THERMAL COMFORT OF SUMMER CLOTHES FOR CONSTRUCTION WORKERS

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INTRODUCTION

Most construction workers work in the open air. Thus, they are exposed to climatic conditions ranging from high temperatures and radiation in summer to cold and often wet conditions during wintertime. The clothing used to protect against these circumstances will not always be proper for each environmental condition. For example, cotton shirts become wet (from sweat) in hot environment and become uncomfortable; woolen sweaters give insufficient protection against cold, windy conditions and make the workers feel cold.

To improve the work conditions for outdoor workers, a new clothing concept was developed to protect against climatic conditions all year long, using the newest clothing materials. In the new concept, attention was focused on climatic protection and improved (thermal) comfort. The total concept consists of seven articles.

This study focuses on the summer articles of dress, in which thermal comfort by transferring sweat from the skin to the environment is the main issue. If the comfort is sufficient, workers will keep their clothes on, which will prevent them from sunburn and the danger of skin cancer (1).

MATERIALS AND METHODS

Thermal comfort and heat strain of the summer articles of the new clothing system were compared with traditional summer clothing in construction work during a heat exposure experiment (environment: T_{air} = 30°C, relative humidity [RH] = 70%, solar radiation = 700 $W \cdot m^{-2}$). Table 1 shows the properties of the clothing ensembles.

Table 1. Properties of the articles of dress used.

	material	thickness	insulation	fit	color
New shirt	Coolmax®	0.45 mm	**0.6** clo	tight	**blue**
New trousers	Cordura®	0.30 mm		**loose**	beige
Trad. shirt	cotton	0.43 mm	*0.6* clo	loose	yellow
Trad. trousers	cotton jeans	0.93 mm		loose	blue

New =new clothing system; Trad. = traditional clothing system

Six male subjects with a mean age (SD) of **23 (±1.9)** years participated in the experiments. All subjects, who worked in pairs, wore both clothing configurations on different days in a random order.

To simulate different jobs during an average working day, the subjects worked at light and heavy workloads (cycling at 50 W and 150 W) alternated by rest periods as shown in Table 2.

Table 2 Alternation of rest and work during the heat stress experiments.

Work	moderate work (50 W)	rest	heavy work (150 W)	rest	moderate work (50 W)	cool rest
Experiment Time (min):	0-30	30-40	40-60	60-75	75-105	105-120

The cool rest period was passed in a neutral environment to simulate resting in a shaded, *drafty* place or in an air-conditioned resting room (environment: T_{air} = 20°C, RH = 50%, solar radiation = 0 $W \cdot m^{-2}$).

Metabolic rate, skin-temperatures at **5** sites (chest, back, arm and upper and lower leg) and core temperature (rectal) were measured. Sweat production over the session and moisture absorption by the clothes was also measured. Sensations were scored continuously by the subjects on the following scales: comfort ("comfortable" to "extremely uncomfortable"), temperature ("very hot" to "very cold") and humidity ("very dry" to "soaking wet").

All data were analyzed with a 2-sample t-test with clothing as grouping variable. Significance was accepted for values of $P \leq .05$.

RESULTS

The results of different periods are analyzed within a session and over the complete session. The 1st method clarifies the functioning of the clothing during different workloads. The 2nd method reflects the working day of **a** construction worker. In Table **3,** the results for the different periods are summarized.

None of the results of these experiments showed a difference in heat strain for the subjects between the new and traditional clothes (T_{skin}: 34.3°C and T_{core}: 37.8°C) over the sessions.

The mean metabolic rate during the sessions was 400 W for both concepts. Also, the mean sweat production (**0.53** $L \cdot h^{-1}$) and the amount of absorbed moisture (0.19 L) did not differ between both clothing systems either.

Only sensation scores showed a significant difference in comfort. Mean vote: "2.0 = little uncomfortable" with the new clothing compared to the traditional **mean** vote: "3.5 = uncomfortable."

Table 3. The results of skin temperature (T_{sk}), core temperature (T_{core}), metabolic rate (meta), heart rate (HR) and temperature (TS), humidity (HS) and comfort (CS) sensations for the new and traditional summer clothes during all session periods, averaged over all subjects.

	Period 1		*Period 2*		*Period 3*		*Period 4*		*Period 5*		*Period 6*	
	new	trad	new	trad	new	trad	new	trad	new	trad	new	trad
T_{sk}	34.9	35.1	34.9	34.7	35.0	35.1	35.4	35.5	34.6	34.8	29.5	29.0
T_{core}	37.4	37.4	37.4	37.5	37.8	37.8	38.3	38.2	38.2	38.1	38.0	37.7
meta	344	374	-	-	869	898	-	-	404	449	-	
HR	107	107	123	114	156	157	153	149	126	131	101	99
TS	3.7	4.0	4.3	4.2	5.6	5.2	3.7	5.5	4.1	4.8	-20	-2.9
HS	-4.0	-28	-5.0	-4.8	-7.5	-6.1	-6.1	-7.4	-6.4	-6.8	-1.6	-3.4
CS	1.6	2.2	1.5	2.8*	3.4	4.5	2.1	4.9*	2.8	4.4	0.8	2.3

All temperatures in °C, metabolic rates in W, and *HR* in beats·min^{-1}
new = **new** concept; trad = traditional clothing; - = not measured;
* = Differs significantly from new ($P \leq 0.05$)

DISCUSSION

The chosen climate and workload are realistic for a sunny, summer day in construction work. The mean workload (**400 W**) over the complete session can be seen **as** heavy work **(2).** For practical and experimental reasons a cycle ergometer **was** chosen because of the reproducibility of the external workload. **A** disadvantage may be that this dynamic exercise is less representative for the often static workloads in construction work **(3).** However, it is not expected that static exercise will give a different comfort experience between both clothing systems.

Caused by tiredness due to the previous work period (meta: 360 W) and the longer exposure to the hot environment, a tendency (P = .06) to an increase in metabolic rate (meta: **430** W) was found during the second period **of** moderate work. This was also reflected in the significantly higher core temperatures and higher HRs.

Although clothing color (yellow vs. blue) may have an impact on radiation absorption (4), no differences on heat load of the clothing were found between both clothing systems. Considering the estimated clothing insulation, differences in heat load for the clothing systems were not expected because the estimated insulation value for both systems was about 0.6 clo ***(5)*** under static conditions. Color of the clothing may have an impact on the heat load (5), and that could have been a disturbing factor in these experiments. For example, a higher radiation absorption of the new clothing could have annulled the improved heat loss possibilities of the clothing.

The experienced comfort did differ between the clothing systems, but this was mainly during the periods of rest. During periods of work, subjects were sweating almost maximal and that influenced the comfort scores. This difference between periods of work and periods of rest can possibly be explained by the better transfer of moisture from the skin to the environment by the Coolmax® **shirt.** However, this is not supported by the humidity sensation and/or the moisture absorption. Though it is stated that Coolmax® is a material that keeps the body dry and comfortable (6,7), it is not proven in these experiments that this is really the case. Possibly the skin contact with the material is more pleasant than with the cotton shirt, resulting in less discomfort.

It is expected that the higher comfort of the Coolmax® shirts prevents the tendency **of** people to take off their shirt, so that they are better protected against harmful W-light.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study showed that under the given experimental conditions no difference in heat load was found between clothing of traditional materials and clothing made of newly developed materials. Thus, it is not expected that the use **of** new clothing materials for summer clothes shall lead to improved working conditions. However, the reduced discomfort **of** the new clothing may encourage people not to take off these clothes in the heat, which will prevent them against **harmful** solar radiation.

In summary, (1) the new summer clothes were experienced **as** more comfortable, (2) differences in comfort were mainly found during the resting periods, (3) no differences were found in other objective or subjective parameters and **(4)** no difference in moisture absorption existed.

In future experiments the effects of color of the clothing materials should play a role too. Finally, the status of the clothing (e.g., look, quality, cleaning, visibility) **is** also important and was studied in a follow-up experiment in the field.

REFERENCES.

1. Everett, S.A. and Colditz, G.A. 1997, Skin cancer prevention: a time for action, ***Journal of Community Health*, 22(3)**, 175-183.
2. Fox, E.L., Bowers, R.W. and Foss, M.L. 1993, ***The Physiological Basis for Exercise and Sport.*** (Dubuque, **USA:** Brown and Benchmark).
3. Molen, **H.,** van der 1996, Maximale arbouwlimiet haalbaar, ***Arbeidsomstandigheden Concreet,*** **5**, 63-65 (in Dutch).
4. Lotens, **W.A.** 1993, Heat transfer from humans wearing clothing, unpublished Ph.D. thesis, Delft University **of** Technology[RTF annotation: **Is** this unpublished or published?].
5. Olesen, B.W. and Dukes-Dobos, F.N. 1988, International standards for assessing the effect of clothing on heat tolerance and comfort, in **S.Z.** Mansdorf, R. Sager and A.P. Nielsen **(Eds.)**, ***Performance of Protective Clothing: 2nd Symposium,*** (Philadelphia, PA: ASTM **STP** 989), 17-30.
6. Figueira, A.J. and Filho, D.C. 1996, Metabolic response during maximum effort test in high competitive level athletes submitted to thermal stress with five different clothes, unpublished results.
7. **Denoth,** J. 1996, **ETH** results —subjective assessment **of** athletes, unpublished results.