한국의류산업학회지
제1권 제3호, 1999
<연구논문>

J. Kor. Soc. Cloth. Ind.
Vol. 1, No. 3, pp.264-274(1999)

Thermal Characteristics of Men's Suit Ensembles

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남성용 정장의 온열특성 연구

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Abstract : The thermal resistance of 60 men's suits for summer and winter was measured to determine their thermal characteristics and physical properties, including air permeability, weight, and thickness of the jackets and trousers consisted of the ensembles were measured to predict the thermal resistance of garments and ensembles. In this study, general physical properties of the men' suit ensembles were determined. In general, thickness and weight of winter ensembles were greater than those of summer ensembles. A factor which could distinguish the difference between summer and winter ensembles was the air permeability. The air permeability of summer ensembles was 3~6 times greater than those of winter ensembles. For the thermal characteristics, the thermal resistance of winter ensembles were higher than those of summer ensembles. When the wind was involved, the thermal resistance of both ensembles decreased up to 30%. In addition, the equations were developed to predict the thermal resistance of the garments and ensembles when there was no air velocity and the thermal resistance of the ensembles with air velocity of 1.2 m/sec. Looking at the equations, thickness, weight, and size of the garments were the definite factors that affect the thermal resistance of the samples.

Key words : thermal resistance, clothing comfort, thermal manikin, air velocity.

1. Introduction

Recently, the clothing comfort is getting more important factor for evaluating the clothing characteristics since the customer needs are various and the standard living gets higher. The importance of the thermal characteristics of the clothing has to be discussed since the thermal characteristics of the clothings is one of the main factors affecting the clothings characteristics. Thus, determining the thermal characteristics of the clothings is very meaningful.

As a previous research, McCullough and *et al* performed the thermal manikin tests with 60 ensembles and 115 garments and they constructed a data base for the thermal characteristics (McCullough and *et al.*, 1985). In another their research, the thermal resistances of 46 indoor garments and 56 ensembles were determined and reported that the thermal resistances for winter and summer garments were 0.74~1.26 clo and 0.32~1.19 clo, respectively and indicated the thermal resistance of the samples increased with the garment weight (McCullough and *et al.*, 1983).

Zhu and *et al.* tested the thermal resistance of 15 Chinese indoor ensembles and reported the thermal resistances for the samples were 1.16~2.93 clo (Zhu and *et. al.*, 1985).

Choi and *et al* performed the thermal manikin test with 19 and 6 Korean traditional garments and ensembles, respectively. They indicated that the thermal resistances of the samples 1.08~2.27 clo and these measured value were higher than those of western traditional clothings (Choi and *et al.*, 1985).

As a functional clothings research, Olesen tested 70 protective garments and they reported the thermal resistances for the garments were 0.17~2.6 clo (Olesen, 1985).

In addition, McCullough and et al tested the dynamic thermal insulation of the garments and ensembles and they

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showed that the thermal resistance of the samples with walking speed of maximum 90 steps/min was 0.32~1.19 clo, while the thermal resistance of the ensembles for stationary state was 0.93~1.93 clo. They indicated air volume within the clothing and garment weight were the factors affecting the thermal resistance (McCullough and Hong, 1993).

Previous researches mentioned so far were performed with the samples which were various in terms of the materials and final uses. Thus, any research has not been performed with a specific item to evaluate its thermal characteristics more deeply.

More importantly, almost researches were performed the thermal characteristics with only a stationary state, for example, not considering the wind or walking factor. Since the natural environment is a changeable as well as human beings are always moving, the thermal characteristic of the clothings should be evaluated at a dynamic state.

Therefore, 60 men's suit ensembles (30 for summer and 30 for winter) were chosen as the samples which are mostly used today and the thermal characteristics and related physical properties were tested to predicting the thermal resistance of the jackets, the trousers, and the ensembles in this study. In addition, the wind effect on the thermal characteristics was analysed.

2. Materials and Methodology

2.1. Test Materials

60 men's suit ensembles (30 for summer and 30 for winter) were used for this study. The construction of the samples showed Table 1 and 2. For materials of summer suits, there were 5 100% wool, 11 wool/polyester, 7 wool/silk, 4 wool/nylon, and etc. For winter suits, there were 24 100% wool, 2 wool/polyester, and etc.

Table 3 showed the garments, including Y-shirt, under-

Table 1. Specification of men's suit for summer

No	Jacket					Trouser			
	Dimension (cm)			Material (%)		Dimension (cm)		Material (%)	
	Chest	Waist	Height	Outer	Inner	Waist	Hip	Outer	Inner
S1	112	99	185	W100	P100	98	112	W100	R55/N45
S2	108	93	180	W100	P100	102	115	W100	R55/N45
S3	100	91	170	W100	P100	102	115	W100	R55/N45
S4	97	85	175	W100	P100	84	100	W100	R55/N45
S5	97	85	170	W100	P100	85	100	W100	R55/N45
S6	100	88	175	W95/P5	P100	84	100	W90/P10	R55/N45
S7	100	88	170	W95/P5	P100	84	100	W90/P10	R55/N45
S8	97	88	165	W95/P5	P100	84	100	W90/P10	R55/N45
S9	100	85	170	W90/P10	P100	84	100	W90/P10	R55/N45
S10	100	85	175	W72/P28	P100	94	109	W50/P50	R55/N45
S11	112	103	175	P50/W50	P100	102	115	W50/P50	R55/N45
S12	109	97	180	W50/P50	P100	102	115	W50/P50	R55/N45
S13	102	103	175	W50/P50	P100	98	112	W50/P50	R55/N45
S14	97	85	175	W50/P50	P100	92	106	W80/S20	R55/N45
S15	94	82	170	W50/P50	P100	98	112	W50/P50	R55/N45
S16	94	79	165	W50/P50	P100	84	97	W50/P50	P100
S17	97	85	175	W95/S5	P55/R45	92	106	W80/S20	R55/N45
S18	103	91	175	W90/S10	W55/R45	104	115	W77/S23	R55/N45
S19	109	97	175	W80/S20	P100	104	115	W77/S23	R55/N45
S20	100	88	170	W77/S23	P100	104	115	W77/S23	R55/N45
S21	100	88	170	W65/S35	P100	104	115	W77/S23	R55/N45
S22	115	103	185	S56/W44	P100	104	115	S56/W44	R55/N45
S23	97	85	175	S56/W44	P100	98	112	S56/W44	R55/N45
S24	109	94	185	W92/N8	P100	96	109	W92/N8	R55/N45
S25	103	91	180	W94/N6	P100	88	103	W94/N6	R55/N45
S26	94	82	170	W94/N6	P100	94	109	W94/N6	R55/N45
S27	94	82	170	W91/N9	P100	82	97	W91/N9	P100
S28	97	82	175	W71/R29	P100	92	106	W80/S20	R55/N45
S29	97	82	170	W67/R27/N4	P100	92	106	W80/S20	R55/N45
S30	103	91	175	W36/L46/R14/N4	P100	98	112	W50/P50	R55/N45

W=Wool, P=Polyester, R=Rayon, N=Nylon, S=Silk, and L=Linen.

Table 2. Specification of men's suit for winter

No	Jacket					Trouser			
	Dimension (cm)			Material (%)		Dimension (cm)		Material (%)	
	Chest	Waist	Hight	Outer	Inner	Waist	Hip	Outer	Inner
W1	109	97	180	W100	P100	102	115	W100	R55/N45
W2	109	97	180	W100	P100	102	115	W100	R55/N45
W3	109	97	175	W100	P100	102	115	W100	R55/N45
W4	106	94	180	W100	P100	98	112	W100	R55/N45
W5	106	94	175	W100	P100	80	97	W100	R55/N45
W6	106	94	175	W100	P100	98	112	W100	R55/N45
W7	106	91	185	W100	P100	98	112	W100	R55/N45
W8	103	91	180	W100	P100	88	103	W100	R55/N45
W9	103	91	175	W100	P100	92	106	W100	R55/N45
W10	103	91	175	W100	P100	92	106	W100	R55/N45
W11	103	91	175	W100	P100	92	106	W100	R55/N45
W12	100	91	170	W100	P100	92	106	W100	R55/N45
W13	100	88	175	W100	P100	92	106	W100	R55/N45
W14	100	88	170	W100	P100	102	115	W100	R55/N45
W15	100	85	175	W100	P100	88	103	W100	R55/N45
W16	100	85	175	W100	P100	88	103	W100	R55/N45
W17	97	85	175	W100	P100	88	103	W100	R55/N45
W18	97	85	175	W100	P100	88	103	W100	R55/N45
W19	97	82	175	W100	P100	92	106	W100	R55/N45
W20	94	82	170	W100	P100	84	100	W100	R55/N45
W21	94	79	165	W100	P100	84	100	W100	R55/N45
W22	94	79	165	W100	P100	84	100	W100	R55/N45
W23	92	78	170	W100	P100	80	97	W100	R55/N45
W24	91	76	165	W100	P100	80	97	W100	R55/N45
W25	109	97	180	W80/P20	P100	96	109	W50/P50	P100
W26	94	82	170	W80/P20	P100	96	109	W50/P50	P100
W27	106	97	180	W68/S32	P55/R45	98	112	W100	R55/N45
W28	97	85	175	W97/N3	P100	84	100	W97/N3	R55/N45
W29	109	97	180	W53/S43/N4	P100	102	115	W100	R55/N45
W30	102	91	175	W85/N13/R2	P100	92	106	W100	R55/N45

W=Wool, P=Polyester, R=Rayon, N=Nylon, S=Silk, and L=Linen.

Table 3. Specifications of inner wears

Wear	Material	Size	Remark
Y-shirt	60% Cotton/40% Polyester	105	Half sleeves, for summer
Y-shirt	60% Cotton/40% Polyester	105	Long sleeves, for winter
Underwear	100% Cotton	105	No sleeves, for summer
Underwear	100% Cotton	105	Half sleeves, for winter
Panty	100% Cotton	105	Triangle shape
Socks	100% Cotton	105	

wear, panty, and socks as ensemble's inner wears.

2.2. Physical tests

Warp and filling density, weight, thickness and air permeability of the samples were tested according to KSK Standard Test Methods (KS, 1997).

2.3. Thermal manikin test

Thermal resistance of the garments and ensembles was measured according to ASTM F1291 Standard Test Methods (ASTM, 1997). The thermal manikin used was made of copper, and was man-type that was similar to the human being in terms of size, shape, and surface area. His total surface area is 1.7804 m^2 and mean skin temperature is 33.72°C. The temperatures of each part were set according to the Kim and *et al.*, which were the men's mean temperature with the age range of 20~44 (Kim and Choi, 1997)

The test method was as follows: The power was supplied to the thermal manikin to keep the temperature of 15 parts constant after it was worn with a test clothing in the environmental chamber (4500×4200 mm) controlled at

20°C and 65% rh. The skin and ambient temperature, consumed wattage, and etc were recorded in every 1 minute for 30 minutes after all values were stabilized. The total thermal resistance of the sample (R_{wtd}) was calculated the following equations with the measured values:

$$T_{wtd}=\frac{\Sigma(T_i \times A_i)}{\Sigma A_i} \quad (1)$$

$$Q/A_{wtd}=\frac{\Sigma(Q/A_i \times A_i)}{\Sigma A_i} \quad (2)$$

$$R_{wtd}=\frac{(T_{wtd}-T_{amb})}{Q/A_{wtd}} \quad (3)$$

R_{wtd} = weighted thermal resistance, $m^2 \cdot$ °C/W
T_{amb} = ambient temperature, °C
T_{wtd} = weighted skin temperature, °C
T_i = temperature of zone i, °C
A_i = surface area of zone i, m^2
Q/A_{wtd} = weighted heat flux, W/m^2
Q/A_i = heat flux of zone i, W/m^2

2.4. Air velocity tests

Air velocity in the environmental chamber was measured with the air velocity equipment (TSI Model 8455-255) to determine the effect of air velocity on the thermal resistance of the garments and ensembles. The thermal manikin was located in front of the fan with a distance of 1.5m from the fan. Air velocity sensors were positioned at the skin temperature sensors on the thermal manikin. Therefore, air velocity was measured at 30 points (15 points front and back). The fan was set to try to make 1 m/sec.

2.5. Statistical Analysis

The stepwise regression and the correlation analysis were done with SAS program to analyse the measured data.

Table 4. Physical properties of jackets for summer

No.	Density (/in)		Linear density (Nm)		Weight (g)	Thick-ness (mm)	Total weight[a)] (g)
	Warp	Filling	Warp	Filling			
S1	90	72	21.4	22.0	791	0.57	1,670
S2	74	60	30	28.1	743	0.46	1,583
S3	70	62	26.5	34.6	660	0.53	1,500
S4	64	64	29.9	37.5	607	0.33	1,333
S5	66	59	34.7	33.6	663	0.33	1,399
S6	98	82	48.2	46.1	634	0.40	1,456
S7	103	88	39.1	39.1	656	0.34	1,478
S8	108	88	44.7	41.1	653	0.35	1,475
S9	93	65	38.9	26.6	687	0.51	1,509
S10	56	46	21.4	21.4	682	0.37	1,417
S11	67	61	33.1	33.1	664	0.31	1,432
S12	70	57	34.6	33.3	683	0.31	1,451
S13	66	60	20.5	20.5	691	0.31	1,481
S14	71	61	38.5	33.6	610	0.31	1,396
S15	84	74	34.7	36.2	638	0.36	1,428
S16	64	54	34.4	28.8	573	0.30	1,267
S17	70	58	32.3	33.6	628	0.33	1,414
S18	128	118	70	80.8	602	0.26	1,397
S19	95	85	25.7	29.0	709	0.37	1,504
S20	64	49	27.5	31.3	633	0.33	1,428
S21	57	47	21.9	21	664	0.54	1,459
S22	60	52	21.4	21.4	806	0.57	1,695
S23	72	71	14.1	33.3	715	0.56	1,584
S24	88	77	32.1	32.1	761	0.45	1,618
S25	73	63	31.6	35	672	0.31	1,385
S26	73	69	32.6	35	622	0.30	1,347
S27	67	57	39.3	40	561	0.28	1,213
S28	71	61	36.8	34.1	591	0.32	1,377
S29	90	74	29.8	43.3	708	0.42	1,494
S30	112	98	38.2	31.1	735	0.48	1,525

a) Total weight=inner wear weight+jacket and trouser. Total inner wear weight for summer (337 g): Y-shirt (half sleeve)=127 g, under wear(no sleeve)=96 g, Panty=60 g, Socks=54 g.

3. Results and Discussion

3.1. General properties of the samples

The physical properties of 60 ensembles including weight, thickness, and fabric density were shown in Table 4~7 and their mean values of these were indicated in Table 8.

The mean weight of the ensemble was 1,457 g and 1,750 g for summer and winter, respectively, and thus, the weight of winter ensembles was 293 g higher than those of summer ensembles.

For the mean garment weight, it was 668.1 g and 452.1 g for summer jackets and trousers, respectively, and 789.5 g and 530.1g for winter jackets and trousers, respectively, and thus, winter garments were 121.4 g for the jackets and 78 g for the trousers higher than those of summer garments.

The mean thickness of the jackets and trousers for summer was 0.39 mm and 0.38 mm and those for winter was 0.78 mm and 0.38 mm, respectively. Thus, the thickness of winter jackets was two times higher than those of summer jackets, while the trousers for both summer and winter were similar in thickness.

The mean fabric density of the samples was 78.8/67.7 (warp/filling, /inch) for summer jackets and 77.0/64.9 for summer trousers, 70.5/60.6 for winter jackets and 77.7/67.1 for winter trousers.

For the mean linear density, it was 32.8/33.9 (warp/filling, Nm) for summer jackets and 30.3/30.8 for summer trousers and 21.9/22.6 for winter jackets and 26.1/27.8 for winter trousers.

Table 5. Physical properties of trousers for summer

No.	Density (/in)		Linear density (Nm)		Weight (g)	Thickness (mm)
	Warp	Filling	Warp	Filling		
S1	90	72	21.4	22.0	542	0.57
S2	74	60	30	28.1	503	0.38
S3	70	62	26.5	34.6	503	0.38
S4	64	64	29.9	37.5	389	0.32
S5	66	59	34.7	33.6	399	0.29
S6	93	65	38.9	26.6	485	0.52
S7	93	65	38.9	26.6	485	0.52
S8	93	65	38.9	26.6	485	0.52
S9	93	65	38.9	26.6	485	0.52
S10	56	46	21.4	21.4	398	0.29
S11	67	61	33.1	33.1	431	0.28
S12	67	61	33.1	33.1	431	0.30
S13	84	74	34.7	36.2	453	0.34
S14	95	85	25.7	29.0	449	0.36
S15	84	74	34.7	36.2	453	0.35
S16	64	54	34.4	28.8	357	0.30
S17	95	85	25.7	29.0	449	0.36
S18	64	49	27.5	31.3	458	0.34
S19	64	49	27.5	31.3	458	0.34
S20	64	49	27.5	31.3	458	0.34
S21	64	49	27.5	31.3	458	0.34
S22	60	52	21.4	21.4	552	0.55
S23	72	71	14.1	33.3	532	0.55
S24	88	77	32.1	32.1	520	0.43
S25	73	63	31.6	35	376	0.30
S26	73	69	32.6	35	388	0.31
S27	67	57	39.3	40	315	0.27
S28	95	85	25.7	29.0	449	0.36
S29	95	85	25.7	29.0	449	0.36
S30	84	74	34.7	36.2	453	0.35

Table 6. Physical properties of jackets for winter

No.	Fabric density (/in)		Linear density (Nm)		Weight (g)	Thickness (mm)	Total Weight[a)] (g)
	Warp	Filling	Warp	Filling			
W1	25	22	7.6	6.4	895	0.97	1,908
W2	90	80	13.6	13.6	818	0.78	1,831
W3	47	41	15.7	13.4	820	0.73	1,833
W4	74	70	16.1	33.3	872	0.70	1,933
W5	70	61	16.0	32.0	829	0.52	1,705
W6	72	60	17.0	33.0	814	0.77	1,875
W7	28	23	7.5	6.9	815	1.32	1,876
W8	103	81	34.4	33.1	865	0.62	1,794
W9	87	72	34.7	30.7	722	0.57	1,680
W10	95	87	29.6	30.9	776	0.59	1,734
W11	82	67	20.5	21.4	679	0.38	1,637
W12	88	76	35	35.9	698	0.62	1,656
W13	73	63	25.0	25.0	808	1.33	1,766
W14	57	47	18.4	19.2	778	0.70	1,791
W15	61	43	30.4	14.4	718	0.67	1,647
W16	78	68	25.5	29.4	763	0.58	1,710
W17	70	61	16.2	33.4	830	1.24	1,777
W18	31	27	7.4	7.8	886	1.33	1,883
W19	106	96	38.2	36.8	752	0.46	1,710
W20	81	68	19.1	18.4	720	0.60	1,638
W21	46	38	19.1	20	690	0.57	1,608
W22	69	59	17.2	31.4	747	0.79	1,665
W23	73	73	34.4	17.6	785	0.69	1,661
W24	100	90	32.1	32.1	680	0.55	1,556
W25	78	38	29	8.2	916	1.22	1,826
W26	80	70	20.5	18.8	695	0.52	1,605
W27	23	20	6.7	5.6	909	1.30	1,970
W28	84	76	22.5	23.7	695	0.52	1,551
W29	100	100	37.2	34.1	757	0.50	1,770
W30	44	40	9.2	11.7	952	1.26	1,910

a) Total weight=Inner wear weight+jacket and trouser.
Total inner wear weight for winter (429 g): Y-shirt(long sleeve)=193 g, underwear (half sleeve)=122 g, Panty=60 g, Socks =54 g.

3.2. Thermal resistance and air permeability of the garments and ensembles

The thermal resistance and air permeability of the garments and ensembles was indicated in Table 9 and 10 and the mean values of those were shown in Table 11.

According to the Tables, the mean thermal resistance of the ensembles was 1.57 clo and 1.69 clo for summer and winter, respectively when there was no air velocity. Therefore, the thermal resistance of winter ensembles was 0.12 clo higher than those of summer ensembles.

If the air velocity existed (1.2 m/sec), the thermal resistance of the garments and ensembles decreased and the thermal resistance of summer ensembles was 1.10clo and those of winter was 1.29 clo. The difference between two increased to 0.19 clo and thus, the difference between summer and winter ensembles got larger when the air velocity existed.

In addition, the decreasing rate due to the wind was 30% and 23.7% of the thermal resistance for summer and winter, respectively.

The thermal resistance of the garments was 0.95 clo and 1.03 clo for summer and winter jackets, and 0.82 clo for both summer and winter trousers. Therefore, the difference between summer and winter garments was 0.08 clo in case of the jackets only. The reason that there was no difference between the thermal resistance of summer and winter in case of the trousers was that the thickness of both was similar.

The air permeability of the jackets was 62.8 and 10.8 $cm^3/cm^2/sec$ and those of the trousers was 44.6 and 17.4 $cm^3/cm^2/sec$ for summer and winter, respectively. Therefore, the air permeability of the garments for summer was much higher than those for winter.

3.3. Predicting the thermal resistance of garments

The Thermal Resistance of the Jackets : According to

Table 7. Physical properties of trousers for winter

No.	Fabric density (/inch)		Linear density (Nm)		Weight (g)	Thickness (mm)
	Warp	Filling	Warp	Filling		
W1	57	47	18.4	19.2	584	0.38
W2	57	47	18.4	19.2	584	0.38
W3	57	47	18.4	19.2	584	0.38
W4	74	70	16.1	33.3	632	0.57
W5	57	47	18.4	19.2	447	0.52
W6	72	60	17.0	33.0	632	0.57
W7	28	23	7.5	6.9	632	0.57
W8	102	81	30	38.7	500	0.32
W9	106	96	38.2	36.8	529	0.33
W10	106	96	38.2	36.8	529	0.33
W11	106	96	38.2	36.8	529	0.33
W12	106	96	38.2	36.8	529	0.33
W13	106	96	38.2	36.8	529	0.33
W14	57	47	18.4	19.2	584	0.38
W15	102	81	30	38.7	500	0.32
W16	78	68	25.5	29.4	518	0.29
W17	78	68	25.5	29.4	518	0.29
W18	78	68	25.5	29.4	518	0.29
W19	106	96	38.2	36.8	529	0.33
W20	81	68	30.5	29.8	489	0.32
W21	81	68	30.5	29.8	489	0.32
W22	81	68	30.5	29.8	489	0.32
W23	57	47	18.4	19.2	447	0.52
W24	57	47	18.4	19.2	447	0.52
W25	84	72	29.8	27.9	481	0.29
W26	84	72	29.8	27.9	481	0.29
W27	23	20	6.7	5.6	632	0.57
W28	87	77	33	33	427	0.35
W29	57	47	18.4	19.2	584	0.38
W30	106	96	38.2	36.8	529	0.33

the correlation analysis, the factors affecting the thermal resistance of the jackets were weight, thickness and size of the jackets (Table 12). Therefore, the thermal resistance of the jackets increased with weight, thickness, and size of the jackets (Fig. 1 and 2).

From the stepwise regression analysis, the equation to predict the thermal resistance of the jackets was as follow:

$$GR = 0.4343+0.0958TH+0.0035WAT +0.0003UWT \quad (R^2=0.70) \tag{4}$$

GR = thermal resistance of the jacket, clo

TH = thickness of the jacket, mm
WAT = circumference of waist of the jacket, cm
UWT = weight of the jacket, g

The Thermal Resistance of Trousers: As shown in Table 12, the factor affecting the thermal resistance of the trousers were thickness of trousers only, although this factor did not affected on the thermal resistance of the trousers greatly (r=0.53).

In here, the thermal resistance of the trousers decreased with increasing the size of the trousers. In case of the trousers, the air gap between skin and fabric layer was greater than those of the jackets. Therefore, since air space between the fabric layer and the skin increased with size of the trousers, the air convection took place, and so the thermal resistance of the trousers decreased. Because of this air gap, the physical properties did not affect to the thermal resistance of the trousers greatly, too.

From the stepwise regression analysis, the equation to predict the thermal resistance of the trousers was as follow:

$$LGR = 0.9169+0.2103LTH-0.0029LWAT +0.0002LWT \quad (R^2=0.43) \tag{5}$$

LGR = thermal resistance of the trouser, clo
LTH = thickness of the trouser, mm
LWAT = thickness of waist of the trouser, cm
LWT = weight of the trouser, g

Table 8. Physical properties of ensembles

		Summer ensemble			Winter ensemble		
		Min.	Max.	Mean	Min.	Max.	Mean
Total weight (g)		1,213	1,695	1,457	1,551	1,970	1,750
Jacket	Weight (g)	561	806	668.1	679	952	789.5
	Thickness (mm)	0.26	0.57	0.39	0.38	1.33	0.78
	Warp density (/in)	56	128	78.8	23	106	70.5
	Filling density (/in)	46	118	67.7	20	100	60.6
	Warp linear density (Nm)	14.1	70.0	32.8	6.7	38.2	21.9
	Filling linear density (Nm)	20.5	80.8	33.9	5.6	36.8	22.6
Trouser	Weight (g)	315	552	452.1	427	632	530.1
	Thickness (mm)	0.27	0.57	0.38	0.29	0.57	0.38
	Warp density (/in)	56	95	77.0	23	106	77.7
	Filling density (/in)	46	85	64.9	20	96	67.1
	Warp linear density (Nm)	14.1	39.3	30.3	6.7	38.2	26.1
	Filling linear density (Nm)	21.4	40.0	30.8	5.6	38.7	27.8

Table 9. Thermal resistance and air permeability of garments and ensembles for summer

No.	TR of ensembles (with no air velocity) (clo)	TR of ensembles (with air velocity) (clo)	TR of jacket (with no air velocity) (clo)	TR of trouser (with no air velocity) (clo)	Air permeablity (jacket) ($cm^3/cm^2/s$)	Air permeability (trouser) ($cm^3/cm^2/s$)
S1	1.517	0.890	0.99	0.920	45.02	19
S2	1.716	1.030	1.021	0.830	45.01	14.6
S3	1.619	1.099	0.975	0.830	65.3	14.6
S4	1.530	0.938	0.918	0.827	106.75	106.25
S5	1.582	1.103	0.937	0.811	24.92	23.5
S6	1.504	1.074	0.937	0.893	25	93.82
S7	1.633	1.104	0.925	0.893	7.86	93.82
S8	1.515	1.178	0.942	0.893	7.55	93.82
S9	1.513	1.153	0.995	0.893	40.0	93.82
S10	1.570	1.098	0.918	0.761	89.92	57.2
S11	1.575	1.076	1.02	0.767	54.15	54
S12	1.681	1.119	0.996	0.767	102.90	54
S13	1.707	1.026	1.023	0.772	40.75	22.7
S14	1.455	1.063	0.902	0.858	55.42	13.0
S15	1.475	1.140	0.850	0.772	23.57	22.7
S16	1.40	0.908	0.901	0.855	39.4	39.5
S17	1.564	1.163	0.950	0.858	90.0	13.0
S18	1.680	1.087	0.971	0.760	22.35	33.0
S19	1.677	1.236	0.977	0.760	15.25	33.0
S20	1.432	1.110	0.962	0.760	31.00	33.0
S21	1.559	1.140	0.973	0.760	90.57	33.0
S22	1.517	1.254	1.069	0.771	47.82	45.6
S23	1.617	1.066	0.941	0.829	48.30	48.3
S24	1.603	1.083	0.992	0.788	31.10	28.7
S25	1.456	1.090	0.890	0.741	66.75	64.1
S26	1.455	1.057	0.947	0.749	69.40	60.0
S27	1.362	0.890	0.870	0.778	81.00	80.0
S28	1.540	1.241	0.940	0.858	20.20	13.0
S29	1.604	1.2	0.930	0.858	23.60	13.0
S30	1.673	1.183	0.980	0.772	11.02	22.7

TR=Thermal resistance, With no air velocity=<0.2 m/sec, With air velocity=1.2 m/sec

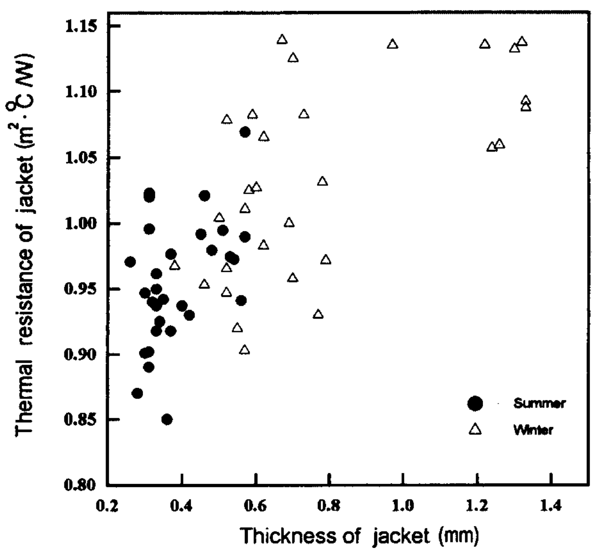

Fig. 1. Relationship between thermal resistance and thickness oif jackets for summer and winter.

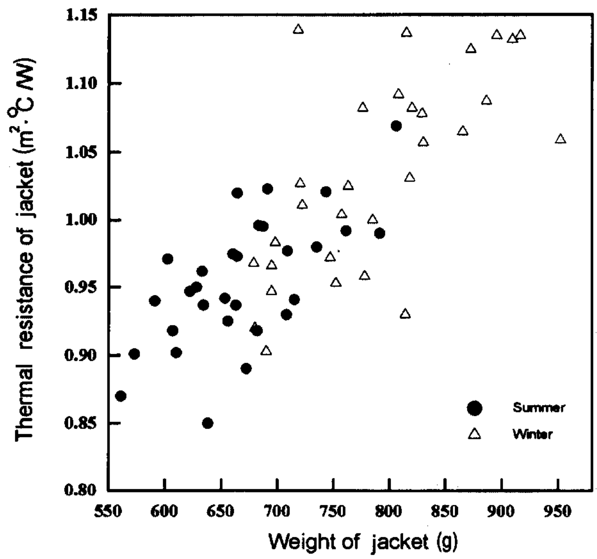

Fig. 2. Relationship between thermal resistance and weight of jackets for summer and winter.

Table 10. Thermal resistance and air permeability of garments and ensembles for winter

No.	TR of ensembles (with no air velocity) (clo)	TR of ensembles (with air velocity) (clo)	TR of jacket (with no air velocity) (clo)	TR of trouser (with no air velocity) (clo)	Air permeablity (jacket) ($cm^3/cm^2/s$)	Air permeability (trouser) ($cm^3/cm^2/s$)
W1	1.802	1.316	1.135	0.827	15.12	23.7
W2	1.668	1.433	1.031	0.827	14.60	23.7
W3	1.790	1.280	1.082	0.827	10.40	23.7
W4	1.839	1.519	1.125	0.853	10.60	24.22
W5	1.636	1.395	1.078	0.876	5.81	9.77
W6	1.602	1.328	0.93	0.853	12.85	24.22
W7	1.816	1.393	1.137	0.853	15.40	24.22
W8	1.680	1.319	1.065	0.861	9.05	19.05
W9	1.589	1.078	1.011	0.771	12.0	14.9
W10	1.707	1.250	1.082	0.771	6.34	14.9
W11	1.714	1.409	0.968	0.771	14.97	14.9
W12	1.762	1.202	0.983	0.771	10.51	14.9
W13	1.638	1.263	1.092	0.771	15.97	14.9
W14	1.574	1.313	0.958	0.827	7.36	23.7
W15	1.744	1.302	1.139	0.861	11.05	19.05
W16	1.689	1.224	1.025	0.876	6.82	10.67
W17	1.738	1.355	1.057	0.876	10.97	10.67
W18	1.791	1.308	1.087	0.876	16.67	10.67
W19	1.656	1.267	0.953	0.771	13.27	14.9
W20	1.640	1.254	1.027	0.795	7.93	15.2
W21	1.480	1.094	0.903	0.795	6.60	15.2
W22	1.641	1.219	0.972	0.795	9.97	15.2
W23	1.640	1.238	1.0	0.826	9.41	9.77
W24	1.544	0.977	0.920	0.826	7.28	9.77
W25	1.875	1.302	1.135	0.737	7.0	21.72
W26	1.599	1.223	0.947	0.737	6.94	21.72
W27	1.700	1.447	1.132	0.853	11.10	24.22
W28	1.629	1.126	0.966	0.809	9.73	13.52
W29	1.790	1.462	1.004	0.827	7.40	23.7
W30	1.747	1.418	1.059	0.771	12.65	14.9

TR=Thermal resistance, With no air velocity=<0.2 m/sec, With air velocity=1.2 m/sec

Table 11. Mean thermal resistance and air permeability of garments and ensembles

	For summer			For winter		
	Min.	Max.	Mean	Min.	Max.	Mean
Thermal resistance of ensembles with no air velocity (clo)	1.36	1.73	1.57	1.48	1.88	1.69
Thermal resistance of ensembles with air velocity (clo)	0.89	1.25	1.10	0.98	1.52	1.29
Thermal resistance of jacket with no air velocity (clo)	0.85	1.07	0.95	0.90	1.14	1.03
Thermal resistance of trouser with no air velocity (clo)	0.74	1.09	0.82	0.74	0.88	0.82
Air permeability of jacket ($cm^3/cm^2/s$)	7.6	155.5	62.8	5.8	16.7	10.8
Air permeability of trouser ($cm^3/cm^2/s$)	13	106.3	44.6	9.8	24.2	17.4

With no air velocity=<0.2 m/sec, With air velocity=1.2 m/sec

Thermal Resistance of the Ensemble with no Air Velocity : As shown in correlation coefficient analysis, the factors that affect the thermal resistance of the ensembles were the thermal resistance, weight, thickness, and the size of the garments (Fig. 3~5). Therefore, the thermal resistance of the ensembles increased with thermal resistance, thickness, weight, and the size of the garment. In here, physical properties of jackets were more effective than those of the trousers to change the thermal resistance of the ensembles.

From the stepwise regression analysis, the equation to predict the thermal resistance of the ensembles was as follow:

$$R = 0.4594+0.8171GR+0.0002WT \quad (R^2=0.70) \qquad (6)$$

R = thermal resistance of the ensemble (air velocity

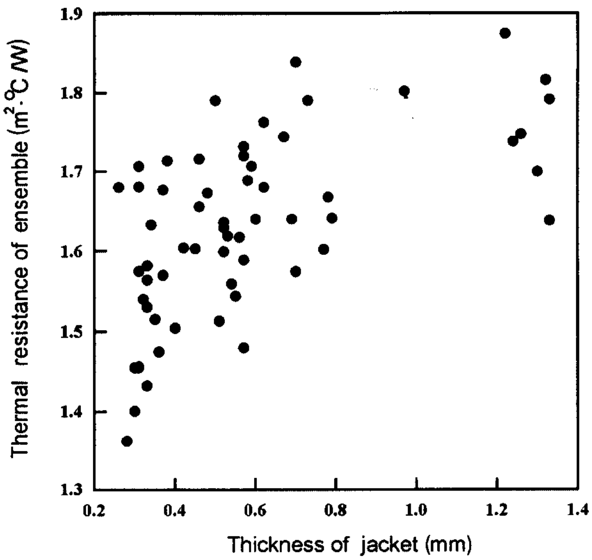

Fig. 3. Relationship between thermal resistance of ensembles and thickness of jackets for summer and wither.

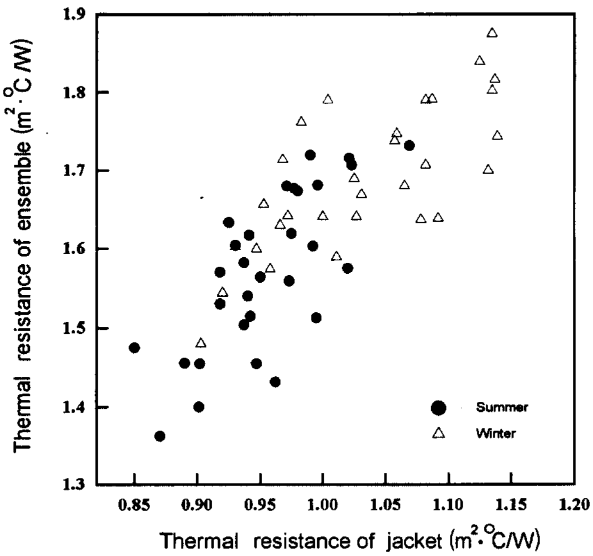

Fig. 5. Relationship between thermal resistance of ensembles and that of jackets for summer and winter.

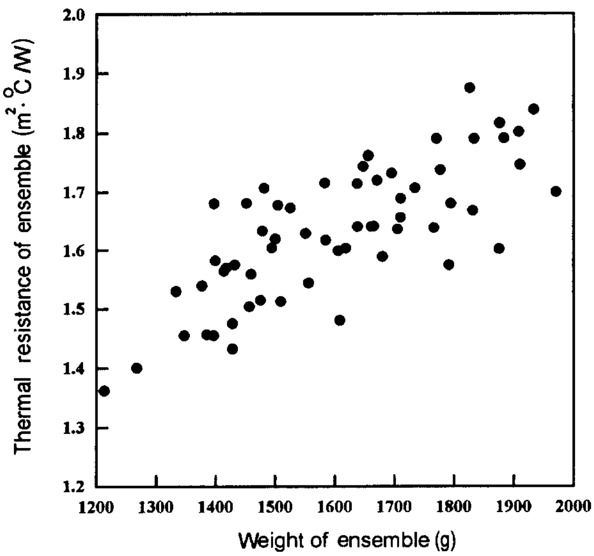

Fig. 4. Relationship between thermal resistance and weight of ensembles for summer and winter.

<0.2 m/sec), clo

GR = thermal resistance of the jacket, clo

WT = weight of the ensemble, g

Thermal Resistance of the Ensembles with Air Velocity : When the air velocity existed, the thermal resistance of the ensembles decreased, but the factors affecting the thermal resistance of the ensembles were almost the same as those with no air velocity. However, the effect of ensemble weight on the thermal resistance of the ensembles was more, while the effect of the size of the garments on the thermal resistance of the ensembles was lesser in case of windy. In addition to this, air permeability of the jackets was a factor effected on the thermal resistance of the ensembles (Fig. 6).

From the stepwise regression analysis, the equation to predict the thermal resistance of the ensembles with the air velocity of 1.2m/sec was as follow:

$$AR=0.177802+0.000636WT \quad (7)$$

AR = thermal resistance of the ensemble (air velocity =1.2 m/sec), clo

WT = weight of the jacket, g

4. Conclusion

The thermal resistance of 60 men's suits for summer and winter was measured to determine their thermal characteristics and physical properties, including air permeability, weight, and thickness of the jackets and trousers consisted of the ensembles were measured to predict the thermal resistance of garments and ensembles.

1. For the physical properties, in general, thickness and weight of winter ensembles were greater than those of summer ensembles. In case of the thickness, winter jackets were 2 times higher than summer jackets, while the trousers both summer and winter were similar.

For the weight, winter ensembles were about 290 g heavier than summer ensembles.

2. A factor which could distinguish the difference between summer and winter ensembles was the air per-

Table 12. Correlation coefficients

	R	AR	GR	LGR
R	1.00	0.68		
AR	0.68	1.00		
WT	0.76	0.83		
GR	0.79	0.66	1.00	
AIR	−0.41	−0.55	−0.36	
UWT	0.75	0.76	0.78	
TH	0.59	0.62	0.70	
CHST	0.52	0.38	0.50	
WAT	0.52	0.32	0.50	
HT	0.55	0.39	0.53	
WD	−0.12	−0.17	−0.34	
FD	−0.13	−0.17	−0.38	
WS	−0.39	−0.50	−0.46	
FS	−0.39	−0.43	−0.53	
LGR	0.06	0.17		1.00
LAIR	−0.42	−0.43		0.08
LWT	0.65	0.74		0.26
LTH	0.13	0.23		0.53
LWAT	0.33	0.22		−0.33
LHIP	0.35	0.24		−0.30
LWD	−0.04	−0.06		−0.01
LFD	−0.00	−0.05		−0.13
LWS	−0.32	−0.42		−0.30
LFS	−0.23	−0.34		−0.37

R = Thermal resistance of the ensembles with no air velocity of <0.2 m/sec
AR = Thermal resistance of the ensembles with air velocity of 1.2 m/sec
WT = Weight of the ensembles
UGR = Thermal resistance of the jackets with no air velocity of <0.2 m/sec
UAIR = Air permeability of the jackets
UWT = Weight of the jackets
UTH = Thickness of the jackets
CHST = Length of chest for the jackets
UWAT = Length of waist for the jackets
UHT = Length of hip for the jackets
WD = Warp density of the jackets
FD = Filling density of the jackets
WS = Warp linear density of the jackets
FS = Filling linear density of the jackets
LGR = Thermal resistance of the trousers with no air velocity of <0.2 m/sec
LAIR = Air permeability of the trousers
LWT = Weight of the trousers
LTH = Thickness of the trousers
LWAT = Length of waist for the trousers
LHIP = Length of hip for the trousers
LWD = Warp density of the trousers
LFD = Filling density of the trousers
LWS = Warp linear density of the trousers
LFS = Fillingp linear density of the trousers

meability. The air permeability of summer ensembles was 3-6 times greater than those of winter ensembles.

3. Mean thermal resistance of ensembles was 1.57 clo for summer and 1.69clo for winter with no air velocity, and 1.10 clo for summer and 1.29clo winter with a air velocity of 1.2m/sec. Therefore, The thermal resistance of winter ensembles always higher than those of summer ensembles regardless of the air velocity. However, if there was a air velocity of 1.2 m/sec, the difference between summer and winter ensembles got larger up to 2 times.

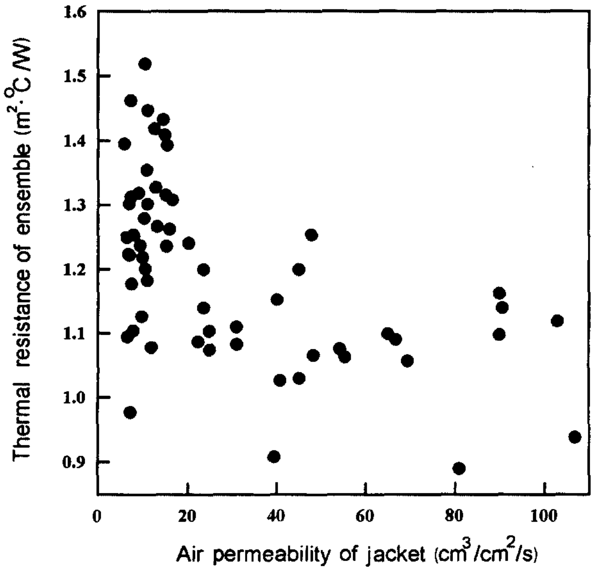

Fig. 6. Relationship between thermal resistance of ensembles and air permeability of jackets for summer and winter with air velocity of 1.2 m/sec.

4. The thermal resistance of the ensembles decreased to 30% for summer and 23.7% for winter with air velocity of 1.2 m/sec compared to those with no air velocity. The reason for this was that the air permeability of summer ensembles much higher than winter ensembles.

5. The equations were developed to predict the thermal resistance of the garments and ensembles when there was no air velocity and the thermal resistance of the ensembles with air velocity of 1.2 m/sec. Looking at the equations, thickness, weight, and size of the garments were the definite factors that affect the thermal resistance of the samples.

국문요약 : 최근에 사용되고 있는 남성용 정장 중, 여름용 30종, 겨울용 30종 등 총 60종을 시료로 하여 이들의 온열특성 중 보온성(무풍시=0.2 m/sec 이하, 풍속시=1.2 m/sec)과 이와 관련된 물성, 즉 공기투과도, 무게, 두께 등을 측정 및 분석하여 앙상블 및 가먼트의 보온성을 예측하는 회귀식을 개발하였다. 그 결과로는 일반적인 남성용 정장의 물성으로 두께 및 무게는 겨울용이 높았으며, 여름용과 겨울용을 확실히 구별할 수 있는 인자는 공기투과도였는데 여름용의 공기투과도는 겨울용보다 약 3~6배 정도 높았다. 남성용정장의 온열특성을 보면 겨울용 정장의 보온성이 여름용보다 높았고, 풍속이 있을 때 앙상블의

보온성은 최대 30% 정도 감소하는 경향을 나타내었다. 또한, 정장상하의 물성을 독립변수로 하여 가먼트 및 앙상블의 보온성을 추정하는 회귀식을 개발하였는데, 회귀식분석결과, 정장앙상블의 보온성에 영향을 주는 인자는 두께, 무게, 및 사이즈로 나타났다.

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(1999년 5월 10일 접수)