Seventh International Conference on Construction in the 21st Century (CITC-VII)
"Challenges in Innovation, Integration and Collaboration in Construction & Engineering"
December 19-21, 2013, Bangkok, Thailand

On-site wear trials to determine construction workers' preference for two types of cooling vest in combating heat stress

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Abstract
It is recognized that construction workers are always exposed to a high risk of heat-related illness during summer months in Hong Kong. Providing suitable personal cooling vest to construction workers is one of the effective and feasible measures to alleviate heat stress. In order to evaluate the effectiveness of two kinds of cooling vest, namely, 'frozen gel vest' (Vest A) and 'frozen gel and fan vest' (Vest B), and determine construction workers' preference for these vests, three field studies were conducted in construction sites during summer months of 2012 to assess the subjective and physiological responses of thirty-six construction workers when wearing these cooling vests. In this survey, no significant physiological differences between the two vests were detected. In terms of subjective preference, construction workers preferred Vest B to Vest A ($p<0.05$). The results of workers' perceptual responses indicated that Vest B was significantly better in the following attributes ($p<0.05$): being drier, lighter, smoother, more pliable, easier to move, more comfortable, and more practical. The common shortcoming of the two cooling vests was their temporary cooling effect as perceived by the workers. Additional comments provided by the subjects shed light for potential improvement on the cooling capacity and acceptability of the cooling vest in future.

Key words
Construction workers, heat stress, cooling vest, wear trial, physiological and subjective response

1. Introduction

Workers performing highly demanding physical workloads such as construction activities under a hot and humid weather are at high risk of heat-related illness (Morioka *et al.*, 2006; Lin and Chan, 2009). Control of heat stress may have multiple co-benefits in terms of better health, improved productivity, lower rates of accidents, lower rates of morbidity (Ayyappan *et al*., 2009) from both moral and economic perspective (Miller *et al.*, 2011). The effectiveness of cooling vests on combating heat stress have been extensively studied in the military field (Burr *et al.*, 1990; Masadi *et al.*, 1991), firefighting (Selkirk *et al.*, 2004; Chou *et al.*, 2008), sports (Webster *et al.*, 2005; Barwood *et al.*, 2009) and industries (Furtado *et al.*, 2007; Choi *et al.*, 2008). Vests with frozen gel pack (Webster *et al.*, 2005; Choi *et al.*, 2008) and fan (Cadarette *et al.*, 2006; Hadid *et al.*, 2008) were found effective at alleviating thermal strain when working in a hot weather. Previous studies have demonstrated that properly designed cooling vests with frozen gel could reduce physiological (Pimental and Avellini, 1992) and subjective (Choi *et al.*, 2008) strains. Personal cooling vest with an integrated blower have been demonstrated to lower physiological strain in reducing skin temperature, physiological strain index, heat storage rate and sweat rate during exercises (Hadid *et al.*, 2008). Furthermore, field study has been used extensively in military, firefighting and sports fields (e.g., Pandolf *et al.*, 1995; Colburn *et al.*, 2011; McDermott *et al.*, 2011) to assess the effectiveness of microclimate cooling systems. Limited studies, however, have investigated the application of cooling vest in the construction industry. The aim of the present study is therefore to fill this gap by evaluating the effectiveness of two selected cooling vests on combating heat stress. In the current study, both physiological and subjective responses will be measured through a series of field studies to examine the cooling capacity and acceptability of the two cooling vests.

2. Methods

2.1 Subjects

This survey consisted of three field studies conducted on three different construction sites in July and August 2012. Twelve subjects were invited to participate in two wear trials in each field study. Altogether, 36 male construction workers employed by two construction companies undertook the wear trial tests. Among them, three subjects only participated in the first wear trial in the morning and refused to participate in the afternoon due to personal reasons. Their working time started at 08:00 and finished at 18:00 with one hour lunch break at 12:00. They had no rest time in the morning but had a tea break of 30 minutes in the afternoon at around 15:00. The subjects' demographic information were as follows: 45.5 ± 13.6 years for age, 168.5 ± 6.1 cm for height, 65.6 ± 10.7 kg for weight, and 17.1 ± 11.9 years for working experience in the construction industry. Among them, one was from Nepal, and the rest were all local workers. The distribution of typical trades was shown in Figure 1.

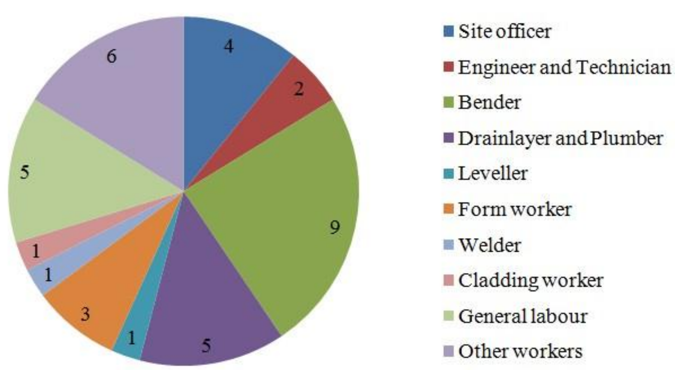

Figure 1: Distribution of subjects' trades of work

2.2 Cooling vests and clothing ensembles

Vest A is a kind of passive cooling vests using frozen gel pads as the heat transfer medium. The khaki Vest

A included four strips of three frozen gel pads inserted into the four pockets (two on the chest and two at the back), with a total weight of 2.3 kg. The fabric of Vest A is fire resistant.

The ultramarine Vest B consisted of two small fans with four 1.5V AA batteries on each side of the waist and three frozen gel pads inserted into the three pockets at the waist and back respectively with a total weight of 1.0 kg. It is a combo system (Chi *et al.*, 2008) combining passive and active cooling methods. The fabric of Vest B is flame retardant. Vest A comes in stretchable size that fits all while Vest B comes in XL and XXL sizes.

Frozen gel-water pads in these cooling vests can be repeatedly frozen. These non-toxic and non-flammable gel pads solidified when frozen and gradually change to gel after absorbing heat when the vest is worn. They were frozen at approximately -10 °C in the freezer for four hours or above before being brought to the construction sites. In each field study, 12 sets of Vest A (with 48 ice pads) and 12 sets of Vest B (with 36 ice pads) were prepared for the subjects. The vests were washed and dried as per the manufacturers' instructions after each field test for hygienic reason.

The subjects took part in the two wear trials by wearing vests A and B in turn. During the test, the subjects wore clothing they normally wear at work. Their clothing ensemble included a short- or long-sleeve shirt, trousers, underwear, socks, safety shoes, gloves, safety helmet, and reflective vest. Some workers wore light-coloured uniform supplied by their companies. For each subject, the clothing ensemble during the morning session and afternoon session were by and large the same. The subjects wore the cooling vest on top of the upper garment and under the reflective vest.

2.3 Field study procedures and questionnaire survey

Each volunteer was asked to participate in two wear trials in the morning and afternoon sessions, respectively; and each trial would last for approximately 2 h. To minimize systematic errors, the 12 volunteers were randomly divided evenly into two groups where one group wore cooling Vest A and the other group wore cooling Vest B in the morning. They then reversed the type of the vest in the afternoon trial. Clean cooling vests were provided for each wear trial. Before the first wear trial, the subjects were briefed the purpose of the wear trial by the research team. Then a four-part questionnaire consisting of consent (approved by the Human Subjects Ethics Sub-committee of The Hong Kong Polytechnic University), personal details, assessment attributes of the two cooling vests, and a record sheet, were provided to the subjects. Informed consent with signature was obtained from each volunteer. And each volunteer was asked to complete the basic demographic information covering age, height, weight, nationality, trade, working experience in the construction industry, and working place. The first record of physiological data including ear temperature, pulses, systolic and diastolic blood pressure, and a subjective rating, namely, rating of perceived exertion (RPE, McGuigan and Foster, 2004) was measured to serve as a baseline for comparison. After completion of the above activities, the subjects started to perform their normal tasks by wearing the selected vests. Immediately after the first wear trial, the participants' physiological data were measured and they were asked to complete a self-administered questionnaire to report their evaluation on the cooling vest they just wore. After the lunch break, the second wear trial was conducted in a similar pattern as that in the first one. Again, the participants were asked to complete the same questionnaire to report their evaluation on the cooling vest with their physiological data measured. Altogether, two sets of assessment attributes of cooling vests (with an extra question being asked after the second wear trial to enable the participant to indicate which cooling vest they prefer), four sets of physiological and RPE data, and additional comments on the two cooling vests were captured (Figure 2). The heat stress index (HI) and outdoor wet bulb globe temperature (WBGT) were recorded per minute by using a heat stress monitor (QUESTemp°36™, Australia) which was placed outdoor near the workplace during the wear trials. The mean values of HI and WBGT for each day were 39.53±3.54 °C and 33.36±2.82 °C, respectively.

Time line

8:30-9:00	9:00-11:00	11:00-11:45	12:45-13:00	13:00-15:00	15:00-15:45
Pre-test	**1st wear trial Group 1 with Cooling vest A; Group 2 with Cooling vest B**	**Post-test**	**Pre-test**	**2nd wear trial Group 1 with Cooling vest B; Group 2 with Cooling vest A**	**Post-test**
Briefing; Consent and personal information; 1st physiological and RPE record	**Last 1-2 hrs**	**Questionnaire; 2nd physiological and RPE record**	**3rd physiological and RPE record**	**Last 1-2 hrs**	**Questionnaire; 4th physiological and RPE record**

Figure 2: Wear trial protocol and measurements

2.4 Measurements

2.4.1 Physiological measurements

All physiological data were measured four times. Two measurements were performed before the two wear trials and two measurements were taken after the trials. The ear temperature was recorded three times at each measurement point using an ear thermometer (OMRON®, MC-509N, Japan) with probes (ThermoScan®, BRAUN™, Germany) to obtain the average ear temperature. The pulses and the systolic and diastolic blood pressure were measured using boso-medistar S™ (Germany). The heartbeat rate was indicated by the value of the pulse.

2.4.2 Subjective data

Before each wear trial, the subjects were asked to provide a rating of their perceived exertion (RPE). Immediately after the wear trials, they were asked to report their RPE and their perceived ratings of the assessment attributes towards the cooling vest they just wore. Each of the assessment attribute was described by opposite adjectives on a scale from one to seven. The meanings of scale 1 to 7 were represented as *from clammy to dry, from sticky to non adhesive, from airtight to breathable, from damp to dry, from heavy to light, from hot to cool, from scratchy to non scratchy, from prickly to non prickly, from itchy to non itchy, from rough to smooth, from stiff to pliable, from movement restricted to movement allowed, from tight to loose, from uncomfortable to comfortable, from dislike to like, from impractical to practical, from job performance interference to no job performance interference,* and *from unsafe to safe*. Moreover, they were required to indicate their perceived effective cooling time of the vests. In addition, the subjects were invited to indicate which cooling vest they preferred after completing the second wear trial. Furthermore, they were asked to write down their comments (if any) on the effectiveness and suitability of each cooling vest.

2.5 Statistical analysis

The values of demographic and environmental parameters, physiological and subjective responses were represented by the mean and standard deviation (mean ± SD). Values of RPE and Perceived effective time were plotted by mean values with standard error. The differences of physiological responses after wear trials between the two cooling vests were examined by ANOVA. The physiological responses before wear trials were set as covariates. The interaction effects between the physiological responses and the vest type were found to be insignificant, but satisfied the Homogeneous Regression Slopes Assumption. The significance level was set at $p<0.05$. All the above analyses were conducted by SPSS software.

3. Results

3.1 Subjective data

The ratings with standard deviation of the 18 assessment attributes given by the subjects were shown in Table 1. Significant differences between the two vests in the following attributes were detected ($p<0.05$): damp–dry, heavy–light, rough–smooth, stiff–pliable, movement restricted–movement allowed, uncomfortable–comfortable, impractical–practical, and dislike–like. No significant differences were detected in other attributes.

Table 1: Subjective assessments

Subjective Responses	Vest A (Mean ± SD)	Vest B (Mean ± SD)	p-value
Clammy---Dry	3.22 ± 1.58	3.75 ± 2.03	.24
Sticky---Non- adhesive	4.61 ± 1.75	4.06 ± 2.06	.24
Air tight---Breathable	2.69 ± 1.60	3.06 ± 1.77	.37
Damp---Dry*	2.15 ± 1.54	3.44 ± 2.14	**.01**
Heavy---Light*	2.13 ± 1.50	4.19 ± 1.83	**.00**
Hot---Cool	3.41 ± 1.76	3.08 ± 1.63	.43
Scratchy---Non-scratchy	5.94 ± 1.58	5.97 ± 1.32	.93
Prickle---Non-prickle	6.55 ± 1.09	5.94 ± 1.53	.07
Itchy---Non-itchy	6.45 ± 1.25	5.94 ± 1.62	.15
Rough---Smooth*	3.82 ± 2.05	5.75 ± 1.65	**.00**
Stiff---Pliable*	2.91 ± 1.49	5.61 ± 1.52	**.00**
Movement restricted---Movement allowed*	3.00 ± 1.72	4.77 ± 2.25	**.00**
Tight---Loose	3.75 ± 1.41	4.19 ± 1.77	.26
Uncomfortable---Comfortable*	2.76 ± 1.62	4.17 ± 1.96	**.00**
Impractical---Practical*	2.55 ± 1.77	3.53 ± 2.14	**.04**
Job performance interference---No job performance interference	3.58 ± 1.98	4.47 ± 2.18	.08
Unsafe---Safe	5.48 ± 1.72	5.83 ± 1.70	.40
Dislike---Like*	2.42 ± 1.70	3.81 ± 2.32	**.01**

*: $p<0.05$. Significant differences of subjective responses between two cooling vests were observed.

3.2 Physiological data

No statistical differences were detected in the physiological values between the two cooling vests ($p>0.05$) (Table 2).

Table 2: Physiological responses toward two cooling vests

Parameter		Vest A	Vest B	Significant level
Ear temperature (°C) (Mean ± SD)	Before wear trial	36.36 ±0.52	36.41 ±0.45	
	After wear trial	36.85 ± 0.54	36.95 ± 0.57	0.293
Heart rate (bpm) (Mean ± SD)	Before wear trial	78.48 ± 11.72	75.53 ± 10.24	
	After wear trial	84.39 ± 21.44	84.50 ±12.33	0.535
Systolic blood pressure (mmHg) (Mean ± SD)	Before wear trial	127.76 ± 15.72	131.00 ± 17.87	
	After wear trial	131.61 ± 17.07	134.53 ± 18.89	0.803
Diastolic blood pressure (mmHg) (Mean ± SD)	Before wear trial	79.61 ±10.16	83.17 ± 11.35	
	After wear trial	85.73 ± 17.20	87.64 ± 19.34	0.776

The RPE values before the test showed no statistical differences between Vest A and Vest B ($p>0.05$). Upon the completion of the test, the mean and standard error of RPE values were 5.03 ± 0.31 for Vest A and 4.78 ± 0.29 for Vest B ($p>0.05$, Figure 3). The mean perceived effective cooling time of the vests were 1.26 ± 0.14 h for Vest A, and 1.37 ± 0.15 h for Vest B respectively ($p>0.05$), as shown in Figure 4.

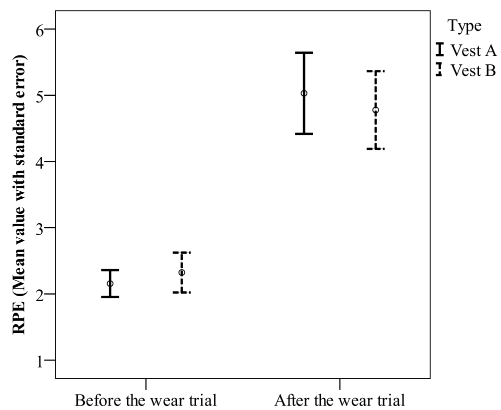

Figure 3: RPE before and after the test of two vests

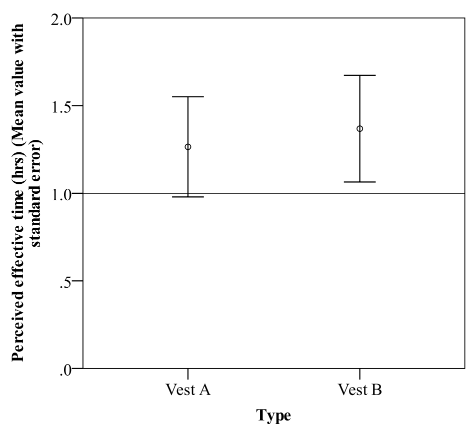

Figure 4: Perceived effective cooling time of two vests

Comments on the cooling effectiveness of the two cooling vests were provided by some subjects. Among the subjects who shared their comments, 14% considered that Vest A was effective in keeping the body cool and 18% of them thought it had a little effectiveness. Nearly 70% of them showed negative views. The most frequent complains focused on its heavy weight and temporary cooling effect. Although it was slightly effective in lowering body temperature for a short time (e.g., from 0.5 h to 1 h), it became heavy, damp and airtight in the long run. Some of them complained it was too heavy to restrict their movement. Moreover, the cooling effect was detected only when the workers were at rest, and the cooling effect disappeared once they started to work. They also complained that the sweat could not be evaporated; the fabric was too thick; and the frozen gel pads melted quickly. For Vest B, 12% of the subjects who provided comments considered it provided a cooling effect, whereas 76% felt the opposite, citing reasons for being too airtight and impractical. Among the workers, 40% opined that the cooling effect was detected only under the following conditions: indoor, without sun, at rest, body area covered by the vest, or in short duration (e.g., 20 min). They also complained that the fan drew hot air from the ambient hot environment, and the dark-coloured fabric absorbed heat from the solar. The common concerns were that the two cooling vests only had a cooling effect on the body area which was covered by the frozen gel, but the heat at the head cannot be dissipated. Moreover, wearing two vests (cooling and reflective vests) was very cumbersome.

Overall, the number of workers who preferred vest B was more than twofold to that for vest A ($p<0.05$, Figure 5). Vest B received more favorable feedback than Vest A.

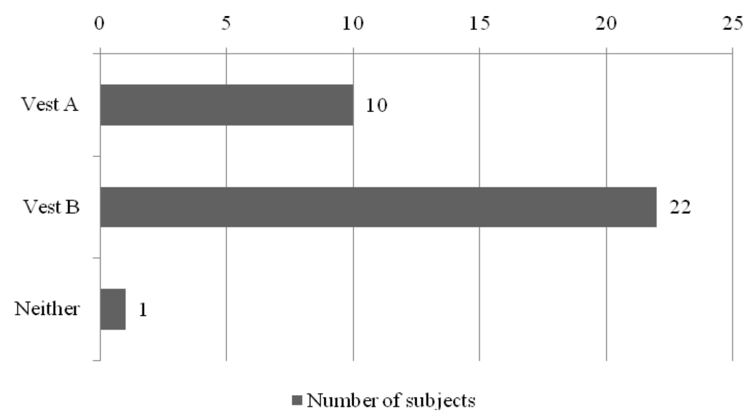

Figure 5: Distribution of subjects' preferences towards two cooling vests

Note: Three workers had not taken part in the second wear trial and so they could not indicate their preferences

4. Discussion

Providing suitable cooling vest could help outdoor workers alleviate heat strain and improve work performance (Hadid *et al.*, 2008). However, besides these objective benefits, subjective perception also affects consumer behaviour on garment (Carlson *et al.*, 2009).

No significant differences of physiological responses, RPE, and perceived effective cooling time were detected between the two cooling vests. The participants perceived that the cooling vests were effective only for a short time. This result was similar to Babski-Reeves and Tran (2003)'s study that the subjects had expressed concerns about using any vest for prolonged durations. Other studies also expressed similar concerns (Bain, 1991; Derion and Pozos, 1994). On the contrary, Kenny *et al.* (2011) demonstrated that an ice vest with equivalent operating characteristics were effective to reduce thermal and cardiovascular strain for prolonged working period (up to 2 h).

The participants were asked to evaluate the two cooling vests based on 18 sets of assessment attributes. Most subjects preferred Vest B to Vest A, considering it to be drier, lighter, smoother, more pliable, allow more movement, more comfortable, more likable, and more practical. Vest B obtained more positive responses in terms of mobility, pliability, smoothness, and lightness where the scores were over 4 out of 7. In contrast, Vest A was considered as less comfortable, heavier, rougher, stiffer, less mobility, and more encumbered, where the ratings were below 4. Vest B was lighter, which might have better capacity to enhance performance during exercises (Webster *et al.*, 2005) and reduce thermal strain under heat (Smolander *et al.*, 2004). Furthermore, some subjects also complained that the cool sensations were felt only under the frozen gel pads, rather than the whole body. Smolander *et al.* (2004) pointed out that the cooler sensations were taken into effect only under the ice vest on the chest and back. Some subjects commented that Vest A was too damp and that sweat could not be evaporated. This led to dehydration and discomfort (Nunneley, 1989). However, Vest B is not without shortcomings. Some subjects felt hot when wearing Vest B because of the dark-coloured fabric which would absorb more heat (Olumide *et al.*, 1983). Exposure to the sun in black clothing will remarkably affect the physiological responses such as diastolic blood pressure and heart rate (Blazejczyk *et al.*, 1999). Therefore, further improvement of the cooling vest could be made by substituting it with a light-coloured fabric to reduce solar radiation heat gain and physiological strain (Nielsen, 1990). Moreover, the cooling vest could have a reflective strap on top; thus, construction workers do not need to wear additional reflective vest which may impede evaporative sweat rate (Nagata, 1978) and reinforce thermal insulation (Gavin, 2003).

5. Conclusion

In this study, no significant physiological differences between the two vests were detected based on the results of the field studies. However, according to a series of subjective evaluation on the attributes of the two cooling vests, construction workers preferred vest B to vest A. Indeed, the subjective results showed remarkable differences between vests A and B. Vest B received positive feedbacks in the following features: dry, light, smooth, pliable, allow movement, comfortable, and practical. Additional comments provided by the subjects shed light for potential improvement on the cooling capacity and acceptability of the cooling vest in future.

6. Acknowledgement

This project is jointly funded by a grant from the Occupational Safety and Health Council (OSHC Research Grant No. CM/4R/2011-01) and Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU5107/11E and PolyU510513). The research team is indebted to the technical support from technicians of the Hong Kong Polytechnic University. In particular, the participation of volunteers in this study is gratefully acknowledged. This paper forms part of the research project on anti-heat stress clothing from which other deliverables will be produced with different objectives/scopes but sharing common background and methodology.

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