Research and development report

Effectiveness of a light-weight ice-vest for body cooling in fire fighter's work

RÄDDNINGS VERKET

Swedish Rescue Services Agency

1999 Swedish Rescue Services Agency, Karlstad, Sweden
Fire & Rescue Services Department
ISBN 91-7253-036-7

Order number P21-309/99
1999 years edition

Effectiveness of a lightweight ice-vest for body cooling in fire fighter's work

Juhani Smolander
Kalev Kuklane
Désirée Gavhed
Håkan Nilsson
Eva Karlsson
Ingvar Holmér

Climate group
Department of Occupational Medicine
National Institute for Working Life
171 84 Solna, Sweden

Contact at the Swedish Rescue Services Agency:
Dan Carlsson, Rescue Services Department
Telephone +46 54 10 42 13, Fax +46 54 10 42 13

Foreword

This study was carried out in cooperation with the Swedish Rescue Services Agency and the Håbo municipal rescue service brigade. (The authors are indebeted to Dan Carlsson, Örjan Bergman for their valuable comments and active support during the investigations.

Table of Contents

Effectiveness of a lightweight ice-vest for body cooling in fire fighter's work

Abstract

The aim of the present study was to examine the physiological and subjective effects of wearing a light-weight ice-vest (1kg, water) in fire fighter's work. The experiments were carried out in a climatic chamber, in a container under extreme radiant heat, and during simulated BA operations. In addition, the physical cooling effect of the ice-vest was measured with a thermal mannequin. Four experienced fire fighters participated in the experiments. In all tests, the subjects wore clothing standard for fire fighters clothing with the self-contained breathing apparatus. The total extra weight carried was 21-23 kg. The ice-vest was worn over the underwear. The laboratory tests consisted of 30 minutes of treadmill walking at a moderate (4km/h, no inclination), and a heavy (4 km/h, inclination of 4 degrees) work intensity in the heat (45°C, 30%) with and without the ice-vest. The results showed that the ice-vest effectively reduced skin temperatures under the vest, especially on the back under the breathing apparatus. Wearing the ice-vest did not affect the metabolic rate, skin temperatures outside the vest or the rise in rectal temperature. On average, heart rate was ca. 10 beats/min lower, amount of sweating was reduced by 13%, and subjective sensation of effort and warmth were lower during work with the ice-vest than when BA operations compared to work without it. The results from tests in the container and in the smoke-diving house largely supported the laboratory results. According to the thermal mannequin tests, the useful energy available from the vest for body cooling was rather high (58%). In conclusion, the light-weight ice-vest clearly reduces circulatory, thermal, and subjective strain during demanding BA operations tasks. It was estimated that the added benefit while working with BA was 10-15%.

Key words: fire fighting, smoke-diving, thermal strain, cooling, ice-vest.

1. Introduction

The work of a fire-fighter, especially BA operations, often involves exposure to heavy physical work and heat stress. This combination of stress factors reduces efficient work time and productivity, and may increase the risk of heat-related illnesses.

Several different auxiliary personal body cooling devices have been developed for the industry (Kamon et al. 1986, White et al. 1991, Muir et al. 1999). They are, however, often of limited value for fire fighters because of their weight. An ideal body cooling device for fire fighters should be rather light-weight, should not interfere with the job performance, and should be easy to use during the call outs.

Swedish Rescue Services Agency has been developing a lightweight (approx 1 kg) ice-vest (water) for fire fighters. In their preliminary tests (results unpublished), they have confirmed two aspects. First, that wearing an ice-vest will not reduce the safety of working in a hot environment. Secondly, wear trials have been carried out in six fire brigades and in four training colleges. In these trials, the instructors and fire fighters have taken a positive attitude to the use of the ice-vest. They felt that it significantly reduced heat strain and improved job performance during and after working in the heat.

The aim of the present study was to examine, in a systematic way, the effects of wearing the ice-vest on physiological and subjective responses in fire fighter's work. The experiments were carried out in a climatic chamber, in a container under extreme radiant heat, and during simulated smoke diving. In addition, the physical cooling effect of the ice-vest was measured with a thermal mannequin.

2. Subjects and methods

2.1. Subjects

Four experienced fire fighters participated in the experiments. They were healthy, moderately physically active, and all had a normal blood pressure. Their physical characteristics are shown in Table 1.

Table 1. Subjects' age, height and body weight. SD= standard deviation

Subject	Age (years)	Height (cm)	Weight (kg)
1	37	185	88
2	36	187	78
3	32	182	84
4	39	188	98
Average	36	186	87
SD	3	3	8

2.2. Description of the clothing and the ice-vest

In all tests, the subjects wore the standard fire fighters clothing (RB90) with the self-contained breathing apparatus (AGA Divator). During the laboratory tests, the face mask was not used because of the measurement of oxygen consumption. The total extra weight carried was 21-23 kg.

The ice-vest is made of cotton. The inside consists of two flat plastic holders, which have several small pockets for water (Fig. 1). Five different vests were used in the tests, and their weight varied slightly (1.0-1.1 kg). In 2 of the vests, the inside is covered with a net, whereas the other 3 have a cotton cloth. The ice-vest covers most of the trunk area, and is worn over the underwear. The vests were kept in a freezer at -20 °C overnight before the experiments..

Figure 1. The frozen ice-vest worn by a fire fighter.

2.3. Description of test protocols

The study consisted of four parts:

1) Standardised laboratory experiments while working in the heat
2) Tests in a container with extreme radiant heat stress
3) Tests in a BA operations house
4) Thermal mannequin tests

Laboratory experiments

Laboratory experiments were carried out in a climatic chamber, where the air temperature was 45 °C, and relative humidity 30 %. In the tests, the subjects walked on a treadmill for 30 minutes twice at a moderate exercise intensity (4 km/h, 0 degrees), and two times at heavy exercise intensity (4 km/h, with an inclination of 4 degrees). At each work intensity, one test was done without and one with the ice-vest. A 5 minute rest period preceded each test. For each subject, only one test a day was carried out (Figure 2).

Figure 2. A fully equipped fire fighter walking on a treadmill in the heat (45 °C)

Container tests

The container test has been developed as a standardised test to evaluate protective clothing for fire fighting. It has been described in detail in an earlier report from the Swedish Rescue Services Agency (Räddningsverket 1997). In short, it consists of a 5 minute exposure to extreme radiant heat (5 kW/m^2, 100-340°C). During the exposure, the subject performs a series of standardised body movements such as standing, kneeling and lying on the floor. The test is psychologically and physiologically very stressful (Räddningsverket 1997).

Each subject performed the container test twice on the same day: once without and once with the ice-vest.

BA operation tests

Three subjects took part in the tests in the BA operation house. Each subject performed the test twice on separate days: once without and once with the ice-vest. The BA operation house has three levels. The 2 upper levels are heated (75-200°C). Inside the house, most of the training drill occurs without visibility. The subject has to lift, carry, climb, descend, and crawl in a standard order. Contrary to the container test, the subject can, to some extent, have a free work pace, which results in different performance times. During both container and BA operation tests, the outdoor weather was sunny with temperatures of about 25°C.

Thermal mannequin tests

The total insulation (clo-value, 1 clo=0.155 m^2°C/W) of the fire fighter´s clothing including the non-frozen ice-vest was calculated from the heat losses measured according to ENV 342 (1997) on a thermal manikin (Figure 3a). The heat losses related to the ice-vest only were measured in a condition where ambient temperature was set to be equal to the manikin surface temperature (34 °C). Two additional temperature sensors were inserted into the ice-vest (Figure 3b). These were used to record the temperatures of the inner and outer surface of the ice layer.

a) 

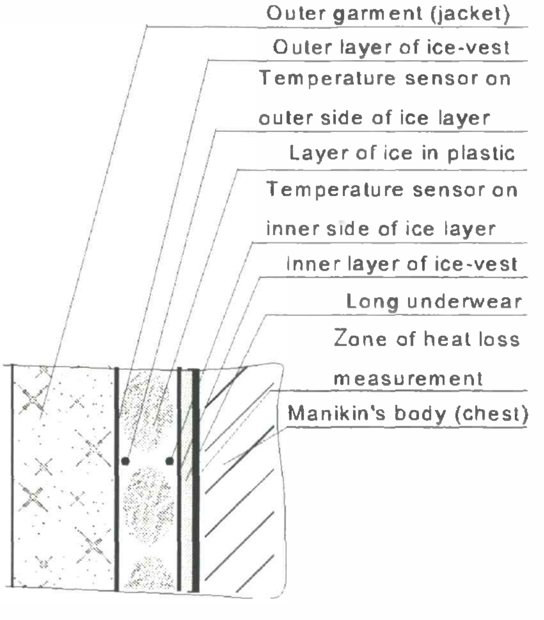
b) 

Figure 3. a) Thermal mannequin TORE walking in full fire fighter´s clothing. b) A schematic drawing showing the location of temperature sensors in the ice-vest near the manikin's chest (see Figure 13).

2.4. Measurements

Rectal temperature was measured only in the laboratory with a thermistor probe (TinyTalk) inserted 10 cm beyond the anal sphincter. Skin temperatures were measured with small thermistors (StowAway) taped to the skin. The sites for skin temperature measurements were forearm, upper arm, chest, back, thigh, and calf. In the container, shoulder skin temperature was also measured.

The thermistors were pre-programmed and recorded temperatures once per minute.

In all tests, heart rate was measured once a minute with the telemetric SportTester system (PolarElectro, Kempele, Finland). Oxygen consumption was measured only during the laboratory tests with a portable gas analysing system (Metamax, Cortex, Germany) twice during each test (10-15 min and 25-30 min). For that purpose the subjects wore a half-face mask during the tests instead of the full-face mask, AGA Divator. During the BA operation tests, the air consumption was recorded from the pressure decreases in the Divator.

Changes in nude body weight during the tests were used to estimate the amount of sweating. In the laboratory, also the amount of evaporated sweat and the amount of sweat in the clothing items was also estimated by weighing (Metler-Toledo, KC 240, ±2 g).

During the tests, the subjects rated their perceived exertion (RPE), thermal sensations, and comfort with standard scales (Table 2).

Table 2. Scales for subjective evaluation of exposure.

Perceived exertion	**Thermal sensation**	**Comfort sensation**
6	-4 Very, very cold	0 Comfortable
7 Very, very easy	-3 Very cold	1 Slightly uncomfortable
8	-2 Cold	2 Uncomfortable
9 Very easy	-1 Slightly cold	3 Very uncomfortable
10	0 Neither cold nor warm	4 Extremely uncomfortable
11 Quite easy	+1 Slightly warm	
12	+2 Warm	
13 Slightly strenuous	+3 Very warm	
14	+4 Very, very warm	
15 Strenuous		
16		
17 Very strenuous		
18		
19 Very, very strenuous		
20		

3. Results

3.1. Laboratory experiments

Oxygen consumption and heart rate

Oxygen consumption was, on average, in the tests with and in those without the ice-vest very similar (Table 3). When expressed in watts, the metabolic heat production varied from 324 to 453 W at the moderate work level, and from 635 to 919 W at the heavy exercise level. The variability in metabolic rate is due to differences in body weight between the subjects.

Table 3. Oxygen consumption (l/min) at the moderate and heavy work levels with and without the ice-vest. The values are means (standard deviations) for 4 subjects.

Work level	Without ice-vest	With ice-vest
Moderate	1.18 (0.06)	1.17 (0.16)
Heavy	2.25 (0.32)	2.23 (0.39)

During the first 15 minutes of walking at the moderate work level the average heart rate was in the tests with and in those without the ice-vest was similar. However, during the last 15 minutes of walking heart rate was lower with the ice-vest. At the end of walking heart rate was ca. 10 beats/min lower with the ice-vest when compared to walking without it (Figure 4).

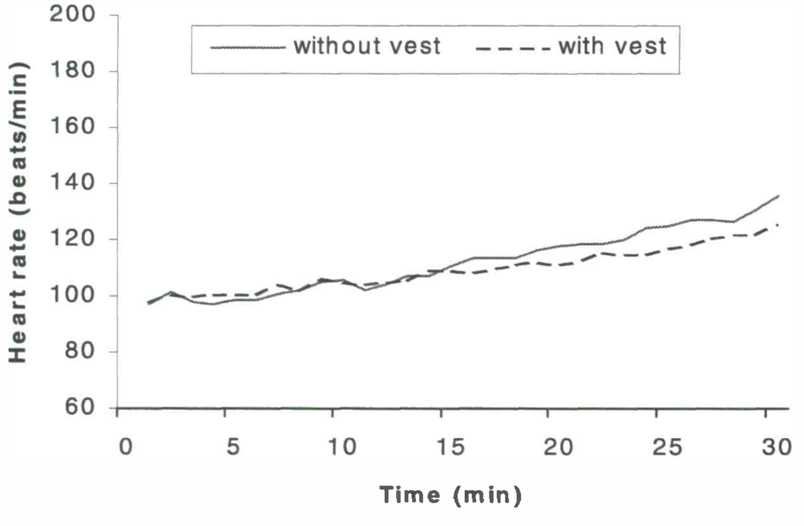


Figure 4. The average heart rate during walking in the heat at the moderate work load with and without the ice-vest.

At the heavy work level heart rate increased continuously during all tests. As shown in figure 5, throughout the walking the average heart rate remained ca. 10 beats/min lower when the ice-vest was worn compared when walking without it.

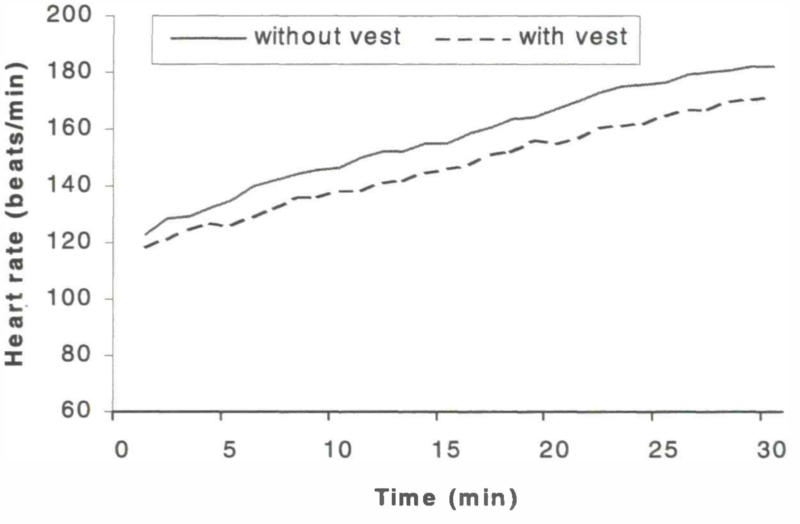


Figure 5. The average hea trate at the heavy work load with and without the ice-vest.

Body temperatures

At both work levels, rectal temperature increased continuously during tests, reaching higher values at the heavy work level (Figures 6 and 7). During both tests, the resting level of average rectal temperature was slightly lower with the ice-vest. Therefore, the increase in rectal temperature was rather similar in tests with and without the ice-vest.

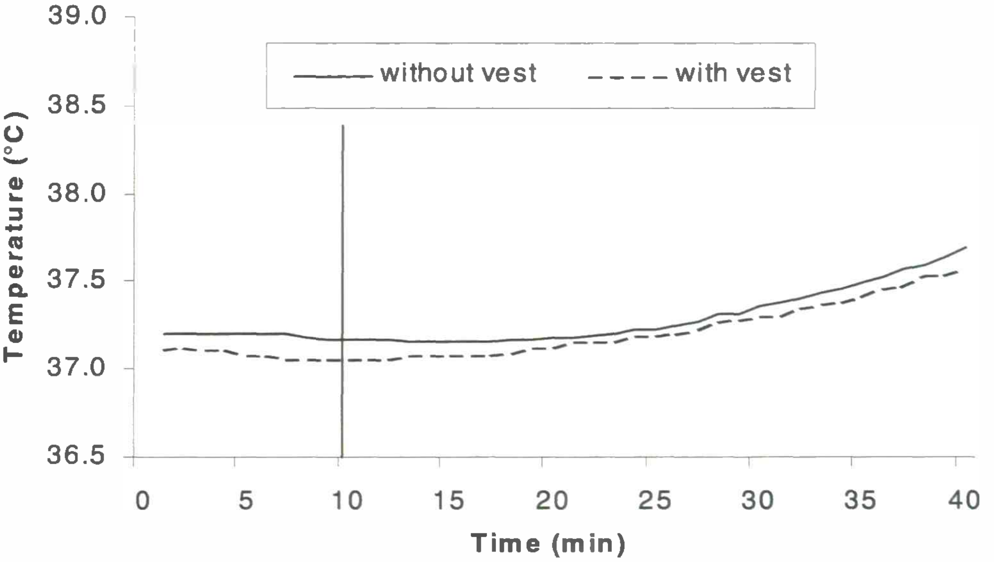


Figure 6. The average rectal temperature during walking at the moderate work load with and without the ice-vest in the heat. The walking started at minute 10.

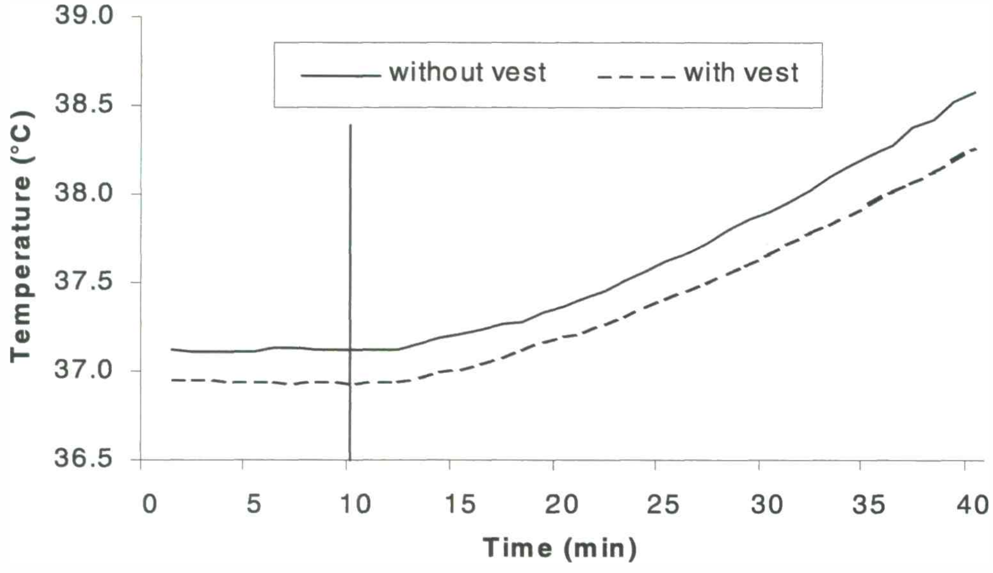


Figure 7. The average rectal temperature during walking in the heat at the heavy work load with and without the ice-vest. The walking started at minute 10.

Skin temperatures during the laboratory tests are shown in figures 8-10. During tests with the ice-vest the back skin temperature (Figure 8) decreased during the first 10-15 minutes over 10°C compared to tests without the vest. Then it gradually started to increase. The decrease in chest skin temperature (Figure 9) with the ice-vest was much less than on the back. In other skin areas the temperature differences were rather small (Figure 10).

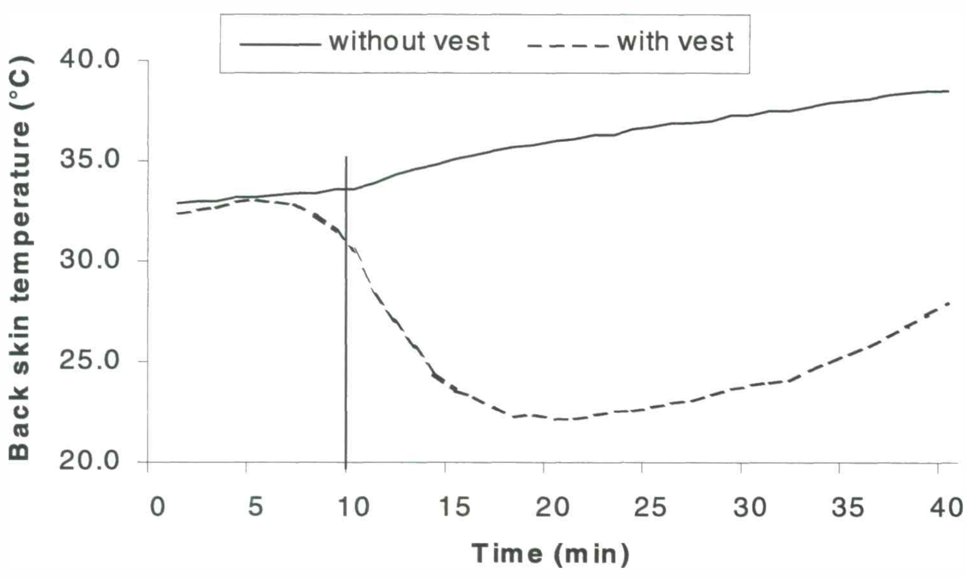


Figure 8. The average back skin temperature during walking in the heat at the heavy work load with and without the ice-vest. The walking started at minute 10.

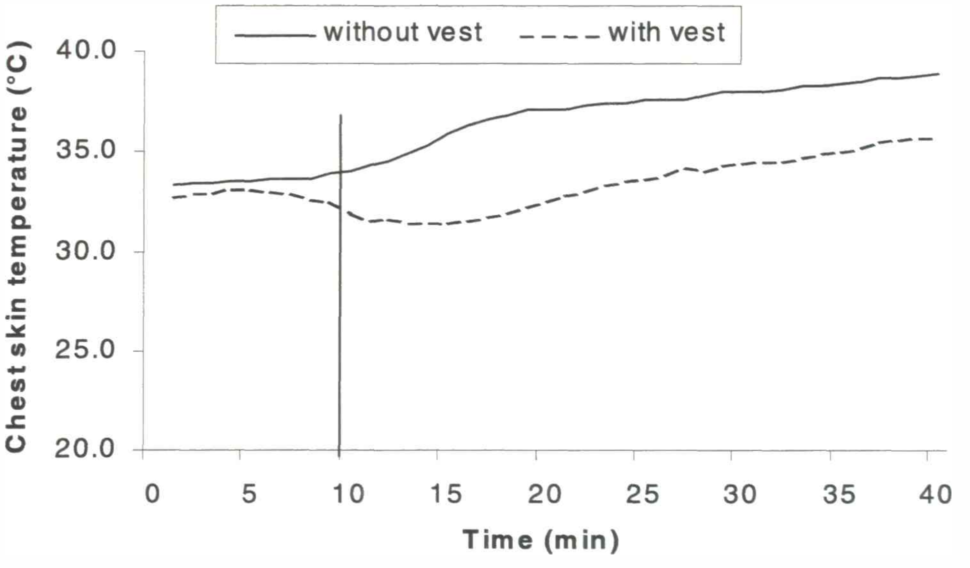


Figure 9. The average chest skin temperature during walking in the heat at the heavy work load with and without the ice-vest. The walking started at minute 10.

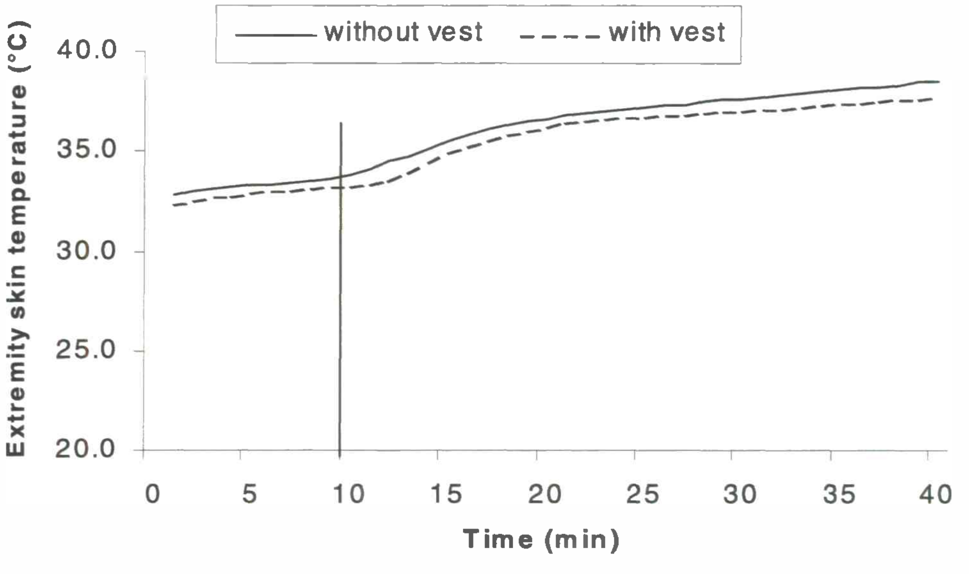


Figure 10. The mean skin temperature outside the ice-vest on extremities (forearm, upper arm, thigh, calf) during walking in the heat at the heavy work load, with and without the ice-vest. The walking started at minute 10.

Sweating

At both work levels the amount of sweating was less with the ice-vest when compared to tests without the ice-vest (Table 4). At the moderate work level the reduction in sweating was 17%, and at the heavy work level 9%.

Table 4. Amount of sweating (g) during the tests with and without the ice-vest at the moderate and heavy work level. The values are the means (standard deviations) for 4 subjects.

Work level	Without ice-vest	With ice-vest
Moderate	443 (70)	369 (84)
Heavy	608 (88)	555 (38)

The amount of sweat in clothing was slightly less when the ice-vest was used (Table 5). Also, the absolute amount of evaporated sweat was slightly less (Table 6). But when expressed in percentage of sweating, the amount of evaporation did not differ between tests with and without the ice-vest (Table 7).

Table 5. Amount of sweat in clothing (g) during tests with and without ice-vest at the moderate and heavy work level. The values are the means (standard deviations) for 4 subjects.

Work level	Without ice-vest	With ice-vest
Moderate	260 (46)	235 (81)
Heavy	398 (111)	360 (46)

Table 6. Amount of evaporated sweat (g) during tests with and without ice-vest at the moderate and heavy work level. The values are the means (standard deviations) for four subjects.

Work level	Without ice-vest	With ice-vest
Moderate	183 (27)	135 (38)
Heavy	210 (32)	195 (16)

Table 7. Amount of evaporated sweat (% of total sweating) during tests with and without the ice-vest at the moderate and heavy work level. The values are the means (standard deviations) for 4 subjects.

Work level	Without ice-vest	With ice-vest
Moderate	41 (2)	38 (13)
Heavy	35 (10)	35 (4)

Subjective responses

At the moderate work level the rate of perceived exertion (RPE) was similar between tests with and without the ice-vest (Table 8). At the heavy work level, RPE was during the first 10 minutes, very similar in the two test conditions, but at 20 and 30 minutes of walking the RPE was ca. 1 unit lower with the ice-vest.

At both work levels, the subjects felt cooler over the whole body when wearing the ice-vest (Table 9). Naturally, the cooler sensations were felt on the chest and back directly under the ice-vest. Also, thermal sensations were slightly lower in other areas with the ice-vest (Table 10), especially at the heavy work level. In addition, the subjects felt more comfortable at the heavy work level when the ice-vest was used compared to when walking without the vest.

Table 8. Rate of perceived exertion during tests with and without the ice-vest at the moderate and heavy work levels, at minutes 10, 20, and 30. The values are the means (standard deviations) for 4 subjects.

Work level	Time	Without ice-vest	With ice-vest
Moderate	10	9.5 (1.9)	10.0 (2.6)
	20	11.5 (3.4)	11.3 (3.1)
	30	12.5 (3.8)	12.8 (2.9)
Heavy	10	13.0 (0.8)	12.8 (1.7)
	20	15.3 (1.0)	14.5 (1.7)
	30	17.3 (1.0)	16.0 (1.3)

Table 9. Thermal sensation over the whole body during tests with and without the ice-vest at the moderate and heavy work level at minutes 10, 20, and 30 minutes. The values are the means (standard deviations) for 4 subjects.

Work level	Time	Without ice-vest	With ice-vest
Moderate	10	1.2 (0.5)	0.0 (2.2)
	20	1.8 (0.5)	0.3 (1.7)
	30	2.0 (0.0)	1.3 (0.5)
Heavy	10	1.5 (0.6)	0.3 (1.7)
	20	2.0 (0.0)	1.0 (0.8)
	30	3.0 (0.0)	1.5 (1.0)

Table 10. Thermal sensation in different body parts during tests with and without the ice-vest at the moderate and heavy work levels at the end of 30 minutes exposure. The values are the means (standard deviations) for 4 subjects.

Work level	Skin area	Without ice-vest	With ice-vest
Moderate	Chest	2.0 (0.0)	0.2 (0.5)
	Back	2.0 (0.0)	0.0 (0.8)
	Face	2.0 (0.0)	1.7 (0.8)
	Hands	2.2 (0.5)	2.0 (0.0)
	Feet	2.0 (0.8)	2.0 (0.0)
Heavy	Chest	2.7 (0.5)	0.2 (1.0)
	Back	2.7 (0.5)	0.0 (0.8)
	Face	2.5 (1.0)	2.2 (0.5)
	Hands	2.7 (0.5)	2.5 (0.6)
	Feet	3.0 (0.8)	2.2 (0.5)

3.2. Container-study

Heart rate

Even the duration of exposure in the container was only 5 minutes, the high radiant heat stress produced relatively high heart rates in subjects (Table 11). Heart rates in tests with and without the ice-vest was rather similar. Only at the end of exposure was the average heart rate somewhat lower with the ice-vest, but the variability between subjects was also higher.

Table 11. Heart rate (beats/min) during the container-test with and without the ice-vest. The values are the means (standard deviations) for 4 subjects.

Exposure time (min)	Without ice-vest	With ice-vest
0	96 (2)	94 (2)
1	123 (5)	123 (5)
2	126 (10)	122 (8)
3	133 (4)	137 (12)
4	139 (10)	136 (11)
5	141 (11)	131 (8)

Skin temperatures

The highest skin temperatures were observed on the forearm reaching close to the pain level (45°C). Also, upper arm and shoulder skin temperatures exceeded 40°C at the end of exposure.

With the ice-vest skin temperature was ca. 5°C lower on the chest and 15°C lower on the back when compared to tests without the ice-vest. On the calf and thigh, the skin temperature in the two tests, was similar. However, on the upper arm, shoulder, and the forearm skin temperatures were slightly higher with the ice-vest (Table 12).

Table 12. Skin temperatures (°C)in different body areas at the end of the container-test with and without the ice-vest. The values are the means (standard deviations) for 4 subjects.

Skin area	Without ice-vest	With ice-vest
Back	39.6 (1.6)	25.1 (1.8)
Chest	38.6 (1.5)	33.9 (3.1)
Forearm	44.1 (1.3)	44.5 (2.7)
Upper arm	41.9 (1.6)	42.8 (1.3)
Shoulder	42.1 (1.3)	42.8 (1.5)
Thigh	38.5 (2.7)	38.3 (2.3)
Calf	43.0 (2.0)	42.2 (5.0)

Sweating

In 2 subjects the amount of sweating was lower and in 2 subjects the sweating was higher with the ice-vest when compared to tests without it. On average, the sweating rate was slightly lower with the ice-vest (154 ± 18 g) than without it (164 ± 55 g).

Subjective responses

The RPE was not different in the container-tests with or without the ice-vest. The values were 13.7 (1.5) and 13.5 (3.0) for tests with and without the ice-vest, respectively.

When the ice-vest was worn, the subjects felt cooler over whole body

(Table 13). In areas other than the chest and the back the differences in thermal sensation were small between the two test conditions.

Table 13. Thermal sensation at the end of the container-test with and without the ice-vest. The values are the means (standard deviations) for 4 subjects.

Skin area	Without ice-vest	With ice-vest
Whole body	2.5 (0.6)	1.8 (1.5)
Chest	2.0 (0.8)	-0.3 (1.7)
Back	2.0 (0.8)	-0.3 (1.7)
Face	3.0 (0.8)	2.8 (1.3)
Hands	2.8 (1.3)	2.5 (1.9)
Feet	2.5 (0.6)	2.0 (0.8)
Arms	3.0 (0.8)	3.3 (1.0)
Legs	2.8 (1.0)	3.0 (0.8)

3.3. Test in the BA operations house

Work time, air consumption, and sweat rate

Three of the subjects participated in the tests in the BA operations house. All subjects performed the task faster when the ice- vest was worn (Table 14). Air consumption was measured only in 2 subjects, and it was slightly lower with the ice-vest. The level of air consumption corresponded to oxygen consumption level of over 3 l/min indicating very high energy expenditure and metabolic heat production level (over 1000 W) during BA use.

In 2 subjects, the sweat rate was lower with the ice-vest, and in one subject slightly higher than without the ice-vest.

Table 14. Work time, air consumption, and amount of sweating during the BA operations test with and without the ice-vest.

	Without ice-vest			With ice-vest		
Subject	1	2	3	1	2	3
Work time (min)	11	15	16	10	12	15
Sweat rate (g)	292	-	256	235	227	288
Air consumption (l/min)	-	109	95	-	100	91

Heart rate and subjective responses

Subject 3 had about the same work time during the BA operations test with and without the ice-vest, but his average heart rate during the task was 8 beats/min lower with the ice-vest (Figure 11). His highest heart was also 7 beats/min lower when the ice vest was worn (197 vs. 190 beats/min).

Subject 2 performed the BA operations 3 minutes faster with the ice-vest, but still his heart rate was, on average 6 beats/min lower with the ice-vest. Also, his highest heart rate during the task was 11 beats/min lower with the ice-vest (180 vs. 191 beats/min).

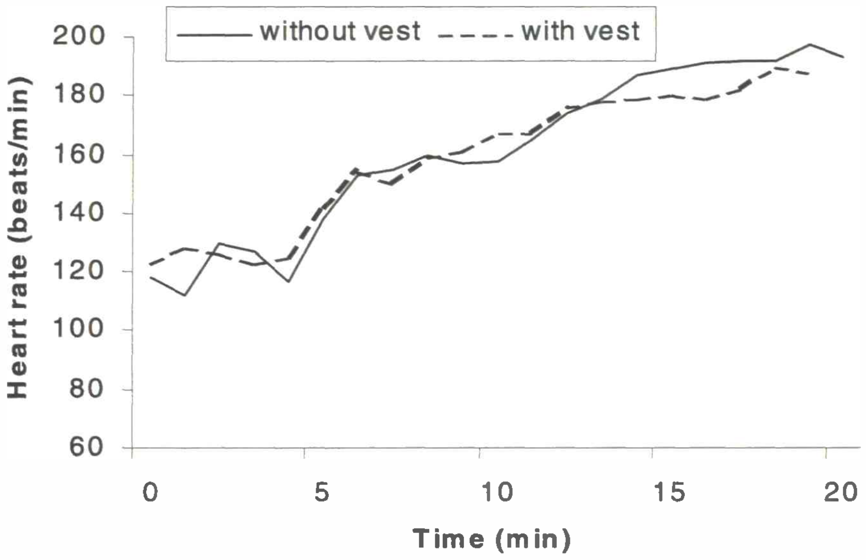


Figure 11. Heart rate of subject 3 during the BA operations with and without the ice-vest. With the ice-vest the work time was 1 minute quicker than without it.

All subjects felt that the BA operations test was less strenuous when the ice-vest was worn. The RPE-values were 16, 15, and 18 without the ice-vest and 15, 12, and 16 with the ice-vest for subjects 1,2, and 3, respectively. With the ice-vest the subjects felt slightly cooler in all skin areas except in the hands (Table 15)

Table 15. Thermal sensation in different skin areas after the BA operations with and without the ice-vest. The values are the means (standard deviations) for 3 subjects.

Skin area	Without ice-vest	With ice-vest
Whole body	1.7 (0.6)	1.0 (0.0)
Chest	1.3 (0.6)	1.0 (0.0)
Back	2.0 (0.0)	1.0 (0.0)
Face	1.0 (1.0)	0.7 (1.2)
Hands	1.3 (0.6)	1.3 (1.2)
Feet	1.3 (0.6)	1.0 (1.0)

3.4. Tests with the thermal mannequin

The thermal insulation of the fire fighter clothing with non-frozen ice-vest was 2.15 clo. With frozen ice-vest the heat losses were higher than with non-frozen ice-vest, and they changed over the time according to the melting process and temperature change in the vest. The heat losses related only to the frozen ice-vest were determined at 34 °C (Figure 12). The values for the beginning of the test that were uncertain due to the initial computer regulation were extrapolated with the help of polynomial regression. According to the data the mean heat losses from the whole body at particular environmental conditions due to the ice-vest were 26 W/m^2 (Table 16). However, for the torso they were 74 W/m^2. Power in Watts shows that the rest of the body stands for less than 11 % of heat losses.

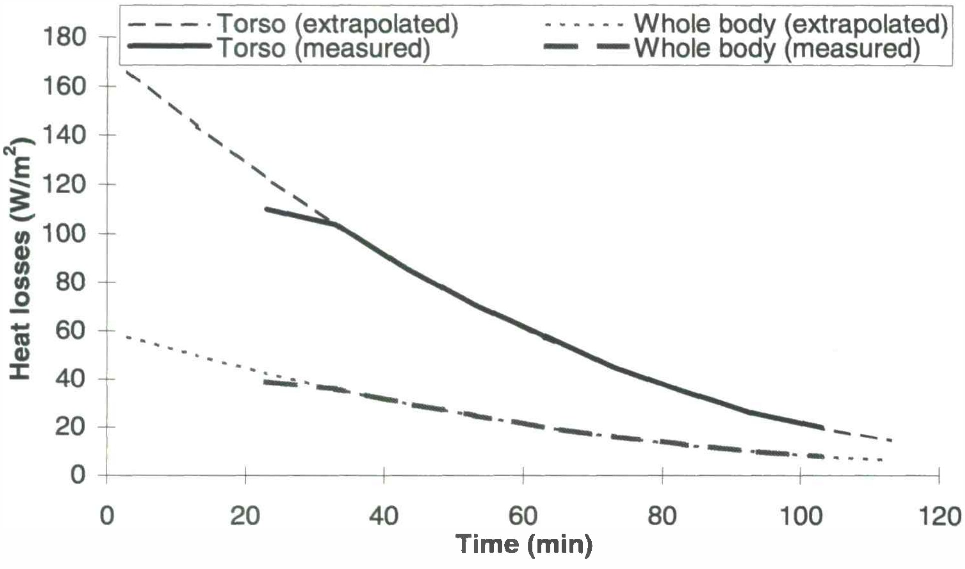


Figure 12. Change in heat losses measured on the thermal manikin with the ice-vest at 34 °C for the whole manikin body surface and for torso only.

Table 16. Mean power and total energy to the whole manikin body and torso only, based on extrapolated measurements with the ice-vest at 34 °C.

	Torso	Whole body
Mean power (W/m^2)	74	26
Mean power (W)	42	47
Energy (kJ)	272	301

The heated manikin test identified clearly the three phases of cooling provided by the ice-vest (Figure 13). The theoretical amount of heat required for the three phases is calculated and presented in Table 17. The warming of 1 kg solid ice from –20 to 0 °C takes about 5 minutes and needs 38.4 kJ corresponding to an average power consumption of 128 W. The melting of the ice takes about 40-45 minutes and needs about 334 kJ. The subsequent warming of the water to 34 °C takes an hour or more with much less energy consumption 142 kJ . Not all of this power is useful for body cooling since heat is taken up from the surrounding air as well. The useful energy available for body cooling was 58 % (301/514 kJoule).

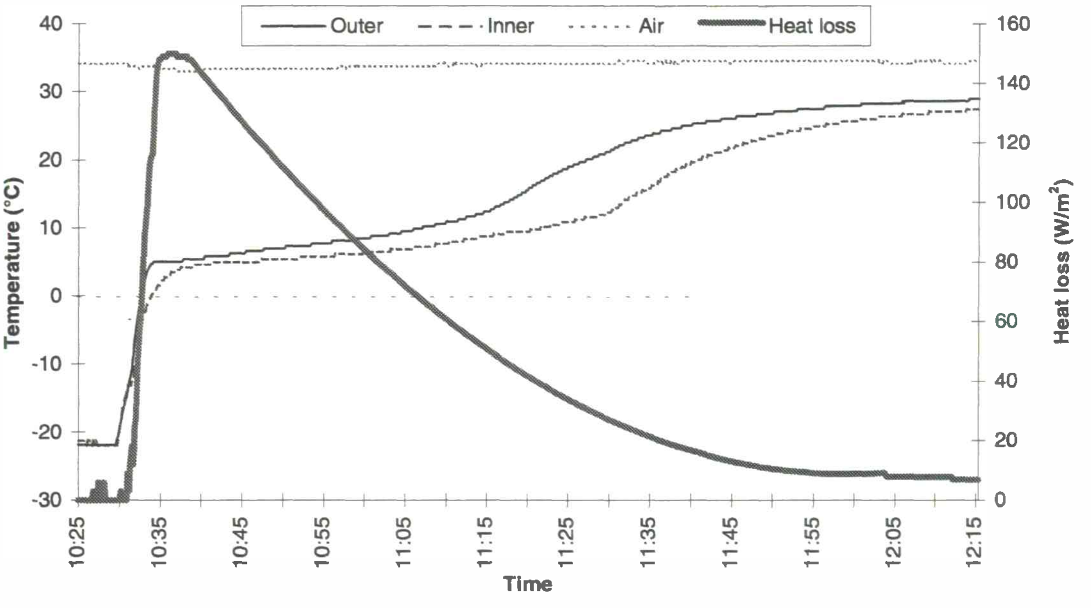


Figure 13. Temperature readings from the inner and outer surfaces of the ice layer (see Figure 3b) in comparison with air temperature (34 °C) and heat losses from the manikin's chest.

4. Discussion

The present series of studies examined the effectiveness of a 1kg ice-vest for body cooling in fire fighters work. The laboratory study was done in a controlled way so that the only changing variable was the exposure to the cold ice-vest on the torso which was compared to tests without the ice-vest. The results showed that the vest did not increase the metabolic rate, and did not affect skin temperatures outside the vest. Also, rectal temperature was not influenced by the ice-vest during the tests. Probably, in these kind of tests the metabolic rate very strongly dominates the rectal temperature response. Physiologically it means that the drive for thermoregulation from the deep thermoreceptors was the same in the 2 different test conditions.

Tabell 17. Calculation of the theoretical energy yield associated with the heating and phase change of the ice in the vest.

Phase	time in minutes	kJoule	%	power in W
1 kg ice from –20 to 0 °C	5	38	7	128
melting of 1 kg of ice	40-45	334	65	139
1 kg of ice from 0 to 34 °C	more than 60	142	28	40

The main findings were that heart rate was 10 beats/min lower, sweating was 13% lower, and subjective sensation of physical effort and warmth were lower when the work was done with the ice-vest. The effects were seen especially more clearly at the heavy work level which was more close to the real demands of BA operations tasks.

The results from tests in the container and in the BA operations house largely supported the laboratory results.

Kamon et al. (1986) have shown that the cooling effect of frozen water-garments is a linear function of the amount of ice. In their study, they used a 3.8 kg ice-vest, and found that sweating was reduced by about 50% which compares rather well to our findings (3.8 x 13%). Also, they observed very clear reductions in body temperatures and heart rate, and large increases in tolerance times. According to their calculations, 1 kg ice-vest gives about a 10% improvement in performance time during work in the heat. Based on the heart rate data, we can also see that reaching the same heart rate (for example 160 beats/min) with the ice-vest as without it takes about 5 minutes, which in 30 minutes work period comes close to 10% increase in possible tolerance time. Even if small amoumts of ice were used in our stdies it needs to be pointed out that fire-fighters could extend their work time in extremely demanding BA operation tasks. Actually, during the BA operatioins test the average performance time was reduced by 12%.

It can be concluded that the light-weight ice vest clearly reduces circulatory, thermal, and subjective strain during demanding BA operation tasks. The added benefit is 10-15%.

Slightly more than 50 % of the energy was available for body cooling according to the manikin test. This figure is dependent on type, construction and arrangement of the layers on both sides of the vest. The figure may be increased by reducing layers to skin and/or adding insulative (or reflective?) layer outside the vest or by more ice. Such arrangements, however need to consider possible effects on thermal sensation, restriction of movements and weight.

Future development of the ice-vest should focus on the following:

1) What effects would the increase in the amount of ice up to for example 1.5 kg have?
2) What is the effect of the ice-vest during recovery between work periods?
3) What is the effect of the ice-vest during consecutive work periods?
4) Can the insulation of the ice-vest towards ambient air be improved on the chest area?

References

ENV 342 (1997) Protective clothing. Ensembles for protection against cold. European Standard, European Committee for Standardization, Brussels

Kamon E, Kenney WL, Deno NS, Soto KI, Carpenter AJ (1986) Readdressing personal body cooling with ice. Am Ind Hyg Assoc J 47: 293-298.

Muir IH, Bishop PA, Ray P (1999) Effects of novel ice-cooling technique on work in protective clothing at 28°C, 23°C, and 18°C WBGTs. Am Ind Hyg Assoc J 60: 96-104.

Räddningsverket (1997) Belastningsstudier av rökdykning vid extrem strålningsvärme. Räddninsverket, Karlstad.

cue Services Agency, 651 80 Karlstad, Sw
0 00, fax +46 54 10 28 89. Internet http://w
Order number P21-309/99. Phone +46 54 10 42 86, fax +46 54
ISBN 91-7253-036-7