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UNIVERSITY OF LOUISVILLE

TEMPERATURE RELATIONSHIPS IN TENT STRUCTURES

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A Thesis

Submitted to the Faculty

of the Graduate School

of the University of Louisville

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF CHEMICAL ENGINEERING

Department of Chemical Engineering

Earl R. Gerhard

///

December, 1947

TEMPERATURE RELATIONSHIPS IN TENT STRUCTURES

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Approved by the Examining Committee.

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December, 1947

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ABSTRACT

This thesis on the temperature relationships in tent structures consists of three parts: (1) Temperature Control in Tents - Winter Phase; (2) Temperature Control in Tents - Summer Phase; and (3) Arctic Shelter Design.

A theory of heat transfer into and from tents was developed and applied to the experimental data. In the winter phase a study was made of large wall tents and squad tents using as insulators, liners of 4 oz. white cotton, 8 oz. O.D. 7 cotton and one-half inch thick fiberglas quilted between two layers of 4 oz. white cotton. Measurements were made of air and fabric temperatures over a range of weather conditions with a known heat input to the tents. Overall heat transfer coefficients were calculated for a comparison of the insulating value of the several liners. The effectiveness of the liners also was indicated by a comfort index for each tent and liner combination. Another comparison was made on the basis of weight, bulk, and fuel savings.

In the summer phase work a study was made of the effect of hooded flies on the comfort conditions within tents. These hooded flies completely shaded the tent from direct solar radiation. Flies of single and double layers of fabrics were used and conclusions reached as to the best method of reducing temperatures within tents.

The design modifications of a vehicle-portable arctic shelter frame are presented, the changes resulting from studies and tests conducted by the Army in the Arctic during the winter of 1946.

INTRODUCTION

With the advent of World War II, an increased interest was shown in the living conditions of soldiers. Since the majority of troop maneuvers did not permit the construction of permanent shelters, the use of tents, especially in overseas areas, became an important consideration. The use of existing tents in tropical and near arctic operations brought out the many deficiencies in the types of tentage then available. Accordingly, a series of research stations were established by the Office of the Quartermaster General to improve the tents and tentage materials for military use. One phase of the research was the study of temperature control in tents, and research on this phase was begun at the University of Louisville Institute of Industrial Research in 1945. This thesis is a presentation of the data and results obtained in 1947 on temperature control in tents for both summer and winter phases, and the design of a vehicle-portable arctic shelter.

During the winter, in moderate or cold climates, considerable heat must be supplied to maintain comfortable conditions in tents and it is necessary to use insulation in addition to that of the tent fabric to keep the fuel consumption to a low value. For this investigation it was considered desirable to use liners to reduce heat loss and to study the effectiveness of liners of different size, shape, and materials of construction. In addition, a study of the effect of wind, relative humidity, ground, and air temperatures on the heat transfer of various tent-liner combinations was necessary.

In summer weather, exposed tent fabrics absorb sufficient solar radiation to raise the fabric temperature and the inside air temperature considerably above ambient air temperature. This temperature rise produces uncomfortable and frequently unendurable conditions within a closed tent,

and even an open tent may be far from comfortable because of radiation from the tent fabric to the occupant.

Preliminary investigations were undertaken of the use of flies to shade the tent deck from direct solar radiation, thereby reducing the inside air and fabric temperatures and tending to make the tent more comfortable. These results indicated the need for additional studies with flies of special design.

The extremes of both summer and winter tentage problems are encountered in the Arctic where satisfactory large tent structures for winter use are nonexistent. The necessity for an all-purpose vehicle-portable arctic shelter led to the design of an aluminum, arched-rib frame to be covered with an insulating fabric. The uneven terrain upon which this shelter would be erected prompted the design of ridged floor beams and ribs. For ease of erection and expansion a sectional type unit, capable of easy assembly under adverse weather conditions, was favored. Although overall dimensions, structure type, and materials of construction were dictated by the housing function to be served by this tent, the perfection or alteration of many details was desirable in order to correct inadequacies of the original design.

HISTORICAL

From the time of primitive man, tents had been used as shelters by nomadic tribes. Later tents became the main housing for mobile army units. During these many centuries, the structural properties of tents essentially remained the same. Soon after the beginning of World War II the necessity of more suitable tent structures led to the establishment of research stations to investigate the problem of improved tent design. One phase of this study was the temperature relationships in tent structures.

The immediate problem was to determine the best methods of making the existing army tentage comfortable in both cold and warm climates. Results of laboratory and field tests conducted between January 1945 and June 1946 on temperature control in tents are presented in an 18 month report on "Improved Design of Tents and Tentage Material ".(1) Included in this report are the results of field tests on summer phase temperature control in tents and laboratory studies of the radiation and convection properties of fabrics. The use of a fly in preference to a liner, and the use of a fabric of high reflectivity and low emissivity are recommended for summer phase temperature control.

Further studies on summer phase temperature control and many of the data in this thesis are presented in a report from the University of Louisville Institute of Industrial Research on Temperature Control Studies covering the period from June 1, 1946, to June 1, 1947. Other literature on the subject of temperature control in tents is to be found in the textile reports from the Office of the Quartermaster General.(2) However, no literature has been located on winter studies of cotton liners although liners periodically have been used for many years in cold climate tentage.

While comparatively little was known of the value of insulation in tents, much work has been done on insulation and heat loss in other

fields. A study of the heating analysis of plywood panels as made by Raber and Hutchinson in their book "Panel Heating and Cooling Analysis"(3) was useful in this study as well as ideas obtained from the American Institute of Heating and Ventilating Engineers (A.I.H.V.E.) publications.

Prior to World War II, army units were housed in either temporary shelters (tents) or permanent solid foundation buildings when time and conditions permitted their erection. However, during this war a vehicle-portable shelter capable of serving in the more adverse weather conditions of the Arctic was found desirable. Accordingly, in June 1946, the design of such a unit was undertaken at the University of Louisville Institute of Industrial Research.(4) The original plans of this unit called for an aluminum frame covered with a fabric-insulation system and although the basic unit remained the same, the many modifications and alterations of details did not permit the completion of the design until recently.

THEORETICAL

WINTER PHASE CONSIDERATIONS

The standard army tent is constructed of 12.29 oz. cotton duck. It is woven into panels 36 inches wide and approximately 0.03 inches thick. The length of these panels depends upon the size and shape of the particular type of tent structure in which they are used. The fabric is supported by wooden poles in the center and at the corners of the tent structure by ropes attached to pegs in the ground. The fabric panels are sewn together at the seams and laced together at the corners and end openings.

When the air inside a tent is heated, it increases in temperature, and, its increased heat content is given by $W C_p (t_2 - t_1)$, where

W = weight of the mass of air

C_p = specific heat of air

t_2 = final air temperature

t_1 = initial air temperature.

This air loses heat by convection to the inside surface of the liner, by conduction through the liner and by radiation and convection to the tent fabric. Finally, this heat is lost from the outside surface of the tent by convection to the ambient air and radiation to the surroundings.

During the heating period

$$\left(\frac{dQ}{d\theta} \right)_{\text{Heaters}} = C_p W \frac{dt}{d\theta} + \left(\frac{dQ'}{d\theta} \right)_{\text{Loss}} \quad (1)$$

where,

$\frac{dQ}{d\theta}$ = heat flow (Q) per unit time (θ)

$\frac{dt}{d\theta}$ = change of air temperature (t) with time (θ)

and

$$\left(\frac{dq'}{d\theta} \right)_{\text{Loss}} = U A \Delta t \quad (2)$$

where

U = overall coefficient of heat transfer

A = area

Δt = temperature difference between the contents of the tent and the outside surroundings.

When equilibrium has been obtained with a constant heat input and unidirectional heat flow, $C_p W \frac{dt}{d\theta}$ becomes 0 and ,

$$q_{\text{heater}} = U A \Delta t \quad (3)$$

where

q = the heat transferred per unit time.

The heat input from the heaters ultimately can be lost by conduction through the ground and by convection and radiation from the outside tent surface. If the heat loss by conduction through the ground is considered negligible, the terms of equation (3) become:

A = area of outside tent surface

Δt = temperature inside air minus temperature outside air

U = overall coefficient of heat loss.

The inside air temperature is an average or bulk temperature of air inside the tent since this air temperature varies with its proximity to the heater and its height above the floor.

It is noted that the above Δt can be used only if the tent is losing heat by radiation to surroundings at the same temperature as the ambient air. Actually, the tent is ultimately radiating to interstellar

space on clear nights, but on overcast days or nights it is radiating to surroundings which are approximately the temperature of the nearby buildings, ground, trees, etc. When the temperature of these surroundings differs appreciably from the ambient air, an equivalent outside air temperature may be calculated depending on the relative amounts of heat lost by radiation and convection.

In similar manner the individual or equivalent film coefficient of heat loss from any surface for unidirectional heat flow at equilibrium is:

$$q_{\text{heater}} = h A \Delta t \quad (4)$$

where

h = the individual coefficient of heat loss

Δt = the temperature difference between the surface and the adjacent air.

This equivalent film coefficient, h , can be considered to consist of two parts, h_c and h_r , where h_c refers to an equivalent film coefficient for convection and h_r refers to an equivalent film coefficient for radiation, and

$$q = (h_c + h_r) A \Delta t = h_c A \Delta t_1 + h_r A \Delta t_2 \quad (5)$$

The quantity of heat lost by radiation (q_r) is

$$q_r = 0.173 A \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] F_A F_E \quad (6)$$

where

T_1 = temperature of radiation surface

T_2 = temperature of receiving surface

A = area of radiating surface

F_A = emissivity factor

F_E = emissivity factor.

If we consider the tent as a completely enclosed body, small compared to the enclosing body, $F_A = 1$ and $F_E = e_1$, where e_1 is the emissivity of the radiating surface. Therefore

$$q_r = 0.173 A_1 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] e_1 = h_r A_1 (t_1 - t_2)$$

and

$$h_r = \frac{0.173 e_1 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]}{T_1 - T_2} \quad (7)$$

Laboratory studies showed the emissivity of 12.29 oz. duck with a JQD 242 finish to be 0.92.(5) (JQD 242 is the Jeffersonville Quartermaster Depot designation for a type of water repellant, flame and fire resistant fabric finish.) Therefore, for a temperature difference of 50-60 °F., h_r is approximately 1 BTU/(Hr.)(sq. ft.)(°F).

The heat loss by convection from a fabric to air is a function of the relative humidity of the air and the velocity of the air past the surface, the latter being the controlling factor. Laboratory studies of fabrics, including 12.29 oz. duck, showed that $h_c = V^{.6}$ for a range of velocities, V , from 2 to 10 mph.(6) For wind velocities of 3 to 4 mph a value of $h_c = 2$ BTU/(Hr.)(sq. ft.)(°F) could be used. Therefore, when the wind velocity is 3 to 4 mph and the temperature difference between the tent deck and the surroundings to which it is radiating is between 50 and 60 °F., the value of h_c is approximately equal to twice the value of h_r and the following relationship may be developed:

$$q = q_r + q_c = h_c A (t_D - t_a) + h_r A (t_D - t_b) \quad (8)$$

where

q_r = heat lost by radiation

q_c = heat lost by convection

t_a = temperature of air

t_b = temperature of surroundings

t_D = temperature of tent surface

but

$$h = h_c + h_r = 3 h_r$$

Then

$$q = 2 h_r A (t_D - t_a) + h_r A (t_D - t_b)$$

$$q = h_r A (2t_D - 2t_a + t_D - t_b)$$

$$q = h A [t_D - (2t_a/3 + t_b/3)] = h A (t_D - t_{ab}) \quad (9)$$

where

$$t_{ab} = 2t_a/3 + t_b/3 \quad (10)$$

and is considered as an equivalent air temperature.

In other words an equivalent air temperature equal to two-thirds of the outside air temperature and one-third of the surrounding temperature should be used when the temperature of the air and surroundings differ appreciably.

In the previous derivations the heat from the heaters was considered to be the only heat input into the tent. However, during the day an additional quantity of heat, q_s , is supplied to the tent by radiation from the sky. On a clear, sunny day this may amount to a large portion of the total heat input, while on overcast days and nights the sky radiation is small, being at a minimum between midnight and 2:00 A.M. By use of a pyrliometer the intensity of solar radiation could be measured. This intensity of solar radiation combined with the air film coefficient and

absorptivity of the surface could be included in a factor which when added to the air temperature would give a sol-air temperature equivalent to an air temperature alone that would give the same heat loss characteristics to the tent.(7) That is,

$$t_e = t_a + \frac{I \alpha}{h} \quad (11)$$

where

t_e = sol-air temperature

I = intensity of radiation

α = absorptivity of tent surface

h = outside surface film coefficient.

The heat input into the tent from solar radiation is a function of the transmissivity, F_t , reflectivity, F_r , and absorptivity, F_a , of the fabric which acts as a radiation interceptor. Hence a white liner which has a high reflectivity will act as a further barrier to radiation.

In defining the terms in equation (3) it was assumed that the heat loss to the ground was negligible. The loss of heat into the ground is a function of the surface film and conductivity of the ground, the temperature difference between the air and the ground, and the ratio of the floor area to the tent area. During the winter months heat flows from the interior of the earth to the surface and then to the surrounding air. Hence, heat conducted into the ground from the tent would be a somewhat complicated function of the type of soil, air and ground temperatures, time of exposure, variation in solar radiation, etc. Although studies of heat losses from basements have shown values of 6 - 8 BTU/(Hr)(sq. ft.) ($^{\circ}\text{F}/\text{in.}$) for a heavy clay soil,(8) some purely qualitative experiments with varying thickness of floor insulation indicated negligible losses into the ground.

A fundamental part of temperature control is the problem of controlling conditions to the "comfort zone".(9) The comfort zone is a range of air temperatures roughly bounded by the extremes of $70^{\circ}\text{F} \pm 10$ degrees, in which the person feels the same degree of comfort as experienced when the temperature of the air and surrounding surfaces are at 70°F and the relative humidity is 50 per cent.

The establishment of comfort conditions depends primarily on the maintenance of an environment in which the body can lose heat at a rate equal to that of its production; and this without need of such extreme physiological adjustments as evaporative regulation or shivering. The question arises that if comfort conditions exist at one temperature, is it possible to maintain comfort at other temperatures. To answer this question and to define the comfort range it is necessary first to analyze the heat losses of the body.

A normal person, seated and at rest, dissipates heat at a rate of approximately 400 BTU/Hr. under standard conditions of light clothing and in air at about 70°F , and 50 per cent relative humidity. Evaporative heat losses amount to approximately 25 per cent of the total, or 100 BTU/Hr. Radiation and convection heat losses vary, but usually, values of 50 per cent and 25 per cent, respectively, are assumed correct.(10)

From heat production, heat-loss, and surface-temperature relations it is possible to develop a quantitative relationship between the comfort temperatures of ambient air and the corresponding surface temperature of the surroundings. The effective temperature of all the surrounding walls, taking into account shape factors and temperatures, is termed the mean radiant temperature, t_{mr} , and is the temperature of a uniformly heated room in which the occupant would experience the same net

radiant heat loss as in an actual room.

The problem of writing a comfort equation is, therefore, one of relating, for a condition of optimum comfort, the air temperature, t_1 , and the mean radiant temperature, mrt. The rate of heat loss by evaporation may be assumed to be constant throughout comfort conditions. The rate of heat loss by radiation is approximately twice that by convection at 74 °F. (11) For optimum comfort the rate of heat loss must remain the same for all equilibrium air temperatures; therefore, when the air temperature is altered, the resulting change in convection heat loss must be exactly offset by radiation heat loss. It follows that,

$$\Delta t_1 (h_c) + \Delta \text{mrt} (h_r) = 0 \quad (12)$$

where h_c and h_r are the convection and radiation heat loss coefficients, and Δt_1 and Δmrt are corresponding, but opposite changes in t_1 and mrt. Since $2(h_c) \doteq h_r$, this equation reduces to the following: (12)

$$\Delta t_1 h_c + \Delta \text{mrt} (2h_c) = 0$$

$$\Delta t_1 + \Delta \text{mrt} (2) = 0$$

$$\frac{\Delta t_1}{\Delta \text{mrt}} = -2 \quad (13)$$

This equation indicates that a 1 °F increase in air temperature would be equivalent to a 0.5 °F decrease in mrt. The above would be true if the body temperature remained constant. Actually, however, experimental data reported in the literature indicate that body surface temperature varies as a function of air temperature. Taking into account this body surface temperature variation, Raber and Hutchinson in their book "Panel Heating and Cooling Analysis", show that the ratio of equation (13) approaches unity. (13) This indicates that for maintenance of comfort conditions a change in air temperature must be accompanied by an opposite change in mrt

of like amount.

If a room having a 70 °F air temperature and a uniform wall surface temperature of 70 °F is taken as representative of optimum comfort, then the one-to-one relationship can be written in the form of a comfort equation,

$$\frac{t_1 + mrt}{2} = 70 \quad (14)$$

giving,

$$t_1 + mrt = 140$$

The term mrt, as used by previous investigators, is impractical for use in calculations where extreme accuracy is not required since it can only be determined by using accurate shape factors and average temperatures. For most cases, it can be shown that by assuming each wall area to have a shape factor of unity and by calculating a weighted average, little error is introduced. (14) The average surface temperature, ast, may be calculated as follows:

$$ast = A_W t_W + A_D t_D + A_F t_F \pm mrt \quad (15)$$

where A and t are area and temperature, and the subscripts W, D, and F stand for walls, deck, and floor.

The comfort equation, therefore, reduces to

$$t_1 + ast = 140 \quad (16)$$

where $t_1 + ast$ is defined as the comfort index. The comfort index in a tent or shelter necessary for comfort conditions will vary over a wide range, depending upon the activity or type of work being done. When a person performs work, heat is liberated within his body. To remain comfortable, this heat should be lost without increasing body surface temperature. This can only be accomplished by reducing air or wall tempera-

ture, or both.

The above equation (16) is based on a normal person, lightly clothed, seated or at rest. However, a lower comfort index would seem reasonable for troops in army clothing and with some activity. Estimating that troops would be comfortable when exposed to air and wall temperatures of 60 to 65 °F a comfort index of 120 to 130 is obtained.

Over a limited range of wind velocities a relationship between the comfort index, the outside air, and the type of liner and tent can be developed.

The heat loss from a tent has been taken as the product of an overall heat transfer coefficient, the area of the fabric in the tent, and the temperature difference between inside and outside air.

$$q = U A (t_i - t_a) \quad (3)$$

This calculation is made neglecting ground heat loss, but nevertheless gives comparative results, since the overall coefficient, U , also is based on the inside area of the tent, thereby neglecting the ground area.

The heat loss from a tent also must equal the heat loss from the contents to the fabric. This loss can be expressed as a product of an individual heat transfer coefficient, the area of the fabric in the tent, and the temperature difference between the air and the fabric.

$$q = h_{1s} A (t_i - t_s) \quad (17)$$

Since the temperature of the fabric in a heated tent varies from place to place, the average surface temperature, ast , is used in place of t_s , and

$$q = h_{1s} A (t_i - ast). \quad (18)$$

Solving equations (3) and (18) for t_i and ast , respectively, gives the

following:

$$t_1 = \frac{q}{UA} + t_a \quad (19)$$

and

$$ast = t_1 - \frac{q}{h_{1s}A} \quad (20)$$

Adding and arranging equations (19) and (20),

$$t_1 + ast = t_a + t_1 + \frac{q}{A} \left(\frac{1}{U} - \frac{1}{h_{1s}} \right) \quad (21)$$

Substituting for t_1 on the right side of equation (21) its equivalent from equation (19),

$$t_1 + ast = 2 t_a + \frac{q}{A} \left(\frac{2}{U} - \frac{1}{h_{1s}} \right) \quad (22)$$

where the left side of the equation had previously been defined as comfort index. Letting $T = t_1 + ast$, and $W = \frac{2}{U} - \frac{1}{h_{1s}}$. Equation (22) reduces to

$$T = 2 t_a + \frac{q W}{A} \quad (23)$$

Then the comfort index is evaluated in terms of the outside air temperature, t_a , the heat input per unit time of the heater, q , the tent area, A , and the overall and the effective coefficient of heat transfer for the liner, U and h_{1s} , respectively.

SUMMER PHASE CONSIDERATIONS

A fly used with a tent as in summer phase temperature control acts as a radiation interceptor. The temperature that this fly attains depends upon its absorptivity, emissivity and the rate at which it loses heat by convection and radiation. Once a fly has been placed between the sun and the tent, the tent receives heat only by radiation from the fly since it is hotter than the ambient air or ground. The tent fabric will absorb radiation from the fly and in turn lose it by radiation to the surroundings, convection to the ambient air, and convection to the air within the tent, thereby raising the inside air temperature. The relation can be expressed mathematically by the following equation:

$$q = \sigma A (T_{\text{fly}}^4 - T_D^4) F_A F_E = \sigma A' (T_D^4 - T_g^4) F_A' F_E' + h_c A' (t_D - t_a) + h_c' A' (t_D - t_1) + \sigma A' (T_D^4 - T_f^4) F_A'' F_E'' \quad (24)$$

where,

$\sigma = 0.173 \times 10^{-8}$, Stefan-Boltzmann constant

A = surface area of the fly

T_{fly} = absolute temperature of the fly

T_D = absolute temperature of the deck

F_A = area factor

F_E = emissivity factor

A' = surface area of the tent

T_g = absolute temperature of the ground or surroundings

h_c' = individual coefficient of heat loss

t_a = temperature of ambient air

t_1 = temperature of air inside the tent

T_f = absolute temperature of the tent floor or ground cloth.

If in order to compare the effectiveness of two flies, two tents of identical size, shape, and material are used, then, the surface area of the tent, A' , the area factors for radiation, F_A' and F_A'' , and the emissivity factors for radiation, F_E' and F_E'' , will be the same for both tents. If the tent-fly combinations are compared at the same time the outside air temperature, t_a , the wind velocity and hence, the coefficient, h_c , a function of the wind velocity, will be identical for both combinations. If the two flies are of identical size and shape, then the surface area of the flies, A , and the area factor for radiation from the fly to the tent, F_A , will be the same. Therefore, in comparing the effectiveness of two flies of similar shape, the factors related to the comfort of the occupants (inside air temperature and inside surface temperatures) are a function of the temperature of the fly and its emissivity factor for radiation, both of which are related to the emissivity and absorptivity of the fly fabric.

From equation (24) it can also be seen that another effective method of reducing inside air and tent surface temperatures would be to increase the wind velocity and thus increase the coefficient of heat loss from the tent, h_c .

EXPERIMENTAL

PART I TEMPERATURE CONTROL IN TENTS - WINTER PHASE

The experimental work was carried out in a cleared area adjacent to the University of Louisville Institute of Industrial Research with the materials and equipment listed below.

(1) Liners and Tentage

- 3 - Large wall tents (15 by 15 ft.)
- 3 - 12.29 oz. ground cloths (15 by 15 ft.)
- 1 - 4 oz. white cotton liner (large wall)
- 1 - 8 oz. O.D. 7 cotton liner (large wall)
- 1 - 1/2 inch thick fiberglass liner (large wall)
- 1 - Squad tent, M-1945
- 1 - 12.29 oz. ground cloth (squad tent)
- 1 - 4 oz. white cotton liner (squad tent)
- 1 - 4 oz. white cotton liner, low profile (squad tent)
- 1 - 1/2 inch thick fiberglass liner, low profile (squad tent).

The regular liners in these tents were suspended so that an air space of approximately 6 inches was formed between the liner and tent. The low profile liners were made with a maximum head height of 7 feet, forming when installed a large dead air space in the peak and a 6-inch space between the liner and the tent on the sides and deck up to 7 feet. Both types of liners were fastened to the ridge pole by tapes passing between the ridge pole and the deck fabrics. Both types also were secured at the eaves by tapes through metal rings sewed to the fabric. The liners in the large wall tents were completely inside the supporting poles, whereas the supporting poles passed through an 8-inch opening in the peak of the squad tent liner.

The fiberglass liner was made of an 1/2 inch thick fiberglass pad quilted between two layers of 4.0 oz. white cotton sheeting.

(2) Heating Units

The heating units consisted of six 550-watt cone heaters in sockets mounted on a transite base and shielded with galvanized iron to prevent direct radiation to the fabric. Each tent was equipped with a 110-volt switch box and connection to the heaters.

(3) Instruments

The heat supplied to each tent was determined by calculations from a measure of the electrical power consumption.

Air temperatures were measured with mercury in glass thermometers. Fabric, and ground temperatures were measured with 30 gauge copper-constantan thermocouples through a selector switch to a direct reading potentiometer.

Humidities were obtained with a sling psychrometer and outside wind velocities with a 3 cup anemometer 7 feet above ground level.

The tents, with ridge poles North-South, were equipped with ground cloth, heaters, selector switches and liners. Thermometers and thermocouples were placed as shown in Figure 1.

At the beginning of a run, air, tent fabric, liner fabric, ground temperatures, and the relative humidity were measured, the heaters turned on, and these data recorded on previously prepared data sheets (see Figure 22) every 15 minutes until equilibrium was obtained. Runs lasted for two or more hours and several readings were made after equilibrium to obtain accurate average temperatures. Electrical power to the heaters, outside weather conditions, such as wind velocity, wet bulb temperature, dry bulb temperature, ground temperature, etc. were recorded during each

LEGEND

- A POTENTIOMETER AND TEN POINT SELECTOR SWITCH
- B SWITCH BOX FOR HEATER
- C ELECTRIC HEATER
- (T) THERMOMETERS 10-220°F
- (TC) THERMOCOUPLE CU-CONSTANTAN
- [TMM] MAX-MIN THERMOMETER
- (H) RELATIVE HUMIDITY
- (AV) AIR VELOCITY

LOCATION OF MEASUREMENTS IN
TEMPERATURE CONTROL TENT

FIGURE I

run. On runs lasting longer than two hours, half hour or hourly readings were taken after equilibrium was reached.

The tents were laced at all times during the runs except for the periodic recording of readings.

A total of 30 runs were made in which data were taken either on three large wall tents or one large wall tent and one squad tent. Of these, 2 were of 2½ hours duration, 8 were at night, and 20 were day runs. Of the day runs, 6 were with a heavily overcast sky and the remainder on days when the sun was shining 30 to 100 per cent of the time. Each tent in each run was assigned a test number. Then all tests were catalogued according to tent assembly, heat input, weather conditions, etc.

In the various runs, air temperatures inside the tent were recorded at levels 3 feet, 5 feet, and 8 feet above the floor. Readings were taken in the four corners (three feet from each wall) and in the center of the tent, as shown on the sample data sheet. These values were used to obtain the average air temperature at each height.

During a run these temperatures varied as the outside air temperature solar radiation varied. A plot of the temperatures at the various levels against the time of day is shown in Figure 2. It is observed that the inside temperatures followed closely the slope of the outside air temperature curve at a given heat input. The relatively high temperatures at 11:00 A.M. and 3:30 P.M. were due to a decrease in heat loss from the tent surface because of the more direct radiation of the sun on the tent deck.

For purposes of calculation it is desirable to obtain a bulk or average inside air temperature. If the air temperature (ordinate) is plotted as a function of some independent variable (x) such as volume

INSIDE AIR TEMPERATURE VERSUS TIME OF DAY
FIGURE 2

(abscissa), its average value can be found by dividing the area under the curve by the abscissa range where the area under the curve is given by

$$\int_{x_1}^{x_2} f(x) dx$$

and

$$t_{ave} = \frac{\int_{x_1}^{x_2} f(x) dx}{x_2 - x_1} \quad (25)$$

A plot of temperature versus cumulative volume produces approximately a straight line, whereas a plot against height gave a curved line. If the straight line relationship is used, equation (25) can be simplified as follows:

$$f(x) = t = a + bV \quad (26)$$

where 'a' represents the intercept of the line with the ordinate, and 'b' the slope of the straight line. Substitution of this function in equation (26) yields,

$$t_{ave} = \frac{\int_0^V (a + bV) dV}{V} = \frac{aV + \frac{bV^2}{2}}{V} = a + \frac{bV}{2}$$

However, $a = t_1$ and $b = \frac{t_2 - t_1}{V}$,

where,

t_1 = air temperature on the floor

t_2 = air temperature at the roof.

Therefore,

$$t_{ave} = t_1 + \frac{t_2 - t_1}{V} \times \frac{V}{2} = \frac{t_1 + t_2}{2} \quad (27)$$

This calculation of t_{ave} is equivalent to selecting the temperature at mid-volume and is the method used in obtaining the values for average inside air temperature used in this work. A typical plot of the temperature versus cumulative volume is shown in Figure 3 for the various tent-liner combinations. In all cases, the best straight line was drawn through the given points. It is noticed that the average temperature did not occur at mid-height but more nearly $1/3$ of the height. A plot of this average inside air temperature versus time of day is shown on Figure 2. It was found to follow the contour of the three-foot level, and was the temperature at about $3\frac{1}{4}$ feet above the floor for the 4 oz. liner. In all future discussion, this average inside air temperature (t_1) will be used.

Figures 4 and 5 show a typical plot of temperature versus time of day for the liner and tent fabric. Since 12.29 oz. duck, O.D. 7, has such a high absorbtivity, it is greatly affected by sun radiation. During the collection of these particular data the sky was overcast except for a short time in both the morning and afternoon, when the east and west decks, respectively, showed marked increases in temperature. It was also observed that even when the sky was heavily overcast, as at 1:30 P.M., the tent was receiving radiation from the sky, as indicated by the higher fabric temperatures before sun-down.

An examination of the data as outlined above indicated a minimum of sky radiation to the tents between midnight and 2:00 A.M. Hence, data from this period were employed in the calculation of heat loss coefficients.

The per cent sun recorded on the data sheets was obtained from the weather bureau station and gives the percentage of the time during the day that the sun's radiation was above a certain minimum intensity, which

INSIDE AIR TEMPERATURE VERSUS CUMULATIVE VOLUME
FIGURE 3

LINER TEMPERATURE VERSUS TIME OF DAY

LARGE WALL TENT

40 OZ. WHITE COTTON LINER

FIGURE 4

TENT FABRIC TEMPERATURE VERSUS TIME OF DAY

FIGURE 5

is the average value recorded on clear or slightly cloudy days. Both the morning and afternoon peaks, on Figure 5, were recorded as 100 per cent sun, though the average for the day was only 24 per cent sun.

For both the tent fabric and the liner, an average temperature was calculated by weighting the temperature of the various tent or liner sections, such as sides, decks, and ends, according to surface area assuming a shape factor of 1. Only these average values were used for calculations.

The hourly readings that showed the most constant condition of equilibrium were chosen for each test and these data used for the calculations. Average values of air, tent fabric, liner, ground, and floor temperatures for these equilibrium periods during all runs are shown in Table 4 in the Appendix.

Figure 6 is a plot of temperature versus time of day for the average air and surface temperatures over a 24-hour period for a large wall tent with 4 oz. cotton liner and, it is observed that the air and fabric temperatures rapidly fall at sundown and remain relatively constant, decreasing slightly until sunrise. This same general trend was found in all tents with the greatest variations in a tent without a liner, and the least when the fiberglass liner was used.

Since a person does not necessarily occupy only that part of the tent showing the average temperature, Figure 7 was made to show the temperature distribution in the various tents and liners. In each case, the average inside air temperature was 62 °F, but the height in the tent at which this exact temperature was found varied from 3 feet for the low profile 4 oz. liner in the large wall tent to 4 1/2 feet for the squad tent with no liner. Again, a man standing in a squad tent with no liner

TEMPERATURE VERSUS TIME OF DAY
 LARGE WALL TENT 4.0 OZ. WHITE COTTON LINER

FIGURE 6

AIR TEMPERATURE DISTRIBUTION INSIDE TENTS

FIGURE 7

would be exposed to a temperature of 64 °F at head level, whereas, if he were in a large wall tent with a low profile 4 oz. cotton liner, the temperature at head height would be 72 °F. The temperatures below the 5 foot level, however, do not vary appreciably for the same type of tent, regardless of the type of liner. The low profile liner did give 1 to 3 degrees higher temperatures at any given level than the same liner in the more conventional position of 6 inches from the tent fabric.

Various surface and overall temperature differences for all the runs are shown in Table 5 in the Appendix. In this table, wide variations in the temperature differences are observed for the same heat input. These differences resulted from the presence or absence of solar or sky radiation. Since no measure of the sun's intensity was made, calculations could be based only on the known heat input of the heaters, and no direct comparison could be made between day-runs and night-runs except in those cases of heavy overcast during the day. For instance, a Δt_{ia} (inside air minus outside air) of 16.5 °F was obtained at night with a heat input of 12,550 BTU/Hr., whereas a Δt_{ia} of 35.8 °F was obtained during a morning run with only 11,750 BTU/Hr. heat input from the electric heaters with other conditions the same.

To compare the insulating value of the several liner-tent combinations, use was made of the overall coefficient of heat transfer, U , expressed in BTU/(Hr.)(sq. ft.)(°F) as calculated from the equation

$$q = U A \Delta t \quad (3)$$

In order to learn more of the nature of the heat transfer, the individual coefficients of heat loss, h' , were calculated according to the equation

$$q = h' A \Delta t' \quad (28)$$

where h' is expressed in the same units as U .

Values of the overall and individual coefficients are shown in Table 6 in the appendix.

In the derivation of the above equations, it was assumed that the heat loss to the ground was negligible. Although undoubtedly the heat lost to the ground from the tent is appreciable, the calculated coefficients are usable for comparisons. Two tents with the same inside air temperature would have the same heat loss to the ground regardless of the type of liner, though not necessarily the same percentage of heat loss to the ground. Furthermore, the value of q employed in the calculations was the total heat loss, whether the loss was through the tent fabric or floor. Therefore, use of coefficients calculated in this manner gave correct heat requirement quantities as long as the outside air and temperature of surroundings were approximately equal. These ideas were substantiated when the use of a one-inch thickness of fiberglass on the floor gave the same overall coefficient of heat loss as was obtained with a regular 12.29 oz. ground cloth and a tent with no ground cloth.

If the temperature of the surroundings is assumed to be the temperature of the ground surface outside the tent, values of equivalent air temperatures can be calculated according to equation (10) which becomes,

$$t_{ag} = 2t_a/3 + t_b/3 \quad (29)$$

where t_{ag} represents the equivalent air temperature. Overall and individual coefficients of heat loss were calculated, using this equivalent air temperature, for all overcast and night runs where the temperature of the surroundings differed appreciably from the outside air temperature. These values are shown in Table 6 in the Appendix.

The table below shows the final averages for the various liner-tent combinations for night and overcast day runs (zero per cent sun).

TABLE 1
AVERAGE HEAT LOSS COEFFICIENTS

Type Liner	Overall Coefficients of Heat Loss (U_{lag}) BTU/(Hr.)(sq. ft.)(°F)
No liner	1.26
4 oz. White Cotton Liner	0.58
8 oz. O.D. 7 Cotton Liner	0.58
1/2 inch Fiberglas Liner	0.39

The maximum deviation of the overall coefficient from the average value is 10 per cent for the tent with no liner, 4 oz. liner, and 8 oz. liner; but 30 per cent for the 1/2 inch thick fiberglas liner.

While the overall coefficients give a good comparison of the relative insulating values of the various liners, they consider only the average inside air temperature to which a tent occupant is exposed. A more useful comparison is based on the comfort index concept as shown by equation (16)

$$\text{Comfort Index} = t_1 + ast . \quad (16)$$

To obtain the comfort index the average surface temperature was calculated by taking a weighted average of the inside surface temperatures of the decks, ends, side walls, and floors and this value added to the average inside air temperature. Comfort index values are shown in Appendix Table 7.

If it is assumed that the overall coefficient is constant for outside air temperatures between 20 and 40 °F, the comfort index for night and overcast day runs can be recalculated for an outside temperature of 32°F.

Figure 8 shows a plot of heat input versus comfort index for an outside temperature of 32 °F. Three groupings of the data were found through which straight lines could be drawn, viz., the data for the 1/2 inch thick fiberglass liner, the 4 and 8 oz. cotton liners, and the tent with no liner. For a comfort index of 120 the relative amounts of heat necessary in large wall tents equipped with these liners may be determined from Figure 8. To maintain this comfort index of 120 with outside air at 32 °F, heat inputs of 7,000, 11,900 and 27,500 BTU/Hr. would be required for large wall tents equipped with 1/2 inch thick fiberglass liner, 4 or 8 oz. cotton liner, and no liner, respectively.

The left hand termini of the comfort index lines of Figure 8 were drawn through a comfort index value of 64, instead of the actual data, as this value is theoretically correct for an air temperature of 32 °F with no heat input. The actual data fell below this value because of the subcooling of the deck at night relative to the ambient air temperature. During the early night hours the ambient air temperature decreases slowly because of the high heat capacity of the earth, whereas the deck fabric of low heat capacity readily lost heat by radiation and cooled the air in the tent. As the night progressed the earth cooled, this subcooling of the tent air diminished and the comfort index approached the theoretical value.

In order to relate all the variables covered with the winter phase considerations of tents, the nomogram of Figure 9 was constructed using equation (23). The nomogram actually was a combination of three nomograms and related the variables, comfort index, ambient air temperature, overall heat transfer coefficient, tent fabric area, and heat requirements. This chart was based on theoretically correct equations

TENT COMFORT INDEX VERSUS HEAT INPUT
LARGE WALL TENT OUTSIDE AIR 32°F

FIGURE 8

NOMOGRAM FOR THE DETERMINATION OF COMFORT HEATING CONDITIONS

FIGURE 9

applying in all cases. The accuracy of the results from this nomograph, however, depended upon the accuracy of the coefficient, U . Since the coefficients calculated for the individual runs included such a variety of uncontrollable factors related to the weather, the U -values used on this chart were calculated from the more consistent overcast day and night runs and the tent fabric area neglecting ground loss.

Example No. 1

It is desired to know the heat requirements of a large wall tent equipped with a 4.0 oz. liner to maintain a comfort index of 130, if the outside air temperature is 25 °F and the sky is overcast and wind velocity is less than 10 mph.

Solution

Connect 130 on the comfort index line with 25 °F on the outside air temperature line and extend to line A. From the intersection on line A, draw a line through the overall coefficient value corresponding to the 4.0 oz. liner (.60) and extend to line B. From the intersection on line B connect a line with 600, the area of the large wall tent and read the heat requirements off the last line - 17,000 BTU/Hr.

Example No. 2

Find the heat requirement for a squad tent equipped with a 1/2 inch thick fiberglass low profile liner with an outside air temperature of 10 °F if it is desired to maintain a comfort index of 120. Assume wind velocity of 6 mph and night operation.

Solution

Connect 120 on the comfort index line with 10 °F on the outside air temperature line and extend to line A. From the intersection on line A draw a line through the overall coefficient value corresponding to the

1/2 inch thick fiberglass liner (0.39) and extend to line B. From the intersection on line B connect a line with 1,150, the area of the squad tent, and read the heat requirements off the last line - 25,00 BTU/Hr.

Example No. 3

Using a large wall tent and a 1/2 inch thick fiberglass liner and a stove with a heat output of 20,000 BTU/Hr., find the lowest outside air temperature during wet and overcast conditions in which a comfort index of 130 may be maintained.

Solution

Connect 20,000 on the heat input line with 600 on the tent area line and extend to line B. From the intersection on line B draw a line through the coefficient of the fiberglass liner (0.39) and extend to line A. From the intersection on line A connect a line with 130 on the comfort index line and read the intersection with the outside air temperature line (-12 °F).

In the above examples the heat requirements were based on U values calculated for night and overcast days. If the same conditions had been desired during a sunny day, less heat input would have been necessary, since the tent would have received a certain amount of heat from the sun.

If the wind velocities in the above examples were sufficiently higher than the range in the experiments, an additional quantity of heat would have been required due to a slight increase in heat loss through the fabric and a much larger heat loss due to air leakage.

The overall coefficient may be considered a function of the type of liner, regardless of the type of tent being used since the heat transfer characteristics of single fabric tents are very similar. For

ease in using the nomograph, various types of liners may be marked on the coefficient line, and no regard need be given the actual value of the coefficient. Likewise, tent types may be marked opposite their appropriate areas for ease in use. These additions have been made to the nomogram in Figure 9.

As a check on the validity of the results which may be obtained from the nomogram, heat requirements for various comfort indexes were determined at 32 °F. These values were then plotted in Figure 8. The theoretical data may be seen to fit very well the actual experimental data as shown in Figure 8. This comparison gives a measure of the accuracy of the results which may be obtained from the nomogram.

It is possible, therefore, to determine heat requirements for any tent-liner arrangement under any temperature condition, so long as the overall coefficient, U , is known. It is believed that the nomogram is accurate down to 0 °F and that reasonably accurate values may be obtained below that temperature.

For the calculated values of U shown in Table 6, the fiberglass liner is three times as effective an insulator as no liner, whereas the 4 and 8 oz. cotton liners are twice as effective. That is, for a given outside air temperature and normal wind velocities encountered in these runs, it would require three times as much heat to maintain a tent with no liner at a given inside air temperature as for a tent with 1/2 inch thick fiberglass liner. It would require twice as much heat to maintain the no liner tent at the same temperature as the 4 or 8 oz. liner tent. Finally, the 1/2 inch thick fiberglass represents a heat saving of two-thirds over the 4 and 8 oz. liner tent.

Although no night runs were made with the low profile liner in

the large wall tent, its effectiveness can be estimated by comparing the coefficients for the day runs with those for the conventional liner on similar day runs. This comparison shows that the 4 oz. white cotton low profile liner has the same overall coefficient of heat loss as the conventional 4 oz. white cotton liner.

Runs 70 through 76 were made in the squad tent (M-1945). All of these runs were made at night, and the coefficients should be approximately the same as the average values obtained for the large wall tent with the same liner. An overall coefficient of 1.23 for a squad tent with no liner compares well with the average value of 1.26 for the large wall tent. However, the next four runs, 72 to 75, gave U values much higher than were expected from the results of the large wall tent. An examination of these data showed that these high results were possibly the result of leakage through the hole in the liner where the vertical supporting tent poles passed. Another run was made with the 4 oz. white cotton liner in which the opening around the vertical pole was closed with 4 oz. cotton cloth. In this run a coefficient of 0.62 was obtained which compared favorably with the average value of 0.58 for the large wall tent with 4 oz. cotton liner. Similarly, the other liners in the squad tent could be equipped with a "turtle-neck" cloth to close the opening around the vertical pole, and reduce the coefficient to a value comparable to the large wall tent for the same liner.

From Table 6 the average values of the equivalent coefficients h_{Dag} , h_{1s} and h_{1D} (both 4.0 oz. and 8.0 oz. liners) are 2.5, 2.5, and 1.3, respectively. The coefficient, h_{Dag} , represents the equivalent air film from the deck to the outside air, h_{1s} , the air film from the inside air to the liner, and, h_{1D} , the two equivalent air films between the liner

and the deck. On the basis of the two air films, the average value of a single air film coefficient between the liner and deck is 2.6.

During these investigations, the wind velocity was relatively low, varying from 0 to 7 miles per hour. At higher wind velocities the outside air film coefficient becomes greater and less resistance is offered to the heat loss, i.e., the resistance of a film is the reciprocal of the coefficient, $R = \frac{1}{h}$. From this stand point, the inside temperatures of the tents without liners are influenced more by winds since the outside film represents approximately one-half of its total resistance to heat flow. On the other hand, the outside film is only one-sixth of the total resistance for the tent with fiberglass liner and wind velocity variations do not influence the inside tent temperature in this case as much as in the case of the tent with no liner.

Grommet holes, door openings, etc., allow a large number of air leaks in a tent, no matter how carefully it is pitched. This source of heat loss increases considerably at high wind velocities, but again, the heavier the liner the lower is the loss from winds at openings. For velocities below 10 miles per hour, as experienced in these tests, the increasing heat loss with increasing wind velocity is small, especially for the fiberglass liner. However, a quantitative evaluation of the effect of the wind was obtained over this range.

The influence of humidity showed no consistent trend, other variables influencing the value of U to such an extent that any humidity effects were obscured for the most part. Run 12, made during a light rain, gave a coefficient of 1.07, compared to the average value of 1.26 for the large wall tent with no liner. Run 61 gave a U of 0.41 for the 1/2 inch thick fiberglass liner during the rain, whereas the average value

was 0.39. The presence of water on the tent deck should decrease the film resistance and increase the heat loss. However, this effect was not observed during those particular runs in which it rained.

Relative humidity inside the tent varied with the outside humidity and decreased as the original volume of air and water were heated, attaining a fairly constant value after the first hour of heating, and varying only slightly thereafter with the outside humidity. The relative humidity in the large wall tent with no liner ran consistently higher than in the tents with liners.

The values in Table 6 show that the coefficient for day runs when the per cent of sun was greater than zero were much lower than the average values calculated for night and overcast runs. As explained previously, this variation was due to the additional heat given to the tent by the fabric absorbing the sun's radiation and transferring it to the inside air.

When equation (3) $q = U A \Delta t$ is plotted, using $A \Delta t_{ia}$ versus q , the heat input from the heaters, the slope of the line is the coefficient U . Then on days with significant solar radiation, Δt_{ia} becomes greater and the slope of the line or U becomes less. For the night runs a U -value of 1.26 is calculated from the slope, whereas the line approximating 100 per cent sun gives a value of 0.51. It is observed in Table 6 that the values of overall coefficients for overcast days approach those for night runs. This figure also shows that for a temperature difference between inside and outside air of 15 °F, 11,200 BTU/Hr. is necessary at night in a large wall tent with no liner, whereas, only 3,700 BTU/Hr. is necessary during the day with 100 per cent sun.

Figure 10 is a plot of the effective heat input from the sun

HEAT INPUT FROM SUN VERSUS TIME OF DAY

LARGE WALL TENT

FIGURE 10

versus the time of day for various tent-liner combinations. This effective heat input was calculated using average values of coefficients from the data of night and overcast runs. Then, using U , A and the measured Δt , the heat input, q , was calculated from equation (3), $q = U A \Delta t$, and the effective solar heat input calculated from the difference between the measured and calculated heat input.

The amount of radiation absorbed by the tent fabric varies with the intensity of the sun's radiation. This intensity varies with the position of the sun in the sky (time of day), month of year, and condition of the sky. The influence of some of these variables on the heat requirements of the tent is observed by comparing the several runs shown in Figure 10. Runs 24, 43, and 70 were for a 100 per cent sunny day in the morning during February. Runs 22, 42, and 53 were for a 100 per cent sunny day in February in the afternoon. Run 26 was for a 100 per cent sunny day in April. It also is noticed that even though the sun was shining with the same intensity on all the tents, it did not effectively heat them all by the same amount, but inversely to the amount of insulation in the form of liners that they contained. In the morning, for instance, the sun effectively added heat in the ratio of 40 to 16 to 8 in the three tents, i.e., the sun increased the temperature difference in the tent with no liner five times as much as in the tent with fiberglass liner. After the the tent fabric has absorbed the radiation from the sun, it re-radiates this heat either to the outside air and ground or to the inside surface. When the tent contains a liner, especially a white one with high reflectivity, the liner offers further resistance to the transfer of the sun's heat to the inside air and hence more is re-radiated to the outside, accounting for the lower effective heat from the sun in the tents with

liners.

In examining the heat transfer characteristics of various fabric combinations in tentage, as in the foregoing section, it was considered important to examine the data to determine what properties or factors were responsible for the differences resulting from using the different liners. For instance, it was desired to know whether fabrics themselves contributed materially to the insulation, or whether the air film resistance on each surface of a fabric was the controlling factor. Experience indicated that the latter should be controlling since the fabrics were thin and relatively good conductors.

The fact that weight, and to some degree, the color and finishing treatment of the fabrics used as liners in tents had little effect upon the overall coefficient or temperature drops across them, was shown by the results from the 4.0 oz. cotton liner (white) and the 8.0 oz. cotton duck liner (O.D. 7). The overall coefficient and temperature drops across both of these liners were identical. This identity of results gave credence to the concept that the two air films constituted the main resistances, and that the weave, weight, and treatment of the fabric had little effect. This theory, of course, may not be rigorous when considering blanket type fabrics with greater thickness and/or larger amounts of nap.

Further evidence of the controlling effect of the number of fabric-to-air interfaces was observed from a plot of temperature differences between the liner and tent fabrics, the inside air and the outside air (as abscissa) versus heat input. This plot is shown on Figure 11 where the lines in ascending order represent the elevation of the following above outside air temperature; (1) tent deck using 4.0 oz. liner or

TEMPERATURE DIFFERENCE vs. HEAT INPUT
FIGURE 11

no liner, (2) inside air temperature using no liner, (3) liner deck using 4.0 oz. liner, (4) inside air using 4.0 oz. liner, and (5) inside air using 1/2 inch thick fiberglass liner. The number of air films encountered between outside air and the points of measurement for the various lines on Figure 11 in ascending order are: (1) one, (2) two, (3) three, (4) four, and (5) six. It is seen from the plot that the temperature differences for the tent and 4.0 oz. liner increase in the ratios of one, two, three, and four and, therefore, indicate an exact correspondence with the number of air films encountered.

From these results it was concluded that the nature of the fabric, be it the tent deck or the liner, has little effect on temperature drops and consequently little effect on the overall coefficients. It was further concluded that addition of another liner, thereby increasing the number of fabrics to three and the number of air films to six, would add a proportionate amount of insulation.

The fiberglass liner consisted of 1/2 inch thick fiberglass between two layers of 4 oz. white cotton. This would give the fiberglass liner four air films, two for each layer of 4 oz. cotton. These four air films plus the two for the tent fabric would give a total of six air films for the 1/2 inch thick fiberglass as shown in Figure 11. This would indicate that the fiberglass offered no additional resistance to the heat flow but acted merely as a spacer for the two sheetings of 4 oz. white cotton.

Although the relative merits of various liners was shown from a heat transfer viewpoint, the liner with the lowest coefficient, i.e., fiberglass, had the greatest bulk and greatest weight. A more realistic valuation should include a practical study of the weight, bulk, and cost

relationships for the various liners.

Each type of liner has a specific weight and bulk and, for fixed conditions has a corresponding weight and bulk requirement of fuel. If the sum of the weight or bulk of the liner and fuel is calculated, the liners may be compared and weight and bulk savings may be calculated. The cost of the fuel required with each liner also may be calculated and savings determined.

For comparative purposes, the following conditions were assumed:

- (1) A one-month field operation using large wall tents for which all tentage and fuel must be carried.
- (2) Heating requirements continuous for 24 hours per day.
- (3) Oil or gasoline heating units.
- (4) Fuel value: 15,000 BTU/lb.
- (5) Desired comfort index of 140.
- (6) Outside air temperature 40 °F and 20 °F.

The following weight and bulk values were found experimentally for liners for large wall tents:

TABLE 2
WEIGHT AND BULK OF LINERS

Type Liner	Weight, lbs.	Bulk, cu. ft.
No liner	0	0
4.0 oz. Liner	20	2
8.0 oz. Liner	40	2
1/2 inch Fiberglass Liner	55	7

The nomogram of Figure 9 was used to determine the heating requirements in BTU/Hr. for the above liners and for no liner at the

temperature of 40 °F and 20 °F. Using the fuel value factor of 15,000 BTU/lb., the hourly fuel consumption was determined, and the hourly fuel savings as compared to a tent with no liner were calculated. Using the weights of each liner, the hours of operation were determined for the fuel weight saving to equal the corresponding liner weight. The volume of fuel saved per hour with the various liners and the days of operation necessary for bulk savings to equal liner bulk were determined. The results of these calculations are summarized in Table 8.

From this tabulation it is apparent that any of the liners become economical for operations of from 15 to 33 hours, and that further operation results in a net savings of fuel weight. The time required for the liner to return a saving is lessened at lower air temperatures. Bulk savings are not quite so impressive, however. At 40 °F, only 3 days are required for the 4.0 oz. or 8.0 oz. liners to pay for themselves on a bulk basis. This value is reduced to less than 2 days at 20° F. The fiberglass liner having considerable bulk requires 8.9 and 5 days to return a savings at air temperatures of 40 °F and 20 °F, respectively. It may be concluded from these results that for operations of one week duration at these temperatures, the 4.0 oz. liner would yield significant savings of both weight and bulk, whereas, the 8.0 oz. liner would not yield quite as much weight saving, and the fiberglass liner would not be practical on a bulk saving basis.

Table 9 is a summary of fuel cost (5 cents per gallon), fuel weight, fuel bulk, total weight of fuel, liner, and container, total bulk of fuel, liner, and container, and savings of cost, weight, and bulk due to the use of a liner for one month's operation at temperatures of 40°F. and 20°F and for a comfort index of 140. The percent saving in cost,

weight, and bulk at 40 °F may be seen to be large with the fiberglass liner, high in cost and weight savings, and equal in bulk savings to the others. At 20 °F, however, the fiberglass liner has savings of approximately 75 per cent for all three, while the 4.0 oz. and the 8.0 oz. liners have only 62 per cent savings. This represents an improvement over the 4.0 oz. and 8.0 oz. liners of about 20 per cent while they each represented an improvement over a no liner operation of 62 per cent. For one month's operation at 20 °F, the 2,210 pounds saved by using a fiberglass liner is considered significant.

From the Table 9 the values of fuel cost, total weight and bulk for one month's operation have been plotted against overall heat transfer coefficients (see Figure 12). Values of these quantities at a coefficient of 0.125 were calculated on a theoretical basis and plotted on the graph to complete the curves and to emphasize the minimum point in the bulk curves.

The curves for weight and cost decrease for decreasing values of the overall coefficient, whereas the bulk curve in both cases goes through a minimum. This minimum may be seen to move toward lower coefficients for lower air temperature. The minimum of the bulk curve varies as conditions change; for long operations, or lower temperatures, the minimum moves toward lower coefficients, whereas, for short operations and milder temperatures, the minimum moves toward higher coefficients.

In general, it may be stated that at temperatures of 20 °F to 40 °F, fiberglass liners should be used on operations of several weeks or longer and the lighter 4.0 oz. liners should be used on short operations. Likewise, semi-permanent tentage should be equipped with fiberglass liners.

The above analysis was made at mild temperatures and specifically for a large wall tent, and, therefore, should not be assumed to hold true

COST-BULK-WEIGHT OF FUEL AND LINER

FIGURE 12

for all tentage. A similar analysis, however, may be made for any tent and conditions desired with the use of the nomogram of Figure 9.

PART II TEMPERATURE CONTROL IN TENTS - SUMMER PHASE

From previous work of this nature, it was known that the flies which shaded the largest portion of a tent from direct solar radiation were the most effective in lowering the air and fabric temperatures of the tent. (16) In accordance with these findings, a fly 18 feet long and 28 feet wide with a hood on one end, as shown in Figure 13, was designed. Since the large wall tents used in this test were pitched with the ridge North-South, it was necessary to have the hood only in the South end.

A second fly was constructed with the same dimensions as the first, but, of two layers of fabric, the outer fabric, 6.5 oz. oxford (O.D. 7), and the inner fabric, 4 oz. white cotton. This technique permitted the maintenance of camouflage and at the same time took advantage of the better reflectivity of the white surface in reducing radiation from the O.D. 7 fly to the tent.

Thermocouples (attached to the inside surface of the tent by a small strip of adhesive tape) were located at the center of the decks, ends, side walls, and ground cloth. Thermocouples also were attached to the underside of the flies. When the tent was open, the inside air temperature was measured with a thermocouple. All of the thermocouples were brought to a selector switch outside the tent, making it unnecessary to enter the closed tents during the runs. In these tests "closed" refers to a tent with side walls pegged down and tightly tied at the corners and end-door openings. "Open" refers to the tent in which the side walls and ends are completely rolled up, leaving only the deck overhead. These two conditions give the extremes of tent usage, and any other partial opening of the tent would give intermediate results.

FLY NO. 1 SINGLE LAYER ~ 7.9 OZ. TWILL, O.D. 7
 FLY NO. 2 DOUBLE LAYER ~ 6.5 OZ. OXFORD, O.D. 7 (OUTSIDE LAYER)
 4.0 OZ. WHITE COTTON (INSIDE LAYER)
 3" AIR SPACE EXCEPT AT SEAMS

FIGURE 13
 DETAIL OF LARGE, HOODED FLY

Four series of runs were made and the data are shown in Table 10 in the Appendix. In run 1, a comparison was made between a large wall tent completely closed and unprotected, and a large wall tent completely closed and protected by a large, hooded, single layer fly. In run 3 comparisons of the same structures were made with the tents open. In runs 2 and 4, the effectiveness of the single layer fly was compared with that of the double layer fly with the tent closed (run 2) and the tent open (run 4).

A comparison of these data is shown in Tables 11 and 12. In the compilations, the average air and surface temperatures for the various conditions are presented. The average inside surface temperatures are weighted averages of the temperatures of the side walls, ends, and decks of the tent, giving a temperature corresponding to a single surface at a temperature such that the total radiation approximates that from the several tent surfaces. Therefore a comparison of the several tents, unprotected or protected by the flies, can be shown as temperature differences. These data are listed in Table 13. From this table it is observed that the inside air of the unprotected tent (closed) is 19 to 34 °F higher than the outside air, whereas, the tent (closed) protected by a single-layer fly is only 4 to 10 °F higher than the outside air. Therefore, under these conditions of outside air (70 to 86 °F), the large, hooded, single layer fly reduced the inside air temperature of the tent 15 to 24 °F as compared to that of the unprotected fly and held the air temperature of the tent within 10 °F of ambient air at all times.

However, the comfort of the individual in a tent is not only a function of the inside air temperature but also a function of the emissivity and temperature of the surface radiating to his body. A comparison of the surface temperatures reveals that the inside surface of the

unprotected tent was 9 to 13 °F higher than the inside air, whereas, in the tent protected by the single layer fly, the inside surface temperature was only 1 to 4 °F higher than the inside air temperature. This result means that the occupant in the unprotected tent was exposed to a surface which was 20 to 37 °F higher than the corresponding surface within the tent protected by a single fabric fly.

In the second series of runs a comparison was made between the double fabric fly and the single fabric fly. The double fabric fly reduced the inside air temperature of the tent to within 6 °F of the ambient air temperature, 2 to 4 °F lower than the inside air in the tent protected by the single fabric fly. It also gave an inside surface temperature 1 to 3 °F lower than the single layer fly. In these runs, the air temperatures remained in the seventies and although good results were obtained with the double layer fly, even better results would be expected at the higher temperatures.

With the tents open the inside air approached the ambient air when either fly was used and was within 4 °F of ambient when no fly was used. However, the inside surface temperature was found to be 15 to 20 °F higher in the unprotected tent than in the tent protected by a fly.

Figure 14 is a plot of air and surface temperatures versus time for one portion of run 1, with a line (dotted) for the double layer fly calculated from the results of run 2. This curve shows the effect of the various liners when the outside air temperature and wind velocity conditions were those that prevailed in this run. All of these data were taken on a clear, 100 per cent sunny day with the wind velocity less than 10 mph at all times.

FIGURE 14

TIME VERSUS AIR AND SURFACE TEMPERATURE

LARGE HOODED FLIES

PART III ARCTIC SHELTER DESIGN

Further consideration of the problems and results of experience in Alaskan tests during the winter of 1946-47 showed the necessity of several modifications in the design of the Arctic shelter frame. Since the shelter was to be vehicle-portable, the members should have a maximum length of 12 feet. Accordingly the design of the Arctic shelter frame was revised so that it fulfilled this specification. This change resulted in a slight change in the height and contour of the frame but did not effect the essentials of the design.

Still further consideration of the design led to several additional changes, and the drawings were again revised to include these new ideas. This final revision is shown in the drawings on pages 63 through 69. It was decided that transportation on the smallest army vehicle available for this use would necessitate a shorter length of the members. Therefore a new maximum of 8 feet in length was set and the structure was again revised. Reducing the length of the I-beam arches made it necessary to change the placement of the purlins, which connected adjacent ribs, and to add an additional purlin to each side of the frame. Therefore the new design has 8 side purlins instead of 6 (drawing no. 1). This change in the maximum length of the members also necessitated breaking the lower verticals in the end sections at their center and using a wing nut clamp to fasten the two sections together.

A second change in the design was the use of an entrance 4 feet wide in the ends, reducing the number of verticals to 4 instead of 6 (drawing no. 3). In order to attach the fabric cover and prevent its excessive flapping during winds, a horizontal tube identical to the verticals was

PLAN VIEW

ARCTIC SHELTER
FRAME DESIGN

SCALE 1"=8'

SIDE ELEVATION

END ELEVATION

THIS DRAWING SUPERSEDES DRAWING NO. 18
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INSTITUTE OF INDUSTRIAL RESEARCH
ARCTIC TENT
DRAWING NO. 1 (REVISION C)
JAN 1, 1947 REVISED NOV 1, 1947

FIGURE 15

FIGURE 16

END SECTION LAYOUT
SCALE $\frac{1}{4}'' = 1'-0''$

FIGURE 17

BILL OF MATERIALS

QUANTITY	DESCRIPTION	DRAWING NO. DETAIL
648'	ALUMINUM STOCK	
250'	3X5" I-BEAM ARCHED RIBS & FLOOR BEAMS	4 SEC. B-B
	1 1/4" X 4 1/2" X 3/16" CHANNEL, I BEAM CONNECTORS & PURLIN CLAMPS	4 SEC. C-C
370'	1 1/2" X 1 1/2" X 3/16" TUBING, PURLINS & END SECTION HORIZONTALS & VERTICALS	6 SEC. H-H
32'	3" X 1 1/2" X 1/4" 'T' SECTION, RIDGE PURLIN	5 G
30'	3" X 3/4" I BEAM, END SECTION HORIZONTAL BEAM	6 SEC. K-K
20'	3/16" PLATE, END SECTION HORIZONTAL TUBING ATTACHMENT AND VERTICAL SPLICE	7 Q, P
5 1/2'	1/4" PLATE, HINGE & ADJUSTABLE TONGUE CONNECTOR	6 J, L, N
4	1/2" X 3/4" PINS WITH HEADS, HINGES	6 N
216	3/8" WASHERS, 2 S AL.	
108	1/2" WASHERS, 2 S AL.	
232	3/8" WASHERS, 2 S AL.	
32	1/8" RIVETS, 5/16" GRAB, RIDGE PURLIN SPRING CLIP	5 O
16	3/16" RIVETS, 2" GRAB, TRUNK LATCH	6 M
40	3/16" RIVETS, 1/16" GRAB, END SECTION VERTICAL SPLICE & HORIZONTAL ATTACHMENT	7 Q, P
61 ST	ALUMINUM EXCEPT WHERE NOTED	
	CASTINGS	
8	AL. ALLOY END SECTION JAW CLAMPS FOR VERTICALS	6 J
4	AL. ALLOY END SECTION JAW CLAMPS FOR HORIZONTALS	6 K
4	AL. ALLOY CONNECTORS BETWEEN HORIZONTAL I BEAM & JAW CLAMP	6 K
8	VERTICAL CONNECTOR PLATES, AL. ALLOY	6 SEC. I-I
64	BRONZE TURNBUCKLES	5 I
	STAINLESS STEEL STOCK	
370'	3/8" DIA. ROD FOR TIE RODS	5 I
16'	1/4" DIA. ROD, RIDGE PURLIN CLAMP HANDLE	5 O
150'	1 1/8" DIA. ROD, CLAMPING PIN	4 B
140'	5/8" DIA. ROD, CLAMPING PIN HANDLE	4 B
1 1/2'	1/2" X 1 1/2" SPRING STEEL	5 O
	CARRIAGE NUTS & BOLTS	
216	5/8" X 1 1/2", SEC. A-A	4 A, C, D
4	1/2" X 4"	6 K
12	1/2" X 2"	6 J
32	1/2" X 1"	6 N
8	3/8" X 4"	6 K
22	3/8" X 3"	6 J, L
24	3/8" X 2"	6 J
40	3/8" X 1 1/2"	6 K, L
8	3/8" X 2", WITH WING NUTS	6 P
130	3/8" NUTS, TIE RODS	5 I
16	TRUNK LATCHES, REMOVABLE END SECTION VERTICALS	6 M
24	4' X 8' SECTIONS OF ALUMINUM SKIN HONEYCOMB, FLOORING	7 R
50'	1 1/2" X 2" OAK, WOOD SILL	7 M, R

NOTE - QUANTITIES ARE EXACT, NO ALLOWANCE MADE FOR WASTE

THIS DRAWING SUPERSEDES DRAWING NO. 38
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ARCTIC TENT
DRAWING NO. 3 (REVISION C)
JAN. 1, 1947 REVISED NOV. 1, 1947

DETAIL - A
FLOOR JOIST OR ARCHED RIB
SPLICE CONNECTION

SECTION E E
FULL SCALE - 1" = 1'

DETAIL B
CLAMPING PIN

DETAIL OF SERRATED PIN
SCALE 2" = 1"

DETAIL-C
FLOOR RIB JOINT

DETAIL - 'D'
RIDGE PIN CONNECTION

SCALE $\frac{1}{2}'' = 1'$ EXCEPT WHERE NOTED

THIS DRAWING SUPERSEDES DRAWING NO. 4 B

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ARCTIC TENT
DRAWING NO. 4.(REVISION C)
JAN. 1, 1947 REVISED NOV. 1, 1947

FIGURE 18

DETAIL - P

SECTION-4.4

SECTION M-M

FLOOR ASSEMBLY DETAIL

(24 FLOOR SECTIONS REQ'D PER 32 FOOT SHELTER)

END SECTION VERTICAL SPLICE
CONNECTION

DETAIL - Q
END SECTION HORIZONTAL
ATTACHMENT

SECTION - N-N

CROSS SECTIONAL VIEW OF FLOOR JOIST
AND PANELS

SECTIONAL FLOOR BOX LAYOUT

DETAIL - R
SECTIONAL FLOORING

THIS DRAWING SUPERSEDES DRAWING NO. 7B

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ARCTIC TENT
DRAWING NO. 7 (REVISION C)
JAN. 1, 1947 REVISED NOV. 1, 1947

FIGURE 21

placed on each side of the end section between the large door vertical member and the arched rib.

The severe cold of the Arctic regions makes it necessary to wear heavy arctic mittens while erecting the shelter. The threading of nuts on bolts entailed considerable difficulty and it was decided to replace nuts and bolts by other types of fasteners wherever possible in the frame design. Originally the floor rib joint and I-beam ridge joint were connected by a nut and bolt gusset plate. The hook and pin arrangement shown in drawing 4 was devised for use at these connections. The hook consists of an aluminum channel 8 inches long permanently attached to one beam by nuts and bolts with a hook extending beyond the end of the beam. The other beam contains a serrated steel pin which slips into the slot of the hook. When one beam is rotated 90 degrees this pin (slightly offset) tightens against the hook and makes a rigid joint.

The I-beam splice in both the arched ribs and floor were connected by a bolted channel plate. This same channel was used permanently bolted to one section of the beam (drawing no. 4). A hole was drilled through the top and bottom flange of both the I-beam and channel and a pin (with a collar) slipped into the hole in the upper flanges. To permit this operation, the two holes were elongated toward the flange edge. The pin had a lever attached at the center so that it could be turned 90 degrees with a cam action, forcing the channel tightly against the I-beam.

The complicated purlin clamp was replaced by the same lever-pin arrangement described above (drawing no. 5).

The new type of hook-pin connection used at the ridge did not permit the use of the original purlin connection. Instead the web of the ridge purlin T section was notched so that it fitted into an oblong hole

in the flange of the channel and was held in place by a clamping pin.

The new boltless fasteners described above were first made with cardboard templets. From these the practicality of the particular fastener was ascertained and working dimensions determined. Then full scale aluminum models were constructed and the fastener was made to work properly before being considered complete.

Discussions with the manufacturers of this shelter frame led to further changes in the method of manufacture of some of the parts. It was decided to use castings for all connector plates in the end section shown on drawing no. 6 and to substitute welding instead of machining wherever possible. These revised drawings of the Arctic shelter frame (shown on pages 63 through 69) include detailed descriptions of the following modifications: maximum length of members, 8 feet; a 4 foot entrance in the end section; a horizontal support in the end section; hook and pin fasteners at the I-beam splices and side purlin connections; oblong slotted connections for the ridge purlin; and aluminum castings for end section connectors.

SUMMARY AND CONCLUSIONS

PART I TEMPERATURE CONTROL IN TENTS - WINTER PHASE

From the results of this study, liners were found to be an effective means of reducing heat loss from tents. The comparative values of the heat loss coefficients gave good indications of the value of the liner-tent combinations. Over the range of wind velocities encountered in these tests a tent with no liner was found to have a coefficient of heat loss of 1.26 BTU/(Hr.)(sq. ft.)(°F) whereas the coefficients for the 4 oz. white cotton conventional, the 4 oz. white cotton low profile liner, the 8 oz. O.D. 7 cotton liner, and the 1/2 inch thick fiberglass liner were 0.58, 0.58, 0.58, and 0.37 BTU/(Hr.)(sq.ft.)(°F), respectively.

From the comfort relations, it was found that the comfort of an occupant in a tent was a function of the average surface temperature to which he was exposed as well as the inside air temperature. A comfort index equal to the sum of inside air temperature and the average inside surface temperature afforded a satisfactory comparison for various liner-tent combinations.

It was found that the color, weight, and material of the liner had little effect on the heat loss. The amount of resistance to heat flow was a function of the number of air films encountered, and double or triple layers of fabrics were considered the best means of insulating a tent.

Also, low profile liners that allow sufficient head room should be superior to conventional liners since they give a more favorable temperature distribution in the tent and have less weight and bulk.

The use of these liners afford significant savings in the cost, weight, and bulk of fuel required for field tent operation. The greater

the insulating value of the liner, the greater is the percentage of saving.

PART II TEMPERATURE CONTROL IN TENTS - SUMMER PHASE

From the results of this work it seems highly desirable to use large flies similar to the hooded flies used in this test; the flies should completely shade the tent from direct solar radiation. The double layer fly improved the comfort of the tent but not sufficiently to justify the additional weight and manufacturing expense. It seems preferable to make the fly of a material lighter than 12.29 oz. duck since it need not be subjected to stresses as severe as the tent itself.

The use of this type of large, hooded fly appears to be the limit of the amount of cooling that can be given a tent by either a fly or liner as long as it is necessary to have the outside surface of camouflage color. It has been shown that the effectiveness of the fly can be increased somewhat by the use of an inner surface which has a low emissivity, for example, such as the double layer fly or light colored under surface. However, these methods have not shown sufficient improvement to warrant their recommendation.

The solution to the problem of summer phase temperature control of tents may be resolved into the following techniques in order of importance: (1) Open tent for air temperature reduction, (2) large, hooded fly for air and interior surface temperature reduction, (3) inner fly surface and/or inner tent surface of low emissivity for radiation reduction.

The combination of (1) and (2) produces an interior tent temperature only slightly above ambient air temperature with reasonably low radiation to the occupants.

PART III ARCTIC SHELTER DESIGN

The Arctic shelter frame has been redesigned as suggested by experience in the Arctic. The frame can easily be erected while wearing Arctic mittens since operations requiring the threading of nuts on bolts have been replaced by boltless fasteners. The length of individual members of the frame has been reduced to a minimum of 8 feet making the shelter vehicle-portable. It now contains a 4 foot entrance with removable verticals for a 16 foot entrance. It is believed that this design fulfills the necessary requirements for a general purpose Arctic shelter frame.

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APPENDIX

LIST OF SYMBOLS

Name	Symbols	Units
Absorptivity	α	
Area	A	sq. ft.
Area Factor in Radiation	F_A	
Coefficient of Heat Transfer, Conduction	h_c	BTU/(Hr.)(sq.ft.)(°F)
Coefficient of Heat Transfer, Individual	h	"
Coefficient of Heat Transfer, Overall	U	"
Coefficient of Heat Transfer, Radiation	h_r	"
Conduction	c	
Emissivity	e	
Emissivity Factor in Radiation	F_E	
Heat Flow, Quantity	Q	BTU
Heat Flow, Rate	q	BTU/Hr.
Radiation	r	
Reflectivity Factor	F_R	
Specific Heat	C_P	BTU/(lb.)(°F)
Temperature	t	°F
Temperature, Absolute	T	°R
Temperature, Air Inside	t_i	°F
Temperature, Air Outside	t_a	"
Temperature, Average Surface	ast	"
Temperature, Equivalent Air	t_{ab}	"
Temperature, Floor	t_f	"
Temperature, Ground	t_g	"
Temperature, Liner Fabric	t_L	"
Temperature, Mean Radiant	mrt	"

LIST OF SYMBOLS (CONTINUED)

Name	Symbols	Units
Temperature, Tent Fabric	t_D	$^{\circ}F$
Temperature, Surface	t_s	"
Temperature, Surroundings	t_b	"
Time	θ	Hr.
Transmissivity Factor	F_t	
Velocity	V	Mi./Hr.
Weight	W	lbs

DERIVATION OF NOMOGRAM

For the construction of the nomogram relating comfort index, outside air, and the types of liners and tents, equation (23) is broken down into the following product or sum equations by introducing two new parameters C and K:

$$K = \frac{q}{A} \quad (30)$$

$$C = K W \quad (31)$$

$$T = 2t_a + C \quad (32)$$

Equation (32) could be represented by a nomogram of three parallel lines and equations (30) and (31) by a "Z"chart, two lines being parallel and one diagonal. These nomograms could be constructed by a relatively simple geometric method since they are all straight lines. However, the more general method of nomogram construction, using determinants, was applied to this particular problem. (17)

The range of variables were fixed as follows:

T	0 to 160
t_a	0 to 70 °F
q	0 to 80,000 BTU/Hr.
U	0 to 1.5 BTU/(Hr.)(sq. ft.)(°F)
A	0 to 1,200 sq. ft.

The value of h_{1s} was assumed equal to 2.35, an average found from previous runs to be representative.

Equation (32) was put in the form,

$$T - 2t_a - C = 0 \quad (32a)$$

The constructional determinant in functional form for equation (32a) was,

$$\begin{vmatrix} -\delta_1 & m_1 f_1(T) & 1 \\ 0 & -\frac{m_1 m_3}{m_1 + m_3} f_2(t_a) & 1 \\ \delta_3 & m_3 f(C) & 1 \end{vmatrix} = 0 \quad (33)$$

where $\delta_3 = \frac{m_3}{m_1} \delta_1$, this equation became,

$$\begin{vmatrix} -\delta_1 & m_1 T & 1 \\ 0 & -\frac{m_1 m_3}{m_1 + m_3} 2 t_a & 1 \\ \delta_3 & -m_3 C & 1 \end{vmatrix} = 0 \quad (34)$$

where δ_1 and δ_3 are distances between parallel lines and m_1 and m_3 are scale moduli.

The width of the nomogram for equation (32a) was chosen as 4 inches, giving,

$$\delta_1 + \delta_3 = 4$$

The length of the scales were set at 6 inches and the scale moduli were determined using the limits of the range of each variable.

The values of δ_1 and δ_3 were then calculated, giving, $\delta_1 = 2$ and $\delta_3 = 2$, when $m_1 = m_3 = 0.0375$.

The resultant determinant for plotting the nomogram then became,

$$\begin{vmatrix} -2.0 & 0.0375 T & 1 \\ 0 & 0.0375 t_a & 1 \\ 2.0 & -0.0375 C & 1 \end{vmatrix} = 0 \quad (35)$$

The nomogram has three parallel lines, 2 inches on center, each with a scale factor of 0.0375, with the C line inverted.

Equation (31) was put in the form,

$$K W - C = 0 \quad (31a)$$

The constructional determinant in functional form for this equation (31a) was, (18)

$$\begin{vmatrix} 0 & m_1 f(C) & 1 \\ \delta_3 m_1 \frac{f(W)}{f(W)+1} & 0 & 1 \\ m_1 - m_3 \frac{f(W)}{f(W)+1} + m_3 & -m_3 f(K) & 1 \end{vmatrix} = 0 \quad (36)$$

Treating this determinant as before, the form used for plotting became,

$$\begin{vmatrix} 0 & -0.0375 C & 1 \\ 4(-0.0375) \left(\frac{W}{W+1} \right) & 0 & 1 \\ (-0.0375 - .09) \left(\frac{W}{W+1} \right) - 0.09 & 0.09 K & 1 \end{vmatrix} = 0 \quad (37)$$

The nomogram resulting from equation (31a) was plotted with the C line coinciding with the C line of the first nomogram and with the K line parallel to it at a distance of 4 inches to the right. The W line was plotted in terms of U as a diagonal between the C and K lines.

Equation (30) was put in the form,

$$\frac{q}{A} - K = 0 \quad (30a)$$

The constructional determinant in functional form for equation (30a) is the same as equation (36). The equation used for plotting the final nomogram became,

$$\begin{vmatrix}
 0 & 7.5 \times 10^{-5} q & 1 \\
 \frac{4 (7.5 \times 10^{-5}) \left(\frac{A}{A+1} \right)}{(7.5 \times 10^{-5} - .09) \left(\frac{A}{A+1} \right) + 0.09} & 0 & 1 \\
 4 & - 0.09 K & 1
 \end{vmatrix} = 0 \quad (38)$$

The nomogram resulting from equation (30a) was plotted with the K line coinciding with the K line of the second nomogram and the q line parallel to it at a distance of 4 inches to the right. The A line was plotted diagonally.

TENT NO.		1	DATE		2-25-47		WEATHER		overcast								
TYPE TENT		Large Wall - No Liner - Ground Cloth															
Time		AM		9	10	11	12	PM		1	2	3	4	5	6	7	8
WATER VAPOR	Inside Tent	Dry Bulb	43		58				56								
		Wet Bulb	35		43				41								
		Rel. Hum.%	45		25				23								
	Outside Tent	Dry Bulb															
		Wet Bulb															
		Rel. Hum.															
AIR TEMPERATURES	INSIDE TENT	3 ft. level	N E	44	47	52	57	62	56	51	50	46	45	44	44		
			N W	44	48	52	58	62	56	52	50	47	46	45	45		
			S E	45	48	52	56	63	57	53	50	47	46	45	45		
			S W	44	47	52	53	56	61	51	49	46	45	44	44		
		5 ft. level	C't'r	51	54	66	68	71	67	65	62	60	58	58	58		
			N E	48	50	58	63	66	60	57	54	51	50	49	49		
			N W	49	52	59	66	69	64	60	56	53	51	51	51		
			S E	49	52	59	65	68	61	57	54	52	51	50	50		
		8 ft. level	S W	48	51	59	64	67	60	57	54	52	50	50	50		
			C't'r	52	54	65	69	72	65	60	60	58	57	56	57		
			N E														
			N W	50	52	62	67	69	65	59	56	55	53	55	55		
			S E														
			S W	50	52	62	67	69	65	59	56	55	53	55	55		
			Outside Air	30	31	31	31	32	34	31	30	29	28	27	27		
SOIL TEMP.	Inside	32	33	32	33	32	32	32	32	30	31	31	30				
	Outside	30	30	31	31	30	30	30	29	29	28	27	27				
FABRIC TEMPERATURES	DECK	East-3 ft.	42	43	44	47	48	40	38	39	36	33	32	32			
		" 6 ft.	48	52	52	57	61	50	43	42	38	36	36	35			
		" 9 ft.	54	55	56	61	64	54	50	48	45	39	40	41			
		West-9 ft.	45	51	53	59	61	50	46	46	41	36	37	38			
		" 6 ft.	46	50	50	55	59	48	43	43	38	32	32	34			
	LINER	" 3 ft.	38	43	44	46	46	42	38	38	36	32	32	32			
		West-3 ft.															
		" 7 ft.															
		East-7 ft.															
" 3 ft.																	
WIND SPEED - mi./hr.			3.5	3.5	3.6	3.6	3.7	3.7	4.0	4.5	5.0	6.5	6	5.0			

SAMPLE DATA SHEET

FIGURE 22

TABLE 3 LIST OF TEST RUNS - TYPE AND WEATHER

Test No.	Date 1947	Time of Run (Approx.) C.S.T.	Ground Cloth	Heat Input BTU/Hr	Outside Air Temp.	Relative Humidity %	Wind Vel. mph	% Sun
LARGE WALL TENT - NO LINER								
1	2/13	12pm-9am	12.29	12,500	24-40	66	-	Night
2	2/12	9am-12pm	"	12,500	29-43	44	-	25
3	2/24	2pm-4pm	"	11,380	28-29	71	5.5	0
4	2/25	10am-12pm	"	12,260	27-30	-	3.5	0
5	2/26	12pm-10am	"	12,260	26-31	-	4.0	Night
6	2/27	2pm-4pm	"	11,120	37-38	42	4.7	100
7	2/28	9am-12am	"	11,750	35-37	33	1.8	97
8	3/4	9am-11am	"	12,200	33-40	60	3.3	22
9	3/7	2pm-4pm	"	11,100	42-44	53	5.7	0
10	3/12	7pm-10pm	"	12,550	47-50	50	0.0	Night
11	4/11	10pm-2am	"	8,000	44-50	-	0.0	Night
12	3/13	10am-1pm	None	8,000	43-46	100	2.3	0
13	3/3	1pm-4pm	12.29	8,700	32-34	70	5.6	43
14	2/21	10pm-12pm	"	7,930	29-34	60	4.2	66
15	2/19	10pm-12pm	"	8,100	23-27	-	3.9	100
16	4/8	2pm-2am	"	6,000	48-49	-	1.3	Night
17	2/19	2pm-4pm	"	6,000	35-36	-	3.9	100
18	4/8	2pm-4pm	"	5,840	32-34	60	6.0	44
19	2/19	9pm-12pm	"	6,000	34-40	59	0.7	44
20	2/21	2pm-4pm	"	6,450	52-53	32	0.4	100
21	3/5	10pm-1am	"	4,000	49-52	-	1.2	Night
22	3/10	2pm-4pm	"	4,000	40-42	-	-	100
23	4/9	2pm-4pm	"	4,000	24-40	66	3.9	0
24	2/27	10pm-12pm	"	4,000	28-34	39	4.4	100
25	3/12	10pm-12pm	"	0	42-47	72	6.9	-
26	4/3	1pm-5pm	"	0	59-63	-	1.7	100
27	4/3	9pm-2am	"	0	50-52	68	1.7	Night
28	3/12	7pm-10pm	None	12,500	47-50	64	0.0	Night
29	3/10	2pm-4pm	"	6,450	52-53	35	2.4	100
LARGE WALL TENT - 4 OZ. WHITE COTTON LINER								
30	2/12	10am-12pm	12.29	12,500	29-43	40	-	0
31	2/12	10am-12pm	"	12,500	29-43	73	-	Night
32	2/13	12pm-10am	"	12,500	24-40	82	-	Night
33	2/25	10am-12pm	"	12,260	27-30	-	3.5	0
34	2/25	10am-12pm	"	12,260	27-30	-	4.5	Night
35	2/26	12pm-10am	"	12,260	26-31	-	3.0	Night
36	2/24	2pm-4pm	"	11,380	28-29	71	5.5	0
37	2/21	10am-12am	"	7,930	29-34	52	4.2	66
38	2/27	2pm-4pm	"	8,000	37-38	40	4.7	100

TABLE 3 (CONTINUED)

Test No.	Date 1947	Time of Run (Approx.) C.S.T.	Ground Cloth	Heat Input BTU/Hr	Outside Air Temp.	Relative Humidity %	Wind Vel. mph	% Sun
<u>LARGE WALL TENT - 4 OZ. WHITE COTTON LINER</u>								
39	2/19	9am-11am	12.29	8,100	23-27	-	3.9	100
40	2/21	2pm-4pm	"	5,840	32-34	60	6.0	33
41	2/28	10am-12am	"	6,000	35-37	40	1.8	97
42	2/11	2pm-4pm	"	4,000	40-42	-	-	100
43	2/27	10am-12am	"	4,000	28-34	39	4.4	100
44	3/4	9am-11am	"	12,200	33-40	56	3.3	22
45	3/3	1pm-4pm	"	8,700	32-34	86	5.6	43
<u>LARGE WALL TENT - LOW PROFILE 4 OZ. WHITE COTTON LINER</u>								
46	3/7	2pm-4pm	"	6,000	42-44	55	5.7	0
47	3/5	9am-11am	"	6,000	34-40	68	0.7	44
48	3/5	2pm-4pm	"	4,000	39-40	66	3.9	0
<u>LARGE WALL TENT - 8 OZ. O.D. 7 COTTON LINER</u>								
49	2/12	10am-12pm	"	12,500	29-43	40	-	0
50	2/12	10am-12pm	"	12,500	29-43	73	-	Night
51	2/13	12pm-10am	"	12,500	24-40	82	-	Night
52	2/19	10am-12am	"	8,100	23-27	-	3.9	100
53	2/11	2pm-4pm	"	4,000	40-42	-	-	100
<u>LARGE WALL TENT - 1/2 INCH FIBERGLAS LINER</u>								
54	2/25	10am-12pm	"	12,260	27-30	-	3.5	0
55	2/25	10am-12pm	"	12,260	27-30	-	4.5	Night
56	2/26	12pm-10am	"	12,260	26-31	-	3.0	Night
57	3/4	9am-11am	"	12,200	33-40	58	3.3	22
58	2/24	2pm-4pm	"	11,380	28-29	77	5.5	0
59	3/12	7pm-9pm	None	12,550	47-50	50	0.0	Night
60	2/21	10am-12am	12.29	7,930	29-34	52	4.2	66
61	3/13	10am-12am	None	8,000	43-46	100	2.3	0
62	3/5	9am-11am	12.29	6,000	34-40	68	0.7	44
63	2/21	2pm-4pm	"	5,840	32-34	60	6.0	33
64	3/10	1pm-4pm	None	6,450	52-53	32	2.4	100
65	3/3	1pm-4pm	12.29	8,700	32-34	83	5.6	43
66	3/5	2pm-4pm	"	4,060	39-40	66	3.9	0
67	3/5	2pm-4pm	"	6,000	42-44	55	5.7	0
68	2/27	2pm-4pm	"	4,000	37-38	42	4.7	100
69	2/28	10am-12am	"	4,000	35-37	33	1.8	97
70	2/27	10am-12am	"	4,040	28-34	39	4.4	100

TABLE 3 (CONTINUED)

Test No.	Date 1947	Time of Run (Approx.) C.S.T.	Ground Cloth	Heat Input BTU/Hr	Outside Air Temp.	Relative Humidity %	Wind Vel. mph	% Sun
<u>SQUAD TENT M-1945 - NO LINER</u>								
71	4/3	9pm-2am	12.29	16,100	50-52	-	2.0	Night
<u>SQUAD TENT M-1945 - 4 OZ. WHITE COTTON LINER</u>								
72	4/8	9pm-2am	12.29	23,800	48-49	95	1.5	Night
<u>SQUAD TENT M-1945 - LOW PROFILE 4 OZ. WHITE COTTON</u>								
73	4/11	9pm-2am	12.29	24,100	44-50	-	0.0	Night
<u>SQUAD TENT M-1945 - LOW PROFILE 1/2 INCH FIBERGLAS LINER</u>								
74	4/9	9pm-1am	12.29	17,400	49-52	-	1.2	Night
<u>SQUAD TENT M-1945 - LOW PROFILE 4 OZ. WHITE COTTON LINER</u>								
75	5/5	9pm-12am	12.29	18,500	50-55	-	0.1	Night
76	5/6	12am-2am	"	18,500	46-50	-	0.0	Night
<u>LARGE WALL TENT - NO LINER</u>								
77	5/5	9pm-2am	12.29 and 1 inch Fiberglas	12,000	46-55	-	0.0	Night

TABLE 4 AIR, GROUND, AND FABRIC TEMPERATURES

Test No.	Average Temperatures °F					
	Outside Ground t_g	Outside Air t_a	Inside Air t_i	Tent Fabric t_D	Liner t_L	Ground Cloth (Floor) t_f
1	28	28	44.5	37.4	—	36
2	32	41	70	66.2	—	46.4
3	29	28	45	38.5	—	36
4	30	34	62	56.8	—	44
5	28	27	43	34.4	—	38
6	31	38	73	69.5	—	48
7	31	36	74.5	73.9	—	50
8	31	39	71	68.0	—	46
9	33	43	59.6	52.2	—	46
10	38	48	60.5	53.0	—	49
11	46	45	55.6	47.1	—	53
12	42	44	56.5	49.5	—	47
13	32	33	71.2	67.5	—	43
14	30	33	72.8	68.1	—	46
15	32	25	52.8	47.6	—	41
16	47	48	57.0	52.0	—	52
17	—	35	58.6	53.4	—	—
18	32	32	45.3	42.2	—	40
19	32	39	68.0	56.0	—	48
20	34	52	74.5	71.0	—	53
21	48	50	54	50	—	52.5
22	30	41	65.3	61.4	—	42
23	32	39	46.3	43.5	—	42
24	32	33	69.5	69.0	—	49
25	40	45	52.0	57.0	—	45.5
26	52	61	83.0	93.5	—	63
27	47	50.5	48.0	47.0	—	49.5
28	38	48	61.0	54.0	—	50
29	34	52.5	73.0	70.0	—	54
30	32	42.0	76.0	55.4	68	49.5
31	31	31	67.0	40.0	56	47.0
32	28	28	62.0	37.0	54	43.0
33	30	31	72.0	46	58	49.0
34	27	27	63.5	32.5	51	45.0
35	28	28	63.0	35.5	53	46.5
36	29	28	61.4	35.4	49.5	41.6
37	31	33	74.5	61.5	69	49.0
38	30	37	76.0	63	72	51.5
39	30	26	63.0	50	59	44.8
40	32	33	54.7	37.4	47	46.0
41	31	36	75.5	67.1	71	48.8
42	30	42	63.3	66.0	65	44.2

TABLE 4 (CONTINUED)

Test No.	Average Temperature °F					
	Outside Ground t_g	Outside Air t_a	Inside Air t_i	Tent Fabric t_D	Liner t_L	Ground Cloth (Floor) t_f
43	32	33	74.0	66.7	70	50.0
44	31	39	79.5	61.0	76	52.7
45	32	33	74.5	60.5	69	47.7
46	33	42	62.0	47.0	58	47.5
47	32	40	74.0	73.0	76.5	49.5
48	33	40	55.5	48.7	54	43.2
49	32	41	78.5	58.9	71	50.0
50	31	31	66.5	40.3	59	45.5
51	28	28	63.0	34.5	55	43.5
52	30	27	66.0	54.0	61	45.8
53	30	42	68.7	65.0	70	46.2
54	29	31	84.5	39.6	82	56.0
55	27	27	81.0	28.5	80	54.5
56	28	28	82.0	28.7	80	55.5
57	31	38	88.5	66.0	90	55.5
58	29	28	76.0	35.4	76	48.3
59	38	48	86.0	50.0	87	60.2
60	31	33	80.0	63.0	77	51.0
61	42	44	76	48.5	75	54.5
62	32	40	79	68.0	79	52.5
63	32	32	63	36.0	59	46.0
64	34	52	83	71.0	82	57.8
65	32	33.5	81	70.0	78	52.7
66	32	39	61.5	42.0	59	46.1
67	33	42	62.5	44.0	59	48.1
68	31	38	74.0	64.0	72	51.3
69	31	36	74.0	67.0	73	49.3
70	32	34	74.0	67.0	74	50.8
71	47	50	61.4	54.0	—	50
72	47.5	48	73.0	52.5	66	55
73	46	45	73.0	48.0	67	60
74	48	50	78.5	48.5	76	56
75	50	50	72.0	53.0	66	62
76	47	46	72.0	52.0	66	61
77	48	48	64.0	56.2	—	58

TABLE 5 TEMPERATURE DIFFERENCES

Test No.	Inside Air Minus Inside Surface ($t_i - t_L$ or t_D) Δt_{is}	Liner Minus Tent Fabric ($t_L - t_D$) Δt_{LD}	Tent Fabric Minus Outside Air ($t_D - t_a$) Δt_{Da}	Inside Air Minus Outside Air ($t_i - t_a$) Δt_{ia}	Equivalent Outside Air Temperature $\frac{2t_a + t_g}{3}$ Δt_{ag}	Tent Fabric Minus t_{ag} ($t_D - t_{ag}$) Δt_{Dag}	Inside Air Minus t_{ag} ($t_i - t_{ag}$) Δt_{iag}
1	7.1	—	9.4	16.5	28	9.4	16.5
2	3.8	—	25.2	29.0	—	—	—
3	6.5	—	10.5	17.0	28.3	10.2	16.7
4	5.2	—	22.8	28.0	—	—	—
5	8.6	—	7.4	16.0	27.3	7.1	15.7
6	3.5	—	31.5	35.0	—	—	—
7	0.6	—	37.9	38.5	—	—	—
8	3.0	—	29.0	32.0	—	—	—
9	7.4	—	9.2	16.6	—	—	—
10	7.5	—	5.0	12.5	44.7	8.3	15.8
11	8.5	—	2.1	10.6	45.3	1.8	10.3
12	7.0	—	5.5	12.5	—	—	—
13	3.7	—	34.5	38.2	—	—	—
14	4.7	—	35.1	39.8	—	—	—
15	5.2	—	22.6	27.8	—	—	—
16	5.0	—	4.0	9.0	47.7	4.3	9.3
17	—	—	—	—	—	—	—
18	3.1	—	10.2	13.3	32	10.2	13.3
19	12.0	—	17.0	29.0	—	—	—
20	3.5	—	19.0	22.5	—	—	—
21	4.0	—	0	4.0	49.3	0.7	4.7
22	3.9	—	20.4	24.3	—	—	—
23	2.8	—	4.5	7.3	—	—	—
24	0.5	—	36.0	36.5	—	—	—
25	-5.0	—	12.0	7.0	43.3	13.7	8.7
26	-10.5	—	32.5	22.0	58.0	35.5	25.0
27	1.0	—	-3.5	-2.5	49.3	-2.3	-1.3
28	7.0	—	6.0	13.0	44.7	9.3	16.3
29	3.0	—	17.5	20.5	—	—	—
30	8.0	12.6	13.4	34.0	38.7	16.7	37.3
31	11.0	16.0	9.0	36.0	31	9.0	36.0
32	8.0	17.0	9.0	34.0	28	9.0	34.0
33	14.0	12.0	15.0	41.0	—	—	—
34	12.5	18.5	5.5	36.5	27	5.5	36.5
35	10.0	18.5	7.5	35.0	28	7.5	35.0
36	11.9	14.1	7.4	33.4	28.3	—	—
37	5.5	7.5	28.5	41.5	—	—	—
38	4.0	9.0	26.0	39.0	—	—	—
39	4.0	9.0	24.0	37.0	—	—	—
40	7.7	9.6	4.4	21.7	—	—	—

TABLE 5 (CONTINUED)

Test No.	Inside Air Minus Inside Surface ($t_i - t_{L \text{ or } D}$) Δt_{is}	Liner Minus Tent Fabric ($t_L - t_D$) Δt_{LD}	Tent Fabric Minus Outside Air ($t_D - t_a$) Δt_{Da}	Inside Air Minus Outside Air ($t_i - t_a$) Δt_{ia}	Equivalent Outside Air Temperature $\frac{2t_a + t_g}{3}$ Δt_{ag}	Tent Fabric Minus t_{ag} ($t_D - t_{ag}$) Δt_{Dag}	Inside Air Minus t_{ag} ($t_i - t_{ag}$) Δt_{iag}
41	4.5	3.9	31.1	39.5	—	—	—
42	-1.7	-1.0	24.0	21.3	—	—	—
43	4.0	3.3	33.7	41.0	—	—	—
44	3.5	15.0	22.0	40.5	—	—	—
45	5.5	8.5	27.5	41.5	—	—	—
46	4.0	11.0	5.0	20.0	—	—	—
47	-2.5	3.5	33.0	34.0	—	—	—
48	1.5	5.3	8.7	15.5	—	—	—
49	7.5	12.1	17.9	37.5	38.0	20.9	40.5
50	7.5	18.7	9.3	35.5	31	9.3	35.5
51	8.0	20.5	6.5	35.0	28	6.5	35.0
52	5.0	7.0	27.0	39.0	—	—	—
53	-1.3	5.0	23.0	26.7	—	—	—
54	2.5	43.4	7.6	53.5	—	—	—
55	1.0	51.5	1.5	54.0	—	—	—
56	2.0	51.3	0.7	54.0	28	0.7	54.0
57	-1.5	24.0	28.0	50.5	—	—	—
58	0	40.6	7.4	48.0	—	—	—
59	-1.0	37.0	2.0	38.0	44.7	5.3	41.3
60	3.0	14.0	30.0	47.0	—	—	—
61	1.0	26.5	4.5	32	—	—	—
62	0	11.0	28.0	39	—	—	—
63	4.0	23.0	4.0	31	32	4.0	31
64	1.0	11.0	19.0	31	—	—	—
65	3.0	8.0	36.5	47.5	—	—	—
66	2.5	17.0	3.0	22.5	36.7	5.3	24.8
67	3.5	15.0	2.0	20.5	39.0	5.0	23.5
68	2.0	8.0	26.0	36.0	—	—	—
69	1.0	6.0	31.0	38	—	—	—
70	0	7.0	33.0	40	—	—	—
71	7.4	—	4.0	11.4	—	—	—
72	7.0	13.5	4.5	25.0	48	4.5	25.0
73	6.0	19.0	3.0	28.0	45.3	—	—
74	2.5	27.5	-1.5	28.5	—	—	—
75	6.0	13.0	3.0	22.0	50	3.0	22.0
76	6.0	14.0	6.0	26.0	46.3	—	—
77	7.8	—	8.2	16.0	48	8.2	16.0

TABLE 6 OVERALL AND INDIVIDUAL COEFFICIENTS OF HEAT TRANSFER

Test No.	Individual Coefficients				Overall Coefficient	
	Inside Air to Inside Surface h_{is}	Liner To Tent Fabric h_{LD}	Tent Fabric To Outside Air h_{Da}	Tent Fabric To tag h_{Dag}	Inside Air to Outside Air U_{ia}	Inside Air To tag U_{lag}
1	2.94	—	2.22	2.22	1.26	1.26
2	5.50	—	0.83	—	0.72	—
3	2.92	—	1.81	1.86	1.12	1.14
4	3.94	—	0.90	—	0.73	—
5	2.38	—	2.76	2.88	1.28	1.30
6	5.30	—	0.59	—	0.53	—
7	32.7	—	0.52	—	0.51	—
8	6.79	—	0.70	—	0.64	—
9	2.50	—	2.01	—	1.11	—
10	2.80	—	4.20	2.52	1.67	1.32
11	1.57	—	6.36	7.47	1.26	1.26
12	1.91	—	2.32	—	1.07	—
13	3.92	—	0.42	—	0.38	—
14	2.81	—	0.38	—	0.33	—
15	2.60	—	0.60	—	0.49	—
16	2.00	—	2.50	2.33	1.11	1.08
17	—	—	—	—	—	—
18	3.12	—	0.96	—	0.73	—
19	0.83	—	0.79	—	0.35	—
20	3.08	—	0.57	—	0.48	—
21	1.67	—	∞	9.60	1.67	1.42
22	1.71	—	0.33	—	0.27	—
23	2.38	—	1.48	—	0.89	—
24	13.3	—	0.19	—	0.18	—
25	—	—	—	—	—	—
26	—	—	—	—	—	—
27	—	—	—	—	—	—
28	3.00	—	3.50	2.26	1.61	1.28
29	3.60	—	0.62	—	0.52	—
30	2.60	1.65	1.55	1.25	0.61	0.56
31	1.89	1.30	2.37	0	0.58	—
32	2.60	1.22	2.32	—	0.61	—
33	1.46	1.70	1.36	—	0.50	—
34	1.64	1.11	3.73	—	0.56	—
35	2.04	1.10	2.72	—	0.58	—
36	1.59	1.35	2.57	—	0.57	—
37	2.41	1.76	0.46	—	0.32	—
38	3.34	1.48	0.51	—	0.34	—
39	3.37	1.50	0.56	—	0.36	—
40	1.34	1.02	2.22	—	0.45	—

TABLE 6 (CONTINUED)

Test No.	Individual Coefficients				Overall Coefficient	
	Inside Air to Inside Surface h_{is}	Liner To Tent Fabric h_{LD}	Tent Fabric To Outside Air h_{Da}	Tent Fabric To t_{ag} h_{Dag}	Inside Air to Outside Air U_{ia}	Inside Air To t_{ag} U_{lag}
41	2.22	2.57	0.32	—	0.25	—
42	-3.92	-6.67	0.28	—	0.31	—
43	1.67	2.02	0.20	—	0.16	—
44	5.82	1.36	0.93	—	0.50	—
45	2.64	1.71	0.53	—	0.35	—
46	2.50	0.91	2.00	—	0.50	—
47	-4.00	2.86	0.30	—	0.29	—
48	4.45	1.26	0.76	—	0.43	—
49	2.78	1.72	1.17	1.00	0.56	0.52
50	2.78	1.12	2.24	—	0.59	—
51	2.61	1.02	3.21	—	0.60	—
52	2.71	1.93	0.50	—	0.35	—
53	-5.13	1.33	0.29	—	0.25	—
54	8.17	.47	2.69	—	0.38	—
55	20.4	.40	13.6	—	0.38	—
56	10.2	.40	29.2	—	0.38	—
57	-13.5	.85	0.73	—	0.40	—
58	∞	.47	2.6	—	0.40	—
59	-21.0	.56	10.5	3.95	0.55	0.51
60	4.4	.94	0.44	—	0.28	—
61	13.3	.50	2.96	—	0.41	—
62	∞	.91	0.36	—	0.26	—
63	2.43	.42	2.43	—	0.31	—
64	10.7	.98	0.57	—	0.35	—
65	4.8	1.81	0.40	—	0.31	—
66	2.7	.40	2.25	1.28	0.30	0.27
67	2.86	.67	5.00	2.00	0.49	0.42
68	3.33	.84	0.26	—	0.19	—
69	6.67	1.11	0.22	—	0.18	—
70	∞	.96	0.20	—	0.17	—
71	1.90	—	3.50	—	1.23	—
72	2.96	1.53	4.60	—	0.84	—
73	3.48	1.10	7.00	—	0.75	—
74	6.05	.55	-10.1	—	0.53	—
75	2.70	1.24	5.36	—	0.73	—
76	2.70	1.15	2.68	—	0.62	—
77	2.57	—	2.44	—	1.25	—

TABLE 6 (CONTINUED)

Type Liner	Individual Coefficients				Overall Coefficient	
	Inside Air to Inside Surface h_{is}	Liner To Tent Fabric h_{LD}	Tent Fabric To Outside Air h_{Da}	Tent Fabric To t_{ag} h_{Dag}	Inside Air to Outside Air U_{ia}	Inside Air To t_{ag} U_{iag}
<u>LARGE WALL TENT</u>						
Average Values (Night and Overcast Runs)						
No Liner	2.5	—	2.6	2.5	1.27	1.26
4 oz. Cotton	2.5	1.3	2.5	2.5	.58	.58
8 oz. Cotton	2.5	1.3	2.5	2.5	.58	.58
1/2 inch Fiberglas	—	0.5	—	—	.40	.39

TABLE 7 COMFORT INDEX

Test No.	Inside Air t_1	Average Inside Surface Temperature t_s	Comfort Index $t_1 + t_s$
1	44.5	37.1	81.6
2	70	60.7	130.7
3	45	37.8	82.8
4	62	53.4	115.4
5	43	35.5	78.5
6	73	63.7	136.7
7	74.5	67.5	142.0
8	71.0	62.1	133.1
9	59.6	50.6	110.2
10	60.5	51.9	112.4
11	55.6	48.8	104.4
12	56.5	48.9	105.4
13	71.2	61.0	132.2
14	72.8	62.1	134.9
15	52.8	45.9	98.7
16	57.0	53.3	110.3
17	58.6	—	—
18	45.3	41.6	86.9
19	68.0	53.9	121.9
20	74.5	66.1	140.6
21	54.0	50.7	104.7
22	65.3	56.1	121.4
23	46.3	43.2	89.5
24	69.5	63.6	133.1
25	52.0	53.9	105.9
26	83.0	85.3	168.3
27	48.0	47.6	95.6
28	61.0	53.0	114.0
29	73.0	65.7	138.7
30	76.0	63.1	139.1
31	67.0	53.7	120.7
32	62.0	51.2	113.2
33	72.0	55.6	127.6
34	63.5	49.5	113.0
35	63.0	51.2	114.2
36	61.4	47.5	108.9
37	74.5	63.7	138.2
38	76.0	66.6	142.6
39	63.0	55.4	118.4
40	54.7	46.8	101.5
41	76.5	65.3	140.8
42	63.3	59.5	122.8

TABLE 7 (CONTINUED)

Test No.	Inside Air t_1	Average Inside Surface Temperature t_2	Comfort Index $t_1 + t_2$
43	74.0	64.9	138.9
44	79.5	69.5	149.0
45	74.5	63.0	137.5
46	62.0	54.9	116.9
47	74.0	68.7	142.7
48	55.5	50.8	106.3
49	78.5	65.6	144.1
50	66.5	55.6	122.1
51	63.0	52.1	115.1
52	66.0	57.0	123.0
53	68.7	64.0	132.7
54	84.5	75.5	160.0
55	81.0	73.6	154.6
56	82.0	73.9	155.9
57	88.5	81.4	169.9
58	76.0	69.0	145.0
59	86.0	80.4	186.4
60	80.0	70.5	150.5
61	76.0	69.9	145.9
62	79.0	72.5	151.5
63	63.0	55.8	118.8
64	83.0	76.0	159.0
65	81.0	71.8	152.8
66	61.5	55.7	117.4
67	62.5	56.3	118.8
68	74.0	66.9	140.9
69	74.0	67.1	141.1
70	74.0	67.9	141.9
71	61.4	53.0	114.4
72	73.0	62.0	135.0
73	73.0	64.0	137.0
74	78.5	69.0	147.5
75	72.0	64.5	136.5
76	72.0	64.3	136.3
77	64.0	56.6	120.6

TABLE 8 FUEL CONSUMPTION AND SAVINGS WITH LARGE WALL TENT

Liner	Comfort Index	Outside Air Temp. °F	Heat Required BTU/ Hr.	Fuel Consumption lb./hr.
None	140	40	32,000	2.13
4.0 oz.	140	40	12,000	0.80
8.0 oz. Reg.	140	40	12,000	0.80
1/2 in. Fiber-glas	140	40	7,000	0.47
None	140	20	55,000	3.67
4.0 oz. Reg.	140	20	21,000	1.40
8.0 oz. Reg.	140	20	21,000	1.40
1/2 in. Fiber-glas	140	20	12,000	0.80
Liner	Lbs. Fuel Saved Per hr. Using Liner	Time For Fuel Saving To Equal Liner Weight	Cu. Ft. Fuel Saved Per Hr. Using Liner	Time For Bulk Saving To Equal Liner Bulk
4.0 oz.	1.33	15 hrs.	.027	3 days
8.0 oz. Reg.	1.33	30 hrs.	.027	3 days
1/2 in. Fiber-glas	1.66	33 hrs.	.033	8.9 days
4.0 oz. Reg.	2.27	9 hrs.	.045	1.9 days
8.0 oz. Reg.	2.27	18 hrs.	.045	1.9 days
1/2 in. Fiber-glas	2.87	19 hrs.	.058	5.0 days

TABLE 9 COST, WEIGHT, BULK SUMMARY FOR ONE MONTH'S OPERATION
USING LARGE WALL TENT
COMFORT INDEX - 140

Liner	Fuel Cost \$	Fuel Weight lbs.	Fuel Bulk Cu. Ft.	Total Weight Fuel and Container and Liner	Total Bulk Fuel and Container and Liner
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Outside Air Temperature - 40 °F

None	11.50	1,530	30.6	1,680	33.7
4.0 oz. Reg.	4.30	576	11.5	650	14.7
8.0 oz. Reg.	4.30	576	11.5	670	14.7
1/2 in. Fiber- glas	4.30	336	6.7	425	14.4

Outside Air Temperature - 20 °F

None	19.80	2,640	52.8	2,900	58.1
4.0 oz. Reg.	7.55	1,000	20.2	1,120	24.2
8.0 oz. Reg.	7.55	1,000	20.2	1,140	24.2
1/2 in. Fiber- glas	4.32	576	11.5	689	19.7

Savings Due to Liner

Liner	Cost		Weight		Bulk	
	\$	%	lbs.	%	Cu. Ft.	%

Outside Air Temperature - 40 °F

None		00		00		00
4.0 oz. Reg.	7.20	63	1,030	61	19.0	62
8.0 oz. Reg.	7.20	63	1,010	60	19.0	62
1/2 in. Fiber- glas	9.00	78	1,255	75	19.3	63

Outside Air Temperature - 20 °F

None		00		00		00
4.0 oz. Reg.	12.25	62	1,780	61	33.9	64
8.0 oz. Reg.	12.25	62	1,760	61	33.9	64
1/2 in. Fiber- glas	15.48	78	2,210	75	38.4	73

TABLE 10 TENT TEMPERATURE DATA
LARGE HOODED FLIES

Time		10	11	2	3	4	4:30	10:30	11:30	12
Temperature °F.										
Outside Air		71	72	75	76	76	75	80	83	86
Outside Ground		80	89	81	78	76	75	88	88	96
Large Wall Tent-No Fly-Closed										
Deck-West	7'	97	118	111	132	129	96	118	132	114
Deck-East	7'	138	135	98	85	86	130	112	138	126
Side Wall-West	2-1/2'	87	92	128	128	129	87	98	104	122
Side Wall-East	2-1/2'	123	108	91	85	85	122	126	113	101
End-South	7'	125	134	125	114	108	120	132	137	114
End-North	7'	92	95	96	86	88	94	104	108	110
Air-Inside	4'	100	104	105	95	95	100	111	117	119
Ground Cloth		79	81	88	84	84	76	85	89	92
Large Wall Tent - Single Layer Fly - Closed										
Deck-West	7'	75	83	95	90	87	82	90	96	101
Deck-East	7'	86	89	84	78	76	95	100	100	96
Side Wall-West	2-1/2'	74	80	89	86	83	80	87	91	94
Side Wall-East	2-1/2'	80	84	83	78	76	87	92	94	92
End-South	7'	82	90	93	85	85	87	94	98	104
End-North	7'	77	80	86	81	78	87	91	94	94
Air-Inside	4'	76	81	85	82	80	83	90	92	95
Ground Cloth		71	75	78	76	75	75	78	80	81
Fly-West	7'	80	98	122	115	107	85	99	110	123
Fly-East	7'	110	116	82	73	70	124	127	120	109
Deck-Outside-East	7'	88	89	83	77	76	97	100	99	96

TABLE 10 (CONTINUED)

Time		10	11	12	1	2	3	1	2	3
Temperature °F										
Outside Air		67	69	71	70	71	70	68	68	67
Outside Ground		95	102	92	97	92	85	80	77	76
Large Wall Tent - Single Layer Fly - Closed										
Fly-West	7'	80	91	92	95	96	93	96	92	—
Fly-East	7'	—	—	—	83	76	70	76	68	66
Deck-West	7'	74	80	81	80	80	80	78	77	79
Deck-East	7'	84	85	81	76	74	73	72	70	71
Side Wall-West	2-1/2'	74	77	78	78	77	77	77	76	78
Side Wall-East	2-1/2'	77	79	78	74	74	73	74	71	72
End-South	7'	84	86	84	84	83	81	85	82	81
End-North	7'	78	79	84	76	76	76	74	74	73
Air-Inside	4'	76	79	79	76	77	76	76	76	75
Ground Cloth		68	70	71	70	71	70	70	70	70
Deck-Outside-East	7'	83	83	83	78	73	73	74	70	70
Large Wall Tent - Double Layer Fly - Closed										
Fly-West	7'	71	84	82	81	90	80	88	93	87
Fly-East	7'	86	93	82	73	73	70	72	68	66
Deck-West	7'	71	77	78	75	79	74	77	80	76
Deck-East	7'	75	80	78	73	74	72	73	72	70
Side Wall-West	2-1/2'	72	77	78	75	75	75	78	79	77
Side Wall-East	2-1/2'	75	79	78	75	75	73	74	74	73
End-South	7'	79	85	81	80	80	77	80	81	79
End-North	7'	71	75	80	75	77	74	71	73	72
Air-Inside	4'	71	75	76	72	74	74	73	74	72
Ground Cloth		65	66	68	67	68	68	66	67	66

TABLE 10 (CONTINUED)

Time		11:30	1:30	3:30	8:30	10:30
Temperature °F						
Outside Air		86	89	88	79	85
Outside Ground		91	98	94	83	94
Large Wall Tent - No Fly - Open						
Deck-West	7'	119	139	124	81	103
Deck-East	4'	128	107	89	122	118
Deck-East	7'	128	105	89	127	126
Deck-East	9'	123	104	92	124	126
Ground Cloth		87	88	85	77	82
Inside Air	2'	88	92	90	80	87
Inside Air	5'	89	93	90	82	89
Inside Air	9'	94	97	93	87	94
Large Wall Tent - Single Layer Fly - Open						
Fly-East	7'	123	100	86	126	131
Fly-West	7'	118	133	122	73	102
Deck-West	7'	98	102	97	78	91
Deck-East	4'	99	95	87	91	94
" "	7'	101	95	89	95	99
" "	9'	94	98	90	90	95
" " (Outside)	7'	97	97	88	96	101
Inside Air	2'	86	90	88	80	86
" "	5'	86	90	88	80	86
" "	9'	89	93	89	84	90
Ground Cloth		83	85	83	77	81

TABLE 10 (CONTINUED)

Time		11:30	12:30	1:30	2:30	3:30
Temperature °F						
Outside Air		65	75	76	76	76
Outside Ground		92	90	92	98	93
Large Wall Tent - Single Layer Fly - Open						
Fly-East	7'	—	—	—	—	—
Fly-West	7'	89	102	103	117	96
Deck-West	7'	78	81	85	87	80
Deck-East	4'	80	81	80	79	74
" "	7'	81	81	80	79	74
" "	9'	77	79	82	78	74
" " (Outside)	7'	87	83	83	79	75
Ground Cloth		70	72	75	74	71
Inside Air	2'	70	75	76	76	76
" "	5'	71	75	76	76	76
" "	9'	71	76	76	76	76
Large Wall Tent - Double Layer Fly - Open						
Fly-East	7'	80	81	85	76	76
Fly-West	7'	77	83	105	100	92
Deck-West	7'	74	76	88	84	80
Deck-East	4'	74	76	82	78	76
" "	7'	74	76	82	78	76
" "	9'	76	75	82	79	76
Ground Cloth		67	66	72	71	70
Inside Air	2'	71	74	77	76	76
" "	5'	71	74	76	76	76
" "	9'	70	74	76	76	75

TABLE 11 AVERAGE TEMPERATURES - TENTS CLOSED

Average Temperature °F							
Time	Outside Air	Inside Air	Inside Tent Surface	Inside Fly Surface	Inside Air	Inside Tent Surface	Inside Fly Surface
No Fly				Single Layer Fly			
10:00	71	100	112	—	76	80	95
11:00	72	104	117	—	81	85	107
2:00	75	105	114	—	85	89	102
3:00	76	95	105	—	82	84	94
4:00	76	95	104	—	80	81	89
9:30	75	100	109	—	83	86	105
10:30	80	111	122	—	90	93	113
11:30	83	117	125	—	92	96	115
12:30	86	119	127	—	95	98	116
Double Layer Fly				Single Layer Fly			
10:00	67	71	74	80	76	79	86
11:00	69	75	79	89	79	82	95
12:00	71	76	79	82	79	80	95
1:00	70	72	75	77	76	78	79
2:00	71	74	77	81	77	78	86
3:00	70	74	74	75	76	77	81
1:00	68	73	75	80	76	77	86
2:00	67	74	72	80	76	75	80
3:00	67	72	74	77	75	76	80

TABLE 12 AVERAGE TEMPERATURES - TENTS OPEN

Time	Outside Air	Inside Air	Inside Tent Surface	Inside Fly Surface	Inside Air	Inside Tent Surface	Inside Fly Surface
				No Fly	Single Layer Fly		
11:30	86	89	123	—	86	98	120
1:30	89	93	121	—	90	99	116
3:30	88	90	105	—	88	93	104
8:30	79	81	102	—	80	85	100
10:30	85	88	114	—	86	93	116
				Double Layer Fly	Single Layer Fly		
12:30	74	74	77	82	75	81	—
1:30	76	77	85	95	76	83	—
2:30	76	76	81	88	76	83	—
3:30	76	76	78	84	76	77	—

TABLE 13 TEMPERATURE DIFFERENCES °F

Time	Inside Air Minus Outside Air			Inside Tent Surface Minus Inside Air		
	No Fly	Single Layer Fly	Double Layer Fly	No Fly	Single Layer Fly	Double Layer Fly
<u>Tents Closed</u>						
10:00	29	5	-	12	4	-
11:00	32	9	-	13	4	-
2:00	30	10	-	9	4	-
3:00	19	6	-	10	2	-
4:00	19	4	-	9	1	-
9:30	25	8	-	9	3	-
10:30	31	10	-	11	3	-
11:30	34	9	-	8	4	-
12:30	33	9	-	8	3	-
10:00	-	9	4	-	3	3
11:00	-	10	6	-	3	4
12:00	-	8	5	-	1	3
1:00	-	6	2	-	2	3
2:00	-	6	3	-	1	3
3:00	-	6	4	-	1	0
1:00	-	8	5	-	1	2
2:00	-	8	6	-	-1	-2
3:00	-	8	5	-	1	2
<u>Tents Open</u>						
11:30	3	0	-	34	12	-
1:30	4	1	-	28	9	-
3:30	2	0	-	15	5	-
8:30	2	1	-	21	5	-
10:30	3	1	-	26	6	-
12:30	-	1	0	-	7	4
1:30	-	0	1	-	6	8
2:30	-	0	0	-	6	5
3:30	-	0	0	-	1	2

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VITA

The author of this thesis, Earl Robert Gerhard, was born August 9, 1922, in Louisville, Kentucky, the son of Edwin Leonard Gerhard and Lillian Just Gerhard. He attended grade school and then Saint Xavier High School in Louisville, from which he graduated in 1940. He entered the Speed Scientific School of the University of Louisville in September 1940 and received his Bachelor of Chemical Engineering degree in September 1943. This period included six months of co-operative work at the Colgate-Palmolive-Peet Company in Jeffersonville, Indiana. He was elected to the honorary engineering fraternity of Sigma Tau and the honorary fraternity of Phi Kappa Phi.

Upon completion of his bachelor work he was employed by the Shell Oil Company as a junior technologist in their Norco, Louisiana, refinery where he worked for eight months. He entered the armed services in July 1944 and served for two years, including one year in the Asiatic-Pacific Theater.

Subsequent to his discharge from the army he entered the graduate school of the University of Louisville and received his Master of Chemical Engineering degree in December 1947. His master work included a fellowship in the Institute of Industrial Research, University of Louisville, where he worked on the project, "Improved Design of Tents and Tentage Materials", sponsored by the Research and Development branch of the Office of Quartermaster General.