©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

DC-83-11 No. 2

Insulation Characteristics of Winter and Summer Indoor Clothing

E.A. McCullough, Ph.D. D.P. Wyon, Ph.D.

ABSTRACT

The thermal insulation (clo) values of clothing ensembles commonly worn by men and women in indoor environments were measured using an electrically heated manikin. The same designs, construction methods, and support materials were used to make a set of winter and summer garments, differing only in fabric type. Garments such as a suit jacket, vest, sweater, and tie were systematically added to basic trouser ensembles and skirt ensembles to study the effect of garment layering and closure. Results indicated that adding or removing certain garments and changing how they are worn on the body affect the level of clothing insulation. Winter ensembles were significantly warmer than comparable summer ensembles, but the insulation provided by most summer ensembles was higher than that indicated by ASHRAE Standard 55-1981 for typical summer attire. In addition, a high correlation between ensemble weight and clo value was found.

INTRODUCTION

Clothing insulation, described in terms of its clo value, is an important modifier of body heat loss and comfort. The type of clothing worn by people in indoor environments is influenced by the season and the outdoor weather conditions. The revised ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy" (ASHRAE 1981), specifies acceptable ranges of operative temperature and humidity for persons clothed in "typical winter and summer clothing" at light activity levels ($\leq$ 1.2 met). Specifically, the operative temperature range for 80% thermal acceptability in the winter is 68-74.5°F (20-23.6°C), with an optimum temperature oF 71°F (21.7°C). These guidelines are based on the assumption that people are wearing 0.8-1.2 clo of insulation. According to the Standard, a typical winter ensemble consists oF heavy slacks, a long-sleeve shirt, and a sweater and provides 0.9 clo of insulation. The operative temperature range specified for summer comfort is 73-79°F (22.8-26.1°C), with an optimum temperature oF 76°F (24.4°C). Summer ensembles have clo values ranging from 0.35-0.6, with a typical ensemble (i.e., light slacks and a short-sleeve shirt) providing 0.5 clo of insulation.

In order to use these new guidelines effectively, an individual needs to know what types of clothing provide the insulation levels given in the Standard. The Standard includes a list of clo values for a few garments, and it suggests adding the clo values of individual garments together and multiplying the sum by 0.82 to estimate the clo value of an ensemble. However, this list is limited in that it lacks adequate representation oF garment designs and fabric

Elizabeth A. McCullough, Associate Professor, Textile Science, Kansas State University, and David P. Wyon, Head of the Human Criteria Laboratory, National Swedish Institute for Building Research.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

weights. (This problem has been addressed in McCullough, Jones, and Zbikowski [1983].) In addition, the variability in clo values for light and heavy or male and female versions of a garment is large due to a number of uncontrolled variables. For example, the standard indicates that the clo value of a woman's pair of heavy slacks is 0.44 clo, but the insulation provided by a man's pair of heavy trousers is only 0.32. Therefore, more information concerning the insulation of clothing ensembles is needed. Specifically, how much flexibility do people actually have in altering their clothing to achieve thermal comfort?

The purpose of this study was to measure the thermal insulation of different clothing ensembles typically worn by men and women in indoor environments during the winter and summer. The objectives were to:

- determine the practical range of clo values attainable for indoor clothing commonly worn by men and women during the summer and winter.
- identify which ensembles have clo values within the range specified by ASHRAE Standard 55-1981 for winter and for summer.
- examine the cumulative effects of layering garments on the clo values of ensembles.
- examine the effect of adjusting garment closure (i.e., buttoned vs. unbuttoned) on the clo value of ensembles.
- compare the insulation provided by winter and summer ensembles with the same design and construction characteristics.
- examine the relationship between ensemble weight and insulation.

In an earlier study by Seppanen et al.(1972), researchers selected "warm" and "cool" examples of garments from stores and measured the clo value of ensembles using a thermal manikin. Consequently, differences (or lack of differences) in clo value between similar ensembles could have been due to a variety of garment features. For example, a warm jacket and a cool jacket were each evaluated over the same set of garments, and no difference in thermal insulation was found between the two. Therefore, a systematic, controlled approach to the problem was used in this study to ensure both internal and external validity.

EXPERIMENTAL PROCEDURE

Clothing

The clothing ensembles used in this project were representative of those worn by men and women in indoor environments during the summer and winter. The ensembles encompass different amounts of garment layering and closure. Most of the ensembles containing trousers could be worn by both men and women, whereas the skirt ensembles would be limited to women. The shirt/skirt combinations also represent dresses of similar design (McCullough, Jones, and Zbikowski 1983).

The trousers, skirts, vests, shirts, and suit jackets were constructed using industrial sewing machines and techniques. The same construction methods, notions, and support fabrics were used in making the garments to minimize the variation between them. The summer garments were made with a 6 oz cotton twill fabric, .028 in. (0.7 mm) in thickness, with a total clo value of 0.88, measured using a guarded hot plate. (Total clo values include an air layer of approximately 0.6 clo). The winter garments were made with 9 oz 80/20 wool/nylon twill, .058 in. (1.5 mm) in thickness, with a total clo value of 0.98. Both fabrics were significantly different with respect to thickness, weight, and insulation value (see table 1). All shirts were constructed of 3 oz 65/35 polyester/cotton broadcloth. Other garments, e.g., sweater, underwear, shoes, were purchased ready-made.

Individual garments were weighed three times on a top-loading balance. Weights of the different ensembles were calculated using these data (see tables 2 through 5).

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

Measuring the Thermal Insulation Values

An electrically heated manikin was used to measure the thermal insulation (clo) value of the clothing ensembles. The thermal manikin, SIBMAN, was developed from a display manikin by researchers at the National Swedish Institute for Building Research. The manikin's shell consists of fiberglass reinforced polyester, and it has movable joints at the shoulders, elbows, hips, and knees. The body is divided into 16 segments--each with an independent proportional integral controller to regulate heating (see figure 1). The manikin's sections are heated to simulate the skin temperature distribution of a human being in thermal comfort. The actual temperature set points used in this experiment are given in figure 1. Copper constantan thermocouples are attached to the outside surface of the manikin on each segment. When the manikin is nude, the temperature measurement at one point on a body section represents the average for that section. A digital computer is used to control the manikin's skin temperature distribution by altering the amount of power needed to keep each section at its prescribed temperature.

The manikin was placed in a computer-controlled environmental chamber. The experimental conditions were controlled as follows: air temperature = 22°C, air velocity = 0.1 m/s, and relative humidity = 40-50%. The manikin was dressed in an ensemble and supported in a standing position. Area-weighted power and temperature measurements were recorded by the computer every 10 minutes, and the corresponding thermal insulation values were calculated. When the correct skin temperature distribution was achieved and the power to all body segments reached equilibrium, the clo value for the ensemble became stable. The data were collected, and the procedure was repeated with a different ensemble. The total thermal insulation value (I_T) was calculated using the following equation:

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

where

I_T = Total thermal insulation of clothing plus air layer, clo

K = Constant = 6.45 clo · W/m^2·°C

$\bar{T}_s$ = Mean skin temperature, °C

T_a = Ambient air temperature, °C

A_s = Manikin surface area, m^2

H = Power input, W

The total insulation value (I_T) of an ensemble was reported as an average of two replications, because all pairs of individual values were within ± 3%.

The intrinsic clo value of the clothing (I_{cl}) was found by subtracting the insulation provided by the air layer surrounding the clothing from the total clo value (I_T).

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

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 nude manikin, clo

f_{cl} = Clothing area factor

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

The value of I_a (0.71) was obtained by operating the manikin without clothing and using the equation for calculating I_T. The clothing area factor (f_{cl}) for each ensemble was determined using a photographic method (McCullough, Jones, and Zbikowski 1983). A planimeter was used to determine the surface area of the garments and the nude manikin from a series of photographs taken at different angles. The f_{cl} was calculated as the surface area of the clothed manikin divided by the surface area of the nude manikin.

RESULTS AND DISCUSSION

The total insulation values (I_T) were used in the statistical analysis because less variability was associated with their measurement than with the I_{cl} values that depend upon both I_T and f_{cl} determinations. One-way analysis of variance was used to test for differences in the insulation provided by the ensembles within the four clothing groups: winter trouser ensembles, winter skirt ensembles, summer trouser ensembles, and summer skirt ensembles. As expected, all four analyses revealed that ensemble type significantly affected thermal insulation at the 0.01 level. A Duncan's multiple range test was used to indicate which ensembles within each group had significantly higher or lower clo values than the others. Comparisons of similar ensembles in different groups were made with t-tests. All differences between ensembles that are mentioned in the following discussion are significant at the 0.05 level. The results are discussed in terms of intrinsic clothing insulation (I_{cl}) rather than total insulation (I_T), because I_{cl} values are reported in ASHRAE Standard 55-1981. In addition, Pearson correlation coefficients were used to determine the relationship between insulation value and ensemble weight for each group.

The clo values measured on SIBMAN appeared to be slightly higher than values reported in the literature for similar ensembles (Seppanen et al. 1972). For example, a two-piece business suit is supposed to represent approximately 1.0 clo of insulation (ASHRAE 1981). The winter version of this ensemble (#11) had a clo value of 1.21, while the summer versions, #7 with a short-sleeve shirt and #16 with a long-sleeve shirt, measured 1.09 and 1.16 clo respectively. In addition, a few clothing items that had been evaluated with a manikin at another laboratory (including the KSU Standard Uniform) were tested using SIBMAN for comparison. The clo values measured for these garments on SIBMAN were approximately 3-5% higher. This finding will be considered when determining which ensembles meet the ranges specified in ASHRAE Standard 55-1981 for thermal acceptability in the summer and winter comfort envelopes.

Winter Trouser Ensembles

The ensembles listed in table 2 represent those commonly worn by people in indoor environments during the winter. They range from #1, trousers, a long-sleeve shirt, underwear, socks, shoes, and a belt (0.74 clo) to #15, trousers, a long-sleeve shirt, T-shirt, underwear, socks, shoes, sweater, closed suit jacket, and a belt (1.26 clo).

Wearing a T-shirt or sleeveless undershirt with an ensemble increased its insulation value. Specifically, shirt/trouser ensemble #1 has a clo value of 0.74, but when a T-shirt (#2) or sleeveless undershirt (#3) was added, the clo value rose to 0.81. There was no difference in the insulation provided by the two types of undershirts because the absence of sleeves in the undershirt was compensated for by a heavier, thicker, ribbed knit fabric. Although women usually do not wear T-shirts under other garments, they often wear brassieres, camisoles, and/or sleeveless undershirts under their clothing for support, warmth, and/or aesthetic reasons. Consequently, the clo values associated with ensembles containing T-shirts could be used to describe both men and women. The clo values listed in table 2 would probably be slightly lower if men and women elected not to wear T-shirts or similar undergarments with the ensembles. The difference would not always be 0.07, however, because as more garments are added, the effect of the additional T-shirt would diminish.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

Adding a vest, sweater, or suit jacket (worn open or closed) to the basic ensemble #2 increased the insulation significantly. Adding a suit jacket (open or closed) to sweater ensembles #6 and 7 or to vest ensemble #5 increased the clo value, too. Adding a vest, sweater, and suit jacket (worn open or closed) to ensemble #4 with a tie, increased the insulation significantly. In all of the ensembles with suit jackets, wearing the jacket buttoned closed resulted in a higher clo value than wearing it open.

Fastening the top button of a shirt and wearing a tie usually increased the insulation provided by an ensemble slightly. Specifically, the ensembles with ties (#6, 10, 11) were significantly warmer than their counterparts without ties, worn open at the neck (#7, 8, 9 respectively). The only exception, #4 did not provide significantly more insulation than #2. Ensemble #6 with a tie and sweater also provided more insulation than #5 with a tie and vest.

Winter Skirt Ensembles

The ensembles listed in table 3 are commonly worn by women in school or office environments during the winter. The coolest ensemble #2, consists of a skirt, a long-sleeve shirt, slip, underpants, pantyhose, and shoes (0.74 clo). The warmest ensembles, #8 with the garments in #2 plus a vest and closed suit jacket, and #10 with the garments in #2 plus a sweater and closed suit jacket, had clo values of 1.21 and 1.23 respectively (i.e., not significantly different).

Wearing knee socks (#1) instead of pantyhose (#2) with the basic garments increased the insulation value of the ensemble from 0.74 to 0.84. As additional garments were added to the top half of the body, the insulation was improved. Specifically, a closed suit jacket (#6) provided more insulation than an open suit jacket (#5), followed by a sweater (#4) and a vest (#3). When the suit jacket was worn closed over a shirt alone (#6) or with a vest (#8) or sweater (#10), the ensembles had significantly higher clo values than when the jacket was worn open (#5, 7, 9 respectively).

Although the skirt ensemble with the sweater (#4) provided more insulation than the ensemble with the vest (#3), these differences were minimized when a suit jacket was added. Specifically, when the suit jacket was worn open over a vest (#7) or over a sweater (#9) and when it was worn closed over a vest (#8) or a sweater (#10), the clo values were not significantly different.

Summer Trouser Ensembles

The ensembles listed in table 4 are frequently worn by men and women in summer indoor environments. The coolest ensemble (#20) consists of a sleeveless shirt, short shorts, underwear, sandals, and a belt and has a clo value of 0.32. Ensemble #19, containing a short-sleeve shirt, bermuda shorts, underwear, socks, shoes, and a belt, also is relatively cool with a I_{cl} value of 0.45. However, formal and informal dress codes prohibit the frequent wearing of these ensembles in schools and offices. Ensemble #18 provided the most insulation, 1.19 clo, and consisted of a summer vest, closed suit jacket, and trousers, a long-sleeve shirt, tie, underwear, socks, shoes, and a belt.

Ensembles #1 through 9 contain short-sleeve shirts, whereas #10 through 18 have long-sleeve shirts. Ensemble #1 with trousers and a short-sleeve shirt was significantly cooler than ensemble #10 with a long-sleeve shirt. This pattern continued as like ensembles were compared, with one exception--ensembles #6 and 15 with the trousers, tie, and open suit jacket worn with the different shirts, were not significantly different.

When similar ensembles were compared with and without a tie, some of the ensembles with an open neck were significantly cooler than those with a closed neck and tie. Specifically, when a tie was added to a shirt/trouser ensemble (#2, 11) it increased the clo value, as compared to the base ensembles without it (#1, 10 respectively). When ensembles with open and closed suit jackets were tested with and without a tie and either a long-sleeve or short-sleeve

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.
shirt, the results were inconclusive. The tie made #6 and 16 warmer than their counterparts, #4 and 14 respectively, but the other combinations were not significantly different (i.e., #5 and 7, 13 and 15).

Summer Skirt Ensembles

Skirt ensembles commonly worn by women in school or office environments during the summer are presented in table 5. The coolest ensemble, #1, consists of a sleeveless U-neck shirt, skirt, underpants, pantyhose, and sandals (0.53 clo). The warmest ensembles, #6 with the basic garments, a closed suit jacket, and a short-sleeve shirt, and #8 with the basic garments, a closed suit jacket, and a long-sleeve shirt, had I_{cl} values of 1.02 and 1.03 respectively (i.e., not significantly different).

A wider variety of shirt designs is available for women to wear in a professional environment than for men. Ensembles #1, 2, and 3 represent shirt designs with different amounts of body coverage. As expected, ensemble #1 with a sleeveless U-neck shirt (0.53 clo) was significantly cooler than #2 with a short-sleeve shirt (0.61 clo); and #2 was cooler than #3 with a long-sleeve shirt (0.70 clo). Most summer skirts and dresses are unlined and often worn without a slip. However, adding a slip (#4) to the short-sleeve shirt/skirt ensemble (#2) increased the insulation from 0.61 clo to 0.70 clo.

Adding a suit jacket to the short-sleeve shirt ensemble and the long-sleeve shirt ensemble increased the insulation values significantly, whether the jacket was worn open or closed. When the suit jackets were worn closed (#6 and 8), they provided significantly more insulation than when they were worn open over the same garments (#5 and 7, respectively). However, there was no difference in the insulation provided by a suit jacket worn open over a short-sleeve shirt (#5) and over a long-sleeve shirt (#7). There was no difference between a suit jacket worn closed over the two type of shirts either (#6 and 8). Apparently, the addition of a jacket minimized the differences in insulation between the long-sleeve and short-sleeve shirts.

Comparison of Winter and Summer Ensembles

Some of the winter and summer ensembles differed only with respect to the fabrics used in the vest, suit jacket, skirt, and trousers. Winter ensembles containing garments made of the thicker, heavier wool blend fabric were significantly warmer than similar summer ensembles containing garments of the cotton fabric. For example, a winter trouser ensemble consisting of a long-sleeve shirt, trousers, underwear, socks, shoes, and a belt (#1) had a higher clo value (0.74) than the comparable summer trouser ensemble (#10, 0.70 clo). Although other winter trouser ensembles contained T-shirts, their clo values can still be compared to similar summer ensembles without T-shirts. The differences between the groups are larger than would be expected, however, since the T-shirt was worn with the winter garments. In all comparable cases, the winter trouser ensembles (#2, 4, 5, 8, 9, 10, 11, 12, 13) were significantly warmer than their summer counterparts (#10, 11, 12, 13, 14, 15, 16, 17, 18); (see tables 2 and 4).

Winter skirt ensemble #2 with a long-sleeve shirt, skirt, pantyhose, underpants, and shoes had a significantly higher insulation (0.74 clo) than its summer counterpart, #3 (0.70 clo). Part of this difference is probably due to the sandals worn with the summer ensembles. When suit jackets were added to these ensembles, the winter ensembles (#5, 6) were still warmer than the comparable summer ensembles (#7, 8); (see tables 3 and 5).

ASHRAE Clo Value Ranges for Typical Winter and Summer Clothing

ASHRAE temperature and humidity boundaries for the winter are based on the assumption that people are wearing 0.8-1.2 clo of insulation. The data in table 2 indicate that to achieve this range in trouser ensembles, a vest, sweater, and/or suit jacket should be added to a long-sleeve shirt, T-shirt, trousers, underwear, socks, shoes, and a belt. For skirt ensembles, a vest, sweater, and/or suit jacket also should be added to a long-sleeve shirt, skirt,

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

underpants, pantyhose, and shoes to provide enough insulation for comfort (table 3). Although some winter ensembles have clo values lower than the specified range, there appears to be no problem with ensembles providing too much insulation.

According to the Standard, typical summer clothing provides 0.35-0.6 clo of insulation. This range is questionable considering the large number of summer trouser and skirt ensembles that provide a greater amount of insulation (see tables 4 and 5). For example, ensembles with a vest and/or suit jacket have clo values higher than the 0.6 clo upper limit. These ensembles are often worn by professional people in their work environments. Only simple shirt/trouser and shirt/skirt ensembles provide the level of insulation necessary for summer indoor comfort.

Correlations between Ensemble Insulation and Weight

The total thermal insulation values and weight measurements were correlated for the ensembles in each category. The correlation coefficients were 0.97 for winter trouser ensembles, 0.98 for winter skirts, 0.96 for summer trousers, and 0.98 for summer skirts. These high, positive correlations between ensemble clo values and weights are due partly to the design of the study: garments were purposefully added to a basic ensemble to examine the potential layering variations that would increase insulation. The systematic addition of more garments to an ensemble not only increased the weight of the ensemble but also the thickness of the clothing and the air trapped between fabric layers. However, it is impossible to determine a thickness value for an entire ensemble, because thickness varies within individual garments and where several garments are layered on top of one another.

Heat Loss Comparisons

The average heat loss (W/m^2) from the total body and from selected body sections (i.e., back, chest, upper arms, lower arms, thighs, calves, and feet) for all ensembles within a clothing group was calculated. T-tests were used to compare the average heat losses from trouser ensembles and skirt ensembles for summer and winter clothing. The results indicated that the sectional heat losses from the manikin's calves and feet were significantly greater for the skirt ensembles than for the trouser ensembles for both summer and winter clothing. These findings reveal a lack of insulation provided by pantyhose as compared to socks and trousers. In addition, sandals were worn with the summer skirt ensembles as compared to shoes with the trouser ensembles (except #20). Surprisingly, the sectional heat loss for the thighs was significantly greater for the trouser ensembles than for the skirt ensembles for both summer and winter clothing. This finding is probably due to the increased still air insulation between the skirts and thighs as opposed to the tight-fitting trousers. Once a person begins moving, forcing air motion around the thighs, the heat lost from the thighs would probably be greater in the skirt ensembles. This illustrates the need for evaluating the thermal insulation of clothing on a moving manikin. Although differences in clo value due to manikin motion have been reported by Olesen et al. (1982), differences in sectional heat loss were not discussed.

Environmental Temperatures for Heat Balance in Different Ensembles

Tables 6 through 9 present the air temperatures necessary for thermal equilibrium for sedentary work (60 W/m^2) and active office work (75 W/m^2) for each clothing ensemble. These are the temperatures for which the dry heat loss would be 48 and 60 W/m^2, respectively (assuming 80% dry heat loss). If the air temperature differs from the temperature specified for a given ensemble and activity level, adjustments must be made in a person's skin temperature distribution to maintain equilibrium.

For winter trouser ensembles, the air temperatures for sedentary work range from 19.1-22.8°C. The temperatures for active office work range from 15.7-20.3°C. For sedentary work in winter skirt ensembles, the temperatures range from 19.7-23.2°C, and for active office work they range from 16.4-20.8°C. It appears that the environmental temperatures can be slightly lower in the

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

winter if people wear trousers instead of skirts. The air temperatures that would permit heat balance for people dressed in summer trouser ensembles and doing sedentary work range from 19.7-23.7°C for long trousers and 25.6°C for shorts. The temperature range for these ensembles and active office work are 16.4-21.5°C and 23.8°C. For sedentary work in summer skirt ensembles, the air temperatures range from 21.1-24.6°C; for active office work, 18.2-22.6°C. The range of temperatures necessary for summer skirt ensembles are higher than those for trousers, with the exception of shorts.

CONCLUSIONS

People can make significant adjustments in their levels of clothing insulation by adding or removing garments and, to a limited extent, by varying the amount of closure. Clo values measured in this study using a thermal manikin range from 0.74 to 1.26 for winter ensembles and from 0.32 to 1.19 for summer ensembles. Many summer suit ensembles provided more insulation than the amount indicated for typical summer clothing in ASHRAE Standard 55-1981.

When a suit jacket was added to a trouser or skirt ensemble, it provided significantly more insulation than the addition of a sweater--which was warmer than the addition of a vest. Wearing a suit jacket buttoned closed provided more insulation than wearing it open for most ensembles. This difference in insulation would probably be more pronounced during body movement. Ensembles with long-sleeve shirts generally had higher clo values than ensembles with short-sleeve shirts, with the exception of some jacket combinations.

Buttoning a shirt at the neck and adding a tie increased the insulation provided by some ensembles (as opposed to opening the shirt collar) and made no difference in others. These findings are in agreement with the inconsistent reports in the literature. For example, Seppanen et al. (1972) found that a tie had no effect on the clo value of ensembles, whereas ASHRAE Standard 55-1981 indicates that a tie increases ensemble insulation by 5%. Consequently, research on human subjects is needed to determine which clothing adjustment strategies produce a significant change in personal thermal comfort.

REFERENCES

1. ASHRAE 1981. "Thermal environmental conditions for human occupancy" ASHRAE Standard 55-1981. Atlanta: ASHRAE.

2. McCullough, E. A.; Jones, B. W.; and Zbikowski, P. J. 1983. "The effect of garment design on the thermal insulation of clothing" ASHRAE Transactions 89, Part 2.

3. Olesen, B. W.; Sliwinska, E.; Madsen, T. L.; and Fanger, P. O. 1982. "Effect of body posture and activity on the thermal insulation of clothing: Measurements by a movable thermal manikin" ASHRAE Transactions 88, Part 2.

4. Seppanen, O.; McNall, P. E.; Munson, D. M.; and Sprague, C. H. 1972. "Thermal insulating values for typical indoor clothing ensembles" ASHRAE Transactions 78, Part 1.

ACKNOWLEDGMENTS

The authors wish to thank Christer Tennstedt, computer programer at the National Swedish Institute for Building Research, for his assistance in operating the manikin.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 1

Description of Ensemble Components

Garment[a]	Description
Suit jacket[b]	Notched collar, front button closure, front breast pocket, 2 front hip patch pockets, acetate lining
Vest[b]	V-neck vest, front button closure, acetate lining
Skirt[b]	A-line skirt, knee length
Trousers[b]	Fitted long trousers, 2 front hip pockets with acetate lining
Bermuda shorts	2 front hip pockets with acetate lining, mid-thigh length, cotton, 6 oz twill
Short shorts	2 front hip pockets with acetate lining, hip length, cotton, 6 oz twill
Long-sleeve shirt	Shirt collar, front button closure, long-sleeves, cuffs, 65/35 polyester/cotton, 3 oz broadcloth
Short-sleeve shirt	Shirt collar, front button closure, short-sleeves, 65/35 polyester/cotton, 3 oz broadcloth
Sleeveless shirt	U-neck in front and back, sleeveless, 65/35 polyester/cotton, 3 oz broadcloth
Sweater	V-neck, long-sleeves, wool jersey knit
Tie	Nylon plain weave
Half-slip	Nylon tricot knit, elastic waistband
Summer pantyhose	20 denier, nylon crepe stitch knit
Winter pantyhose	40 denier, nylon crepe stitch knit
Socks	Cotton knit
Knee socks	Wool knit
Men's underwear	Cotton knit, elastic waistband
Women's underpants	Cotton knit, elastic waistband
T-shirt	Round neck, short sleeves, cotton jersey knit
Sleeveless undershirt	U-neck, sleeveless, cotton rib knit
Shoes	Covers foot; ties, leather
Sandals	Open-lattice shoes, vinyl
Belt	1 in. wide, leather

[a] Illustrations of the outer garments are presented in McCullough, Jones, and Zbikowski (1983).

[b] These garments are constructed of 80/20 wool/nylon, 9 oz twill suiting fabric when used in winter ensembles. Garments used in summer ensembles are constructed exactly the same using cotton, 6 oz twill fabric.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 2

Characteristics of Winter Trouser Ensembles

	Ensemble Description	Weight oz (g)	Total Clo (I_T)	Clothing Area Factor (f_{cl})	Intrinsic Clo (I_{cl})
1	Basic garments[a] without T-shirt	60.4 (1,713)	1.34	1.19	0.74
2	Basic garments	63.8 (1,810)	1.41	1.19	0.81
3	Basic garments, sleeveless undershirt instead of T-shirt	64.8 (1,838)	1.41	1.19	0.81
4	Basic garments, tie	65.1 (1,847)	1.42	1.20	0.83
5	Basic garments, tie, vest,	72.5 (2,054)	1.51	1.21	0.92
6	Basic garments, tie, sweater,	74.2 (2,105)	1.61	1.22	1.03
7	Basic garments, sweater	72.9 (2,067)	1.58	1.21	0.99
8	Basic garments, open suit jacket	88.5 (2,509)	1.69	1.25	1.12
9	Basic garments, closed suit jacket	88.5 (2,509)	1.75	1.23	1.17
10	Basic garments, tie, open suit jacket,	89.8 (2,546)	1.72	1.26	1.16
11	Basic garments, tie, closed suit jacket	89.8 (2,546)	1.78	1.24	1.21
12	Basic garments, tie, vest, open suit jacket	97.1 (2,753)	1.78	1.26	1.22
13	Basic garments, tie, vest, closed suit jacket	97.1 (2,753)	1.81	1.24	1.24
14	Basic garments, sweater, open suit jacket	97.6 (2,767)	1.78	1.25	1.21
15	Basic garments, sweater, closed suit jacket	97.6 (2,767)	1.84	1.23	1.26

[a] Basic garments common to all ensembles include trousers, long-sleeve shirt, men's underwear, T-shirt, socks, shoes, and belt.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 3

Characteristics of Winter Skirt Ensembles

	Ensemble Description	Weight oz (g)	Total Clo (I_T)	Clothing Area Factor (f_{cl})	Intrinsic Clo (I_{cl})
1	Basic garments[a], knee socks	58.6 (1,660)	1.35	1.30	0.80
2	Basic garments, panty-hose	55.6 (1,577)	1.29	1.30	0.74
3	Basic garments, panty-hose, vest	62.9 (1,784)	1.43	1.31	0.89
4	Basic garments, panty-hose, sweater	64.7 (1,834)	1.49	1.32	0.95
5	Basic garments, panty-hose, open suit jacket	80.3 (2,276)	1.61	1.36	1.09
6	Basic garments, panty-hose, closed suit jacket	80.3 (2,276)	1.66	1.34	1.13
7	Basic garments, panty-hose, vest, open suit jacket	87.6 (2,483)	1.69	1.36	1.17
8	Basic garments, panty-hose, vest, closed suit jacket	87.6 (2,483)	1.74	1.34	1.21
9	Basic garments, panty-hose, sweater, open suit jacket	89.4 (2,534)	1.71	1.36	1.19
10	Basic garments, panty-hose, sweater, closed suit jacket	89.4 (2,534)	1.76	1.34	1.23

[a] Basic garments common to all ensembles include skirt, long-sleeve shirt, slip, women's underpants, and shoes.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 4

Characteristics of Summer Trouser Ensembles

	Ensemble Description	Weight oz (g)	Total Clo (I_T)	Clothing Area Factor (f_{cl})	Intrinsic Clo (I_{cl})
1	Basic garments[a], short sleeve shirt	54.3 (1,539)	1.22	1.15	0.60
2	Basic garments, short-sleeve shirt, tie	55.6 (1,576)	1.25	1.16	0.64
3	Basic garmens, short-sleeve shirt, tie, vest	60.9 (1,726)	1.33	1.17	0.72
4	Basic garments, short-sleeve shirt, open suit jacket	72.6 (2,057)	1.58	1.25	1.01
5	Basic garments, short-sleeve shirt, closed suite jacket	72.6 (2,057)	1.64	1.23	1.06
6	Basic garments, short-sleeve shirt, tie, open suit jacket	73.9 (2,095)	1.63	1.26	1.07
7	Basic garments, short-sleeve shirt, tie, closed suit jacket	73.9 (2,095)	1.66	1.24	1.09
8	Basic garments, short-sleeve shirt, tie, vest open suit jacket	79.1 (2,244)	1.68	1.26	1.12
9	Basic garments, short-sleeve shirt, tie, vest, closed suit jacket	79.1 (2,244)	1.70	1.24	1.13
10	Basic garments, long-sleeve shirt	55.7 (1,579)	1.30	1.19	0.70
11	Basic garments, long-sleeve shirt, tie	57.0 (1,616)	1.34	1.20	0.75
12	Basic garments, long-sleeve shirt, tie, vest	62.3 (1,766)	1.42	1.21	0.83
13	Basic garments, long-sleeve shirt, open suit jacket	74.0 (2,097)	1.61	1.25	1.04
14	Basic garments, long-sleeve shirt, closed suit jacket	74.0 (2,097)	1.70	1.23	1.12
15	Basic garments, long-sleeve shirt, tie, open suit jacket	75.3 (2,135)	1.61	1.26	1.05

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

16	Basic garments, long-sleeve shirt, tie, closed suit jacket	75.3 (2,135)	1.73	1.24	1.16
17	Basic garments, long-sleeve shirt, tie, vest, open suit jacket	80.6 (2,284)	1.71	1.26	1.15
18	Basic garments, long-sleeve shirt, tie, vest, closed suit jacket	80.6 (2,284)	1.76	1.24	1.19
19	Short-sleeve shirt bermuda shorts, socks, shoes, underwear, belt	50.6 (1,435)	1.08	1.13	0.45
20	Sleeveless shirt, short shorts, sandals, underwear, belt	27.3 (774)	0.97	1.10	0.32

[a] Basic garments include trousers, men's underwear, socks, shoes, and belt.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 5

Characteristics of Summer Skirt Ensembles

	Ensemble Description	Weight oz (g)	Total Clo (I_T)	Clothing Area Factor (f_{cl})	Intrinsic Clo (I_{cl})
1	Basic garments[a], sleeveless shirt	26.4 (750)	1.10	1.25	0.53
2	Basic garments, short-sleeve shirt	27.8 (789)	1.17	1.27	0.61
3	Basic garments, long-sleeve shirt	29.3 (829)	1.25	1.30	0.70
4	Basic garments, short-sleeve shirt, slip	31.6 (895)	1.26	1.27	0.70
5	Basic garments, short-sleeve shirt, open suit jacket	46.1 (1,308)	1.50	1.34	0.97
6	Basic garments, short-sleeve shirt, closed suit jacket	46.1 (1,308)	1.56	1.32	1.02
7	Basic garments, long-sleeve shirt, open suit jacket	47.5 (1,348)	1.52	1.34	0.99
8	Basic garments, long-sleeve shirt, closed suit jacket	47.5 (1,348)	1.57	1.32	1.03

[a] Basic garments common to all ensembles include skirt, women's underpants, pantyhose, and sandals.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 6

Winter Trouser Ensembles: Neutral Temperatures (°C) for Sedentary Work (60 W/m^2) and Active Office Work (75 W/m^2), Assuming 80% Dry Heat Loss[a]

Ensemble Description		Air Temperature (°C) Necessary for Dry Heat Loss of: 48 W/m^2 (sedentary work)	60 W/m^2 (active office work)
1	Basic garments[b] without T-shirt	22.8	20.3
2	Basic garments	22.3	19.7
3	Basic garments, sleeveless undershirt instead of T-shirt	22.3	19.7
4	Basic garments, tie	22.2	19.6
5	Basic garments, tie, vest	21.6	18.8
6	Basic garments, tie, sweater	20.8	17.8
7	Basic garments, sweater	21.0	18.1
8	Basic garments, open suit jacket	20.2	17.1
9	Basic garments, closed suit jacket	19.8	16.5
10	Basic garments, tie, open suit jacket	20.0	16.8
11	Basic garments, tie, closed suit jacket	19.6	16.2
12	Basic garments, tie, vest, open suit jacket	19.6	16.2
13	Basic garments, tie, vest, closed suit jacket	19.3	16.0
14	Basic garments, sweater, open suit jacket	19.6	16.2
15	Basic garments, sweater closed suit jacket	19.1	15.7

[a] Temperatures for which dry manikin heat loss would be 48 and 60 W/m^2, respectively.

[b] Basic garments common to all ensembles include trousers, long-sleeve shirt, men's underwear, T-shirt, socks, shoes, and belt.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 7

Winter Skirt Ensembles: Neutral Temperatures (°C) for Sedentary Work (60 W/m^2) and Active Office Work (75 W/m^2), Assuming 80% Dry Heat Loss[a]

	Ensemble Description	Air Temperature (°C) Necessary for Dry Heat Loss of: 48 W/m^2 (sedentary work)	60 W/m^2 (active office work)
1	Basic garments[b], knee socks	22.8	20.2
2	Basic garments, pantyhose	23.2	20.8
3	Basic garments, pantyhose, vest	22.2	19.5
4	Basic garments, pantyhose, sweater	21.7	18.9
5	Basic garments, pantyhose, open suit jacket	20.8	17.8
6	Basic garments, pantyhose, closed suit jacket	20.4	17.4
7	Basic garments, pantyhose, vest, open suit jacket	20.2	17.1
8	Basic garments, pantyhose, vest, closed suit jacket	19.9	16.6
9	Basic garments, pantyhose, sweater, open suit jacket	20.1	16.9
10	Basic garments, pantyhose, sweater, closed suit jacket	19.7	16.4

[a] Temperatures for which dry manikin heat loss would be 48 and 60 W/m^2, respectively.

[b] Basic garments common to all ensembles include skirt, long-sleeve shirt, slip, women's underpants, and shoes.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

TABLE 8

Summer Trouser Ensembles: Neutral Temperatures (^{o}C) for Sedentary Work (60 w/m^2) and Active Office Work (75 w/m^2), Assuming 80% Dry Heat Loss[a]

	Ensemble Description	Air Temperature (^{o}C) Necessary for Dry Heat Loss of: 48 W/m^2 (sedentary work)	60 W/m^2 (active office work)
1	Basic garments[b], short-sleeve shirt	23.7	21.5
2	Basic garments, short-sleeve shirt, tie	23.5	21.2
3	Basic garments, short-sleeve shirt, tie, vest	22.9	20.4
4	Basic garments, short-sleeve shirt, open suit jacket	21.0	18.1
5	Basic garments, short-sleeve shirt, closed suit jacket	20.6	17.5
6	Basic garments, short-sleeve shirt, tie, open suit jacket	20.7	17.6
7	Basic garments, short-sleeve shirt, tie, closed suit jacket	20.4	17.4
8	Basic garments, short-sleeve shirt, tie, vest, open suit jacket	20.3	17.2
9	Basic garments, short-sleeve shirt, tie, vest, closed suit jacket	20.2	17.0
10	Basic garments, long-sleeve shirt	23.1	20.7
11	Basic garments, long-sleeve shirt, tie	22.8	20.3
12	Basic garments, long-sleeve shirt, tie, vest	22.2	19.6
13	Basic garments, long-sleeve shirt, open suit jacket	20.8	17.8
14	Basic garments, long-sleeve shirt, closed suit jacket	20.2	17.0
15	Basic garments, long-sleeve shirt, tie, open suit jacket	20.8	17.8
16	Basic garments, long-sleeve shirt, tie, closed suit jacket	19.9	16.7

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

17	Basic garments, long-sleeve shirt, tie, vest, open suit jacket	20.1	16.9
18	Basic garments, long-sleeve shirt, tie, vest, closed suit jacket	19.7	16.4
19	Short-sleeve shirt, bermuda shorts, socks, shoes, underwear, belt	24.8	22.8
20	Sleeveless shirt, short shorts, sandals, underwear, belt	25.6	23.8

[a] Temperatures for which dry manikin heat loss would be 48 and 60 W/m^2, respectively.

[b] Basic garments include trousers, men's underwear, socks, shoes, and belt.

TABLE 9

Summer Skirt Ensembles: Neutral Temperatures (^oC) for Sedentary Work (60 W/m^2) and Active Office Work (75 W/m^2), Assuming 80% Dry Heat Loss[a]

	Ensemble Description	Air Temperature (^oC) Necessary for Dry Heat Loss of: 48 W/m^2 (sedentary work)	60 W/m^2 (active office work)
1	Basic garments[b], sleeveless shirt	24.6	22.6
2	Basic garments, short-sleeve shirt	24.1	21.9
3	Basic garments, long-sleeve shirt	23.5	21.2
4	Basic garments, short-sleeve shirt, slip	23.4	21.1
5	Basic garments, short-sleeve shirt, open suit jacket	21.6	18.9
6	Basic garments, short-sleeve shirt, closed suit jacket	21.2	18.3
7	Basic garments, long-sleeve open suit jacket	21.5	18.7
8	Basic garments, long-sleeve shirt, closed suit jacket	21.1	18.2

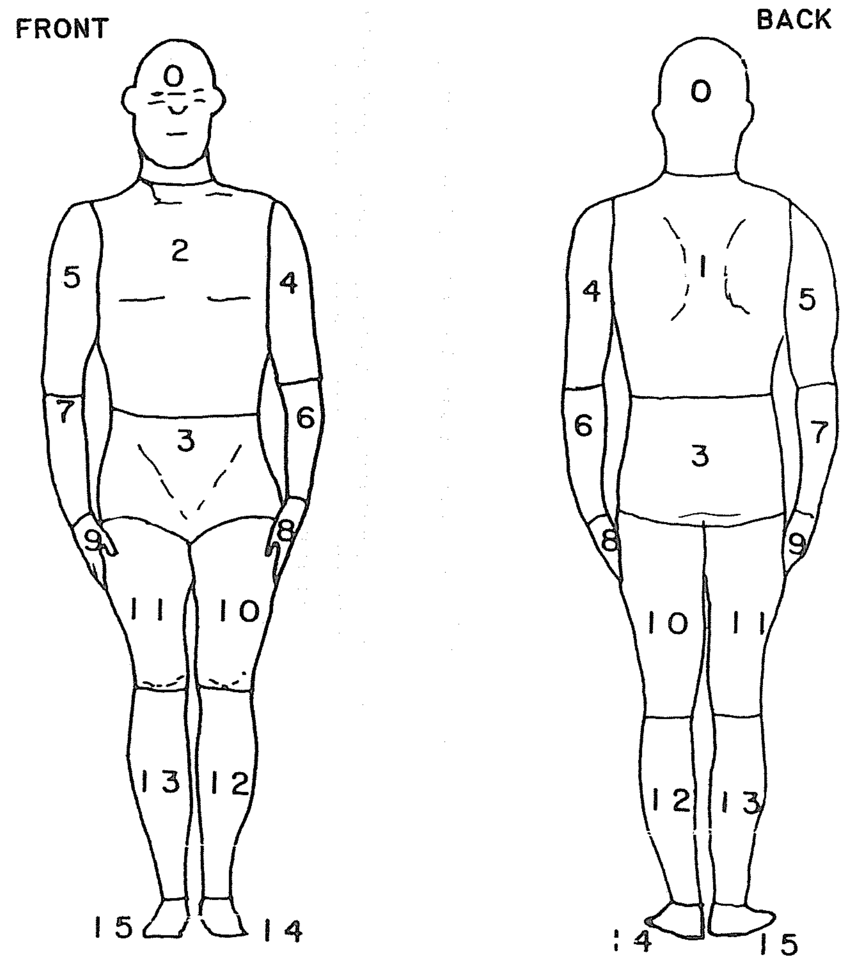
[a] Temperatures for which dry manikin heat loss would be 48 and 60 W/m^2, respectively.

[b] Basic garments common to all ensembles include skirt, women's underpants, pantyhose, and sandals.

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

	Body Sections	Surface Area (m^2)	Temperature Set Point (^oC)
0	Head	0.1476	33.0
1	Back	0.1658	34.0
2	Chest	0.1522	34.0
3	Hips	0.1292	34.0
4	Left upper arm	0.0723	33.0
5	Right upper arm	0.0715	33.0
6	Left lower arm	0.0649	32.0
7	Right lower arm	0.0655	32.0
8	Left hand	0.0524	31.0
9	Right hand	0.0532	31.0
10	Left thigh	0.1480	33.0
11	Right thigh	0.1611	33.0
12	Left calf	0.1689	32.0
13	Right calf	0.1606	32.0
14	Left foot	0.0493	31.0
15	Right foot	0.0512	31.0
	Total Body	1.7137	32.8[a]

[a] Area weighted average temperature for the body.



Thermal Manikin Body Sections

Figure 1. Diagram of the Thermal Manikin, SIBMAN

©ASHRAE. All rights reserved. Courtesy copy for SSPC 55 Committee to exclusively use for standards development. May not be distributed, reproduced nor placed on the internet.

DISCUSSION

E. SKAARET, Norwegian Inst. of Technology, Trondheim, Norway: Is the fact that the human body emits water vapor taken into consideration? Does it influence the real clo value?

McCULLOUGH: In this research, we measured the resistance to dry heat transfer, not the resistance to total heat transfer (which would include evaporative heat transfer). Our manikin does not emit moisture from his copper skin as a person would. On a human body in sedentary conditions, the moisture emitted from the skin would tend to raise the humidity of the air close to the skin. The clo values of clothing ensembles have been measured at different levels of relative humidity and found to remain essentially the same across all humidity levels.