First Line Technology
Technical White Paper

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Integrated Approach to Reducing the Effects of Heat Stress in Firefighters

1. Abstract

Firefighters face heat stress on a regular basis. By combining the use of advanced phase change cooling vests as a prehab protocol with immersion cooling equipment during rehab, the debilitating effects of heat stress can be diminished, reducing deaths, injuries, and rehab times.

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2. Preface

Your turnout gear protects your skin from flames.

But turnout gear does little or nothing to protect you from the debilitating effects of heat stress.

In fact, the very qualities that make it so effective in stopping skin damage make it difficult to dissipate heat buildup from both the fire environment as well as the ambient temperature and humidity.
The National Fire Administration cautions that wearing protective gear increases body temperature by an average of ten degrees Fahrenheit.

The National Fire Protection Association's (NFPA) Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises, NFPA 1584, as well as The U.S. Fire Administration's USFA) Guide, Emergency Incident Rehabilitation set out excellent guidelines for determining when conditions could lead to heat stress, recognizing the symptoms of heat stress, and providing effective rehab protocols.

However, new technologies and products may enable emergency response organizations to reduce both the effects of heat stress and the amount of rehab time needed by firefighters.

By combining the use of professional grade personal cooling equipment as a "pre-hab" protocol with access to an Immersion Cooling Equipment system, firefighters can reduce the debilitating effects of heat stress and the time needed for rehab to reduce overheated body core temperature.

3. Factors Contributing to Heat Stress

To better understand the risks and impact of heat stress we need to examine the factors that are major contributors to creating the conditions that cause the problem.

3.1 Environmental Temperature

The most obvious factor influencing heat stress is the environmental temperature, which can be defined as a measure of how hot the material or objects surrounding the body are. This is sometimes also referred to as the ambient temperature. Environmental temperature is measured in degrees (°) in reference to standard temperature scales such as Fahrenheit (°F) or Celsius (°C).

3.2 Thermal Radiation

Another important factor is thermal radiation, which occurs between objects of unlike temperature via invisible infrared rays and is related only to the difference in temperature between the objects, such as firefighters' protective clothing and a flame front. Measurement of thermal radiation is made of the rate of heat transferred per unit area per unit time and is expressed in watts per square centimeter (watts/cm2) or calories per square centimeter per second (cal/cm2/sec), where 1.0 watts/cm2 equals approximately 0.24 cal/cm2/sec. Thermal radiation can transfer heat from hot objects to the body or from the body to cold objects depending upon object temperatures. Research suggests that thermal radiation is the most important component of heat exposure during actual interior structural firefighting.

3.3 Conduction

Heat also can be transferred between objects of different temperatures by conduction. Transfer of heat by conduction requires direct contact between materials. Examples relevant to firefighters include kneeling or crawling on a hot or cold surface or touching hot or cold objects. It must be noted that the heat transferring ability of materials can vary greatly. For example, water and steam transfer heat many times faster than air; metals transfer heat faster than nonmetals.

3.4 Convection

Another component of heat transfer is by convection. If the conducting medium surrounding the body, such as air or water, is moving, significantly more heat transfer can occur than in still conditions.

A commonly used example of convective heat transfer is the wind chill Index. The wind chill Index is a system that attempts to express the cooling effect of air movement on humans exposed to cold temperatures in terms of equivalent wind chill temperatures.

For example, for an environmental temperature of 32 °F (0 °C) with a wind velocity of 40 miles/hour, the equivalent wind chill temperature is 2 °F (-16.7 °C). This means that although the skin temperature does not fall below the environmental temperature, the body loses heat at the same rate as it would at the equivalent wind chill temperature.

A similar effect occurs at high environmental temperatures. Above about 100 °F (37.8 °C), air movement above 10 mph can significantly increase heat transfer to the body. In general, this is the concept by which a convection oven operates and is the reason this type of oven cooks food much more quickly than a standard oven.

It should be noted that regardless of the type of heat transfer that is occurring, heat always travels from the warmer object to the colder object. It is physically impossible to transfer "cold" to a warmer object. The warmer object always loses heat as it transfers some of its heat to the colder object.

3.5 Relative Humidity

Relative humidity is also a contributory factor because it determines the rate of heat transfer by evaporation. When liquid water changes to steam or water vapor, heat is dissipated. Relevant examples include the cooling that occurs from the evaporation of sweat and the vaporization of water by thermal radiation from a fire when a fog nozzle is in service. The higher the relative humidity, the less evaporation can occur to remove heat. Relative humidity is measured in terms of the amount of humidity contained in the air relative to the maximum amount that can be contained at that temperature.

For example, if the air temperature is 60 °F (15.6 °C) and the relative humidity is 50 percent, the air contains one-half of the total water vapor that it can hold at that temperature.

The Steadman Apparent Temperature Index expresses the combined effect of environmental temperature and humidity, sometimes referred to as the humiture, on the body (Figure 1) **(Appendix A)**. It should be noted that exposure to direct sunlight will also increase apparent temperature by about 10 °F (-12.2 °C). The apparent temperature is determined in a manner similar to wind chill. For example, with an environmental temperature of 90 °F (32.2 °C) and a relative humidity of 90 percent, the apparent temperature is 122 °F (50 °C). Thus, the firefighter exposed to these conditions will experience discomfort similar to that associated with an environmental temperature of 122 °F at low humidity.[1]

It is important to remember that the above descriptions identify climatic conditions, not areas or climate types. Many areas experience two or more climatic conditions on a regular basis depending on the short-term weather cycles and the day-night or seasonal variations. Additionally, unusual conditions of weather or geography can prevail that will cause an area to experience conditions far more severe than normal. Since the firefighter is required to function efficiently at all times, it is important that equipment and training appropriate for the most severe conditions is provided.[2]

In evaluating the possibility of heat stress using the chart above, remember to add 10° Fahrenheit if the individual is wearing protective gear, and another 10° Fahrenheit if the individual is working in direct sunlight.

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[1] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pgs. 22 and 23.

[2] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pgs. 24 and 25.

A person working in direct sunlight, and in an environment with a dry bulb temperature of 100° Fahrenheit, and humidity of 66% wearing protective gear would experience a relative temperature of 139° Fahrenheit.

4. Thermal Conditions When Engaged in Fire Combat

Now that we have examined the many factors that contribute to heat stress for the firefighter, it is time to confront the reality of the range of thermal conditions faced by firefighters when actively engaged in fire suppression or fire rescue activities.

Research by the National Bureau of Standards (NBS) they would later change their name to the National Institute of Standards and Technology or NIST) and the U.S. Fire Administration (USFA) examined the fire environment both in simulated laboratory fires and by placing thermocouples and heat-sensitive tape on firefighters while they were engaged in interior structural firefighting. In general, four conditions are faced by structural firefighters.

Class I conditions occur when a small fire is burning in a room. Environmental temperatures up to 140 °F (60 °C) and thermal radiation up to 0.05 watts/cm2 are encountered for up to 30 minutes (Figure 2) **(Appendix B)**.

Class II conditions occur in a room that has been totally involved after the fire has been "knocked down." In this case, environmental temperatures from 105 to 203 °F (40.6 °C to 95 °C) and thermal radiation from 0.050 to 0.100 watts/cm2 are encountered for up to 15 minutes.

Class III conditions exist in a room that is totally involved. Environmental temperatures from 204 to 482 °F (95.6 °C to 250 °C) and thermal radiation from 0.175-4.2 watts/cm2 are encountered for up to 5 minutes.

Class IV conditions occur during a flash-over or backdraft, where environmental temperatures from 483 to 1,500°F (250.6 to 815.6 °C) and thermal radiation from 0.175-4.2 watts/cm2 are encountered for about 10 seconds.[3]

5. Physiological Effects of Heat Stress

Humans are "warm-blooded" animals, which means that regardless of external conditions, our bodies attempt to maintain a nearly constant internal core (head, neck, and internal

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[3]*Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pgs. 25 and 26.

organs of the torso) temperature of approximately 98.6 °F (37 °C). The figure of 98.6 °F is an average among all humans and it is not uncommon for an individual's "normal" body temperature to be as much as 2 °F above or below this figure.

The body, like any machine, burns fuel and produces heat as a byproduct of producing energy from food. To maintain body temperature within safe limits, body functions are regulated to conserve or dissipate heat, depending on the external thermal environment. For a nude resting human, the range of environmental temperature for which no physiological compensation is needed is only about 6 °F (14.4 °C). When exposed to air temperatures lower than about 80 °F (26.7 °C), body heat must be conserved; for temperatures in excess of about 86 °F (30 °C), body heat must he dissipated.

Physiological body temperature regulation is accomplished mainly by automatic responses controlled by the brain, which monitors body temperature by continuously measuring skin temperature and the temperature of the circulating blood. When the brain determines that body temperature has deviated from normal, temperature control mechanisms are activated. For heat stress these include dilation of the blood vessels in the skin and extremities (arms and legs), increase in heart and respiratory rates, and initiation of the sweating mechanism. When these mechanisms are not able to cope with the thermal stress imposed upon the body, the body temperature deviates from normal.[4]

While some of the effects of heat stress are minor such as Miliaria or "prickly heat", Heat Syncope, and Heat Cramps, others are more debilitating and dangerous.

5.1 Heat Exhaustion

Firefighters who engage in structural and wildland fire suppression without adequate rehabilitation may eventually fall victim to heat exhaustion. The condition is also common in hazardous materials operations in which firefighters wear encapsulating suits.

Heat exhaustion occurs when excessive sweat loss and inadequate oral hydration cause depletion of the body's fluid volume. This results in peripheral vascular collapse and hypoperfusion of the body's organs. While heat exhaustion often is related to excessive dehydration, it can also occur from fatigue and overheating alone.

[4] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pg. 44.

Symptoms of heat exhaustion many include any of the following:

- Fainting;
- Profuse sweating;
- Headache;
- Tingling sensations in the extremities;
- Pallor (ashen color of the face);
- Dyspnea (shortness of breath);
- Nausea
- Vomiting
-

Heat cramps may or may not be present with heat exhaustion. Trembling, weakness, and poor coordination, often coupled with disorientation and/or momentary loss of consciousness also may be noted. National Institute for Occupational Safety and Health (NIOSH) studies stress that impairment of judgment may occur well before other symptoms are noted.

Physical examination of a possible heat exhaustion victim typically will reveal a mild to severe peripheral circulatory collapse with pale, moist, cool skin and a rapid (100 to 200 beats/minute), thready pulse. Systolic blood pressure generally will have been quite elevated (130 mm Hg or higher) prior to onset of heat exhaustion, followed by a rapid drop and commonly reaches the normal range by the time of examination. However, the pulse pressure (the difference between systolic and diastolic blood pressure) usually will remain decreased and this is a clue indicating possible heat exhaustion at the time of physical examination. The oral temperature may be subnormal due to hyperventilation, or slightly elevated, but the rectal temperature is usually slightly elevated. It is not uncommon in heat exhaustion cases to find rectal temperatures in the range of 99 to 104 °F (37.2 to 40 °C) depending on the type and duration of physical activity prior to onset.

If the condition is unrecognized and untreated, a firefighter with heat exhaustion may develop more classic signs of shock or hypoperfusion. These signs include increased heart rate, increased respiratory rate, and eventually, reduced blood pressure. If allowed to progress the firefighter may evolve into a deadly heat stroke situation.[5]

5.2 Heat Stroke

Heat stroke is the most severe of the three types of heat-related injuries. Heat stroke victims have a high probability of permanent disability or death as a result of this injury. Heat stroke results when the body's temperature regulating and cooling mechanisms are no longer functional. Immediately prior to onset of heat stroke, fainting,

[5] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pgs. 52 and 53.

disorientation, excessive fatigue, and other symptoms of heat exhaustion may be present. Onset of heat stroke may be rapid with sudden delirium, loss of consciousness, and convulsions occurring. Typically, the skin is hot, flushed, and dry, although the skin may be wet and clammy in later stages of the condition when shock may be present. Any emergency personnel found in a hot environment with altered mental status and skin that is hot and dry, or moist to the touch, should be presumed to have a life-threatening heat-related emergency.

Rectal temperatures associated with heat stroke are elevated, frequently in excess of 106 °F. A special high-temperature reading rectal thermometer may be needed to document actual internal core temperature. A rectal temperature of 108 °F is not uncommon and indicates a poor prognosis. Pulse is full and rapid, while the systolic blood pressure may be normal or elevated and the diastolic pressure may be depressed to 60mm Hg or lower. Respirations are rapid and deep. As a patient's condition worsens, symptoms of shock including low blood pressure, rapid pulse, and cyanosis occur. Incontinence, vomiting, kidney failure, pulmonary edema, and cardiac arrest may follow.

Even if effective treatment is initiated and the patient survives the initial episode, severe relapses can occur for several days, while rectal temperatures of 102 to 103°F (33 to 39°C) will persist along with disorientation, delirium, and headache. If effective treatment was not initiated, brain cell damage caused by a high temperature may persist even if the patient survives. It is important to note that even after apparent recovery, temperature regulation may be impaired for some time, perhaps permanently in severe cases. Research by the U.S. Army indicates that about 10 percent of surviving heat stroke patients have long-term reduced tolerance to heat following their initial injury.[6]

6. Rehab SOP

Both NFPA 1584 and FA 314 set out SOP guidelines for incident and training ground rehabilitation practices. These include both self-rehab and formal rehab procedures.

In most cases the self-rehab process will contain two simple components: taking a break and drinking fluids to replenish personal hydration levels. During training activities self-rehab is often built into the rotation process for firefighters working their way through a series of training ground evolutions. After every so many evolutions or on a time-measured basis, the firefighters will report to a rest area for a prescribed period of time. While at the rest area the firefighters will doff appropriate protective clothing, sit down, and drink fluids that are provided at that location. These may either be water or sport beverage-type fluids. At a minimum, firefighters should drink 2 to 4 ounces of an appropriate beverage after every 20

[6] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pgs. 53 and 54.

minutes of training or emergency scene activities. Greater amounts may be required depending on the activity level, atmospheric conditions, and the needs of each individual firefighter.[7]

The formal rehab process includes performing an initial assessment of their medical condition and well-being. Then they shed their protective gear, rehydrate and rest.

7. An Alternative Approach to Rehab SOP

The current practices for incident and training ground rehab are fine as far as they go. But new improvements in personal cooling technology offer approaches that can reduce the dangerous and debilitating effects of heat stress and reduce the time firefighters need to spend in rehab.

Instead of waiting until after the firefighter experiences heat stress, a new generation of phase change cooling gear allows the firefighter to "pre-hab" by extracting excess heat from the body from the time they don their turnout gear, or when they enter the fire ground.

The salt-based phase change packs used in advanced cooling vests such as the PhaseCore vests manufactured by First Line Technology are a significant improvement over ice vests and gel packs.

Ice vests can chill the wearer's surface temperature and cause vasoconstriction which increases heart rate and blood pressure. Prolonged vasoconstriction can decrease athletic performance and unnecessarily tax the operator's system.

Instead of chilling the wearer, the salt-based phase change packs absorb excess body heat, reducing the level of heat stress the wearer experiences.

The following graphs represent data collected from The National Institute for Nuclear, Chemical and Biological Protection of the Czech Republic (SUJCHBO), which is a public research institution established by the State Office for Nuclear Safety in 2016.

The data collected shows a comparison between the same user with and without a PhaseCore cooling vests while exercising on a Proband Test on a treadmill going (4km/h; 10° slope) in Tychem F clothing in an environment of 40°C while their heart rate and rectal temperature was monitored.

The physiological data shows that when a participant used a PhaseCore Cooling Vest they could exercise for 20+ minutes longer without becoming overheated and extremely elevating

[7] *Emergency incident rehabilitation*. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pg. 114

their heart rate (Figure 3, Figure 4) **(Appendix C)**. When not using a cooling vest – the participant hit their upper core temperature because of their inefficiency to cool themselves properly. PhaseCore vests assist regulating both HR and Core Temp while in PPE.

The salt-based phase change packs can continue to absorb excess body heat for up to four hours. Reducing the amount of heat stress means the firefighter can rehab in less time during operations and may suffer fewer long-term effects.

8. Effects of Extremity Cooling in Reducing Heat Stress

Once the firefighter enters the rehab area, the effects of heat stress can be further reduced quickly through use of arm immersion cooling utilizing ad hoc solutions such as buckets or coolers full of ice water, or a purpose-built solution such as the Immersion Cooling Equipment (ICE) System manufactured by First Line Technology.

In a 2015 study conducted by the U. S. Army, "Impact of Arm Immersion Cooling During Ranger Training on Exertional Heat Illness and Treatment Costs", the authors described the limitations of some of the personal cooling apparatus that was previously used.

Use of existing commercially available cooling solutions in military training or certain occupational settings presents particular challenges such as power requirements, transport and set up logistics, which limits their feasibility. Furthermore, these commercial systems are often costly, limited in their cooling power and the number of individuals that a single system can treat. Extremity immersion, specifically Arm Immersion Cooling (AIC), in cool or cold water has been demonstrated to be an effective body cooling method.[8]

In the study cited above, the authors utilized a purpose-built solution similar to the Immersion Cooling Equipment (ICE) System. The ICE system folds flat, sets up quickly, and allows up to six individuals at a time to insert their arms for rapid cooling. Unlike buckets and coolers that are used as ad hoc solutions, the ICE system is at a convenient height and can also be used to fully immerse a six-foot individual in the event of life-threatening heat stress.

The study found that units using the arm immersion cooling system had fewer cases of serious heat stress related illnesses, and those that did occur had fewer days of lost work and significantly lower medical treatment costs.

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[8] Degroot, D. W., Kenefick, R. W., & Sawka, M. N. (2015). Impact of Arm Immersion Cooling During Ranger Training on Exertional Heat Illness and Treatment Costs. Military Medicine,180(11), 1178-1183.

9. Conclusions

Firefighters face heat stress on a regular basis. By combining the use of advanced phase change cooling vests as a prehab protocol with immersion cooling equipment during rehab, the debilitating effects of heat stress can be diminished, reducing deaths, injuries, and rehab times.

For those interested in PhaseCore cooling technologies, please contact +1.703.955.7510 or email phasecore@firstlinetech.com.

Appendix A

Dry Bulb Temperature (°F)	Relative Humidity (percent)									
68	61	62	63	64	65	66	67	68	69	70
70	63	65	66	67	68	69	70	71	72	72
72	66	67	68	69	70	71	72	73	74	75
74	68	69	70	71	72	73	74	75	76	77
76	71	72	73	74	75	76	77	78	79	80
78	74	75	76	77	77	78	79	80	81	83
80	76	77	78	79	80	81	82	83	85	87
82	78	79	80	81	82	83	85	87	89	92
84	79	80	81	83	84	86	88	90	93	97
86	81	82	83	85	86	89	91	95	99	105
88	82	84	85	86	89	91	95	99	105	113
90	84	85	87	89	92	95	99	104	112	
92	85	87	89	92	95	99	104	112		
94	87	89	91	95	98	103	110	120		
96	88	91	94	97	102	108	117			
98	90	93	96	100	105	113				
100	92	95	98	103	109	119				
102	93	96	100	106	114					
104	95	98	103	110	120					
106	96	100	106	114						
108	97	102	109	118						
110	99	104	112	122						
112	100	106	115							
114	102	108	118							

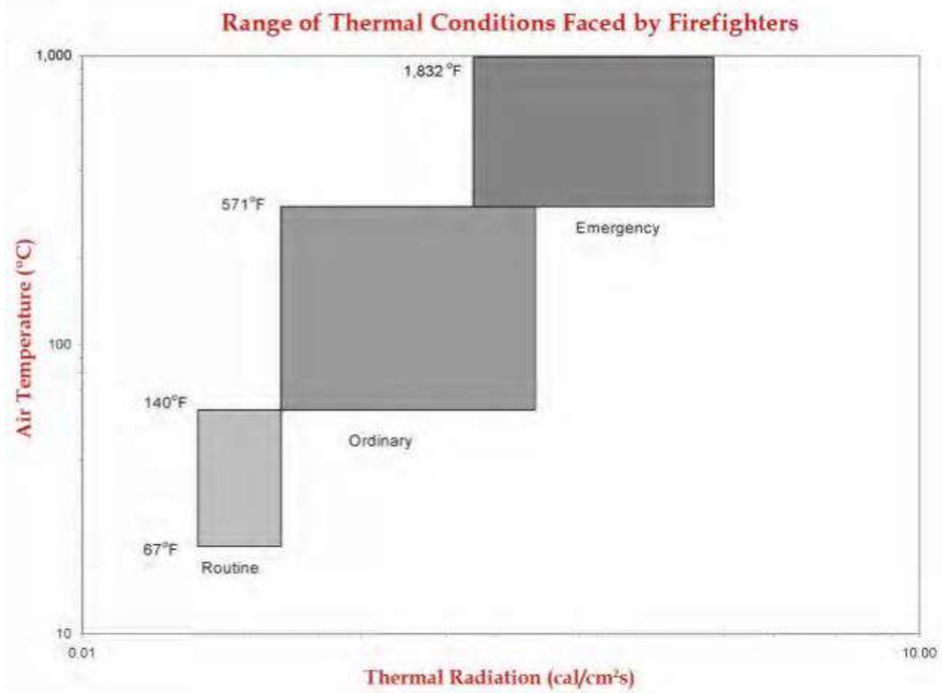
- Hot-Wet conditions are characterized by environmental temperatures exceeding 68 °F (20 °C), but rarely exceeding 100 °F. Relative humidity is in excess of 75 percent and rain is experienced regularly, especially in the form of thundershowers. Hot-wet conditions are experienced commonly in much of North America during the summer months.

- Hot-Dry conditions are characterized by environmental temperatures exceeding 68 °F and regularly exceeding 100 °F. Relative humidity is less than 75 percent, and is commonly less than 25 percent. Long periods without precipitation are common. Hot-dry conditions are experienced commonly in areas of the southwestern U.S.

- Cold-Wet conditions are characterized by environmental temperatures of between 14 °F (-10 °C) and 68 °F. Temperatures can change rapidly and daily freeze/thaw cycles can occur. Precipitation in the form of rain, freezing rain, sleet, or snow can be experienced regularly. Most areas of North America experience cold-wet conditions at some time during the year. Even tropic, desert, and polar areas regularly experience conditions of this type.

- Cold-Dry conditions are characterized by environmental temperatures of less than l4 °F. Below-zero and windy conditions are often experienced and temperatures of less than -60 °F (-51.1 °C) have been recorded in many areas. Above-freezing conditions are uncommon. Precipitation is in the form of dry snow. Areas of North America commonly experiencing cold-dry conditions include the north-central U.S., portions of the northeastern U.S., central and northern Canada, Alaska, and areas with mountainous terrain such as the Rockies and Sierras.

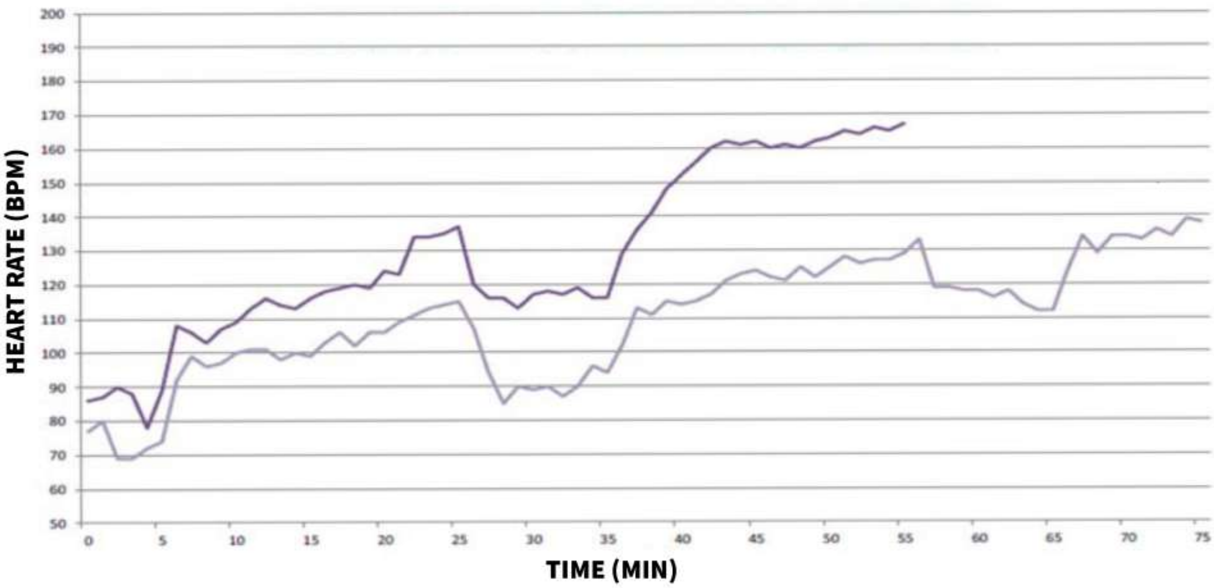
Appendix B



Emergency incident rehabilitation. (2008). Washington, D.C.: International Association of Fire Fighters. Division of Occupational Health, Safety and Medicine, pg. 114

Appendix C

Figure 3. Heart Rate Over Time With and Without PhaseCore Cooling Vest



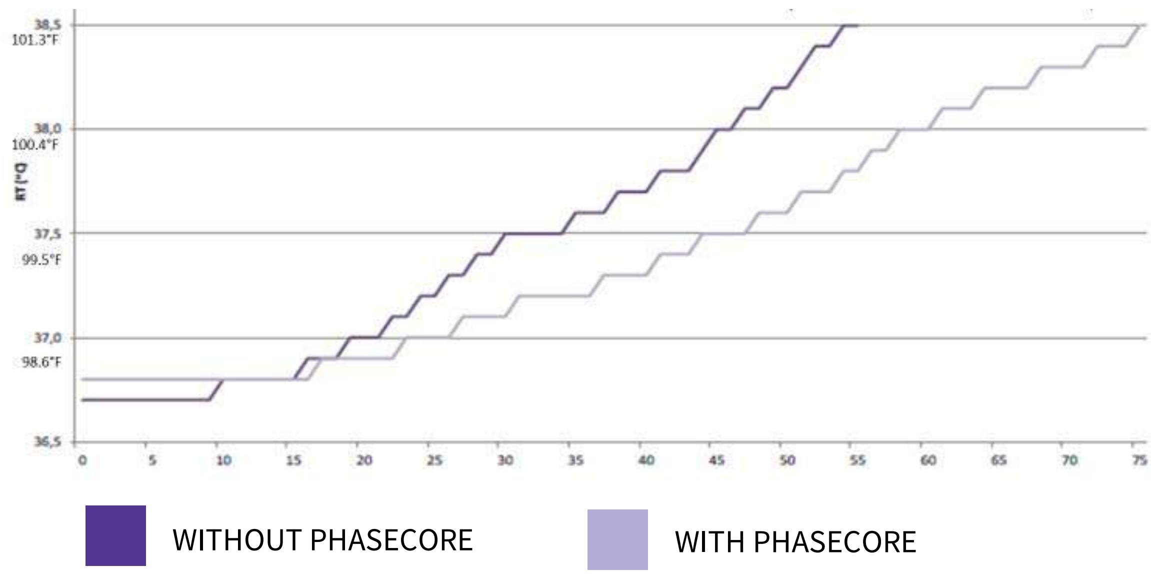
WITHOUT PHASECORE WITH PHASECORE

Heart Rate vs. Time a proband test on treadmill (4 km/h; 10º slope) in Tychem F clothing and the undergarment at 40ºC.

Testing provided by SUJCHBO, Czech Republic, 2016.

Appendix C (Cont.)

Figure 4. Rectal Temperature Over Time With and Without PhaseCore Cooling Vest



Rectal Temperature vs. Time a proband test on treadmill (4 km/h; 10° slope) in Tychem F clothing and the undergarment at 40°C.

Testing provided by SUJCHBO, Czech Republic, 2016.