# THERMAL INSULATION VALUES OF CERTAIN LAYERED ASSEMBLAGES OF MEN'S WEAR

by

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# CHAPTER I

## INTRODUCTION

While the primary function of clothing the human body is often disputed, it is seldom disputed that one function is protection from the environmental elements. Since two principal factors a consumer considers when selecting clothing are appearance and thermal insulating properties, any research attempts concerning the way clothing accomplishes the insulative purpose immediately leads into environmental research. Rohles (39) has listed physical factors, organismic factors, and reciprocative factors interacting to constitute the variables which must be considered for human factors research. Physical factors include area-volume, radiation, inspired air, atmospheric pressure, force field, air movement, and temperature-humidity. Organismic factors include age, diet, rhythmicity, and BMR. Finally reciprocative factors include activity, clothing, exposure, and social elements. Due to the complexity it is understandable that little research of this nature was found in the literature and most studies were attempts to determine the transfer of heat through textile systems disregarding the human factor. This study was undertaken to develop a better understanding of the insulative utility of various jacket linings and/or shell combinations worn singly or in layers on the human body in still air conditions.

Most studies found in the literature considered the human body as a body of one temperature, and the environment a body of another temperature thus producing a temperature gradient. A property of the second law of thermodynamics provides that if one body is at higher temperature than another, heat will flow from the body of higher to the body of lower temperature. The greater the gradient, the greater will be this flow of heat. Thus the human body, when at a higher temperature than its surroundings, will lose heat to the surroundings. If the equilibrium of body temperature is to be maintained, the rate of heat loss from the body must be equal to its rate of production within the body. If a textile system can help to reduce this gradient the heat regulatory function of clothing to the body becomes obvious.

Heat regulation is most important to comfort. Cassie (12), Black and Matthew (9), and Pierce and Rees (34) compare the human body to a delicately regulated thermostat. Indirectly energy is constantly supplied to the body in the form of food. The food is converted to heat and work by oxidation. Dissipation of the metabolic work is handled by the respiratory apparatus and the skin; the former loosing heat by expelling warm air and water vapor as well as dissipating carbon dioxide; and the latter loosing it by radiation, convection, and evaporation of moisture. With exposure of the skin to various conditions of temperature and humidity the heat flow varies. The internal body temperature remains approximately 37$^{\circ}$C. and that of the skin approximately 33$^{\circ}$C. when comfortable sedentary conditions are maintained. The nerve endings in the dermis and epidermis act as thermojunctions detecting differences in the surface and body temperatures producing feelings of chilliness or warmth.

Most of the studies (7, 8, 11, 22, 38) found in literature concerning the thermal insulative value of men's wear garments have been conducted in extreme weather conditions, or are those that would be worn in arctic and tropical climates and are studied to determine the effectiveness in such conditions. Little research was found reporting studies concerning the thermal insulative value of men's garments in normal weather conditions such as those in which men's hip length jacket shells and/or liners are apt to be worn.

Franz (18) recognizing that consumers have no quantitative means for judging the thermal insulative value of garments, conducted a study to determine the clo value for three types of windbreakers worn in normal climatic conditions. With the many acrylic pile faced linings available today the question arises, does the thickness and compactness of the pile make a significant difference in thermal insulative value provided and what effect does the layer principle have in reference to these pile linings? This study was planned as an outgrowth and continuation of the previous study by Franz (18).

The objectives of this study were three-fold. They were:

1. To further develop methods and procedures for using the copper manikin.
2. To determine the thermal insulative value, stated in clo, for single yarn poplin, two ply yarn poplin, and corduroy jacket shells: and light, medium, and heavy weight acrylic pile linings used in these jacket shells and combinations thereof.
3. To analyze the additive effect of the layer principle using the above combinations.

# CHAPTER II

# REVIEW OF THE LITERATURE

While clothing is usually added to help maintain surface body temperature paradoxically it also creates an avenue for the escape of heat, that of conduction. Using conduction in the pure sense of the word, Angus (2) stated that for thick fabric the largest portion of heat loss from the body is by conduction through the clothing. Speakman and Chamberlain (43) and Rees (37) referred to thermal conductivity of textile fabric as the flow of heat through a heterogeneous system. This is not pure conduction but includes convection and radiation through the spaces in the fabric. Furthermore, textile fabrics are hygroscopic so there will be some thermal transmission due to evaporation and condensation of moisture. It becomes obvious that conduction, convection, radiation, and evaporation interact to transfer heat across a temperature gradient even if a textile system modifies the path. The degree of insulation the textile system provides will depend partially upon the properties of the textile system, but to evaluate these properties the researcher must first thoroughly understand the methods of heat transfer from the body.

## I. METHODS OF HEAT TRANSFER FROM THE HUMAN BODY TO AND THROUGH THE CLOTHING SYSTEM

Cassie (12) stated that under resting conditions 75 per cent of body heat loss is by conduction and convection through clothing systems.

The remaining 25 per cent is lost by evaporation from the skin. Hardy (24) more thoroughly subdivided the methods of heat transfer from the body claiming that 90 per cent of the heat produced by the body is dissipated from the surface of the skin by conduction, convection, radiation, and evaporation. The other 10 per cent is exhaled and lost through excretions.

Conduction

Newburgh (32) defined conduction as "the flow of heat through a medium without the physical transfer of material" or more specifically as Selle (41) stated it is "the transfer of heat from one molecule to another through gases, liquids, and solids by direct contact." Specifically conduction in contrast to convection can take place in solids as well as gases and liquids. Although in the latter media conductive heat loss occurs only when circumstance prevents or limits convective heat loss. Conductive heat loss through gas or liquid is a type of heat transfer in which there is no streaming but the molecules of the medium remain essentially in their original locations, passing the heat energy from one to another by molecular vibrations and collisions.

Newburgh (32) stated that in a medium with uniform physical properties the amount of conductive heat that flows from a warm surface to a cool surface is inversely proportional to the length of the path, and directly proportional to the nature of the medium, thermal gradient and the area for heat flow. If a textile system is the medium the insulating value of it depends upon the thermal conductivity of the fibers, the orientation of the fibers, and the amount of fiber present in a given volume of fabric.

## Convection

Convection is the second major method of heat loss through the fabric system across a temperature gradient. Cassie (12) stated, "The convective heat loss is the physical transfer of heat by the circulation or movement of heated parts of a liquid or gas." Logically this is effected by the nature of the textile system's air spaces. According to Rees (35) it is also dependent upon the rate of air movement within the fabric and the temperature of the gradient. He established experimentally that convective heat loss is proportional to the square root of the atmospheric pressure.

With the temperatures of the human body and the temperature of the environment producing the gradient, it was found by Black and Matthew (9) that as the temperature of the environment approaches that of the human body the losses of bodily heat to the environment by radiation and convection decrease. As the body and environment reach equilibrium there is no transfer and when the environmental temperature exceeds the temperature of the human body there is a gain of heat to the body. The flow direction of heat loss in this case is from the environment to the human body.

## Radiation

Newburgh (32) defines radiation as "the exchange of thermal energy between objects, through a process depending only on the temperature and nature of the radiative surfaces." It does not depend upon the presence of any medium and therefore heat transfer by this process will take place even through a vacuum.

Hardy (24) stated that the amount of heat lost by the body to the environment by radiation is dependent upon the difference in the temperature of the skin and the surrounding wall or the radiant environment. Rees (35) reported it will also depend upon the surface property of the fabric.

When the human body is covered by a textile system the radiant environment would be the textile system. The radiant heat transfer depends on the emissivity of the surface of the clothing. The emissivity "is the ratio of the intensity of radiation emitted by a body to the corresponding intensity of the radiation of a black body, and is usually expressed in percentage" as expressed by Hardy (24). Rees (36) said that color had no effect on the emission of radiation by the human body; fabrics of any color behaved almost like a black body.

Marsh (29) found that smooth shiny surfaced fabric had a high insulating value concerning heat loss. Recently it has been shown fabrics have an emissivity ten times as great as polished copper, but yet this heat loss is almost negligible when considered that less than 10 per cent of the total clothed body heat loss is by radiation to the clothing.

## Evaporation

Newburgh (32) defines evaporative heat loss as "the transfer of heat due to the vaporization process." The entire vaporization process in the human body involves the passage of moisture from a liquid at or near the skin temperature to a vapor at skin temperature and finally the cooling and expansion of vapor to atmospheric conditions.

The amount of evaporative heat loss is primarily dependent upon the vapor pressure gradient between the surface and its immediate environment, and secondarily a function of air movement and vapor resistance offered by any materials placed between the wet surface and the environment. The air movement is in turn dependent on the shape of the exposed surface as well as the air velocity.

The passage of moisture from the skin surface to the outside atmosphere was divided into three stages by Gregory (23): (1) Passage between the skin surface and underside of the fabric by diffusion, (2) passage through the fabric, and (3) passage between the outer surface of the fabric and the free atmosphere with which it is in contact. The latter step is by diffusion assisted by convection to an amount depending on the degree of motion of the air.

The whole vaporization process involves heat loss from the body, but the significance of this form of heat loss is debatable. Dubois and Solderstrom (17) reported that about 25 per cent of the metabolic heat is carried away from the body by evaporation from the lungs and skin. This might appear to be a significant amount but it must be noted that this figure includes loss through expired air.

Angus (3) stated that generally when dealing with a temperature gradient of a warmer human body and a low environmental condition it is safe to ignore sweat, and/or insensible perspiration and the consequent cooling of the skin by evaporation. The assumption is made that under extreme conditions of cold when warm clothing is most necessary the skin will be to all practical purposes free from body moisture resulting from the effect of vasoconstriction. Similar findings were reported by Black and Matthew (9).

Heat loss from the human body to a cooler environment is primarily by conduction, convection, and radiation. More specifically it is due to the cooling of the skin by conduction or direct contact with the cloth materials, infiltration of cold air through the material or through openings in the clothes with accompanying displacement of warm air next to the skin; cooling of the enclosed layer of air between the skin and the material near to but not touching the skin; and radiative effects from the warm skin to the cooler inner surface of the textile system.

After body heat has conducted, convected and radiated through the clothing system it is further lost to the environment from the outer surface of the clothing largely by radiation and convection.

## II. PREVENTION OF HEAT TRANSFER BY TEXTILE SYSTEMS

If a textile system is to effectively prevent heat transfer across a temperature gradient it must combine insulative properties to counteract all methods of heat loss. A system preventing conductive heat loss would not necessarily prevent convective, radiative or evaporative heat loss.

Density and Thickness

Many writers (4, 9, 33, 40, 47) indicated that it is not the fiber content or weight of clothing but rather the thickness and density that determines the amount of insulative value a textile system provides. Black and Matthew (9), believe the insulating value of any cloth, irrespective of the fiber employed, might be adjusted to any desired value by suitable adjustment of the porosity in manufacturing by simple modifications of its structure.

The amount of air entrapped in fabric affects the density. Cassie (13) reported the thermal conductivity of wool felts plotted against density. It was seen that after inconsistent results at very low densities conductivity increased steadily and rapidly with the density of the felt. The increase was due to wool fibers having a thermal conductivity ten times as great as air, so decreasing the air content and increasing the fiber content increased the thermal conductivity of the felt. Silk fibers have a conductivity fifteen times that of air, and the conductivities of plant fibers are almost thirty times that of air. The conductivities of man-made fibers are not well known, but they are likely to be nearer the value given by the natural cellulose fibers than the protein fibers, as expressed by Black and Matthew (9).

The very irregularity of natural fibers is an asset for it prevents the spinning of densely packed yarns, an enemy to warmth. The bulk density of wool fabrics seldom exceeds 0.5 gm./c.c. and it is clear that at densities below this value the thermal conductivity of the fabric is closer to that of air than to that of fibers. From the above Cassie (13) concluded that it is the air entrapped in a fabric and resulting low density that gives good heat insulation.

Thermal conductivity of all fibers is greater than that of air. Air is one of the best known thermal insulators provided it can be kept stationary and a function of the fibers is to prevent air movement. Fiber orientation has an emphatic influence on the thermal conductivity of a textile system. It would appear that the higher the air to fiber ratio of a textile system the lower the heat loss. This, however, is only true up to a point. For maximum heat insulation there is an optimum density of fiberous materials which is 0.03 to 0.06 gm./c.c. Below this point heat loss by convection within the fabric becomes a major problem.

The fabric system density depends upon the construction of the fabric as well as fiber density. Baxter and Cassie (6) reported that uniform structure such as quilted wadding and felts are the most efficient structures for trapping air within the fabric in small pockets. They said the minimum bulk density useable is primarily determined by the wearing qualities required of the material and the pressure if any it must withstand. Efficient insulation for clothing of a given weight is accomplished by using fabrics of minimum bulk density compatible with wearing qualities. The measurement of weave structure affects the thermal conductivity of a fabric only indirectly through the variation it causes in thickness and density reported Speakman and Chamberlain (43).

It was generally agreed (32, 9, 34, 43) that the thickness of a material is the chief operating factor in providing thermal insulation where the densities of the fabric system are fairly comparable.

## Entrapped Air

Air entrapped in a fabric gives good heat insulation. It is well known from aerodynamics research that air immediately in contact with a solid surface is always at rest. Cassie (14) explained the phenomena in the following manner. If air is moving over a solid surface, there is a velocity gradient from the surface to the moving air; at the surface the air is stationary and at some distance from it the air moves with the observed speed. The velocity gradient, caused by the air being at rest at the solid surface, exerts a drag on the moving air tending to bring it to rest. The greater the solid surface the greater is the drag on any air movement; the greater in fact is the amount of entrapped air. Fibers have enormous total surfaces imposing a drag on air movement and account for the fact that staple or textured yarns are much better for entrapping air than filament yarns. Filament yarns are automatically close packed leaving only the yarn surfaces available for air drag. This supports findings by Black and Matthew (9) and Fonesca (18) that an empty air space is not as good insulation as space filled with pile. The fibers of the pile produce drag on the air.

Marsh (29) stated that, between the garment and the skin is another important space for entrapping air. Even if a garment is uncomfortably tight there is usually a film of air beneath it, caused by the projecting hairs from the skin, or projecting fibers from the fabric. These minute air films have a great thermal insulating value.

Producing still air conditions within a textile system and consequently improving thermal insulation is a difficult task. Rees (35) stated that even when so called still air conditions exist, a certain air movement must be assumed because of natural convection currents from the human body. Cassie (14) further pointed out that clothing fabrics are continually subjected to slight air pressures, even when worn in a so called still atmosphere. Every movement of the body produces a bellows action under clothing and air pressures result which tend to force air through the clothing.

Layer Principle

When several layers of fabrics with air spaces between them are worn heat transfer from one to another is by radiation and convection through the air. The surface character of neighboring fabrics provides thermal resistance as does the thermal properties of the fabrics themselves. It has been shown many times that layering fabric is a good method for achieving thermal insulation. Angus (3) even found that contrary to the law of diminishing returns after five layers of fabric had been added to a testing device a sixth and seventh layer still showed equally steady increments of insulation. The resistance of several layers of fabric is additive and likewise are the temperature drops across them when the flow of heat is steady. The resistance of several layers of fabric of normally close construction, is found to be equal to the sum of the resistances of separate layers.

When the layer system is employed fabrics with low surface emissivities will give clothing a low heat loss reported Baxter and Cassie (6). They stated that smooth surfaced fabrics with their relatively large surface emissivities will give good heat transfer from fabric to fabric and presumably from skin to fabric. This will be true though the individual fabrics have the same thermal conductivity and thickness as fabric with surface cover. Smooth surface fabrics are therefore likely regarded as cool fabrics and those with surface cover as warm fabrics. Although evidence reported by Cassie (12) and Rees (35) would imply that this reduction in heat loss is primarily due to the inhibition of convective heat.

Air Movement and Humidity

Environmental conditions will effect the rate of heat loss by the various methods. Angus (3) reported, there is a marked increase in the amount of protection a given covering will afford to a warm body in still air as opposed to moving air. The fit of clothing is important. The protection against wind was generally shown more markedly by the tight parts of clothing then by the loose part, where in still air the loose parts showed 10 to 40 per cent higher insulation than the tight parts.

Angus (3) also reported that in moving air the weave used in fabric construction is most important. A tight twill weave such as a cotton gabardine has exceptional insulative value in moving air.

Another environmental factor strongly affecting the insulative value of a textile system is the relative humidity. Clayton (15) reported that from dryness up to about 90 per cent relative humidity there is a straight line relationship between air permeability and humidity, but after that the curve falls more rapidly, the air permeability in the wet state being approximately zero at the air pressure used. The cloth tested by Angus (3) allowed six times as much air to pass through at 3 per cent relative humidity than at 97 per cent relative humidity.

Black and Matthew (9) and Hodge (27) stated that although moisture present in a textile system may inhibit wind penetration and evolve heat by adsorption and condensation, excessive amounts will encourage loss of heat by conduction. Even though water vapor is a poorer thermal conductor than air, liquid improves the thermal contact between fibers, and enhances heat flow by conduction.

## III. METHODS AND UNITS FOR MEASURING THERMAL INSULATION

Dr. Kreigner as reported by Black and Matthew (9) was amongst the earliest researchers in heat transmission by fabrics. He used in 1892 a water-filled cast-iron cylinder which he covered with material, and measured its time to fall in temperature from $60^{\circ}$C. to $10^{\circ}$C. Much research has taken place since this crude method was used resulting in development of several methods for measuring thermal insulation.

Methods

The methods used for measuring thermal insulation can be grouped into four basic categories as suggested by Marsh (24) and similarly by Cleveland (16). They are:

(1) The fabric is held between two plates. The plates are at different temperatures producing a gradient. The rate of heat flow through the fabric across the gradient is measured. This gives what is usually called the thermal conductivity of the fabric and may be termed the disc or hot plate method.

(2) A hot body is wrapped with the fabric and the transfer of heat from the body to the cooler environment is measured by its rate of cooling. The outer surface of the fabric is exposed to the air and is not in contact with a solid surface. This is commonly referred to as the cooling method.

(3) A hot body is wrapped with the fabric and maintained at a constant temperature by a controlled supply of energy. This is commonly referred to as the constant temperature method.

(4) Miscellaneous methods which includes methods that cannot be put into any of the three classes.

It is found that the disc or hot plate method in which the fabric is held between two surfaces, gives the thermal conductivity of the fabric under the conditions of experiment. Properties will thus be altered due to pressure being exerted on the fabric. A great amount of pressure produces good thermal contact, but property changes will be large, whereas if the pressure is small, the thermal contact may be so poor that the surface resistance may be comparable with the resistance of the fabric. This method has been used and was reported by two authors (51, 24).

Marsh (29), and Cleveland (16) stated that the cooling method is perhaps the simplest of all for roughly estimating the thermal insulating properties of a fabric. The results of all experiments using the cooling method are reported by T. I. V., Thermal Insulating Value, units of cooling and apply only to the apparatus and temperature used. They do not provide a basis for comparison from one experiment to another.

With the constant temperature method, there is one predominant problem. Experiments with damp cloth may lead to erroneous results, owing to the absorption of the latent heat of water evaporated. The chief advantage of the constant temperature method lies in the fact that the measurements of heat are replaced by those of electrical energy and can therefore be made more easily and accurately.

Obviously for one reason or another none of the above are perfect methods for measuring thermal insulation but it appears that method three provided the least number of problems, particularly in the dry state.

The guard plate method described by Cleveland (16) may be considered a type of the constant temperature method. A textile fabric is placed over two thermostatically controlled constant temperature plates with a copper hood. The difference in temperature from the central plate to the top of the hood is measured by a thermocouple and microammeter. The amount of heat supplied to the central heater per unit of time divided by the difference in temperature from the central plate to the hood and by the area of the hot plate is taken as a measure of the thermal transmission of the specimen. The results are usually reproducible to about 1 per cent. Similar apparatuses are reported by Selle (41) and Schiefer (40). They are all out growths of the original hot plate method.

Each of the above methods measure insulative value of a textile system usually in a flat state and not as a clothing system on a body. Fitzgerald (20) and Belding (7) report that the most successful physical device for testing clothing values of a clothing system on a body is an electrically heated copper manikin. Newburgh (32) describes the electrically heated copper manikin as having an accurately metered internal electrical heat source which may be used to closely duplicate physiological testing in static conditions. Determinations have shown that this copper manikin used properly need not have dressing and instrumental errors exceeding 2 per cent in comparison to physiological methods being considered at best about 15 per cent.

One limitation of the manikin reported by Schiefer (40) was that it is impractical to use for measuring the thermal insulation of thin materials. It was found with fabrics such as underwear and dress fabric, that they may only contribute thermal resistance of 10 to 20 per cent of that of the layer of still air. Two limitations were reported by Breckenridge (10): (1) the manikin may be efficient for measuring conductive, convective, and radiative heat loss but since it does not perspire it cannot measure the evaporative heat loss; and (2) it was noted that the bellows action of clothing produced by movement of a normally active man of course was not duplicated on the manikin and the insulative values obtained even for the resting man were not completely correct. Therefore he suggested the copper manikin be used only for comparative purposes.

Units

Rees (35) reports the TOG as a unit for measuring the thermal resistance by using a hot plate apparatus. He defines TOG as, "One tenth of the ratio of the temperature difference in degrees centigrade to the heat flow in watts per square meter." Practically it is "the resistance that will maintain a temperature difference of 10°C. with a flux of 1 watt per square decimeter." This is the resistance of a light summer suit, and 10 TOGS represents about the thickest clothes that are practical to wear.

Marsh (29) defines T.I.V. as a means of measuring thermal resistance according to the following formula:

$$\frac{\text{"Heat lost by covered Heater"}}{\text{"Heat lost by uncovered Heater"}} \times 100$$

In this case the unit was developed to be used in measuring heat lost by a heater uncovered and covered by a fabric in a definite specified way.

Finally the clo unit, the most recent development was devised to be used to determine the insulative value of clothing. The clo is a unit of insulation, and "is the amount of insulation necessary to maintain comfort and mean skin temperature of 92°F. in a room 70°F. with air movement not over 10 feet per minute, humidity not over 50 per cent, with a metabolism of 50 Calories per square meter per hour" as defined by Gagge, Burton and Bazett (21).

Assuming 76 per cent of the heat loss from the body is through clothing systems physically a clo may be defined as "the amount of insulation that will allow the passage of 1 Calorie per square meter per hour with a temperature gradient of 0.18°C. between the two surfaces," according to Gagge, Burton and Bazett (21).

To determine the number of clo units of protection a clothing assemblege will give the following formula may be used to determine that by the copper manikin on the authority of Newburgh (32).

$$\frac{3.09\ (Ts - Ta)}{\frac{Watts \times 0.86}{S.A.}} = Ia + Iclo$$

Where:
Sa is the surface area in square meters
Ts is the manikins surface temperature
Ta is the ambient air temperature
Watts is the electrical input to the manikin
Ia is the insulative value of air determined with the manikin nude
Iclo is the insulative value of clothing determined with the manikin clothed.

## CHAPTER III

## METHOD OF PROCEDURE

Several operational procedures used by Franz (19) in the study utilizing a copper manikin have been refined or modified for this study. The apparatus, start-up procedure, test procedure, clo value calculation methods, and clothing assemblages will be described.

### I. APPARATUS

#### Copper Manikin

A one-eighth inch thick copper shell, physically resembling the human body in contour was used to determine the thermal insulative value, expressed in clo, of the clothing tested. This copper shell had been annodized, turning the shell black to simulate the emissivity of human skin.

The manikin, weighing approximately eighty pounds and standing nearly five feet ten inches high, was supported vertically by a stand with a removable metal frame that encompassed the head. The manikin embodied construction details that simplified dressing: (1) A pully permitted raising and lowering the manikin from the stand base. (2) The arms rotated approximately ninety degrees. (3) Power and control cables from the instrumentation entered the manikin in the neck area.

All the heating elements were distributed within the copper shell. Three circuits were employed: (1) a main series circuit was used throughout the manikin except, (2) distally from the wrist a parallel circuit was utilized and (3) distally from the ankle another parallel circuit was used. Rheostats located in the upper sternal and frontal abdominal region respectively enabled independent hand and feet temperature adjustment.

The manikin's surface temperature was measured by sixteen thermocouples distributed within the copper shell at the positions indicated by Appendix A, and the terminal wires were joined into a switch box which respectively was connected to a digital thermometer.

## Test Chamber

A conditioned laboratory of $70^{o}$F. ± 2 and 65 ± 2 per cent relative humidity was used for testing. An air movement profile of this laboratory indicated an increase in air movement with increasing altitude and some fluctuation with varying lateral locations, although at no point in the room did air movement exceed 30 feet per minute. Because of the slight air movement and the manikin's extreme sensitivity the manikin was located near the center of the room and left there throughout testing. The manikin location was approximately five feet from the east wall, centered in the room facing west. The instrument rack was approximately three feet north of the copper manikin and the experimenter sat on a stool beside the instrument rack.

All clothing was allowed to reach equilibrium with the standard condition environment before testing was undertaken. They were kept in the conditioned laboratory at least twenty-four hours prior to testing so they might come in equilibrium with the environment. The clothing was hung on a rack allowing ample space for air circulation during conditioning.

Since the manikin was sensitive to air movement only the experimenter was allowed in the test chamber during the test period. The experimenter limited his movement to the minimum necessary for operational procedures.

## II. START-UP PROCEDURE

The start-up procedure employed for this study is found in Appendix B. The start-up procedure includes connection of the electrical equipment, instrumentation, setting, and initial warm-up. A discrepancy between the present study and the previous start-up procedure by Springer (43) was noted. For this study, under full power conditions the power recorder indicated 67 per cent of full scale potential, approximately 268 watts on the 20 millivolt setting instead of the 85 per cent full scale as indicated in the Springer (43) report. Consultants of the Mechanical Engineering Department, Kansas State University, could find no reason for the differences, but felt it would not affect the operation of the manikin as under normal operating conditions the power requirements of the copper manikin was still less than 50 per cent of the full power available.

## III. TEST PROCEDURE

The test procedure may be divided into two sections, the procedure for dressing and operational test procedure.

Dress Procedure

Due to the tendency of clothing to settle, preliminary research indicated the most satisfactory method for dressing the manikin to be as follows:

A. Dress the manikin with the basic set of clothing, a description of which is found in Appendix C. Be careful at all times to keep each layer of fabric smooth, for example where the shirt is tucked into trousers.

B. Smooth all areas of the basic set immediately preceding testing.

C. Add a test shell and/or liner to this assemblage.

D. Check that all areas of the basic set are still laying smooth particularly the shirt sleeves within the shell sleeves when a jacket shell is being tested.

E. Adjust the shell to set properly making sure the sleeves are pulled down to the wrist, the collar is at the neckline, the shoulder seam is at the shoulder line, the sleeves are not twisted, and the garment is pulled down resting at the proper place at the hip line. In the case of lining only the later condition would apply.

F. Smooth the shell, using a downward hand stroke on the right and left front chest, right and left back, and the right and left sleeve front and back. In the case of a lining being tested only the first two conditions would apply.

Operational Test Procedure

The terms used in the operational test procedure explanation are defined as follows.

$\Delta T$ - difference in the temperature between the manikin's surface and the air temperature.

$I_a$ - Insulative value of air.

$I_c$ - Insulative value of clothing.

Fcl - Area factor which represents the increase in body surface due to clothing. (For the basic clothing assemblage Fcl represents a 10 per cent increase in the manikin's surface area and for the basic clothing and jacket assemblage Fcl represents an increase of 15 per cent. For only a liner and basic set assemblage Fcl represents an increase of 10 per cent.)

The operational test procedure is as follows:

A. The experimenter selects a $\Delta T$ that is representative of the expected external clothing temperature and air temperature differences. For this study $\Delta T$'s of 19°F., 23°F., and 27°F. were used.

B. Using Fig. 1 find the set point temperature that corresponds to the previously selected $\Delta T$.

C. Set the proportional control at that set point.

D. Smooth the clothing as previously described.

E. Follow the start-up procedure in Appendix B.

F. Allow the copper manikin to come into equilibrium with the environment before taking readings. Figure 2 may be used as a guide line for how much time this will require. Any time to the right of the diagonal hash line provides equilibrium of the copper manikin with the environment at that skin temperature. The experimenter must allow ample time for each set of thermocouple readings. It will take approximately six minutes to take one complete set of readings. A set of readings consists of one reading at each of the sixteen thermocouple locations.

G. Record the skin temperature, air temperatures, power, and set point temperatures on the Thermal Insulation of Men's Wear Data Sheet shown in Fig. 3 of Appendix E. Record the power at the time air temperatures were recorded.

H. Check Figs. 4 and 5 as calibration curves to determine if results being obtained are correct. Figure 4 shows the power that was required to obtain the desired $\Delta T$ for the copper manikin in basic clothing. This data was used to obtain the clothing plus air clo values versus $\Delta T$, temperature of surface minus temperature of air, curve shown in Fig. 5.

I. Calculate clo value.

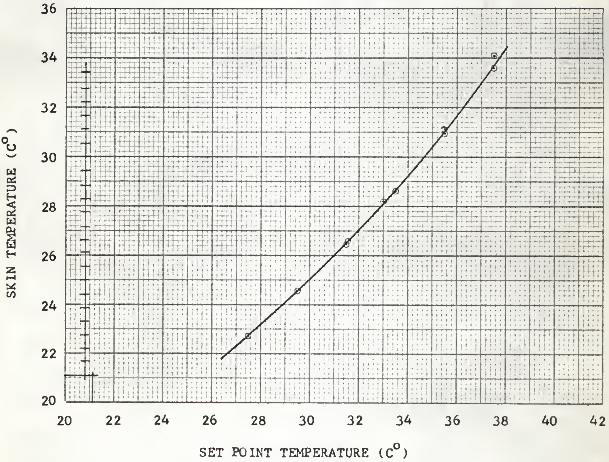



FIGURE 1

COPPER MANIKIN SKIN TEMPERATURE VS. SET POINT TEMPERATURE BASIC CLOTHING CALIBRATION CURVE (ROOM TEMPERATURE 70°F., R.H. 65%, AIR VELOCITY 30-35 F.P.M.)

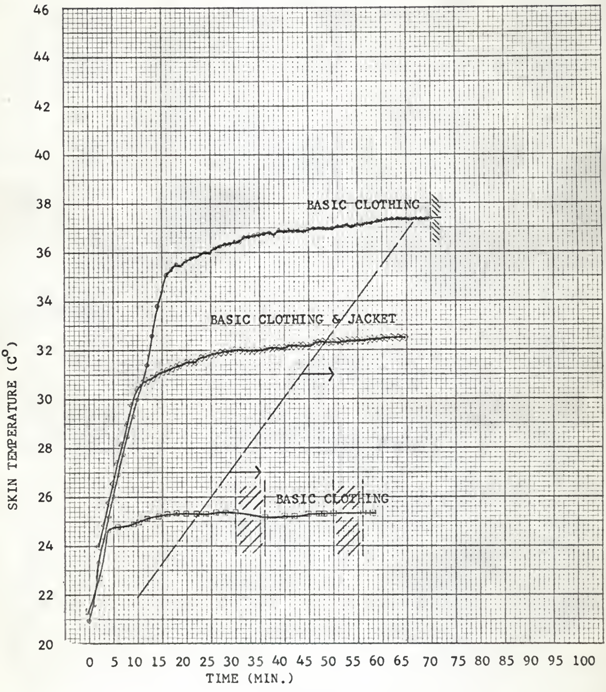



FIGURE 2

COPPER MANIKIN SKIN TEMPERATURE VS. TIME BASIC CLOTHING AND JACKET CURVE TEST POINT A (RIGHT CHEST) (ROOM TEMPERATURE 70°F., R.H. 65%, AIR VELOCITY 30-35 F.P.M.)

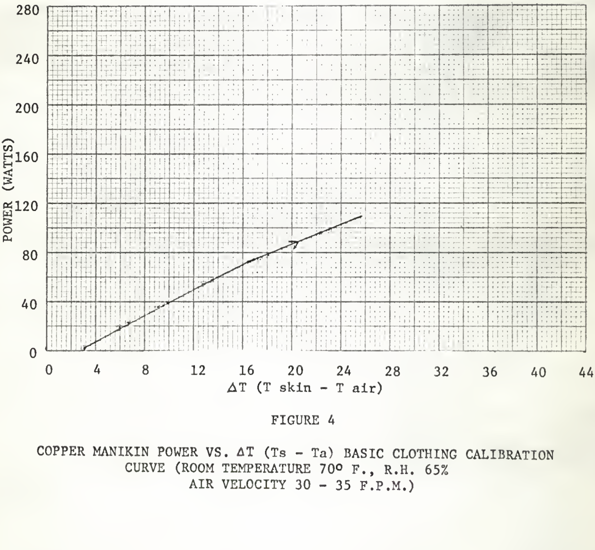



FIGURE 4

COPPER MANIKIN POWER VS. ΔT (Ts - Ta) BASIC CLOTHING CALIBRATION CURVE (ROOM TEMPERATURE 70° F., R.H. 65% AIR VELOCITY 30 - 35 F.P.M.)

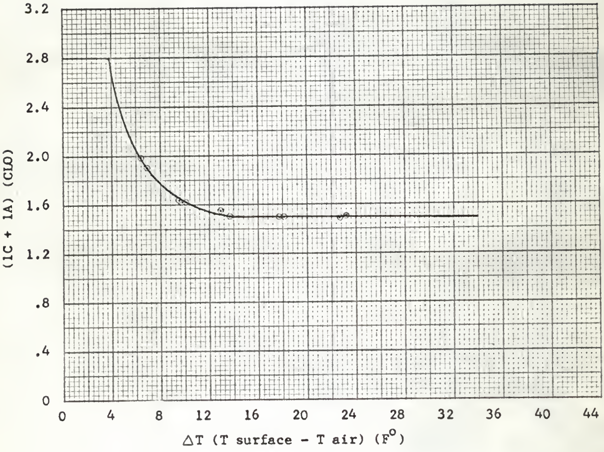



FIGURE 5

COPPER MANIKIN CLO VALUE VS. ΔT (Ts - Ta) BASIC CLOTHING CALIBRATION CURVE (ROOM TEMPERATURE 70°F., R.H. 65%, AIR VELOCITY 30-35 F.P.M.)

Clo Value Calculation Methods

The clo value calculated from the data sheet of step G of the test procedure gives the clo value of clothing plus entrapped air films and surface air film. The clo value of the clothing alone is calculated as follows.

A. Find the clothing plus air clo value (Ia and Ic) on Fig. 5 using the $\Delta T$ investigated.

B. Using the power recorded for the clothed copper man at the $\Delta T$ investigated, find (using Fig. 6) the corresponding $\Delta T$ this represents for the "nude" copper manikin.

C. Using the "nude" $\Delta T$ enter Fig. 7 to find the air clo value, Ia.

D. Divide the air clo value, Ia, by an area factor, Fcl, which represents the increase in body surface due to the clothing.

E. To find the clothing clo value, Ic, subtract the corrected air clo value, $\frac{Ia}{fcl}$ , from the clothing plus air clo value $\frac{Ia + Ic}{fcl}$ . This will be the clo value for the clothing assemblage for the $\Delta T$ investigated.

Clothing

To insure consistency in the structure, style, and design features of the jackets tested yard goods were obtained allowing construction of shells and liners. The shells were designed with a convertible collar, zipper front, and set in sleeves with button cuffs as illustrated in Fig. 8. The shells were all designed with zippers facilitating the interchanging of liners, illustrated in Fig. 9, among the shells. The sleeves were constructed with stationery liners. A description of the fabric used for shells and liners is found in Table III and Table IV

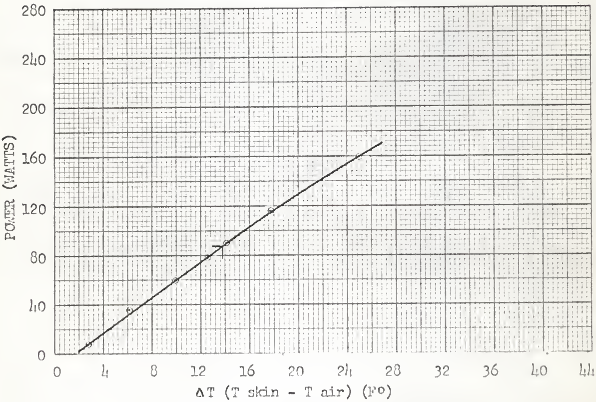



FIGURE 6

COPPER MANIKIN POWER VS. ΔT (Ts - Ta) NUDE CALIBRATION CURVE (ROOM TEMPERATURE 70°F., R.H. 65%, AIR VELOCITY 30 - 35 F.P.M.)

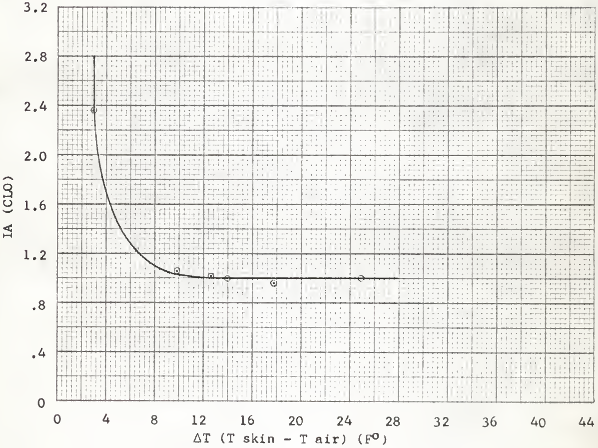
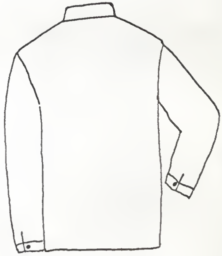



FIGURE 7

COPPER MANIKIN CLO VALUE VS. ΔT (Ts - Ta) NUDE CALIBRATION CURVE (ROOM TEMPERATURE 70°F., R.H. 65%, AIR VELOCITY 30-35 F.P.M.)

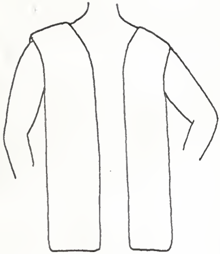
Front view



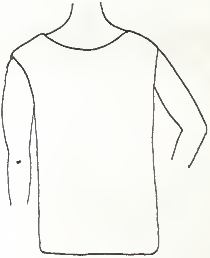
Back view

FIGURE 8

DIAGRAM OF JACKET SHELL



Front view



Back view

FIGURE 9

DIAGRAM OF JACKET LINER

respectively. The following combinations were tested.

1. Single ply yarn poplin shell
2. Two ply yarn poplin shell
3. Corduroy shell
4. Lightweight acrylic pile faced liner
5. Mediumweight acrylic pile faced liner
6. Heavyweight acrylic pile faced liner
7. Single yarn poplin shell and lightweight acrylic pile faced liner
8. Single yarn poplin shell and mediumweight acrylic pile faced liner
9. Single yarn poplin shell and heavyweight acrylic pile faced liner
10. Two ply yarn poplin shell and lightweight acrylic pile faced liner
11. Two ply yarn poplin shell and mediumweight acrylic pile faced liner
12. Two ply yarn poplin shell and heavyweight acrylic pile faced liner
13. Corduroy shell and lightweight acrylic pile faced liner
14. Corduroy shell and mediumweight acrylic pile faced liner
15. Corduroy shell and heavyweight acrylic pile faced liner

Throughout testing the basic set of clothing was left on the manikin and various jacket shell and/or liner assemblages were added to the basic set.

The shell and lining fabrics were tested for yarn count, and weight per square yard according to the standards of the American Society for Testing Materials, Committee D-13 (2). Any finish on the fabric was removed by the Department of Biochemistry, Kansas State University according to the American Association of Textile Chemists and Colorists (1) standards. The thickness, compressibility, and resiliency were determined through use of the compressometer according to test procedures methods advocated by Schiefer (40). Standard thickness was determined at 1 lb. pressure per square inch. The compressibility was the ratio of work done on the specimen to the standard thickness. A range of .1 lb. pressure to 2 lb. pressure was used observing points within this range. Results were expressed in inches squared per pound. The resilience was the amount of work recovered unloading using a range of .1 lb. pressure to 2 lb. pressure per inch squared compared to the amount of work done loading. The result was expressed in percentage.

## CHAPTER IV

## DISCUSSION OF FINDINGS

The purpose of this research was threefold: to further establish procedures for using the copper manikin, to assess clo values to the assemblages studied, and to study the layer principle.

Total assemblage clo values were assigned for fifteen jacket shell and/or liner combinations. Table I gives the description and data for each assemblage tested. Table II shows the average total insulative value for each of the assemblages. Contrary to expectation, for all the assemblages tested the middleweight liner whether used alone or in combination with a shell gave a lower clo value than the lightweight liner in the same situation. The heavyweight liner showed a constantly higher clo value than that for the other liners.

A fabric analysis recorded in Table IV gave the following characteristics in the light and mediumweight liners. Both had a 100 per cent Orlon acrylic pile and a 100 per cent Acrilan acrylic back with a yarn count of twelve loops per inch in the wale direction. Both fabrics were constructed with a knit background and a pile face. The course of the lightweight liner was 24 loops per inch while in the mediumweight it was 23 loops per inch. The lightweight liner was made up of 71.64 per cent pile and 28.36 per cent backing. In the mediumweight it was 74.73 per cent pile and 25.23 per cent backing. The thickness of the lightweight liner was only .0850 inches while the mediumweight liner had a thickness of .1000 inches. The lightweight liner had a compressibility

TABLE 1

DATA FOR CLO DETERMINATION FOR TOTAL ASSEMBLAGE

| Description of Clothing Assemblage | Set Point C.° | Ave. Surface Temp. F.° | Ave. Ambient Air Temp. F.° | Col. 1-Col. 2 F.° | Electrical Input Watts | Insulation of Assemblage Clo |
|---|---|---|---|---|---|---|
| | 32 | 80.18 | 70.64 | 9.54 | 36.00 | 1.72 |
| | 34 | 84.40 | 70.90 | 13.50 | 57.00 | 1.53 |
| Basic | 36 | 88.32 | 70.59 | 17.73 | 76.00 | 1.51 |
| | 32 | 80.73 | 70.66 | 10.07 | 33.60 | 1.93 |
| Basic and | 34 | 84.92 | 71.89 | 13.03 | 48.00 | 1.75 |
| Lightweight Liner | 36 | 89.11 | 71.83 | 17.28 | 63.50 | 1.75 |
| | 32 | 80.73 | 70.57 | 10.16 | 36.25 | 1.81 |
| Basic and | 34 | 84.34 | 70.39 | 13.95 | 52.25 | 1.72 |
| Mediumweight Liner | 36 | 88.53 | 70.40 | 18.13 | 67.75 | 1.72 |
| | 32 | 81.10 | 71.36 | 9.74 | 34.00 | 1.85 |
| Basic and | 34 | 84.54 | 71.31 | 13.23 | 46.00 | 1.86 |
| Heavyweight Liner | 36 | 88.38 | 70.98 | 17.40 | 63.00 | 1.80 |
| | 32 | 81.23 | 70.88 | 10.35 | 36.40 | 1.83 |
| Basic and | 34 | 84.64 | 70.58 | 14.06 | 50.00 | 1.82 |
| Single Yarn Poplin Shell | 36 | 88.73 | 70.61 | 18.12 | 65.00 | 1.80 |
| | 32 | 80.52 | 70.89 | 9.63 | 31.00 | 2.00 |
| Basic, Lightweight Liner and | 34 | 83.92 | 70.42 | 13.50 | 41.00 | 2.13 |
| Single Yarn Poplin Shell | 36 | 87.74 | 70.36 | 17.18 | 54.50 | 2.06 |
| | 32 | 80.71 | 71.05 | 9.66 | 30.30 | 2.06 |
| Basic, Mediumweight Liner and | 34 | 85.63 | 71.13 | 14.50 | 48.50 | 1.93 |
| Single Yarn Poplin Shell | 36 | 88.35 | 70.54 | 17.81 | 60.25 | 1.91 |
| | 32 | 80.50 | 69.85 | 10.65 | 31.40 | 2.16 |
| Basic, Heavyweight Liner and | 34 | 83.80 | 70.13 | 13.67 | 41.00 | 2.15 |
| Single Yarn Poplin Shell | 36 | 87.80 | 70.25 | 17.55 | 53.00 | 2.14 |
| | 32 | 81.45 | 70.60 | 10.85 | 35.50 | 1.98 |
| Basic and | 34 | 84.96 | 70.48 | 14.48 | 50.75 | 1.83 |
| Two Ply Yarn Poplin Shell | 36 | 90.00 | 70.58 | 19.42 | 65.50 | 1.92 |
| | 32 | 80.71 | 70.28 | 10.43 | 31.16 | 2.13 |
| Basic, Lightweight Liner and | 34 | 84.37 | 70.92 | 13.45 | 40.50 | 2.15 |
| Two Ply Yarn Poplin Shell | 36 | 88.17 | 70.70 | 17.47 | 54.00 | 2.11 |
| | 32 | 81.25 | 70.38 | 10.87 | 35.00 | 2.06 |
| Basic, Mediumweight Liner and | 34 | 84.64 | 70.58 | 14.06 | 47.75 | 2.06 |
| Two Ply Yarn Poplin Shell | 36 | 88.73 | 70.61 | 18.12 | 56.00 | 1.99 |
| | 32 | 80.31 | 69.84 | 10.47 | 32.60 | 2.07 |
| Basic, Heavyweight Liner and | 34 | 84.45 | 70.62 | 13.83 | 42.75 | 2.09 |
| Two Ply Yarn Poplin Shell | 36 | 88.26 | 70.44 | 17.82 | 56.00 | 2.06 |
| | 32 | 80.26 | 69.74 | 10.52 | 35.40 | 1.92 |
| Basic and | 34 | 84.21 | 70.32 | 13.89 | 47.50 | 1.89 |
| Corduroy Shell | 36 | 88.26 | 70.11 | 18.15 | 63.50 | 1.85 |
| | 32 | 80.52 | 70.70 | 9.82 | 30.80 | 2.06 |
| Basic, Lightweight Liner and | 34 | 83.79 | 70.56 | 13.23 | 41.70 | 2.05 |
| Corduroy Shell | 36 | 87.55 | 70.21 | 17.34 | 55.75 | 2.01 |
| | 32 | 80.98 | 70.74 | 10.24 | 32.00 | 2.07 |
| Basic, Mediumweight Liner and | 34 | 84.18 | 70.81 | 13.37 | 43.00 | 2.01 |
| Corduroy Shell | 36 | 88.09 | 70.66 | 17.43 | 57.00 | 1.98 |
| | 32 | 80.43 | 70.24 | 10.19 | 31.90 | 2.06 |
| Basic, Heavyweight Liner and | 34 | 83.70 | 70.34 | 13.36 | 41.00 | 2.10 |
| Corduroy Shell | 36 | 87.46 | 70.08 | 17.38 | 54.00 | 2.10 |

TABLE 11

DATA FOR CLO DETERMINATION FOR EACH LAYER OF ASSEMBLAGE

| Description of Clothing Assemblage | Set Point C.° | Power Read Watts | ΔT F.° | Ia Clo | Fcl Clo | It Clo | Ia/Fcl Clo | Ib Clo | Il&/or Is Clo |
|---|---|---|---|---|---|---|---|---|---|
| | 32 | 42.00 | 7.8 | 1.13 | 1.10 | 1.60 | 1.03 | .59 | ---- |
| | 34 | 62.00 | 10.2 | 1.04 | 1.10 | 1.52 | .95 | .59 | ---- |
| Basic | 36 | 82.00 | 12.8 | 1.00 | 1.10 | 1.50 | .91 | .59 | ---- |
| | 32 | 33.60 | 6.6 | 1.21 | 1.10 | 1.93 | 1.10 | .59 | .24 |
| Basic and | 34 | 48.00 | 8.4 | 1.08 | 1.10 | 1.75 | .98 | .59 | .18 |
| Lightweight Liner | 36 | 63.50 | 11.0 | 1.02 | 1.10 | 1.75 | .93 | .59 | .23 |
| | 32 | 36.25 | 6.8 | 1.20 | 1.10 | 1.81 | 1.09 | .59 | .13 |
| Basic and | 34 | 52.25 | 8.9 | 1.07 | 1.10 | 1.72 | .97 | .59 | .16 |
| Mediumweight Liner | 36 | 67.75 | 10.9 | 1.02 | 1.10 | 1.72 | .93 | .59 | .20 |
| | 32 | 34.00 | 6.4 | 1.24 | 1.10 | 1.85 | 1.13 | .59 | .13 |
| Basic and | 34 | 46.00 | 8.0 | 1.12 | 1.10 | 1.86 | 1.02 | .59 | .25 |
| Heavyweight Liner | 36 | 63.00 | 13.0 | 1.00 | 1.10 | 1.80 | .91 | .59 | .30 |
| | 32 | 36.40 | 6.8 | 1.20 | 1.15 | 1.83 | 1.04 | .59 | .20 |
| Basic and | 34 | 50.00 | 8.6 | 1.07 | 1.15 | 1.82 | .93 | .59 | .30 |
| Single Yarn Poplin Shell | 36 | 65.00 | 10.4 | 1.02 | 1.15 | 1.80 | .89 | .59 | .32 |
| | 32 | 31.00 | 6.0 | 1.28 | 1.15 | 2.00 | 1.11 | .59 | .30 |
| Basic Lightweight Liner and | 34 | 41.00 | 7.4 | 1.16 | 1.15 | 2.13 | 1.01 | .59 | .53 |
| Single Yarn Poplin Shell | 36 | 54.50 | 9.2 | 1.06 | 1.15 | 2.06 | .92 | .59 | .55 |
| | 32 | 30.30 | 6.3 | 1.25 | 1.15 | 2.06 | 1.09 | .59 | .38 |
| Basic, Mediumweight Liner and | 34 | 48.50 | 9.4 | 1.06 | 1.15 | 1.93 | .92 | .59 | .42 |
| Single Yarn Poplin Shell | 36 | 60.25 | 10.0 | 1.04 | 1.15 | 1.91 | .90 | .59 | .42 |
| | 32 | 31.40 | 6.0 | 1.28 | 1.15 | 2.16 | 1.11 | .59 | .46 |
| Basic, Heavyweight Liner and | 34 | 41.00 | 6.4 | 1.23 | 1.15 | 2.15 | 1.07 | .59 | .49 |
| Single Yarn Poplin Shell | 36 | 53.00 | 9.0 | 1.08 | 1.15 | 2.14 | .94 | .59 | .61 |
| | 32 | 35.50 | 6.6 | 1.22 | 1.15 | 1.98 | 1.06 | .59 | .33 |
| Basic and | 34 | 50.75 | 9.5 | 1.06 | 1.15 | 1.83 | .92 | .59 | .32 |
| Two Ply Yarn Poplin Shell | 36 | 65.50 | 10.6 | 1.02 | 1.15 | 1.92 | .89 | .59 | .44 |
| | 32 | 31.60 | 6.2 | 1.26 | 1.15 | 2.13 | 1.10 | .59 | .44 |
| Basic, Lightweight Liner and | 34 | 40.50 | 7.2 | 1.17 | 1.15 | 2.15 | 1.02 | .59 | .54 |
| Two Ply Yarn Poplin Shell | 36 | 54.00 | 9.0 | 1.08 | 1.15 | 2.11 | .94 | .59 | .58 |
| | 32 | 35.00 | 6.8 | 1.20 | 1.15 | 2.06 | 1.04 | .59 | .43 |
| Basic, Mediumweight Liner and | 34 | 47.75 | 8.4 | 1.08 | 1.15 | 2.06 | .94 | .59 | .53 |
| Two Ply Yarn Poplin Shell | 36 | 56.00 | 9.6 | 1.04 | 1.15 | 1.99 | .90 | .59 | .50 |
| | 32 | 32.60 | 6.2 | 1.26 | 1.15 | 2.07 | 1.10 | .59 | .38 |
| Basic, Heavyweight Liner and | 34 | 42.75 | 7.6 | 1.14 | 1.15 | 2.09 | .99 | .59 | .51 |
| Two Ply Yarn Poplin Shell | 36 | 56.00 | 9.4 | 1.06 | 1.15 | 2.06 | .92 | .59 | .55 |
| | 32 | 35.40 | 6.5 | 1.23 | 1.15 | 1.92 | 1.07 | .59 | .26 |
| Basic and | 34 | 47.50 | 8.1 | 1.12 | 1.15 | 1.89 | .97 | .59 | .33 |
| Corduroy Shell | 36 | 63.50 | 10.2 | 1.04 | 1.15 | 1.85 | .90 | .59 | .36 |
| | 32 | 30.80 | 7.0 | 1.18 | 1.15 | 2.06 | 1.03 | .59 | .44 |
| Basic, Lightweight Liner and | 34 | 41.70 | 7.6 | 1.14 | 1.15 | 2.05 | .99 | .59 | .47 |
| Corduroy Shell | 36 | 55.75 | 9.4 | 1.06 | 1.15 | 2.01 | .92 | .59 | .50 |
| | 32 | 32.00 | 6.2 | 1.26 | 1.15 | 2.07 | 1.10 | .59 | .34 |
| Basic, Mediumweight Liner and | 34 | 43.00 | 7.6 | 1.14 | 1.15 | 2.01 | 1.00 | .59 | .42 |
| Corduroy Shell | 36 | 57.00 | 9.5 | 1.06 | 1.15 | 1.98 | .92 | .59 | .47 |
| | 32 | 81.90 | 6.2 | 1.26 | 1.15 | 2.06 | 1.10 | .59 | .31 |
| Basic, Heavyweight Liner and | 34 | 41.00 | 7.4 | 1.16 | 1.15 | 2.10 | 1.01 | .59 | .50 |
| Corduroy Shell | 36 | 54.00 | 9.0 | 1.08 | 1.15 | 2.10 | .94 | .59 | .57 |

Chart Code:

- .T - Difference in the temperature between manikin's surface and the air temperature
- Ia - Insulative value of air
- It - Total insulative value of air and clothing
- Ia/Fcl - Insulative value of air adjusted by a surface area factor
- Il - Insulative value of liner
- Is - Insulative value of shell

TABLE III

FABRIC DESCRIPTION OF JACKET SHELLS

| | Single Yarn Poplin Shell | Two Ply Yarn Poplin Shell | Corduroy Shell | Sleeve Liner |
|---|---|---|---|---|
| Fiber Content | Poplin - Single Yarn<br>65% Dacron<br>35% Cotton | Poplin - Two Ply Yarn<br>65% Dacron<br>35% Cotton | 100% Cotton | Face - 100% Acetate<br>Back - Polyurethane Foam |
| Yarn Count | | | | |
| Warp | 128 per inch | 133 per inch | 51 per inch | 95 per inch |
| Filling | 61 per inch | 62 per inch | 55 per inch | 62 per inch |
| Weight per Square Yard | 4.32 ounces | 5.65 ounces | 10.41 ounces | 6.33 ounces |
| Standard Thickness 1 lb. pressure | .0113 inches | .0120 inches | .0416 inches | .0341 inches |
| Compression | ——— | ——— | ——— | ——— |
| Resiliency | ——— | ——— | ——— | ——— |
| Color | Natural Tan | Natural Tan | Dark Brown | Natural Tan |
| Fabric Structure | Plain Weave | Plain Weave | Pile Weave Medium Wide Wale | Face - Rib Weave<br>Back - Polyurethane Foam and Cotton Scrim Quilted Together |
| Finish | | | | |
| Trichloroethylene Extract | .87% | .87% | 1.17% | ——— |
| Ash | .45% | .44% | .87% | ——— |

TABLE IV

FABRIC DESCRIPTION OF JACKET LINERS

| | Lightweight Liner | Mediumweight Liner | Heavyweight Liner |
|---|---|---|---|
| Fiber Content | Pile 100% Orlon Acrylic<br>Back 100% Orlon or Acrilan Acrylic | Pile 100% Acrilan Acrylic<br>Back 100% Orlon Acrylic | Pile 100% Orlon Acrylic<br>Back 100% Dynel Modacrylic |
| | 77.64% Pile<br>28.36% Back by wt. | 74.73% Pile<br>25.27% Back by wt. | 70.73% Pile<br>29.27% Back by wt. |
| Yarn Count | | | |
| Wales | 12 Loops per inch | 12 Loops per inch | 13 Loops per inch |
| Courses | 24 Loops per inch | 23 Loops per inch | 25 Loops per inch |
| Weight per Square Yard | 8.45 ounces | 9.42 ounces | 15.28 ounces |
| Standard Thickness 1 lb. pressure | .0850 inches | .1000 inches | .1370 inches |
| Compression | .32 in.$^2$/lb. | .50 in.$^2$/lb. | .50 in.$^2$/lb. |
| Resiliency | 13% | 11% | 12% |
| Color | Green | Gold | Brown |
| Fabric Structure | Pile and Warp Knit Back | Pile and Warp Knit Back | Pile and Warp Knit Back |
| Finish | ______ | ______ | ______ |

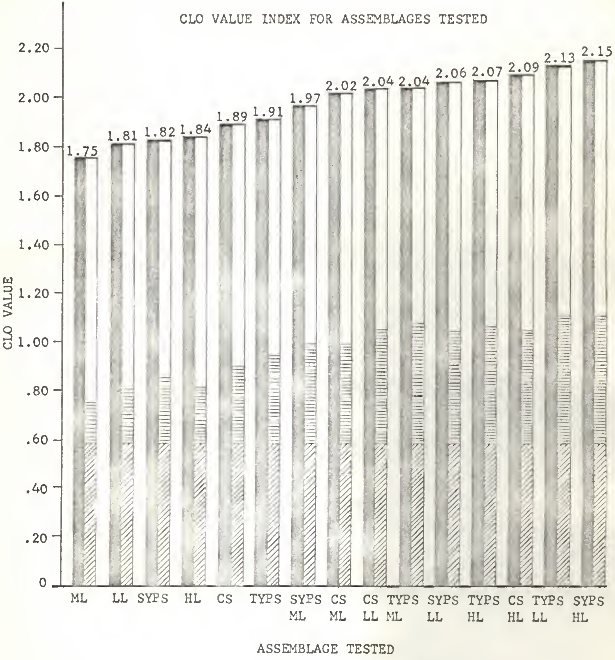
of .32 in.$^2$/lb. where the mediumweight liner compressed .50 in.$^2$/lb. The resilience of each was 13 per cent and 11 per cent respectively for the light and mediumweight liners.

The basic clothing and lightweight liner and basic clothing with mediumweight liner both entrapped 1.00 clo of air insulation while the heavyweight liner entrapped 1.02 clo air insulation. Also the heavyweight liner had a higher yarn count in both the course and filling direction, was considerably heavier in weight per square yard, was considerably thicker and was equally compressible to the mediumweight liner, with about the same resilience providing a good amount of air entrapment for the amount of fiber content.

In all cases a shell and liner combination provided higher clo values than either did separately as is indicated by Fig. 10. It is also apparent as the proportion of total insulation provided by the shell and/or liner increased the proportion of insulation provided by the air film decreased.

Figure 11 indicated that as $\Delta T$ increased the insulation value provided by air decreased. The curve in Fig. 5 and 11 indicated a variation in total assemblage clo value dependent upon $\Delta T$.

Table V, which is calculated from the data on Table II, indicated layering garments increased the total insulation value but apparently the increase was not a result of the increase in number of air films. The total insulative value for the basic set, lightweight liner, and single yarn poplin shell assemblage when tested was 2.06 where theoretically the total insulative value of each item of the assemblage plus




Code:

- LL - Lightweight Liner
- ML - Mediumweight Liner
- HL - Heavyweight Liner
- SYPS - Single Yarn Poplin Shell
- TYPS - Two Ply Yarn Poplin Shell
- CS - Corduroy Shell

Code for rating scale:

- Total Assemblage Set
- Basic Set
- Shell and/or Liner
- Air Film

FIGURE 10

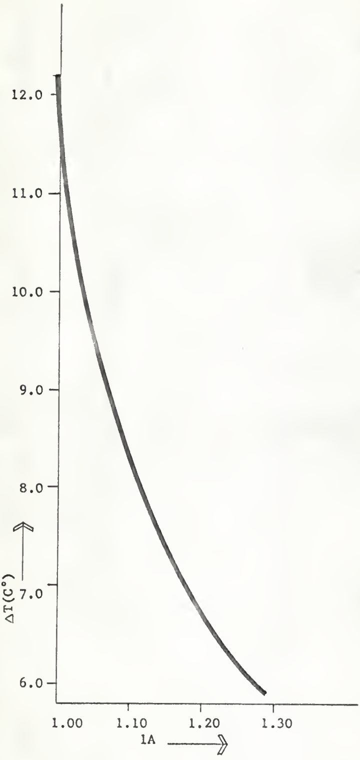



FIGURE 11

RELATION OF ΔT TO INSULATION PROVIDED BY AIR

TABLE V

THEORETICAL AND EXPERIMENTAL CLO VALUES OF BASIC CLOTHING, LINERS, SHELLS AND AIR

| Basic | Liners | | | Shells | | | Total | Air Film Under Basic | Theoretical Total | Environmental Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | L.W. | M.W. | H.W. | SYPS | TYPS | CS | | | | |
| .59 | | | | | | | .59 | .96 | 1.55 | 1.55 |
| .59 | .21 | | | | | | .80 | .96 | 1.76 | 1.78 |
| .59 | | .18 | | | | | .77 | .96 | 1.73 | 1.75 |
| .59 | | | .28 | | | | .87 | .96 | 1.83 | 1.84 |
| .59 | | | | .31 | | | .90 | .96 | 1.86 | 1.82 |
| .59 | .21 | | | .31 | | | 1.11 | .96 | 2.07 | 2.06 |
| .59 | | .18 | | .31 | | | 1.08 | .96 | 2.04 | 1.97 |
| .59 | | | .28 | .31 | | | 1.18 | .96 | 2.04 | 2.15 |
| .59 | | | | | .38 | | .97 | .96 | 1.93 | 1.97 |
| .59 | .21 | | | | .38 | | 1.18 | .96 | 2.07 | 2.13 |
| .59 | | .18 | | | .38 | | 1.15 | .96 | 2.11 | 2.04 |
| .59 | | | .28 | | .38 | | 1.25 | .96 | 2.21 | 2.07 |
| .59 | | | | | | .34 | .93 | .96 | 1.89 | 1.89 |
| .59 | .21 | | | | | .34 | 1.14 | .96 | 2.10 | 2.04 |
| .59 | | .18 | | | | .34 | 1.11 | .96 | 2.07 | 2.03 |
| .59 | | | .28 | | | .34 | 1.21 | .96 | 2.17 | 2.09 |

Code to Table V

L.W. - Lightweight Acrylic Pile Faced Liner
M.W. - Mediumweight Acrylic Pile Faced Liner
H.W. - Heavyweight Acrylic Pile Faced Liner
SYPS - Single Yarn Poplin Shell
TYPS - Two Ply Yarn Poplin Shell
CS - Corduroy Shell

the .96 clo for the one air film layer established with the basic set over the manikin gave a 2.07 clo value. The clo value total for an assemblage, was no higher than summed individual basic, shell and/or liner clo values plus insulation of the air film created when the manikin was clothed in the basic set. For instance a basic set of clothing, lightweight liner and single yarn poplin shell combination provided nine possible surfaces for air to cling; the manikin's outer surface, inner surface of underwear, outer surface of underwear, inner surface of basic set, outer surface of basic set, inner surface of liner, outer surface of liner, inner surface of shell, outer surface of shell. The basic set on the manikin provided five surfaces to produce air drag, the outer manikin surface, inner surface of underwear, outer surface of underwear, inner surface of basic set, and outer surface of basic set. Tests showed that the latter five surfaces entrapped .96 clo of insulation.

## CHAPTER V

## CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken with the purpose of further establishing procedures for using the copper manikin, assessing clo value to certain items of men's wearing apparel, and analyzing the layer principle effect in clothing assemblages.

Men's hip length jacket shells and/or liner were constructed and used for testing. The liners were made of light, medium, and heavyweight acrylic pile. The shells were made of single yarn cotton poplin, two ply yarn cotton poplin and cotton corduroy. Fifteen combinations of the above shells and/or liners were tested utilizing the copper manikin. A start-up and test procedure was developed for the copper manikin and used in testing. The tests were all conducted in the conditioned laboratory of 70 $\pm$ 2$^{o}$F. and 65 $\pm$ 2 per cent relative humidity and air velocities not exceeding 30 feet per minute. Readings were taken at three set point conditions giving a $\Delta$T range of 7$^{o}$F.

A method for determining the clo value of air films as well as each layer of clothing within an assemblage was developed. The method utilized the $\Delta$T principle and compensated for the increase in surface area when an item of clothing was added to the copper manikin and corrected the amount of insulation provided by air.

It is suggested that further studies be conducted to determine the reliability of the method. Specifically a procedure should be developed for determining the increase in surface area when clothing is added to the copper manikin. The 10 per cent surface area increase used when the manikin was clothed with the basic set, and the 15 per cent surface area increase assessed when the manikin was wearing the basic set and a shell were only estimations.

At full power the manikin read only 67 per cent of the power recorder scale deflection where in earlier studies it had been reading 87 per cent. Although engineer consultants felt this would not affect the results of this study before further study is undertaken with the copper manikin it is recommended that this discrepancy be further investigated.

It was found in still air conditions that the mediumweight liner used alone or in combination with any shell gave a slightly lower clo value than the lightweight liner under the same circumstances. This study would indicate that unless there is a significant increase in fiber surface area to incorporate a drag on air a small increase in fiber content lowers the insulative value by increasing the conductive heat escape route.

The mediumweight liner being slightly heavier in weight, slightly thicker, and almost twice as compressible but yet less resilient would not entrap enough more air in the compressed state to compensate for the increase in fiber content enhancing the conductive heat escape route. With the liner on the manikin, particularly under a shell there will be a certain degree of compression providing the above conditions. This surprising finding also may have resulted from the still air condition of testing. The increase in pile probably decreased the convective heat loss but there was not a sufficient convective heat loss in these still air conditions to warrant the increase in pile. The slight pile increase therefore actually provided less warmth because of the increase in conductive heat loss due to the increase in pile. It is questioned that the same results would be attained in moving air conditions under which jackets of this nature are most apt to be worn and it is recommended that these liners be studied in moving air conditions. The same suggestion would be made for the outer shells as in still air conditions there was little difference in the warmth of the three shells tested.

The higher yarn count, heavier weight per square yard, considerably greater thickness, and the same compressibility with a 1 per cent higher resilience providing a large portion of air entrapment for fiber content probably accounts for the increase in insulation provided by the heavyweight liner and various combinations thereof.

It is recommended that other types and styles of men's clothing be tested to establish a more complete index of clo values and provide guide posts for warmth expectations for various types of clothing.

The indication that $\Delta T$ increases as the insulative value provided by air decreases would indicate that in test situations the higher the set point the less insulation will the air provide up to a certain point. Projected into authentic environmental conditions indication would be that to a certain point the greater the temperature gradient between the environment and human body, smaller will be the amount of insulation provided by entrapped air films. Observing the curve in Fig. 5 and 11 it is apparent for testing, a sufficiently large $\Delta T$ must be provided to give consistent results for total assemblages including air films. If only the insulative value of clothing disregarding the insulation provided by air films is to be considered then the size of $\Delta T$ is not so important as can be seen in Fig. 10.

The layer principle under still conditions appeared to increase the clo value of an assembly. More detailed analysis indicated that insulation given by the clothing produced an additive effect for each layer of clothing but there was no increase in insulation created by the increase in number of air films. Approximately the same amount of air insulation was provided by one air film as for three layers of air films. A possible explanation of the phenomena would be as follows. As clothing layers are added the air space between layers decrease in thickness due to compression and in reality air volume does not increase. For this reason approximately the same results are attained for one air film space as several smaller ones. This indicated that perhaps it is the thickness or volume of entrapped air rather than the number of layers of air making the difference in air insulation. It would be suggested that a method be devised for measuring the thickness and volume of air entrapped and determine if there is any correlation to air insulative value of the assembly. It would also be suggested that the layer principle be investigated under moving air conditions.

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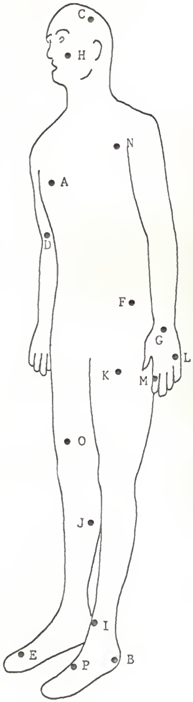
APPENDIX A




A Right Chest
B Left Heel
C Back of Head
D Right Arm
E Right Foot
F Left Hip
G Back Left Hand
H Left Cheek
I Top Left Ankle
J Right Calf
K Left Leg
L L.H. Small Finger
M L.H. Index Finger
N Left Scapula
O Right Thigh
P Left Foot

FIGURE 12

THERMOCOUPLE LOCATIONS ON MANIKIN

APPENDIX B

START-UP PROCEDURE FOR COPPER MANIKIN

A. Connect thermal converter as shown in the schematic in Appendix D.

B. Connect amphenol 2-pin connector (labeled #3)* to man at throat. Caution must be taken to complete this connection before the power lead is connected to prevent electrical arcing.

C. Connect recorder leads (labeled #1 and #2) originating in thermal converter and terminating in the terminal jacks of the Honeywell recorder. Negative lead is on extreme right when facing connection box on thermal converter.

D. Check recorder to insure switch is in off.

E. Connect recorder to 110 VAC, 60 cycle, 1 phase.

F. Turn on and calibrate recorder according to instruction books.

G. Turn span selector to "20 mv".

H. Connect power lead from the thermal converter and manikin (labeled #4) to the back of the proportional controller (standard 3-prong 110 V appliance connection).

I. Connect temperature sensing lead from the manikin to proportional controller (labeled #5 — one fourth inch standard phone plug).

J. Set proportion temperature controls to desired setting. For this study they were set at 32°C., 34°C. and 36°C. (Temperature of the hands and feet are adjusted as follows: to increase temperature of hands, rotate upper rheostat clockwise; to increase temperature of feet, rotate lower rheostat counter-clockwise.)

K. Check "Band Width" control for proper setting. The normal width ranges from 0.7°C. to 1.0°C.; the width was set at .85°C. for this study. Insure power switch is off.

L. Connect proportional controller power lead to 110 VAC, 60 cycle, 1 phase.

M. Start warm-up by placing proportional controller switch in "on" position. With the recorder span knob positioned to the 20 mv.

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*Labeled numbers indicate specific electrical connections on the manikin and operational equipment.

setting, the recorder moves to 65 per cent of the full scale, approximately 268 watts, while the manikin "warms up." When the desired temperature is reached, the power requirements will drop to less than 50 per cent of the "warm up" power. At this time, the span selector may be positioned to the 10 mv setting, 200 watts of the 100 per cent scale deflection. This procedure may be repeated whenever the power drops to a point lower than 50 per cent turning to 5 mv setting; 100 watts of a 100 per cent scale deflection; 2 mv setting, 40 watts of a 100 per cent scale deflection; 1 mv setting, 20 watts of a 100 per cent scale deflection; and 0.5 mv setting, 10 watts of a 100 per cent scale deflection in that order. At no time is it recommended to set the span selector at or less than the 0.5 mv. setting.

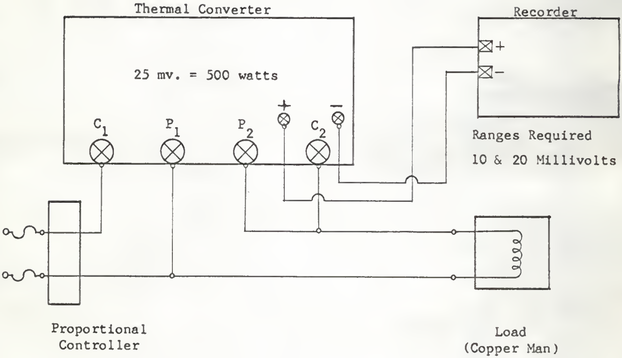
From Springer (44)

APPENDIX C

BASIC SET OF CLOTHING WORN BY COPPER MANIKIN

| | |
|---|---|
| T shirt | 100 per cent cotton knit |
| Shorts | 100 per cent cotton knit |
| Long-Sleeved Shirt | 100 per cent cotton chambray |
| Trousers | 50 per cent Fortrel Polyester and 50 per cent combed cotton. Special finishes: Koratron Permanent Crease and Scotchguard Stain Repellent |
| Socks | 100 per cent cotton knit |
| Shoes | PolyVinyl sole and heel molded to leather |

APPENDIX D




From Springer (43)

FIGURE 13

SCHEMATIC DIAGRAM FOR CONNECTIONS FOR THERMOCOUPLE CONVERTER

APPENDIX E

THERMAL INSULATION OF MEN'S WEAR
Data Sheet

Date: ____________ 196__

Test: ____________ Nude
____________ Basic
____________ Basic and Jacket # ________
____________ Basic, Jacket # ___________, and Lining __________.

| Test 1 Time: | ΔT: | Test 2 Time: | ΔT: | Test 3 Time: | ΔT: |
|---|---|---|---|---|---|
| A. ______ | Q. ______ | A. ______ | Q. ______ | A. ______ | Q. ______ |
| B. ______ | R. ______ | B. ______ | R. ______ | B. ______ | R. ______ |
| C. ______ | S. ______ | C. ______ | S. ______ | C. ______ | S. ______ |
| D. ______ | Avg. C | D. ______ | Avg. C | D. ______ | Avg. C |
| E. ______ | ______ F | E. ______ | ______ F | E. ______ | ______ F |
| F. ______ | | F. ______ | | F. ______ | |
| G. ______ | | G. ______ | | G. ______ | |
| H. ______ | | H. ______ | | H. ______ | |
| I. ______ | | I. ______ | | I. ______ | |
| J. ______ | | J. ______ | | J. ______ | |
| K. ______ | | K. ______ | | K. ______ | |
| L. ______ | | L. ______ | | L. ______ | |
| M. ______ | | M. ______ | | M. ______ | |
| N. ______ | | N. ______ | | N. ______ | |
| O. ______ | | O. ______ | | O. ______ | |
| P. ______ | | P. ______ | | P. ______ | |
| Avg. C | | Avg. C | | Avg. C | |
| ______ F | | ______ F | | ______ F | |

| | | |
|---|---|---|
| Set Point Temperature ____________ | Set Point Temperature ____________ | Set Point Temperature ____________ |
| Average surface T. ___ | Average surface T. ___ | Average surface T. ___ |
| Ambient Air T. ______ | Ambient Air T. ______ | Ambient Air T. ______ |
| Surface area 1.795 sq. meters | Surface area 1.795 sq. meters | Surface area 1.795 sq. meters |
| Power reading ___ watts | Power reading ___ watts | Power reading ___ watts |
| Clo value __________ | Clo value __________ | Clo value __________ |

Figure 3. Thermal Insulation of Men's Wear Data Sheet

# THE THERMAL INSULATIVE VALUE OF CERTAIN LAYERED ASSEMBLAGES OF MEN'S WEAR

by

DEANNA MARIE McCRACKEN

B. S., Kansas State University, 1965

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Clothing and Textiles

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

This study developed procedures for using the copper manikin, and employed these procedures to determine the clo value, a unit of thermal insulation, for men's hip length jacket shells and/or liners. A method for calculating clo values for each layer of a clothing assemblage was developed. With this method the effect on clo value of layering clothing was analyzed.

All testing was conducted in a laboratory with still air conditions, a temperature of $70^{\circ}$F. ± 2 and 65 ± 2 per cent relative humidity. Light, medium, and heavyweight acrylic pile faced liners and jacket shells of single yarn cotton poplin, two ply yarn cotton poplin, and corduroy were tested singly and in all combinations over a basic set of clothing. Since these garments are usually worn in moving air conditions it was recommended further investigation be conducted with varying air velocities and temperatures.

Lower clo values given by the mediumweight liner as compared to the lightweight liner were believed to be a function of fabric characteristics and still air conditions of testing.

In still air conditions as $\Delta T$ (the difference in clothing surface temperature and air temperature) increased the insulation value decreased indicating variations in total assemblage clo value were dependent upon $\Delta T$.

Insulation stayed essentially the same for nine and five layer assemblages. The general trend was that layering of clothing increased the total insulation but this was not due to the increase in the number of air films within the assemblage.