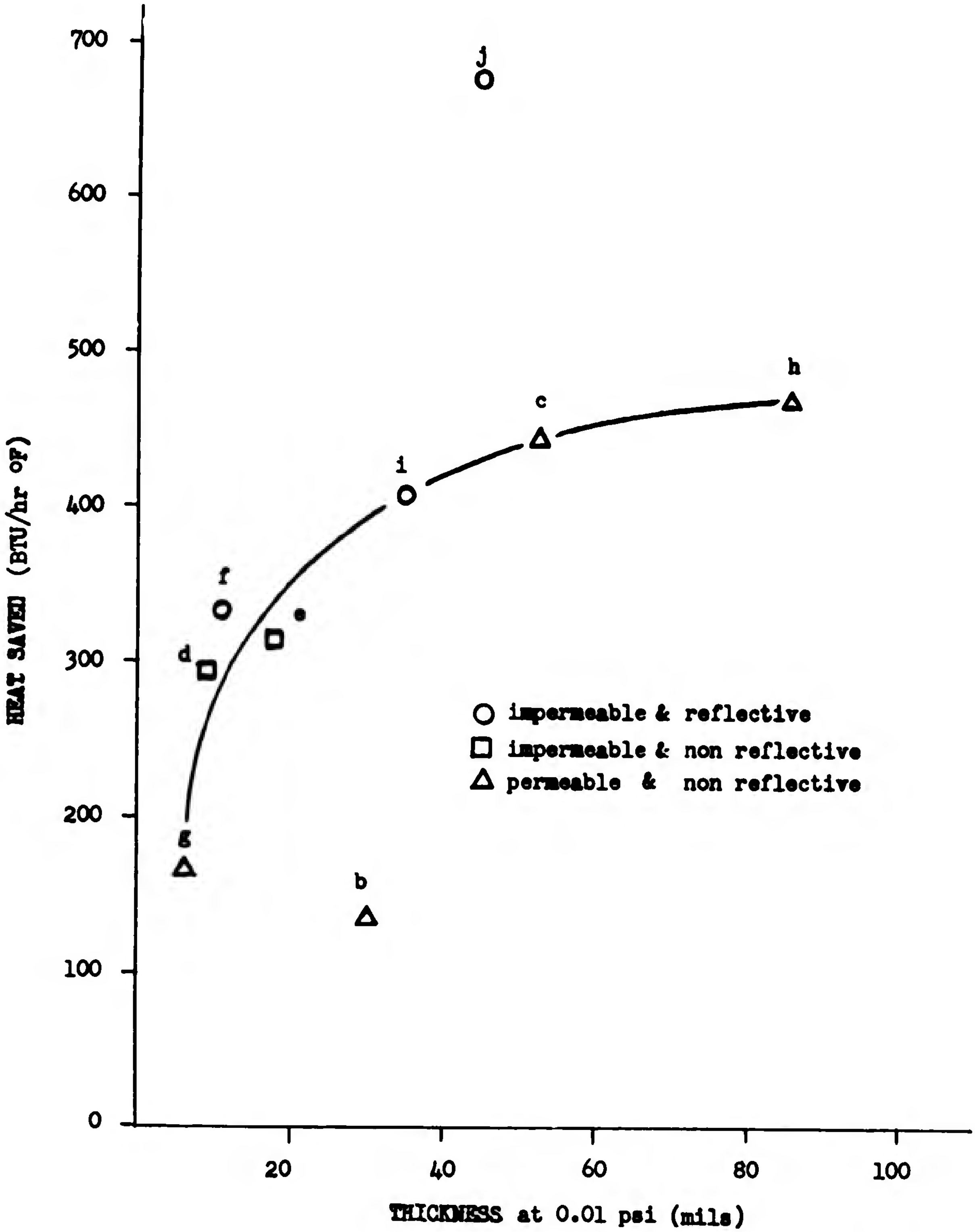


Figure 5. Relation of Liner Fabric Thickness to Heat Savings

lower thicknesses, the curve rising sharply between 0 and 40 mils of thickness. After 40 mils, the curve tapers off, increasing only 1 BTU per mil, approximately, for thicknesses between 40 and 86 mils (the greatest thickness recorded). This indicates that the thickness of tent liner fabrics should be greater than 40 mils.

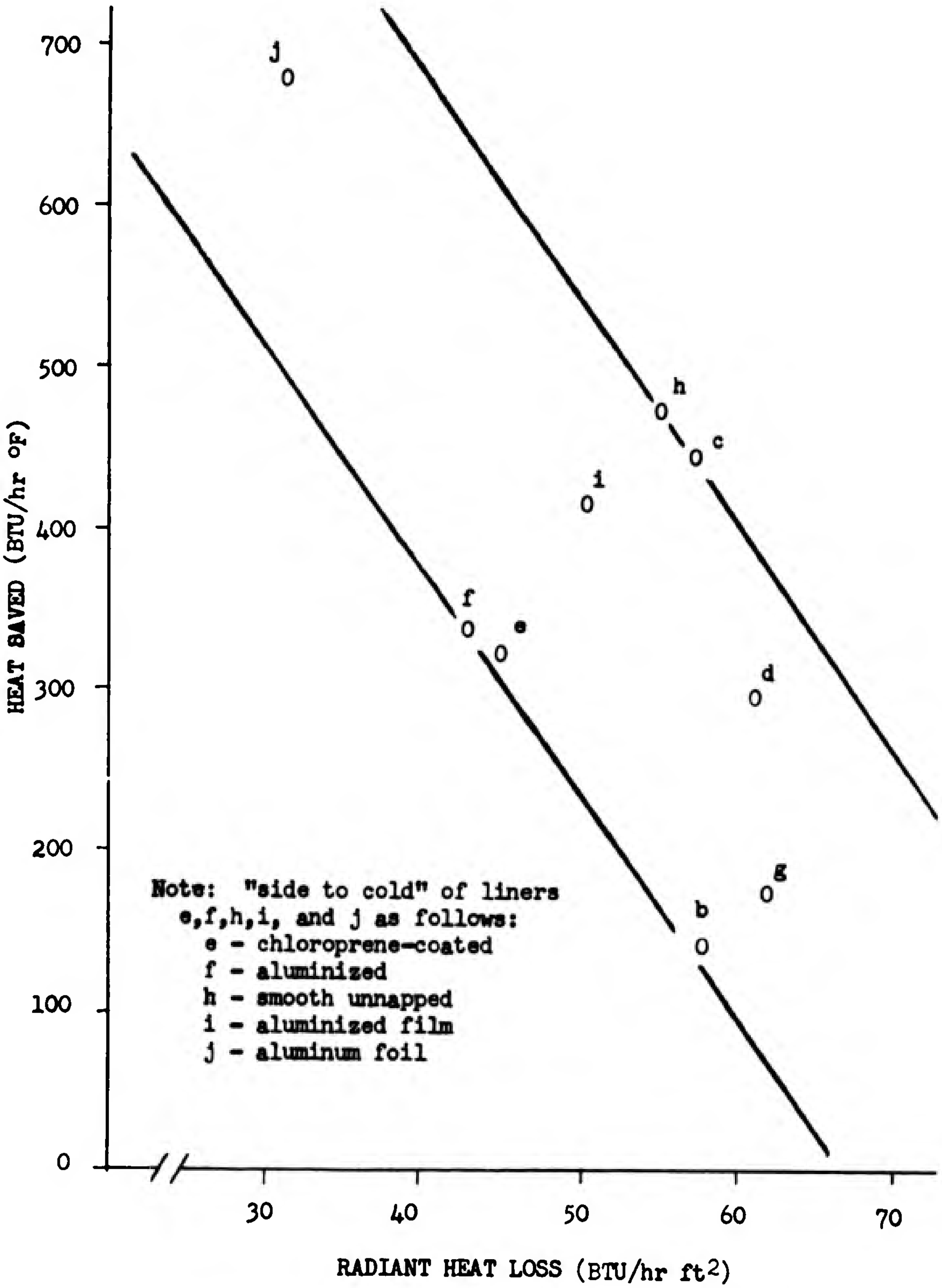
The absence of a point for a non-reflective fabric between 18 and 53 mils casts some doubt as to the minimum thickness that would provide the high level of heat savings indicated by the flat portion of the curve. Notwithstanding this fact, 50 mils appears to be a good value to consider.

2) Air permeability. The data on air permeability are such as to prevent any generalization on the influence of this property on heat savings. Tabulated below are the air permeability and thickness data for four of the liner fabrics. In the case of the two thinner fabrics, the 2.1-oz nylon "g" (7 mils) and the 3.8-oz cotton sheeting "b" (31 mils), the highly permeable "b" (186 as against 57 units) shows less heat savings (136 or 11% as against 170 or 14%). In the case of the two thicker fabrics, the 9-oz sateen "c" (53 mils) and 7.2-oz napped modacrylic "h" (86 mils), the more permeable "h" (55 as against 5 units) shows more heat savings (473 or 38% as against 443 or 35%). More data are required before any generalization can be made.

| Liner | Air Permeability | Thickness | Avg Heat Savings | |
|---|---|---|---|---|
| | ($ft^3/min/ft^2$) | (mils @ 0.01 psi) | (BTU/hr °F) | (%) |
| b | 186 | 31 | 136 | 11 |
| c | 5 | 53 | 443 | 35 |
| g | 57 | 7 | 170 | 14 |
| h | 55 | 86 | 473 | 38 |

3) Surface emissivity. Highly reflective surfaces derive their effectiveness from their low transmission of radiant heat, their low "total normal surface emissivity." Total normal surface emissivity can be expressed in absolute units of BTU/hr x square feet or in terms of dimensionless numbers ranging from zero (complete nonemission) to unity (complete radiation), with low emissivity values or high reflectivity indicating more effective insulating performance. A perfect heat reflector would have an emissivity value of "0" and would permit no heat loss through radiation.

In Figure 6, the radiant heat loss or surface emissivity of each liner fabric is related to the amount of heat saved, using the values



Note: "side to cold" of liners
e,f,h,i, and j as follows:
e - chloroprene-coated
f - aluminized
h - smooth unnapped
i - aluminized film
j - aluminum foil

Figure 6. Relation of Radiant Heat Loss to Heat Savings

as adjusted for Table I. In this study the most effective surface for heat savings was that provided by the highly reflective aluminum foil, liner "j", with the lowest surface emissivity. The surface emissive properties of fabrics, films, and coatings are inherent to the specific materials and are closely related to their ability to emit heat. Therefore, control of the emissivity of tent liner fabrics requires control of the fibers in the fabrics and of the surface characteristics of fabrics and coating (9).

There are several problems involved in the use of reflective surfaces to conserve heat in flexible structures like tents. Aluminum foil, which was used in this study (liner "j") to test the effect of reflective surfaces, is not yet practical for application to Army tent liners because: 1) it is excessively heavy in relation to the strength of the fabric, 2) it lacks durability, 3) it is difficult to secure firmly to a flexible fabric or to fabricate a tent liner from a fabric foil laminate by sewing techniques, 4) it is impermeable, thus causes moisture condensation*, and 5) it is very noisy when the wind blows. In addition, reflective surfaces can become wrinkled or contaminated with nonreflective substances such as mud, dirt, and moisture (10, 14, 15, 20, 21, 22) and thus lose some of their heat-saving potential through a gain in their surface emissive properties (Table II).

## TABLE II

### Emissivity of Aluminum Surfaces
(as expressed in dimensionless numbers)

| | |
|---|---|
| Polished aluminum plate @73°F | 0.04♦ |
| Aluminum foil @123°F | |
| Commercial, new | 0.43 |
| Wrinkled, new | 0.48 |
| Dusted with ground dirt | 0.48* |
| Visibly wet | 0.90θ |
| Liner "j" before use | 0.43 |
| Liner "j" after 2 seasons of use | 0.48 |

♦ Ref. 15, p. 393

* Tentative value, surface completely covered with dirt showed valued as high as 0.85

θ Tentative value, value remained constant for 10 min., then fell to 0.51 as water evaporated.

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* The test of the aluminum foil-coated poplin liner "j" was conducted in a tent without human occupancy. This minimized the moisture problem (20), which can reduce the surface emissivity of aluminum foil surfaces by from 10 to 30 percent.

It can be seen from Table II that the emissivity or radiant heat loss from a commercial aluminum foil reflective surface was found to be 10 times greater than the published value for a polished aluminum plate (15). A difference in radiant heat loss was expected and the reasons for the difference have been published elsewhere (10,14,20,22). What is surprising, however, is that the radiant heat loss should have been so great for a new, unused foil. The value for foil that had been wrinkled and the tentative value for the foil that had been covered with ground dirt showed only a slight increase in radiant heat loss. However, the wet foil showed more than double the heat loss of the new foil because of the high emissivity of a wet surface. Measurements of the emissivity of liner "j", before and after two seasons of use, were made to determine whether a liner covered with aluminum foil would lose any of its efficiency during use. The results show that emissivity remains fairly constant and that, as field tests had already indicated, this surface has a good heat-saving potential.

In order to place the amount of heat saved due to surface emissivity (reflective insulation or radiation) in its proper perspective, it is necessary to consider this value in relation to the overall heat loss. Heat may be lost (transferred) through tent liners by conduction, convection, and/or radiation. The overall heat transfer coefficient, or $U_2$, of the liner materials was determined in the Quartermaster Textile Engineering Laboratory, in units of BTU/hr °F ft$^2$, by means of a Guarded Ring Hot Plate* (4). Simultaneously, the radiant heat loss from the surface of the materials (surface emissivity) was determined, in BTU/hr ft$^2$, by means of a Beckman Whittey Thermal Radiometer (8). The product of the $U_2$ and the difference between the hot plate temperature when the $U_2$ was determined and the room temperature represents the overall heat loss. The difference between the radiant heat loss and the overall heat loss represents the heat loss due to conduction and convection. By dividing this conduction-convection value by the difference between the hot plate and ambient room temperatures, the conductive-convective heat transfer coefficient is obtained. Table III presents these data for both sides of the Phase II liners "b", "h", "i", and "j".

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*The hot plate had a painted surface with a 0.98 emissivity value.

# TABLE III

## Heat Loss and Heat Transfer Coefficients for Liners of Phase II

| Liner | Heat Loss Overall (BTU/hr ft$^2$) | Heat Loss Radiant (BTU/hr ft$^2$) | Heat Loss Cond-Conv (BTU/hr ft$^2$) | Temperature Difference* (°F) | Heat Transf. Coeff Overall ($U_2$) (BTU/hr °F ft$^2$) | Heat Transf. Coeff Cond-Conv (BTU/hr °F ft$^2$) |
|---|---|---|---|---|---|---|
| b. Cotton sheeting | | | | | | |
| Face to cold | 418 | 57 | 362 | 48.1 | 8.70 | 7.50 |
| Back to cold | 418 | 57 | 362 | 48.1 | 8.70 | 7.50 |
| h. Napped modacrylic | | | | | | |
| Napped face to cold | 107 | 56 | 51 | 48.9 | 2.19 | 1.04 |
| Smooth side to cold | 100 | 55 | 45 | 48.7 | 2.06 | 0.92 |
| i. Alum. polyester film poplin | | | | | | |
| Face to cold | 113 | 57 | 56 | 48.3 | 2.34 | 1.16 |
| Film to cold | 107 | 50 | 57 | 47.6 | 2.26 | 1.19 |
| j. Alum. polyester film-alum. foil | | | | | | |
| Film to cold | 116 | 49 | 67 | 51.4 | 2.26 | 1.26 |
| Foil to cold | 91 | 31 | 60 | 48.7 | 1.87 | 1.23 |

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* Difference between hot plate and ambient temperatures when $U_2$ was determined

The data of Table III show that heat loss from a fabric varies with its placement in relation to the cold area. There was less overall heat loss from the smooth side of the modacrylic liner, from the aluminized film surface of liner "i", and from the aluminum foil surface of liner "j" when these sides were exposed to the cold in the laboratory and within the temperature range of this test. The data in Table III also show that radiant heat loss from a fabric surface can amount to as much as 55 percent of the overall heat loss (see "h"). This, then, becomes the amount of heat that could be saved if radiant heat loss from the surface of a fabric can be eliminated.

These laboratory studies on the insulating properties of liner fabrics were carried out under relatively still air conditions. The results should not be confused with the "heat saved" values obtained on the tent liners under field test conditions (Table I). There should, however, be a correlation between the insulating properties of the liner materials and the heat saved in the lined tents as compared to the unlined tent. The following tabulation shows that there is a general correlation for the Phase II liners:

| Liner | Overall Heat Loss (BTU/hr ft$^2$) | Heat Saved (BTU/hr °F) |
|---|---|---|
| b. Cotton sheeting | 418 | 136 |
| h. Napped modacrylic, smooth side to cold | 100 | 473 |
| i. Cotton poplin, alum. film to cold | 107 | 406 |
| j. Cotton poplin, alum. foil to cold | 91 | 677 |

To recapitulate, it is clear that a theoretical reflective surface with zero emissivity, and therefore no radiant heat loss, could improve the insulating efficiency of tent liners by about 50 percent. The best reflective surface found in this study (the fabric with the lowest surface emissivity) was the aluminum foil "j", which showed a radiant heat loss of only 31 BTU/hr ft$^2$ or 33 percent of an overall heat loss of 91 BTU/hr ft$^2$. The aluminized polyester film-coated surface of "i" was much less efficient in this respect, showing radiant heat loss of 46.5 percent of the overall heat loss. The modacrylic fabric, without any reflective surface, showed a radiant heat loss of 55 percent of the overall amount.

Even though heat savings of about 50 percent are theoretically possible for reflective-surfaced tent liners, they cannot be achieved by means of materials that are available today. The best reflective surface used in this study, the aluminum foil, showed savings of only 33 percent. Until suitable reflective materials are available, we must be satisfied with lesser savings. The reflecting surface of aluminum foil can be used to reduce radiant heat loss but the foil must be kept clean and dry for maximum efficiency. This would add to the maintenance problems and, furthermore, the aluminum foil now available, particularly that which is thin and light in weight, is not sufficiently durable for a flexible Army tent liner and has other deficiencies already noted.

## 6. Conclusions

a. The most efficient of the tent liners tested, from the standpoints of both high heat savings and practicality, was found to be the napped modacrylic liner "h". This liner demonstrated the high heat-saving potential (38%) when relatively thick fabrics are used as tent-liner materials.

b. The liner with the aluminum foil reflective surface actually showed the greatest savings in heat, but a liner of this type is not considered to be practical at this time for use in tent liners.

c. The liner properties found to be most significant in heat savings are fabric thickness and surface emissivity. Air permeability is significant but to a much less degree. Light colors were found to improve comfort but did not appreciably affect the heat requirements.

d. The effects on heat loss in lined and unlined tents of such environmental conditions as windspeed, radiation, and temperature differential are discussed in detail in the appendixes.

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# APPENDIX A

## DETAILS OF HEAT-RETENTION STUDY OF TENT LINERS, PHASE I
(February-March 1959)

# APPENDIX A

## DETAILS OF HEAT-RETENTION STUDY OF TENT LINERS, PHASE I
## (February-March 1959)

The first of two series of tests designed to measure the heat-retention properties of tent liners (Phase I) was conducted during February and March 1959.

The wide range of results found in earlier tests had suggested that certain variables affect heat retention in tents. Phase I was designed to account for as many of these variables as possible.

The influence of the position of the tents in relation to one another was studied by measuring the heat requirements of the test tents for an equal length of time in each of three relative positions: position 1, to the west; position 2, in the center; and position 3, to the east (see frontispiece).

The influence of tent liner construction was studied by noting the heat requirements 1) of tents with the vents open and closed an equal number of days in each of the three positions; and 2) between tents enclosing different volumes of air.

The uncontrollable variables of the environment were studied by conducting the test series on 13 days dispersed over a 2-month period and making careful note of temperature, windspeed, and environmental radiation.

Finally, the influence of liner-fabric properties was studied by including, in addition to the standard fabric liner and the standard unlined tent as controls, fabrics varying in weight, air permeability, thickness, and surface emissivity.

### 1. Physical Properties of Liner Fabrics

The physical properties of the liner fabrics, as found at the Quartermaster Research and Engineering Center in Natick, Mass., are given in Table IV. The code letter for each liner is also given. (The unlined tent was given the code letter "a").

The 3.8-oz sheeting "b" represents the standard liner available from stock. It is a highly permeable fabric easily penetrated by wind.

## TABLE IV

### Physical Properties of Coded Tent Liner Fabrics - Phase I

| | (b) Standard Sheeting | (c) Cotton Sateen | (d) Nylon, Chloropr-Coated | (e) Nylon, CSP*- & Chloropr-Coated | (f) Nylon, Aluminized & Chloropr-Coated | (g) Nylon (low twist) |
|---|---|---|---|---|---|---|
| Weight (oz/yd$^2$) | 4.4 | 10.2 | 6.0 | 8.3 | 4.7 | 2.5 |
| Thickness (mils @0.01 psi) | 31 | 53 | 9 | 18 | 11 | 7 |
| Air permeability (ft$^3$/min/ft$^2$) | 186 | 5 | Impermeable | Impermeable | Impermeable | 57 |
| Surface emissivity** Face and back | 0.68x0.68 | 0.68x0.66 | 0.73x0.58 | 0.54x0.52 | 0.50x0.25 | 0.74x0.74 |
| Heat transf coef ($U_2$)*** Face and back | 8.7x8.7 | 5.2x5.2 | 17.7x14.2 | 9.5x9.0 | 12.7x7.0 | 38.0x38.0 |
| Thermal resistance (clo) Face and back | 0.13x0.13 | 0.22x0.22 | 0.09x0.08 | 0.12x0.13 | 0.09x0.16 | 0.03x0.03 |
| Volume of air enclosed by liner (ft$^3$) | 2815 | 2515 | 2805 | 2775 | 2745 | 2700 |
| Ends and picks/inch | 52x45 | 110x94 | 122x74 | 66x35 | 126x72 | 40x43 |
| Break strength, Grab (lb) Warp and filling | 46x45 | 177x166 | 58x78 | 346x299 | 90x71 | 160x172 |
| Tear strength, Elmendorf (lb) Warp and filling | 4.0x3.3 | 8.0x11.3 | 1.0x0.6 | 11.7x12.6 | 0.8x0.6 | 24.2x23.0 |
| Flexibility (lb x $10^{-4}$) Standard temperature Warp and filling | 8x7 | 30x60 | 30x20 | 170x110 | 30x20 | 6x12 |
| Low temperature (-40°F) Warp and filling | - | - | 940x980 | 2000x2110 | 720x480 | - |

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* CSP = chlorosulphonated polyethylene

** Expressed in terms of dimensionless numbers (0 = no emissivity; 1 = total emissivity)

*** In units of BTU/hr °F ft$^2$

The 9-oz cotton sateen "c" represents a fabric of low air permeability. It was the thickest liner tested in this series.

The 4.5-oz chloroprene-coated nylon "d" and the 8.5-oz nylon liner "e", chlorosulphonated polyethylene-coated on one side and chloroprene-coated on the other side, were included because they are impermeable fabrics having similar surface characteristics but different thicknesses.

The 4.5-oz nylon "f", aluminized on one side and chloroprene-coated on the other side, was included to show the effect of a reflective surface. Liners "d", "e", and "f" are impermeable to air; liners "d" and "f" differ in thickness by only 2 mils (at 0.01 psi).

The final experimental liner of this series, a 2.1-oz nylon (low-twist yarns) "g", was included to show the effect of porosity, particularly in relation to an impermeable fabric of comparable thickness, in this case the 4.5-oz chloroprene-coated liner "d". These two fabrics differ not only in porosity but also in surface emissivity, a property important in heat transfer.

The overall heat transfer coefficient, or $U_2$, includes heat transfer by conduction, convection, and radiation combined.

Thermal resistance is expressed in "clo"*, a value calculated from the heat transfer coefficient.

Volume of air enclosed within each tent was calculated from the tent dimensions. The volume was reduced by lining the tents. Heavy liners that tended to sag lowered the ceiling of the tent and reduced the volume (Fig. 7).

The data relative to ends and picks per inch, breaking strength, tearing strength, and flexibility are listed for information purposes only or for possible future specification action. It should be noted that the flexibility of the coated fabrics decreased considerably at the low temperature of -40°F.

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*The "clo" is a unit of insulation: the amount of insulation necessary to maintain comfort and a mean skin temperature of 92°F in a room at 70°F, with air movement not over 10 ft/min, with humidity not over 50%, and with a metabolism rate of 50 $cal/m^2/hr$. Ordinary business clothing has an insulation value of about 1 clo.

Figure 7. Tent, Interior, Showing Sagging of Liner

During a pretest run made to check the equipment and procedures, the increase in effective insulation (amount of heat saved) due to the use of a liner reached a high of 683 BTU/hr °F. (See below.) The average amount of heat saved was 312 BTU/hr °F (or 23 percent) for the standard sheeting "b", and 428 BTU/hr °F (or 31 percent) for the cotton sateen "c".

| | (a) Unlined Tent | (b) Standard Sheeting Liner | | (c) Cotton Sateen Liner | |
|---|---|---|---|---|---|
| **DATE** | Heat Input (BTU/hr °F) | Heat Input (BTU/hr °F) | Heat Saved (BTU/hr °F) | Heat Input (BTU/hr °F) | Heat Saved (BTU/hr °F) |
| 19-20 Jan | 1331 | 1092 | 239 | 990 | 341 |
| 20-21 " | 1433 | 1058 | 375 | 922 | 511 |
| 26-27 " | 1468 | 1058 | 410 | 1126 | 342 |
| 27-28 " | 1265 | 990 | 275 | 956 | 309 |
| 28-29 " | 1265 | 990 | 275 | 956 | 309 |
| 29-30 " | 1160 | 887 | 273 | 682 | 478 |
| 31 Jan - 1 Feb | 1570 | 1230 | 340 | 887 | 683 |
| Average | 1356 | 1044 | 312 | 931 | 428 |
| Average Heat Saved (%) | 0 | — | 23 | — | 31 |

The tents in which the liners were used were 16- by 32-foot Standard, Medium, General Purpose, FWWMR-treated, Olive Drab, manufactured according to Specification MIL-T-1712E. Each tent liner had two ventilating ports and was tested with the ports open and also with the ports closed.

## 2. Test Results

The test conditions and results of Phase I are given in detail in Table V. The results will be discussed according to the effect of each of the variables, insofar as the test conditions permit.

## TABLE V

### Heat Requirements of Tents and Tent Conditions - Phase I

| Test No. | Date of Test (1959) | Tent Pos. | Liner (code)[x] | Liner Vent | Lapsed Time (hrs) | Heat Requirement (KWH) | Heat Requirement (BTU/hr °F)[#] | Temperature Outdoor Ambient | Temperature Indoor[†] | Temperature Dif | RH[@] | Windspeed (knots) | Wind Dir. | General Weather Conditions | Net Exchange Radiation (BTU/hr ft²) Outside Tents High | Outside Tents Low | Outside Tents Avg (Wtd) | Inside Tents High | Inside Tents Low | Inside Tents Avg (Wtd) | Total Nighttime Radiant Cooling (BTU/ft²) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 2 Feb | 1 | a | - | 16.0 | 320 | 1365 | 18 | 68 | 50 | 35 | 2-3 Gusts-7 | WNW<br>WSW | Fair | -31.0 | -35.6 | -33.3 | +12.8 | -2.4 | +5.2 | -21,539 |
| | | 2 | b | open | | 255 | 1160 | | 65 | 47 | | | | | -31.8 | -35.1 | -33.4 | - | - | - | |
| | | 3 | c | closed | | 198 | 785 | | 68 | 50 | | | | | -28.8 | -32.4 | -30.6 | - | - | - | |
| II | 5 Feb | 1 | b | open | 16.0 | 194 | 1297 | 36 | 68 | 32 | 55 | 3-5 Gusts less than 10, Calm | WNW | Fair | - | - | - | - | - | - | -11,589 |
| | | 2 | g | closed | | 150 | 1024 | | 67 | 31 | | | | | - | - | - | - | - | - | |
| | | 3 | c | open | | 169 | 1092 | | 69 | 33 | | | | | - | - | - | - | - | - | |
| III | 6 Feb | 1 | d | open | 16.0 | 273 | 1229 | 18 | 65 | 47 | 40 | 2-4 Gusts-7 | NNW<br>W | Fair, Clear | - | - | - | - | - | - | -26,669 |
| | | 2 | g | open | | 264 | 1160 | | 66 | 48 | | | | | - | - | - | - | - | - | |
| | | 3 | b | closed | | 273 | 1195 | | 67 | 49 | | | | | - | - | - | - | - | - | |
| IV | 9 Feb | 1 | e | open | 15.5 | 237 | 1092 | 20 | 68 | 48 | 87 | Calm | | Snow, Sleet | - | - | - | - | - | - | +1,150 |
| | | 2 | c | closed | | 178 | 819 | | 68 | 48 | | | | | - | - | - | - | - | - | |
| | | 3 | b | open | | 230 | 1092 | | 67 | 47 | | | | | - | - | - | - | - | - | |
| V | 12 Feb | 1 | e | closed | 15.5 | 189 | 922 | 25 | 69 | 44 | 78 | 2-4 Gusts-4 | SW | Clear to ptly cldy | -18.7 | -28.9 | -23.8 | - | - | - | -7,519 |
| | | 2 | f | open | | 175 | 956 | | 65 | 40 | | | | | -16.1 | -17.6 | -16.8 | - | - | - | |
| | | 3 | a | - | | 255 | 1297 | | 68 | 43 | | | | | -23.1 | -28.8 | -25.9 | +7.6 | -2.8 | +2.3 | |
| VI | 15 Feb | 1 | g | open | 15.0 | 226 | 1195 | 23 | 66 | 43 | 61 | 2-4 Variable & calm | | Fair, Clear | - | - | - | - | - | - | -23,308 |
| | | 2 | f | closed | | 199 | 1092 | | 65 | 42 | | | | | - | - | - | - | - | - | |
| | | 3 | d | open | | 221 | 1160 | | 67 | 44 | | | | | - | - | - | - | - | - | |
| VII | 16 Feb | 1 | f | closed | 15.5 | 132 | 785 | 36 | 72 | 36 | 78 | 3-4 | SW | Ptly cldy | - | - | - | - | - | - | -4,644 |
| | | 2 | e | open | | 173 | 1195 | | 68 | 32 | | | | | - | - | - | - | - | - | |
| | | 3 | d | closed | | 149 | 1024 | | 68 | 32 | | | | | - | - | - | - | - | - | |
| VIII | 19 Feb | 1 | g | closed | 15.5 | 284 | 1092 | 9 | 66 | 57 | 42 | 7-10 Gusts-10 | NW<br>WSW | Clear, Fair | -31.9 | -35.2 | -33.6 | - | - | - | -26,713 |
| | | 2 | e | closed | | 247 | 956 | | 65 | 56 | | | | | -32.5 | -34.2 | -33.4 | - | - | - | |
| | | 3 | f | open | | 284 | 1126 | | 64 | 55 | | | | | -36.0 | -36.4 | -36.2 | - | - | - | |
| IX | 20 Feb | 1 | c | closed | 16.0 | 227 | 819 | 11 | 69 | 58 | 28 | 2-4 Gusts-8 | WNW | Fair, Clearing | -25.1 | -28.6 | -27.8 | - | - | - | -22,158 |
| | | 2 | d | open | | 282 | 1092 | | 65 | 54 | | | | | -33.9 | -38.9 | -36.4 | - | - | - | |
| | | 3 | f | closed | | 231 | 887 | | 67 | 56 | | | | | -39.6 | -41.5 | -40.6 | - | - | - | |
| X | 24 Feb | 1 | f | open | 15.5 | 237 | 1092 | 21 | 68 | 47 | 46 | 2-4 Gusts-8, Variable | | Rain, Clearing | - | - | - | +30.5 | +11.1 | +20.8 | -11,720 |
| | | 2 | d | closed | | 189 | 922 | | 66 | 45 | | | | | - | - | - | +10.3 | -3.8 | +3.2 | |
| | | 3 | e | closed | | 189 | 922 | | 67 | 46 | | | | | - | - | - | +13.6 | +3.8 | +8.7 | |
| XI | 25 Feb | 1 | b | closed | 15.5 | 219 | 887 | 14 | 67 | 53 | 38 | Calm | | Fair, Clear | - | - | - | +14.7 | +0.2 | +7.4 | -11,145 |
| | | 2 | c | open | | 211 | 922 | | 65 | 51 | | | | | - | - | - | +15.6 | +1.5 | +8.6 | |
| | | 3 | e | open | | 226 | 922 | | 68 | 54 | | | | | - | - | - | +14.6 | +3.8 | +9.2 | |
| XII | 26 Feb | 1 | d | closed | 15.5 | 197 | 921 | 26 | 72 | 46 | 68 | Calm | | Ptly cldy, Cldy, Rain | - | - | - | +10.3 | +3.8 | +7.0 | -6,634 |
| | | 2 | a | - | | 210 | 1092 | | 68 | 42 | | | | | - | - | - | +1.2 | -6.8 | -2.8 | |
| | | 3 | g | open | | 197 | 1024 | | 69 | 43 | | | | | - | - | - | +28.6 | +9.5 | +19.0 | |
| XIII | 5 Mar | 1 | c | open | 15.5 | 170 | 990 | 35 | 72 | 37 | 74 | 1-2 Gusts-4, Variable | | Ptly cldy turning to snow | - | - | - | - | - | - | -4,953 |
| | | 2 | b | closed | | 178 | 1263 | | 66 | 31 | | | | | - | - | - | - | - | - | |
| | | 3 | g | closed | | 177 | 1126 | | 69 | 34 | | | | | - | - | - | - | - | - | |

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[x] a. no liner; b. cotton sheeting; c. cotton sateen; d. chloroprene-coated nylon; e. chlorosulphonated polyethylene- and chloroprene-coated nylon; f. aluminized and chloroprene-coated nylon; g. nylon (producer's twist)

[#] Adjusted for temperature difference and lapsed time.

[†] At 4 feet from ground

[@] As measured at main weather station

### a. Effect of a Liner

The amount of heat saved in the Phase I lined tents with vents closed as compared to the unlined tent reached a high of 443 BTU/hr °F, or an average heat saving of 282 BTU/hr °F (Table VI).

### TABLE VI

### Heat Requirements and Savings for Lined and Unlined Tents - Phase I (BTU/hr °F)

| Liner | Open Vents | | | | | Closed Vents | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pos.1 | Pos.2 | Pos.3 | Avg | Saved | Pos.1 | Pos.2 | Pos.3 | Avg | Saved | Grand Avg | Avg Saved |
| a | 1365 | 1092 | 1297 | 1251 | - | - | - | - | - | - | 1251 | - |
| b | 1297 | 1160 | 1092 | 1183 | 68 | 887 | 1263 | 1195 | 1115 | 136 | 1149 | 102 |
| c | 990 | 922 | 1092 | 1001 | 250 | 819 | 819 | 785 | 808 | 443 | 904 | 347 |
| d | 1229 | 1092 | 1160 | 1160 | 91 | 921 | 922 | 1024 | 956 | 295 | 1058 | 193 |
| e | 1092 | 1195 | 922 | 1070 | 181 | 922 | 956 | 922 | 933 | 318 | 1002 | 249 |
| f | 1092 | 956 | 1126 | 1058 | 193 | 785 | 1092 | 887 | 921 | 330 | 990 | 261 |
| g | 1195 | 1160 | 1024 | 1126 | 125 | 1092 | 1024 | 1126 | 1081 | 170 | 1103 | 148 |
| Avg* | 1149 | 1081 | 1069 | 1100 | 151 | 904 | 1013 | 990 | 969 | 282 | 1034 | 217 |

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* Tent "a" had no liner, therefore "a" was not used in calculating column averages.

### b. Effect of Relative Position of Tents

The advantages or disadvantages inherent to the relative positions of the tents were determined by averaging the heat requirements for each liner in each of the three positions during the 13 test days. The liners were tested twice in each position. The average heat requirements for each position were remarkably uniform (Table VII); this indicates that the test results were not influenced by position.

## TABLE VII

### Average Heat Requirements* in Three Tent Positions - Phase I (BTU/hr °F)

| | Position 1 | Position 2 | Position 3 |
|---|---|---|---|
| Average heat requirement | 1053 | 1050 | 1050 |
| Lowest and highest values | 785-1365 | 819-1263 | 785-1297 |
| Range of requirements | 580 | 444 | 512 |

---

*Including "a" and lined tents with open and closed vents.

### c. Effect of Tent and Liner Construction

1) Ventilators. The difference in heat requirements between the unlined tent and the lined tents with vents open and closed is shown in Table VIII. The data show that the lined tents with vents closed required, on an average, 22 percent less heat than the unlined tent, representing substantial savings in fuel during the varied weather conditions of the 13 test days. The insulating value of the tents with liner vents open averaged only slightly more than half that of the tents with vents closed.

## TABLE VIII

### Average Heat Requirements and Savings with Liner Vents Open and Closed - Phase I (BTU/hr °F)

| | Unlined Tent (no vent) | Lined Tent | |
|---|---|---|---|
| | | Open Vent | Closed Vent |
| Heat input | 1251 | 1100 | 969 |
| Heat saved due to liner | - | 151 | 282 |
| Heat saved (%) | - | 12 | 22 |

2) Volume of air enclosed. The volume of air enclosed within the lined tents was found to be considerably less for liner "c", probably due to its greater weight and thus greater sagging. The low heat requirements of this tent probably were largely due to the reduced volume. The data on volume and average (open and closed vent) heat requirements in Table IX indicate a general relationship between heat requirements and volume and suggest the value of lowering the tent ceiling.

## TABLE IX

## Relation of Volume of Air Enclosed to Average Heat Requirements and Savings - Phase I

| Liner | Volume (cu ft) | Heat Input (BTU/hr °F) | Heat Saved (BTU/hr °F) |
|---|---|---|---|
| a. unlined tent | 3610 | 1251 | 0 |
| b. 3.8-oz sheeting standard | 2815 | 1149 | 102 |
| c. 9-oz cotton sateen | 2515 | 904 | 347 |
| d. 4.5-oz nylon, chloroprene-coated | 2805 | 1058 | 193 |
| e. 8.5-oz nylon, CSP* - and chloroprene-coated | 2775 | 1002 | 249 |
| f. 4.5-oz nylon, alum. and chloroprene-coated | 2745 | 990 | 261 |
| g. 2.1-oz nylon (low twist) | 2700 | 1103 | 148 |

*CSP = chlorosulphonated polyethylene

### d. Effect of Environment

The spread in heat requirements can be accounted for in part by considering the effect of windspeed, temperature difference between the inside and outside of the tent, and environmental radiation. Although these variables are discussed separately, they interacted so that evaluation of one necessarily includes the others as well. Evaluation of each variable alone would require a test in which each environmental condition is isolated.

1) Windspeed. That the heat requirements of a tent increase with windspeed has been shown by the Quartermaster R&E Field Evaluation Agency* and by the University of Louisville** under contract with the Quartermaster Corps. The same phenomenon was observed in the

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* Sanders, J.L., A Field Test of Heat Requirements for General Purpose Tents. QMFEA Tech Rpt T-21, 55097F.

** Barnes, W.R. et al, Improved Design of Tents and Tentage Materials. Progress Reports to OQMG, 1946-53, Ft. Lee, Va., 1957.

unlined tent of the present test, even though the maximum windspeed seldom exceeded 7 knots (Table V). On Test Day I, during which the maximum windspeed was 7 knots, the heat requirements of the unlined tent were greater than those of either of the lined tents, and greater for the lined tent with the ventilators open than for the lined tent with the ventilators closed (Table X). The same relationship was demonstrated on Test Days V and XII. These data demonstrated for the first time that the percentage of heat saved in a lined tent as compared with an unlined tent increases with even an intermittent breeze of 4 to 7 knots. For data on higher windspeeds, further testing is required.

## TABLE X

### Heat Requirements (BTU/hr °F) and Percentage of Heat Saved in Lined and Unlined Tents under Various Wind Velocities - Phase I

| Test Day | Maximum Windspeed (knots) | Unlined Tent | Lined Tents | | | Heat Saved (%) |
|---|---|---|---|---|---|---|
| | | | Vent Open | Vent Closed | Average | |
| I | 7 | 1365 | 1160 | 785 | 972 | 29 |
| V | 4 | 1297 | 956 | 922 | 939 | 28 |
| XII | calm | 1092 | 1024 | 921 | 972 | 11 |
| Average | | 1251 | 1047 | 876 | 961 | 23 |

2) Temperature difference. The differences between the outside and inside ambient temperatures on the three days the unlined tent was tested are summarized in Table XI. It appears that, in general, the lower the outside temperature (the greater the temperature difference) the greater the percentage of heat saved in a lined tent as compared with an unlined tent.

## TABLE XI

### Relation of Difference between Outside and Inside Temperatures to Heat Requirements and Savings - Phase I (BTU/hr °F)

| Test Day | Avg. Temp. Difference (°F) | Heat Requirements | | Heat Saved by Liner | Percentage Heat Savings |
|---|---|---|---|---|---|
| | | Unlined Tent | Lined Tents (avg) | | |
| I | 49 | 1365 (pos.1) | 972 | 393 | 29 |
| V | 42 | 1297 (pos.2) | 939 | 358 | 28 |
| XII | 44 | 1092 (pos.3) | 972 | 120 | 11 |

3) Environmental radiation. It was expected that environmental cooling at night would influence the heat requirements. It was also expected that on clear, cool nights, the radiant heat loss to the sky would be greater than on cloudy, relatively warm nights. The data presented in Table XII and Figure 8 confirm this. With clearer skies, environmental radiation increased and heat requirements increased. In general, however, the increase was small, amounting to a maximum average difference of only 9 percent for the extremes of radiation encountered.

## TABLE XII

## Relation of Environmental Radiation to Heat Requirements (BTU/hr °F) on Three Test Days - Phase I

| Environ. Radiation* (BTU/ft²) | Weather | Unlined Tent | Lined Tents Vent Open | Lined Tents Vent Closed | Average Requirement | Increase (%) |
|---|---|---|---|---|---|---|
| -6,634 | Ptly cldy, rain, 26° | 1092 | 1024 | 921 | 1012 | - |
| -7,519 | Clear to ptly cldy, 25° | 1297 | 956 | 922 | 1056 | 4.3 |
| -21,539 | Fair, 18° | 1365 | 1160 | 785 | 1103 | 9.0 |

---

* Total nighttime radiant cooling

### e. Effect of Liner Fabric Properties

1) Thickness. Table XIII compares the heat requirements of two liners, one with double the thickness of the other. Liner "e", the thicker, required approximately 5.3 percent less heat than the thinner liner "d".

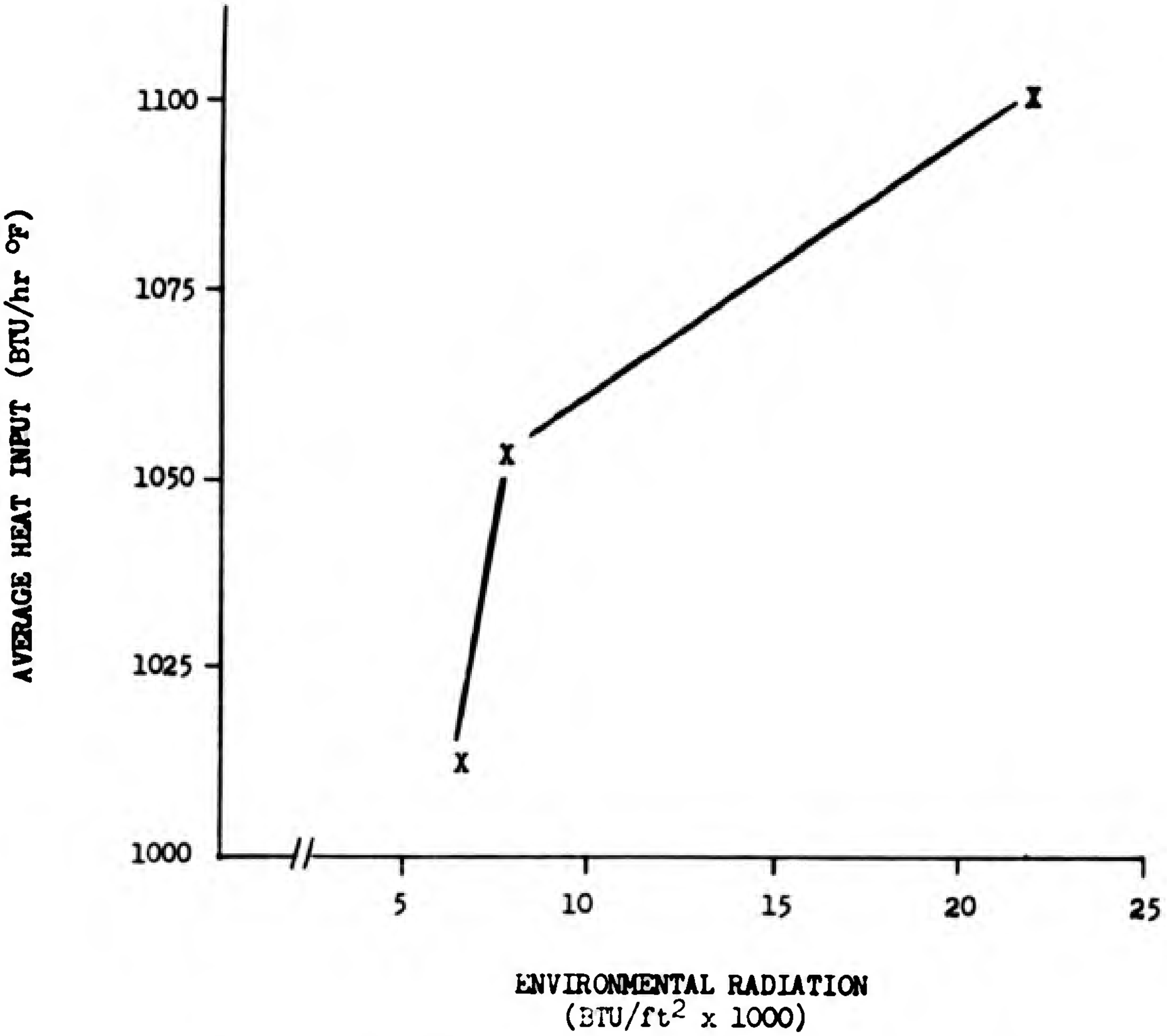

**Figure 8. Relation of Environmental Radiation to Heat Requirements of Lined Tents - Phase I**

## TABLE XIII

### Relation of Liner Thickness to Heat Requirements of Tents - Phase I (BTU/hr °F)

| Liner | Thickness (mils @ 0.01 psi) | Heat Input Requirements* | | |
|---|---|---|---|---|
| | | Vent Open | Vent Closed | Average |
| d. Nylon, chloroprene-coated | 9 | 1160 | 956 | 1058 |
| e. Nylon, CSP**- & chloroprene-coated | 18 | 1070 | 933 | 1002 |

---

* Average of 3 positions

** CSP = chlorosulphonated polyethylene

The thickest and heaviest fabric ("c") was consistently lowest in heat requirements (Table VI), which at first glance might be attributed to its greater thickness. However, this liner enclosed the smallest volume of air. Further study on thickness is indicated.

In Figure 9, the thickness of two coated ("d" and "e") and two uncoated ("b" and "c") liner fabrics is plotted against their thermal resistance measured in clo; also given is Burton's insulation values on filled air spaces*. Since the liner values found in this study follow the Burton curve, extrapolated, a thickness-insulation relationship to filled air spaces is indicated. Figure 9 shows that all four of these liners fall below the 0.1-inch thickness that is considered practical from the standpoint of insulation.

2) Air permeability. Table XIV shows the air permeability and heat requirements of liners "b", "c", "e", and "g". Although these liners vary in air permeability by from 0 to 186 cu ft/min/sq ft, they differed in their averaged heat requirements by only 21 percent (from a high of 1149 BTU/hr °F to a low of 904). The data are insufficient to permit definite conclusions about this property.

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* Burton, A.C., Insulation by Reflection and the Development of a Reflecting Cloth, QMC Res Lab., Lawrence, Mass., 1943.

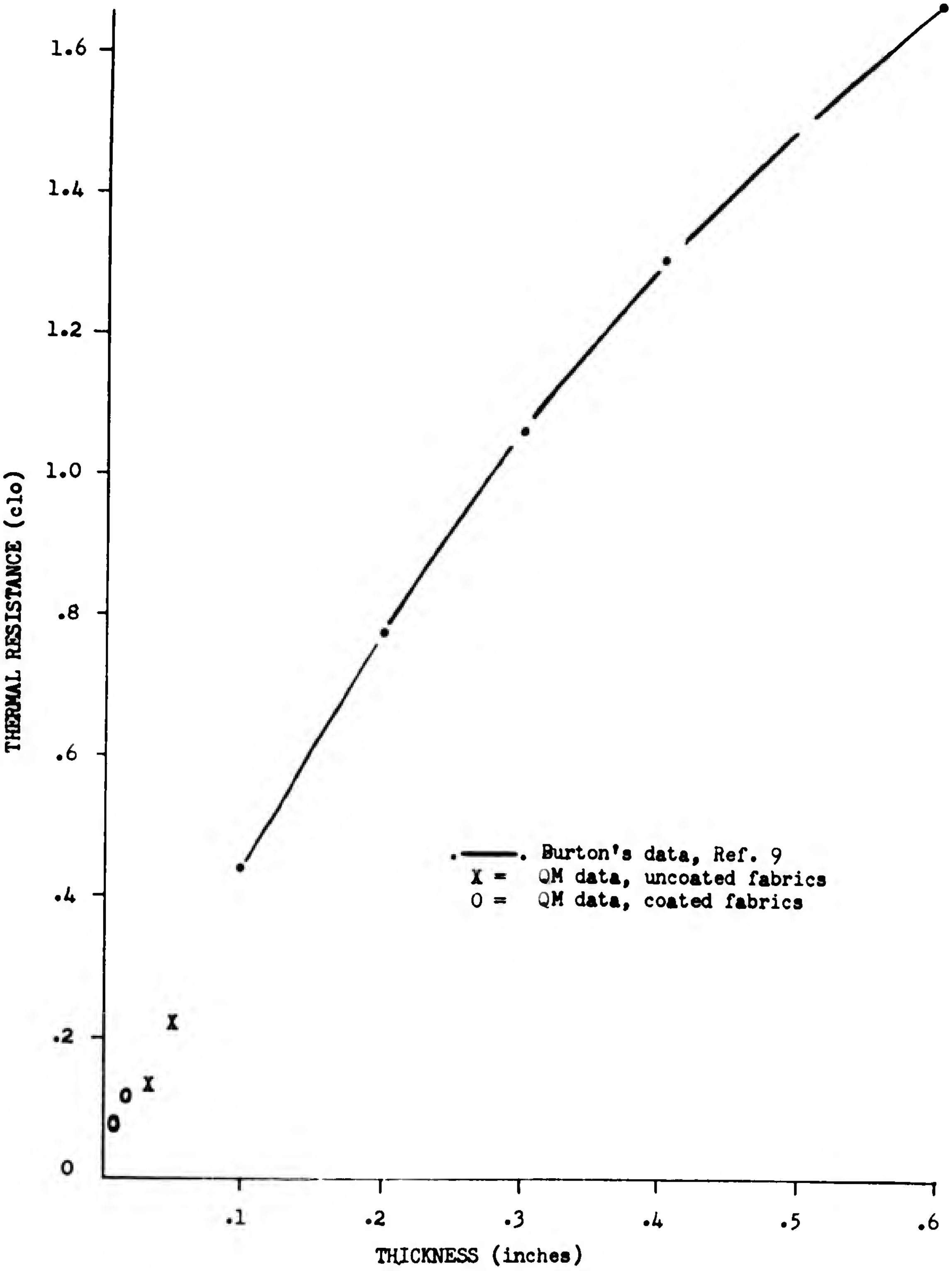

Figure 9. Liner Thickness Compared to Thermal Resistance by Filled Air Spaces - Phase I

## TABLE XIV

### Relation of Air Permeability to Heat Requirements and Savings - Phase I (BTU/hr °F)

| Liner | Air Permeability (ft³/min/ft²) | Heat Requirements* Vent Open | Vent Closed | Avg | Heat Saved by Closed Liner** |
|---|---|---|---|---|---|
| b. Cotton sheeting | 126 | 1183 | 1115 | 1149 | 136 |
| c. Cotton sateen | 5 | 1001 | 808 | 904 | 443 |
| e. Nylon, CSP***- & chloropr-coated | 0 | 1070 | 933 | 1002 | 318 |
| g. Nylon (low twist) | 57 | 1126 | 1081 | 1103 | 170 |

---

* Average of 3 positions, see Table VI
** Based on unlined average heat requirement of 1251 BTU/hr °F
*** CSP = chlorosulphonated polyethylene

3) Surface emissivity. To show the effect of surface emissivity on heat requirements, two chloroprene-coated liners ("d" and "f") were compared in the laboratory. The data on heat requirements, surface emissivity, and thermal conductance (or heat transfer coefficient) are shown in Table XV. Because the two surfaces of the fabrics (the black chloroprene-coated face and uncoated back of "d", and the black chloroprene-coated face and aluminized back of "f") could be expected to have different emissive characteristics, the surface emissivity and heat transfer coefficient were measured for both sides of these fabrics.

## TABLE XV

### Relation of Surface Emissivity and Heat Transfer Coefficient to Heat Requirements and Savings - Phase I

| Tent Liners | Surface Emissivity (in dimensionless numbers) | Heat Transfer Coefficient ($U_2$) (BTU/hr °F ft²) | Average Heat Required (BTU/hr °F) | Saved* |
|---|---|---|---|---|
| Liner "d": nylon, chloroprene-coated: | | | | |
| Chloroprene face to cold (black) | 0.73 | 17.7 | 1058 | 193 |
| Uncoated back to cold | 0.58 | 14.2 | not tested | |
| Liner "f": nylon, alum. & chloroprene-coated: | | | | |
| Chloroprene face to cold (black) | 0.50 | 12.7 | 990 | 261 |
| Alum back to cold | 0.25 | 7.0 | not tested | |

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* Based on unlined tent average heat requirement of 1251 BTU/hr °F

It should be noted that the average heat requirements for the two liners, with their black surface facing the cold, differed by only 68 BTU/hr °F, representing a saving of only 6.5 percent. This saving is low when compared to the difference between their emissive properties (31%) and thermal conductance (28%).

The data in Table XV show that, when placed toward the cold area, a reflective surface loses less radiant heat (has lower surface emissivity) and is therefore a better insulator (has a lower heat transfer coefficient) than a black surface. Indeed, when the reflective surface of liner "f" faced the warmer area (and the black side faced the cold), surface emissivity and radiant heat loss practically doubled, bringing its overall insulation close to that of liner "d" with its uncoated side to the cold. Therefore, in order to obtain the full benefit from reflective insulation, the reflective surface must face the colder area.

To determine whether the emissive properties of the liner fabrics, as determined in the laboratory, would influence radiant heat transfer from the tent to the sky or inside the tent from the liner to the ground, field test measurements were made of the net-exchange radiation or radiant heat transfer for each liner. The results are shown in Table XVI.

## TABLE XVI

### Radiant Heat Transfer Outside and Inside Tents - Phase I (BTU/hr ft$^2$)

| | Deck Fabric to Sky (outside, nighttime) | | | Liner to Ground (inside tent) | | |
|---|---|---|---|---|---|---|
| | High | Low | Average | High | Low | Average |
| a. Unlined tent | -31.0 | -35.6 | -33.3 | +12.8 | -2.4 | +5.2 |
| b. Standard sheeting liner | -31.8 | -35.1 | -33.4 | +14.7 | +0.2 | +7.4 |
| c. Cotton sateen liner | -28.8 | -32.4 | -30.6 | +15.6 | +1.5 | +8.6 |
| d. Nylon liner, chloroprene-coated | -33.9 | -38.9 | -36.4 | +10.3 | -3.8 | +3.2 |
| e. Nylon liner, CSP*- and chloroprene-coated | -32.5 | -34.2 | -33.4 | +13.6 | +3.8 | +8.7 |
| f. Nylon liner, aluminized and chloroprene-coated | -36.0 | -36.4 | -36.2 | +30.5 | +11.1 | +20.8 |
| g. Nylon (low-twist) liner | -31.9 | -35.2 | -33.6 | +28.6 | +9.5 | +19.0 |

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* CSP = chlorosulphonated polyethylene

The data in Table XVI clearly show that radiation to the sky (a negative value) was about the same for each tent, indicating a similar amount of radiant cooling from lined and unlined tents. However, the amount of radiation within the tent, from the liners to ground, differed markedly and appeared to be dependent on the emissive properties of the liner. As was expected, the aluminized liner "f" (with aluminized side towards the warm interior) showed the highest positive radiation, followed, in decreasing amounts, by the OD-colored low-twist nylon "g", the white cotton sateen "c", the offwhite standard cotton sheeting "b", liner "e", the OD duck of the unlined tent "a" and, finally, the chloroprene-coated nylon "d" liner (with black surface towards the warm interior). It should be noted that the OD duck of the unlined tent ("a") and the black chloroprene-coated liner ("d") also showed some negative radiation, indicating that radiant heat was received by the fabric from the ground. This negative radiation occurred near the end of the "off period" of the thermostatically-controlled heating cycle and continued for a short time after the stoves were turned on again.

These findings suggest that liners having a light or aluminized surface are desirable from the standpoint of comfort and heat savings. The light surfaces tested appeared to continue to reflect heat to the interior of the tent and to allow the occupants to sustain lower interior temperatures than would have been possible with liners having dark or nonreflecting surfaces, which indicates that the emissive properties of fabrics are important to comfort. This is in agreement with Herrington's conclusion in his "Comfort Conditioning of Tents"*.

## 3. Conclusions

Results of the Phase I tests, while not conclusive, indicate that:

a. The relative position of a tent within the group does not significantly change the heat requirements of the tent.

b. Heat requirements are decreased by: using a liner with its ventilators closed (savings of up to 22%); diminished tent volume; lack of wind; warm outside temperature (low temperature differential); and rainy or overcast weather.

c. Air permeability and thickness appear to exert only a minor influence on the insulating properties of a liner; however, the results indicate the need for further tests.

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* Herrington, L. P., Report to OQMG, May 1954

d. Based on laboratory data alone, a reflective liner appears to be able to help conserve heat if its reflective surface faces outward. In the field test, the reflective surface of liner "f" faced inward and, while that improved the comfort appreciably, it did not affect the heat requirements to any great extent.

e. Liners that are light in color or highly reflective inside (for example, white, offwhite, or aluminized), will reflect radiant heat to the occupants and allow them to sustain lower ambient temperatures (and still be comfortable) than would be possible with darker liners.

# APPENDIX B

## DETAILS OF HEAT-RETENTION STUDY OF TENT LINERS, PHASE II
## (February-March 1960)

# APPENDIX B

## DETAILS OF HEAT-RETENTION STUDY OF TENT LINERS, PHASE II
(February-March 1960)

Phase I of this study (Appendix A) permitted certain tentative conclusions about the effect of tent position, liner construction and fabric, and the environment on the heat requirements of tents. However, the limitations imposed by low windspeeds (none higher than gusts of 10 knots) and the limited data on environmental radiation and on the reflectivity or surface emissivity of the liners made it desirable that an additional test be run to provide more quantitative information about the effect of high winds and environmental radiation and of a wider range of liner fabric properties. Accordingly, a second test (Phase II) was set up for February and March 1960.

The testing techniques and heating equipment were the same for Phase II as for Phase I.

To determine the effect of high winds on the insulating properties of the tent liners, a more exposed test site was selected. As in Phase I, the relative position of each tent was considered,to ensure that the results would not be influenced by any advantage or disadvantage due to a particular position or to the position of one tent with respect to the other. The new site provided space for only two tents: position 1 to the north, and position 2 to the south. The ridgepoles of both tents were pointed in an east-west direction.

The original plan for Phase II called for the evaluation of windspeed and environmental radiation on a 3-point intensity scale of low, medium, and high, with 10 tests at each position on the scale. However, the weather and time limited the number of testing days to 28 instead of 30. (Phase I had covered only 13 days.) In order to extend the windspeed curve, a fourth category was added to make a 4-point scale of high, medium high, medium low,and very low windspeeds.

Three new experimental liners were included in Phase II: a napped modacrylic liner "h", a cotton poplin liner "i" laminated on one side with polyester film, and a cotton poplin liner "j" with aluminized polyester film on one side and aluminum foil cemented to the other side. These fabrics permitted the study particularly of increased thickness and surface reflectivity. The liner fabrics were selected for test purposes only and do not necessarily represent practical tent liner materials. The unlined tent "a" and the standard 3.8-oz sheeting liner "b" of Phase I remained as controls in order to permit the results of both phases to be correlated.

Since in Phase I the greatest heat savings were achieved with closed vents, only closed vents were used in Phase II.

## 1. Physical Properties of Liner Fabrics

Table XVII lists the Phase II liners and gives their physical properties as found in the laboratory or in the literature.

TABLE XVII

Physical Properties of Coded Tent Liner Fabrics - Phase II

| | (b) Standard Sheeting | (h) Napped Modacrylic | (i) Poplin* with Alum. Polyester Film | (j) Poplin* with Alum. Film & Alum. Foil |
|---|---|---|---|---|
| Weight (oz/yd$^2$) | 4.4 | 7.2 | 8.1 | 12.2 |
| Thickness (mils @0.01 psi) | 31 | 86 | 35** | 45** |
| Air permeability (ft$^3$/min/ft$^2$) | 186 | 55 | impermeable | |
| Surface emissivity*** Face and back | 0.68x0.68 | 0.67x0.64 | 0.68x0.60 | 0.58x0.43 |
| Heat transfer coef. ($U_2$)**** Face and back | 8.7x3.7 | 2.19x2.06 | 2.34x2.26 | 2.26x1.87 |
| Volume of air enclosed (ft$^3$) | 2815 | 2755 | 2838 | 2850 |
| Ends and picks/inch | 52x45 | 43x29 | - | - |
| Breaking strength, Grab (lb) Warp and filling | 46x45 | 157x31 | - | - |

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* Cotton poplin base fabric: 5.5-oz/yd$^2$, 28 mils thick

** Thickness at 1.0 psi due to wrinkled condition of liner (at 0.01 psi: 75 and 95 mils respectively)

*** Expressed in terms of dimensionless numbers, with "zero" representing complete non-emission and "1" complete radiation.

**** In units of BTU/hr °F ft$^2$

The 7.2-oz modacrylic liner "h", napped on one side, represents the thickest fabric tested in either Phase II or Phase I. Its raised surface fibers increased thickness (insulation) without increasing weight. The liner was constructed and tested with the napped surface of the fabric facing the warm interior of the tent. This enhanced the insulating properties of the material by taking advantage of the relatively thick layer of heated air trapped by the protruding fibers.

The 8.1-oz cotton poplin liner "i", laminated with a 1-mil, 1-oz/yd$^2$ aluminized polyester film on one side, represents an impermeable material with one surface highly reflective. Since the Phase I laboratory tests had indicated that the emissive properties (low radiant heat loss when facing a cold surface) of a reflective surface are more important to heat-retention than the ability to reflect heat to the warm interior of the tent, this liner was tested with the aluminized surface facing the cold canvas deck.

The 12-oz cotton poplin liner "j" was constructed from the same basic fabric as "i". In addition to the aluminized polyester film laminated on one side, liner "j" has a 0.5-mil aluminum foil cemented to the other side. This fabric was included to show the effect of a relatively smooth metal reflective surface on heat retention. However, in cementing the aluminum foil to the fabric, it was difficult to obtain a firm bond. A good deal of the "j" liner material could not be used because of air pockets formed by the loose foil and because of bare spots where the foil had peeled off. Also, it was difficult to sew this liner because the foil separated and peeled along the line of stitching. Enough material having the aluminum suitably bonded to the fabric was available for the roof of this liner (from the peak of the liner to where it joined the side walls), but the side walls had to be made from the "i" fabric (without the aluminum foil). Liner "j" was constructed so that its aluminized polyester film surface would face the warm interior of the tent and its aluminum foil surface (or else its uncoated surface) would face the cold canvas of the tent.

Volume differences between the Phase II tents were small and therefore, in this series of tests, volume was discounted as a factor influencing heat retention.

The data on ends and picks per inch, breaking strength, and air permeability are listed but for information purposes only, or for possible future specification action.

## 2. Test Results

In Table XVIII the test conditions and results of Phase II are.

## TABLE XVIII

### Heat Requirements of Tents and Test Conditions - Phase II

| Test No. | Date of Test (1960) | Tent Pos. | Liner (code)* | Lapsed Time (hrs) | Heat Input Requirement (KWH) | Heat Input Requirement (KW/°F) | Heat Input Requirement (BTU/hr °F)# | Temperature Outdoor (°F) | Temperature Indoor (°F) | Temperature Dif (°F) | RH | Windspeed High (knots) | Windspeed Low (knots) | Windspeed Avg (knots) | Wind Dir | Nighttime Radiationø High (BTU/ft²) | Nighttime Radiationø Low (BTU/ft²) | Nighttime Radiationø Total (BTU/ft²) | Sky Cover# |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 4 Feb(61) | 1 (N) | a | 17.00 | 279 | 0.350 | 1191 | 21 | 68 | 47 | 74 | 21.0 | 4.0 | 11.5 | ENE | - | - | - | 6.0 |
| | (a recheck) | 2 (S) | i | 17.00 | 162 | 0.194 | 664 | | 70 | 49 | | | | | | | | | |
| II | 3 Feb | 1 (N) | a | 16.00 | 211 | 0.425 | 1452 | 30 | 61 | 31 | 62 | 12.0 | Calm | 4.4 | NNE-NNW | +133 | -1,194 | -16,541 | 0.2 |
| | | 2 (S) | b | 16.00 | 179 | 0.267 | 909 | | 72 | 42 | | | | | | | | | |
| III | 4 Feb | 1 (N) | h | 16.00 | 90 | 0.160 | 546 | 34 | 69 | 35 | 57 | 3.0 | Calm | 0.8 | W-NNW | +708 | -1,128 | -13,467 | 1.3 |
| | | 2 (S) | b | 16.25 | 163 | 0.250 | 854 | | 74 | 40 | | | | | | | | | |
| IV | 7 Feb | 1 (N) | h | 15.50 | 100 | 0.154 | 525 | 28 | 70 | 42 | 51 | 16.0 | 10.0 | 13.4 | NW | +597 | -1,592 | -19,570 | 2.3 |
| | | 2 (S) | b | 15.50 | 191 | 0.398 | 1358 | | 59 | 31 | | | | | | | | | |
| V | 10 Feb | 1 (N) | h | 16.25 | 74 | 0.147 | 502 | 42 | 73 | 31 | 90 | 6.0 | Calm | 2.1 | SE | +265 | -398 | -929 | 9.4 |
| | | 2 (S) | i | 16.25 | 101 | 0.240 | 819 | | 68 | 26 | | | | | | | | | |
| VI | 13 Feb | 1 (N) | h | 17.50 | 110 | 0.149 | 511 | 26 | 71 | 45 | 54 | 10.0 | Calm | 4.2 | N-E | -464 | -531 | -2,432 | 10.0 |
| | | 2 (S) | i | 17.50 | 136 | 0.216 | 738 | | 62 | 36 | | | | | | | | | |
| VII | 14 Feb | 1 (N) | h | 17.75 | 139 | 0.260 | 887 | 24 | 55 | 31 | 64 | 23.0 | 10.0 | 16.2 | WNW | +243 | -1,459 | -13,511 | 5.7 |
| | | 2 (S) | i | 17.75 | 164 | 0.328 | 1119 | | 53 | 29 | | | | | | | | | |
| VIII | 16 Feb | 1 (N) | a | 16.00 | 158 | 0.254 | 866 | 30 | 69 | 39 | 58 | 7.0 | Calm | 2.1 | WNW-WSW | +1,614 | -1,327 | -14,595 | 1.8 |
| | | 2 (S) | i | 16.00 | 115 | 0.199 | 679 | | 66 | 36 | | | | | | | | | |
| IX | 17 Feb | 1 (N) | b | 16.00 | 120 | 0.234 | 798 | 33 | 65 | 32 | 76 | 26.0 | 4.0 | 12.0 | NE-SE | +1,747 | -420 | -1,703 | 10.0 |
| | | 2 (S) | h | 15.75 | 100 | 0.181 | 659 | | 68 | 35 | | | | | | | | | |
| X | 19-22 Feb | 1 (N) | b | 88.00 | 727 | 0.236 | 805 | 30 | 65 | 35 | 66 | 10.0 | Calm | 3.6 | N-NNW | - | - | - | 5.2 |
| | | 2 (S) | h | 88.00 | 614 | 0.179 | 611 | | 69 | 39 | | | | | | | | | |
| XI | 23 Feb | 1 (N) | b | 15.75 | 151 | 0.266 | 908 | 28 | 64 | 36 | 55 | 9.0 | 2.0 | 5.7 | N-NNW | +2,233 | -1,459 | -19,482 | 0.0 |
| | | 2 (S) | h | 15.75 | 144 | 0.234 | 798 | | 67 | 39 | | | | | | | | | |
| XII | 24 Feb | 1 (N) | a | 16.00 | 177 | 0.284 | 969 | 28 | 67 | 39 | 58 | 8.0 | Calm | 2.6 | S-E | - | - | - | 0.0 |
| | | 2 (S) | h | 16.00 | 124 | 0.194 | 662 | | 68 | 40 | | | | | | | | | |
| XIII | 25 Feb | 1 (N) | i | 15.75 | 102 | 0.240 | 818 | 35 | 62 | 27 | 86 | 13.0 | 4.0 | 9.8 | S-E | - | - | - | 10.0 |
| | | 2 (S) | h | 15.75 | 137 | 0.229 | 781 | | 73 | 38 | | | | | | | | | |
| XIV | 26 Feb | 1 (N) | i | 16.25 | 116 | 0.188 | 641 | 35 | 73 | 38 | 60 | 11.0 | 4.0 | 8.4 | NNW-W | -66.3 | -1,429 | -14,683 | 4.7 |
| | | 2 (S) | a | 16.25 | 203 | 0.338 | 1152 | | 72 | 37 | | | | | | | | | |
| XV | 27 Feb | 1 (N) | i | 16.00 | 132 | 0.206 | 703 | 31 | 71 | 40 | 53 | 22.0 | 10.0 | 13.7 | NW | +2,786 | -1,459 | -17,868 | 2.5 |
| | | 2 (S) | a | 16.00 | 191 | 0.254 | 867 | | 66 | 35 | | | | | | | | | |

TABLE XVIII (Continued)

| Test No. | Date of Test (1960) | Tent Pos. | Liner (code)* | Lapsed Time (hrs) | Heat Input Requirement (KWH) | Heat Input Requirement $(\frac{KW}{^oF})$ | Heat Input Requirement (BTU/hr °F)■ | Temperature Outdoor (°F) | Temperature Indoor (°F) | Temperature Dif | RH | Windspeed High (knots) | Windspeed Low (knots) | Windspeed Avg (knots) | Wind Dir | Nighttime Radiation◊ High (BTU/ft2) | Nighttime Radiation◊ Low (BTU/ft2) | Nighttime Radiation◊ Total (BTU/ft2) | Sky Cover⊕ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XVI | 28 Feb | 1 (N) | i | 15.25 | 107 | 0.146 | 498 | 29 | 77 | 48 | 52 | 10.0 | Calm | 3.5 | NW | +3,184 | -1,283 | -13,887 | 5.0 |
| | | 2 (S) | a | 15.25 | 182 | 0.272 | 928 | | 73 | 44 | | | | | | | | | |
| XVII | 29 Feb | 1 (N) | i | 16.00 | 145 | 0.189 | 645 | 27 | 75 | 48 | 87 | 7.0 | 5.0 | 5.5 | NW | +1,017 | -1,526 | -13,445 | 4.3 |
| | | 2 (S) | b | 16.00 | 223 | 0.297 | 1012 | | 74 | 47 | | | | | | | | | |
| XVIII | 1 Mar | 1 (N) | a | 16.00 | 209 | 0.409 | 1395 | 19 | 61 | 42 | 40 | 15.0 | 8.0 | 11.2 | N-NW | +2,587 | -398 | -17,027 | 0.0 |
| | | 2 (S) | b | 16.00 | 247 | 0.360 | 1228 | | 62 | 43 | | | | | | | | | |
| XIX | 3 Mar | 1 (N) | b | 16.00 | 196 | 0.255 | 870 | 27 | 75 | 48 | 88 | 27.0 | 8.0 | 11.7 | E-NE | - | - | - | 10.0 |
| | | 2 (S) | a | 16.00 | 212 | 0.294 | 1003 | | 72 | 45 | | | | | | | | | |
| XX | 10 Mar | 1 (N) | b | 16.00 | 205 | 0.273 | 931 | 28 | 65 | 47 | 34 | 14.0 | 3.0 | 8.3 | NE | +1,216 | -1,459 | -19,261 | 0.7 |
| | | 2 (S) | h | 16.00 | 199 | 0.204 | 696 | | 77 | 49 | | | | | | | | | |
| XXI | 15 Mar | 1 (N) | b | 16.50 | 155 | 0.224 | 765 | 27 | 69 | 42 | 63 | 7.0 | Calm | 0.9 | NE-NW | +1,260 | -1,305 | -14,816 | 0.7 |
| | | 2 (S) | j | 16.50 | 138 | 0.164 | 656 | | 78 | 51 | | | | | | | | | |
| XXII | 17 Mar | 1 (N) | a | 16.00 | 205 | 0.291 | 992 | 34 | 78 | 44 | 94 | 9.0 | Calm | 3.8 | N-SE | +398 | -1,039 | -2,256 | 9.3 |
| | | 2 (S) | j | 16.00 | 115 | 0.144 | 491 | | 84 | 50 | | | | | | | | | |
| XXIII | 20 Mar | 1 (N) | i | 16.50 | 148 | 0.176 | 600 | 34 | 85 | 51 | 60 | 4.0 | Calm | 1.0 | N-NW | +1,482 | -1,150 | -13,932 | 2.9 |
| | | 2 (S) | j | 16.50 | 115 | 0.122 | 416 | | 81 | 47 | | | | | | | | | |
| XXIV | 22 Mar | 1 (N) | h | 16.00 | 162 | 0.184 | 628 | 28 | 83 | 55 | 62 | 8.0 | Calm | 4.7 | ESE-N | +1,725 | -1,459 | -18,465 | 2.0 |
| | | 2 (S) | j | 16.00 | 130 | 0.133 | 454 | | 79 | 51 | | | | | | | | | |
| XXV | 24 Mar | 1 (N) | j | 16.00 | 115 | 0.126 | 430 | 34 | 91 | 57 | 62 | 10.0 | Calm | 5.7 | SSW | - | - | - | 6.8 |
| | | 2 (S) | a | 16.00 | 200 | 0.261 | 890 | | 72 | 38 | | | | | | | | | |
| XXVI | 28 Mar | 1 (N) | j | 16.00 | 116 | 0.148 | 505 | 38 | 87 | 49 | 46 | 6.0 | Calm | 3.5 | ESE-SW | +1,327 | -1,747 | -18,133 | 4.1 |
| | | 2 (S) | b | 16.00 | 171 | 0.254 | 868 | | 80 | 42 | | | | | | | | | |
| XXVII | 29 Mar | 1 (N) | j | 16.00 | 83 | 0.115 | 393 | 42 | 87 | 45 | 77 | 2.0 | Calm | 1.5 | SSE | +3,980 | -1,327 | -7,497 | 9.0 |
| | | 2 (S) | a | 16.00 | 170 | 0.253 | 861 | | 84 | 42 | | | | | | | | | |
| XXVIII | 1 Apr | 1 (N) | j | 16.50 | 112 | 0.145 | 493 | 40 | 87 | 47 | 86 | 9.0 | Calm | 5.0 | ESE-N | -22.11 | -442 | -2,897 | 10.0 |
| | | 2 (S) | i | 16.75 | 129 | 0.160 | 546 | | 88 | 48 | | | | | | | | | |

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* a. no liner; b. cotton sheeting; h. napped modacrylic; i. cotton poplin with alum polyester film; j. Cotton poplin alum polyester film & alum foil

■ Adjusted for temperature differences and lapsed time

◊ Nightly net exchange radiation (positive=heat gain from sky to tent; negative=heat loss from tent to sky)

⊕ A subjective estimate of the sky area covered by clouds (0=clear sky; 10= completely overcast) given in detail. Of the environmental conditions cited, only windspeed and nighttime environmental radiation will be discussed. The other weather data are included only to make the weather record complete.

### a. Effect of Relative Position of Tents

During the 28 tests of Phase II, liners "a", "b", "h", and "i" were tested 6 times and liner "j" 4 times in each of two locations (Table XIX). The average heat requirements (Table XX) show that the north location (position 1) required 6.4 percent less heat than the south location (position 2), indicating the north location to have been more sheltered. In order to permit a comparison of the test values of this phase, those obtained at the north location were adjusted by a factor of 1.068.

TABLE XIX

Heat Requirements (BTU/hr °F) in Two Tent Positions - Phase II

| Unlined tent "a" | | Liner "b" | | Liner "h" | | Liner "i" | | Liner "j" | |
|---|---|---|---|---|---|---|---|---|---|
| Pos.1 | Pos.2 | Pos.1 | Pos.2 | Pos.1 | Pos.2 | Pos.1 | Pos.2 | Pos.1 | Pos.2 |
| 1191 | 1152 | 798 | 909 | 546 | 659 | 818 | 664 | 430 | 656 |
| 1452 | 867 | 805 | 854 | 525 | 611 | 641 | 819 | 505 | 491 |
| 866 | 928 | 908 | 1358 | 502 | 798 | 703 | 738 | 393 | 416 |
| 969 | 1003 | 870 | 1012 | 511 | 662 | 498 | 1119 | 493 | 454 |
| 1395 | 890 | 931 | 1228 | 887 | 781 | 645 | 679 | - | - |
| 992 | 861 | 765 | 868 | 628 | 696 | 600 | 546 | - | - |

TABLE XX

Average Adjusted* Heat Requirements (BTU/hr °F) in Two Tent Positions - Phase II

| | Position 1 (North) | | Position 2 (South) |
|---|---|---|---|
| | Measured | Adjusted | Measured |
| Average heat requirement** | 759 | 811 | 811 |
| Lowest and highest values | 393-1452 | 420-1551 | 416-1358 |
| Range of heat requirements | 1059 | 1131 | 942 |

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*Adjustment factor: 1.068

**Average before conversion to BTU

### b. Effect of Environment

The heat requirements of the tents were influenced, as in Phase I, by uncontrollable environmental variables of which only windspeed and radiation will be discussed.

1) Windspeed. In Phase I, it was shown that the heat requirements during winds of up to 7 knots were greatest in the unlined tent, and were greater in a lined tent with the ventilators open than in a lined tent with the ventilators closed. During this phase, the windspeed seldom exceeded 7 knots.

In Phase II, the average daily windspeed varied from 0.8 to 16.7 knots, with gusts of up to 27 knots. There were 8 high-wind-velocity test days with windspeeds ranging from 9.8 to 16.7 knots (average of 13.2); 10 medium-high-wind test days with windspeeds ranging from 4 to 9.8 knots (average of 5.6); 5 medium-low-wind test days with windspeeds ranging from 1.8 to 4 knots (average of 2.5); and 5 very-low-wind test days with windspeeds ranging from 0.8 to 3.6 knots (average of 1.8). The heat savings by the use of a liner under these various windspeeds and the average increase in heat requirements due to increasing wind velocity are given in Table XXI.

## TABLE XXI

### Heat Requirements and Savings (BTU/hr °F) Due to Liners under Various Wind Velocities - Phase II

| Avg.Windspeed (knots)<br>Number of tests | High (13.2) (8) | | Med High (5.6) (10) | | Med Low (2.5) (5) | | Very Low (1.8) (5) | |
|---|---|---|---|---|---|---|---|---|
| | Req. | Saved | Req. | Saved | Req. | Saved | Req. | Saved |
| Unlined tent "a" | 1158 | 0 | 1163 | 0 | 981 | 0 | 893 | 0 |
| Liner "b" | 1092 | 66 | 971 | 192 | 842 | 139 | 857 | 36 |
| " "h" | 737 | 421 | 677 | 486 | 599 | 382 | 597 | 296 |
| " "i" | 852 | 306 | 664 | 499 | 675 | 306 | 660 | 233 |
| " "j" | - | - | 483 | 680 | 594 | 387 | 418 | 475 |
| Avg. all tents | 960 | | 792 | | 738 | | 685 | |
| " lined tents | 893 | 264 | 699 | 464 | 677 | 303 | 633 | 260 |
| " saved by liner (%) | | 23 | | 40 | | 30 | | 29 |

The "j" liner (aluminized polyester film/aluminum foil) showed the greatest heat savings under each of the windspeed groups in which it was tested. (Liner "j" was not tested on any high windspeed days.) Liner "h" (napped modacrylic) was a close second best in the medium-low group, narrowly third in the medium-high group, second in the very-low group, and by far the best under high wind conditions.

These data and the curves in Figure 10 confirm the findings of Phase I and point out that heat savings due to a liner increased as the windspeed built up to about 5.6 knots, after which savings slowly decreased. It should be noted that the average heat requirements increased as the wind velocity increased.

2) Environmental radiation. The Phase I tests had indicated that heat requirements increased on clear, cold nights. To further check these results, the environmental or total nighttime radiation was again determined during Phase II. The results are given in Table XXII, grouped under a 3-point scale, and also in Figure 11.

TABLE XXII

Relation of Nighttime Environmental Radiation (BTU/ft$^2$) to Heat Requirements and Savings (BTU/hr °F) - Phase II

| Environ. Radiation<br>Number of tests | High (-18,421)<br>(8) | | Medium (-11,919)<br>(10) | | Low (-907)<br>(10) | |
|---|---|---|---|---|---|---|
| | Req. | Saved | Req. | Saved | Req. | Saved |
| Unlined tent "a" | 1236 | 0 | 1028 | 0 | 984 | 0 |
| Liner "b" | 1021 | 215 | 909 | 119 | 890 | 14 |
| " "h" | 677 | 559 | 714 | 314 | 630 | 354 |
| " "i" | 751 | 585 | 699 | 329 | 774 | 210 |
| " "j" | 548 | 688 | 454 | 574 | 475 | 509 |
| Avg. saved by liner | | 512 | | 334 | | 272 |
| " " " " (%) | | 41 | | 32 | | 28 |

The data in Table XXII and in Figure 11 confirm the Phase I findings and clearly show the general differences among the liners in heat requirements and savings during high, medium, and low nighttime environmental radiation. The curves of Figure 11 point up the consistantly high value for liner "j" in reducing radiant heat loss (in increasing heat saved) at each level. The "h" liner showed greater heat savings than the "i" liner at low levels of radiation, but at higher levels of radiation, the "i" liner showed slightly more heat savings than the "h" liner. These data suggest the value of insulating tents against radiant heat loss by the use of a reflective surface.

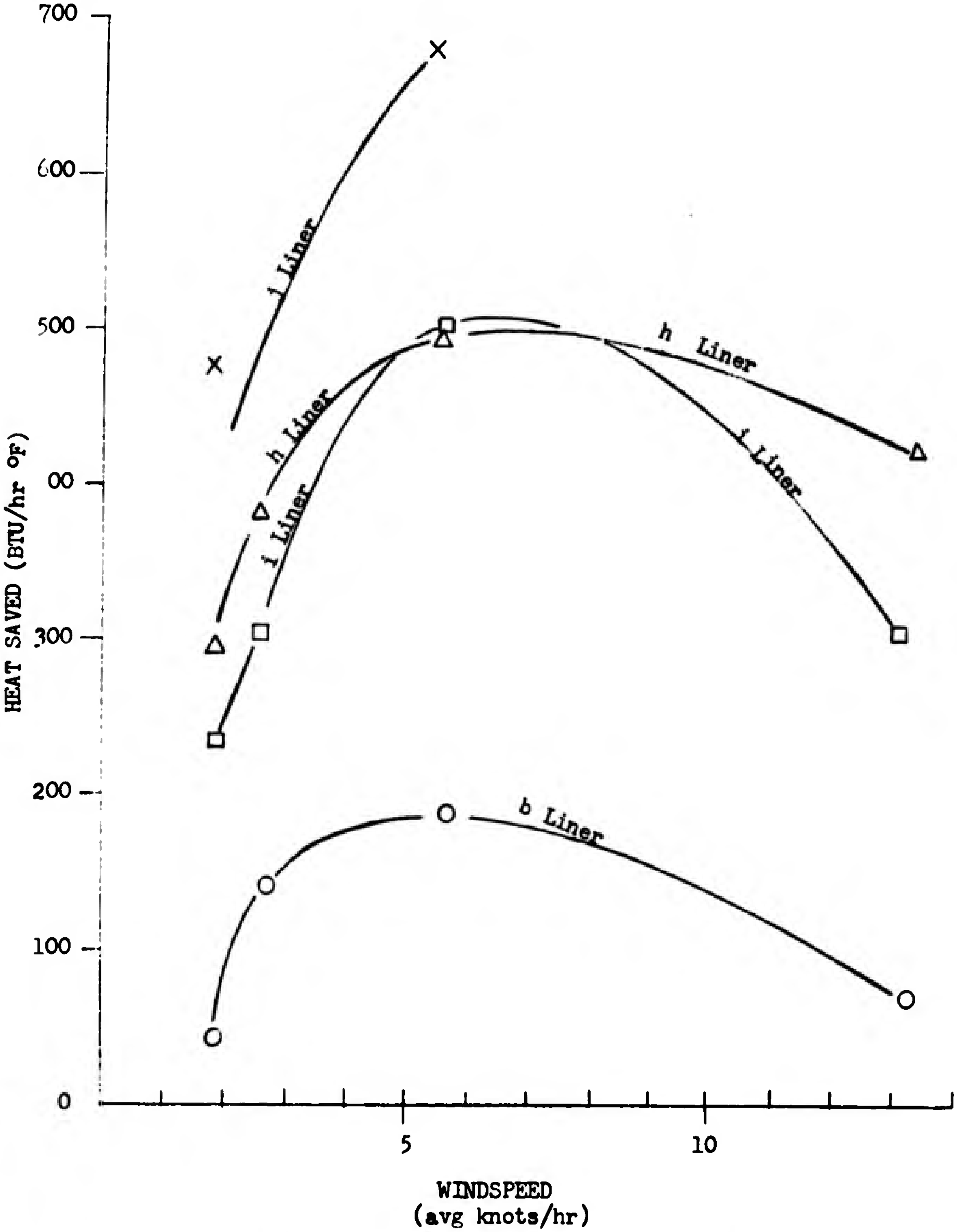

Figure 10. Relation of Windspeed to Heat Savings - Phase II

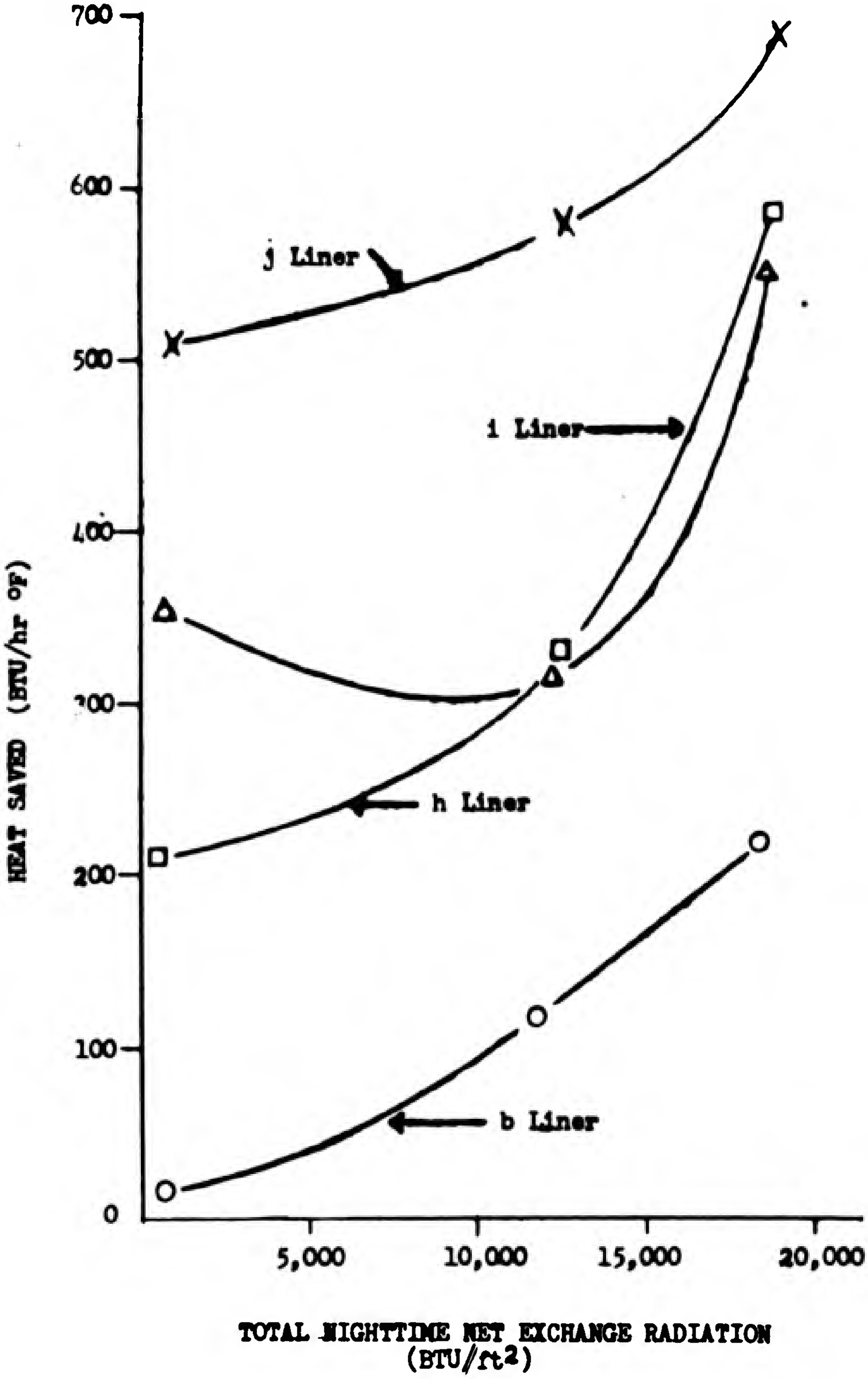

Figure 11. Relation of Total Nighttime Radiation to Heat Savings - Phase II

The correlation between total nighttime negative radiation and subjectively determined sky cover (Fig. 12) suggests that the subjective evaluation of sky cover can be useful in estimating nighttime radiant heat loss.

### c. Effect of Liner Fabric Properties

From the heat-requirement data summarized in Table XIX, it is clear that, under the climatic conditions encountered, the tent lined with the "j" fabric (aluminized polyester film/aluminum foil) required the least amount of heat. The other liners, in the order of low to high heat requirements, are the "h" (napped modacrylic) and the "i" (aluminized polyester film).

1) Thickness. Table XXIII compares liner thickness with average heat requirements.

### TABLE XXIII

### Relation of Liner Thickness to Average Heat Requirements - Phase II (BTU/hr °F)

| Liner | Thickness (mils @0.01psi) | Average Heat Requirements | | | Average Heat Saved |
|---|---|---|---|---|---|
| | | Position 1 (adj)* | Position 2 | Overall | |
| a | - | 1222 | 950 | 1086 | - |
| b | 32 | 904 | 1038 | 971 | 115 |
| h | 86 | 641 | 701 | 671 | 415 |
| i | 35** | 695 | 761 | 728 | 358 |
| j | 45** | 486 | 504 | 495 | 591 |

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* Adjustment factor: 1.068

** At 1.0 psi due to wrinkled condition of liner (at 0.01 psi: "i" and "j" were 75 and 95 mils respectively).

The thickest liner (napped modacrylic "h"), and the only Phase II experimental liner that at present is practical for use, showed an overall average heat requirement (adjusted) of 671 BTU/hr °F as against 1086 for the unlined tent. This represents heat savings of 415 BTU/hr °F, or 38 percent.

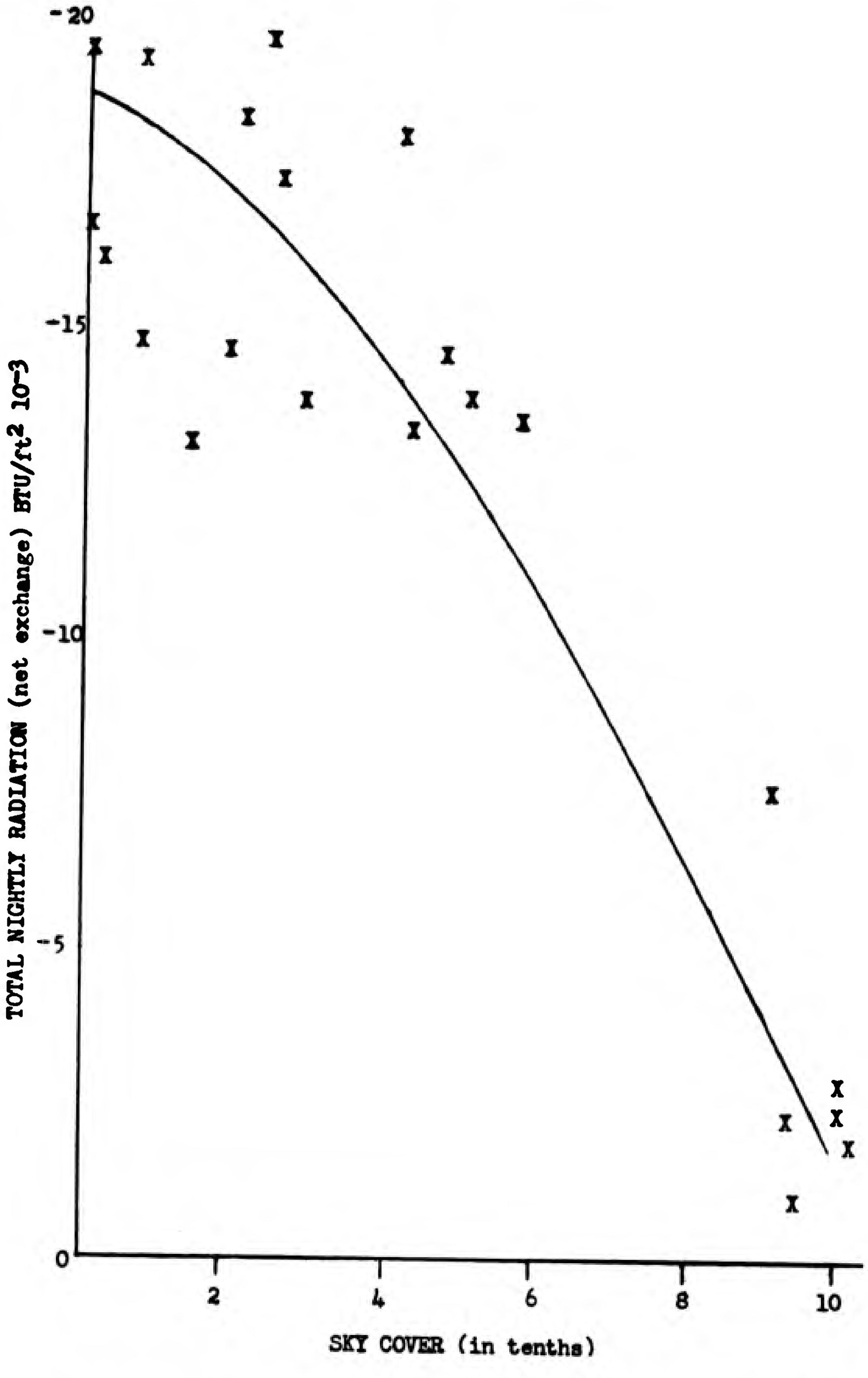

Figure 12. Relation of Total Nighttime Radiation to Sky Cover – Phase II

Figure 13 compares the heat savings of the permeable liners (solid line) with those of the impermeable reflective liners (broken line). In each group, the thicker fabric gives the greater heat savings. This is particularly true at low levels of nighttime environmental radiation (on nights when the sky is overcast), probably because the insulation of a thick material introduces a greater temperature gradient between the warmer and colder sides of the fabric.

2) Surface emissivity. Table XXIV gives the surface emissivity and heat transfer coefficient data of the liners together with their heat savings as averaged in Table XXIII.

### TABLE XXIV

### Relation of Surface Emissivity and Heat Transfer Coefficient to Heat Requirements and Savings - Phase II

| Liners | Surface Emissivity (in dimensionless numbers) | Heat Transfer Coefficient ($U_2$) (BTU/hr °F ft$^2$) | Overall Amount of Heat Req* (BTU/hr °F) | Overall Amount of Heat Saved** (BTU/hr °F) |
|---|---|---|---|---|
| Sheeting "b" | | | | |
| Face to cold | 0.68 | 8.70 | - | - |
| Back to cold | 0.68 | 8.70 | 971 | 115 |
| Modacrylic "h" | | | | |
| Napped face to cold | 0.67 | 2.19 | - | - |
| Smooth back to cold | 0.64 | 2.06 | 671 | 415 |
| Alum.polyester film poplin "i" | | | | |
| Uncoated face to cold | 0.68 | 2.34 | - | - |
| Film to cold | 0.60 | 2.26 | 728 | 358 |
| Polyester film/foil poplin "j" | | | | |
| Film side to cold | 0.58 | 2.26 | - | - |
| Foil side to cold | 0.43 | 1.87 | 495 | 591 |

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* Position 1 adjusted by factor of 1.068

** Based on unlined tent average heat requirement of 1086 BTU/hr °F

The low emissivity aluminum foil liner "j" shows the greatest heat savings: 591 BTU/hr °F or 54 percent of the heat requirements of the unlined tent. The napped liner "h" is second best in heat savings.

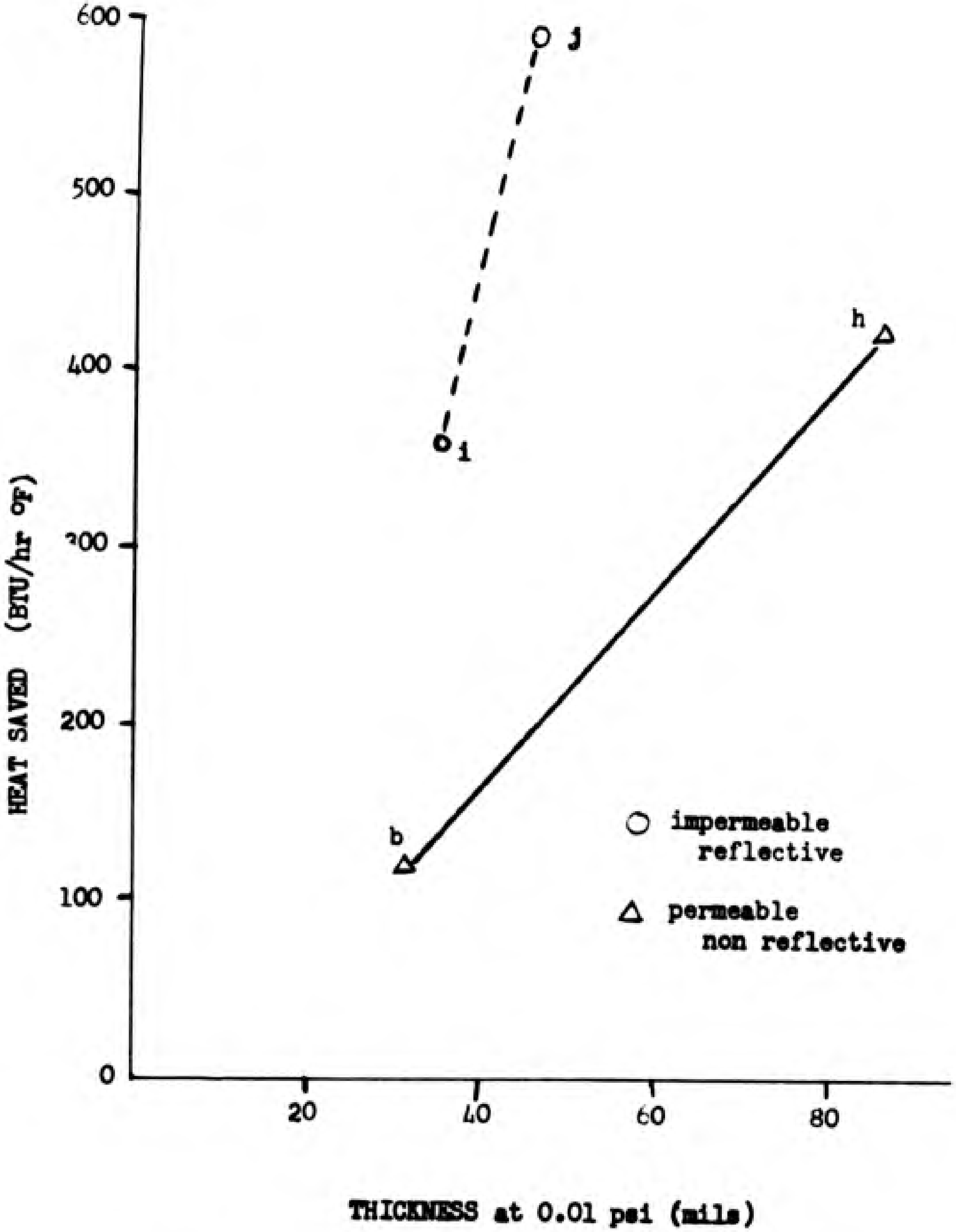

Figure 13. Relation of Fabric Thickness to Heat Savings - Phase II

The data in Tables XXIII and XXIV suggest that the most effective combination of properties in a tent liner, from the standpoint of conserving heat, is thickness (by napping one side of the material) and surface emissivity (with the reflective surface facing the cold). A combination of an aluminum foil reflective surface and a thick, napped fabric should, therefore, ensure highly efficient heat conservation.

3. Conclusions

a. The results of the Phase II test show that the most practical tent liner fabric of the four studied is the napped modacrylic liner "h". This liner permitted an overall heat saving of 38 percent under the climatic conditions encountered in this study. The greatest savings in Phase I were from the cotton sateen liner (35%).

b. The cotton poplin "j", with the aluminized polyester film/aluminum foil laminate, though not now practical for tent liner application, showed the highest heat savings of all the liners tested (54%). This liner demonstrated the value of a reflective surface in reducing the amount of heat input to a lined tent.

c. Aluminum foil is a more efficient reflector than aluminized polyester film when the latter is used with the aluminized side cemented to the supporting fabric.

d. The heat-saving capabilities of the liners increased with increased wind velocity, up to a maximum of 5.6 knots, and with increased nighttime environmental radiation (increased clearness of the sky). Above 5.6 knots, the heat-saving capabilities of the liners decreased. The combined data on the effect of windspeed and environmental radiation suggest that on calm, cloudy nights, the heat savings due to the use of liners could be negligible.

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Quartermaster Research & Engineering Center, Natick, Mass. HEAT-RETENTION PROPERTIES OF TENT LINERS by Constantin J. Monego and Herbert J. Rasor, November 1962, 71 pp illus (Textile Series Report No. 122)

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5. Textiles
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