# THERMAL INSULATION CHARACTERISTICS

of

# SLEEPWEAR AND ROBES

by

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# Chapter 1

## INTRODUCTION

Since the energy crisis of the 1970's, consumers have become more conscious of their energy consumption. In an effort to conserve energy and ultimately save money, consumers have responded in a variety of ways.

Air temperature is often manipulated to higher or lower levels to decrease energy consumption. The night set back of thermostats to reduce energy consumption has become common practice during the winter months. During the summer months consumers can reduce their energy consumption by maintaining a higher thermostat set point for cooling (32).

In hot environments, fans can be used to increase air velocity. As air velocity increases, body heat loss through evaporation will increase. This is desirable in high temperature conditions, but the air flow must be uniform or people will feel discomfort from drafts (32).

The most economical and effective strategy for providing thermal comfort in a changing thermal environment is the adjustment of clothing (33). Clothing can be added in cool environments and removed in warm environments to maintain thermal comfort.

ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy," specifies conditions in which 80% or more of the occupants will find the environment thermally acceptable (3). The standard contains a list of insulation (clo) values for selected garment types and a formula for estimating the insulation provided by a total clothing ensemble. This standard is used in the following ways: 1) to prescribe the type of clothing that occupants should wear in a given environment and 2) to describe the types of garments that people are wearing in an environment, estimate the levels of clothing insulation, and adjust the environmental conditions accordingly.

Clo value information is also useful to researchers who must control or evaluate clothing in their studies, but do not have the facilities for measuring clothing insulation.

Many people live and work in places where they have no direct control over their thermal environment. For example, there are many elderly individuals living in nursing homes and sick and chronically ill people living in hospitals. For these people, many or all of their waking hours are spent in some form of sleepwear and/or robes. The activity levels of the patients are low compared to those of the employees of these institutions. As the level of activity is increased, less insulation is needed to maintain thermal comfort. Additional clothing worn by the patients would create a balance between the difference in activity levels of the two groups.

Very little information concerning the clo values of garments is available to consumers. Some manufacturers of outdoor garments have attempted to specify comfort ranges and minimum temperature ratings for their clothing items. However, test methods and rating scales vary from one company to another and often lack reliability and validity (19). It is important for consumers to learn to estimate clothing insulation so that thermal comfort can be maintained in a given environment. In a recent study (20), consumers indicated an interest in obtaining assistance from the apparel industry in identifying warm clothing. Consumers indicated a strong desire for garment labeling which would express insulation values.

Extension specialists use clo value information in the development of literature (34, 36), training sesions, and radio programs to better educate the general public. These programs are primarily based on information provided in the ASHRAE standard.

Unfortunately, no information concerning clothing insulation of sleepwear and robes is included in the ASHRAE standard. In addition, no research could be found which quantified the thermal insulation provided by these garments. Therefore, the purpose of this study was to measure the insulation provided by a variety of sleepwear and robes constructed in different garment designs and fabric types.

## Objectives

The methodological objectives of this study were:

1. To measure the thermal insulation (clo) value, clothing area factor, weight, and amount of body surface area covered for a variety of sleepwear items and robes constructed in typical winter (warm) and summer (cool) fabrics.
2. To measure the thermal insulation (clo) value and clothing area factor for selected warm and cool sleepwear ensembles for men and women.
3. To measure the thermal insulation (R) value, thickness, and weight of fabrics used to construct the garments.

Definitions

1. Clo value: A unit used to express clothing insulation where, 1 clo = 0.155 $m^2$ K/W (0.88 $ft^2$hF/Btu) (3, 14).

2. Total insulation ($I_T$): The insulation from the skin surface to the environment, including the effect of the increased surface area ($f_{cl}$) and the resistance at the surface of the clothed body ($I_a$) (30).

3. Effective clothing insulation ($I_{cle}$): The insulation from the skin to the clothing surface, excluding the effect of the increased surface area of the clothed body ($f_{cl}$) (30).

4. Intrinsic clothing insulation ($I_{cl}$): The insulation from the skin to the clothing surface (30).

5. Clothing area factor ($f_{cl}$): The ratio of the surface area of the body when clothed to the surface area of the body when nude (24).

6. Garment: A single item of clothing such as a nightgown.

7. Ensemble: Several garments worn together on the body such as a nightgown, robe, and slippers.

Assumptions

The sleepwear and robes chosen were representative of those worn by male and female consumers.

Limitations

This study was limited to the garment designs and fabric types chosen.

A two-circuit, non-segmented manikin was used to measure the clothing insulation values of the sleepwear items and selected ensembles.

A non-segmented manikin will not detect small changes in styling (e.g., change in neckline design), but will show how major design changes affect the thermal insulation value of clothing.

The manikin was used in a stationary, standing position in this study. Consequently, air trapped in loose-fitting garments (e.g., gowns) provided additional insulation, creating artificially higher thermal insulation values. Similar tests conducted on a movable manikin would provide more realistic results by including the effect of increased convective heat transfer between the body and the clothing layers.

# Chapter 2

## REVIEW OF LITERATURE

### Introduction

Under normal atmospheric conditions the object of clothing the body is to ensure that the rate of heat loss approximates the rate of heat production by the body. The body loses heat by conduction, convection, and radiation, and by evaporation of perspiration. The body is able to adjust to slight variations in air temperature by its vascomotor mechanism, (the variation of blood flow). However, the main purpose of clothing is to prevent excessive heat loss from the body (22).

Thermal insulation is the resistance to the flow of heat. Several factors contribute to and influence the amount of thermal insulation provided by a garment or ensemble. Factors involving fiber, yarn, fabric, and garment characteristics will be discussed.

### Fabric Properties

Most apparel fabrics are composed of 60-90% air (13). The thermal conductivity of fabrics is known to be dependent upon the air entrapped in the fabric (9). The volume of air per unit area of fabric is one of the main factors which determine insulating capacity since the insulating value of air is greater than that of fibers (23). This is shown in Table 1 where the thermal conductivity of selected fibers is related to that of air.

TABLE 1

Thermal Conductivity of Fibers

| Fiber | Thermal Conductivity Index (air = 1) |
| --- | --- |
| Polypropylene | 6.0 |
| Polyvinylchloride | 6.4 |
| Polyester | 7.0 |
| Wool | 7.3 |
| Acrylic | 8.0 |
| Acetate | 8.6 |
| Viscose Rayon | 11.0 |
| Polyethylene | 13.0 |
| Cotton | 17.5 |

Source: (1)

The ability of a fabric to trap air is related to its large fiber surface. Air immediately in contact with a solid surface is always at rest. The drag or resistance to air movement through a mass of fibers comes from the solid surfaces of the fibers. The greater the solid surface the greater is the drag on air movement and the greater is the amount of entrapped air (9). For most apparel fabrics, the requirements for good heat insulation are relatively low fabric density, and the exposure of fiber surfaces to air so that the large total fiber surface in the fabric can be effectively used to entrap air (9). However, this relationship between fabric density and insulation is not a linear one. Extremely low levels of density (i.e., characteristic of some fibrous battings), provide poor insulation because there is more opportunity for radiant and convective heat loss. At high levels of fabric density, there is considerable heat loss from conduction.

The thermal insulation of fabrics depends largely on the thickness of the fabric and is independent of the fiber material (22). Increasing thickness and decreasing density have been found to increase the thermal insulation of most apparel fabrics (22), allowing for the maximum amount of air entrapment. Bulk density is the weight of fibers in a given volume (12). Apparel fabrics of low bulk densities allow for more entrapment of air and provide more warmth than do fabrics of high bulk densities (11).

As measured on a flat hot plate apparatus, approximately 1.6 clo of insulation is provided for 1 cm of material thickness, regardless of fiber content and construction characteristics (18).

In addition to air spaces between and around the fiber surfaces, air is also trapped between layers of fabric. Morris (23) found that the thermal insulation of multiple layers was greater than the sum of the insulation for single layers.

Fabric insulation is determined by fiber arrangement as well as fabric thickness (8). According to Bogaty (8), Finck found that the thermal conductivity of fabrics made of fibers arranged parallel to the direction of heat flow is two-to-three fold greater than when fibers are arranged perpendicular to the direction of heat flow for fabrics of the same bulk densities (8).

The thermal resistance of fabrics is proportional to both thickness and applied pressure (8). For wool-like, fuzzy fabrics, the decrease in thermal resistance with pressure is counterbalanced by the change of fiber arrangement (e.g., fibers are now parallel to the direction of heat flow). As a result, the overall resistance remains essentially unaltered even at high pressures, for fabrics of this type. For smooth fabrics of cotton and synthetic fibers a decrease in thermal resistance with pressure is appreciable since fiber arrangement undergoes only a minor change (8).

Fabric finishes affect the thermal insulation of fabrics. Finishes that control fabric porosity, hairiness, and weight affect the amount of air space present. Finishing techniques such a tentering and napping can significantly alter the thermal characteristics of a fabric (18).

Fiber modifications can change the characteristics of a particular fiber and offer a greater resistance to heat flow. Hollow fibers (e.g., Hollofil) trap air within the fiber providing additional insulation. Very fine fibers (e.g., Sontique) also increase the fiber surface per unit weight and provide more air drag or resistance on the fiber. Fabrics made from crimped or texturized fibers provide more insulation than fabrics made from smooth filament fibers. Consequently, fiber modifications can create fabrics that are both light weight and warm.

Yarn structures and fabric constructions which increase the fiber to air ratio increase the thermal insulation value of a fabric. A fabric of low thread count constructed from loosely twisted yarn would provide more insulation than a tightly woven fabric of highly twisted yarns. Pile fabrics such as terrycloth and velour provide more insulation than thin, smooth fabrics such as tricot and broadcloth.

## Clothing Properties

The amount of "trapped" air within a clothing ensemble greatly affects the insulation of clothing (26). Air is trapped between fabric layers in a single garment, (e.g., pockets, seams, hems), and between different garment layers in an ensemble.

Marsh (21) simulated the fit of a garment in a fabric test and investigated a variety of fabrics. This investigation showed that tightness of fit of the sample around a hot body had a marked effect on the thermal insulation and demonstrated the increase in insulation when an air gap was left between the hot body and the fabric. Rees (31) and others have since shown the marked improvement in the insulation with increasing the air gap up to a maximum of 0.3 inch. Table 2, reproduced from Rees' results, illustrates this effect.

TABLE 2

Thermal Insulation Values of Blankets for Selected Gap Widths

| Gap Width (in.) | Percent Thermal Insulation Value[1] | |
|---|---|---|
| | Cotton Blanket | Rayon Blanket |
| 0.0 | 62.7 | 62.4 |
| 0.05 | 67.1 | 65.9 |
| 0.15 | 73.1 | 71.8 |
| 0.20 | 75.7 | 74.0 |
| 0.25 | 77.1 | 75.8 |
| 0.30 | 78.2 | 77.4 |
| 0.35 | 78.8 | 77.9 |
| 0.40 | 77.4 | 76.6 |

[1] $\%T.I.V. = \frac{1 - \text{heat loss from covered hot body}}{\text{heat loss from uncovered hot body}} \times 100$

Source: (31)

In a still air environment, when the air gap increases above about 0.35 inch, convective currents have a greater effect and cause a reduction in insulation (31).

Design variations related to changes in the amount of body surface area covered and the looseness or tightness of fit affect garment clo value. McCullough, Jones, and Zbikowski (25) found a strong relationship between the amount of body surface area covered and garment insulation. For broadcloth shirts of similar design, the long-sleeve shirts were warmer than short-sleeve shirts, (0.36 clo versus 0.27 clo).

The same study (25) also found that the loose-fitting, long-trousers provided more insulation than tight-fitting trousers did (0.34 versus 0.24 clo). Air trapped between the garment and the manikin's legs probably contributed to a higher clo value for the loose trousers when measured on a standing manikin. During movement, more air would circulate inside the legs of loose-fitting trousers, than in tight-fitting trousers, causing an increase in the convective heat transfer. Consequently, people may not perceive differences in the insulation provided by the two types of trousers.

As a person dons additional items of clothing, the surface area of a person increases. This increase in surface area provides a larger area for heat loss from the body and decreases the efficiency of a clothing system (30). This effect is related to the clothing area factor which is defined as the ratio of the surface area of the body when clothed to the surface area of the body when nude (24).

The three most common ways of reporting the thermal insulation (clo) values of clothing are: $I_T$, the total insulation (19, 25, 26), $I_{cle}$, the effective clothing insulation (27, 28); and $I_{cl}$, the intrinsic clothing insulation (25, 26). For purposes of data comparison, similar types of clo values must be used. The advantages and disadvantages associated with these measures of clothing insulation have been discussed in the literature (24, 29).

Estimating Ensemble Insulation

Since clothing items are most often worn in ensemble form, it is important to be able to estimate the amount of clothing insulation provided by an ensemble. Sprague and Munson (36) were the first to develop a method of estimating the insulation of a total ensemble from the sum of the individual clothing items. Separate formulae were developed for men and women. The results from the Sprague and Munson study were used as the basis for the ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy," (3). This standard includes a list of garment clo values and one formula for estimating ensemble insulation. Unfortunately, this list is incomplete, and no clo values for sleepwear and robes are found in the list.

The ASHRAE Standard also suggests a way to roughly estimate clothing insulation by measuring the weight of an ensemble (0.35 clo/1 kg clothing weight). In a study on the insulation of winter and summer indoor clothing, McCullough and Wyon (26) found a high correlation between ensemble weight and clo value. The authors indicated that the results were expected because the design of the study involved adding different garments to basic ensembles causing an increase in both weight and insulation. McCullough, Jones, and Zbikowski (25) found that variations in fabric weight without major changes in thickness did not affect the thermal insulation value of garments.

Azer (5) developed a model to determine the thermal insulation values of garments from the physical data of their fabrics. Once insulation values of garments were established, the individual values could be used in the Sprague and Munson (35) formula for predicting the insulation value of an ensemble.

# Chapter 3

# METHODOLOGY

The purpose of this study was to measure the insulation (clo) value of a variety of sleepwear garments and robes constructed in different garment designs and fabric types.

## Independent and Dependent Variables

The independent variables for this study were garment design and fabric type. The dependent variable was the thermal insulation value of the clothing, expressed in terms of a clo unit.

## Garment and Fabric Selection

Sleepwear and robes in catalogs and retail establishments were examined to determine the garment designs and fabric types used. An effort was made to choose designs and fabrics that were most representative of those worn by both male and female consumers.

McCullough, Jones, and Zbikowski (25) found that major differences in garment clo were related to the amount of body surface area covered and looseness or tightness of fit. These findings were considered when selecting specific design variations for sleepwear and robes. Figures 1 through 7 provide sketches of designs evaluated in this study.

Typical winter (warm) and summer (cool) fabrics were chosen for construction of the garments. For some garments, a representative fabric worn by consumers during all seasons was chosen (e.g., tricot nightgown).

One of a kind items (e.g., hospital gown and body sleeper) were borrowed or purchased, since no comparisons of these items were made with others.

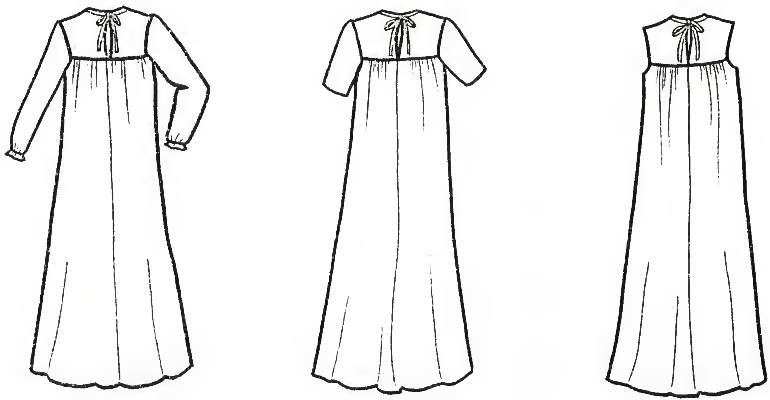

Figure 1. Long Gown in Three Sleeve Lengths

Figure 2. Short Gown in Three Sleeve Lengths

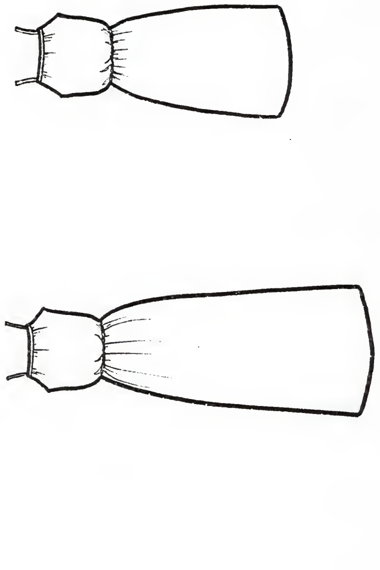

Figure 3. Long and Short Thin Strap Gown

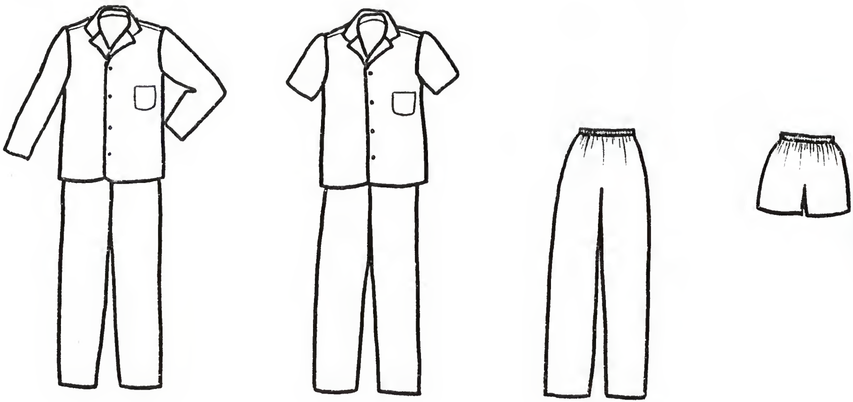

Figure 4. Long and Short Sleeve Pajamas; Pajama Trousers and Boxer Shorts

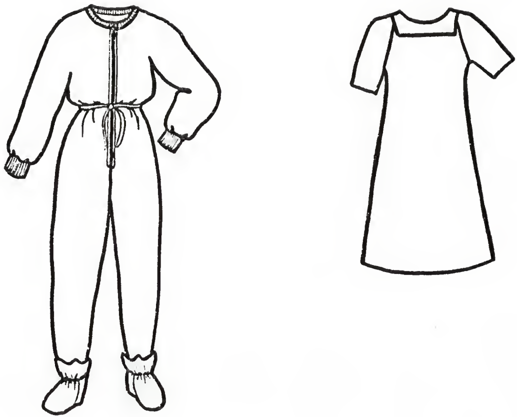

Figure 5. Body Sleeper and Hospital Robe

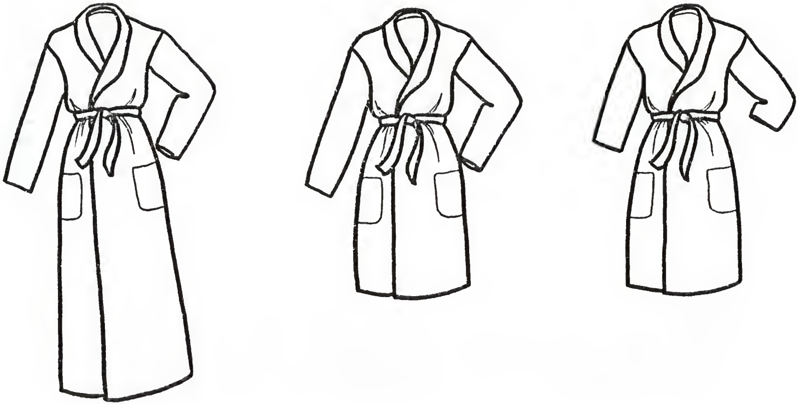

Figure 6. Long and Short Wrap Robe with Long Sleeves; Short Wrap Robe with 3/4 Length Sleeves

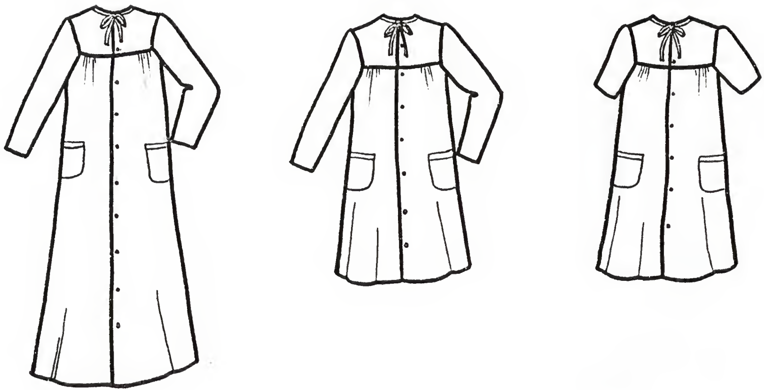

Figure 7. Long Button Front Robe with Long Sleeves; Short Button Front Robe with Long and Short Sleeves

Six representative ensembles were selected which included both winter (warm) and summer (cool) garments for both men and women.

Fabric characteristics are given in Table 3, and garment characteristics are presented in Tables 4 and 5.

Laboratory Procedures

All fabrics were cleaned once, according to AATCC Standard Test Method 135 (2), prior to textile analysis and garment construction.

Fabrics were purchased from wholesalers and retailers. Commercial pattern pieces were cut from the appropriate fabrics, and garments were constructed using industrial sewing machines and techniques. Identical notions (e.g., thread and buttons) and support materials (e.g., interfacings) were used for each garment type. In some cases, design comparisons for sleeve length and garment length were made by cutting sleeves and skirts after the data for long verions of the garments had been collected.

Textile specimens were cut from fabrics and conditioned according to ASTM D-1776. Fabric weight was determined according to ASTM D-3776 and reported in $g/m^2$. Fabric thickness was determined according to ASTM D-1777 and reported in mm. (4).

ASTM D-1518 was used to determine the thermal insulation value of the fabrics. The guarded hot plate was used in an environmental chamber with conditions of $10 \pm 0.5^{\circ}C$ and 40-50% relative humidity. The average temperature of the test plate and guard section was maintained at $31.3\text{-}35.6^{\circ}C$. Thermal insulation (R) values for the fabric and the fabric plus the air layer were reported. Specific fabric characteristics are found in Table 3.

TABLE 3

Fabric Characteristics

| Type/ Construction | Fiber Content | Thickness (mm)[1] | Thermal Insulation of Sample Plus Air Layer (R value) | Thermal Insulation of Sample (R value) | Weight ($g/m^2$) |
|---|---|---|---|---|---|
| Tricot/Warp Knit | 100% Nylon | 0.31 | 0.77 | 0.07 | 89.83 |
| Broadcloth/ Plain Weave | 65% Polyester 35% Cotton | 0.38 | 0.92 | 0.22 | 102.01 |
| Print Cloth/ Plain Weave | 100% Cotton | 0.48 | * | * | 125.46 |
| Flannel/ Plain Weave | 100% Cotton | 0.99 | 0.98 | 0.28 | 140.89 |
| Velour/ Brushed Warp knit | 80% Triacetate 20% Nylon | 1.47 | 0.97 | 0.27 | 200.45 |
| Quilted/ Multicomponent Fabric | Face 50% Polyester 50% Rayon Fill 100% Polyester Back 100% Nylon | 3.03 | 1.53 | 0.83 | 206.13 |
| Terry Cloth/ Warp Slack Tension, Plain Weave | 88% Cotton 12% Polyester | 3.13 | 1.22 | 0.52 | 334.88 |
| Fleece Back Double Knit | 100% Acrylic | 3.34 | * | * | 240.57 |
| Fleece/ Pile Jersey Knit | Face 50% Polyester 50% Acrylic Back - 100% Polyester | 5.91 | 1.82 | 1.12 | 467.31 |

[1] Measured using a 3 in. diameter presser foot and 0.01 psi pressure.
* Not enough fabric was available to measure fabric insulation.

TABLE 4

Garment Characteristics for Sleepwear

| Design Description | Fabric Type | Weight (g) | Body Surface Area Covered (%) | Clothing Area Factor ($f_{cl}$) |
|---|---|---|---|---|
| Long-sleeve, Long Gown | Tricot | 260 | 81 | 1.49 |
| Long-sleeve, Long Gown | Flannel | 435 | 81 | 1.49 |
| Long-sleeve, Short Gown | Tricot | 180 | 66 | 1.25 |
| Long-sleeve, Short Gown | Flannel | 305 | 66 | 1.25 |
| Short-sleeve, Long Gown | Tricot | 239 | 74 | 1.44 |
| Short-sleeve, Short Gown | Tricot | 157 | 59 | 1.20 |
| Sleeveless, Long Gown | Tricot | 217 | 65 | 1.42 |
| Sleeveless, Short Gown | Tricot | 138 | 50 | 1.18 |
| Thin Strap, Long Gown | Tricot | 157 | 58 | 1.33 |
| Thin Strap, Short Gown | Tricot | 94 | 42 | 1.12 |
| Hospital Gown | Printcloth | 270 | 57 | 1.23 |
| Long-sleeve, Long Pajamas | Broadcloth | 327 | 80 | 1.30 |
| Long-sleeve, Long Pajamas | Flannel | 447 | 80 | 1.30 |
| Short-sleeve, Long Pajamas | Broadcloth | 297 | 71 | 1.26 |
| Long Pajama Trousers | Broadcloth | 149 | 45 | 1.20 |
| Body Sleeper with Feet | Fleece Back Double Knit | 599 | 86 | 1.38 |
| Boxer Shorts | Broadcoth | 66 | 18 | 1.05 |

TABLE 5

Garment Characteristics for Robes

| Design Description | Fabric Type | Weight (g) | Body Surface Area Covered (%) | Clothing Area Factor ($f_{cl}$) |
|---|---|---|---|---|
| Long-sleeve, Long Wrap | Broadcloth | 363 | 81 | 1.39 |
| Long-sleeve, Long Wrap | Velour | 690 | 81 | 1.40 |
| Long-sleeve, Long Wrap | Terrycloth | 1196 | 81 | 1.43 |
| Long-sleeve, Long Wrap | Quilted | 783 | 81 | 1.43 |
| Long-sleeve, Long Wrap | Fleece/Pile Jersey Knit | 1535 | 81 | 1.47 |
| Long-sleeve, Short Wrap | Broadcloth | 298 | 68 | 1.24 |
| Long-sleeve, Short Wrap | Velour | 556 | 68 | 1.25 |
| 3/4 Length Sleeve, Short, Wrap | Velour | 514 | 62 | 1.20 |
| Long-sleeve, Long Button Front | Broadcloth | 268 | 82 | 1.47 |
| Long-sleeve, Long Button Front | Velour | 586 | 82 | 1.48 |
| Long-sleeve, Short Button Front | Broadcloth | 260 | 69 | 1.32 |
| Long-sleeve, Short Button Front | Velour | 472 | 69 | 1.33 |
| Short-sleeve, Short Button Front | Broadcloth | 231 | 60 | 1.28 |

The weight of individual garments was measured using a digital, single pan balance.

Measurement of Clothing Insulation

Morris (22) described several methods which have been used to evaluate the thermal insulation of a fabric. Although this information is helpful, heat transfer measurements on small, flat pieces of fabric may have little relationship to those of actual garments made of the same fabric. Huck and McCullough (19) found significant differences in insulation between some fabrics measured on a guarded hot plate, but when these same fabrics were made into garments, and tested on the manikin, fewer significant differences in insulation values were found.

The most realistic results are obtained by using a thermal manikin. This procedure measures the effect of "trapped" air between the body and the garments, between the fabric layers in a single garment, and between different garment layers on the total thermal insulation of a clothing ensemble. Both stationary and movable manikins exist and have been used to evaluate clothing insulation.

Human subjects may also be used to measure clothing insulation. This method of measurement is very time consuming, expensive, and the results are not always reliable (29).

Therefore, for this study the thermal insulation (clo) value of the clothing was measured on a stationary copper manikin. The copper manikin was instrumented with 16 skin temperature thermistors (see Figure 8), and heated internally to simulate the skin temperature distribution of a human. A proportional temperature controller was used to regulate the

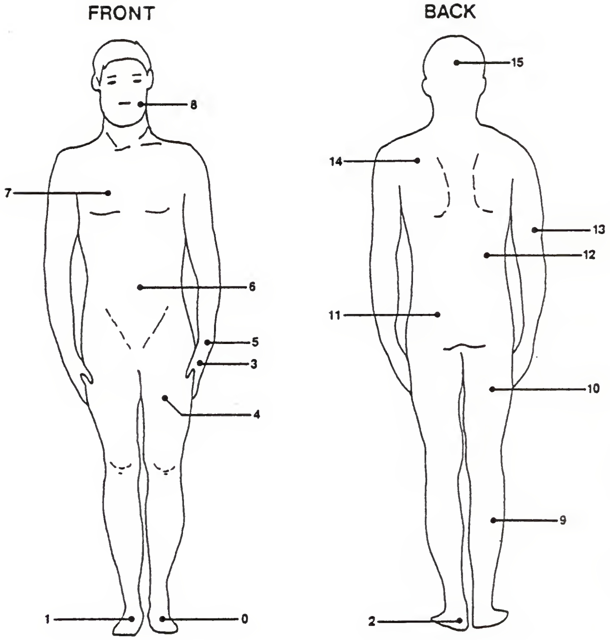


Figure 8. Location of Thermistors on Copper Manikin

heating of the manikin so as to produce a mean skin temperature of $33.3 \pm .5^{\circ}C$. The power to the extremities was manually regulated by a variable transformer to maintain a lower mean skin temperature of $29.4 \pm .5^{\circ}C$ in the hands and feet. The manikin was housed in an environmental chamber. Four ambient temperature thermistors were used to measure the air temperature in the chamber. Air temperature was set at $22.2 \pm .5^{\circ}C$, and air velocity in the chamber was limited to 0.1 m/s. Mean radiant temperature was equal to the air temperature. Relative humidity was less than 50%.

Individual garments and selected ensembles were tested on the copper manikin. Great care was taken to avoid inconsistencies in dressing procedures. When a steady-state was obtained, the power was monitored continuously for 30 minutes using a watt-hour meter. Skin and air temperatures were digitally recorded on paper every 10 minutes during the test period; then the individual values were averaged. The total insulation ($I_T$) of a garment or ensemble was calculated as follows:

$$I_T = \frac{K\,(\bar{T}_s - T_a)\,A_s}{H} \qquad (1)$$

where

$I_T$ = total thermal insulation of clothing plus air layer - clo

H = power input - W

K = units constant = 6.45 clo $\cdot$ W/m$^2$ $\cdot$ $^{\circ}$C

$A_s$ = manikin surface area - m$^2$

$\bar{T}_s$ = mean skin temperature - $^{\circ}$C

$T_a$ = ambient air temperature - $^oC$

This procedure was repeated two additional times on different days; the average of the three replications was recorded as the total clo value.

The intrinsic clo value ($I_{cl}$) of the individual garments and ensembles was determined by subtracting the insulation provided by the adhering air layer from the total clo value ($I_T$), using the following equation:

$$I_{cl} = I_T - \frac{I_a}{f_{cl}} \tag{2}$$

where

$I_{cl}$ = intrinsic thermal insulation of clothing - clo

$I_T$ = total thermal insulation of clothing plus air layer - clo

$I_a$ = thermal insulation of air layer around the nude manikin - clo

$f_{cl}$ = clothing area factor

The value for $I_a$ was obtained by operating the manikin without clothing in the same environmental conditions and using Eq. 1.

Measurement of Clothing Area Factor

The clothing area factor for garments and ensembles was determined using the photographic method described by Olesen et al. (30). The manikin was photographed from three azimuth angles: $0^o$ (front view), $45^o$, and $90^o$ (side view) by turning the manikin on a revolving stand. Two 35 mm cameras with lenses of the same focal point were used to take each set of three photographs from $0^{o}$ (horizontal) altitude and $60^{o}$ altitude. The pictures were printed on 10 x 25 cm photographic paper, and the manikin's surface area was measured using a planimeter. The clothing area factor was calculated as:

$$f_{cl} = \frac{A_{cli}}{A_{ni}} \qquad (3)$$

where

$f_{cl}$ = clothing area factor

$A_{cl}$ = projected surface area of clothed manikin

$A_{n}$ = projected surface area of nude manikin

Measurement of Body Surface Area Covered

The nude manikin was divided into 17 body segments, with each segment covering a specific amount of the total body surface area (see Figure 9). To determine the amount of body surface area covered by a garment, pictures were taken of the clothed manikin from front, side, and back views. Each segment of the clothed manikin was then examined to determine the percent of the segment that was actually covered by clothing. The total amount of body surface area covered by the garments was then determined. Figure 10 shows the worksheet used in this project to determine the amount of body surface area covered.

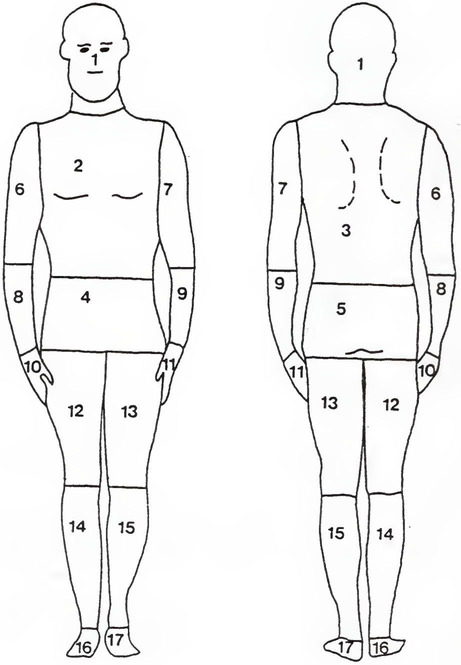


Figure 9. Body segments Used to Determine the Amount of Body Surface Area Covered

Clothing Code and Description________________________________

| Body Segment | | % of Total Body Surface Area Represented by Each Segment | % of Each Body Segment Covered | % of Total Body Surface Area Covered |
|---|---|---|---|---|
| Head and neck | 1 | 8.7 | | |
| Chest | 2 | 10.2 | | |
| Back | 3 | 9.2 | | |
| Abdomen | 4 | 6.1 | | |
| Buttocks | 5 | 6.6 | | |
| Right upper arm | 6 | 4.7 | | |
| Left upper arm | 7 | 5.2 | | |
| Right lower arm | 8 | 3.2 | | |
| Left lower arm | 9 | 3.0 | | |
| Right hand | 10 | 2.5 | | |
| Left hand | 11 | 2.5 | | |
| Right thigh | 12 | 9.1 | | |
| Left thigh | 13 | 9.3 | | |
| Right calf | 14 | 6.1 | | |
| Left calf | 15 | 6.2 | | |
| Right foot | 16 | 3.6 | | |
| Left foot | 17 | 3.8 | | |
| Total Body | | 100.0 | /////////// | |

Figure 10. Work Sheet used to Determine the Amount of Body Surface Area Covered.

# Chapter 4

## RESULTS AND DISCUSSION

In this study, a copper manikin was used to determine the thermal insulation values of selected sleepwear and robes constructed in winter (warm) and summer (cool) fabrics. Fabric type was held constant to evaluate garment design and garment design was held constant when evaluating fabric type. One-way analysis of variance was used to determine if 1) garment design had a significant effect on the thermal insulation provided by garments constructed in a given fabric and 2) fabric type had a significant effect on the insulation provided by each garment design. As expected, significant differences in clo values (i.e., $I_T$ and $I_{cl}$) were found for both design and fabric variations (see Tables 6-16 in Appendix). Duncan's multiple range tests were conducted to determine where specific differences in means existed.

Values for effective clothing insulation ($I_{cle}$) were not used in the statistical analysis. Effective clothing insulation can be determined by subtracting the resistance of the air layer ($I_a$) from the total insulation value ($I_T$). $I_a$ was determined by running the manikin nude in the same environmental conditions used for testing the clothing. The value for $I_a$ in this study was 0.71 clo. Since $I_{cle} = I_T - I_a$, the $I_{cle}$ data would have provided the same results as the $I_T$ data in the analysis of variance.

### Fabric Variations

The results of the Duncan's multiple range test for fabric variations in a given design are presented in Tables 17 through 23 in the Appendix.

The statistical results were the same for $I_T$ and $I_{cl}$ data. Consequently, clo value differences will be discussed using $I_{cl}$ values only.

The long-sleeve, long gown and the long-sleeve, short gown were tested in both flannel and tricot. In both cases the flannel garments were significantly warmer than the tricot garments (see Tables 17 and 18). Similar results were found when flat pieces of the fabrics were tested on the guarded hot plate. The thicker, napped flannel fabric was warmer than the thinner tricot.

The long-sleeve, long pajamas were tested in both flannel and broadcloth. The pajamas constructed in flannel were warmer than the pajamas constructed in broadcloth, 0.73 clo compared to 0.65 clo, respectively (see Table 19). The difference in insulation provided was due to the difference in fabric thickness and fabric insulation value.

The long-sleeve, long wrap robe was constructed in five fabrics which varied considerably in thickness and type of construction. Insulation values ranged from 1.24 clo for the pile knit/fleece robe to 0.63 for the broadcloth robe (see Table 20). The thicker pile, napped, and quilted fabrics provided more fiber surface per unit area than the thinner, smooth broadcloth and tricot fabrics did. The results obtained for clothing insulation are in agreement with those obtained for fabric insulation as measured on the guarded hot plate (see Table 3). The great variability of clo values was due to the wide range of fabrics used.

The long-sleeve, short wrap robe, the long-sleeve, long button front robe, and the long-sleeve, short button front robe were constructed in both velour and broadcloth. For every design, the garment constructed in velour was warmer than its counterpart constructed in broadcloth (see

Tables 21-23). These results were the expected since the thermal insulation for the velour fabric was higher than that of the broadcloth fabric as measured on the guarded hot plate (0.27 R value compared to 0.22 R value).

Fabric Thickness/Insulation Relationship

The fabric insulation (R) values were converted to clo units and plotted against the fabric thickness values (see Figure 11). The relationship of 0.16 clo/mm thickness which was suggested in the literature (18), was drawn on the figure for reference. Data for the seven fabrics tested in this study seem to support that relationship. However, data points for very thin fabrics tend to fall above the line, indicating higher insulation values than expected. This finding is probably due to the difficulty of measuring very thin fabrics on the hot plate without trapping air between the fabric and plate.

The quilted fabric provided more insulation per unit thickness than predicted by the 0.16 clo/mm thickness relationship. The fabric compressed more than others at 0.01 psi during the thickness measurement. During the hot plate test, it was not compressed, and it was one of the thickest fabrics. In addition, the multicomponent structure with polyester batting probably allowed for the entrapment of more air than conventional woven or knitted structures.

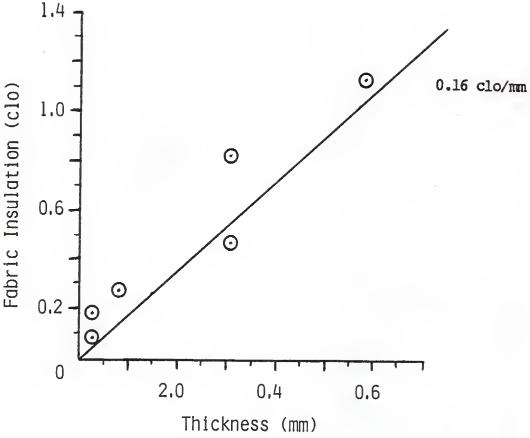


Figure 11. Fabric Thickness/Insulation Relationship

## Design Variations

When garment design was varied, results from the Duncan's multiple range tests were sometimes different for $I_T$ and $I_{cl}$ data (see Tables 24-31). $I_{cl}$ is a function of both the clothing area factor ($f_{cl}$) and the air layer ($I_a$). Since $f_{cl}$ changed as the designs changed, the $I_{cl}$ values reflected this variability. For example, if two different garments with $I_T$ values of 1.00 clo had different $f_{cl}$ values (e.g., 1.15 and 1.35), the smaller $f_{cl}$ value would yield a smaller $I_{cl}$ value (0.38 clo), and the larger $f_{cl}$ value would yield a larger $I_{cl}$ (0.47 clo). This is because $f_{cl}$ is divided into the clo value for the air layer resistance (i.e., 0.71) and subtracted from $I_T$. Consequently, variations in $f_{cl}$ can greatly affect $I_{cl}$ values.

The major differences in clo value due to comparable design variations will be discussed using $I_{cl}$ data.

Designs in tricot. Changes in sleeve design and garment length significantly affected the insulation provided by nightgowns constructed in tricot. For both long and short versions, the long-sleeve gowns were significantly warmer than the short-sleeve gowns which were significantly warmer than the sleeveless gowns. A thin strap long gown with a gathered waistline provided more insulation than its shorter counterpart (see Table 25). Changes in clothing insulation were related to changes in the amount of body surface area covered (see Table 4). These results are in agreement with McCullough, Jones, and Zbikowski (25) who found that design changes which alter the amount of body surface area covered have the greatest affect on the thermal insulation of a garment.

Designs in broadcloth. Trouser pajamas were constructed in broadcloth in short- and long-sleeve versions. The $I_{cl}$ value for the long-sleeve pajamas was significantly higher (0.65 clo) than the $I_{cl}$ value for the short-sleeve design (0.56 clo). The pajama trousers were tested individually and then cut to boxer shorts. As expected, the pajama trousers alone were significantly warmer than the boxer shorts, but both provided much less insulation than either pair of pajamas. These differences result from design changes which alter the amount of body surface area covered (see Table 27).

Robes were constructed in broadcloth in both button front and wrap designs in both long and short versions. For both designs, the long robe was significantly warmer than the short robe. No significant difference was found between the long button front and wrap robes or between the short versions of these robes (see Table 27). These results seem to contradict McCullough, Jones, and Zbikowski (25) who found significant differences between the clo values of single- and double-breasted suit jackets. However, the clothing area factor and fit were the same for both versions of the jacket. In this study, the wrap robe was belted and had a lower $f_{cl}$ value (1.39) than the loose-fitting button front robe (1.47). The wrap robe also covered less body surface area than the button front robe because of its V-neck. It appears that the increase in insulation expected from the frontal overlap of fabric in the wrap design was "offset" by a lower $f_{cl}$ and amount of body surface area covered. The clo value of the button front robe was probably higher than expected due to the entrapment of heated air between the manikin's surface and the loose-fitting robe. During movement, air would be "pumped" between the body and garment, causing convection heat loss to increase and the insulation value to decrease.

Designs in flannel. A long-sleeve, flannel gown was constructed in both long and short versions. The long gown was significantly warmer (0.69 clo) than the short gown (0.53 clo). As indicated previously, differences in insulation provided by each design were related to the amount of body surface area covered (see Table 29).

Designs in velour. Long-sleeve button front and wrap robes were constructed in velour in both long and short versions. The results were in agreement with the same design comparisons in broadcloth. There was no significant difference in the insulation provided by a long-sleeve button front robe and a wrap robe, in both long and short lengths. However, the long designs provided more insulation than their shorter counterparts did (see Table 31).

The short wrap robe was constructed in a long-sleeve version and a three-quarter length sleeve design. The $I_{cl}$ value for the long-sleeve robe (0.60 clo) was significantly warmer than the $I_{cl}$ for the robe with the shorter sleeve (0.55 clo). This difference is attributable to the change in body surface area covered by the robe sleeves.

One of kind items. These garments were not considered in the statistical analysis since no direct comparisons were made between these items with respect to design or fabric changes. The $I_{cl}$ value for the hospital gown was 0.44 clo, and the insulation provided by the body sleeper was 0.92 clo. The clo value for the hospital gown can be compared to the clo value of 0.33 for the tricot short-sleeve, short gown. Both garments covered a similar amount of body surface area, 57% and 59% respectively. The higher clothing insulation value for the hospital gown could be due to the garment design; the hospital gown overlapped in the back and tied on the side, creating a layering affect and additional insulation.

The body sleeper with feet covered the largest amount of body surface area (86%). The knit fleece fabric used in the body sleeper was thicker than any of the other fabrics used to construct sleepwear garments. Consequently, this garment provided the most insulation of any of the sleepwear items tested.

Ensemble Data

A number of representative ensembles were chosen that men and/or women would wear either during the winter and/or summer. No statistical analysis was conducted on the ensemble data since relatively few ensembles were tested, and they varied greatly with respect to component garments. The $I_T$, $I_{cl}$, and $f_{cl}$ values for the ensembles are presented in Table 32. The $I_{cl}$ values ranged from 1.71 for the ensemble with a warm, long-sleeve, long wrap robe, a flannel long-sleeve, long gown, and warm slippers, to 0.25 for the ensemble consisting of a T-shirt and boxer shorts. According to Figure 1 in ASHRAE Standard 55-1981 (3), optimal thermal comfort would be achieved by sedentary people dressed in the 1.71 clo ensemble when the air temperature was 16.7°C (62°F). The air temperature would have to be 31.4°C (78.5°F) if a person were wearing the 0.25 clo ensmble. These findings indicate that sleepwear ensembles can help people achieve thermal comfort over a wide range of indoor temperatures. This is because nightwear garments vary considerably in garment design (i.e., the amount of body surface area covered, the clothing area factor, and looseness or tightness of fit) and fabric type (i.e., thickness, R value). In addition people are probably more willing to change their clothing insulation to achieve comfort in their home environment than in public indoor environments. This is because they need to compensate for energy conservation strategies (e.g., adjusting the thermostat settings) that make their home cooler in winter and warmer in summer, and there is little social pressure to dress fashionably, attractively, or modestly in the home environment.

The $I_{cl}$ values for the component garments for each ensemble were summed (see Table 32). As expected, these figures were higher than the ensemble $I_{cl}$ values measured on the manikin. This finding is in agreement with previous studies (24, 25, 35) which found that the contribution that each additional garment makes toward the clo value of an ensemble is usually less than the individual garment's clo value. This phenomenon occurs because 1) the clothing insulation does not uniformly cover all of the body, 2) some garment layers and air layers are compressed when additional garments are added, and 3) the addition of more garments may increase the body/clothing surface area for heat loss (i.e., $f_{cl}$).

The ASHRAE formula (3) was used to predict ensemble $I_{cl}$ from the sum of the $I_{cl}$ values for the garments in each ensemble. Measured $I_{cl}$ values were plotted against the predicted $I_{cl}$ values in Figure 12. Points were close to the $45^{\circ}$ angle line, indicating that the ASHRAE formula is an adequate method for predicting the clothing insulation provided by the sleepwear ensembles used in this study. However, more sleepwear ensembles should be evaluated to verify that the ASHRAE formula is a good predictor of $I_{cl}$ for sleepwear ensembles.

Statistical Differences vs. Meaningful Differences

The statistical procedures used were very powerful, and differences in garment insulation values of 0.03 clo were found to be significant. The variance associated with each mean was low because only one sample garment of each type was tested, and the reproducibility of test results (replications) was very high. Consequently, some small differences between garment clo values may not be perceived by people, even though the differences were significant statistically.

Figure 1 of ASHRAE Standard 55-1981 (3) indicates that a change of 0.1 clo results in a preferred temperature change of $0.6^{o}C$ ($1^{o}F$). Therefore, some of the sleepwear design changes or fabric variations that made a significant improvement in insulation, may not influence a person's comfort. However, when several garments are worn together, in an ensemble, small changes in garment clo values can make a cumulative impact (i.e., be greater than 0.1 clo). In addition, smaller changes in clo value may be perceived by people in asymetric environments, where part of the body is subjected to high radiant temperature loads or high levels of air velocity.

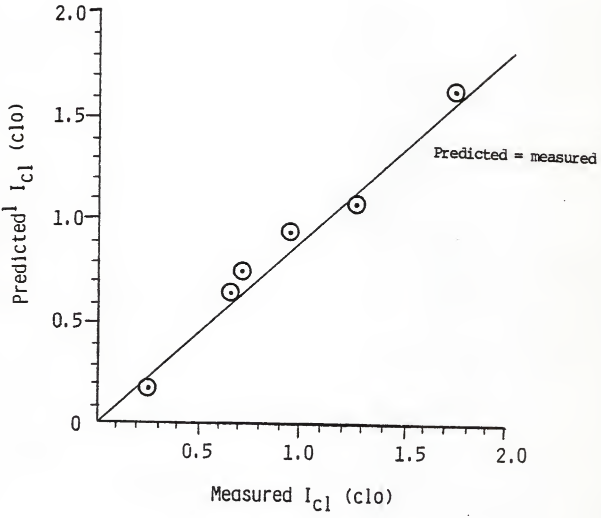


Figure 12. Relationship Between Measured and Predicted $I_{cl}$ Values for Representative Sleepwear Ensembles

[1] Predicted using the ASHRAE formula: $I_{cl}$ ensemble = $\Sigma$ ($I_{cl}$ garments) x 0.82

# Chapter 5

## CONCLUSIONS

This study measured the thermal insulation provided by a variety of robes and sleepwear garments, and ensembles composed of these garments. Garment design and fabric type were varied so that summer and winter versions of garments for both men and women were studied.

When fabric type was controlled, differences in the thermal insulation provided by different garment designs were related to the amount of body surface area covered by the designs. Garments with the highest clo values covered the largest amount of body surface. When garment design was controlled, the garments constructed of thicker fabrics with higher R values were warmer than the garments made of thinner fabrics with lower R values.

The ASHRAE formula was used to predict the clothing insulation ($I_{cl}$) of 6 selected sleepwear and robe ensembles. A broad range of warm and cool ensembles were represented. When the predicted $I_{cl}$ values were compared with the measured $I_{cl}$ values, ASHRAE formula seemed to be an adequate method for predicting the clothing insulation provided by the sleepwear ensembles. This is an important finding since sleepwear and robes were not part of the original data base in the Sprague and Munson (35) study where the formula was developed. Now that these data have been collected, they can be added to the ASHRAE list of garment clo values and the existing formula can be used to predict ensemble insulation.

The $I_{cl}$ values of the sleepwear garments studied ranged from 0.13 clo for the boxer shorts to 0.92 clo for the body sleeper with feet. The clo values for the robes ranged from 0.50 for the broadcloth, short-sleeve, short button front style to 1.24 for the pile knit, long-sleeve, long wrap robe. When these garments are combined and worn with underwear and footwear items, a great range of insulation values is possible. Consequently, people can use nightwear ensembles to achieve thermal comfort in a variety of indoor environments.

## Recommendations for Further Study

With the completion of this study, the thermal insulation provided by a variety of sleepwear garments, robes, and ensembles of these garments has been documented. The thermal properties of bedding fabrics (e.g., sheets, blankets) have been reported in the literature also (31). It would be interesting to study the insulation provided by different types and combinations of bedding and sleepwear using a manikin in bed. In addition, the effect of the amount of body surface area covered by the bedding alone, the bedding and sleepwear, and the sleepwear alone should be studied. After research on bedding/sleepwear systems has been completed using the manikin, thermal comfort studies using people could be conducted.

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# APPENDIX

TABLE 6

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Long Gown

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0417 | 156.25** | 0.0417 | 156.25** |
| Error | 4 | 0.0011 | | 0.0011 | |
| Total | 5 | 0.0427 | | 0.0427 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 7

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Short Gown

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0353 | 49.21** | 0.0353 | 49.21** |
| Error | 4 | 0.0029 | | 0.0029 | |
| Total | 5 | 0.0381 | | 0.0381 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 8

Analysis of Variance for Fabrics Constructed in Long-sleeve, Long Pajamas

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0104 | 24.04** | 0.0104 | 24.04** |
| Error | 4 | 0.0017 | | 0.0017 | |
| Total | 5 | 0.0122 | | 0.0122 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 9

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Long Wrap Robe

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 4 | 0.6153 | 200.64** | 0.6753 | 220.20** |
| Error | 10 | 0.0077 | | 0.0077 | |
| Total | 14 | 0.6230 | | 0.6830 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 10

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Short Wrap Robe

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0024 | 13.09* | 0.0030 | 16.26 |
| Error | 4 | 0.0007 | | 0.0007 | |
| Total | 5 | 0.0031 | | 0.0037 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 11

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Long Button Front Robe

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0060 | 11.65* | 0.0067 | 12.88* |
| Error | 4 | 0.0021 | | 0.0021 | |
| Total | 5 | 0.0081 | | 0.0087 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 12

Analysis of Variance for Fabrics Constructed in a Long-sleeve, Short Button Front Robe

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Fabric | 1 | 0.0033 | 19.60** | 0.0039 | 23.14** |
| Error | 4 | 0.0007 | | 0.0007 | |
| Total | 5 | 0.0039 | | 0.0045 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 13

Analysis of Variance for Designs Constructed in Tricot

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Design | 7 | 0.0460 | 23.55* | 0.1866 | 95.50* |
| Error | 16 | 0.0045 | | 0.0045 | |
| Total | 23 | 0.0505 | | 0.1911 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 14

Analysis of Variance for Designs Constructed in Broadcloth

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Design | 8 | 0.3995 | 156.79** | 0.7467 | 293.03** |
| Error | 18 | 0.0057 | | 0.0057 | |
| Total | 26 | 0.4053 | | 0.7524 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 15

Analysis of Variance for Designs Constructed in Flannel

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Design | 2 | 0.478 | 82.65** | 0.0660 | 114.32* |
| Error | 6 | 0.0017 | | 0.0017 | |
| Total | 8 | 0.0495 | | 0.0678 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 16

Analysis of Variance for Designs Constructed in Velour

| | | Total Insulation ($I_T$) | | Intrinsic Insulation ($I_{cl}$) | |
|---|---|---|---|---|---|
| Source | df | SS | F value | SS | F value |
| Design | 4 | 0.0178 | 13.89** | 0.0755 | 58.99** |
| Error | 10 | 0.0032 | | 0.0032 | |
| Total | 14 | 0.0210 | | 0.0787 | |

* Indicates significance at the 0.05 level.

** Indicates significance at the 0.01 level.

TABLE 17

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Long Gown

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Flannel | 3 | 1.17 | A | 0.69 | A |
| Tricot | 3 | 1.00 | B | 0.52 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 18

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Short Gown

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Flannel | 3 | 1.10 | A | 0.53 | A |
| Tricot | 3 | 0.95 | B | 0.38 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 19

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Long Pajamas

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Flannel | 3 | 1.28 | A | 0.73 | A |
| Broadcloth | 3 | 1.19 | B | 0.65 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 20

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Long Wrap Robe

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Pile Knit/Fleece | 3 | 1.73 | A | 1.24 | A |
| Quilted | 3 | 1.48 | B | 0.98 | B |
| Terry | 3 | 1.39 | C | 0.89 | C |
| Velour | 3 | 1.24 | D | 0.73 | D |
| Broadcloth | 3 | 1.14 | E | 0.63 | E |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 21

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Short Wrap Robe

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Velour | 3 | 1.17 | A | 0.60 | A |
| Broadcloth | 3 | 1.13 | B | 0.55 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 22

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Long Button Front Robe

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Velour | 3 | 1.20 | A | 0.72 | A |
| Broadcloth | 3 | 1.14 | B | 0.66 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 23

Duncan's Multiple Range Test for Fabrics Constructed in a Long-sleeve, Short Button Front Robe

| | | $I_T$ (clo) | | $I_{cl}$ (clo) | |
|---|---|---|---|---|---|
| Fabric | N | Mean | Grouping[1] | Mean | Grouping[1] |
| Velour | 3 | 1.16 | A | 0.63 | A |
| Broadcloth | 3 | 1.11 | B | 0.58 | B |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 24

Duncan's Multiple Range Test for a Variety of Designs Constructed in Tricot

| | | $I_T$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Gown | 3 | 1.00 | A |
| Short-sleeve, Long Gown | 3 | 0.97 | B |
| Long-sleeve, Short Gown | 3 | 0.95 | B, C |
| Short-sleeve, Short Gown | 3 | 0.92 | C, D |
| Thin Strap, Long Gown | 3 | 0.91 | D, E |
| Thin Strap, Short Gown | 3 | 0.89 | E, F |
| Sleeveless, Long Gown | 3 | 0.89 | E, F |
| Sleeveless, Short Gown | 3 | 0.86 | F |

1 Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 25

Duncan's Multiple Range Test for a Variety of Designs Constructed in Tricot

| | | $I_{cl}$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Gown | 3 | 0.52 | A |
| Short-sleeve, Long Gown | 3 | 0.48 | B |
| Sleeveless, Long Gown | 3 | 0.39 | C |
| Long-sleeve, Short Gown | 3 | 0.38 | C |
| Thin Strap, Long Gown | 3 | 0.37 | C |
| Short-sleeve, Short Gown | 3 | 0.33 | D |
| Sleeveless, Short Gown | 3 | 0.26 | E |
| Thin strap, Short Gown | 3 | 0.26 | E |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 26

Duncan's Multiple Range Test for a Variety of Designs Constructed in Broadcloth

| | | $I_T$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Pajamas | 3 | 1.19 | A |
| Long-sleeve, Long Wrap Robe | 3 | 1.14 | B |
| Long-sleeve, Long Button Front Robe | 3 | 1.14 | B |
| Short-sleeve, Long, Pajamas | 3 | 1.13 | B |
| Long-sleeve, Short Wrap Robe | 3 | 1.13 | B |
| Long-sleeve, Short Button Front Robe | 3 | 1.11 | B |
| Short-sleeve, Short Button Front Robe | 3 | 1.05 | C |
| Long, Pajama Trousers | 3 | 0.88 | D |
| Boxer Shorts | 3 | 0.82 | E |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 27

Duncan's Multiple Range Test for a Variety of Designs Constructed in Broadcloth

| | | $I_{cl}$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Button Front Robe | 3 | 0.66 | A |
| Long-sleeve, Long Pajamas | 3 | 0.65 | A |
| Long-sleeve, Long Wrap Robe | 3 | 0.63 | A |
| Long-sleeve, Short Button Front Robe | 3 | 0.58 | B |
| Short-sleeve, Long pajamas | 3 | 0.56 | B |
| Long-sleeve, Short Wrap Robe | 3 | 0.55 | B |
| Short-sleeve, Short Button Front Robe | 3 | 0.49 | C |
| Long, Pajama Trousers | 3 | 0.29 | D |
| Boxer Shorts | 3 | 0.14 | E |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 28

Duncan's Multiple Range Test for a Variety of Designs Constructed in Flannel

| | | $I_T$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Pajamas | 3 | 1.28 | A |
| Long-sleeve, Long Gown | 3 | 1.17 | B |
| Long-sleeve, Short Gown | 3 | 1.10 | C |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 29

Duncan's Multiple Range Test for a Variety of Designs Constructed in Flannel

| | | $I_{cl}$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Pajamas | 3 | 0.73 | A |
| Long-sleeve, Long Gown | 3 | 0.69 | B |
| Long-sleeve, Short Gown | 3 | 0.53 | C |

1 Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 30

Duncan's Multiple Range Test for a Variety of Designs Constructed in Velour

| | | $I_T$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Wrap Robe | 3 | 1.24 | A |
| Long-sleeve, Long Button Front Robe | 3 | 1.20 | B |
| Long-sleeve, Short Wrap Robe | 3 | 1.17 | C |
| Long-sleeve, Short Button Front Robe | 3 | 1.16 | C |
| 3/4 Length Sleeve, Short Wrap Robe | 3 | 1.14 | C |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 31

Duncan's Multiple Range Test for a Variety of Designs Constructed in Velour

| | | $I_{cl}$ (clo) | |
|---|---|---|---|
| Design | N | Mean | Grouping[1] |
| Long-sleeve, Long Wrap Robe | 3 | 0.73 | A |
| Long-sleeve, Long Button Front Robe | 3 | 0.72 | A |
| Long-sleeve, Short Button Front Robe | 3 | 0.63 | B |
| Long-sleeve, Short Wrap Robe | 3 | 0.60 | B |
| 3/4 Length Sleeve, Short Wrap Robe | 3 | 0.55 | C |

[1] Means with the same letter designations are not significantly different from one another at the 0.05 level.

TABLE 32

Thermal Characteristics of Representative Sleepwear Ensembles

| Component Garments | | | Garment | Ensemble | | | |
|---|---|---|---|---|---|---|---|
| Fabric | Design | | $I_{cl}$ | $I_T$ | $f_{cl}$ | $I_{cl}$ | Predicted[1] $I_{cl}$ |
| Pile Knit | Long-sleeve, Long Wrap Robe | | 1.24 | | | | |
| Flannel | Long-sleeve, Long Gown | | 0.69 | | | | |
| Quilted w/Pile Lining | Slippers | | 0.06 | | | | |
| | | Sum | 1.99 | 2.19 | 1.49 | 1.71 | 1.63 |
| Velour | Long-sleeve, Long Wrap Robe | | 0.73 | | | | |
| Flannel | Long-sleeve, Long Pajamas | | 0.65 | | | | |
| Quilted w/Pile Lining | Slippers | | 0.06 | | | | |
| | | Sum | 1.44 | 1.75 | 1.42 | 1.25 | 1.18 |
| Broadcloth | Long-sleeve, Short Wrap Robe | | 0.55 | | | | |
| Broadcloth | Short-sleeve, Long Pajamas | | 0.57 | | | | |
| Vinyl | Thongs | | 0.03 | | | | |
| | | Sum | 1.15 | 1.46 | 1.33 | 0.93 | 0.94 |
| Broadcloth | Long-sleeve, Short Button Front Robe | | 0.58 | | | | |
| Tricot | Sleeveless, Short Gown | | 0.29 | | | | |
| Vinyl | Thongs | | 0.03 | | | | |
| | | Sum | 0.90 | 1.24 | 1.31 | 0.70 | 0.74 |
| Broadcloth | Short-sleeve, Short Button Front Robe | | 0.50 | | | | |
| Tricot | Thin Strap, Short Gown | | 0.23 | | | | |
| Vinyl | Thongs | | 0.03 | | | | |
| | | Sum | 0.76 | 1.21 | 1.29 | 0.66 | 0.62 |
| Jersey Knit | Short-sleeve, T-Shirt | | 0.10 | | | | |
| Broadcloth | Boxer Shorts | | 0.13 | | | | |
| | | Sum | 0.23 | 0.91 | 1.07 | 0.25 | 0.19 |

[1] Predicted using the ASHRAE formula: $I_{cl}$ ensemble = ($I_{cl}$ garments) x 0.82

THERMAL INSULATION CHARACTERISTICS

of

SLEEPWEAR AND ROBES

by

VIRGINIA MAY NOON

B. S. Framingham State College, 1981

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AN ABSTRACT OF A MASTER'S THESIS

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Department of Clothing, Textiles and Interior Design

Kansas State University

Manhattan, Kansas

1984

The purpose of this study was to determine the thermal insulation values of selected sleepwear and robes constructed in winter (warm) and summer (cool) fabrics. Fabric type was held constant to evaluate garment design, and garment design was held constant when evaluating fabric type. A number of representative ensembles also were evaluated that men and/or women would wear in both winter and summer.

An electrically heated copper manikin, located in an environmental chamber, was used to measure the amount of clothing insulation provided by each garment and ensemble. The total insulation value ($I_T$), the intrinsic insulation value ($I_{cl}$), and the clothing area factor ($f_{cl}$) were reported for each garment and ensemble. Garment weight and the amount of body surface area covered by each garment also were determined. The thermal insulation (R) value, thickness, and weight of fabrics used to construct the garments also were measured.

When garment design was controlled, the winter fabrics with the greatest thickness and R values provided more garment insulation than did the summer and representative fabrics with lower thickness and fabric insulation. When fabric type was controlled, differences in thermal insulation provided by different garment designs were related to the amount of body surface area covered. Garments with the highest clo values covered the largest amount of body surface area.

The $I_{cl}$ values for the sleepwear garments studied ranged from 0.13 clo for boxer shorts to 0.92 clo for the body sleeper with feet. The clo values for the robes ranged from 0.50 for the short-sleeve, short button front style made of broadcloth to 1.24 for the pile knit, long-sleeve, long wrap robe. It appears that a great range of ensemble insulation values are possible when sleepwear garments and robes are worn with underwear and footwear items. Consequently, people can use nightwear ensembles to achieve thermal comfort in a variety of indoor environments. In addition, the clo value data for the garments and ensembles used in this study indicated that the ASHRAE formula is an adequate method for predicting the insulation provided by sleepwear ensembles.