A QUANTITATIVE MEASURE OF THE THERMAL INSULATION VALUE OF CERTAIN ITEMS OF MEN'S WEAR

by

DELORES FRANCES FRANZ

B. S., Kansas State Teacher's College, Emporia, 1961

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

1966

Approved by:

Jessie A. Warden

Major Professor

ACKNOWLEDGMENTS

The writer would like to express her sincere appreciation to Dr. Jessie Warden, Head of Clothing and Textiles Department, for her encouragement and invaluable assistance in directing this investigation; to Miss Esther Cormany, Associate Professor of Clothing and Textiles, and Dr. Frederick Rohles, Associate Professor of Mechanical Engineering, for their helpful suggestions; and to Mr. Wayne Springer, Instructor in Mechanical Engineering, for his excellent guidance.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

Man possesses a complicated and elaborate mechanism of heat regulation in which a balance between thermogenesis and thermolysis must be maintained. This process is of vital importance to the physical, mental, and emotional health of the human body. Kleitman and Jackson (27) reported that a high correlation existed between the body's temperature and its physical and mental performances and that body temperature furnished a reliable method for estimating alertness and efficiency.

Of utmost importance to the body's maintenance of heat regulation is clothing. Rees (35) stated that the principal function of clothing in cold weather was "to slow down the rate at which man loses heat to his environment to a value which can be balanced by that generated within his body by metabolic processes." Consequently, if comfort is to be attained, the thermal qualities of clothing should be contemplated by the wearer.

The protective value of clothing is realized by consumers, but garments intended to provide warmth are often purchased on the basis of advertisements, hearsay, or general experience. The buyer has no objective means by which to determine the insulating qualities of a garment.

The first step toward objectivity of the regulatory function of clothing was made by Gagge, Burton, and Bazett (16). They found that thermal comfort depended on three primary factors: the temperature of the environment, the rate of body heat production, and the insulating value of clothing. The latter was defined in terms of "clo" which is, according to Newburgh (32):

> the clothing required to keep a resting subject in a comfortable state with a mean skin temperature of 92° F. in a room at 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.

The most successful physical device for testing clo values as reported by Fitzgerald (14) and Belding (4), is an electrically heated copper manikin. With this device, instrumental and dressing errors need not exceed 2 per cent. Schiefer et al. (39) stated, however, that it was impractical to measure the thermal resistance of thin materials, such as light underwear and dress fabrics, since the thermal resistance contributed by their fabrics may amount to only 10 to 20 per cent of that of the layer of still air.

Since previous research workers have defined the clo value and developed an effective instrument for its measurement, this study was designed to establish procedures for evaluating the insulation of clothing with the copper manikin. The purpose of this research was threefold: (1) to determine, under a specified environmental condition, the clo values of various items of clothing worn by college men; (2) to determine the clo values of additional layers of clothing; and (3) to analyze reasons for differences in the thermal resistance of clothing.

Although a considerable amount of research has been conducted on the thermal qualities of clothing in relation to temperature, humidity, and air movement, the major portion of this work was done at extremes of environmental conditions which would be encountered by the armed services and in isolated industrial situations. Innovations in textiles used for civilian clothing under less severe conditions indicate the importance of evaluating and comparing the improvements with a standard measure.

A universal acceptance of the clo value would be beneficial in directing the manufacturer's research program to improve winter clothing. After the measurement has been established, an educational program could be directed toward the consumer who would then have an objective method by which to judge the thermal qualities of clothing.

CHAPTER II

REVIEW OF THE LITERATURE

Many theories of why clothing is worn appear in the literature today. Considered to be one of the most important is the protective value of clothing to the body. Rees (35) stated that an average man when nude and at rest was comfortable at an ambient temperature of about 85° F. (30° C.). Below this temperature, clothing became a physiological necessity.

Physiological Aspects of the Comfort of the Human Body

The balance of maintaining and controlling a constant body temperature was found by Selle (40) to be of greatest significance to the body's economy and well-being. Black and Matthew (6), Cassie (9), and Rees (36) reported that the deep internal temperature of a healthy human body was about 98.6° F. (37° C.) and any appreciable variation from this temperature led to discomfort and in extreme cases to death.

In order to maintain a constant internal temperature, Hardy, Ballou, and Wetmore (19) stated that the body regulated the temperature of the skin by dilating or constricting blood vessels near the surface and by varying the amount of perspiration on the skin. When metabolism or ambient air temperature increased rapidly, or when extra clothing was worn, the normal state of dynamic equilibrium was upset and the body reacted by increasing the skin temperature or skin wetness, or both.

According to Hardy, Ballou, and Wetmore (19), about 10 per cent of heat produced by the body was carried away by warmed, exhaled breath and other bodily secretions. The other 90 per cent was dissipated from the surface of the skin by the physical processes of radiation, convection, conduction, and evaporation. Hardy (20) added that heat was transferred to the body by the same four methods, but evaporation was in the reverse direction, condensation, and occurred only under rare, extreme conditions.

Howell (25) defined radiation as:

> the transfer of heat from the surface of one object to that of another with which it is not in contact, by way of electromagnetic waves, similar in all respects to light waves and subject to interference, reflection, refraction, and polarization.

Selle (40) stated that since air was a poor conductor of heat, the human body, as a result of heat produced by metabolism, radiated energy through the air to living and inanimate bodies.

Convection, a form of heat transfer by currents of air and water, was defined by Selle (40) as:

> a simple mechanical process of mixing in which a cooler fluid or gas comes in contact with a warmer one, and, becoming heated by conduction, the gas or fluid rises and carries heat elsewhere.

The forcing of cool air over the body was found to reduce the temperature of the body.

Selle (40) defined conduction as "the transfer of heat from one molecule to another through gases, liquids, and solids by direct contact." The rate of transfer depended on the difference in temperature and on the thermal conductivity of the substance. The direction of heat transfer often tended to be in opposition to the need of the body; low air temperature cooled the body, while a high temperature prevented heat dissipation.

Evaporation, the changing of water to water vapor, was reported by Newburgh (32) to be the chief protective mechanism of the body against overheating. Selle (40) added that the process was dependent upon the fact that a certain amount of heat was needed to change a liquid to a gas. The loss of heat from the surface on which the change occurred caused a layer of cooler air to surround the body.

Physiological facts indicate that clothing must be designed so that the thermal exchanges between man and his environment are maintained at a comfortable rate under different conditions. Hardy, Ballou, and Wetmore (19) stated that heat dissipated from the skin must pass through the layers of clothing which normally surround the body.

Peirce and Rees (34) reported that at the outer surface of the clothing, heat was lost by convection and by radiation; the loss by conduction was of importance only when the clothing was in actual contact with a good thermal conductor. Belding et al. (5) stated that as sweat was normally vaporized from the skin, moisture was taken up chiefly by the outer layers of clothing. Responsible for this fact were the vapor pressure differences: the difference was large between the relatively warm inner layers and the relatively cool outer layers, while the difference between the outer layers and the cool environment was small.

Description of Thermal Measurements

The thermal conductivity or insulating ability of a fabric must be separated from the warmth of a human subject. Kaswell (26) reported that warmth was a physiological and psychological measure definable in terms of body comfort. "It was a sensation," he stated, "produced by the interaction of several physical criteria: thermal conductivity, convection, radiation, moisture transfer, air transfer, and fabric texture (smoothness or roughness in terms of the amount of textile in contact with the skin)."

Various terms were used to define thermal insulation and warmth properties. As defined by Gagge, Burton, and Bazett (16) thermal insulation was the resistance offered to the flow of heat.

M. C. Marsh (29) emphasized that when considering end-use, thermal conductivity alone was not a true criterion of thermal insulation ability. He used the term Thermal Insulation Value (T.I.V.). Baxter and Cassie (3) defined T.I.V. as "the per cent saving in heat loss from the surface due to covering it with a fabric." T.I.V.'s were discussed in terms of fabric thickness, thermal conductivity, and surface emissivity.

Gagge, Burton, and Bazett (16) used the clo as a measurable unit of insulation. Newburgh (32) defined the clo as:

> the amount of insulation necessary to maintain comfort and a mean skin temperature of 92° F. in a room at 70° F. with air movement not over 10 feet per minute, humidity not over 50 per cent, with a metabolism of 50 calories per square meter per hour.

Moncrieff (31) described the clo as "a measure of the resistance offered by the clothing to the flow of heat out from the body to the air." He stated that one clo was that value of the insulation of one's everyday clothing and of a heavy top coat alone.

To calculate the clo value of clothing on a copper manikin, Breckenridge (7) used the following expression:

$$\text{Clo} = \frac{3.09\ (Ts - Ta)\ A}{P \times 0.86}$$

where Ts was the average surface temperature in degrees F., Ta was the ambient temperature in degrees F., A was the surface area of the manikin in square meters, and P was the average power to the heating elements in watts.

Niven (33) stated that if the skin temperature was 92° F., one was led to the conclusion that one clo was needed for every 22° F. that the air temperature was below 92° F. The ideal amount of clothing, expressed in clo value, necessary for comfort for various degrees of rest and exercise in different outdoor environmental temperatures was predicted by Gagge, Burton, and Bazett (16) and is shown in Appendix A, page 51.

Garner (18) agreed with the convenience of expressing insulation in terms of clo values, but he emphasized that the thermal resistance value for comfortable clothing was modified greatly by the degree of activity of the subject, the air speed at the surface of the clothing, the evaporation properties of the surface for moisture, the transmissive powers of the clothing for evaporated perspiration, and the reflective power of the surface for heat rays.

Although Gagge, Burton, and Bazett (16) did not completely overlook heat lost by evaporation, the factor was not treated quantitatively in the clo formula. Quite recently Woodcock (46) extended the formula to include heat losses from sweat evaporation. His moisture permeability index described the efficiency of a fabric to transfer moisture from the skin to the ambient air. Moncrieff (31) stated that Woodcock's basic concept was attractive, but its practical development required additional work.

Factors Which Influence Thermal Insulation

Kaswell (26) reported that the thermal insulation of a fabric was substantially independent of inherent properties of the fibers. Likewise, J. T. Marsh (28) stated that textile fibers in themselves possessed no great insulating powers and M. C. Marsh (29) reported the difficulty of comparing relative values of different fibers for thermal insulation. In a study by Werden, Fahnestock, and Galbraith (45), no significant differences were found among the fiber types in relation to thermal comfort of clothing.

Thickness and Weight Per Unit Area

M. C. Marsh (29) studied the thermal insulation value, weight, thickness, and air permeability of fabrics. He concluded that the chief factor determining the T.I.V. of a fabric was its thickness, the thickness excluding the projecting fibers. "From this work it is believed that it would be possible to make a fabric of a given insulating value from any of the textile materials. It would only be necessary to make it sufficiently thick and of close structure."

Research by Schiefer et al. (39) substantiated the fact that the relationship of thermal transmission to thickness was linear. Rees (36), who tested cotton, wool, cotton and wool mixtures, rayon, rayon mixtures, silk, linen, casein, wool and casein, and kapok, also found that thermal insulation of a fabric was dependent upon its thickness, irrespective of the type of fiber used.

Almost no correlation between T.I.V. and weight per unit area was found in studies by M. C. Marsh (29) and Baxter and Cassie (3). Rees (37) found a very low correlation for heat loss vs. weight per unit area, but he stated, however, that heavier samples are generally warmer because such samples are usually also thicker.

Fabric Density

Several writers reported that the state of aggregation of the fibers in the fabric structure was of utmost importance in thermal transmission. Kaswell (26) commented that as long as requisite thickness was attained, concomitant insulation would result, but the ability to maintain that thickness under normal use conditions must be considered.

Two fabrics may have the same thickness and thermal conductivity, but because of different bulk densities, different amounts of fiber may have to be used to construct the fabrics. Kaswell (26) reported that aggregates of different fibers may have different bulk densities so that one fiber may exhibit advantage over another on a weight basis within a fabric structure.

Speakman and Chamberlain (42) compared fabrics composed of materials other than wool with all-wool fabrics of equal weight and thickness. They concluded that the wool fiber was inherently a better insulator than other fibers. However, work published since their study was conducted does not agree with their findings. Kaswell (26) concluded that any advantage of wool as a thermal insulator came from its ability to maintain a given state of aggregation under end-use conditions. Similar statements were made by J. T. Marsh (28), Schiefer (38), and Skinkle (41).

Baxter and Cassie (3) showed that for a material of a given weight, the maximum T.I.V. was obtained by making the bulk density as small as possible. Cassie (10) noted that the irregularity of natural fibers prevented the spinning of densely packed yarns; the uniformity of man-made fibers gave a dense yarn with little entrapped air and little warmth.

Air Movement and Wind Velocity

Rees (37) studied the effect of wind velocity on the heat loss of fabrics. He found that, at higher wind speeds, air was circulated in the interstices of loosely woven fabrics, resulting in greater heat loss.

The conclusion that fabric structure, not fiber property, controlled the effect of air on thermal transmission was made in other studies. Cassie (9) pointed out that warmth was due, in part, to thermal insulation which in turn was dependent upon entrapped air at rest. He stated that:

> Fibres cannot entrap air in cells or in closed small spaces within a fabric. They entrap air because air clings to a solid surface, and fibres have enormous total surfaces. A fabric composed of thousands of fibres forms a 'wind break' because air clings to the fibres, thus bringing the air to rest. . . . When we say that fabrics entrap air, we really mean that their fibres impose a drag on air movement.

Hoge and Fonseca (23) and Hollies and Bogaty (24) agreed that a layer of fabric tended to immobilize a layer of air and that the thermal conductivity of this layer of air offered resistance to heat flow. Estimations by Newburgh (32) showed that, with low rates of air movement, clothing which was close to the skin could lie within the still air zone which would be present even without clothing.

Breckenridge and Woodcock (8) indicated that the insulation provided by cold-weather clothing assemblies was markedly reduced under windy conditions. There was an 18 per cent reduction in clo value of an Army Arctic uniform when the wind speed was increased from 3 mph to 14 mph. The rate of insulation reduction appeared to be influenced by the design characteristics as well as by the materials used in an assembly. Angus (2) found a great loss of warmth retention in wind as a result of excessive wear in a comparison of new and worn clothing.

After a wind penetration study, Fonseca and Breckenridge (15) reported that two moderately air permeable windbreaks with a space between them could provide protection from wind penetration equal to or greater than a single windbreak of low permeability. Another possible benefit of the double construction, they stated, was that with air circulating over the inner windbreak, evaporated sweat would be less likely to condense in the outer layers. Newburgh (32) reported that air layers approached their optimum insulating efficiency at a thickness of one-quarter inch; greater widths of air space caused the development of small convective currents which decreased the insulation value of the clothing assembly.

Moisture Content

Black and Matthew (6) measured the thermal insulation of wool, cotton, and linen fabrics at different moisture contents. They observed a marked reduction in thermal insulation as the moisture content increased from 0 to 75 per cent of the dry weight. However, they stated that the relative permeability of clothing materials to moisture was of little importance in regard to ventilation compared with the openings in clothes and their general construction. Clayton (12), testing preconditioned samples of canvas, found that the air permeability of fabrics was increased six fold on reducing the relative humidity from 97 to 3 per cent.

In a study of the thermal insulation of a cotton and a wool blanket of equal weight and thickness, Schiefer (38) found that after 100 per cent water was added to each blanket, the thermal insulation decreased. The total decrease was greater for cotton than for wool because it decreased appreciably in thickness upon the addition of water. After a correction was made for the decrease in thickness, the decrease in thermal insulation was exactly the same for wool and cotton.

In an experiment with napped fabrics, Hollies and Bogaty (24) exposed one napped face to a cold plate and another to a warm plate. They found that as long as the napped surface was kept warm, the conductivity remained relatively low even up to 49 per cent added moisture. If the nap was allowed to cool and moisture condensed in that region, the conductivity increased very markedly with increase in moisture content. These results are consistent with the practice of placing the napped surface of a fabric towards the body in a cold weather garment.

Cassie (11) pointed out that the absorption of water vapor by the fibers was accompanied by a large evolution of heat, so that exchange of water vapor between the fibers and their surrounding air also involved large heat exchanges. This amount of heat gave protection against the chill of the sudden temperature change, provided it was liberated at a suitable rate. If the absorbed water gave surface wetting of the fibers, the degree of protection was decreased.

Galbraith et al. (17) reported the effect of wearing suits made of cotton, water repellent cotton and Orlon acrylic fabrics of similar construction under hot, humid conditions. In no case did either the fiber content or the water repellent treatment affect the physiological thermal comfort measurements used in this study.

Werden, Fahnestock and Galbraith (44) found humidity did not greatly affect the comfort votes at lower temperatures. At higher temperatures, however, the subjects indicated that they felt more discomfort when the humidity was raised from 40 to 80 per cent.

Emissivity

Cleveland (13) commented that thermal conductivity alone was not a sufficient measure of the thermal transmission of fabrics. The insulating power of the fabric depended to some extent upon its surface emissivity. This, in turn, as reported by Meredith (30), was a combination of two processes, heat transfer to the surrounding air and radiation losses.

Baxter and Cassie (3) found that when clothing was composed of several layers of fabric with air space between them, the overall conductivity depended on the transfer of heat from one fabric to another; clothing with low heat loss was made from fabrics with low surface emissivities. They noted that:

> Heat transfer by radiation will depend upon the radiation properties of the fibres composing the fabric and on the colour of the fabric. Transfer by convection will depend on the roughness of the fabric surface.

"Metal-coated" lining fabrics were designed to reflect the radiant energy emanating from the body back towards the body. Herrington (21) cautioned against the assumption that any shiny surfaced material would provide the same reflective insulation for dark or invisible infra-red radiation as opposed to visible, high temperature radiation. Under different circumstances, aluminum happened to be effective for both types of radiation. It was stated by Herrington that it was unsafe to estimate the long infra-red reflecting character of an aluminized fabric by its visible appearance. He advocated the use of technical measurements of reflectance as the only method for determining the value of such fabrics for insulation uses.

Baxter and Cassie (3) calculated that the saving in heat loss obtained by using reflecting outer surfaces in cold weather was too small to be of practical value. Some value was attained when the air was completely still.

J. T. Marsh (28) commented that most people referred to fabrics as being warm or cold as a result of the immediate sensation on contact with the skin. This initial sensation should not be confused with the thermal insulation value of the fabric, but surface emissivity does affect the hand.

Baxter and Cassie (3) compared a rough surface wool blanket of low surface emissivity to a relatively smooth all-wool serge fabric. They concluded the following:

> Smooth surfaced fabrics with their relatively large surface emissivities will give good heat transfer from fabric to fabric and presumably from skin to fabric; they will thus give clothing of large heat transfer even though the individual fabrics have the same thermal conductivity and thickness as fabrics with surface cover. Smooth surfaced fabrics are thus likely to be regarded as 'cold' fabrics, whilst those with surface cover will be regarded as 'warm.'

Rees (36) observed the differences in the "cold feel" of fabrics by noting the drop in temperature of a hot plate when the fabric was brought into contact with it. He found the temperature varied markedly in different fabrics. Wool and cotton blankets showed no chill effect, whereas the chill effect was quite marked with a smooth bleached cotton cloth.

Hock, Sookne, and Harris (22) reported on the "chilling effect" or "clamminess" of moist fabrics in contact with the skin. Their tests showed that the intensity of the sensation varied with different fibers and fabrics, but warmth was not dependent upon fiber or fabric thermal conductivity per se. Fabrics which produced considerable chilling in subjective tests were found to make good contact and to cause a substantial drop in skin temperature. The converse of the preceding statement was also true. Spun wool and cotton fabrics were superior to continuous filament acetate, viscose, and nylon. Because of differences in yarn construction, no absolute conclusions concerning these fabrics could be made. However, results showed that special types of construction, especially napped or fuzzy surfaces, reduced the contact appreciably and thereby lessened the chilling effect.

J. T. Marsh (28) stated that the nature of the weave was important in determining the immediate sensation of warmth or coldness. There was a slow increase in the coldness of fabrics with increase in the closeness of the weave; this was due to the fact that more fibers per unit area made contact with the skin. The plain weave with the maximum number of intersections gave the coolest fabrics, and warmer materials were produced in twill and crepe constructions.

Physical Methods For Evaluating Thermal Insulation

A simple physical measure used for determining the thermal transmission of fabrics was called the disc or plate method. Using this method, Rees (37) positioned a selected fabric between two plates at different temperatures and measured the rate of heat flow through the fabric. Skinkle (41) warned against the danger of committing a serious error in determining thermal transmission with this method because the degree of pressure exerted on the fabric altered its propeties.

A cooling method for measuring thermal transmission was utilized when a warm vessel was wrapped with a selected fabric and the time required for the cylinder to cool a given number of degrees was measured. Black and Matthew (6) used this method in the form of a kata-thermometer, an alcohol thermometer with a cylindrical bulb. In their experiment, the cloth was made into a cylinder by wrapping it over a wooden form. The entire apparatus was placed into an enclosure where the temperature was constant and the time of cooling from 100° F. to 95° F. was noted with and without the fabric.

A constant temperature method was used by Angus (1) in comparing thermal insulating values of fabrics. A tank was wrapped with the fabric to be tested and the amount of energy required to maintain a fixed temperature was determined.

Belding (4) stated that the most successful physical device for testing insulation of clothing, as contrasted to textile materials, has proved to be an electrically heated copper form. After a study of the copper manikin, Fitzgerald (14) concluded that the relative merits of several fabric types could be established by use of a cylinder or flat plate, but the copper manikin was far superior in evaluating complete uniforms.

Breckenridge (7) described a very early model of a manikin. It was constructed of stovepipes of various diameters. Heat was generated by a central light bulb and distributed to all surfaces by a fan in the torso. Present day manikins consist of blackened copper shells resembling the human body both geometrically and thermally.

The copper manikin can be used advantageously in measuring thermal transmission. However, as with all physical apparatus, this device has certain limitations.

Breckenridge (7) reported that relationships describing heat losses by conduction, convection, and radiation were the same for the copper manikin and the human body. However, because the manikin did not perspire, it was difficult to assess the vapor transfer characteristics of the clothing.

By Newton's Law of Cooling, the heat loss through a given insulation per unit of temperature difference is constant as is the reciprocal, insulating value. Breckenridge (7) stated that numerous studies validated this constancy for clothed surfaces so that it was possible to use any convenient operating temperature for the copper manikin in conjunction with any reasonable ambient temperature.

It is believed by Breckenridge (7) that the insulating values obtained with a heated manikin were not strictly correct for a resting man, and certainly not correct for an active man whose body movements reduced insulation. For this reason the copper manikin was reported to be most useful in tests where comparative values were studied.

CHAPTER III

METHOD OF PROCEDURE

This study, the first at Kansas State University to utilize the copper manikin, was designed to establish procedures. The description of the apparatus and test clothing is followed by the start-up and test procedures.

Apparatus

Copper Manikin

A copper manikin was the physical device used to determine the thermal insulation, or clo value, of the clothing. The structure had a shell approximately one-eighth inch thick of electroplated copper which had been blackened by oxidation to equal the emissivity characteristics of the human skin.

The anthropomorphic structure was about 5 feet 10 inches high and weighed, with equipment, approximately 80 pounds. To support the figure vertically without adding extraneous insulation, a stand had been constructed whereby a removable metal frame supported the head.

The following construction details facilitated clothing the copper manikin: (1) The manikin could be raised from the base by a pulley secured to a supporting rod. (2) The arms could be rotated slightly to the rear. (3) The cables carrying power to the manikin and others used to control and measure temperature were brought out through the neck area.

Heating elements were positioned on the inside surface of the copper shell. In order to more nearly duplicate the temperature pattern of the human body, three circuits were utilized: (1) a main, series circuit covering the entire manikin except for the hand distally from the wrist and the feet distally from the ankle; (2) a parallel circuit for the hands; and (3) a parallel circuit for the feet. The temperature of the hands and feet could be changed independently by adjusting the rheostats located in the upper sternal region and frontal abdominal region respectively.

The surface temperature was controlled electronically by six thermistor sensors located in the shell. To measure the temperature, sixteen thermocouples were distributed over the surface. (Exact positions of the thermocouples are shown in Appendix B, page 53). The thermocouples were fed into a switch; the common terminals of the switch were connected to a potentiometer which determined the electromotive force generated by the thermocouples. An ice bath constituted the reference junction.

Test Chamber

The tests were conducted in a room where environmental conditions were controlled. The relative humidity was 65 $\pm$ 2 per cent and the ambient air temperature was 70° F. $\pm$ 2.

Clothing

In selecting clothing for the research project, present day "wearer acceptability" was considered. After a discussion with local merchants, clothing worn by college men in the area was selected. Sizes of clothing used for the copper manikin are given in Appendix C, page 55.

Basic Set

A set of clothing remained on the manikin throughout the testing period and was, therefore, labeled the "basic set." (Figure 1, page 24). This basic set included:

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	Poly Vinyl sole and heel molded to leather

Sweater

The yarns used in the sweater were described as 100 per cent imported Kiama-Cape Lambs' Wool. The construction details were as follows: V-neck and long sleeves with three-fourths inch cuffs. (Figure 2, page 26).

Jackets

Three "windbreakers" were chosen for the study. The following details were similar in all three jackets: unlined, attached hood with drawstring, set-in sleeves, elastic cuffs, slash pockets, drawstring

FIGURE 1

Plate Showing Basic Set of Clothing

Evaluated on the Copper Manikin

FIGURE 1

FIGURE 2

Plate Showing Sweater Evaluated

on the Copper Manikin

FIGURE 2

at hips, 27 inches in length, zipper front, similar thickness. (Figure 3, page 29). Table I summarizes the differences in jackets.

TABLE I

DESCRIPTION OF JACKETS

		Jacket 1	Jacket 2	Jacket 3
Shell		100% nylon	100% nylon coated with modified urethane on outside (Nylothane)	100% nylon coated with modified urethane on inside (K-Kote)
Color		Black	Blue	Black
Price		$4.99	$5.99	$8.95
Thread count	warp	106	105	105
	filling	88	82	90

All clothing was placed in the conditioning room 24 hours before tests were begun. The clo values were determined for the following clothing assemblies:

1. Basic set
2. Basic set and sweater
3. Basic set and jacket with hood
4. Basic set and jacket without hood
5. Basic set, sweater, and jacket with hood
6. Basic set, sweater, and jacket without hood

Procedure

Start Up Procedure

The following procedure as suggested by Springer (43), was developed to heat the manikin:

FIGURE 3

Plate Showing Jacket Evaluated

on the Copper Manikin

FIGURE 3

a. Connect thermal converter as shown in the schematic in Appendix D, page 57.

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 "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." and select chart speed. For this study, the chart speed was 10 minutes per inch during heating period.

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

i. Connect temperature sensing lead from manikin to proportional controller (Labeled #5--one-fourth inch standard phone plug).

j. Set proportional temperature controls to desired setting. For this study, these controls were set at 40° C. (Temperature of 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 $.5^{\circ}$ C. for this study. Insure power switch is "off."

l. Connect proportional controller power lead to 110 Vac, 60 cycle, 1 phase.

---

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

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 should move to about 85 per cent of full scale (approximately 340 watts) while the manikin "warms up." When the desired temperature is reached, the power requirements will drop to less than fifty per cent of the "warm-up" power. At this time, the span selector may be positioned to the 10 mv setting (200 watts for 100 per cent scale deflection).

Test Procedure

a. Adjust the clothing assembly before the start of each test to counteract the tendency of clothing to settle on the manikin.

b. Permit the heating system to stabilize. If necessary, make adjustments of temperature controls. After final adjustments, tests should be delayed for approximately one-half hour; heavier clothing will require a longer waiting period for the manikin and clothing to come into equilibrium.

c. Make test observations. Collect the following data for each test:

(1) Temperature of the surface area. Thermocouples are read on the potentiometer and recorded according to the code illustrated in Appendix B, page 53. Readings from the potentiometer in use at the present time are expressed in millivolts which are then converted to ^{o}Fahrenheit by a Leeds and Northrup Table. (Inconsistant readings from the thermocouples will be reported if the reference junction, an ice bath, is not kept in the same condition throughout testing.) The average surface temperature of the manikin is calculated by determining the mean value of measurements. For this study, readings from the hands were omitted.

(2) Ambient temperature. Three thermocouples are placed near the upper, middle and lower portions of the manikin to measure the temperature of the immediate surroundings. The three millivolt readings are converted to ^{o}Fahrenheit and averaged to obtain the mean ambient temperature.

(3) Voltage input to the heating circuits. The span of time for each testing period must be marked on the chart of the recorder. Within the marks, readings of the watts supplied to the manikin are taken at various intervals to obtain the average power. The calculated number is taken times 200 if the recorder span knob is set at 10 mv.

d. Make necessary calculations according to the following formula:

$$Clo = \frac{3.09\ (Ts - Ta)\ A}{P \times 0.86}$$

where Ts is the average surface temperature in degrees F., Ta is the ambient temperature in degrees F., A is the surface area of the manikin in square meters (1.795), and P is the average power to the heating elements in watts.

e. Repeat the test procedure as a check on the results of the first test.

CHAPTER IV

RESULTS AND DISCUSSION

Since this research was designed to establish procedures for operating the copper manikin, preliminary investigations were made under various environmental conditions. It was known that thermal insulation was affected by relative humidity, but the difference it would make in determining the clo value was not known.

The copper manikin, wearing the "basic set" of clothing, was placed in a test chamber where adjustments in temperature and relative humidity could be made. Results of the experiment are summarized in Table II.

TABLE II

EFFECT OF CHANGES IN RELATIVE HUMIDITY ON CLO VALUES

Test number	Relative humidity	Ambient air temperature	Manikin surface temperature	Clo value
1	16%	73.2° F.	92.96° F.	1.274
2	29%	72.7° F.	92.01° F.	1.297
3	87%	72.6° F.	91.40° F.	1.347

It can be noted that the ambient air temperature and manikin surface temperature varied only slightly throughout the three testing periods. With the temperature nearly constant, the relative humidity was increased from 16 per cent to 87 per cent in three separate testing periods. With the increase in relative humidity, there was also an increase in clo value from 1.274 to 1.347.

Tests with controlled percentages of relative humidity and a lower ambient air temperature were not successful. Therefore, it is not known whether a similar increase in clo value would occur with increased humidity at lower air temperatures.

The absorption of water by hygroscopic textile materials is accompanied by an evolution of heat. Rees (36) stated that the amount of heat evolved depended upon four factors: (1) the nature of the textile material; (2) the moisture regain of the material before absorption commenced; (3) the amount of water absorbed; and (4) whether the water was absorbed from the liquid or from the vapour phase. Since the basic set of clothing tested on the manikin was primarily cotton, a hygroscopic fabric, it is logical to believe that water absorbed by the fiber when the relative humidity was increased caused a liberation of heat to give more protection.

The second test chamber in which the copper manikin was placed had the following variations in environmental conditions: ambient air temperature ranged from 37.0° F. to 40.5° F. and relative humidity ranged from 62 per cent to 75 per cent. A ceiling fan circulated the air. Under these conditions, it was found that the clo values could not be calculated accurately because the power input to the manikin was inconsistent.

The next series of tests were conducted in a test chamber where the relative humidity was 65 ± 2 per cent and the ambient air temperature was approximately 70° F. Using the basic set of clothing, tests were made and controls were adjusted until similar readings were obtained for the clo value calculations.

From this experimentation, it was apparent that the condition of the ice bath which served as a reference junction for the thermocouples was an important factor affecting the consistency of temperature readings. The ice bath should not be allowed to melt to a point where the temperature is above 32.0° F.

A slight variation in ambient air temperature was another factor found to influence the clo value calculations. To establish more accuracy in determining the insulation value of the clothing, three thermocouples were placed at different heights near the manikin. Temperatures read from the thermocouples were averaged for each individual test. Throughout the testing period, a variation of 67.5° F. to 69.2° F. was found.

To calculate the clo value, the average surface temperature of the manikin is needed. This value may be found by two methods: (1) by averaging temperature readings from the 16 thermocouples, or (2) by finding the weighted mean. To compare the differences between the methods, one set of pretest readings was selected at random. According to Newburgh (32), the weighted mean is determined by using the following proportions: feet 7 per cent, lower leg 13 per cent, upper leg 19 per cent, trunk 35 per cent, arms 14 per cent, hands 5 per cent, head 7 per cent. The average surface temperature for this particular test was found to be 93.8° F. for the arithmetic mean calculation and 93.94° F. for the weighted mean calculation. Since the difference was small, the average surface temperatures for the following tests were not weighted.

Table III, page 37, gives the description and data for the tests conducted after procedures were established. If results for the first two tests were inconsistent, additional readings were taken until two consecutive tests showed similarities. The information shown in the table is for the last two tests made for each change of clothing.

The effect of multiple layers of clothing is shown in Figure 4, page 38. As would be expected, the addition of successive layers increased the clo value. The combination of sweater and jacket was more effective in retaining heat than either alone.

In Figure 4, page 38, it can also be seen that the thermal insulation value of the wool sweater worn over the basic set was slightly lower than that for the nylon jackets when worn over the same basic set of clothing. However, it is unsafe to generalize about the warmth of certain fibers because of the many factors, such as equal thickness and density of yarns and fabric, influencing thermal insulation.

From this exploratory study, general trends in clo values may be observed, such as those in Figure 4, page 38. However, when analyzing the clo values to three decimal points, it is apparent that one or more unknown variables existed.

The three nylon jackets tested were similar in most respects; the major difference was in the finishing. Jacket 1 was 100 per cent nylon, Jacket 2 was 100 per cent nylon with an outside coating of

TABLE III

DATA FOR CLO DETERMINATION

Description and Clothing Used For Each Test	Test No.	Average Surface T. °F.	Average Ambient T. °F.	Surface T. minus Air T. °F.	Electrical Input W.	Insulation Clo
Basic	1	94.6	68.9	25.7	116.8	1.419
	2	94.6	68.3	26.3	117.2	1.447
Basic and Sweater	1	92.1	68.5	23.6	98.8	1.540
	2	92.0	68.2	23.8	99.0	1.550
Basic and Jacket 1 - with hood	1	93.0	68.9	24.1	95.8	1.622
	2	93.0	68.5	24.5	95.2	1.659
Basic and Jacket 1 - without hood	1	92.4	68.1	24.3	100.2	1.564
	2	92.4	68.2	24.2	99.5	1.568
Basic, Sweater and Jacket 1 - with hood	1	92.6	68.8	23.8	85.6	1.793
	2	92.5	68.9	23.6	85.6	1.778
Basic, Sweater and Jacket 1 - without hood	1	91.4	68.3	23.1	88.2	1.689
	2	91.2	68.2	23.0	88.8	1.670
Basic and Jacket 2 - with hood	1	93.3	69.0	24.3	97.0	1.615
	2	93.2	68.8	24.4	96.4	1.632
Basic and Jacket 2 - without hood	1	93.3	69.1	24.2	97.8	1.596
	2	93.5	69.2	24.3	97.0	1.615
Basic, Sweater and Jacket 2 - with hood	1	91.7	68.9	22.8	83.8	1.754
	2	91.8	68.8	23.0	84.0	1.765
Basic, Sweater and Jacket 2 - without hood	1	91.0	68.1	22.9	86.2	1.713
	2	90.8	68.2	22.6	86.2	1.690
Basic and Jacket 3 - with hood	1	92.1	68.0	24.1	100.0	1.554
	2	91.9	67.5	24.4	99.4	1.583
Basic and Jacket 3 - without hood	1	93.6	69.0	24.6	100.0	1.586
	2	93.4	68.9	24.5	100.0	1.580
Basic, Sweater and Jacket 3 - with hood	1	92.6	69.1	23.5	84.6	1.791
	2	92.7	69.2	23.5	84.4	1.795
Basic, Sweater and Jacket 3 - without hood	1	91.9	68.8	23.1	87.8	1.696
	2	91.8	68.6	23.2	86.2	1.736

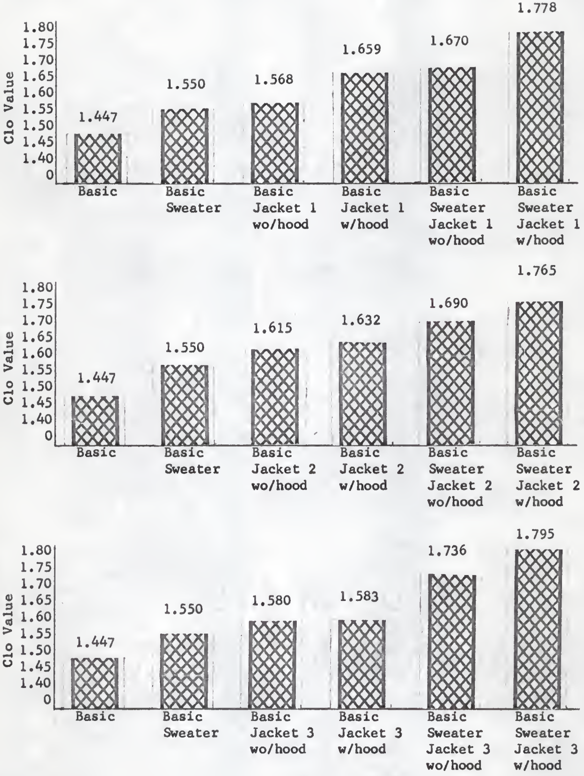


FIGURE 4

EFFECT OF MULTIPLE LAYERS OF CLOTHING ON THE CLO VALUE modified urethane and Jacket 3 was 100 per cent nylon with an inside coating of modified urethane. Table IV, page 40, shows that the data are unsuitable for comparisons to be made between jackets on the basis of their calculated clo values. It seems logical to believe that one jacket should receive the same rating throughout the four tests listed. However, when the jackets and hoods were worn over the basic set of clothing, Jacket 1 had the highest clo value, followed by Jackets 2 and 3 in that order. When the hood was removed, the order changed to the following: Jacket 2 rated highest, Jacket 3 had the middle rating, and Jacket 1 rated lowest.

When the sweater was placed underneath the jacket, the clo values for Jacket 3 were highest both with and without the hood. The second and third ratings alternated between Jackets 1 and 2. The discrepancies may be accountable to variations in procedures used to dress the manikin.

Figure 5, page 41, shows a comparison of clo values for jackets worn with and without hoods. The insulation value in all cases was higher when hoods were worn, compared to when they were not worn. The graph shows that Jacket 1 (100 per cent nylon), both with and without the sweater, had the largest increase in clo value when the hood was added. Jacket 2 (100 per cent nylon with an outside coating of modified urethane) had the second highest increase in clo value with the addition of the hood. The lowest increase was for Jacket 3 (100 per cent nylon with an inside coating of modified urethane).

Although general trends for jackets worn with and without hoods are observable, Figure 5, page 41, shows that the per cent increase for

TABLE IV

COMPARISON OF JACKETS ON VARIOUS TESTS

Clothing Variations on Manikin	Clo Value Rating: Highest	Middle	Lowest
Jacket 1			
With hood	X		
Without hood			X
Sweater with hood		X	
Sweater without hood			X
Jacket 2			
With hood		X	
Without hood	X		
Sweater with hood			X
Sweater without hood		X	
Jacket 3			
With hood			X
Without hood		X	
Sweater with hood	X		
Sweater without hood	X		

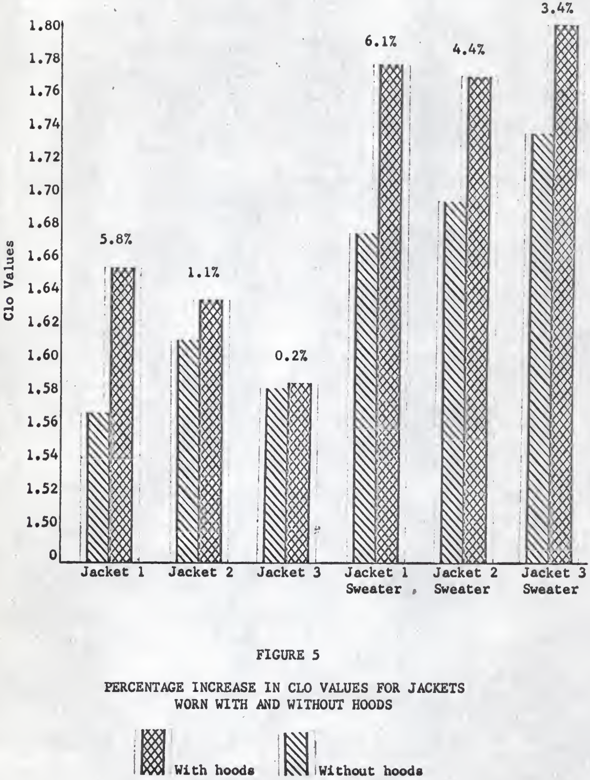


FIGURE 5

PERCENTAGE INCREASE IN CLO VALUES FOR JACKETS WORN WITH AND WITHOUT HOODS

Jackets 2 and 3 worn without the sweater are low. It is believed that the tightness of the drawstring around the hood may have accounted for this difference.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

This study was exploratory in nature and was designed to establish procedures for operating the copper manikin, an anthropomorphic structure heated electrically to equal the skin temperature of the human body. Three test chambers were utilized to determine that variations in environmental conditions affected the clo value, the unit of thermal insulation calculated for the tests.

To determine the clo value, the following formula was used:

$$\text{Clo} = \frac{3.09\ (Ts - Ta)\ A}{P \times 0.86}$$

where Ts was the average surface temperature in degrees F., Ta was the ambient temperature in degrees F., A was the surface area of the manikin in square meters (1.795), and P was the average power to the heating elements in watts.

A room in which the relative humidity was 65 $\pm$ 2 per cent and the ambient air temperature ranged from 67.5° F. to 69.2° F. was used to determine the clo values for men's clothing. A basic set of clothing was used under all garments tested and consisted of underclothes, shirt, trousers, shoes and socks. Added to the basic set in various combinations were a 100 per cent wool sweater and 100 per cent nylon jackets with the following variations in finishes: (1) no special finish (2) coat of modified urethane on outside of garment; and (3) coat of modified urethane on inside of garment.

Thermal 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 a definite set of circumstances. The calculations for this study showed that the clo values for the 100 per cent wool sweater worn over the basic set of clothing was slightly lower than that for any nylon jacket worn over the basic set. The combination of the sweater and jacket was more effective in retaining heat than either alone. An upward trend in clo values was also apparent when the hoods on the jackets were placed on the head of the manikin.

Although some general trends may be observed in these experimentations, a detailed analysis of the data shows inconsistencies which may be attributable to one or more unknown variables. One possible explanation for the discrepancies may be that different procedures were used when dressing the manikin. It is known that clothing "traps" a layer of air between the fabric and the body; therefore, the calculated clo value is actually a measure of the resistance offered to the body by the textile substance and entrapped air. Newburgh (32) stated that "the dead air layers, so essential to the efficiency of clothing, can easily be destroyed if the fabric layers are pressed together."

The jackets used in the tests had elastic at the cuffs and a drawstring at the hips, both of which gave a slight ballooning effect. The amount of air space between the basic set of clothing and the jacket could have varied enough from test to test to make a difference in the calculation of clo values since one-fortieth inch of air is equal to approximately 0.1 clo. Not only does clothing tend to settle after being placed on a body, but the tightness of the drawstrings around the hood and hips may have allowed different amounts of air to escape.

It is now apparent that, even though basic operational procedures have been established, extreme caution should be taken to use a consistent method in dressing the manikin. Future research should develop this procedure before comparative studies are conducted.

For this basic research, it was decided to choose jackets which were similar in many respects. In order to detect differences, however, clo values were calculated to three decimal places. Because some allowance must be made for experimental errors, it would be desirable to learn whether the clo value is a measure which shows an actual difference when calculated to this degree of accuracy.

It is known that environmental conditions have an important effect on the thermal insulation of a garment. With an ambient air temperature of approximately 73° F., this investigation showed that the clo value increased when the relative humidity was changed from 12 to 87 per cent. Further research should be conducted under various percentages of relative humidity: (1) to determine if the clo value increases when the ambient air temperature is low; and (2) to determine whether the clo value is stable or whether the increase noted in this study was an initial reaction due to added moisture.

Before further study is done on thermal insulation, it is suggested that the air movement in the test chamber be measured near the manikin. After refining basic procedures, provision should be made to conduct research under various degrees of wind velocity and ambient air temperatures.

SELECTED BIBLIOGRAPHY

1. Angus, T. C. "Heat Retaining Properties of Clothing, Computed on a Physiological Basis," Journal of the Textile Institute, XXVI (February, 1935), T83-T86.

2. ________. "The Heat Retaining Properties of Clothing Computed on a Physiological Basis," Part II, Journal of the Textile Institute, XXVII (November, 1936), T273-T284.

3. Baxter, S. and A. B. D. Cassie. "Thermal Insulating Properties of Clothing," Journal of the Textile Institute, XXXIV (July, 1943), T41-T54.

4. Belding, H. S. "Protection Against Dry Cold," Chapter II in L. H. Newburgh's Physiology of Heat Regulation and the Science of Clothing. Philadelphia: W. B. Saunders Company, 1949.

5. Belding, H. S., H. D. Russell, R. C. Darling, and G. E. Folk. "Thermal Responses and Efficiency of Sweating When Men Are Dressed in Arctic Clothing and Exposed to Extreme Cold," American Journal of Physiology, CXLIX (April 1, 1947), 204-222.

6. Black, C. P. and J. A. Matthew. "Physical Properties of Fabrics in Relation to Clothing," Journal of the Textile Institute, XXV (June, 1934), T197-T276.

7. Breckenridge, J. R. "Copper Man Facts." Natick, Massachusetts: U. S. Army Institute of Environmental Medicine, 1964. (mimeographed)

8. Breckenridge, J. R. and Alan H. Woodcock. Effects of Wind on Insulation of Arctic Clothing. Office of the Quartermaster General, Department of the Army, Report No. 164. Massachusetts: Quartermaster Climatic Research Laboratory, July, 1950.

9. Cassie, A. B. D. "Characteristics for Warmth in Underwear Fabrics," Journal of the Textile Institute, XL (May, 1949), P444-P453.

10. ________. "Natural Fibers vs. Man Made Fibers," Journal of the Textile Institute, XXXVII (December, 1946), P556-P568.

11. ________. "Physical Properties of Fibres and Textile Performances," Journal of the Textile Institute, XXXVII (July, 1946), P154-P167.

12. Clayton, Frederick H. "The Measurement of the Air Permeability of Fabrics," Journal of the Textile Institute, XXVI (June, 1935), T171-T186.

13. Cleveland, Richard S. "An Improved Apparatus for Measuring the Thermal Transmission of Textiles," Journal of Research of the National Bureau of Standards, XIX (December, 1937), 675-684.

14. Fitzgerald, J. E. A Study of the Copper Man. Phase I Quartermaster Climatic Research Laboratory, Report No. 107, August 28, 1946.

15. Fonseca, G. F. and J. R. Breckenridge. "Wind Penetration Through Fabric Systems," Part I, Textile Research Journal, XXXV (February, 1965), 95-103.

16. Gagge, A. P., A. C. Burton, and H. C. Bazett. "A Practical System of Units for the Description of the Heat Exchange of Man With His Environment," Science, XCIV (November 7, 1941), 428-430.

17. Galbraith, Ruth L., Jane E. Werden, M. K. Fahnestock, and Barbara Price. "Comfort of Subjects Clothes in Cotton, Water Repellent Cotton, and Orlon Suits," Textile Research Journal, XXXII (March, 1962), 236-242.

18. Garner, Walter. Textile Laboratory Manual. New York: Chemical Publishing Co., Inc., 1951.

19. Hardy, H. B. Jr., J. W. Ballou, and O. C. Wetmore. "The Prediction of Equilibrium Thermal Comfort From Physical Data on Fabrics," Textile Research Journal, XXIII (January, 1953), 1-10.

20. Hardy, J. D. "Heat Transfer," Chapter 3 in L. H. Newburgh's Physiology of Heat Regulation and the Science of Clothing. Philadelphia: W. B. Saunders Company, 1949.

21. Herrington, L. P. "Clothing From a Biophysical Point of View," Papers of the American Association of Textile Technologists, (December, 1951), P30.

22. Hock, C. W., A. M. Sookne, and M. Harris. "Thermal Properties of Moist Fabrics," Journal of Research of the National Bureau of Standards, XXXII (May, 1944), 229-252.

23. Hoge, Harold J. and George F. Fonseca. "The Thermal Conductivity of a Multilayer Sample of Underwear Material Under a Variety of Experimental Conditions," Textile Research Journal, XXXIV (May, 1964), 401-410.

24. Hollies, R. S. and Herman Bogaty. "Some Thermal Properties of Fabrics - Part II: The Influence of Water Content," Textile Research Journal, XXXV (February, 1965), 187-190.

25. Howell, William Henry. Howell's Textbook of Physiology. Fifteenth edition. Philadelphia: W. B. Saunders Company, 1946.

26. Kaswell, Ernest P. Textile Fibers, Yarns, and Fabrics. New York: Reinhold Publishing Corporation, 1953.

27. Kleitman, Nathaniel and Dudley P. Jackson. "Body Temperature and Performance Under Different Routines," Journal of Applied Physiology, III (December, 1950), 309-328.

28. Marsh. J. T. Textile Science. London: Chapman and Hall Ltd., 1958.

29. Marsh, M. C. "The Thermal Insulating Properties of Fabrics," Journal of the Textile Institute, XXII (May, 1931), T245-T273.

30. Meredith, R. Physical Methods of Investigating Textiles. New York: Textile Book Publishers, Inc., 1959.

31. Moncrieff, R. U. "Clothing and Body Moisture Losses," Man-Made Textiles, XL (November, 1963), 75-77.

32. Newburgh, L. H. The Physiology of Heat Regulation and the Science of Clothing. Philadelphia: W. B. Saunders Company, 1949.

33. Niven, C. D. "A Simplified Hot Plate Apparatus," Textile Research Journal, XXXII (November, 1962), 890-897.

34. Peirce, F. T. and W. H. Rees. "The Transmission of Heat Through Textile Fabrics," Part II, Journal of the Textile Institute, XXXVII (September, 1946), T181-T204.

35. Rees, W. H. "Lightweight Warmth," Textile Institute and Industry, II (February, 1964), 29-31.

36. _________. "The Protective Value of Clothing," Journal of the Textile Institute, XXXVII (July, 1946), P132-P153.

37. _________. "The Transmission of Heat Through Textile Fabrics," Journal of the Textile Institute, XXXII (August, 1941), T149-T165.

38. Schiefer, H. F. "Factors Relating to the Thermal Insulation of Fabrics," Symposium on the Functional Properties of Clothing Fabrics. New York: Textile Research Institute, November, 1943.

39. Schiefer, H. F., H. T. Stevens, P. B. Maek, and P. M. Boyland. "A Study of the Properties of Household Blankets," Journal of Research of the National Bureau of Standards, XXXII (June, 1944), 261-284.

40. Selle, W. A. Body Temperature. Its Changes With Environment, Disease and Therapy. Illinois: Charles C. Thomas, 1952.

41. Skinkle, John H. Textile Testing. New York: Howes Publishing Company, 1940.

42. Speakman, J. B. and N. H. Chamberlain. "The Thermal Conductivity of Textile Materials and Fabrics," Journal of the Textile Institute, XXI (March, 1930), T29-T56.

43. Springer, W. E. "Operation of Copper Manikin." Manhattan, Kansas: Kansas State University, 1965. (mimeographed)

44. Werden, Jane E., M. K. Fahnestock, and Ruth L. Galbraith. "Clothing Comfort," Illinois Research (Winter, 1959), 12-13.

45. Werden, Jane E. et al. "Thermal Comfort of Clothing of Varying Fiber Content," Textile Research Journal, XXIX (August, 1959), 640-651.

46. Woodcock, A. H. "Moisture Transfer in Textile Systems," Part I, Textile Research Journal, XXXII (September, 1962), 628-633.

APPENDIX A

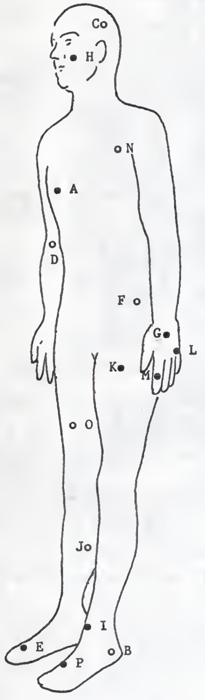
TABLE V

IDEAL CLOTHING FOR COMFORT

Environmental Temperature	Resting Sitting	Slow Level Walking	Normal Level Walking	Fast Level Walking
70^{o} F. - Normal outdoors	1.5	.7	.4	.3
50^{o} F. - Normal outdoors	3.1	1.5	.9	.7
30^{o} F. - Normal outdoors	4.7	2.3	1.5	1.1
0^{o} F. - Normal outdoors	7.2	3.5	2.3	1.7

From Gagge, Burton, and Bazett (16).

APPENDIX B



- FRONT THERMOCOUPLE LOCATIONS
- BACK THERMOCOUPLE LOCATIONS

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 6

LOCATION OF THERMOCOUPLES ON COPPER MAN

APPENDIX C

TABLE VI

CLOTHING SIZE CHART FOR THE COPPER MANIKIN

Clothing	Size
T shirt	Medium
Shorts	32
Sports shirt	16-16½
Trousers	31-29
Socks	13
Shoes	13
Sweater	42
Jackets	42

APPENDIX D

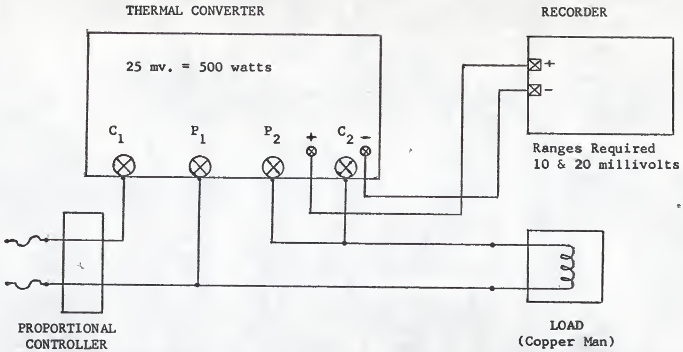


FIGURE 7

DIAGRAM OF CONNECTIONS FOR THERMAL CONVERTER

From Springer (43).

A QUANTITATIVE MEASURE OF THE THERMAL INSULATION VALUE OF CERTAIN ITEMS OF MEN'S WEAR

by

DELORES FRANCES FRANZ

B. S., Kansas State Teacher's College, Emporia, 1961

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

1966

This exploratory study was designed to establish procedures for operating a copper manikin, a blackened copper shell constructed to simulate the human body both geometrically and thermally. Using the manikin as a physical device, the clo value, a unit of thermal insulation, was determined for various items of men's wear worn in the following environmental conditions: relative humidity 65 $\pm$ 2 per cent and ambient air temperature 70° F. $\pm$ 2.

A basic set of clothing consisting of underclothes, shirt, trousers, shoes, and socks remained on the manikin throughout the testing period. Placed over this basic set in separate tests were three unlined 100 per cent nylon jackets with the following variations in finishes: (1) no special finish; (2) outside coating of urethane; and (3) inside coating of urethane. After calculating the clo values for the basic set, and the basic set plus each jacket both with and without hoods, a 100 per cent wool sweater was added to the assembly and the series of tests were repeated.

Thermal properties of fabrics can be assessed and compared accurately only in terms of specific cases involving a definite type of garment and a definite set of environmental conditions. This study showed that the clo value of the 100 per cent wool sweater worn over the basic set of clothing was slightly lower than that for any of the unlined 100 per cent nylon jackets worn over the basic set.

The combination of sweater and jacket was more effective in retaining heat than either alone. The addition of the sweater to the basic set of clothing added 0.103 clo to the assembly. The clo values calculated for the combination of the basic set, sweater, and jacket showed that the porous sweater was more effective than 0.103 clo when worn under any of the jackets with hoods.

Tests comparing the jackets worn with and without hoods showed that a higher clo value for the jacket was obtained when the hoods were worn. This upward trend was true for all jackets.

Although general trends may be observed in this investigation, a detailed analysis shows discrepancies in results. From this, it is apparent that one or more unknown variables influenced the data collected.

It is known that clothing "traps" a layer of air between the fabric and the body; therefore, the calculated clo value is actually a measure of resistance offered to the body by the textile substance and the air. Jackets used in this study had elastic or drawstrings around the closures at the cuffs, hips, and hood. Both of the preceding construction details gave a slight ballooning effect so that the amount of air between the jacket and basic clothing may have varied enough to affect the calculated clo value from test to test.

This study established basic operational procedures, but further investigation is needed to determine a dressing procedure which will yield consistent results. It is suggested that this procedure be established before comparative studies are conducted.