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Relationships between Insensible Perspiration and Thermo Physiological Factors during Wearing Seasonal Clothing Ensembles in Comfort

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쾌적한 상태에서 계절별 의복을 착용하고 있는 동안 불감증설과 온열 생리 요소들 간의 관련성

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Abstract

The purpose of this study was to examine the relationships between thermo-physiological factors and the insensible loss of body weight(IL) of resting women wearing seasonal comfortable clothing. Air temperature was maintained at a mean of 22.5, 24.7, and 16.8 for spring/fall, summer and winter, respectively. We selected a total of 26 clothing ensembles(8 ensembles for spring/fall, 7 ensembles for summer, and 11 ensembles for winter). The results showed that 1) IL was 19±5g · m^{-2}·hr for spring/fall environment, 21±5g · m^{-2}·hr for summer, 18±6g · m^{-2}·hr for winter(p<.001). 2) Insensible water loss through respiratory passage(IWR) showed the reverse tendency to IL. IWR was 6±1g · m^{-2}·hr for winter and 5±1g · m^{-2}·hr for summer. This difference was significant(p<.001). 3) The proportion of IWR out of whole insensible water loss(IW), had a mean of the mean 28% for summer and 38% for winter(p<.001). 4) In comfort, the heat loss by IW out of heat production had a mean of 25% for spring/fall, 27% for summer, and 23% for winter. 5) There was a weak negative correlation between IL and clothing insulation/ body surface area covered by clothing. 6) There were significant correlations between IL and air temperature(T_a), air humidity(H_a), energy metabolism, ventilation, mean skin temperature($\overline{T}_{sk}$), and clothing microclimate humidity(H_{clo}). However, the coefficients were less than 0.5. In conclusion, there were weak relationships between the IL and thermo-physiological factors. However, when subjects rested in thermal comfort, the IL was maintained in a narrow range even though the clothing insulation and air temperature were diverse.

Key words: Insensible water loss(IW), Insensible perspiration(IP), Respiratory water loss(IWR), Thermal comfort(TC), Clothing insulation(I_{cl}); 불감수분손실, 불감증설, 호흡에 의한 수분손실, 온열 쾌적감, 의복의 보온력

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I. Introduction

Water in the body continuously vaporizes to the air through the skin and the respiratory passage both with and without perception. Cutaneous water exchange passing through the skin can be divided into insensible and sensible perspiration. Sensible perspiration means sweating. Insensible perspiration (IP) is the mass of water passing through the skin by diffusion(IUPS Thermal Commission, 2001). Respiratory water loss through respiratory passages can be also considered as insensible water loss. That is, insensible water loss consists of insensible perspiration and respiratory water loss. However, there have been some inconsistencies in using these terms. Some classic literatures have referred to IP as meaning perspiration that evaporates before it is perceived as moisture on the skin and 'lungs'(Renbourn, 1960). This present study follows the definition of the Commission for Thermal Physiology of the International Union of Physiological Sciences(IUPS Thermal Commission, 2001) as stated above.

IP is one of the classic issues in human physiology from the view of maintenance of health and homeostasis of thermoregulation. According to Renbourn (1960), the first record about IP appears from the Greek physician, Empedocles(BC 5). In 1733, Stephen Hales appears to have been the first to weigh separately the insensible perspiration of lungs and skin. Modern textbooks do not seem to give attention to the subject of IP as much as those in classical ages. However, the IP is especially an important factor to consider when wearing impermeable protective clothing, being isolated in closed space for a long time, or deciding the amount of water to provide patients in surgery. Therefore, this subject is required to get re-attention.

There have been various factors reported that influence the IP: The IP is related to air temperature (Bell et al., 1980; Lamke et al., 1977; Wiley & Newburgh, 1931), air humidity(Kuno, 1956; Sedin et al., 1985; Vasti, 1932; Wiley & Newburgh, 1931), air pressure(Yamaguchi et al., 1999), sex(Lee, 1999), posture(Benedict & Wardlaw, 1932), activity(Lavietes, 1935; Newburgh et al., 1930; Sedin et al., 1983; Vasti, 1932), disease(Anderson, 1938; Gilligan & Edsall, 1935), circadian rhythm(Tokura et al., 1978), skin temperature(Pinson, 1942; Tokura et al., 1978), maturity of skin(Rutter, 1996), skin capillary pressure (Musin et al., 1990), and diet(Johnston & Newburgh, 1942; Wiley & Newburgh, 1931).

Even though with this long history, there have been few studies focusing on the effect of seasonal clothing ensembles on IP. The human body is surrounded by a microclimate which is enclosed by clothing. It can be hypothesized that the differences of seasonal clothing ensembles, even if in thermal comfort, may have an effect on IP. Therefore, the purpose of the present study was 1) to examine IP in thermal comfort wearing seasonal clothing in each seasonal environment, and 2) to investigate relationships between IP and thermo-physiological factors such as air temperature(T_a), air humidity(H_a), energy metabolism, ventilation, and mean skin temperature($\overline{T}_{sk}$).

II. Methods and Materials

1. Subjects and the Environment of a Climatic Chamber

Five young females served as volunteers in this study(Mean±SD 22.4±1.3yrs; 51.4±1.7kg; 162.3±1.88 cm; 1.57±0.02m^2; BMI 19.5±0.7). Prior to their participation, written and informed consents were obtained from all subjects. The seasonal environment of Korea was simulated in a climatic chamber. The physical environment was simulated the seasonal environments inside building. The air temperature during experiments was maintained at the mean of 22.5(20.7~24.4)°C for the spring/fall environment (EN-SF), 24.7(22.8~26.5)°C for the summer environment(EN-SS), and 16.8(14.1~19.8)°C for the winter environment(EN-W), so that all subjects could always feel comfortable without chill or uncomfortable warmth according to the various clothing insulation of seasonal ensembles. The air humidity was set in the range of 20~70%RH and the air speed was less than 0.1m·s^{-1}.

2. The Measurement of Clothing Insulation with a Thermal manikin

A total of 26 clothing ensembles for women(8 clothing ensembles for spring/fall, 7 for summer, and 11 for winter) were selected based on our previous survey(Choi et al., 2006). Clothing insulation values were determined using a thermal manikin(Newton, Measurement Technology NORTHWEST, USA). The measurement process was the same as the previous study(Lee et al., 2007). Thermal insulation(I_{cle}) of the 26 clothing ensembles was in the range of 0.23 to 1.35 clo(Table 1). Single garments in each clothing ensemble were weighed twice using an electronic balance(Sartorius Company, Germany, Sensitivity 1g) in the climatic chamber maintained at 23±1°C and 40±10%RH. For the calculation of body surface area covered by clothing, we calculated the surface area covered by clothing ensembles based on the photographic methods and the previous studies(Lee, 2005; McCullough et al., 1985).

3. Physiological Measurements

The insensible loss of body weight(IL) is caused by the outward passage of water vapor(H_2O) and car-

Table 1. Insensible perspiration in thermal comfort by seasonal clothing ensemble

Item		Description	Mass *(g)	I_{cle}	CA (%)	IL**±SD ($g \cdot m^{-2} \cdot hr^{-1}$)
Spring/Fall	SF1	(**B**[1]+Tee with long sleeves)+(Brief+**P**[2])+(**Ss**[3]+**S**[4])	726	0.483	86	19.6±3.7
	SF2	(**B**+Tee with long sleeves)+(Brief+Knee length skirt)+(**S**)	493	0.344	72	19.8±6.4
	SF3	(**B**+Sleeveless undershirt+Tee with long sleeves)+(Brief+**P**)+(**Ss**+**S**)	797	0.470	86	21.5±5.4
	SF4	(**B**+Tee with long sleeves)+(Brief+Knee length skirt)+(**PH**[5]+**S**)	517	0.363	86	18.7±7.1
	SF5	(**B**+Tee with long sleeves+Jacket)+(Brief+**P**)+(**Ss**+**S**)	1,132	0.560	86	19.5±5.9
	SF6	(**B**+Tee with long sleeves+Jacket)+(Brief+Knee length skirt)+(**S**)	899	0.412	72	18.0±2.8
	SF7	(**B**+Tee with long sleeves+Jacket)+(Brief+Knee length skirt)+(**PH**+**S**)	923	0.444	86	18.4±4.1
	SF8	(**B**+Sleeveless undershirt+Tee with long sleeves+Jacket)+(Brief+**P**)+(**Ss**+**S**)	1,203	0.596	86	19.7±4.3
Summer	S1	(**B**)+(Brief+Sleeveless dress)+(Sandle)	345	0.228	54	22.3±5.9
	S2	(**B**+Seeveless)+(Brief+Mini skirt)+(Sandle)	405	0.160	45	21.0±5.8
	S3	(**B**+Tee with half sleeves)+(Brief+Knee length skirt)+(Sandle)	345	0.244	64	21.6±3.9
	S4	(**B**+Tee with half sleeves)+(Brief+**P**)+(Sandle)	450	0.322	78	20.3±5.0
	S5	(**B**+Tee with half sleeves)+(Brief+Mini skirt)+(Sandle)	426	0.218	51	21.8±4.9
	S6	(**B**+Under top+Tee with half sleeves)+(Brief+Knee length skirt)+(Sandle)	508	0.267	64	21.1±3.3
	S7	(**B**+Under top+Tee with half sleeves)+(Brief+**P**)+(Sandle)	367	0.367	78	20.3±4.9
Winter	W1	(**B**+**S**[6]+**WC**[7])+(Brief+**P**)+(**Ss**+**S**)	2,210	0.976	88	17.7±3.7
	W2	(**B**+**S**+**WC**)+(Brief+Long legged under pants+**P**)+(**Ss**+**S**)	2,349	1.157	88	21.0±6.7
	W3	(**B**+Sleeveless undershirt+**S**+**WC**)+(Brief+**P**)+(**Ss**+**S**)	2,281	1.105	88	18.9±4.4
	W4	(**B**+Sleeveless undershirt+**S**+**WC**)+(Brief+Long legged underpants+**P**)+(**Ss**+**S**)	2,420	1.16	88	16.9±4.9
	W5	(**B**+Sleeveless undershirt+**S**+Cardigan+**WC**)+(Brief+**P**)+(**Ss**+**S**)	2,540	1.157	88	17.6±5.9
	W6	(**B**+Sleeveless undershirt+**S**+Cardigan+**WC**)+(Brief+Long legged underpants+**P**)+(**Ss**+**S**)	2679	1.222	88	18.7±5.5
	W7	(**B**+Sleeveless undershirt+Tee with long sleeves+**WC**)+(Brief+**P**)+(**Ss**+**S**)	2,225	1.015	88	18.7±4.9
	W8	(**B**+Tee with long sleeves+Cardigan+**WC**)+(Brief+**P**)+(**Ss**+**S**)	2,413	1.11	88	15.5±6.6
	W9	(**B**+Sleeveless undershirt+**S**+**WC**)+(Brief+Knee length skirt)+(**PH**+**S**)	2,139	0.912	88	17.4±5.0
	W10	(**B**+Sleeveless Undershirt+**S**+**WC**)+(Brief+**P**)+(**Ss**+**S**+Gloves+Muffler)	2,444	1.299	93	17.8±8.2
	W11	(**B**+SleevelessUndershirt+**S**+**WC**)+(Brief+**P**)+(**Ss**+**S**+Gloves+Muffler+Hat)	2,535	1.351	98	18.2±5.7

1) B=Bra; 2) P=Pants; 3) Ss=Socks; 4) S=Shoes; 5) PH=Panty Hose; 6) S=Sweater; 7) WC=Winter Coat;
*Exclusion of the weight of shoes (or boots); **Insensible loss of body weight.

bon dioxide(CO_2), both of which reduce the individual's weight. Simultaneously, IL is augmented by the absorption of oxygen(O_2)(Wiley & Newburgh, 1931) (Eq.1).

Insensible loss of body weight(IL)
$= H_2O + CO_2 - O_2$ ······································ <Eq. 1>

IL was simply determined through body weight loss measured before and after one-hour of exposure on a balance(Satorius company, Germany, sensitivity 1g). IW consists of both water vapor from the skin and the lungs. IW through the skin, that is insensible perspiration(IP), was calculated by deducting body weight loss caused by respiratory gas exchange(the mass of VO_2 and VCO_2) and respiratory water loss (IWR) from total body weight loss(IL). The percentage of the IW out of IL was estimated by the <Eq. 2> (Lavietes, 1935). Insensible water loss through respiratory passage(IWR, $\tilde{m}_e$) was calculated by using the following (Eq.3)(Mitchell et al., 1972).

Insensible water loss(IW)
$= 0.91 \times$ Insensible loss of body weight(IL) <Eq. 2>
$\tilde{m}_e = 0.019 VO_2 (44 - P_a)$ ······························ <Eq. 3>

Where, $\tilde{m}_e$ is the rate of evaporative water loss in the expired air($g \cdot min^{-1}$), VO_2 is the oxygen uptake ($L \cdot min^{-1}$ STPD) and P_a is the ambient water vapor pressure(mmHg). The expired and inspired air was analyzed by indirect calorimetry using a gas analyzer (Quark b^2, COSMED Company, Italy) continuously for one hour in a sitting position.

Twelve skin temperatures were measured on the forehead, chest, abdomen, forearm, hand, right front thigh, right calf, foot, back, lower back, back of left thigh, back of left calf, at one minute intervals(LT8A, Gram Corporation, Japan). Mean skin temperature ($\bar{T}_{sk}$) was calculated as a weighted average based on the regional body surface area of Korean women (Lee, 2005). Clothing microclimate temperature and humidity were measured on the chest and the back using a portable thermo recorder(TR 71, T&D Corp., Japan) at one minute intervals.

After donning the experimental garments and equipment, subjects sat on a chair and rested for 30~60 minutes. After resting, subjects were weighed on a body scale(Sartorius Company, Germany, Sensitivity 1g), and then, rested on a chair in a climatic chamber for 60 minutes without any sweating, shivering, or uncomfortable feelings such as warm/chilly. After the 60 minute-exposure, body weight was measured again on a same body scale. For the exposure, T_a, H_a, T_{sk}, clothing microclimate humidity on the chest and back(H_{clo}), and energy metabolism were measured. Every measurement was done twice for each subject. Each seasonal clothing ensemble was worn in corresponding seasonal climate. To avoid the effect of circadian rhythm on physiological responses, all experiments by individual were conducted at the same time.

4. Statistical Analysis

Correlation coefficients between IL and thermo-physiological factors(T_a, H_a, I_{cle} and Covering area, etc) were calculated using SPSS V12.0. ANOVA was conducted for testing the differences of IL among subjects by three seasonal environments. The significant difference was set at $p<.05$.

III. Results

While subjects were resting in thermal comfort without any sweating, shivering or uncomfortable feeling, IL was significantly higher in the summer than in the winter environment($19 \pm 4 g \cdot m^{-2} \cdot hr^{-1}$ for Spring/Fall; $21 \pm 4 g \cdot m^{-2} \cdot hr^{-1}$ for Summer; $18 \pm 4 g \cdot m^{-2} \cdot hr^{-1}$ for Winter)(Table 2, $p<.001$). However, IWR showed an inverse relationship compared to IP. IWR was higher in winter than in summer($6 \pm 1 g \cdot m^{-2} \cdot hr^{-1}$ for winter; $5 \pm 1 g \cdot m^{-2} \cdot hr^{-1}$ for summer)($p<.001$). The present study estimated the insensible water loss (IW) as 91% out of IL according to the previous study(Eq. 3)(Lavietes, 1935). Based on <Eq. 2> and <Eq. 3>, the percentage of IWR out of IW was a mean of 28% in summer and a mean of 41% in winter ($p<.001$). Energy metabolism did not show any significant differences by seasonal conditions(Table 2). The mean heat loss due to IW out of the whole heat produced through energy metabolism was 25% for spring/fall, 27% for summer and 23% for winter.

Table 2. Insensible weight loss, insensible water loss, energy expenditure, ventilation and mean skin temperature in comfortable environments

	Spring/Fall	Summer	Winter	Total Mean (Range)
Air temperature(°C)	22.5±0.6	24.7±0.7	16.8±0.5	20.7 (14.1~26.5)
Relative humidity(%RH)	44±5	48±5	48±6	47 (23~68)
Insensible loss of weight, IL($g \cdot m^{-2} \cdot hr^{-1}$)	19±4[a]	21±4[b]	18±4[a]	19 (4~32)
Insensible water loss estimated, IW($g \cdot m^{-2} \cdot hr^{-1}$)	18±3[a]	19±4[b]	16±4[a]	18 (3~31)
Insensible water loss from skin estimated, IWS($g \cdot m^{-2} \cdot hr^{-1}$)	12±4[a]	14±4[b]	11±4[a]	12 (1~25)
Insensible water loss from respiratory exchange, IWR($g \cdot m^{-2} \cdot hr^{-1}$)	6±1 [ab]	5±1[a]	6±1[b]	6 (2~9)
IWR/IW(%)	32.7±8.9[a]	28.1±6.7[a]	40.6±14.4[b]	33.6 (7~67)
IWR/IL(%)	29.7±5.9[b]	25.5±6.0[a]	34.1±8.4[c]	30.4 (13.3~64.7)
Energy metabolism($Kcal \cdot m^{-2} \cdot hr^{-1}$)	42.1±5.6	43.0±8.3	42.0±6.5	42.4 (21.9~69.0)
Ventilation($Liter \cdot m^{-2} \cdot hr^{-1}$)	321±46[a]	349±60[b]	309±59[a]	323 (184~495)
Mean skin temperature(°C)	32.7±0.4[b]	33.0±0.3[c]	32.3±0.6[a]	32.6 (30.2~34.0)
Microclimate humidity, chest(%RH)	31±4[b]	33±5[c]	26±3[a]	29 (12~51)
Microclimate humidity, back(%RH)	27±4[b]	30±4[c]	20±4[a]	25 (11~55)

[a,b,c] showed the results of ANOVA and Duncan's post hoc test among seasons.

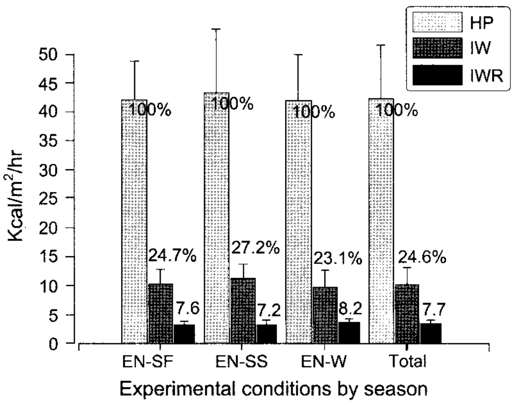

Fig. 1. Heat production through energy metabolism (HP), insensible water loss (IW) and respira-tory water (IWR) in thermal comfort by season(EN-SF, Spring/Fall; EN-SS, Summer; EN-W, Winter).

About 25% of energy metabolism in thermal comfort was lost through IW. The mean heat loss through IWR was 8% of energy metabolism(Fig. 1).

There were no differences of IL by a total of 26 clothing ensembles(Table 1). When comparing by season, IL for wearing skirts in summer(S1, S2, S3, S5, & S6) was little larger than wearing pants, but the difference was not statistically significant(Table 1). Regarding the relationships between IL and clothing factors, IL showed significant but weak correlations with I_{clo}/covering area(Fig. 2). Regarding the relationships between IL and environmental factors, IL showed a positive correlation with T_a(p<.001) and a negative correlation with H_a(p<.01). However, the coefficients were less than 0.3. Likewise, IL showed the positive correlation with energy metabolism, ventilation, and $\overline{T}_{sk}$, but the coefficients were all less than 0.5(p<.001).

Regarding individual differences, there were statistically significant differences by individual in IL, IW, energy metabolism, ventilation, $\overline{T}_{sk}$, and clothing microclimate humidity, even though their body shape and physique were similar in the narrow range(Table 3, p<.05). In particular, when comparing subject A (49.6kg; 164.1cm) with subject C(54.2kg; 163.3cm) per body surface area, subject A showed significantly greater values in IL, IWR, EE, and ventilation than subject C(Table 3, p<.001).

IV. Discussion

The body water is lost as a form of vapor through the skin and the respiratory passage or as a form of liquid through sweating, urine, and feces. The amounts of insensible water loss through the skin and the respiratory passage has been reported as approxi-

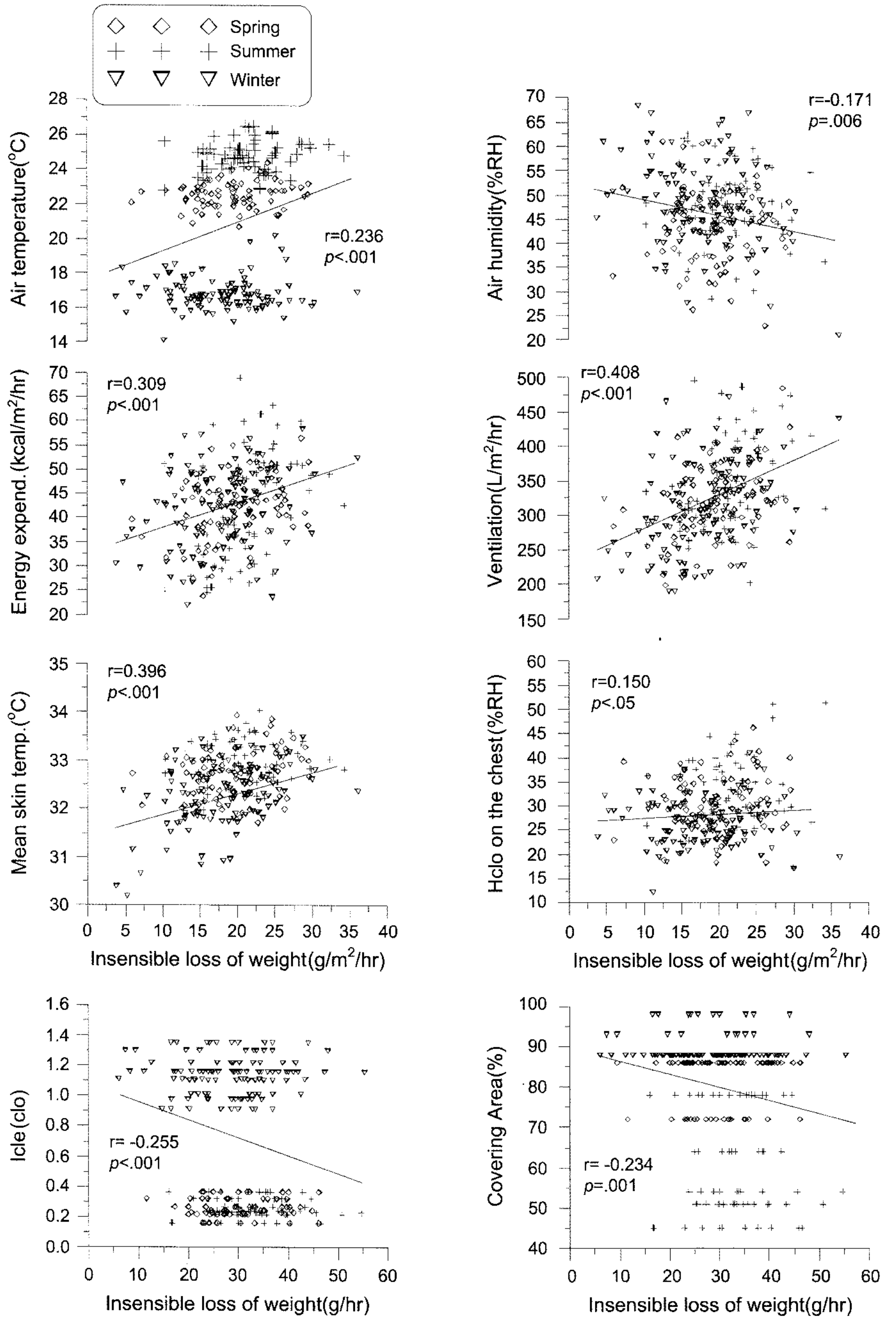

Fig. 2. Relationships between insensible loss of weight and environmental factors, clothing factors and respiratory factors.

mately 4~35g·hr^{-1}(Jeje & Koon, 1989). According to previous reports conducted as 24-hour observational studies, 24-hour insensible water showed 1,019 to 1,524g·day^{-1}, that is, 42.5~63.5g·hr^{-1}(Newburgh et al., 1930). Johnston and Newburgh(1930) noted that the IL was in the range of 844 to 1,713g·day^{-1}

Table 3. Individual insensible perspiration and estimated dry heat loss in thermal comfort

	Subject A (n=57) 49.6kg;164cm	Subject B (n=52) 50.5kg;160cm	Subject C (n=53) 54.2kg;163cm	Subject D (n=52) 51.2kg;161cm	Subject E (n=51) 51.5kg;163cm
Insensible loss of weight, IL($g \cdot m^{-2} \cdot hr^{-1}$)	21^{bc}	20^{b}	17^{a}	17^{a}	22^{c}
Insensible water loss estimated, IW($g \cdot m^{-2} \cdot hr^{-1}$)	19^{bc}	18^{b}	15^{a}	17^{a}	20^{c}
Insensible water loss from the skin estimated, IWS ($g \cdot m^{-2} \cdot hr^{-1}$)	13^{bc}	12^{bc}	11^{a}	12^{ab}	14^{c}
Insensible water loss from respiratory exchange, IWR ($g \cdot m^{-2} \cdot hr^{-1}$)	6.6^{c}	6.1^{bc}	4.7^{a}	4.9^{a}	5.8^{b}
IWR/IW(%)	36.1^{b}	35.2^{b}	33.7^{ab}	33.0^{ab}	30.0^{a}
IWR/IL(%)	32.7^{b}	31.5^{ab}	31.3^{ab}	29.2^{ab}	27.3^{a}
Energy metabolism($Kcal \cdot m^{-2} \cdot hr^{-1}$)	48.9^{d}	44.5^{c}	36.0^{a}	38.9^{b}	43.1^{c}
Ventilation($Liter \cdot m^{-2} \cdot hr^{-1}$)	384^{e}	359^{d}	264^{a}	287^{b}	318^{c}
Mean skin temperature(°C)	32.7^{b}	32.7^{b}	32.4^{a}	32.2^{a}	33.0^{c}
Microclimate humidity on the chest(%RH)	28^{ab}	27^{a}	30^{bc}	29^{abc}	31^{c}
Microclimate humidity on the back(%RH)	25^{ab}	23^{a}	27^{b}	25^{ab}	24^{ab}

^{a,b,c} showed the results of ANOVA and Duncan's post hoc test among subjects.

(35.2~71.4$g \cdot hr^{-1}$). IL obtained from the present study had the mean 19$g \cdot m^{-2} \cdot hr^{-1}$, and IW showed the mean 18$g \cdot m^{-2} \cdot hr^{-1}$. These results were smaller than in the previous reports.

There may be various reasons to explain the difference: gender, activity, posture, and food. Regarding sex, IL per BSA was greater in males(24$g \cdot m^{-2} hr^{-1}$) than in females(19$g \cdot m^{-2} \cdot hr^{-1}$)(Lee, 1999). This may be related to ventilation, not skin perspiration. In most previous studies, male subjects participated, while only female subjects took part in this present study. Regarding posture, the subjects of the present study rested in a sitting position, but subjects of the previous 24-hr studies were in various postures and activities. Benedict and Carpenter(1910) found that during 6-hr sleep, 17 subjects eliminated by vaporization 27% of the total heat produced, while during waking hours the average for the same subjects was 21%(as cited in Lavietes, 1935). The IW increased 20% on average in the sitting position as compared with the lying position(Benedict & Wardlaw, 1932).

Regarding the relationships between IL and environmental factors, it has been reported that IL is smaller in cool than warm environments because IP from the skin decreases somewhat due to peripheral vasoconstriction in low air temperature(Johnston & Newburgh, 1930). This response is advantageous in thermoregulation. An increase of 1 to 2°C, to an ambient temperature above or near the top of the neutral zone, produced a significant rise in the IW from 1.9±0.8 to 3.1±1.2$ml \cdot kg^{-1} hr^{-1}$(Bell et al., 1980). When T_a went up from 18 to 25°C, the heat dissipated by the vaporization of water increased slowly(Wiley and Newburgh, 1931). In the present study, IL was significantly smaller in winter than in the summer environment. The difference showed, however, a mean 2$g \cdot m^{-2} \cdot hr^{-1}$.

What is more focused on the relationships between T_a and IP is that IWR showed the reverse tendency with IW. That is, IWR was greatest in winter. Furthermore, the percentage of IWR out of IW was a mean of 38% for winter but 28% for summer. It is known that air temperature expired through respiratory passage from the lung is about 33-37 and relative humidity is almost close to 100%RH(Nakayama, 1981). The characteristics of expired air may account for an appreciable heat loss in cold weather.

How much heat is lost through respiration passage in seasonal thermal comfort environments? According to the present study, about 8% out of the whole heat production was lost through respiratory water loss. IWR accounted for a mean of 34% out of IW.

This result means that insensible water loss through the skin accounts for 66% out of IW. The percentage was, interestingly, similar to that of most previous studies, while the absolute amounts were diverse between studies. Benedict and Root(1926) determined that the loss from the lungs among a variety of human individuals averages 35% of the total IW in the resting individual. Benedict and Benedict(1927) have also shown that under basal conditions approximately 40% of the total water vaporized comes from the respiratory passages(as cited in Lavietes, 1935).

The insensible water loss from the skin in the present study showed as much as $12g \cdot m^{-2} \cdot hr^{-1}$. Tokura et al.(1978) reported that the insensible perspiration from the skin had the mean $14g \cdot m^{-2} \cdot hr^{-1}$ for daytime and $9g \cdot m^{-2} \cdot hr^{-1}$ for sleep. Reithner et al. (1980) noted that the water loss from the skin during surgery was about $10g \cdot m^{-2} \cdot hr^{-1}$. Lamke et al.(1977) reported that the average total cutaneous insensible perspiration of a naked resting subject with a body surface area of $1.75m^2$ was estimated to be 381± 18ml and 695±35ml per day at an ambient temperature of 22 and 30, respectively (30%RH). The IWR for the normal adult resting in thermal comfort seems to be in the narrow range of $8\sim15g \cdot m^{-2} \cdot hr^{-1}$, and about 30~40% of the whole IW.

IP is influenced H_a as well as T_a(Hammarl-nd et al., 1977; Sauer et al., 1984). Sedin et al.(1983) has found an inverse linear relationship between H_a and IP($g \cdot m^{-2} \cdot hr^{-1}$) from the skin. Wiley and Newburgh (1931) noted that an increasing relative humidity caused a decreasing vaporization of water from the skin. The present study could not examine the effect of humidity on IP. Instead, we measured the clothing microclimate humidity(H_{clo}) and found the reverse tendency with H_a. That is, the higher H_{clo} is, the greater IW is. Based on this result, we can consider that H_{clo} is affected by IW from the skin rather than influencing to IW from the skin.

Regarding energy metabolism, for the present study, the relationship between energy metabolism and IL was significant but weak. Benedict and Root (1926) have shown that the amount of IP bears a definite quantitative relationship to the metabolic rate under basal condition. They accordingly concluded that the 24-hour basal heat production could be predicted from the hourly basal insensible loss of body weight.

How much does the heat eliminated by IP account for in the whole energy metabolism? The present study showed that heat loss by IP accounted for 25% in average out of the whole energy metabolism. Interestingly, values reported in most previous reports were in narrow ranges with this result. Levine and Wilson(1926) already pointed out that 'Despite the enormous differences in metabolic rates in the age periods from infancy to adult life, apparently a definite and unvarying fraction of the total amount of heat produced by all subjects was removed from the body by vaporization of water through skin and lungs (average of 26%)'. Yoshimura et al.(1968) also reported that about 25% of total heat loss in resting men in a thermo-neutral environment is eliminated by means of IP. Soderstrom and DuBois(1917) reported that the proportion of heat eliminated by vaporization approximated closely to the average value of 24%. Levine and Wilson(1926), in 53 experiments with infants, found that vaporization of water accounted on the average for 26% of the heat production.

Regarding clothing ensembles, we found that IP was smaller when wearing clothing ensembles with higher I_{cle} and when there was a greater body area covered by clothing. However those relationships were not remarkable. Wiley and Newburgh(1931) measured IP of a normal male while wearing clothes and while nude in air temperature of 18~36°C. As a result, IP in the nude increased as air temperature increased, but changing air temperature while wearing clothes did not affect the amount of IP. Lee (1999) measured the IL in 19°C air temperature. IL between two kinds of clothing feeling cool and comfortable did not show any significant difference ($22g \cdot m^{-2} \cdot hr^{-1}$ for the feeling cool; $23g \cdot m^{-2} \cdot hr^{-1}$ for the feeling comfortable).

Lastly, the individual factor seems to be the more influencing factor on the IP than the environmental or clothing factors. One of the interesting results was that among the five subjects the leanest subject showed significantly greater IL, IWR, energy metabolism and ventilation per body surface area than the subject with the greatest BMI. Wiley and Newburgh (1931) measured IP of eight subjects with different anthropometric characteristics(9~47yrs; 125~180cm; 16~99kg). The results showed that heat loss by vaporization of water out of total heat loss was diverse in the range of 19~34% and they conclude this due to the individual differences. According to Lavietes(1935), however, even though individual differences are significant, it is probably correct that for normal subjects, a fairly constant proportion of the heat production is eliminated through the process of vaporization of water under conditions of rest or slight activity. It has been noted that the individual variability is of the order of ±10%, however, and that certain individuals tend to vary constantly in one direction from the mean.

V. Summary and Conclusions

The results of the present study showed that 1) insensible loss of body weight(IL) was $19\pm5g \cdot m^{-2} \cdot hr^{-1}$ for spring/fall environment, $21\pm5g \cdot m^{-2} \cdot hr^{-1}$ for summer, and $18\pm6g \cdot m^{-2} \cdot hr^{-1}$ for winter($p<.001$). 2) Insensible water loss through respiratory passage (IWR) showed the inverse tendency to IL. 3) The proportion of IWR out of the whole insensible water loss(IW), had a mean of 28% for summer and 38% for winter($p<.001$). 4) In thermal comfort, the heat lost by insensible water loss(IW) accounted for around 20~30% of heat production. 5) There were weak but significant correlations between insensible loss of body weight(IL) and air temperature(T_a), air humidity(H_a), energy metabolism, ventilation, mean skin temperature($\bar{T}_{sk}$), and clothing microclimate humidity(H_{clo}). In conclusion, there were significant but weak relationships between insensible loss of body weight(IL) and thermo-physiological factors, when subjects rested in thermal comfort. Insensible loss of body weight(IL) was maintained in narrow range even though the clothing insulation and air temperature were diverse.

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요 약

본 연구의 목적은 계절별 의복을 착용하고 쾌적한 상태를 유지하는 동안 불감체중손실과 온열 생리적 요소들간의 관련성을 살펴보는 것이다. 이를 위해 한국의 계절별 실내 환경이 인공기후실에 조성되었고 (봄/가을 환경 기온 평균 22.5, 여름 24.7, 겨울 16.8), 설문조사를 바탕으로 총 26 종의 계절별 한벌의복이 선정되었다(봄/가을 옷 8 종, 여름 옷 7종, 겨울 옷 11종). 다섯 명의 젊은 여성이 피험자로 참여하였으며, 결과는 다음과 같다: 1) 불감체중손실(IL)은 봄/가을 의복을 착용한 경우 19±5g · m^{-2} · hr, 여름 옷 21±5g · m^{-2} · hr, 겨울 옷 18±6g · m^{-2} · hr으로, 겨울 환경보다 여름 환경에서 더 컸다(p<.001). 2) 호흡기를 통한 불감수분손실(IWR)은 불감체중손실과 반대의 경향을 보여 주어, 겨울 옷을 입은 경우 6±1g·m^{-2}·hr, 여름 옷을 입은 경우 5±1g · m^{-2}·hr 였다(p<.001). 3) 불감수분손실 (IW)에서 호흡기를 통한 불감수분손실이 차지하는 비중은 여름 옷을 착용한 경우 평균 28%, 겨울 의복의 경우 38% 였다(p<.001). 4) 쾌적한 상태에서, 산열량 중 불감수분손실이 차지하는 비율은 봄/가을 의복을 착용한 경우 25%, 여름 옷의 경우 27%, 겨울 옷의 경우 23%였다. 5) 불감체중손실과 의복의 보온력 간, 그리고 불감체중손실과 피복면적 간에는 모두 약한 역상관 관계가 관찰되었다. 6) 불감체중손실은 기온, 기습, 에너지 대사, 환기량, 평균피부온도, 의복내 습도 등의 요소와 유의한 상관을 보였으나, 상관계수들은 모두 0.5 이하였다. 결론적으로, 불감체중손실과 온열 생리 요인들 간에는 약한 상관이 존재했으나, 피험자들이 온열 쾌적을 유지하는 경우 착용한 의복 종류 및 노출 기온에 상관없이 불감체중손실량은 좁은 범위를 유지했다.