

# The Effect of Evaporative Cooling Vests on the Physiological and Perceptual Strain Indices of Construction Workers

Habibollah Dehghan, Mohammad Reza Mirzabe

Department of Occupational Health and Safety Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

## Abstract

**Aim:** One of the most harmful agents in construction sites is heat exposure. The aim of this study was to evaluate the performance of new evaporative cooling vests in construction workers. **Materials and Methods:** This case-control study was implemented on 60 construction workers in hot conditions (air temperature 49.0°, relative humidity 5.5%) in the summer of 2019. In this study, 30 people with cooling vests (case group) and 30 people without cooling vests (control group) were working for 120 min in a hot environment. In both groups, heart rate oral temperature and wet bulb globe temperature (WBGT) index were measured. Moreover, the Perceptual Strain Index (PeSI) and Heat Strain Score Index (HSSI) questionnaires were completed by the workers. Data were analyzed after inter to SPSS16 software. **Results:** All of the WBGT values were higher than occupational exposure limit. The mean and standard deviation (SD) of the work heart rate in the case and control groups, was equal to  $111.1 \pm 7.6$  beats per minute (bpm) and  $114.3 \pm 7.9$  bpm respectively ( $P < 0.05$ ). Also the average and SD of the oral temperature in the case and control groups, respectively, was equal to  $36.36 \pm 0.41$  and  $36.37 \pm 0.55$ . There was no statistically significant difference. Mean and SD of Physiological Strain Index (PSI), in case and control groups, were  $2.53 \pm 0.66$  and  $3.64 \pm 0.81$ , respectively. The mean and SD of the PeSI and the HSSI in the case group were  $4.64 \pm 0.79$  and  $10.12 \pm 1.71$ , respectively, and in the control group,  $6.41 \pm 0.85$  and  $15.88 \pm 0.143$ . Statistically, the difference between PSI, PeSI, and HSSI means was significant. **Conclusions:** This study results showed that hot environmental conditions were stressful for construction workers and also Iranian evaporative cooling vests (Hifitcool brand) were able to reduce perceptual and physiological heat strain in construction workers in the hot conditions.

**Keywords:** Evaporative cooling vests, heart rate, heat strain score index, oral temperature, perceptual strain index

## INTRODUCTION

During performing activities such as work, sports etc., the human body has its own mechanisms such as vasodilation and sweating to thermoregulation.<sup>[1]</sup> Through the cooling action of these mechanisms, core body temperature is kept within a tolerable narrow range being necessary for vital functions. However, the body may not be able to regulate the core temperature in hot and humid environments and in these conditions, external cooling aids are needed.

Outdoor workers, especially, in the tropical and subtropical countries may experience such conditions for several months of each year.<sup>[2]</sup> In such environments, they may be at risk of heat stress exposure problems such as progressive loss of performance capability and disorganized nervous system activity.<sup>[1]</sup> Furthermore, heat stress exposure might lead to heat illnesses and injuries including heat stroke, heat exhaustion, heat cramps, or heat rashes and even death.<sup>[3]</sup>

Similar environments can also lead to a decrease in work capacity, efficiency, and productivity.<sup>[4]</sup> Since providing the air conditioning is not possible for outdoor activities and in many developing countries access to the water resources is limited,<sup>[5]</sup> researchers tried to develop personal cooling clothes so as to protect the workers from the heat stress-related problems and increase the workers efficiency. Therefore, certain designs of cooling vests were provided commercially to enhance the workers' tolerance of hot environments. Until now, researchers all around the world have attempted to find out the effectiveness of different designs of cooling vests on

**Address for correspondence:** Dr. Habibollah Dehghan,  
Department of Occupational Health and Safety Engineering, School of  
Health, Isfahan University of Medical Sciences, Isfahan, Iran.  
E-mail: ha\_dehghan@hlth.mui.ac.ir

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**How to cite this article:** Dehghan H, Mirzabe MR. The effect of evaporative cooling vests on the physiological and perceptual strain indices of construction workers. *Int J Env Health Eng* 2023;12:4.

**Received:** 02-09-2020, **Accepted:** 01-09-2021, **Published:** 12-04-2023

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10.4103/ijehe.ijehe\_50\_20

different target population. A study that was conducted by the Yi *et al.* showed that a newly designed hybrid cooling vests may be effective on the reducing of heat strain and in a hot and humid environment could enhance the work performance.<sup>[6]</sup> Furthermore, approximately, the same findings were reported for a hybrid personal cooling system (combination of phase change materials [PCMs] and ventilation fans) by Lu *et al.*<sup>[7]</sup> The point that the performance can be improved by making the use of an additional air-diffusing garment, was reported by Glitz *et al.* study.<sup>[8]</sup> Dehghan *et al.* study also showed that utilizing vests containing water and paraffin could reduce the physiological strain, reaction time, and error rate of laboratory workers.<sup>[9]</sup>

Among different design techniques of cooling vests, evaporative techniques are passive, so they do not require substantial energy to operate. Furthermore, around a third of the world's population lives in areas classified as dry lands where evaporative cooling should be effective. In such circumstances, this kind of cooling vests can be used as an efficient heat strain protection tool. However, a few studies.<sup>[10]</sup> have been conducted on the effectiveness of this kind of cooling vests until now. According to our knowledge, no study has been conducted on the effectiveness of evaporative cool vests of the outdoor workers such as construction workers. Hence, the aim of this study was the measurement and comparing of physiological and perceptual indicators of construction workers with and without using of evaporative cooling vests.

## MATERIALS AND METHODS

### Participants

This cross-sectional analytical study was conducted on the construction workers in summer 2019. Participants for entering to this study needed to have a normal body mass index (BMI) and not to have a record of cardiovascular, respiratory, neurological, and musculoskeletal diseases. Furthermore, not having epilepsy, seizure, and diabetes and not consuming any blood pressure control medications were considered as the inclusion criteria. Since measurement of parameters was done for two participants groups (one group use of cooling vest and the other group, not using it) every time, so in each time, we tried to minimize the age, height, and weight differences (<15%) between two subjects [Table 1]. Metabolism rate and clothing type were similar in two groups.

**Table 1: Mean and standard deviation of demographic data in workers with and without evaporative cooling vest**

Demographic data	Mean ± SD	
	Evaporative cooling vest (case)	No evaporative cooling vest (control)
Age (years)	35.14±4.90	34.17±5.36
Weight (kg)	79.40±8.95	84.20±11.10
Height (cm)	168±8.4	170±9.1
BMI (kg/m <sup>2</sup> )	26.73±5.25	27.55±4.54

SD: Standard deviation, BMI: Body mass index

Furthermore, simple random selection method was used for the division of two subjects. Finally, sixty subjects were entered this study, 30 in case group (users of cooling vests) and 30 in control (non-users of cooling vests). They were also controlled for not taking coffee, caffeine, alcohol, and narcotic materials, 12 h before the measurements. Furthermore, written informed consent forms were obtained from all participants.

### Evaporative cooling vest

Evaporative cooling vest (Hifitcool Brand) was made of highly absorbent fabric. Rapidly, water absorbed when it submerged in it. After soaking, water evaporates from the cooling vest over the course of several hours, usually between 5 and 10, providing a cooling effect in contact with skin [Figure 1].

### Instruments and protocol

Physiologic, perceptual, and environment parameters were measured in thermal comfort conditions (air temperature 20–25), as basal values, and work conditions.

Time duration was 120 min for work conditions (between 1.00 and 3.00 p.m.); measurement of parameters was done under direct light of sun based on ISO 9889 for both case and control subjects. Parameters such as heart beat (Polar sport device) in every 5 min, and oral temperature (Brauer oral thermometer IRT4520, accuracy 0.1°C) in every 15 min were measured. Environmental parameters including dry temperature, globe temperature, relative humidity, and wet bulb globe temperature (WBGT) were recorded every 15 min, using WBGT meter (model: AZ 877). Furthermore, indices including Physiological Strain Index (PSI) using presented formula,<sup>[11]</sup> The Perceptual Strain Index (PeSI),<sup>[12]</sup> and Heat Strain score Index (HSSI)<sup>[13]</sup> using presented methods and questionnaires were measured. A simple questionnaire including variables such as age, weight (before and after the tests), and height was used for recording demographic data of the participants.

### Data analysis

The descriptive statistic including mean and standard deviation (SD) were calculated and reported for the quantitative variables. One-sample Kolmogorov–Smirnov and Independent



**Figure 1: Evaporative cooling vest used in the study**

Sample *t*-tests were used for checking variables normality and also the examination of differences between case and control groups, respectively. Statistically significant difference was accepted at the  $P < 0.05$ . All statistical tests were implemented by means of SPSS 16 software (SPSS Inc., Chicago, IL, USA).

## RESULTS

All of the participants were male. The mean  $\pm$  SD of the demographic characteristic of participants including age, weight, Height, and BMI are presented in Table 1. The mean of age and weight was significantly different in case and control groups, but the difference between height and BMI means was not statistically significant.

The mean of the dry bulb temperature, globe temperature, WBGT index, and humidity ratio were 49°C, 60.8°C, 31.9°C, and 5.6%, respectively [Table 2]. All of the mean environmental parameters in two groups were not significantly different. Moreover, metabolism rate and clothing type were similar in case and control subjects. Changes in the environmental parameters including dry temperature, globe temperature, relative humidity, and WBGT during the process of measurements are showed in Table 2. All of the WBGT values (range 28.0°C–36.1°C) in the worksites and also mean of WBGT (31.9°C) were higher than occupational exposure limit (WBGT for moderate workload and normal clothing is 28°C) showing that environmental conditions were stressful for all of the workers.

The mean and SD of the heart rate in the case and control groups were equal to 111.1  $\pm$  7.6 and 114.3  $\pm$  7.9 bpm, respectively.

**Table 2: Mean and standard deviation of demographic, environmental, physiologic, and perceptual variables in case and control groups**

Variables	Test groups, mean $\pm$ SD		P
	Case	Control	
Demographic characteristic			
Age (year)	37.14 $\pm$ 6.31	34.17 $\pm$ 5.36	0.006
Weight (kg)	73.99 $\pm$ 12.40	84.02 $\pm$ 11.13	0.001
Height (m)	1.68 $\pm$ 0.1	1.70 $\pm$ 0.09	0.59
BMI (kg/m <sup>2</sup> )	26.73 $\pm$ 6.17	27.55 $\pm$ 5.54	0.39
Environmental parameters			
Dry bulb temperature	49.10 $\pm$ 6.7	49.2 $\pm$ 6.9	0.92
Globe temperature	60.80 $\pm$ 14.8	60.70 $\pm$ 15.6	0.84
Humidity ratio	5.60 $\pm$ 2.62	5.50 $\pm$ 2.8	0.93
WBGT index	31.96 $\pm$ 3.52	31.80 $\pm$ 3.63	0.76
Physiologic indices			
Heart rate (bpm)	111.1 $\pm$ 7.6	114.3 $\pm$ 7.9	0.11
Oral temperature (C)	36.36 $\pm$ 0.41	36.37 $\pm$ 0.55	0.95
PSI	2.53 $\pm$ 0.66	3.66 $\pm$ 0.81	0.005
Perceptual indices (score)			
PeSI	4.64 $\pm$ 0.79	4.61 $\pm$ 0.85	0.002
HSSI	10.12 $\pm$ 1.71	15.88 $\pm$ 1.43	0.001
Thermal sensation	3.42 $\pm$ 0.46	3.82 $\pm$ 0.45	0.002

PSI: Physiological strain index, PeSI: Perceptual strain index, HSSI: Heat strain score index, SD: Standard deviation, BMI: Body mass index, WBGT: Wet bulb globe temperature

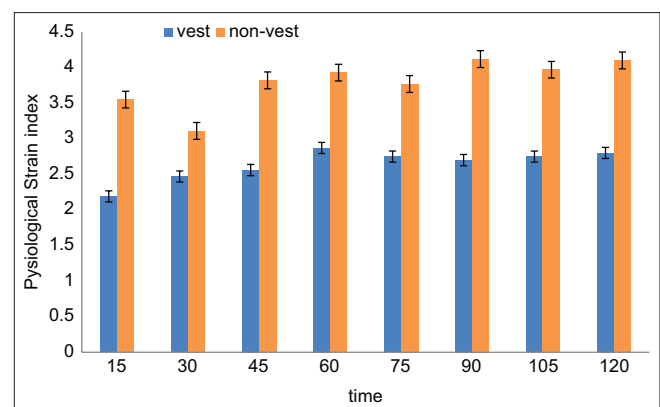
Furthermore, the average and SD of the oral temperature in the case and control groups, respectively, were equal to 36.36  $\pm$  0.41 and 36.37  $\pm$  0.55. Independent sample *t*-test results revealed that heart rate and oral temperature difference between the two groups at the measured times were not found to be statistically significant (all  $P > 0.05$ ). Maximum mean of heart beat in case group (vests users) was recorded as 121, while it was 125 in the case of the control group. Furthermore, maximum mean of oral temperature in case group was recorded as 36.38, while it was 36.42 in the control group.

Mean and SD of PSI, in case and control groups were, 2.53  $\pm$  0.66 and 3.64  $\pm$  0.81, respectively. The mean and SD of the PESI and the HSSI in the case group were found to be 4.64  $\pm$  0.79 and 10.12  $\pm$  1.71, respectively, and in the control group, 6.41  $\pm$  0.85 and 15.88  $\pm$  0.143. Statistically, the differences between PSI, PESI, and HSSI means were significant [Table 2 for more details].

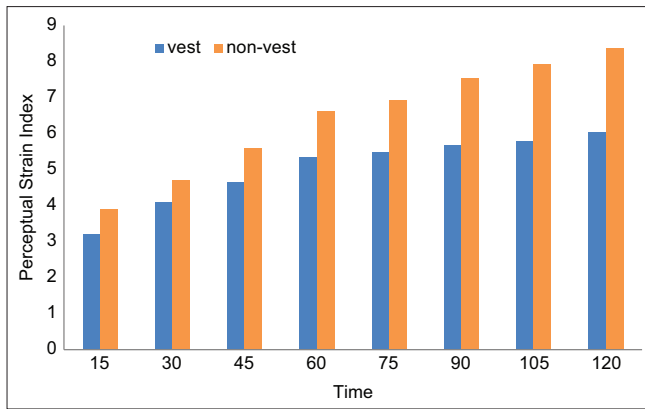
Time trend of changes in the PSI are presented in Figure 1. The value of the PSI at all times of measurement was lower in workers wearing a cooling vest than in those without a cooling vest. Furthermore, as Figure 2 shows, the value of the PeSI at all times of measurement was higher in workers without cooling vests than in workers with cooling vests. In Figure 3, values of the HSSI at start time (time 0) and finishing time (time 120) are shown; as it is clear, while the value of the HSSI, at the beginning of the test was the same for both groups, at the end of the test, this value was significantly lower in people with a cooling vest than in those without a cooling vest. In Figure 4, time trend of changes in the thermal sensation is shown. At all times, the value of the heat sensation scale was lower in the users of the cooling vest, and this difference was found to be statistically significant.

## DISCUSSION

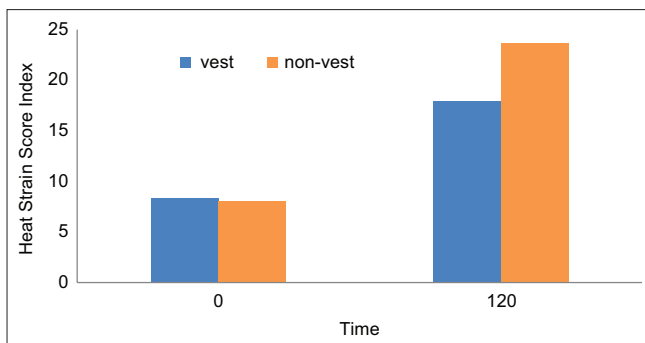
In this study, the effect of evaporative cooling vests on physiological and perceptual strain indices of construction workers was evaluated. Outdoor construction workers with or without direct sunlight are exposed to heat. In addition, they need a high metabolic due to their physical work.



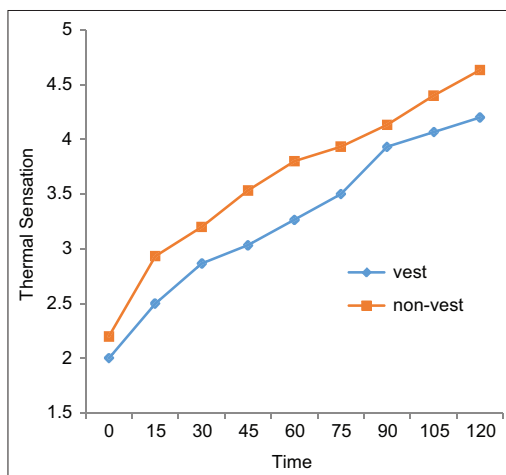
**Figure 2: Time-trend of changes in the physiological strain index in cooling vest and noncooling vest group in construction workers**



**Figure 3:** Time-trend of changes in the perceptual strain index in cooling vest and noncooling vest group in construction workers



**Figure 4:** Changes in the heat strain score index in cooling vest and non-cooling vest group in construction workers



**Figure 5:** Time trend of changes in the thermal sensation in cooling vest and noncooling vest group in construction workers

In the heat exposure, reducing the heat load on the body of outdoor workers is important to maintain health, safety, and productivity. One practical way to protect workers from excess heat load is to use individual cooling systems. According to the existing design and environmental conditions, the effectiveness of this type of personal protective equipment may vary. In this study, the effectiveness of Iranian evaporative

cooling vests Hifitcool Brand, as an operational method, was evaluated in outdoor construction workers. According to the results of this study, at all intervals, heart rate and oral temperature of workers with cooling vests were lower than those without cooling vests. These findings showed that the use of evaporative cooling vests could reduce heart rate and oral temperature in outdoor construction workers, but this reduction was not sufficient to make a statistically significant difference compared to those without cooling vests. The results of studies on the effect of cooling vests on heart rate and oral temperature are contradictory so that while in the study by Zhao *et al.*, investigating the effect of two types of cooling vests of PCMs and ventilated on heart rate of female students in an environment with temperature of 32°C and relative humidity of 50% on the treadmill, results showed no significant difference between the heart rate in two groups using the phase change cooling vests and the control group;<sup>[14]</sup> the findings of Radovan and Eijsvogels showed that the heart rate decreased significantly when using a cooling vests. In another study, Yazdanirad and Dehghan examining the effect of a paraffin-ice cooling vests on ten male students in climatic chamber (40°C and 40% relative humidity) found that there was a significant difference in mean heart rate, oral temperature, and skin temperature of participants with and without cooling vests.<sup>[15]</sup> The results of some of these studies are in line with the results of our study, while they are not in line with the results of some other ones. Possible reasons for the difference in the results of these studies can be different cooling capacity of the cooling vests being used, different environmental conditions in terms of temperature and humidity, surveying environments (laboratory environment or real work environment), and different physical activities of individuals. PSI values, which were calculated using oral temperature and heart rate, were significantly lower during the work time in the group with cooling vests (2.53) than the group without cooling vests (3.66) so that the evaporative cooling vest could reduce the PSI by almost 1.1 unit, however, no significant difference was observed between these values in the two groups with and without cooling vests. The mean values of PSI index in both groups were low (range of changes from 0 to 10), and the effectiveness of evaporative cooling vests may be clear with increasing work intensity and changing PSI index from low to medium, high, and very high. PeSI values, which were calculated using the thermal sensation and the intensity of perceived mental effort, were significantly lower during the work time in the group with cooling vests (5.04) than the group without cooling vests (6.41) so that the evaporative cooling vest could reduce the PeSI by almost 1.4 unit. It seems that the use of evaporative cooling vests can increase the thermal comfort of construction workers; a feeling scale that would have many benefits for the workers and can increase their productivity.<sup>[16]</sup> This part of the findings of the study is consistent with the findings of other similar studies.<sup>[14,17]</sup> For example, Gao *et al.*, in the study of the effect of individual cooling vests on the feeling of heat at a temperature of 34 °C, concluded that the temperature of the body skin decreases

by about 2°–3° and the thermal sensation improves in the individual.<sup>[18]</sup> Furthermore, Haghshenas *et al.* investigated the effect of two types of cooling vests on 90 workers (30 people with cooling vests containing ice gel cooling packages, 30 people with paraffin phase change cooling vests and 30 people without vests) with the same level of physical activity and clothes in Assaluyeh region with an average temperature of 39°C and a relative humidity of 98%; the results showed that the mean of PeSI in the group using paraffin phase changes cooling vests was significantly lower compared to the control group.<sup>[19]</sup> Therefore, the results of the present study were consistent with the results of the above studies. Arngrimsson *et al.* showed that wearing a cooling vests by runners greatly reduced the feeling of thermal discomfort compared to the control group.<sup>[20]</sup> In addition, Zare *et al.* measured thermal strain parameters in atmospheric conditions chamber with a temperature of 40°C and a relative humidity of 40%; the results showed that there was a significant difference between PSI and PeSI and HSSI in conditions with and without cooling vests.<sup>[21]</sup> One of the limitations of this study was the impossibility of measuring skin temperature in the trunk area as a key index in evaluating the performance of the cooling vest.

## CONCLUSIONS

In the present study, the mean values of PSI, PeSI, and thermal sensation were found to be significantly lower in the time of using evaporative cooling vests than the time when workers did not use any cooling vests. The parameters of environmental conditions were not significantly different in case (vest-wearing) and control (nonvest wearing) groups. Therefore, it can be concluded that the difference between physiological and perceptual indices of workers in this test is not related to weather conditions but is due to the cooling effect of the evaporative cooling vests.

Therefore, this study showed that, in the hot and dry conditions, the use of Iranian evaporative cooling vests (Hifitcool Brand) can reduce PSI, PeSI, HSSI indices as well as the thermal sensation. In other words, this cooling vest is able to reduce the level of heat strain in construction workers.

## Acknowledgments

I wish to thank construction workers for their contribution to this project; Occupational health and safety engineering department, for their help in collecting the data and all the technicians who helped me in handling the instruments.

## Financial support and sponsorship

This research was supported by a grant (no: 50363) from Isfahan University of Medical Sciences Ethics Code: IR.MUI.RESEARCH.REC.1399.451.

## Conflicts of interest

There are no conflicts of interest.

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