Investigation of Comfort of Uniform Shirt Made of Cellulose Considering Environmental Load

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Abstract. The purpose of this study is to evaluate the wearing comfort of uniform-shirts and to investigate the suitable value for the preset temperature of air conditioners thorough measuring material properties and psychophysiological responses. The uniform shirt was made of cellulose materials such as rayon and tencel for wearing in hot conditions like summers in Japan. Material properties measurement were made according to Kawabata Evaluation System (KES), Japan Industrial Standards (JIS) and Moisture Management Tester (MMT). Physiological response measurements were electrocardiogram (ECG), respiration, skin temperature and the humidity inside the clothes. Psychological response measurements were by semantic differential method and ranking method. We concluded that the uniform shirts made of rayon are comfortable even in hot conditions like summer in Japan. 29˚C as the temperature setting of air conditioners is too hot for people. Respiration seems to be an important factor for evaluation of wearing comfort.

1 Introduction

In Japan, the summer is a hot season with high humidity. For Japanese workers, thermal stress is a great annoyance in the summer. A uniform shirt is something that workers must wear. So the thermal stress of uniform shirts should be minimized. Cellulose materials such as tencel and rayon have characteristics such as high thermal conductivity and hydrophilicity suitable for reducing thermal stress. Cellulose also has low environmental impact since it can be turned back into soil. The purpose of this study is to develop comfortable uniform shirts made of cellulose. We used rayon and tencel as the cellulose materials. In terms of environment loading, tencel is lower than rayon because the waste fluid can be recycled as a soap. We manufactured trial uniform shirts and evaluated the wearing comfort by psychophysiological measurements and material properties evaluation.

The Japanese government recommends setting the air conditioner to 28˚C in the summer. If the temperature setting of the air conditioner is increased by 1˚C, power consumption will be reduced by 13%[1]. So we examined the temperature setting of air conditioners by comparing 28˚C and 29˚C from the viewpoint of wearing comfort.

2 Experiment

2.1 Samples

Table 1 shows the information of 3 types of samples with flat woven structure. Tencel, rayon, cotton and polyester were used to create the samples. R100 was composed of 100% rayon. The materials of R/T were rayon and tencel. The warp of R/T was 100% rayon. The weft of R/T was 100% tencel. P/C was composed of blended yarn made of 65% polyester and 35% cotton. P/C was the conventional product and R100 and R/T were the improved products.

Table 1. Samples

Symbol		R100	R/T	P/C
Material	Warp	Rayon100% (Filament)	Rayon100% (Filament)	Polyester65%/ Cotton35%
	Weft	Rayon100% (Filament)	Tencel100% (Spun)	Polyester65%/ Cotton35%
Yarn count	Warp	120 d (≒44.291S)	120 d (≒44.291S)	45S
	Weft	120 d (≒44.291S)	40S	45S
Density	Warp	105 thread/inch	106 thread/inch	136 thread/inch
	Weft	77 thread/inch	85 thread/inch	72 thread/inch
Structure		Flat Woven Structure		

2.2 Material properties Evaluation

This experiment was for evaluation of the heat and moisture transport properties of the 3 fabrics shown in Table 2. All items were measured 5 times. The mean value of those measurements was used as the representative value.

2.2.1 Japan Industrial Standards

For moisture transfer properties, moisture permeability and moisture content were measured. Moisture permeability was measured using the water method defined in JIS L 1099 A-2. A moisture-permeable cup is filled to 10mm of the upper rim of the cup with water at 40°C. The fabric is attached to the top of the cup so that the back side faces the water surface. Then, the cut surfaces of the test piece are covered with vinyl tape so that water vapors cannot escape. The cup prepared in this way is placed in a constant-temperature, constant-humidity environment at 40°C and 50%RH for 1 hour. Then the initial weight of the cup (a_1) is measured. Next, the weight of the cup after one hour has elapsed (a_2) is measured. The moisture permeability (MP) is then derived from the following equation. In this equation, *S* is the water-vapor-permeating surface area of the test piece.

$$MP = \frac{10 \times (a_1 - a_2)}{S} [\mathrm{g / m^2 \cdot h}]$$

The moisture absorbency of textile products is determined according to the moisture ratio which is the percentage of atmospheric moisture that is absorbed. Dry-state textiles placed in the atmosphere absorb water vapors in the air to reach equilibrium. The moisture content (*MC*) defined in JIS L 1096 is expressed using *Wd* and *Ww* according to the following equation.

$$MC = \frac{Ww - Wd}{Wd} \times 100[\%]$$

In this equation, *W*d is the weight of the textile in its absolute dry state, and *Ww* is the weight of the textile after being left in a constant-temperature, constant-humidity environment for more than 24 hours. In this research, the moisture content was measured at 28°C and 65% RH.

2.2.2 Kawabata Evaluation System

The air permeability property *R* was measured using KES-F8. *R* is the air flow resistance. The thermal properties *q-max*, *K'* and *Qd* were measured using KES-F7. *q-max* is the initial maximum heat flux when the copper plate heated to 30°C was put on the fabric. *K'* is the steady state thermal conductivity when a heat source at 30˚C is placed on the fabric on top of a cool box at 20˚C. *Qd* is the thermal insulation rate when air is blown on at an air flow of 0.3m/s. Measurement conditions were 20˚C and 65% RH.

2.2.3 Moisture Management Tester

The Moisture Management Tester (MMT) is the device for analyzing 3 dimensional water transport properties. Measurement items were *wetting time*, *water absorption rate*, *maximum wetted radius*, *spreading speed*, *one way transport capacity* (*OWTC*) and *overall moisture management capacity* (*OMMC*). Data were measured on both sides except for *OWTC* and *OMMC*. *OWTC* is the difference of the integral value of the time series data of moisture content calculated by subtracting the value of the bottom side from the value of the top side. *OMMC* is the calculated from the *absorption rate* of the top side, *spreading speed* of the bottom side and *OWTC*. As each value becomes greater, *OWTC* become greater. The measurement values were classified by software. Water injection time was 20 seconds. Observation time was 100 seconds. Water content of fabric at the end of the experiment could be confirmed by the images. Measurement conditions were 20˚C and 65% RH.

Table 2. Measurement items

Block property	Symbol	Property	Unit	Reference	Condition
Moisture transport	*MC*	Moisture content	%	JIS L 1096	28°C65%RH
	MP	Moisture permeability	g / m² · h	JIS L 1099 A-2	40°C50%RH
Thermal	*q-max*	Initial maximum heat flux	W/㎠	KES-F7	20°C65%RH
	Qd	Thermal insulation rate (Dry method)	%		
	K'	Steady state thermal conductivity	W		
Ventilation	*R*	Airflow resistance	KPa・s/m	KES-FB8	20°C65%RH
Water transport	*Wt*	Wetting time	s	MMT	20°C65%RH
	Ar	Absorption rate	%		
	Mwr	Maximum wetted radius	mm		
	Ss	Spreading speed	mm/s		
	OWTC	One way transport capacity	–		
	OMMC	Overall moisture management capacity	–		

2.3 Wearing Experiment

To evaluate the wearing comfort of the uniform shirts, psychological responses and physiological responses of subjects were measured while wearing the shirt. The items measured for the physiological responses were electrocardiograms (ECG), respiration, skin temperature and humidity inside the clothes. For the psychological response, impression data on the feelings of warmth and comfort were obtained by the SD method and ranking method.

This experiment aimed to observe the body temperature increase after moving from a room at 25°C and 50% RH to the room with hot condition. Experimental conditions were 28°C and 65% RH or 29°C and 65% RH.

Fig. 1 shows the protocol of the experiment. Each subjects participated for 2 days at the pace of 1 condition per day. 3 samples were evaluated for each condition. At first, subjects were in a room at 25˚C and 50% RH for 13minutes wearing T-shirts, shorts, underwear and socks. In the next 2 minutes, subjects moved from 25˚C and 50% RH to the hot conditions and then took off the T-shirts and put on the uniform shirts. After that, evaluation of the sample was carried out for 22 minutes. The subjects remained seated and relaxed in a chair except for 2 minutes of moving. Skin temperature and humidity inside the cloth were measured every minute from the beginning of the experiment. The temperature and humidity sensor was the Hygrochron from KN Laboratories. Skin temperature was measured by Ramanathan 4-points method. Humidity was measured at 4 points: On the chest, the abdomen, the upper part of the back and the lower part of the back. Measurement periods of ECG and respiration were 2 minutes. ECG and respiration measurements were taken twice, once at 5 minutes after the start of the experiment and again at the end of experiment. ECG was measured by the bipolar chest lead method. Respiration was measured by a thermistor

(BIOPAC TDS202A) attached below the nose of subjects. Data of ECG and respiration were input to a BIOPAC MP100, and were recorded on the computer at a sampling frequency of 2000Hz. Table 3 shows the terms used for the SD method. The terms were selected to cover all feelings about wearing comfort. The evaluation scale was a seven-step scale (Word on left end of scale: Extremely ~ Very ~ Slightly ~ Neither ~ Slightly ~ Very ~ Extremely: Word on right end of scale). After examination, a score of -3 to +3 was given to quantify evaluation. The SD method was conducted 2 times: once immediately after putting on the sample shirt, and then again 15 minutes after putting on the sample shirt. Ranking was performed after the third sample had been evaluated. After all of the experiments had finished, subjects asked "Which was the day corresponding to 28˚C or 29˚C?" and "Please tell me the standards for comfort evaluation of the uniform shirts". The presentation order of samples and conditions were random. The subjects were 5 healthy male college students in their 20's. All samples were conditioned in an artificial weather room at the same conditions as the experiment for more than 24 hours before evaluation. The experiment time was unified for each subject taking into consideration their circadian rhythms. The experiment was conducted after 2 hours had elapsed since eating. The sample shape was a short-sleeved shirt with buttons in front. The size of each sample was essentially the same size as each subject normally wore.

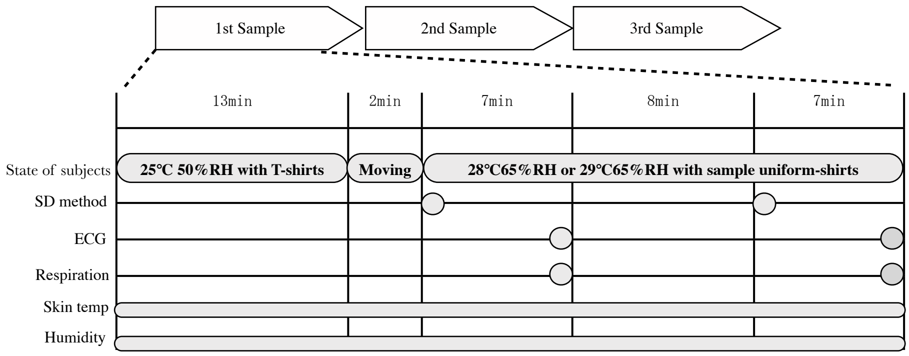

Fig. 1. Protocol of the wearing experiment

Table 3. Terms used in the SD method

Comfortable feeling overall	Comfortable⇔Uncomfortable
Thermal & moisture transport	Cool⇔Warm Refreshing⇔Hot Dry⇔Damp Well-ventilated⇔Poorly-ventilated
Mechanical properties	Good texture⇔Poor texture Rough ⇔Smooth Soft⇔Hard Restrictive⇔Not restrictive Thin⇔Thick

3 Result and Discussion

3.1 Material Properties Evaluation

Fig. 2 shows the results of evaluation by JIS and KES. R100 had high moisture content, high moisture permeability, high *q-max*, high *K'*, low *Qd* and low *R*. R100 seemed to transfer heat and moisture easily to outside the garment. Fig. 3 shows the results by MMT. R100 and R/T ware easy to wet, and P/C was difficult to wet. The size of the variation was in the following order: R100 < R/T < P/C.

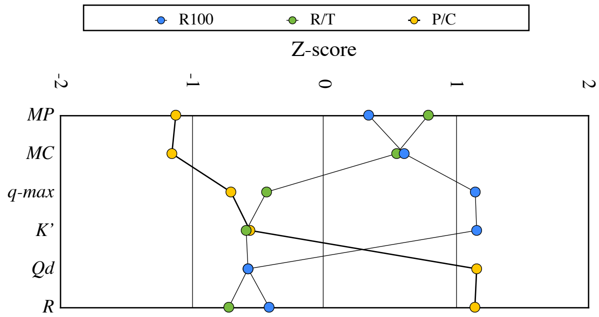

Fig. 2. Results of Japan Industrial Standards and Kawabata Evaluation System

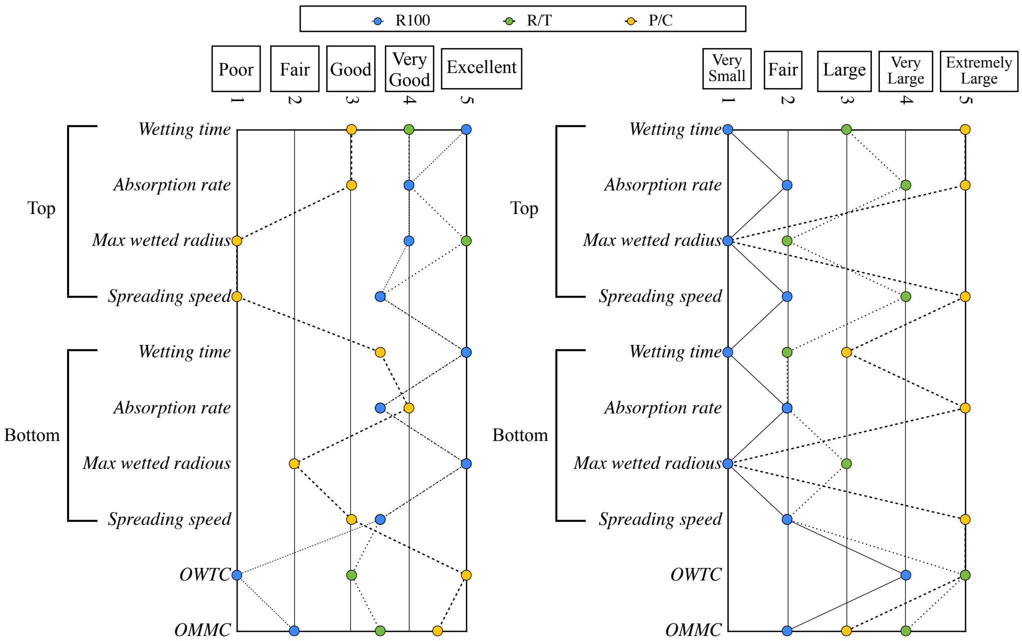

Fig. 3. Grade results by MMT : Left graph shows measured value and right graph shows variance

Fig. 4 shows a picture of the wetting by MMT[2]. R100 was the easiest to wet and had high diffusivity. The higher the variation of sample measurement values, the more difficult it was to wet the sample. R100 seems to be the most comfortable sample from the point of heat- and moisture-transfer properties.

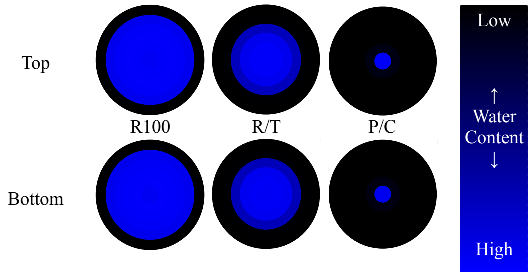

Fig. 4. Picture of fabric wetting

3.2 Wearing Experiment

Fig. 5 shows the mean values for subjects of the measurement results for temperature and humidity inside the shirts. Humidity data of one subject was expected because of noise. The mean skin temperature was low when R100 and R/T were worn. The humidity of P/C was higher than others in 29˚C. The reason is considered to be it's low diffusion properties and starting temperature of sweating. Sweating of human begin when temperature become 29˚C[3]. Skin temperature and humidity were both higher in the 29˚C environment than in the 28˚C one.

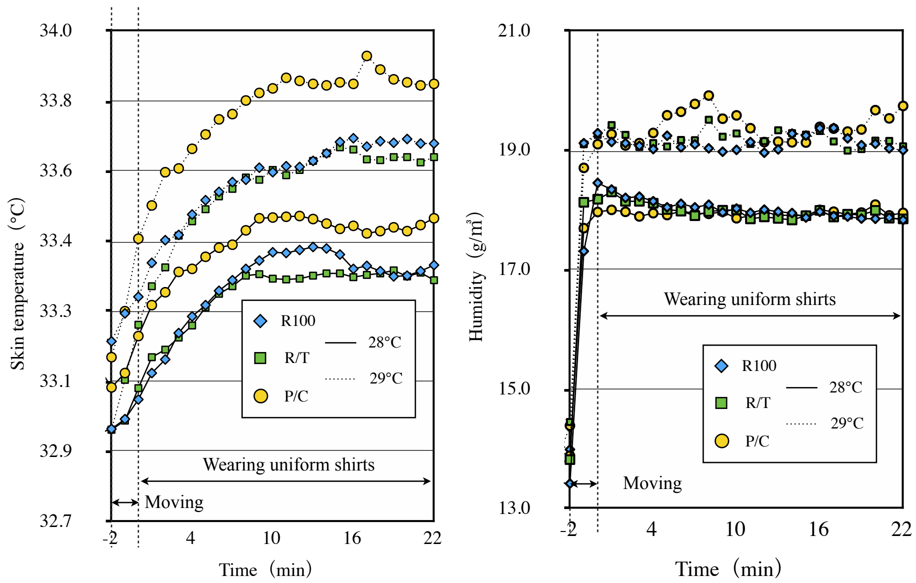

Fig. 5. Skin temperature (left) and humidity inside the cloth (right)

Table 4 shows the results of ranking of comfort criteria by introspection investigation. All subjects felt comfort with cool or chilly sensation except Subject 5. *W's* coefficient of concordance[4] matched significantly excluding Subject 5. The criteria of Subject 5 seem to be different from other subjects. The most comfortable sample was R100 because of its cool feeling and good texture.

Table 4. Results of ranking

Subject	Condition	R100	P/C	R/T	Comfort Criteria
Subject 1	28℃	2	1	3	When it's hot, cool is better. If it's thin, it becomes uncomfortable.
	29℃	1	2	3	
Subject 2	28℃	1	3	2	It's comfortable if it's well-ventilated,soft and not restrictive. Good texture against skin is also important.
	29℃	1	3	2	
Subject 3	28℃	1	3	2	It's comfortable if it feels a little chilly.
	29℃	2	1	3	
Subject 4	28℃	1	3	2	Comfort when feel soft,good texture & cool.
	29℃	1	3	2	
Subject 5	28℃	3	1	2	It's uncomfortable if it's cool.
	29℃	2	1	3	
Average except Subject 5		1	2	3	*W's* coefficient of concordance $S=80>72$ $p<0.01$

Fig. 6 shows the mean values of the scores for all subjects by SD method. Statistically significant differences were examined by ANOVA. 15 minutes after putting on samples, the effect of conditions were statistically significant for "Poorly-ventilated↔Well-ventilated". Stuffiness was felt more strongly at 29˚C than at 28˚C. R100 had the characteristics of being refreshing, cool, dry, well-ventilated, good texture, soft and thin. R/T was similar to R100 but the heat- and moisture-transfer characteristics were inferior compared to R100. One of the reason is considered to be it's low diffusion properties. Even though there were no difference of humidity inside the cloth between R100 and R/T, water diffusion property seem to effect human sensation from the result of MMT. P/C had characteristics which were the opposite of those of the others.

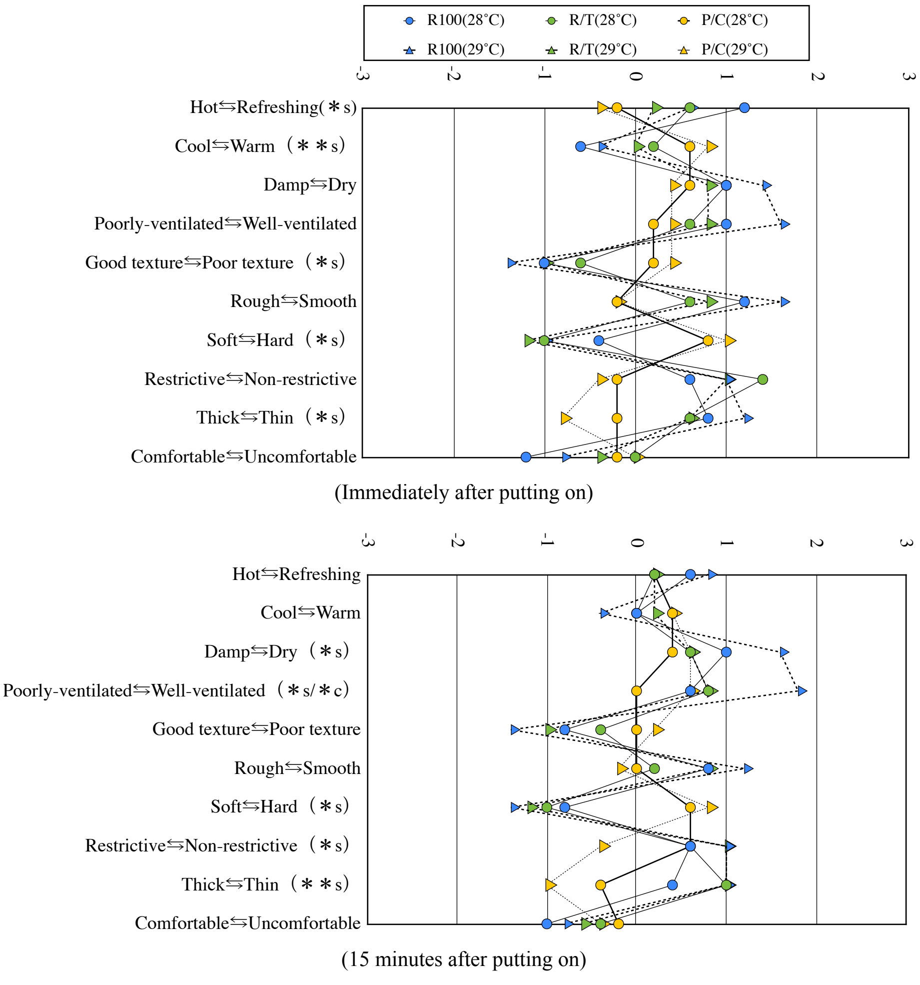

Fig. 6. Results of SD method : ** $p<0.01$ ANOVA, * $p<0.05$ ANOVA, s = Significant difference of sample, c = Significant difference of condition

Fig. 7 shows the mean values of the respiration cycles for all subjects. Long respiration cycles reflect relaxation[5]. R100 is considered more comfortable than the others because the respiration cycles for R100 were marginally significant longer than for the others. Fig. 8 shows the mean values of the expiratory phase times for all subjects. The tendencies of the expiratory phase times were similar to the respiration cycles. They were significantly longer for R100 than for others. Respiration could be considered useful for evaluation of wearing comfort.

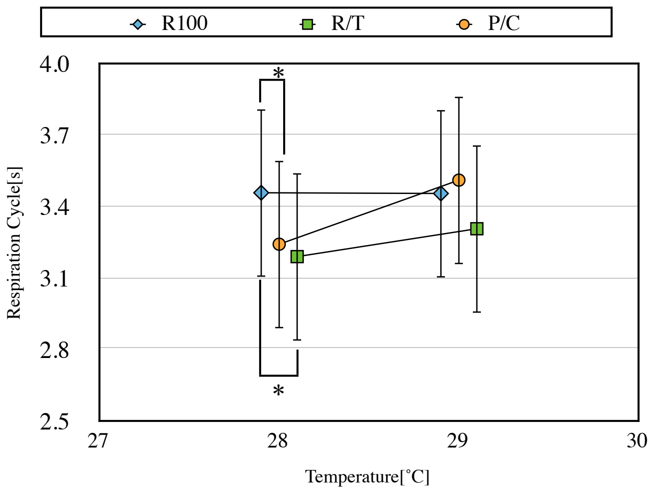

Fig. 7. Respiration cycles : * p<0.1 ANOVA and p< 0.05 Tukey's test

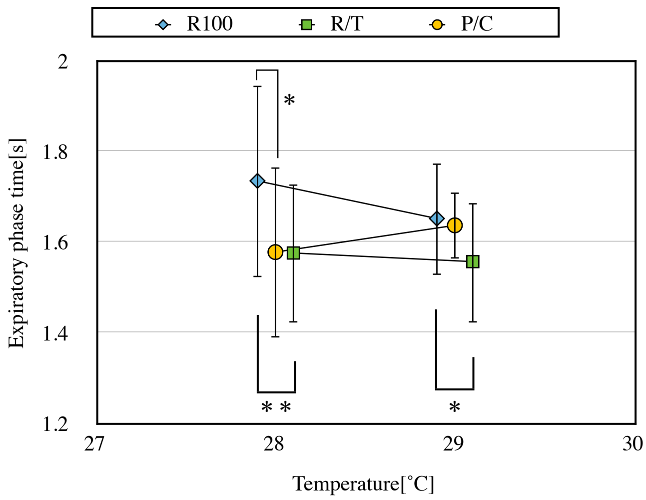

Fig. 8. Expiration phase times : ** p<0.01 ANOVA and Tukey's test, * p<0.05 ANOVA and Tukey's test

Fig. 9 shows the results for skin temperature 13 minutes after the beginning of the experiments standardized by subtracting the first data. Skin temperature in the 29˚C environment increased more than in the 28˚C environment. Fig. 10 shows the results for heart rate by ECG. Marginally significant differences exist between 28˚C and 29˚C for each samples. Heart rate increased in the hotter conditions. Circulation could be considered to be increasingly active for heat dissipation. 4 subjects could distinguish between the 28˚C and 29˚C environments by introspection investigation. The temperature setting of 29˚C seems too hot for people.

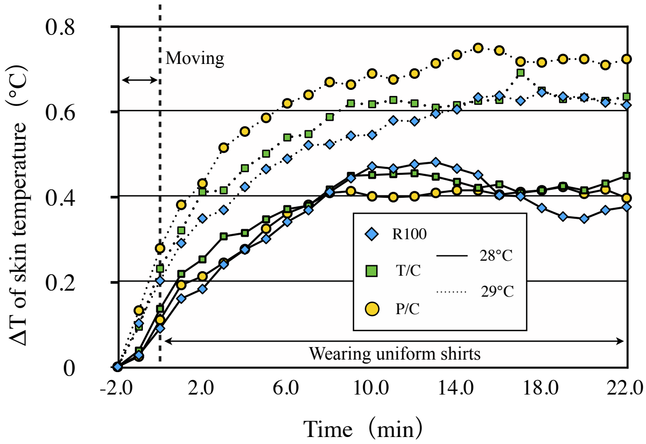

Fig. 9. Skin temperature

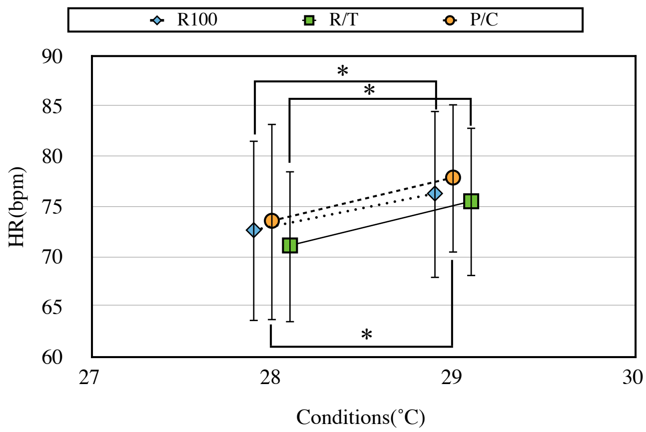

Fig. 10. Heart rate : * p<0.1 ANOVA and p<0.05 Tukey's test

4 Conclusion

R100 is the most comfortable uniform shirts because of its heat- and moisture-transfer properties. If R/T had been easier to wet, the result of evaluation would be more comfortable. The psychophysiological responses were different between the 28˚C and 29˚C environments. The temperature setting should be 28˚C because 29˚C was too hot for people. Wearing comfort could be evaluated by respiration.

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References

1. Ministry of the Environment of Japan : Power-saving actions that can taken in the office (URL:https://funtoshare.env.go.jp/setsuden/office/saving01.html)
2. Junyan Hu, Yi Li, Kwok-Wing Yeung, Anthony S. W. Wong, Weilin Xu : Moisture Management Tester : A Method to Characterize Fabric Liquid Moisture Management Properties , Textile Research Journal, Vol.75, No.1 (2005) 57-62
3. Shizuko Yamaguchi : SENSORY EVALUATION HANDBOOK , JUSE Press Ltd. (1973) 301-304
4. Ashoff J (1960) Warmenhaushalt In Lehrbunch der Physiologie des Menschen (Ed. Landois-Rosemann).Munchen-Berlin p331-369
5. Akio Umezawa, Kensuke Terai : Paradigm of relaxation evaluation : Respiration and relaxation Vol.19, No.2, Japan Journal of Physiological Psychology and Psychophysiology (2001) 69-74