Experimental study on cooling effect and improving comfort of cooling vest

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Abstract. In order to provide a comfortable working space in a warm or hot environment, it is necessary to cool these spaces to consume energy. In the context of global warming, the ability to provide comfort is becoming more and more challenging. With the increase of energy consumption, the demand for cooling is also increasing [1]. In previous studies, different types of individual and local cooling methods have been used to reduce the thermal stress of outdoor workers [1-7] and improve the comfort of indoor workers in office and commercial buildings. Local cooling can improve the macro climate air temperature, because the microclimate of workers is cooled, so the space air conditioning system needs less energy [1]. In addition, the thermal comfort of the transition space can be improved by using local passive cooling technology.

Keywords: construction worker, cooling vest, heat strain, hot and humid environment.

1. Introduction

In many working environments, the existence of extreme high temperature conditions may have a serious negative impact on the health and safety of employees. This extreme situation is often encountered in many occupational environments, such as steel manufacturing, glass factory, mining, textile, ceramics, food canning factory and outdoor operation. The construction industry involves many of these occupational environments and is more vulnerable to heat stress than other industries. Construction workers should not only bear the thermal stress of outdoor physical labor, but also bear the more severe thermal stress of confined space.

Reinforcement engineering is one of the most labor-intensive and lasting tasks in construction. Unfortunately, it is reported that 10% of the steel workers in Hong Kong suffer from heatstroke[2]. It is reported that one steel worker fell into water on a construction site due to heat stroke last summer. Therefore, thermal stress will seriously threaten the health and safety of steel workers. In order to ensure the health and safety of workers exposed to high temperature, it is urgent to study the physiological response of steel workers under high temperature stress.

Different experiments and numerical studies have confirmed that PCM cooling vest can minimize the discomfort of human activities in different environmental conditions. In Gao et al's study, lower core and average skin temperatures were obtained, and subjects cycled on a dynamometer and then walked on a treadmill. Webster et al. Reported that when wearing PCM cooling vest before exercise,
the core and skin temperature is lower, and the sweating rate is lower. Similarly, people who exercise in a hot environment wearing a cool vest will lower skin temperature, heart rate and sweat loss rate than people who exercise under the same conditions but do not have a cold vest. In addition, the thermal acceptability of working in moderate thermal conditions becomes positive, which means that the thermal conditions are acceptable when wearing a cooling vest[5].

Arngrimsson et al. Found that wearing a cold vest during an active warm-up can reduce 1.1% of running time and improve the performance of 5K. Other researchers have relied on numerical simulation and demonstrated the effectiveness of PCM vest in cooling the body. The heat exchange among the body, PCM cooling vest and environment was simulated by using computational fluid dynamics (CFD) model. The results show that the use of PCM cooling vest can reduce the rise of human skin temperature and improve personal sports performance. Hamdan et al. And Itani et al. Developed a comprehensive model to predict the thermal response of a person wearing a PCM vest. The results of Hamdan et al. Show that the PCM package with lower melting temperature increases the heat loss of human body due to the higher temperature gradient between skin and melting temperature. Itani et al. Found that comfort can be improved by targeting sensitive areas of the trunk, such as the back.

2. Materials and methods

2.1. study design and procedures
The hybrid cooling vest uses a ventilation fan to cool the body through sweat evaporation, while the PCM package provides reasonable cooling. Fig. 1 shows a schematic diagram of (a) a rear view of a hybrid vest with PCM grouped in a vest and (b) a side view of the vest layer. The inner layer of the vest is the inner fabric layer, which can be a cotton shirt worn by human beings. When sweat is produced on the surface of the skin, it absorbs the sweat. The outer fabric layer of the vest is exposed to the environment and can also be made of cotton. The heat insulation performance is about 0.04 clo and the evaporation resistance is 0.005 m2kpa / W. PCM bags with fixed dimensions and characteristics (e.g. melting temperature, density and melting latent heat) can be fixed by a mesh polyester fabric bag located in a cooling vest. There should be sufficient space between PCM packages to allow effective air circulation within the cooling vest[6]. The intake and exhaust fans located in the lower part of the forebody and the upper part of the hindquarters are used together with the louvers to prevent the circulation of ambient air and unwanted heat exchange in the vest when the fans are off. It should be noted that the openings at the waist, collar and cuff are very tight, so the ambient air can only enter and exit through the fan during operation.

As the cooling effect is the focus of the study, ventilation devices are placed in different parts of the trunk in the design phase. The design of Ub and UF may cause discomfort and aesthetic problems due to the fan being placed on prominent body parts. In addition to the MB design which includes two areas of the back and buttocks, the design of the other four ventilation locations includes one area each. For ordinary clothes, the collar and cuff are the main ventilation channels. Three open zippers on the chest and upper back provide additional air outlet channels.
Fig. 1 Schematic showing:(a) back view of the hybrid vest with the PCM packets placed inside the vest and (b) side view of the vest layers.

2.2. participants
Twelve male college students participated in the experiment. None of the participants were aware of the health problem, and they were considered apparently healthy. They exercise about three times a week, which is considered physical activity. Before informed consent to participate in the study, participants had a clear understanding of the trial procedure.

2.3. measurement and calculation
The core temperature is measured by an edible disposable capsule. On the day before the test, the calibration procedure was carried out to ensure that the capsules worked normally with an accuracy of ± 0.1 °C. In a water cup (about 85 ml of water), the capsule measures the water temperature from 42 °C to 30 °C at a sampling rate of 30 seconds. Check the temperature recorded by the capsule (precision thermometer) with a certified temperature probe (accuracy of 0.01 °C). The calibration results show that the temperature difference recorded by thermometer and used capsule is 0.04 (± 0.03) °C. The capsule is remotely connected to a data recorder, which is monitored by a small digital camera in the combustion bag. Throughout the experiment, the bag was fixed at the waist of the participants and the core temperature was continuously recorded.

The heart rate monitor wirelessly records the heart rate when resting for 30 minutes in the laboratory at a sampling rate of 60 seconds. During any activity in the laboratory, another belt (polar T34 transmitter of the United States) continuously collects the heart rate at the sampling rate per second. The heart rate transmitter transmits data to the computer through a sensor on the treadmill, which synchronously records the running distance and duration. The power output is calculated by treadmill speed, slope, and weight.

Participants’ weight (with underwear) was measured in the climate chamber before and after each running cycle with an electronic scale with an accuracy of ± 0.01 kg. Hong Kong Limited. In order to regulate the hydration state of the two participants, the warm water intake in the first 5 minutes of the second test was controlled by the weight difference before and after exercise. Record the water intake. The sweating rate (SR, in L/h) was calculated as a function of exercise time based on weight change after adjusting for any urinary loss and total water intake (assuming a water volume of 1l = 1kg). None of the participants passed any urine tests or drank water during exercise. In addition, participants were asked to report their overall feeling of the whole exercise using a perceived exertion (RPE) score (from 0 = rest to 10 = very hard).
3. Results

Figure 2 shows the characteristics of the subjects. There was no significant difference between the two groups. Figure 3 shows the amount of sweat loss in each group under different climatic conditions. The amount of sweating in HD group and HH group was significantly higher than that in N group, but there was no significant difference between HD group and HH group. In different climate conditions, the sweat amount of SS group and int group was the same.

![Subject characteristics](image)

**Fig. 2** Subject characteristics

For intermittent exercise (Fig. 3), HR in HD and HH was again slightly higher than N at rest. With the extension of exercise cycle, the heart rate increased and decreased with exercise and meditation under all conditions. In the exercise cycle, the HR of HD and HH was the highest, but there was no difference between them. TR was the same under all conditions and did not change significantly in any condition for 60 minutes. PSI increased with exercise and decreased with rest within 60 minutes. PSI remained high during HD and HH, but there was no difference between the two conditions. The resting and peak values of HR, TR and PSI were compared between the two exercise schemes (SS and int). The resting and peak HR and tr values were similar between the two schemes. Under the same conditions, the PSI of int is less than SS at HD and HH.
4. Discussion
Thermal comfort is related to the thermal balance of human body, which indicates that the heat generated in human body is approximately equal to the heat loss of environment. Considering that construction workers usually need to complete intensive construction work in hot outdoor environment, a cooling vest with relatively high cooling power is needed to disperse metabolic heat generated during construction and avoid excessive heat storage. This study evaluated a newly developed unit B in a sweating dummy and reported a cooling power of 68W, which is higher than the a unit (51w) used in the cooling vest promotion program. According to the questionnaire survey of Chan et al., compared with the control group, the thermal comfort of construction personnel wearing cooling vest (inserted into unit a) was improved. However, the cooling power of unit a seems to be insufficient to reduce core temperature and prevent thermal strain. Previous studies have compared several ventilated cooling suits with different cooling powers (32, 59 and 80 W) in humid and hot environments, and found that ACG with higher cooling power significantly attenuates the thermal regulation response.

Despite these limitations, the current study provides laboratory evidence that new HCV can be considered for use during short breaks as an alternative to the use of uncooled vests. First, HCV use during exercise breaks may reduce the risk of mild hyperthermia (about 38.5 °C) while lowering core temperature. The cooling rate of this kind of vest is slightly lower than that of other reports (i.e. 0.03-0.04 °C · min⁻¹). Interestingly, these higher cooling rates did not result in a significant difference compared to that without a vest. In contrast, in the current study, the cooling rate of HCV is not only statistically significant, but also has a greater effect[7].

5. Conclusion
In this study, the air flow rate and cooling power of the ventilators are tested and compared. The newly designed unit B can produce 8-22l / s air flow for 7h, which shows better performance than commercial unit a in terms of air flow and working time. The sweating dummy test further proves that the cooling power of unit B is higher than that of unit a (51w). In this study, the cooling effect of different ventilation devices in the cooling vest was specially evaluated. PCM module can be used in future research to provide mixed cooling effect. Human trials are necessary to test this hybrid cooling vest, so it will be in our follow-up study.

When the ventilation device is placed in the ventilation area, the cooling effect of the corresponding area is the best. Under different ventilation conditions, the location of local trunk
cooling was significantly different, but there was no significant difference in the position of open ventilation.

Workers engaged in different trade activities may have different degrees of sensitivity to heat stress. Trade by trade studies will better reflect the actual situation. While this study is particularly applicable to the steel bending and fixing industry, more work is needed to further investigate other industries and other countries to provide an overall view of the future. According to the enhanced thermal stress model, a set of good working hours, work and rest methods and indicators can be formulated to ensure the health and safety of field personnel in hot weather. It is of great significance to reduce the occurrence of heat stress and better protect the health and safety of workers.

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