THERMAL INSULATION VALUES OF CERTAIN MEN'S TROUSERS AS DETERMINED BY THE USE OF A COPPER MANIKIN

by

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CHAPTER I

INTRODUCTION

Although the origins of clothing can be debated, most people agree that one function of clothing is to protect the body from harm. The actual garment man wears is determined by the culture in which he lives. Most consumers select clothing based on appearance and thermal insulative properties (comfort) for specific environmental conditions. Franz (17) is one of many who have realized that the consumer does not have an objective method by which to judge the thermal qualities of clothing.

It is essential for man to remain comfortable in various climatical changes to insure mental and physical health. Comfort is difficult to define as it is based on physical, social and psychological variables. One definition of thermal comfort is "the absence of any unpleasant sensations of being too cool or too warm or having too much perspiration on the skin" (Hardy, Ballow and Wetmore, 21). The range of temperatures at which the nude human body maintains itself without a significant change in the 37°C. (98.6°F.) internal temperature is limited to 24-45°C. (75-114°F.). Clothing affects the heat transfer between the body and environment and can aid the body in maintaining the proper internal temperature for a healthy person.

The insulative value of clothing is measured in units of clo which were defined by Gagge, Burton and Bazett (18) in 1941, one clo unit being the

> insulation necessary to maintain a sitting resting subjectin comfort in a normally ventilated room (air movement of 20 feet per minute) at a temperature of 70°F. (21°C.) and a humidity of the air which is less than 50 per cent.

The insulation offered by clothing ranges from 0.5 clo units for midsummer dress to 5.0 clo units for clothing worn in bitter cold climates. The clothing worn indoors has an approximate value of 1.0 clo units with 3.0 clo units being the maximum for comfort indoors (Meier, 30).

Research on the thermal qualities of civilian clothing has been limited. Further research is needed to provide an objective means of determining the thermal insulative qualities of clothing for the consumer. Little research has been conducted with emphasis on the insulative quality of men's trousers, particularly washable slacks of blends available to Midwestern college men. With this in mind, the objectives of this study were firstly to determine clo values of total clothing assemblages as tested under controlled conditions and secondly, to analyze the effect of fiber content, fabric construction (type of weave and yarn count), thickness, permeability to air and weight of the trouser fabrics in relation to clo values for the total clothing assemblage.

CHAPTER II

REVIEW OF LITERATURE

One important reason man wears clothing is to enable him to maintain his body temperature at a level to insure mental and physical health. Clothing acts as an insulator against both heat and cold. Some previous research in the thermal insulation of clothing, methods of heat transfer, regulation of heat by the human body, and factors which influence thermal insulation will be discussed.

A. THERMAL INSULATION OF CLOTHING RESEARCH

Research on the comfort of clothing has been conducted for many years. The American physicist, Benjamin Thompson (Count Rumford of Bavaria) had the task of clothing the Bavarian army about 1779 (Brown, 8). He sought the fabrics which would give maximum warmth yet which were economical. He studied heat conductivity of clothing materials and analyzed convection currents (which were named such twenty years after his death). In his studies, Count Rumford found that fur and feathers are better insulators than plain air which lead him to hypothesize that layers of air adhering to the surface of the fibers are responsible for thermal insulation. He also found that dry air is a better insulator than moist air.

Dearborn (12) in 1918, discussed the physiological protection of clothing in psychological terms. In discussing the relation of clothing to body temperature, he evaluated texture, fiber and colors. Textured materials, according to Dearborn (12), prevented the formation of a layer of still air against the body, thus keeping the body warm in winter and cool in summer by exposing more surface from which moisture could be evaporated. The fibers which in

Dearborn's opinion provided the best warmth were fur and wool followed by silk, cotton and linen. Except for white and black which reflect and absorb more sunlight than other colors, Dearborn felt the effect of color on warmth was primarily psychological.

More recent research has been conducted on thermal qualities of men's wear using a copper manikin by the Army Research Institute for Environmental Medicine. The copper manikin is a hollow copper shell which resembles the human body in contour. The outer surface of the shell has been blackened to simulate the emissivity of the human skin and the inside is electrically wired in a "normal" skin temperature pattern of a resting human in a comfortable environment. The Army's research has been concerned with military clothing in extreme weather conditions, tropic and arctic (Belding, 4; Forbes, 15).

Other research has made use of small samples of fabric and flat or cylindrical thermal conductivity apparatus. This type of testing gives conductivity values for the fabric only and not the insulative value of a garment made of the fabric (Andreen, Gibson and Wetmore, 2; Marsh, 27; Rees, 36; Rees and Ogden, 37).

Civilian research at Kansas State University using a copper manikin has been concerned with thermal qualities of men's jackets (Franz, 17; Leung, 26; McCracken, 28). Initial research with civilian clothing at Kansas State University by Franz (17) in 1965 with the copper manikin was to establish procedures for operating the equipment and its use in determining clo values for certain men's garments, particularly nylon jackets. Testing was conducted in a controlled environment of 70 ± 2°F. and 65 ± 2 per cent relative humidity. Two other environments, one based on changes in relative humidity and the other on lowered ambient air temperature were also used. McCracken's study (28) in 1966 further developed procedures for using the same manikin, including dress procedures. Tests were then conducted to determine the clo value of various jacket and lining assemblages. Leung (26) in 1967 used the same manikin to find the amount of clothing required for human comfort at various air temperatures and body activities, to measure and compare the senible heat loss from the nude body and the copper manikin surface with previous literature and to analyze the additive effect of the combination of several clothing layers.

B. METHODS OF HEAT TRANSFER

Heat is a manifestation of the energy of motion and can be transferred in three ways: by conduction, convection and radiation (Jackob and Hawkins, 24). Evaporation is often considered as another method of heat transfer from the human body (Bazett, 3; Hardy, Ballow and Wetmore, 21; Rees, 36). Heat flows from the area of higher temperature to one of lower temperature. In a given environment, a state of equilibrium is reached when the environment and the body do not continue to change temperature with the passage of time. Thermal regulation depends on this state of equilibrium, a balance of heat production and heat loss. If the exchange of heat is from the body surface to the environment, the flow of heat is said to be positive with respect to the body. A reverse flow is negative.

Conduction

Conduction is the flow of heat through a medium without physical transfer of material even if the material is impermeable to any kind of ray. The term flow is used to actually mean a transfer of molecular vibration from a rapidly vibrating material to a body whose molecules are vibrating more slowly (Hardy, 20; Rees, 35; Taylor, 42). Conduction occurs only when two surfaces are touching. For a man standing on the floor, the transfer of heat through conduction to the floor is negligible as the area of direct contact is small and the insulating value of the shoe soles is significant (Leung, 26). Pierce and Rees (34) reported that conduction was important only when the clothing was in actual contact with a good thermal conductor. If a textile system is the medium through which heat is transferred through conductivity, the thermal conductivity of the fibers and the orientation of the fibers have an important effect on the insulating value (Newburgh, 33).

Convection

Convection occurs when heated molecules move from one location to another by means of currents (Cassie, 10; Hardy, 20; Selle, 39). Convection can be natural or forced (Hardy, 20; Leung, 26). Natural convection is seen in the rising of air which is warm compared to its surrounding by buoyant effects. Forced convection forces heated molecules in a specific direction as in the case of a fan moving air.

Convection losses from the human body are variable depending on the layer of air next to the skin. Rees (36) stated that convection also depended upon the rate of air movement within the fabric and the temperature gradient. Body movements cause a shift in the air space between the body and clothing allowing for more or less convection depending on the amount of air space created. In addition, the amount of convection that can occur within a fabric system depends on the openness of the fabric and the amount of air which is admitted through the fabric.

Radiation

Radiation is the transfer of energy by electromagnetic waves, such as light and radio waves. Emissivity is the property of surfaces which describes its ability to emit thermal radiation. Absorptivity is the ability of a surface to absorb thermal radiation. The surface of the human skin and clothing are radiating surfaces (Hardy, 20).

DuBois (13) stated that Negroid and white human skin are ninety-seven per cent perfect black body radiators with the radiation at wave lengths beyond the visible. According to Newton's Law, the amount of radiation is proportional to the surface area, emissivity and differences in temperature between the surface area and surroundings. This is an approximation when used in engineering when the temperatures in question are close together, such as 70°F. and 100°F.

Artificial or indirect light does not affect the thermal qualities of fabrics of differing colors in that the absorption of energy from visible light of relatively low temperatures (light bulbs as opposed to the sun) is not a problem. In bright sunlight, however, the use of dyes can aid the absorption of light energy as heat or reflect the energy as demonstrated by the use of light colored clothing for coolness. Darker shades absorb more light energy than do lighter hues, thus increasing the amount of heat transmitted to the body (Fourt and Harris, 16). The use of exposed metal (space capsules and the astronauts' space suits) or aluminum backed fabrics (Milium) of low absorptivity reduces the potential of large amounts of heat being transferred to the body when the environmental temperature becomes extremely high as in space or large fires.

When the body is clothed, the surface of the clothing is the radiant surface. The emissivity of a surface is the "ratio of the intensity of the radiation of a black body" (Hardy, Ballow and Wetmore, 21). Rees (35) stated that fabrics of any color behave almost like a black body. Marsh (27) found that a smooth shiny surfaced fabric has a high insulating value concerning heat loss compared with other fabrics.

Evaporation

The human body loses heat through evaporation of moisture from the lungs and skin. In a human the loss of moisture from the skin is greater than that from the lungs. Many studies have been conducted to evaluate the effect of surface moisture on the insulative qualities of clothing and humans (Andreen, Gibson and Wetmore, 2; David and Macpherson, 11; Galbraith, et al., 19).

Heat Transfer and the Copper Manikin

The copper manikin standing on the floor has only a small area of direct contact with the floor and therefore, little heat is transferred by conduction to the floor. The clothing on the manikin touches the manikin and also other layers of fabric, in such instances, heat is partially conducted from within the manikin to the clothing.

The copper manikin at a higher temperature than the room radiates energy from the surface of the exposed body and exposed clothing and also between the body and layers of clothing. If the manikin's surface had not been blackened the radiation from the copper would be much less than that of the human skin and the manikin would not be a good analog of the human body.

Air surrounds the manikin and is a part of the clothing assemblage so that convection is one means of heat transfer from the surface of the manikin to the clothing and surrounding atmosphere. Since the copper manikin is not capable of producing moisture, evaporation heat loss cannot be studied with it.

C. REGULATION OF HEAT BY THE HUMAN BODY

The human body is an intricate mechanism that must have an internal temperature of approximately 37 C. (98.6°F.) over a range of heat production and environmental temperatures in order for life to be maintained (Cassie, 10; Hardy, 20; Hardy, Ballow and Wetmore, 21; Rees, 36). Selle (39) stated that the complex pattern of local areas of heat production and heat loss throughout the body gives only rough indications of "normal" temperatures. This is seen in the variation in the body temperature of one person throughout a day and the variation among people.

Food is the fuel which supplies heat to the body. Metabolism of food produces carbon dioxide, water and heat. The surface of the skin has a temperature lower than the internal body temperature (about 33°C.) due to the transfer of heat (Black and Matthew, 5; Meier, 30; Morris, 31). Approximately ninety per cent of the heat produced by the body is dissipated from the skin surface by conduction, convection, radiation and evaporation. The remaining ten per cent is moisture lost from the lungs (Hardy, Ballow and Wetmore, 21). Bazett (3) stated that the nude body at rest has a minimum skin temperature of 30°C. without a change in internal temperature. According to Meier (30), the nervous system will register a mild but definite protest if the skin temperature varies 3°C. Real discomfort or illness results from a change of 5°C. or more. The body adjusts to changes in heat production to protect the inner organs and the brain. Variations in internal temperature results in a noticeable loss of mental functions.

The human body has various controls for heat regulation: alteration in mean surface temperature, changes in the pattern of heat distribution on the surface and alterations in conditions of the body surface affecting heat losses (Selle, 39). The limbs are particularly useful in regulating heat loss. Limbs have a large amount of surface area in proportion to the rest of the body, thus allowing more area from which heat may be transferred. Limbs are able to move freely because of the muscle and bone structure and this movement can cause warmth through heat production or allow cooling to take place when movement reduces the still air layer which surrounds the body. With increased movement, there may be a decrease in the amount of blood supplied to the periphery because of an increased flow to the working muscles (Bazett, 3; Hardy, Ballow and Wetmore, 21; Wood, 44).

Clothing is used to slow or increase the rate of heat loss to the environment, especially when the temperature difference is great, thus maintaining the equilibrium between the body and the environment. The state of equilibrium can be upset temporarily by environmental changes, extra clothing or metabolism. Readjustment of the balance is made in skin temperature and perspiration and also by the removal or addition of clothing or a change in environment.

D. FACTORS INFLUENCING THERMAL INSULATION

Environmental Conditions

Temperature. Environmental temperatures can vary a great deal throughout the year and even within one day. The body must be able to cope with such changes. Clothing absorbs heat and moisture from the environment and the body depending on relative conditions. Most clothed people feel comfortable in an environment of about 75°F. When the environmental temperature falls below 50°F., it is difficult to maintain thermal comfort at low levels of activity. Comfort in such temperatures can be obtained though at an inconvenience to activity by wearing additional clothing and gloves (Meier, 30). The tropics pose the opposite problem, that of high temperatures. People in the tropics use light colored clothing or remove one or more layers of clothing or use fabrics and garment construction to provide comfort (Newburgh, 33).

Moisture. The relative humidity or moisture in the atmosphere affects the way people feel. At a high temperature with a high level of moisture in the atmosphere, man is usually uncomfortable as moisture produced by the body cannot be readily evaporated from the surface of the skin (Werden, Fahnestock and Galbraith, 43). At extremely low humidity levels, man loses moisture easily to the atmosphere and may feel too dry for comfort. His skin may feel dry, itch and crack and his nose may feel dry.

The effect of clothing in relation to moisture is dependant on the fabric and the amount of moisture present. Galbraith, et al. (19) found that the comfort of a person depended in part on the ability of clothing to allow for the escape of perspiration from the skin surface. Mehrtens and McAlister (29) found that a clinging garment was a source of discomfort. When a garment feels wet and clammy the person wearing it feels uncomfortable. Perspiration running down the body is another source of discomfort when garments are not designed to allow for the exchange of water vapor. Acrylic, cotton and water repellant cotton were tested by Galbraith, et al. (19) and no effects were noted due to the varying water absorption power of the fabrics. It has been found that increased moisture content in fabrics reduced the insulating ability of the fabrics (Black and Matthew, 5; Cassie, 10; Hollies and Fronseca, 23). Regain of a fabric's normal moisture content after wear in exercise was found to occur in two stages: rapidly at first and then at a lower rate over a longer time period (David and Macpherson, 11).

Air Movement. The body has a thin layer of still air surrounding it. In still air, this layer of air is an effective insulator. Clothing which does not cling to the body adds to this layer of dormant air (clinging to the hairs on the body and fibers on the clothing) by extending the personal atmosphere and keeping it relatively motionless. The layer of air has been given as approximately 0.71 inch thick. The value of 0.25 inches of still air is said to equal one clo unit. Air movements below ten feet per minute are considered still air conditions and will usually not penetrate a fabric and strip away the layer of still air completely. Greater wind velocities remove the air layer causing chilling of the body or wind chill (Newburgh, 33). Fabric construction varies for garment use depending on conditions under which it will be worn to insure thermal comfort. Clothing which is worn in strong wind conditions must be less permeable to air movements, whether by closeness of weave or layered construction (Rees, 36). Clothing to be worn in relatively still air conditions can be of more open weaves or of less layers depending on the factors of temperature and humidity.

Fabric and Garment Features

In 1953, Hardy, Ballow and Wetmore (21) reported that the properties of fabrics can be assessed and compared accurately only in terms of specific, individual cases, each one involving a definite type of garment and some definite set of characteristics.

Fabric Thickness. Thickness is the distance between one surface of fabric and its opposite. It is "determined by showing the linear distance that a moveable plane is displaced while under a specific pressure" (American Society for Testing Materials, 1). Thickness is one of the basic physical properties of all textile materials. The thickness of a material varies inversely with the pressure applied. A gauge with a weight attached to the pressure foot is lowered to the material specimen and allowed to rest ten seconds, then the dial is read to the nearest 0.001 inch. This method of determining thickness is intended for flat woven or knitted cloth, but is not suitable for piled or napped cloth (Federal Specifications, 14). A cross-section of napped or piled fabrics measured microscopically is reccomended to obtain their thickness (Labarthe, 25). It is desireable to measure thickness at the lowest possible pressure or the conditions most similar to use. Differences in fabric thickness show more at lower pressures than at higher pressures (Fourt and Harris, 16). Bulk and warmth can be estimated from thickness values for some fabrics. The thickness of a fabric is an indication of the amount of air held in a dormant state, the thicker the fabric, the greater the amount of air held by the fibers thus making the fabric warmer (Dearborn, 12).

Fourt and Harris (16) agree that the main factor in the insulating value of cloth is thickness. Rees (36) stated that when fabrics were of equal thickness, one being of open construction and the other of close construction, the warmer fabric was the more closely constructed. He used the thermal resistance to heat flow (tog units) per inch of fabric thickness as a basis to obtain a ratio of thermal resistance to thickness. Marsh (27) plotted thermal insulation values against thickness and in a linear relationship showed that air in fabrics plays an important part in insulation.

Flexibility, the ability of a fabric to bend and regain its original shape, is related to thickness and the effective thickness of layers of clothing and its relation with surrounding air. Clothing constructed of a stiff fabric has a bellows action, pumping air out of the interlaying spaces with movement. Extremely limp fabrics on the other hand, collapse onto the skin minimizing the air space between the garment and the skin.

Weight. Linear density equals the weight per unit length of the fabric and is a "useful general way of describing the fineness or coarseness of textile fabrics" (Morton and Hearle, 32). Determination of the weight per unit area based on small samples of a fabric determines the weight of the end product. It is important to hand, comfort and appearance. Rees (36) stated a ratio of thermal resistance to weight per unit area equaling a measure of efficiency of the fabric structure as a heat insulator. In his testing of cellular construction, Rees (36) found that when weight was equal the fabric of cellular construction was warmer than that of non-cellular construction.

Mehrtens and McAlister (29) in their study of knit shirts found that fabric weight and thickness were the only objective properties needed to explain warmness and heaviness sensations. They found that high values of fabric weight times the thickness of the fabric gave low comfort ratings by testers.

Fiber Content. Werden, Fahnestock and Galbraith (43) found no significant differences among fibers in relation to thermal comfort. Their testing was based on the assumption that there was a difference in thermal comfort of clothing based on fiber content and that absorption characteristics of fibers could be the reason.

In a study by Galbraith, et al. (19), hot and humid testing conditions were used. It was found that fiber content and the use of water repellant finishes did not affect the physiological measures of thermal comfort.

Forbes (15) explained the reason wool garments are warmer than any other except fur. For a given thickness, the fibers show little measureable difference in insulation. Most wool clothing has a greater thickness than other fabrics and thus is warmer by the amount of air held in the interstices of the fabric. Wool also is able to absorb more moisture than other fibers before feeling wet to the touch and therefore clammy or cool. Most wool fabrics do not cling to the body as do some other fabrics so they do not reduce the air space surrounding the body.

Fabric Construction. Fabric construction allows air to be held within the fabric structure and under the fabric (between the body and the garment) thus aiding thermal insulation. A weave which holds more still air between the fibers is warmer than one which holds less air. An open weave allows air to penetrate the fabric and set the still air in motion which results in greater cooling. Some permeability to air is desireable as is some permeability to water vapor. These are channels by which heat and moisture can be removed from the body surface through clothing maintaining the body at a comfortable level. A shield from wind to help insure thermal insulation is a thin closely woven cloth of low permeability to air.

Garment Style. Maximum insulation can be obtained only if clothing is worn loosely and compression avoided. Dormant air layers, essential to the efficiency of clothing can be easily destroyed if fabric layers are pressed tightly together (Siple, 40). Materials used for insulative clothing should be evaluated on the basis of their capacity to immobilize air. Belding (4) stated that two garments of equal weight, one which allowed for free body movement and the other restricting body movement, the garment allowing for more freedom of movement will seem less heavy. Modern advances in textiles make it possible to obtain warmth without having weight.

According to Rees (35), clothing should be designed so that thermal exchanges between man and the environment are maintained at a comfortable rate under vastly different environmental conditions. Marsh (27) said that 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 the projecting fibers from the fabric. It is shown that these minute air films have a great thermal insulating value and must therefore be considered.

The use of present design and fit of garments for protection in cold weather rates style and appearance over utility and warmth (Rees, 35).

CHAPTER III

MATERIALS AND PROCEDURES

The thermal insulation of the total assemblage of clothing and entrapped air was determined in this study. The manikin, laboratory, clothing and procedures will be described below.

A. MANIKIN AND LABORATORY

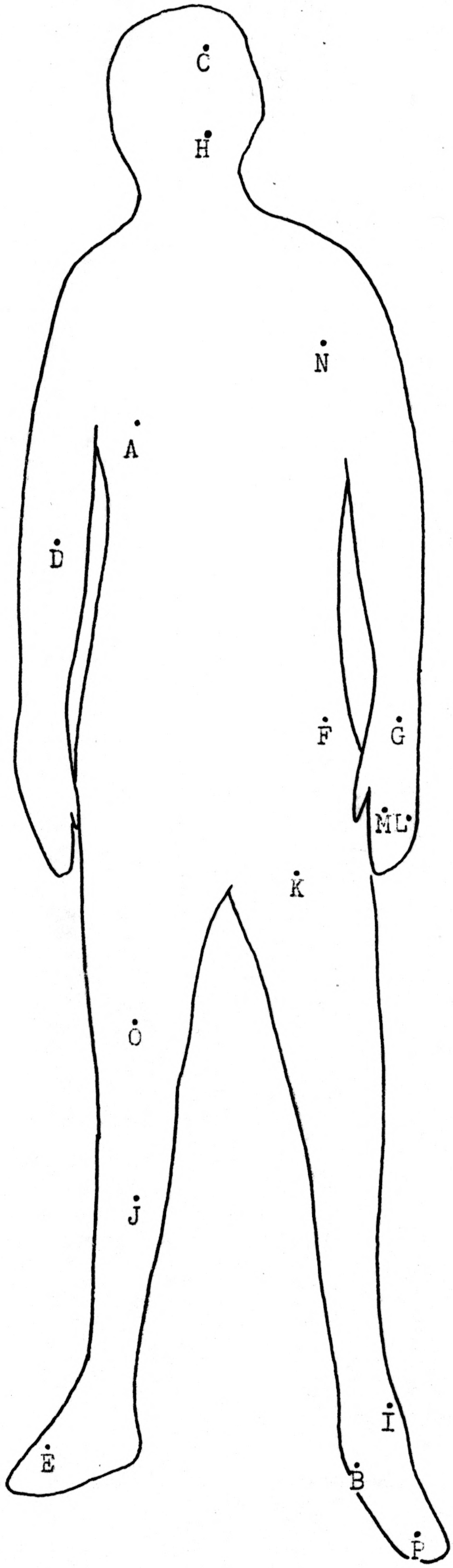
Copper Manikin

The copper manikin, a hollow shell resembling the human body in contour, of one-eighth inch thick copper which had been blackened to simulate the emissivity of the human body was used to determine thermal insulative values of men's clothing in terms of clo units.

The manikin stands five feet ten inches tall and weighs about eighty pounds with a surface area of 1.795 square meters. It is electrically wired on the inside of the shell in a "normal" skin temperature pattern of a resting human in a comfortable environment. Three electrical circuits are utilized to heat the manikin: (1) a main series circuit used throughout the manikin except, (2) hands distally from the wrists through a parallel circuit controlled by a rheostat in the upper sternal region and (3) feet distally from the ankles through a parallel circuit controlled by a rheostat in the frontal abdominal region.

Surface temperatures of the manikin were measured by sixteen thermocouples located within the shell at positions indicated on Figure 1. The terminal wires were joined into a switch box which was in turn connected to a digital thermometer.

The manikin was supported in a vertical position by a stand with a remove-



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 Left Hand Small Finger
M Left Hand Index Finger
N Left Scapula
O Right Thigh
P Left Foot

FIGURE 1

THERMOCOUPLE LOCATIONS ON MANIKIN

able frame that encompassed the head. Three construction details facilitated dressing the manikin: (1) a pulley secured to the supporting stand permitted the manikin to be raised from the base, (2) the arms rotated about ninety degrees to the rear and (3) power and control cables from the instrumentation to the manikin entered in the neck area.

Laboratory

A conditioned laboratory of 70 ± 2°F. and 65 ± 2 per cent relative humidity was used for testing. An unpublished study by Kansas State University engineers showed that the air movement in the laboratory averaged thirty feet per minute but had a slight increase with increasing altitude and also slight fluctuation in some lateral locations.

Because of the manikin's extreme sensitivity to air movement, it was located near the center of the room facing west. The instrument rack was located about three feet to the north of the manikin and the investigator sat on a stool beside the rack.

B. CLOTHING

Basic Set

The manikin wore the same shirt, underwear and shoes throughout the entire test period. These items of clothing were termed the basic set and included the following:

T-shirt........................100 per cent cotton knit
Boxer shorts...................100 per cent cotton broadcloth
Long-sleeved shirt.............100 per cent cotton chambray
Socks..........................100 per cent cotton knit
Shoes..........................Polyvinyl sole and heel molded to leather

The sizes of clothing used for the manikin are given in Appendix A.

Trousers

The style of the trousers selected for testing was based on casual observation of trousers worn by men in Kramer Food Center and other parts of the Kansas State University campus during the month of January, 1968. The stores in Manhattan, Kansas which sell men's wear were visited to determine the trousers which were available in the selected style. The fiber content of the trousers selected for the study was based on the most frequent fiber contents found in locally available trousers. Within each group of at least four pairs of trousers of a given fiber content one pair was selected at random and purchased.

The trouser style selected was a trim looking slack with plain front, belt loops and cuffed hems measuring sixteen inches in circumfrance. The trousers had two side pockets and two back pockets. The washable permanent press slacks were of 50 per cent polyester, 50 per cent cotton; 65 per cent polyester, 35 per cent cotton; 65 per cent polyester, 35 per cent rayon; and 50 per cent acrylic, 35 per cent rayon and 15 per cent acetate. The colors selected were similar in value, medium dark. The size marked on the trousers was 32 inch waist and 29 inch inseam; however, a difference in cut from one manufacturer to another was noticed in the way the trousers fit the manikin. Trousers #1 were one half inch shorter than the other three pairs; trousers #2 fit more snugly in the waist than the others; and trousers #3 had more ease in the waist and hip than the others.

Further description of the trousers is found in Table I. The results of physical tests for weight, yarn count, thickness and permeability to air carried out under American Society for Testing Materials standards (1) are summarized. Data from these tests are given in Table II, Appendix B. Appendix C has fabric samples of the trousers tested.

TABLE I

FABRIC DESCRIPTION OF TROUSERS AND CLO VALUE OF TOTAL ASSEMBLAGE

FIBER CONTENT AND COLOR	WEIGHT oz./sq. yd.	YARN COUNT yarns/in. WARP	FILLING	THICKNESS in.	PERMEABILITY TO AIR *	CLO VALUE IaFcl + Ic**	FABRIC STRUCTURE
#1 50% Polyester/ 50% Cotton Olive	7.09	132	62	0.0147	13.38	1.89	Basket Weave
#2 65% Polyester/ 35% Cotton Brown	6.79	99	50	0.0127	13.54	1.86	Plain Weave
#3 65% Polyester/ 35% Rayon Brown	8.50	55	56	0.0220	164.52	1.81	Basket Weave
#4 50% Acrylic/ 35% Rayon/ 15% Acetate Gray	7.42	51	41	0.0127	58.38	1.91	Plain Weave

*cu. ft. air flow/sq. ft. fabric/min. at a pressure drop across the fabric of 0.5 in. of water.

**Total Assemblage IaFcl + Ic at an 18 F. temperature difference between the manikin's surface and air.
Ia: Insulative value of air surrounding manikin.
Fcl: Factor of the increased surface due to clothing.
Ic: Insulative value of clothing on the manikin.

C. PROCEDURES

Procedures used in the testing can be divided into three sections: dressing, start-up and operational test procedures. Some terms used in the procedures are as follows:

Set point: May be any temperature setting on the proportional controller which approximately maintains the manikin's surface temperature level by controlling the electrical power input into the manikin.

Skin temperature: Refers to the manikin's surface temperature.

ΔT: The difference in temperature between the manikin's surface and the surrounding air.

Ia: Insulative value of air surrounding the manikin.

Ic: Insulative value of clothing on the manikin.

Fcl: Factor due to the increase in surface due to clothing.

Dress Procedure

Clothing to be tested was hung in the conditioned laboratory during the entire test time. Dressing the manikin was done at least twenty-four hours prior to testing so the clothing would reach equilibrium with the standard environment after the handling that was necessary to dress the manikin.

The following method was used to dress the manikin in preparation for testing.

A. Dress manikin in T-shirt and long-sleeved shirt, keep each layer smooth. Raise manikin with pulley and put on shorts and socks.

B. With manikin in a raised position, pull trousers up but keep unfastened. Place manikin's socks and shoes on its feet.

C. Lower manikin, fasten trousers after making certain all layers are smooth and in position (shirt tails down, pockets in position of use).

D. Before testing, smooth all clothing with a downward motion.

Start-Up Procedure

The start-up procedure recommended by Springer (41) and revised by McCracken (28) was used. The procedure outlined in Appendix D includes hook up of electrical equipment, instrumentation, setting and initial warm up.

Operational Test Procedure

The operational test procedure is as follows:

A. Select ΔT that is representative of the expected difference in temerature between the manikin's surface and the air. For this study ΔTs of 8, 12 and 18°F. were chosen. It was felt that these ΔTs were indicative of the conditions under which the trousers would be worn.

B. Set the proportional controller at a chosen set point based on experimentation to obtain the chosen ΔTs. The set points used in the study were 32, 34 and 36°C.

C. Smooth clothing.

D. Follow start-up procedure in Appendix D.

E. Allow copper manikin to come into equilibrium with the environment before taking readings, at least 60 minutes.

F. Take readings at each of the sixteen thermocouple locations. About six minutes is needed for the readings.

G. Record skin temperature at each location, air temperature, power input and set point temperature on the Thermal Insulation of Men's Trousers Data Sheet shown in Figure 2.

H. Calculate the clo value for the entire assemblage (clothing plus air) using the formula

$$\frac{3.09\,(Ts-Ta)}{\dfrac{\text{watts}\,(0.86)}{sa}} = IaFcl + Ic$$

Where:

3.09 - constant required to obtain insulation in clo when °F. is used. (1 clo = 0.18°C./ hr./m^2/kgcal.)

Ts - surface temperature of manikin in °F.

Ta - air temperature in °F.

watts - electrical input into manikin.

0.86 - constant to convert watts to kgcal./hr.
(1 watt = 0.86 kgcal./hr.)

sa - surface area of manikin in square meters.

Ia - insulative value of air surrounding manikin.

Fcl - factor of the increased surface due to clothing.

Ic - insulative value of clothing on manikin.

THERMAL INSULATION OF MEN'S TROUSERS
Data Sheet

Date: ______________
Run: _________ Trousers # _________

Test 1		Test 2		Test 3	
Time:	ΔT:	Time:	ΔT:	Time:	ΔT:
A________	Q________	A________	Q________	A________	Q________
B________	R________	B________	R________	B________	R________
C________	S________	C________	S________	C________	S________
D________		D________		D________	
E________		E________		E________	
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________	
Set point temperature__________		Set point temperature__________		Set point temperature__________	
Average surface temp.__________		Average surface temp.__________		Average surface temp.__________	
Ambient air temp.__________		Ambient air temp.__________		Ambient air temp.__________	
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 (IaFcl + Ic)__________		Clo value (IaFcl + Ic)__________		Clo value (IaFcl + Ic)__________	

FIGURE 2

CHAPTER IV

RESULTS

The clo value of the total clothing assemblage (clothing and air) was calculated using the manikin's average surface temperature which had been computed by two methods. The first method was to use only a simple average of the readings at the sixteen thermocouple locations. In the second method a weighted mean was obtained using the percentage of body area as given by DuBois (13) and Yaglou in Newburgh (33) as the weighting factor. The following proportions with corresponding thermocouple locations were used: head (C, H) 7%; trunk (A, F, N) 35%; arms (D) 14%; hands (G, L, M) 5%; legs (J, K, O) 32%; and feet (B, E, I, P) 7%. The difference in the average surface temperature at an 8°F. temperature difference between the body surface and air was 0.66°F.; at a 12°F. temperature difference was 1.32°F.; and at an 18°F. temperature difference was 2.37°F. The weighted mean gave the higher average temperature.

Analysis showed that there was no statistical difference between the simple mean and the weighted mean (see Appendix E). Therefore, the simple mean has been used in the calculation of the clo values. Table III summarizes the data obtained from testing four pairs of trousers using a copper manikin.

TABLE III

SUMMARY OF DATA OBTAINED FROM TESTING CLOTHING

TROUSERS	ΔT	SURFACE TEMPERATURE		AIR TEMPERATURE		POWER READING		CLO VALUE TOTAL ASSEMBLAGE IaFcl + Ic*	
	°F.	RANGE °F.	MEAN °F.	RANGE °F.	MEAN °F.	RANGE Watts	MEAN Watts	RANGE	MEAN
50% Polyester/ 50% Cotton	8	81.46 to 81.67	81.51	73.88 to 74.45	74.18	27.6 to 29.6	28.3	1.60 to 1.82	1.71
	12	85.45 to 85.65	85.55	74.27 to 74.69	74.47	43.4 to 44.6	43.8	1.62 to 1.70	1.66
	18	91.40 to 91.87	91.62	72.47 to 73.95	73.69	61.6 to 64.0	62.8	1.82 to 1.95	1.89
65% Polyester/ 35% Cotton	8	81.40 to 81.54	81.46	73.83 to 74.30	74.08	28.6 to 30.0	29.1	1.62 to 1.73	1.66
	12	85.46 to 85.86	85.65	74.09 to 75.02	74.47	43.2 to 44.6	44.2	1.60 to 1.80	1.67
	18	92.31 to 92.92	92.56	73.79 to 74.30	73.98	64.0 to 68.0	65.8	1.73 to 1.98	1.86

TABLE III CONTINUED

TROUSERS	ΔT °F.	SURFACE TEMPERATURE RANGE °F.	SURFACE TEMPERATURE MEAN °F.	AIR TEMPERATURE RANGE °F.	AIR TEMPERATURE MEAN °F.	POWER READING RANGE Watts	POWER READING MEAN Watts	CLO VALUE TOTAL ASSEMBLAGE IaFcl + Ic* RANGE	CLO VALUE TOTAL ASSEMBLAGE IaFcl + Ic* MEAN
65% Polyester/ 35% Rayon	8	82.09 to 82.29	82.19	73.24 to 73.84	73.59	33.6 to 35.2	34.4	1.60 to 1.74	1.65
	12	86.10 to 86.77	86.26	73.29 to 73.80	73.49	49.8 to 51.6	50.6	1.59 to 1.73	1.66
	18	91.24 to 92.41	91.72	72.82 to 74.79	73.50	65.6 to 68.0	66.6	1.73 to 1.87	1.81
50% Acrylic/ 35% Rayon/ 15% Acetate	8	81.08 to 81.65	81.40	72.66 to 74.06	73.54	31.6 to 34.0	32.6	1.49 to 1.64	1.58
	12	85.49 to 85.71	85.55	73.35 to 73.91	73.73	47.8 to 50.2	48.8	1.56 to 1.66	1.60
	18	91.71 to 92.13	91.96	73.35 to 74.03	73.70	63.6 to 64.6	64.0	1.83 to 1.97	1.91

*Ia: Insulative value of air surrounding manikin.
Fcl: Factor of the increased surface due to clothing.
Ic: Insulative value of clothing on the manikin.

CHAPTER V

DISCUSSION AND CONCLUSIONS

This study was undertaken to determine the clo value of the total assemblage of clothing and air using trousers of four different fiber contents as tested under a specified environmental condition using a copper manikin. Furthermore, the effects of fiber content, fabric construction (weave and yarn count), thickness, permeability to air and weight of the trouser fabrics in relation to the clo values of the total clothing assemblages were analyzed. In accordance with the definition of clo by Gagge, Burton and Bazett (18) which utilized a temperature difference of 22°F., only the clo values at a temperature difference of 18°F. will be discussed in relation to the parameters given above.

Analysis of the relation of fiber content and clo value showed that there was no variation in clo value due to varying fiber contents. This finding agrees with the earlier finding of Galbraith, et at. (19) and Werden, Fahnestock and Galbraith (43) who used human subjects in their research. Analysis of variance of the fiber contents and clo values are given in Table IV.

TABLE IV

ANALYSIS OF VARIANCE
FIBER CONTENTS AND CLO VALUES OF TOTAL ASSEMBLAGES

Source	Degrees of Freedom	Sums of Squares	Mean Squares
Among Group (treatment)	3	155.52	51.84
Within Group (error)	32	5440.78	170.02
Total	35	5596.30	

Using the hypothesis that there is no difference in the relation of the various fiber contents to clo value

H_o: $t = 0$; H_a: $t \neq 0$
$\alpha = 0.5$
$F\ (3, 32)$
reject if $t \leq 2.95$

$$\frac{51.84}{170.02} = 0.3049 = t$$

therefore, we fail to reject the hypothesis.

Statistical tests for correlation were done to determine if there was a linear relationship between clo value and the factors of weight, yarn count (warp and filling), thickness and permeability to air and if so, how great was the correlation. The correlation coefficient r has any value between -1 and +1. Values near ±1 indicate that the variables are highly correlated. If r is equal to zero, the variables are uncorrelated in a linear relationship. Table V gives the correlation coefficient values obtained at an eighteen degree temperature difference.

TABLE V

PARAMETERS AND CORRESPONDING CORRELATION COEFFICIENT TO CLO

Parameter	r Value
Permeability to air	-0.72
Weight	-0.66
Yarn Count - Filling	-0.39
Thickness	-0.33
Yarn Count - Warp	0.24

From this table it can be seen that there is a strong correlation between permeability to air and clo value. Also as seen in Table I and graphically in Figure 3, as permeability to air increases generally the clo value decreases. Weight has a similar relation to clo value.

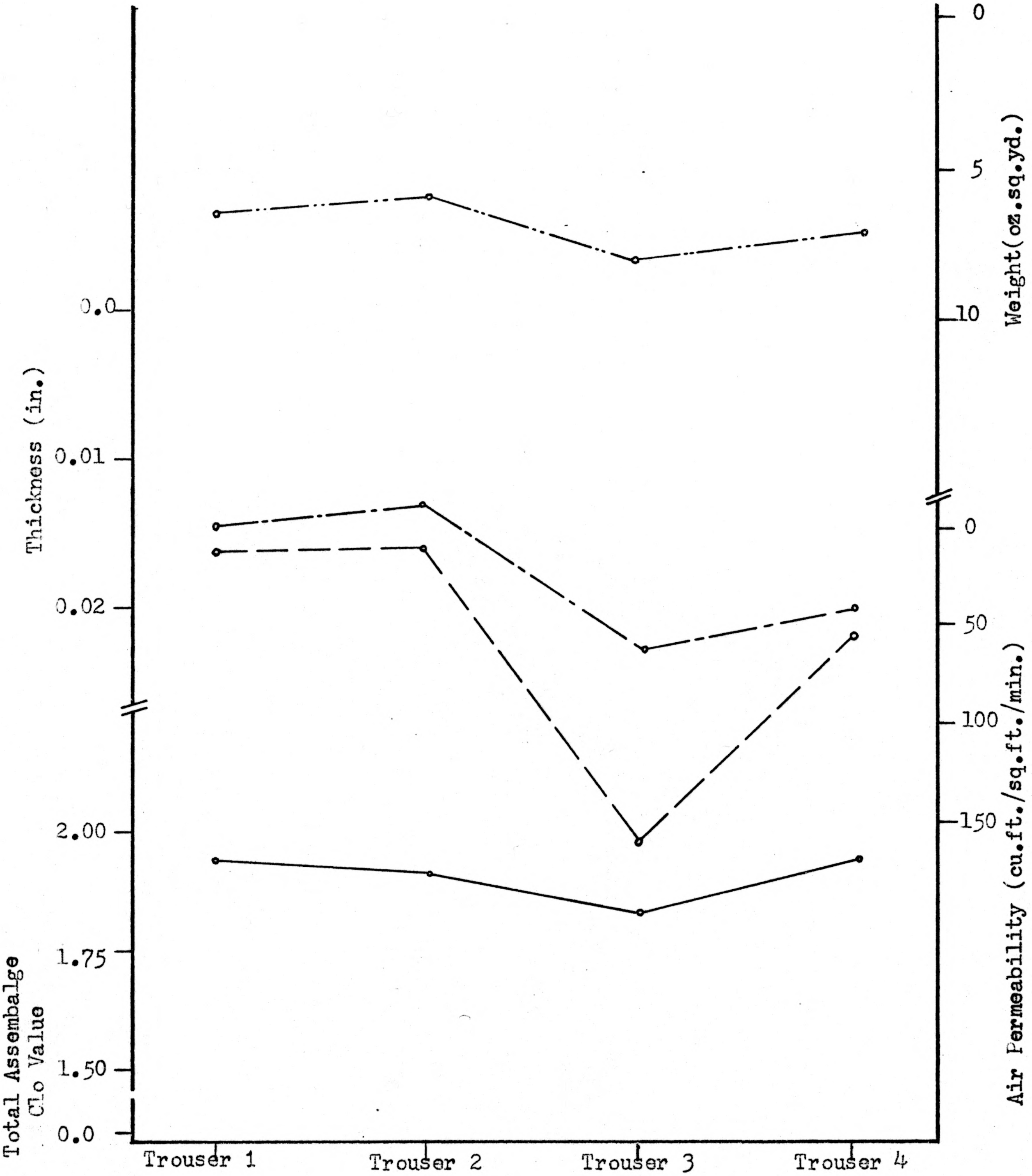


FIGURE 3
SOME PARAMETRIC VALUES OF THE TROUSERS PLOTTED INVERSELY TO CLO VALUES
(See Table 1 for data used.)

Clo Value ———— Thickness —·—·—
Permeability — — — Weight —··—··—

Filling yarn count and fabric thickness have less important relations to clo value. Warp yarn count has an even less important correlation with clo value.

This has been an analysis of each parameter as if it acted independantly to determine clo value. In reality, the clo value depends upon these parameters in combination rather than individually. This is demonstrated by the fact that clo value does not show the expected relationship to thickness and weight (Fourt and Harris, 16; Hardy, Ballow and Wetmore, 21; Mehrtens and McAlister, 29; Rees, 36). Since the permeability to air by the trouser fabric is an overriding factor in the total assemblage in determining the clo values (see Figure 3), note that the parameters of permeability to air, thickness and weight are plotted with increasing values downward to show the effect of the parameters on clo value which are inversely related.

This limited study has shown that a total assemblage of high insulative value can be obtained best if the trousers have low permeability to air (less than 60 cubic feet per square foot per minute), and a weight about 7 ounces per square yard with the other parameters having less importance.

CHAPTER VI

RECCOMENDATIONS

This study has been a limited one, utilizing only four pairs of trousers. The results have shown the overriding influence of permeability to air. Further work needs to be done in this field using trousers in which all parameters are equal except one which would then be able to show its true effect on clo value.

This study was limited in the number of trousers tested; it would be advisable to repeat the experiment with more trousers of varying fiber contents and other parameters and also a greater number of trousers within each grouping to give a more complete picture of the insulative value of given trousers. Determination of the clo value for the trousers alone in addition to the clo value of the air alone and the toal clothing assemblage clo value would be very beneficial. Analysis of the type of yarn and its effect on the clo value of a garment would give a better understanding of the effect of all parameters on clo value.

Trousers cover approximately one-third of the body area and therefore, are an important aspect in clothing insulation provided by clothing. A study incorporating various combinations of jackets, hats, gloves and other garments with select trousers would give total clothing assemblage insulation values which would be useful in the selection of clothing for warmth in cold weather. Statistical analysis of each item of clothing should be done in order to determine the effect of each item on the total insulation of the assemblage.

A comparison of insulation values as determined with the copper manikin and one of the methods described by Marsh (27), such as a flat thermal conductivity apparatus would be interesting and useful in knowing the actual differences in the measurements of the different methods. The same fabric and environmental conditions would have to be used in order for comparison.

Since wind is often a factor in man's environment, the introduction of air movements of varying velocities into the test chamber would enable the results of the tests to be used in determining the trousers which will give the best insulation in various wind conditions.

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APPENDIX A

CLOTHING SIZE CHART FOR THE COPPER MANIKIN

Clothing	Size
T-shirt	Medium
Shorts	32
Sports shirt	16-16½
Trousers	32-29
for looser fit (more ease)	33-30
Socks	13
Shoes	13

APPENDIX B

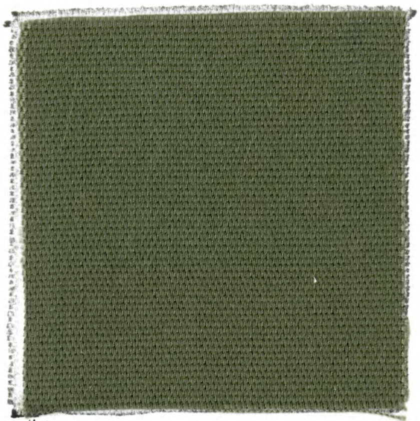
TABLE II

DATA FROM PHYSICAL TESTING OF SELECTED TROUSERS

TROUSERS Fiber Content	WEIGHT oz./sq. yd.	YARN COUNT yarns/in.		THICKNESS in.	PERMEABILITY TO AIR cu. ft./sq. ft./min.
		Warp	Filling		
#1 50% Polyester/ 50% Cotton	6.925	131	62	0.0145	14.4
	7.465	132	62	0.0150	13.7
	6.890	132	62	0.0150	13.4
	7.119	132	62	0.0142	12.7
	7.071	132	62	0.0150	12.7
#2 65% Polyester/ 35% Cotton	7.039	98	49	0.0130	14.3
	6.589	100	49	0.0125	13.4
	6.907	101	50	0.0130	13.7
	6.689	99	51	0.0127	13.4
	6.657	99	50	0.0127	12.9
#3 65% Polyester/ 35% Rayon	8.470	54	57	0.0220	172.0
	8.270	54	57	0.0216	172.0
	8.465	54	55	0.0225	167.2
	8.758	55	56	0.0225	155.2
	8.568	55	57	0.0215	155.2
#4 50% Acrylic/ 35% Rayon/ 15% Acetate	7.354	52	41	0.0190	62.9
	7.126	51	41	0.0200	48.0
	7.550	52	41	0.0200	64.4
	7.525	50	41	0.0200	53.2
	7.564	52	41	0.0202	63.4

APPENDIX C

FABRIC SAMPLES OF TROUSERS
USED FOR TESTING



#1
50% Polyester/
50% Cotton

#2
65% Polyester/
35% Cotton

#3
65% Polyester/
35% Rayon

#4
50% Acrylic/
35% Rayon/
15% Acetate

APPENDIX D

START-UP PROCEDURE FOR COPPER MANIKIN

A. Connect thermal converter as shown in the schematic diagram in Figure 4.

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 the extreme right when facing connection box on thermal converter.

D. Check recorder to insure switch is in OFF position.

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 manikin to proportional controller (labeled #5--one-forth inch standard phone plug).

J. Set proportional control 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 the hands, rotate upper rheostat clockwise; to increase temperature of feet, rotate lower rheostat counter-clockwise.

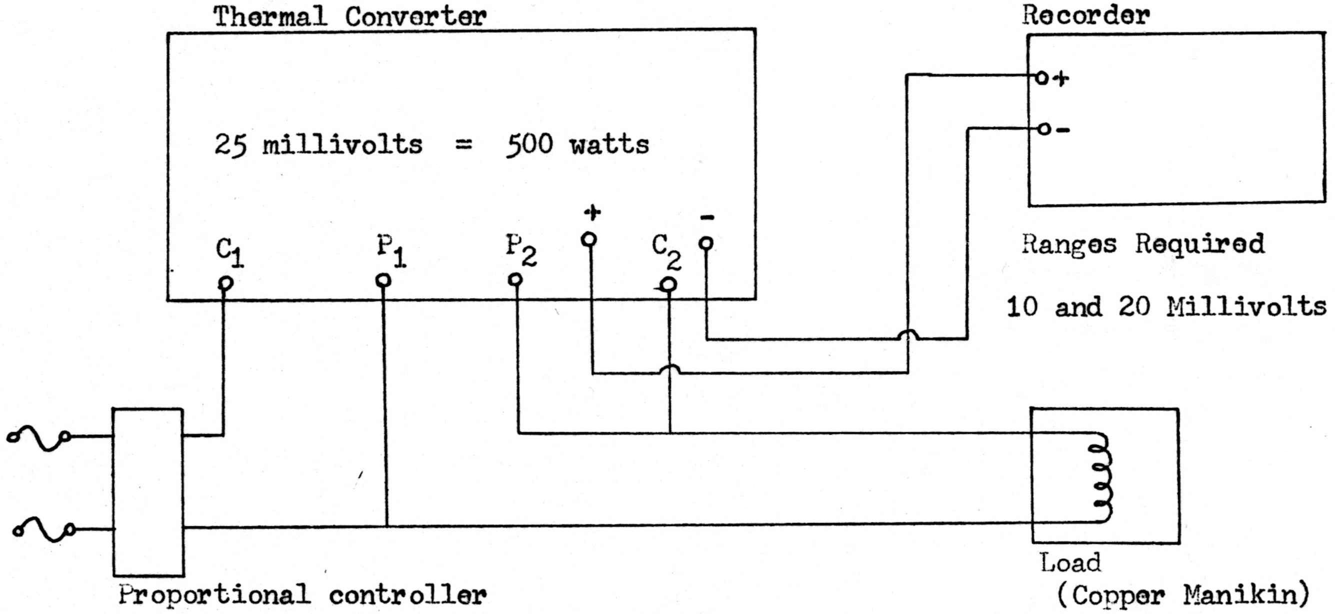
K. Check "Band Width" control for proper setting. The normal width ranges from 0.7 to 1.0°C.; the width was set at 0.85°C. for this study. Insure power switch is OFF.

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 setting, the recorder moves to 65 per cent of 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 by turning to 5 mv setting, 100 watts of a 100 per cent scale deflection; 2 mv setting, 40 watts of a

---

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



From Springer (41)

FIGURE 4

SCHEMATIC DIAGRAM FOR CONNECTIONS FOR THERMOUPLE CONVERTER

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 reccomended to set the span selector at or less than the 0.5 mv setting.

From McCracken (28)

APPENDIX E

ANALYSIS

METHODS FOR OBTAINING MANIKIN'S AVERAGE SURFACE TEMPERATURE

H_o: $M_1 = M2$ H_a: $M_1 \neq M_2$

$\alpha = 0.05$

reject H_o if $-2.13 \leq t \geq 2.13$

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{S^2\ (1/16 + ci^2/\ (ci)^2)}}$$

Set Point Temperature 32 °C.

Trousers #1

$$t = \frac{27.51 - 27.85}{\sqrt{2.43\ (.0625 + .0988)}} = \frac{-.34}{\sqrt{.3920}} = \frac{-.34}{.626} = -.543$$

Trousers # 2

$$t = \frac{27.44 - 27.77}{\sqrt{4.44\ (.1613)}} = \frac{-.33}{\sqrt{.7161}} = \frac{-.33}{.846} = -.390$$

Trousers #3

$$t = \frac{27.83 - 28.26}{\sqrt{.528\ (.1613)}} = \frac{-.43}{\sqrt{.0851}} = \frac{-.43}{.292} = -1.473$$

Trousers # 4

$$t = \frac{27.31 - 27.68}{\sqrt{.3693\ (.1613)}} = \frac{-.37}{\sqrt{.0595}} = \frac{-.37}{.244} = -1.517$$

Set Point Temperature 36 °C.

Trousers #1

$$t = \frac{33.04 - 34.79}{\sqrt{5.502\ (.1613)}} = \frac{-1.75}{\sqrt{.8875}} = \frac{-1.75}{.942} = -1.434$$

Trousers #2

$$t = \frac{33.66 - 34.79}{\sqrt{4.45\ (.1613)}} = \frac{-1.13}{\sqrt{.7177}} = \frac{-1.13}{.847} = -1.335$$

Trousers #3

$$t = \frac{33.16 - 34.62}{\sqrt{27.36\ (.1613)}} = \frac{-1.42}{\sqrt{4.411}} = \frac{-1.42}{2.09} = -.679$$

Trousers #4

$$t = \frac{33.36 - 34.71}{\sqrt{3.40\ (.1613)}} = \frac{-1.35}{\sqrt{.549}} = \frac{-1.35}{.740} = -1.824$$

THERMAL INSULATION VALUES OF CERTAIN
MEN'S TROUSERS AS DETERMINED BY
THE USE OF A COPPER MANIKIN

by

CAROLE ANN NELSON

B. S., Valparaiso University, 1966

AN ABSTRACT OF A MASTER'S THESIS

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Manhattan, Kansas

1969

The objectives of this study were to determine clo values of the total assemblage of clothing and air using trousers of four different fiber contents as tested under a specified environmental condition using a copper manikin. Furthermore, the effects of fiber content, fabric construction (weave and yarn count), thickness, permeability to air and weight of the trouser fabric in relation to clo value of the total assemblage were analyzed.

Trousers of a style worn by men on the Kansas State University campus were chosen for the study. The trouser style selected was most available locally in four different fiber contents. One pair of trousers of each fiber content was chosen at random for testing. Physical tests (weight, thickness, permeability to air, yarn count) were conducted under American Society for Testing Materials standards. Clo values were determined for the clothing assemblage consisting of underwear, shirt, trousers and shoes using the copper manikin.

Results of testing showed the following clo values for the total assemblage at an eighteen degree difference in temperature between the manikin's surface and the air: 50% polyester/ 50% cotton 1.89; 65% polyester/ 35% cotton 1.86; 65% polyester/ 35% rayon 1.81; and 50% acrylic/ 35% rayon/ 15% acetate 1.91. Although the parameters of permeability to air, weight, thickness and yarn count are interrelated to give the total insulation value of clothing, permeability to air gave the best indication of the anticipated clo values in this study. The fiber content of the trousers had no effect on the clo value.