J. Kor. Soc. Cloth. Ind.
Vol. 3, No. 5, pp.479-485(2001)
<Transaction>

The Effect of Adjustable Garment Closures and Layering on Insulation in Cold Weather

Chil Soon Kim[1] and Elizabeth McCullough[2]

1) Dept. of Textile and Clothing Design, Kyung Hee University, Seoul, Korea
2) Dept. of Clothing, Textiles and Interior Design, Kansas State University at Manhattan, U.S.A

Abstract : This study was to determine the effect of garment closures and layering systems on insulation, using a thermal movable manikin in cold weather conditions. The insulation values of ensembles with opened and closed features were measured, and those of four different layered clothing ensembles were tested while standing and while walking. Our research indicated that when there was an opening involved in design the system, insulation decreased; even a zip-out lining in the armpit affected little. If a light weight jacket and pants are put on over a fleece shirt and pants instead polyester underwear, the amount of insulation increase was 0.43 clo.

Key words : opening, layering, total insulation, intrinsic insulation, cold weather

INTRODUCTION

People spend lots of time in cold environments where they enjoy outdoor recreational activities. They are also exposed to cold environments in working places such as food processing plants, military fields, and cold rooms.

The thermal insulation value of clothing is particularly important in maintaining body heat balance in cold environments. People use cold weather clothing for thermal protection when they leave their homes and go about their everyday activities (i.e., travel to work, school, shopping, etc.). They also wear it in cold work environments--both indoors and outdoors. Sports activities, which commonly take place in cold climates such as snow skiing, hunting, and camping require specialized garments for thermal protection also.

A person generally adapts his clothing to the environment by taking off or putting on pieces of clothing or by opening or closing them. By opening the apertures of clothes, a person can increase the exchange between the air inside clothing and the ambient air, allowing ventilation. This ventilation is further increased by the pumping effect of the body movements (Mecheels & Umbach, 1977).

The garment opening can be defined as the distance between the outermost clothing layer and the skin or between the outermost clothing layer and the tightly closed inner layer in such areas as neckline, the end of sleeve, bottom of pants, skirt or jacket or front opening. When garment openings are added, more body heat is lost (Belding *et al.*, 1947; Fonseca & Breckenridge, 1965a). The effects of ventilation can be observed most clearly when the air temperature is significantly lower than the body skin temperature. In addition, ventilation is dependent on body motion and wind speed. Under dynamic conditions, the garment-opening area was used to predict pumping effect using the thermal movable manikin and it was found to be a relatively good predictor of percent change in I_T (McCullough & Hong, 1994).

Lotens & Havenith (1988) showed that the introduction of ventilation openings in a rain suit allowed a significant increase in its vapor permeability. Further it was shown that the placement of these openings was very important for the resultant effect. Also, introducing a small air gap between garment and body at the shoulder was shown to increase clothing ventilation and thus reduce insulation. Taketa & Wada (1982) reported that in shirts the combination of an air outlet at the yoke and a larger size and open structure at the neck and hem are very effective in increasing ventilation.

Since the body is a continuous heat source, with its heat production proportional to the level of physical exertion, air exchange between clothing and the ambient environment would limit increases in the internal clothing air temperature (Reischl & Stransky, 1980). The amount of insulation needed will vary a great deal with the physical activity of an individual and his/her body's basal metabolic rate (Watkins, 1984). For instance, a jogger might

Corresponding author; Chil Soon Kim
Tel. +82-31-201-2935, Fax. +82-31-202-0224
E-mail: cskim@khu.ac.kr

be quite comfortable running in a T-shirt and shorts in 0°C, whereas someone else might not be comfortable sitting in the same outfit unless the outside temperature was about 27°C. Thus sports clothing should be adapted to particular environments by equipping it with detachable parts that can be attached or detached according to temperature, and by providing it with controlled ventilation systems during exercise in cold environments. Thus, the design of cold weather clothing is important to enhance ventilation while the wearer is moving. Controlled ventilation provides the most effective method of varying the thermal insulating properties of sports clothing, thereby increasing its comfort range. The best types of controlled ventilation can be achieved by means of air vents which can be opened or closed in the clothing, e.g., slits in the chest, shoulder, and hip areas as well as a yoke at the back. In addition, variable ventilation can be created for specific items of clothing with variable width sleeve and leg closures, with draw strings at the hips, and with reversible collars which can be worn as a roll neck or a flat collar (Umbach, 1993).

The design of cold weather garments has improved in recent years with functional features such as zip-out liners, adjustable closures, and detachable hoods becoming widely available. Little research has been done on how such functional features as those given above effect insulation values in cold weather conditions.

Therefore the purpose of this study was to determine the insulation values of several ensembles while the manikin was standing and walking by employing adjustable closures, detachable hoods and layering which can help the wearer to adapt to cold environment.

METHOD

Measurements of clothing characteristics

Clothing ensemble weight was determined by adding the weight of each component garment for an ensemble. The weight of shoes and belts was excluded because they were made of materials other than textiles and covered only a small amount of body surface area. They would provide more weight relative to insulation than other types of garments (McCullough *et al.*, 1985).

Opening areas were determined by measuring the area between the outermost clothing layer and the skin or between the outermost clothing and a tightly closed inner layer at the sleeve hemline, the jacket or coat hemline, and pants bottom hemline. If a jacket or vest covered pants at the hip and waist area, there was an opening area between jacket and pants underneath. In this case, the circumference of a jacket or vest hemline and the circumference of pant hemline underneath a jacket or vest were measured for determining the area of the opening. The following equation was used for the calculation.

$$A_o = \pi\left[\left(\frac{C_c}{2\pi} - t_{oc}\right)^2 - \left(\frac{C_{pants,\,hip}}{2\pi}\right)\right] \tag{1}$$

Where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer of clothing at the jacket or vest hemline, cm

t_{oc} = thickness of the outermost layer of clothing, cm

$C_{pants,hip}$ = circumference of pants underneath the jacket or vest hemline at the hip area, cm

The following equation was used for the opening area of the coat hemline or jacket hemline over pants at the thigh area.

$$A_o = \pi\left(\frac{C_c}{2\pi} - t_{oc}\right)^2 - 2\pi\left(\frac{C_{pants,\,leg}}{2\pi}\right)^2 \tag{2}$$

Where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer of clothing at the coat or jacket hemline, cm

t_{oc} = thickness of the outermost layer of clothing, cm

$C_{pant,\,leg}$= circumference of one outer pant leg underneath the coat or jacket hemline, cm

The following equation was also used for the opening area between the coat hemline over the skirt and nude legs.

$$A_o = \pi\left(\frac{C_c}{2\pi} - t_{oc}\right)^2 - 2\pi\left(\frac{C_{leg}}{2\pi}\right)^2 \tag{3}$$

Where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer in the coat hemline, cm

t_{oc} = thickness of coat and skirt at the hemline area, cm

C_{leg} = circumference of one nude leg underneath the coat hemline, cm

The sum of the opening areas was determined by adding those three areas together. To determine the number of garment layers on the torso, arms, thighs, and calves, each garment was counted as one layer only if it covered more than 80% of the body part. A detachable liner in a garment was counted as one separate layer. The total thickness of garment layers was determined by adding the thickness of each garment layer for an ensemble. The thickness of the component conventional fabrics as they are sewn in the garments was measured according to

ASTM D 1777 with a C & R tester. The thickness of fiberfil or down filled fabrics was measured using the pendulum method. First the length of the thread/needle of the pendulum was recorded as a baseline when the needle just touched the surface of a flat table. Specimens were placed under the pendulum on the same flat surface. Then the length of the thread/needle of pendulum was recorded in five different places when the needle just touched the fabric surface without any pressure. The fabric thickness value was obtained by subtracting the initial baseline reading from the average fabric reading.

Measurement of clothing insulation values: the movable thermal manikin

The insulation value of the clothing ensembles was determined by the manikin test in an environmental chamber according to ASTM F 1291-90, Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin (ASTM, 1991). Fred is a computerized, movable, thermal manikin with 18 electrically separated segments. Each segment has independent temperature measurement and control. His height is 179.1 cm (70.5 in) and his surface area is 1.82 m^2.

At the beginning of the manikin test, the resistance of each temperature sensor on Fred was calibrated at three air temperatures; 28°C, 33°C, 38°C, and recalibrated with one air temperature which is close to his skin temperature (33°C) to adjust the Y-intercept of the regression line of the resistances of each body section, without power supplies. Throughout the project, Fred was routinely recalibrated at only one temperature, 33°C. However, if he broke down, a three point calibration was used again.

The selected air temperature was 14°C (57°F); it did not fluctuate more than "1°C from test to test throughout the project. Air velocity was maintained at 0.15 m/s with fans. The mean skin temperature of the manikin was maintained at 33.2± 0.5°C (92°F).

Fred was dressed in the ensemble and his wrist and ankles were connected to locomotion device. After the manikin system was stable, the manikin test was conducted for 30 min to get standing insulation while the manikin was standing on the floor with his arms at his sides. Then the manikin's locomotion device was turned on. After an 8-10 minute warm-up walking period, a test was conducted for 8 minutes to get the dynamic insulation while the manikin was walking at 90 steps/min. Two replications of these tests were conducted. The deviation from the mean was not more than 3% for standing and 5% for walking. This procedure was repeated with other ensembles.

Total insulation (I_T) is the resistance from the body surface to the environment and includes the air layer around the clothed body. This value for each ensemble was reported as an average of two replications. Total insulation was calculated as follows:

$$I_T = \frac{K \cdot A \cdot (T_s - T_a)}{Q} \tag{4}$$

Where,

I_T = total thermal insulation of the clothing plus air layer, clo
K = constant = 6.45 clo·W/m^2·°C
T_s = mean skin temperature, °C
T_a = ambient air temperature, °C
A_s = manikin surface area, m^2
Q = power input, W

Intrinsic clothing insulation (I_{cl}) is the insulation from the skin to the clothing surface. This value was determined as follows:

$$I_{cl} = I_T - \frac{I_a}{f_{cl}} \tag{5}$$

Where,

I_{cl} = intrinsic thermal insulation of clothing, clo
I_a = thermal insulation of air layer around the nude manikin, clo
f_{cl} = clothing area factor

In the above equation, the value for I_a was obtained by operating the manikin without clothing while standing (0.68 clo) and walking (0.49 clo). The absolute change in insulation (clo) was calculated by subtracting dynamic insulation (measured while walking) from the static insulation (measured while standing). Dividing the absolute change in insulation by the static insulation value and multiplying by 100 obtained the percent change in insulation.

RESULTS AND DISCUSSION

The results of the insulation measurements for the one-piece ski ensemble are provided in Table 1. The material of the ski ensemble is 100% polyester named Obestoff for the shell, and 65% olefin/35% polyester named Thinsulate for the filling. The material for the lining is 100% nylon named Zwischenfutter. Ensemble 1-O and 1-C (See Table 1) had the same garments except that ensemble 1-C had no hood, and was unzipped at the armpit and front zippers. After the zippers were opened, the decrease in both total standing and dynamic insulation was 0.15 clo. Total insulation and intrinsic insulation value while standing was 2.35, 1.82 clo respectively. Total insulation and intrinsic insulation in walking was 1.77 clo and 1.39 clo. The amount of decreased intrinsic insulation due to walk-

Table 1. Insulation of opened vs. closed wearing feature in one piece ski ensemble

Code No.	Ensemble description	Feature	Opening areas, (cm^2)	Total Insulation, clo Intrinsic Insulation, clo		
				Standing	Walking	Change, %
1-O	• Polyester thermal underwear top and bottom • One-piece ski suit with hood	Opened: Unzipped armpit zippers & front zippers to waist line, fastened front 2 buttons, and opened neck in v shape	0 + α^a	2.35 1.82	1.77 1.39	24.7 23.7
1-C	• Goggles, Insulated ski gloves • Knee length socks • Insulated water proof boots	Closed: Collar up inside hood, gloves over sleeves, tightened waist belt, pant legs over the top of bots, & integrated gaiters in boots	0	2.50 1.97	1.92 1.53	23.2 21.9
Change after closures, %				6.0 7.6	7.8 9.1	

Notes : Opening area was not measured at armpit and neck area due to the difficulty of irregular shape of opened area.

ing was 23.7%. However, with a zipped up armpit and front zipper, and tightened waist belt, the amount of increased intrinsic insulation was 7.6% while standing and 9.1% while walking.

Ensemble 2-O and 2-C consists of a 3-layered system, which has briefs for its 1^{st} layer, a fleece shirt and pants for the 2^{nd} layer, and a light jacket and pants for the 3^{rd} layer. This ensemble had opened apertures at the front zipper, armpit zipper, and pantcuff side zipper, while 2-C had closed apertures in those areas. Ensembles 2-O and 2-C consisted of the same garments.(See Table 2.) The material of the light jacket was Gore-Tex & Supplex combination for the shell, and 100% polyester (cool mesh) & 100% nylon taffeta for the lining. The ensembles tested in this study show that the opening of adjustable zippers has little effect on standing insulation, dynamic insulation, and change in insulation. When the adjustable zippers at the armpit, the front of the jacket, and the side of the pantcuffs were opened, the amount of decrease was 2.3% in total standing insulation and 2.0% in total dynamic insulation. These differences are not even comparable to a 1 ^{o}F change in preferred temperature. However, while waking, the amount of decreased insulation was about 30%. In this study, opening zippers to increase ventilation was found to have little effect on insulation values. There might be two reasons for this. The activities in this study were restricted to the mobility of the manikin because the manikin's limbs were moving only backward and forward; the manikin could not simulate the movement of lifting human arms, which could

Table 2. Insulation of opened vs. closed wearing feature of light weight jacket and pants ensemble

Code No.	Description of Ensemble	Feature	Opening areas, (cm^2)	Total Insulation, clo Intrinsic Insulation, clo		
				Standing	Walking	Change,%
2-O	• Briefs • Long sleeve fleece shirt • Light weight hip length jacket with hood • Thin pants, • Calf length athletic socks • Soft soled athletic shoes	Opened: No hood, loosened drawstrings of jacket on waist & hip and cuff closures, unzipped front zipper but fastened snap closure except top snaps, unzipped pantcuffs armpit of jacket & fleece shirts, front zipper of fleece shirts to the top 2nd snap	683.3	2.12 1.63	1.49 1.14	29.7 30.3
2-C		Closed: No hood, fleece shirt over pants, loosened jacket waist, hip ties, & wrists, unzipped 13 cm front zipper of jacket from the top	683.3	2.17 1.67	1.52 1.16	30.0 30.6
Change after closures, %				2.3 2.4	2.0 1.7	

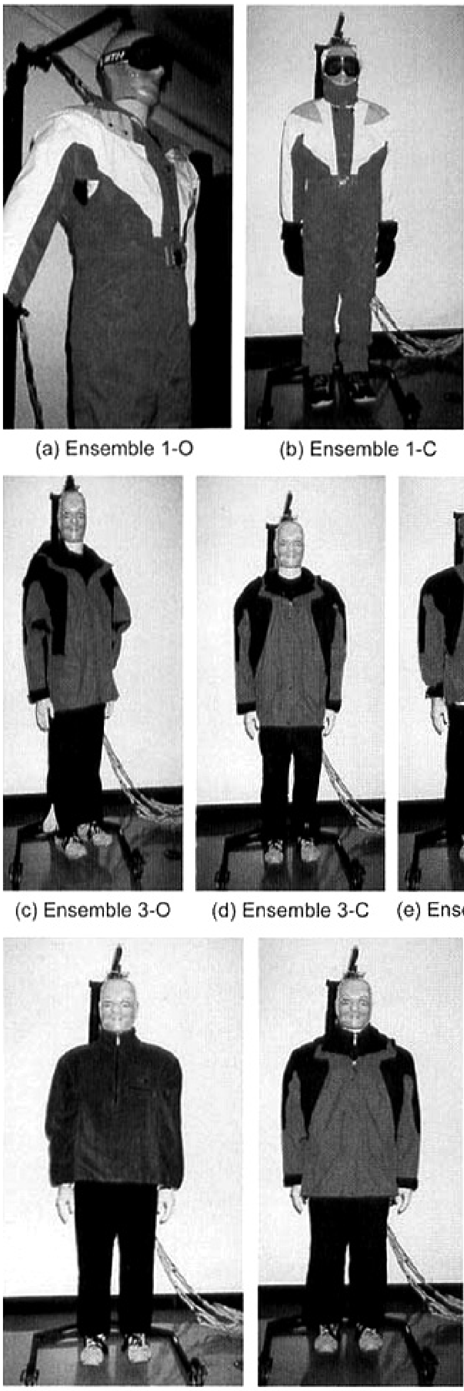

Fig. 1. Photographs of ensembles.

increase the ventilation. Thus, even if the zippers in the armpit were opened, little air was pumped through this opening during walking. In addition, most cold weather clothing ensembles had a multi-layered system, and they were very thick. Thus, opening zippers on one or two outer garment layers had little influence on the total insulation because other inner layers still insulated the body.

Table 3 shows the results of the insulation of the light jacket and pants ensemble with three features; one is opened but has no hood, another has a closed zipper of inner layer but has no hood, and the other is tightly closed and with hood. Components of ensemble in Table 2 and Table 3 are the same except thermal underwear which is made of 100% capilene single interlock knitted polyester.

If we loosened the drawstrings of hemline, unzipped up to the top 2 jacket buttons, unzipped armpit of jacket/ fleece shirts as well as unzipped pantcuffs, total standing insulation was 2.30 clo and intrinsic standing insulation was 1.81clo, while total dynamic insulation was 1.65clo and intrinsic dynamic insulation was 1.30 clo, i.e., 28.4 % of insulation was decreased due to walking.

If we unzipped the 13cm front zipper of the jacket but zipped up the fleece shirt, total standing insulation was 2.31 clo and intrinsic standing insulation was 1.81 clo. Total dynamic insulation was 1.70 clo and intrinsic dynamic insulation was 1.34 clo. We realized that there was little difference in standing insulation of ensemble 3-O and 3-C. But dynamic insulation was 0.05 clo higher with closed features (ensemble 3-C). The area of the opening of ensemble 3-C was smaller than that of ensemble 3-O.

If we tightened the waist, hip, sleeves and sides of the hood with drawstrings of jackets (ensemble 3-H), then 0.08 clo of standing insulation was increased (4.2%), compared to that of ensemble 3-O. But dynamic intrinsic insulation was increased to 8.5% in ensemble 3-H after the opening was closed. The amount of change in insulation due to walking became lower, because of the reduction of the size of the opening area, which gives pumping effectless.

In an outdoor clothing system in winter, the use of head wear is important to reduce heat loss because the vasoconstriction of blood vessels does not occur in the head so that the blood flow to the brain must be maintained. A high percentage of body heat can be lost through an uncovered head. Therefore, a hood can be useful for the reduction of heat loss by covering the head.

Nielsen *et al.* (1985) found a 10% reduction in intrinsic clothing insulation with an open jacket as compared to a closed jacket while walking with a wind velocity of 1.1 m/s, and an 8% reduction during walking with no wind. The results of our study for cold weather were found to be similar to those of Nielsenís study for indoor clothing.

Table 4 shows how insulation values are different according to different layering systems.

When we put on only a fleece shirt and pants as the 1st layer (ensemble 4A), total standing insulation was 1.72 clo and intrinsic insulation was 1.19 clo. Total walking insu-

Table 3. Insulation of light weight jacket and pants ensemble with thermal underwear, varing different wearing features

Code no.	Ensemble	Wearing features	Opening areas, (cm²)	Total Insulation, clo Intrinsic Insulation, clo		
				Standing	Walking	Change,%
3-O	• Briefs, • Polyester thermal long underwear top & bottom, • Long sleeve fleece shirt • Fleece pants, • Light weight hip length jacket with hood, • Thin pants, • Calf length athletic socks, • Soft-soled athletic shoes	Opened: No hood, Loosened drawstrings, unzipped and buttoned front opening except top 2 buttons, unzipped pantcuffs, armpit of jacket & fleece shirts, & unzipped front zipper of fleece shirts at top 2nd button	675.5	2.30 1.81	1.65 1.30	28.3 28.4
3-C		Closed #1: No hood, fleece shirt over pants, loosened jacket waist, hip ties, & wrists, unzipped 13 cm front zipper of jacket from the top	589.6	2.31 1.81	1.70 1.34	26.4 26.0
3-CH		Closed #2: With hood, tightened waist, hip, sleeves & sides of hood with drawstrings of jacket, & fleece shirt over pants	0	2.38 1.89	1.77 1.42	25.6 25.0
	Change after closures (3O vs 3CH), %			3.4 4.2	6.8 8.5	

Table 4. Insulation of ensembles with different garment layering systems

Code No.	Ensemble composition: underwear + other garments		Opening areas, (cm²)	Total Insulation, clo Intrinsic Insulation, clo		
				Standing	Walking	Change,%
4-F	Nothing	Long sleeve fleece shirt & fleece pants	0	1.72 1.19	1.24 0.86	27.9 27.9
4-UFL	Polyester thermal long underwear top & bottom		0	1.87 1.34	1.42 1.04	24.1 22.5
	Change, %			8.0 11.2	12.7 17.3	
5-UJ	Polyester thermal long underwear top & bottom	Briefs, light weight hip length jacket with hood, thin pants, calf length athletic socks, soft-soled athletic shoes,	710.4	1.74 1.24	1.09 0.73	37.4 41.2
5-FJ	Long sleeve fleece shirt Fleece pants		683.3	2.17 1.67	1.52 1.16	30.0 30.6
	Change, %			19.8 25.7	28.3 37	

lation was 1.24 clo and intrinsic walking insulation was 0.86 clo. However, if we put on underwear and put on fleece shirt and pant as a second layer (ensemble 4B), 0.15 clo was increased in standing (11.2%) and 0.18 clo was increased in walking (17.3%). Ensemble 4B had more ensemble weight and was thicker than ensemble 4A(see Table 5). If we put on a lightweight jacket and pants over the polyester thermal underwear, the area of opening was larger, therefore insulation was decreased. Also the amount of change in insulation was higher due to walking. But if we put on the jacket and pants over the fleece shirt and pants instead (ensemble 5B), the insulation value became 0.43 clo higher than over the underwear. Thus fleece underwear and closed wearing feature is desirable to adjust

Table 5. Characteristics of ensembles

Code No.	Ensemble Wt, g	Number of garment layers and their thickness (mm)[a]			
		Upper torso	Arms	Thighs	Calves
1-O/1-C	2,494	2 (7.09)	2 (7.09)	2 (7.09)	2 (7.09)
2-O/2-C	2,009	2 (5.74)	2 (5.74)	2 (6.66)	2 (6.66)
3-O/3-C/3-CH	2,466	3 (6.68)	3 (6.58)	3 (7.60)	3 (7.60)
4-F	913	1 (5.31)	1 (5.31)	1 (6.30)	1 (6.30)
4-UFL	1,370	2 (6.25)	2 (6.25)	2 (7.24)	2 (7.24)
5-UJ	1,665	2 (1.37)	2 (1.27)	2 (1.30)	2 (1.30)
5-FJ	1,990	2 (5.74)	2 (5.64)	2 (6.66)	2 (6.66)

[a]Pantyhose and socks were not included. Garments, which have linings, were treated as one layer, but those, which have detachable liners, were counted as a separate layer

cold environment, depending on activity levels.

Further information on descriptions of characteristics of each garment, which consists of above ensemble for this study is available in Kimís research.

CONCLUSIONS

We observed the effect of closures on insulation while standing and while walking. It was found that if one piece ski ensemble had unzipped armpit zippers & front zippers to the waist line, fastened front top 2 buttons, and opened neck in v shape, there was a 7.6% increase in standing insulation and 9.1% in intrinsic insulation, compared to when garment parts were opened. However, in the lightweight jacket and pants ensemble opening zippers to increase ventilation were found to have little effect on insulation values. In a different layered clothing system, if we put on underwear, 11.2% of total insulation and 17.3% of intrinsic insulation were increased. Also if we made the inner clothing with fleece instead of polyester thermal underwear, 25.7% of intrinsic standing insulation and 37% of intrinsic dynamic insulation was increased. Thus fleece underwear and closed garment parts in wearing feature are desirable on clothing to help the wearer to adjust cold environments, depending on activity levels.

REFERENCES

American Society for Testing and Materials (1991) "Annual Book of ASTM Standards". Philadelphia, PA: ASTM.

Belding H.S., Russell H.D., Darling R.C. and Folk G.E. (1947) Analysis of factors concerned in maintaining energy balance for dressed men in extreme cold; effects of activity on the protective value and comfort of an Arctic uniform. *American Journal of Physiology*, **149**, 223-239.

Fonseca G.F. and Breckenridge J.R. (1965a) Wind penetration through fabric systems (part I). *Textile Research Journal*, **35**(2), 95-103.

Kim C.S. (1995) An insulation data base for cold weather clothing under static and dynamic conditions. Unpublished Ph.D. Dissertation, Kansas State University.

Lotens W.A. and Havenith G. (1988) "Ventilation of Rain Wear determined by a Trace Gas Method". In I.B. Mekjavic, E.W. Banister & J.B. Morrison (Eds.), Environmental Ergonomics, Taylor & Francis, New York, pp.162-176.

Mecheels J.H. and Umbach K.H. (1977) "The Psychometric Range of Clothing System". In N.R.S. Hollies & R.F. Goldman (Eds.), Clothing Comfort : Interaction of Thermal, Ventilation, Construction and Assessment Factors. Ann Arbor, MI: Ann Arbor Science Publisher Inc., pp.133-152.

McCullough E.A., Jones B.W. and Huck J. (1985) A comprehensive database for estimating clothing insulation. *ASHRAE Transactions*, **91**(part 2), 29-47.

McCullough E.A. and Hong S. (1994) A data base for determining the decrease in clothing insulation due to body motion. *ASHRAE Transactions*, **100**(part 1), 765-775.

Nielsen R., Olesen B.W. and Fanger P.O. (1985) Effect of physical activity and air velocity on the thermal insulation of clothing. *Ergonomics*, **28**(12), 1617-1631.

Reischl U. and Stransky A. (1980) Assessment of ventilation characteristics of standard and prototype firefighter protective clothing. *Textile Research Journal*, **50**(3), 193-201.

Taketa S. and Wada O. (1982, March) "Cool, Dry Shirt? No Sweat!". America's Textiles, pp.26-40.

Watkins S.M.(Ed.) (1984) "Clothing: The Probable Environment". Iowa State University Press, Iowa.

Umbach K.H. (1993) Aspects of clothing physiology in the development of sports wear. *Knitting Technique*, **15** (3), 165-169.

(Received October 19, 2001)