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Comparing the Effect of Two Portable Cooling Vests on Physiological Parameters under Hot Laboratory Conditions

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ABSTRACT
Personal protective clothing (PPC) can cause heat strain. The purpose of this study was Heat strain control by two portable cooling vests under wearing vapor protective suit and hot condition. An experimental study was conducted in a climatic chamber on 15 male students under warm conditions (ambient temperature =40°C, relative humidity=40%). Each participant performed the test without a cooling vest and with Spadana (Of 70% cotton and 30% polyester with 10 pockets for PCM: Hydrogel packages and a total weight of 2.3kg) and Techkewl-7026 (100% cotton with 4 pockets for PCM packages and a total weight of 2 / 2kg) phase change material cooling vests. The activity rate on a treadmill was light (2.8km/h) and the test lasted 30 minutes for each stage. Cooling effects were evaluated by measuring heart rate, oral temperature and skin temperature. Results showed that the mean and standard deviation for heart rate, oral temperature and skin temperature with a Spadana cooling vest were 100.55 (8.12)(bpm), 36.83 (0.25)°C and 31.52(1.85)°C, respectively, and for Techkewl-7026 cooling vests were 103.64 (10.9)(bpm), 36.98(0.34)°C and 34.2 (1.4)°C, respectively, and for without cooling vest were 113.33(11.23)(bpm), 37.05(0.35) °C and 37.93(0.48) °C, respectively . The difference between parameters with cooling vests and without cooling vest was statistically significant ($p < 0.05$). The use of Spadana and Techkewl-7026 phase change material cooling vests can reduce thermal stress through a reduction in heart rate, oral temperature, skin temperature and sweating rate.
Keywords: Cooling Vest, Phase Change Materials, Heat Strain, Hot and Dry Conditions

INTRODUCTION
Heat can be a harmful factor in workplaces, which may be process-induced as energy in the industry [1]. Moreover, heat may be due to climatic conditions, and prolonged exposure to heat in these areas, such as the southern part of Iran may cause a person to suffer from heat stress [2]. Occupational heat stress can be created at occupation such as fire-fighting, industrial activities, military drills and operations, and sports, due to exposure with radiant, conductive and convective heat and humidity. In extremely hot conditions, the human body shows physiological responses called "strain", such as increased sweating, elevated skin temperature, elevated deep body temperature, and increased heart rate [3]. If thermal stress verges toward a human's tolerance threshold, it can cause heat stress in workers [4]. If not controlled, heat stress can lead to illnesses such as heat syncope, heat exhaustion, heat cramps, heat shock, confusion, poor concentration, and fatigue [5-7]. In addition to heat-related illnesses, heat exposure in workplaces can reduce productivity and also increase the number of accidents [8, 9]. Moreover, soldiers are required to put on personal protective clothing in military services to prevent harmful exposure to chemical and physical hazards [10]. Although protective clothing is designed to enhance safety, they may also impose a negative effect on personal ability and the body's thermal balance [11, 12].

Personal protective clothing (PPC) may be made up of several layers of vapor-barrier (or resistant) material and are often of heavy weight [13]. Of all PPC factors, the nature of the work and the potential of climate changes can significantly affect adjustments to temperature and cardiovascular strain on an individual [13, 14]. High levels of protection by PPC severely inhibit the evaporation of heat through sweating. According to statistics from 1980 to 2002, a total of 37 US soldiers have lost their lives because of heat-related illnesses [15]. The deployment of military forces in hot areas of the world such as Iraq and Afghanistan have led to a significant number of troops being hospitalized due to effects caused by heat and some 1,050 heat-related incidents have been reported among US soldiers in these areas during the period of 2008 to 2012 [16]. To control the heat stresses caused by wearing such types of clothing, there are various strategies in terms of engineering and management control.

One of the available strategies to avoid heat strain and to reach a state of thermal comfort in warm environments is the use of personal cooling equipment that absorbs the excess heat and reduces the heat stress [17-19]. Cooling vests are also considered a part of personal cooling equipment. A group of cooling vests are made up of phase-change materials. In phase-change vests, the heat generated by the circulatory system under the skin is absorbed by the phase change materials [20]. Phase change materials possess the capability to change their phase within a certain temperature range. Considering the fact that military forces are obligated to use vapor protective suits in the hot and humid conditions of the Persian Gulf, and because of the insulation of such clothing, air is not exchanged on the surface of the skin and it is prevented from being removed by body heat through a conduction and convection mechanism, and consequently the person can be affected by heat stress. The purpose of this study was Heat strain control by two portable cooling vests under wearing vapor protective suit and hot condition.

MATERIALS AND METHODS

Participants

The study was interventional and conducted on 15 male students. Entrance criteria for the study included no history of pulmonary, cardiovascular, musculoskeletal, neuromuscular diseases, seizures, diabetes, epilepsy, and not taking drugs and medications affecting heart rate and blood pressure, and not taking caffeine, coffee and alcohol for 12 hours before the test. During the test, whenever a person's heart rate increased higher then180 beats per minute, or became exhausted and didn't want to continue, the test was stopped [21]. A general practitioner examined volunteers according to the study inclusion criteria. Volunteers approved by the doctor were notified of experiment visit times. The volunteers were given explanations on how to fill out the questionnaires and were also given a consent form about their participation in the study. Demographic information was collected for height, age and weight.

Place of study

The study was conducted from in Isfahan University of Medical Sciences.

Cooling vests:

In this study, spadana PCM cooling vest (Of 70% cotton and 30% polyester with 10 pockets for PCM: Hydrogel packages with melting point of 0 °C that packed in a plastic bag while internal side of packages was covered to prevent cold burning, total weight was 2.3kg) and Techkewl-7026 PCM cooling vests (100% cotton with 4 pockets for PCM package with melting point of 14 °C and a total weight of 2 / 2kg) were used. In preparation, cooling packs were placed in the freezer the night before the test.

Test protocol:

In this study, the subjects were tested under hot and dry climate conditions with ambient temperature (AT) = 40℃, and relative humidity (RH) = 40% in a climate chamber (length: 4m, width: 3m, height: 2.7m and equipped with intelligent heating and cooling). The temperature and humidity inside the chamber were monitored during tests by a WBGT meter (Casella Model). To remove the effect of different clothing, each subject was given a sports shirt to put on during the test. Each subject underwent the test three times: without a cooling vest (A), with a Techkewl-7026 cooling vest (B), and with a Spadana cooling vest (C). To do the test in light intensity mode, the treadmill was adjusted to a speed of 2.8 Km/h and a slope of 0% (21). The test was conducted as follows: initially, the subject was asked to stay outside the chamber for 30 min., and then measurements were taken for body temperature, oral and skin temperatures (at four predefined points of the trunk, including left upper part of the chest, the right side of the abdomen, behind the right shoulder, and the waist) and heart rate. Subjects were then given the vapor protective suits to wear. After that, the subject wearing the vapor protective suits exercised for 60 min. on a treadmill. During the test, measurements were taken for heart rate (using a sport tester, the model polar) and oral temperature (using a Beurer oral thermometer with accuracy ± 0.1 degrees in Celsius) every 5 minutes and skin temperature (using a Thermo focus 0700 non-contact thermometer with accuracy ±0.1) every 15 min. The subjects were given no fluids during the tests. Finally, measurements were taken for the mean of the skin temperatures measured at above four points of the body as trunk skin temperature.

Statistical analyzes:

Data were analyzed using SPSS 16 Software. Normal data distribution and P-value were calculated using the Kolmogorov-Smirnov test and Repeated Measurement ANOVA, respectively.

RESULTSts

Participant demographic information, including age, height, weight, physical activity and body mass index (BMI) are shown in Table 1. The Kolmogorov-Smirnov test showed normal data distribution ($p > 0.05$). The results of statistical analysis showed that ambient temperature (Ta), relative humidity (RH) and Wet Bulb Globe Temperature (WBGT) showed no meaningful difference among three modes of activity without a cooling vest, activity with a Techkewl-7026 cooling vest, and activity with a Spadana cooling vest, with the same conditions in all three modes. During the tests, the mean and the standard deviation Ta, RH, and WBGT were 39.91 and 0.24, 39.92 and 2.92, 31.88 and 0.47, respectively.

Table1: Range, the mean and standard deviation for participant characteristics

Parameters	Range	Mean(±SD)
Age (year)	21-27	24(2.32)
Height (m)	1.69-1.88	1.76(0.05)
Weight (kg)	60-90.32	74.03(9.03)
Physical activity (In hour /week)	0-9	4.36(3.44)
BMI (Kg / m^2)	21.01-25.35	23.16(1.33)

Table 2 shows the values of the range, the mean and standard deviation of the measured physiological parameters related to participant activities without a cooling vest, with a Techkewl-7026 cooling vest, and with a Spadana cooling vest.

Table 2: Range, mean and standard deviation of measured physical parameters for activities without a cooling vest (A), with a PCM cooling vest (Techkewl-7026)(B), and with a Spadana PCM cooling vest (C).

Parameters	Range	Mean (±SD)
HR res (bpm)	65-91	80.84(7.26)
HR A (bpm)	97-133	113.33(11.23)
HR B (bpm)	81-118	103.64(10.9)
HR C (bpm)	84-110	100.55(8.12)
T_{or} **res**	35.7-36.87	36.29(0.36)
T_{or} **A**	36.54-37.55	37.05(0.35)
T_{or} **B**	36.44-37.73	36.98(0.34)
T_{or} **C**	36.49-37.22	36.83(0.25)
T_{skin} **res**	34.69-36.67	35.57(0.58)
T_{skin} **A**	36.99-38.64	37.93(0.48)
T_{skin} **B**	32.11-36.44	34.2(1.4)
T_{skin} **C**	28.61-35.19	31.52(1.85)

Note: res: rest mode A: without a cooling vest B: with a Techkewl-7026 cooling vest C: with a Spadana cooling vest HR: Heart Rate T_{or} : Oral temperature T_{skin}: Skin temperature

Fig. 1 shows the mean values of heart rate during the test every 5 min. for activities without a cooling vest, with Techkewl-7026 cooling vest, and with Spadana cooling vests. The results from the statistical analysis showed a significant difference in terms of the mean values of heat rate between an activity without a cooling vest and activities with a Techkewl-7026 cooling vest (P = 0.022) and a Spadana cooling vest (P = 0.002). There was no difference between the mean values of heart rate at rest and prior to the test without a cooling vest and those with a Techkewl-7026 cooling vest (P=0.18) and those with a Spadana cooling vest (P = 0.70).

The mean values for oral temperature measured every 5min. during the test in activities without a cooling vest, with a Techkewl-7026 cooling vest, and with a Spadana cooling vest are shown in Fig.2. The statistical analysis showed that there was a significant difference between the mean values of oral temperature during activity without a cooling vest and activity with Spadana cooling vests (P = 0.043), but there was no significant difference between the mean values of oral temperature during activity without a cooling vest and activity with a Techkewl-7026 cooling vest (P = 0.335).

There was no difference between the mean values of oral temperature at rest and prior to the test without a cooling vest and those with a Techkewl-7026 cooling vest (P=0.12) and those with a Spadana cooling vest (P = 0.68).

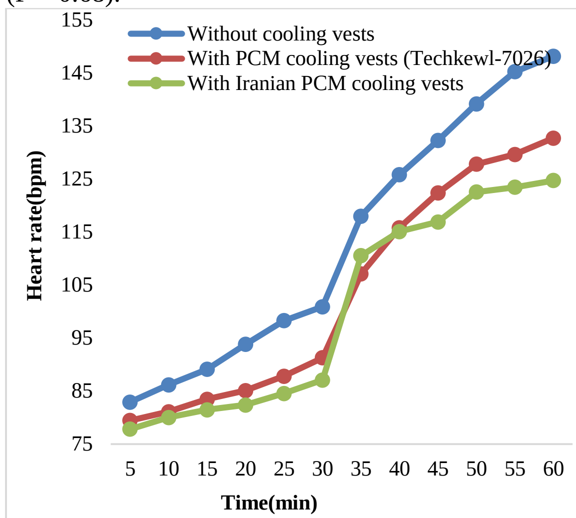

Fig. 1: Mean values of heart rate during the test every 5 min. for activities without a cooling vest, with a PCM cooling vest (Techkewl-7026), and with an Iranian PCM cooling vest.

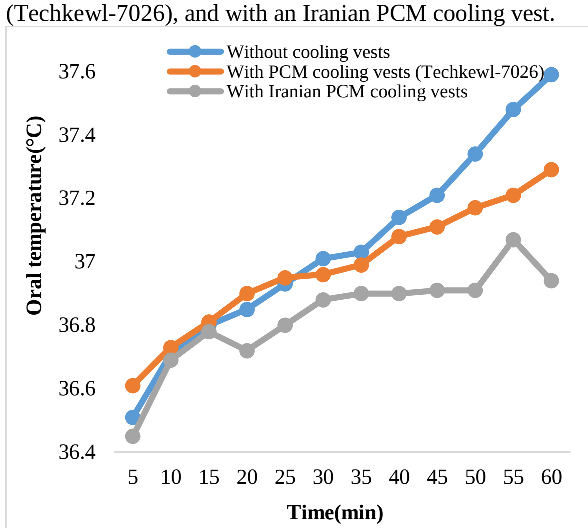

Fig. 2: Mean values of oral temperature every 5 min. during the activity without a cooling vest, with a PCM cooling vest (Techkewl-7026), and with an Iranian cooling vest

The mean values of skin temperature every 15min. during the activity without a cooling vest, with a Techkewl-7026 cooling vest, and with a Spadana cooling vest are shown in Fig. 3. Statistical analysis showed a significant difference between the mean values of subject skin temperature during activity without a cooling vest and those with a Techkewl-7026 cooling vest (P= 0.023) and those with a Spadana cooling vest (P= 0.004).

The mean values of skin temperature at rest prior to the test without a cooling vest showed no significant difference to the mean values of heart rate at rest prior to the test with a Techkewl-7026 cooling vest (P=0.67) and those with a Spadana cooling vest (P = 0.46).

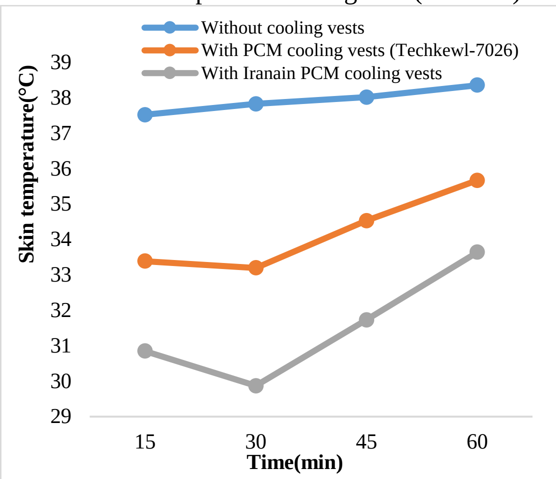

Fig. 3: Mean values of skin temperature every 15 min. during the activity without a cooling vest, with a PCM cooling vest (Techkewl-7026), and with a Spadana cooling vest.

DISCUSSION

In this experimental study, the mean values for subject heart rate, oral and skin temperatures during the workout on a treadmill with vapor protective suits in hot conditions using Techkewl-7026 and Spadana cooling vests were significantly lower than those using no cooling vests. Meanwhile physiological parameter values measured at rest prior to the tests showed no significant differences and they were the same. There were no significant differences in parameters for climate conditions. Therefore, it can be concluded that the observed difference between the mean values of heart rate, oral temperature and skin temperature in this test is a result of the cooling effect of Spadana and Techkewl-7026 cooling vests.

The cooling vests were placed on the trunk, which forms the largest part of the body. The cooling packs touch the skin of the trunk, and a large amount of heat is absorbed through a conduction mechanism by the phase change material. By absorbing the heat, the phase change materials change their phase and turn into the liquid phase. Walking on the treadmill results in the displacement of airflow under the vests and this cooling air flow cools other parts. In addition, the cooling effect induced by the vests reduces sweating, and consequently, the risk of dehydration is prevented. All of these mechanisms reduce the physiological parameters of heat strain during activity with a cooling vest compared to those during activity without a cooling vest, and hence heat strain is controlled.

Other studies on the cooling effect of the phase change cooling vests in hot conditions with different protective clothing showed similar results. For example, Jovanovic *et al.* studied the cooling effect of the phase change material paraffin n-hexadecane ($C_{16}H_{34}$) in a phase change cooling vest on the reduction of heat strain in 10 male soldiers in hot conditions of 40℃ in a climate chamber. The participants wore camouflage clothing while working out on the treadmill at a speed of 5.5km/h. The results confirmed that the cooling vest can reduce physiological strain during the activity. The results from thermography also showed that heat produced inside the body is the main factor influencing the melting time of phase change materials [22]. In another study by Jovanovic *et al.*, the cooling effect of phase change material cooling vests on 10 male soldiers wearing NBC type protective clothing and exercising on a treadmill at a speed of 5.5Km/h was investigated. The results also showed that the produced heat strain was reduced by using phase change material cooling vests beneath NBC type protective clothing during hot conditions of 40 ℃ in a climate chamber [23]. Chou *et al.* investigated the effectiveness of ice packs and phase-change material cooling vests on the reduction of the physiological load on 8 male students wearing firefighting protective clothing and exercising on an ergometer bicycle in an environment with relatively high temperatures (30℃, RH %50). The results showed that the increase in skin temperature was low when using cooling clothing and the participants felt low heat and humidity [24]. Relevant studies conducted in Iran also showed the effectiveness of phase change materials cooling vests on the control of the heat strain. For example, in a study by Yazdani and Dehghan, a cooling vest was made up of the phase change material paraffin, and the results showed that the vest designed into ordinary work clothing was able to control heat strain from light and moderate exercise on a treadmill under hot conditions (40 ℃ and RH=40) [25].

In another study, Dehghan and Gharabaghi investigated the performance of an Iranian cooling vest designed with ordinary work clothing for light and moderate exercise on a treadmill under climate conditions of 8.38℃ and relative humidity of 9.32. The results showed that the vest was able to control heat strain only during low exercise [26]. The results from the present study with vapor protective suits were consistent with their study.

The results from the present study showed that mean skin temperature during activity with Techkewl-7026 and Spadana cooling vests were 34.2℃ and 31.5℃, respectively, which are close to normal skin temperature (35℃), and thus the vests didn't cause skin irritation and discomfort due to extreme coldness. The results of a study by Gao *et al*. showed that the skin temperature of the trunk fell about 2-3℃ using phase-change material cooling vests and remained at 33.3℃ This temperature was felt as comfortable by the subjects [25]. The results from the present study showed that the Spadana cooling vest is able to control thermal strain and also has better efficiency than the Techkewl-7026 vest. During the tests, all physiological parameters were less with the Spadana cooling vest compared to using a Techkewl-7026 vest. The results also showed that the Techkewl-7026 cooling vest failed to control the parameter of oral temperature, and there was no difference in this parameter between exercise with a Techkewl-7026 cooling vest and without a cooling vest, whereas using a Spadana cooling vest resulted in a significant difference in this parameter.

CONCLUSION

The results showed that both Techkewl-7026 and Spadana cooling vest effectively control heat strain with vapor-protective suits in a hot environment and can prevent the occurrence of heat-related illnesses. Having a suitable melting point, these vests don't allow the skin temperature to fall too much, and this property prevents cold irritation and also provides thermal comfort when using such clothing. The results also showed that in controlling the heat strain, the Spadana cooling vest had better efficiency than the Techkewl-7026. As such, the newly manufactured Spadana cooling vest can be applied with suitable efficiency to reduce heat-related illnesses. Further studies under other different climate conditions are recommended in order to confirm the efficiency of the newly designed Spadana cooling vest.

ETHICAL ISSUES

The authors have observed ethical issues such as plagiarism.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTION

The study was directed by Mansour Zare Seqin Sara (cosponsoring author). Firouz valipour (First author) and Habibollah Dehghan did a guide to doing the plot. Saeed Yazdani Rad performed statistical analysis and was involved in the discussion of the results.

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REFERENCES

[1] Mohammadyan M, Sepehri P. Design of cool spot and assessment of its effect on WBGT index among furnace workers' position in Shimi Madani industry in Hamadan. Journal of Mazandaran University of Medical Sciences. 2010;20(76):2-7.

[2] Dehghan H, Mortazavi SB, Jafari MJ, Maracy MR. Combination of wet bulb globe temperature and heart rate in hot climatic conditions: The practical guidance for a better estimation of the heat strain. International Journal of Environmental Health Engineering. 2012;1(2):18-23.

[3] Jalil M, Sani MA, Dor Z, Yahya MS, Mohideen Batcha MF, Hasnan K. Heat stress investigation on laundry workers. International Conference on Ergonomics 2007 (ICE07); December 3 - 5 December; Kuala Lumpur, Malaysian, 2007.

[4] Hygienists ACoGI, editor Threshold limit values for chemical substances and physical agents and biological exposure indices 1995: American Conference of Governmental Industrial Hygienists.

[5] Holmér I, Kuklane K, Gao C. Test of firefighter's turnout gear in hot and humid air exposure. International journal of occupational safety and ergonomics. 2006;12(3):297-05.

[6] Moran DS, Epstein Y. Evaluation of the environmental stress index (ESI) for hot/dry and hot/wet climates. Industrial health. 2006;44(3):399-03.

[7] Wan M. Occupational exposure to hot environments: Florida workers need help. Florida Public Health Review. 2004;1:53-55.

[8] Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity "an increasing challenge for low and middle-income countries during climate change. Global Health Action. 2009;2(1):20-47.

[9] Morabito M, Cecchi L, Crisci A, Modesti PA, Orlandini S. Relationship between work-related accidents and hot weather conditions in Tuscany (central Italy). Industrial health. 2006;44(3):458-64.

[10] Tamas R. Review Article: Heat stress and the role of protective clothing in military service. Journal of College of Medicine. 2011;14(2):82-84

[11] Adams PS, Slocum AC, Monroe Keyserling W. A model for protective clothing effects on performance. International Journal of Clothing Science and Technology. 1994;6(4):6-16.
[12] Havenith G. Heat balance when wearing protective clothing. Annals of Occupational Hygiene. 1999;43(5):289-96.
[13] Cheung SS, McLellan TM, Tenaglia S. The thermophysiology of uncompensable heat stress. Sports Medicine. 2000;29(5):329-59.
[14] Borg DN, Stewart IB, Costello JT. Can perceptual indices estimate physiological strain across a range of environments and metabolic workloads when wearing explosive ordnance disposal and chemical protective clothing? Physiology & behavior. 2015;147:71-77.
[15] Carter III R, Cheuvront SN, Williams JO, Kolka MA, Stephenson LA, Sawka MN, *et al*. Epidemiology of hospitalizations and deaths from heat illness in soldiers. Med Sci Sports Exerc. , 2005; 37(8):1338-44.
[16] Center AFHS. Update: Heat injuries, active component, US Armed Forces, 2013. Msmr. 2014;21(3):10-13.
[17] Nishihara N, Tanabe S-i, Hayama H, Komatsu M. A cooling vest for working comfortably in a moderately hot environment. Journal of physiological anthropology and applied human science. 2002;21(1):75-82.
[18] Jetté F-X, Dionne J-P, Rose J, Makris A. Effect of thermal manikin surface temperature on the performance of personal cooling systems. European journal of applied physiology. 2004;92(6):669-72.
[19] Reinertsen RE, Færevik H, Holbø K, Nesbakken R, Reitan J, Røyset A, *et al.* Optimizing the performance of phase-change materials in personal protective clothing systems. International Journal of Occupational Safety and Ergonomics. 2008;14(1):43-53.
[20] Bendkowska W, Kłonowska M, Kopias K, Bogdan A. Thermal Manikin evaluation of PCM cooling vests. Fibres & Textiles in Eastern Europe. 2010;18(1):70-74.
[21] Bennett BL, Hagan RD, Huey K, Minson C, Cain D. Comparison of two cool vests on heat-strain reduction while wearing a firefighting ensemble. European journal of applied physiology and occupational physiology. 1995;70(4):322-28.
[22] Jovanovic DB, Karkalić R, Tomić L, Veličković Z, Radaković S. Efficacy of a novel phase change material for microclimate body cooling. Therm Sci. 2014;18:657-65.
[23] Jovanovic D, Karkalic R, Radakovic S. Physiological tolerance to uncompensated heat stress in soldiers: effects of various types of body cooling systems. Vojnosanitetski pregled. 2014;71(3):259-64.
[24] Chou C, Tochihara Y, Kim T. Physiological and subjective responses to cooling devices on firefighting protective clothing. European journal of applied physiology. 2008;104(2):369-74
[25] Yazdanirad S, Dehghan H. Designing of the cooling vest from paraffin compounds and evaluation of its impact under laboratory hot conditions. International journal of preventive medicine. 2016; 7(1):47
[26] Dehghan H, Gharehbaei S, Mahaki B. Performance evaluation of Iranian cooling vest on the physiological indices in hot climatic chamber. Journal of Education and Health Promotion. 2016;5:15