Firefighter Trainee Dies From Hyperthermia After Live-Fire Training—Oklahoma

Executive Summary

On May 31, 2008, a 28-year-old male volunteer firefighter trainee ("Trainee A") participated in live-fire training at the State's Fire Service Training Professional Skills Center (PSC). The weather was hot and humid with a heat index of 97° Fahrenheit (F). While wearing full bunker gear with self-contained breathing apparatus (SCBA), Trainee A completed the following rotations over 10 hours with periods of rest and rehabilitation of varying duration between rotations: interior burn building fire suppression, hidden wall fire, fire extinguisher, pallet/dumpster fire, and car fire. The Trainee was reportedly "hot and sweaty." Upon completion of the training, the Trainee entered the apparatus building to change clothes. A short time later, an instructor found the Trainee unresponsive in the restroom. 9-1-1 was called as instructors began cardiopulmonary resuscitation (CPR). An ambulance provided advanced life support as the Trainee was transported to the hospital's Emergency Department (ED). Resuscitation efforts continued in the ED, but these efforts were unsuccessful and the Trainee was pronounced dead. The Trainee's core body temperature was not measured during rehab or in the ED, but, based on the clinical scenario, the death certificate and autopsy completed by the Medical Examiner listed "hyperthermia" as the cause of death, with "hypertensive atherosclerotic cardiovascular disease" and "obesity" as other significant medical conditions. The findings of the NIOSH investigation support this conclusion.

NIOSH investigators offer the following recommendations to the State facility and the Trainee's fire department to prevent similar incidents and to address general safety and health issues.

Key Recommendations

- *Conduct live-fire training exercises consistent with National Fire Protection Association (NFPA) 1403,* ***Standard on Live-fire Training Evolutions***
- *Formulate and institute a heat stress program, incorporating elements before, during, and after all training courses*
- *Institute a rehabilitation (rehab) program consistent with NFPA 1584,* ***Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises***
- *Provide medical evaluations to fire fighters and a medical oversight program consistent with NFPA 1582,* ***Standard on Comprehensive Occupational Medical Program for Fire Departments***
- *Phase in a comprehensive wellness and fitness program for fire fighters consistent with the IAFF/IAFC Wellness Fitness Initiative and NFPA 1583,* ***Standard on Health-Related Fitness Programs for Fire Department Members***
- *Perform an annual physical performance (physical ability) evaluation as listed in NFPA 1500,* ***Standard on Fire Department Occupational Safety and Health Program***
- *Provide fire fighters with medical clearance examinations to evaluate their ability to wear a SCBA*
- *Ensure standard treatment guidelines are followed for firefighters who may have a heat-related illness*

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Firefighter Trainee Dies From Hyperthermia After Live-Fire Training—Oklahoma

Introduction

On May 31, 2008, a 28-year-old male volunteer fire fighter trainee (referred to as "Trainee A" in this report) died due to hyperthermia after strenuous live-fire training conducted in hot and humid environmental conditions. The National Institute for Occupational Safety and Health (NIOSH) was notified of this fatality on June 4, 2008 by the United States Fire Administration. NIOSH contacted the affected fire department on June 16, 2008 to obtain further information, and on July 16, 2008 to initiate the investigation. On August 4, 2008, a Safety and Occupational Health Specialist from the NIOSH Fire Fighter Fatality Investigation Team conducted an on-site investigation of the incident.

During the investigation, NIOSH personnel interviewed the following people:

- Fire Chief of the Volunteer Fire Department
- Manager of the State Fire Fighter Certifications and Volunteer Programs
- State Fire Service Training PSC coordinator
- State Fire Service Training instructors
- State Fire Fighter Fatality Investigation Team
- Crew members of Trainee A
- Trainee A's spouse and family

NIOSH personnel reviewed the following documents:

- State Fire Service Training incident reports
- State Fire Fighter Fatality Investigation Team report
- Crew members' witness statements
- Fire department 2007 annual response report
- Ambulance service emergency medical report
- Local hospital ED record
- Autopsy report
- Primary care physician records

State's Fire Service Training Professional Skills Center (PSC)

The PSC is the State's host site for fire fighter academies and various live-burn training sessions. Live-fire training is required for Fire Fighter I (FFI) certification. Live-fire exercises at the PSC consist of interior and exterior fire suppression.

The interior live-fire rotation takes place in the burn building (Photo 1). During the morning, trainees are led through the building on a walkthrough and then observe the instructors performing a live-fire evolution. In the afternoon, trainees conduct the interior live-fire suppression evolutions.

There are 5 exterior live-fire rotations conducted in both the morning and afternoon sessions. The exterior rotations consisted of hidden wall fire (Photo 2), fire extinguisher (Photo 3), pallet/dumpster fire (Photo 4), and car fire (Photo 4). Appendix A has a complete description of each training exercise. As with the interior rotation, trainees are led on a walkthrough of the prop prior to the live-fire evolution.

Personal Protective Equipment (PPE) is worn on all rotations. PPE consists of boots, turnout gear, gloves, helmet, and SCBA. While the SCBA must be worn on all rotations, only the trainees on nozzle operation are "on air." The other tasks are performed off-air.

There is a shaded rehab pavilion located near the burn building (Photo 5). Between rotations trainees visit the designated rehab stations during which time they could doff their turnout gear, drink fluids, and rest. However, sometimes there was not enough time between rotations to receive rehab at the rehab station.

Instructors

There were 7 instructors and 5 staff members present during this training session. Instructors and staff members filled the roles of command, ignition officer and assistants, safety officer, support sector (water supply and medical), fire attack sector, rapid intervention team (RIT) sector, and rehab sector. All instructors and staff follow the incident command system and are equipped with portable radios. Appendix B provides a listing of the responsibilities and qualifications of the instructors.

Prior Training Requirements

Prior to participating in the live-fire training, trainees are required to attend a 6-week FFI training program and demonstrate skills in safety, fire behavior, portable extinguishers, PPE, ladders, fire hose, hose appliances, fire streams, overhaul, water supply, ventilation, and forcible entry. Student training must be verified by their respective fire chief who signs a training verification form maintained at each local fire department.

Weather Conditions

The weather on May 31 was hot and humid. Temperature measurements were made at the nearby regional airport by National Oceanic and Atmospheric Administration (NOAA) and are listed in Table 1. No black globe reading was available to account for the sun's or the fire's radiant heat, therefore a wet bulb globe temperature (WBGT) could only be estimated [ABM 2010; Lugo-Amador et al. 2004].

Investigation

On May 31, 2008, Trainee A, and 24 other trainees, arrived at the State PSC at about 0700 hours to participate in a live-burn training class. Upon arrival, trainees completed course registrations forms. On the back page of the registration form, trainees were asked to identify any health concerns, medical history, or medications in case first aid or medical treatment was needed. The Trainee listed "ulcerative colitis," but did not mention that he had suffered "flare-ups" over the last 2 days. The lead instructor (also known as the instructor-in-charge) reviewed all the registration forms and noted the reported medical problems.

At 0800 hours, the lead instructor and PSC coordinator introduced the training instructors and staff and began their safety briefing. They orientated the trainees to the:

- facility [restrooms, designated smoking area, rehab areas, hazardous material (fuels) locations, material safety data sheets, fire alarms, exits, and mustering locations];
- PSC policies and procedures [incident command, walkthroughs prior to evolutions, PPE, rehabilitation, roll call, and accountability (use of colored and numbered accountability tags, buddy teams of 2 trainees, and rotation board)];
- the day's scheduled rotations (Appendix A).

During the safety briefing, hydration was emphasized. To prevent dehydration, the PSC coordinator reminded the trainees to drink the liquids provided at 3 locations: (1) in the shaded rehab pavilion near the burn building, (2) near the car/dumpster fire prop, and (3) in the apparatus bay near the classroom.

The lead instructor completed the compliance plan for NFPA 1403, Standard on Live-Fire Training Evolutions [NFPA 2007]. The 25 trainees were then divided into 3 groups of 6 trainees and a fourth group of 7 trainees. Trainee A was assigned to this last group, also known as the Blue group. After a 10-minute break, the groups reported to their respective props. Appendix C lists the timeline and sequence of the Blue group's rotations.

The Blue group's first assignment was rehab at the pavilion (Photo 5). During this rehab assignment, several trainees, including Trainee A, were asked to fluff the excelsior. While fluffing for about 20 minutes Trainee A wore his boots, bunker pants, gloves, and helmet. Trainee A then returned to rehab for the remaining 20–30 minutes of the rotation.

At approximately 1000 hours, the Blue group began their walkthrough and observation of the burn building rotation in full PPE. The rotation lasted about 50 minutes and the group had 10 minutes to get to their next rotation (Hidden Wall Fire). This 10-minute break did not allow enough time for the group to walk to the rehab station and then to the Hidden Wall prop. During the hidden wall fire exercise, a Blue group trainee ("Trainee B") suffered heat exhaustion at approximately 1100 hours.

The Blue group instructor summoned the lead instructor (a certified paramedic) who also was the training medical officer. The lead instructor/medical officer obtained the medical kit, drove to the Trainee B's location, and treated him. The Trainee B's vital signs were taken with the following results: blood pressure of 130/80 millimeters of mercury (mmHg), a heart rate of 140 beats per minute, a respiratory rate of 22 breaths per minute, and his blood sugar level was 123. He was given oxygen and an ambulance was requested through 9-1-1. Vital signs taken a second time revealed a blood pressure of 130/100 mmHg, heart rate of 97 beats per minute, and a respiratory rate of 18 breaths per minute. The ambulance arrived and transported Trainee B to the local hospital's ED where he was treated for dehydration and released approximately 2 hours later.

While treating Trainee B, a second Blue group trainee ("Trainee C") suffered heat exhaustion at approximately 1120 hours. Trainee C's vital signs were within the normal range and he seemed to be improving. After a period of removal from training, including time spent in front of a cooling fan, Trainee C returned to the Blue group.

The remaining members of the Blue group completed the hidden wall fire and the fire extinguisher rotation. These two rotations were the only actual live-fire evolutions during the morning hours. There was a short break of 5–10 minutes prior to the next rotation (pallet/dumpster fire and car fire). During this short break, trainees were able to get a drink at the un-shaded rehab station but did not have enough time to remove bunker gear or cool down completely. After completing the walkthroughs of the pallet/dumpster/car fire props, the Blue group joined the other groups for their lunch break at approximately 1220 hours.

After removing their bunker gear, Trainee A called his wife to bring bottles of Gatorade® to the PSC. Trainee A had lunch in the shade near the apparatus building, eating a sandwich, and drinking a 32-ounce bottle of Gatorade®. Everyone that had contact with Trainee A during the morning rotations or lunch reported that he was happy, enthusiastic and ready to keep going. Although his classmates and staff noted he was sweating profusely, he did not appear to be in any distress and reported feeling able to continue with the training day.

Throughout the day, trainees were encouraged to notify an instructor when they needed a break. Instructors watched the trainees for signs of fatigue or heat-related illness (HRI) and granted rest breaks when requested. However, many instructors reported difficulty seeing the trainee's faces through the SCBA facepieces, thus they could not adequately assess the trainee's condition. One trainee from the Blue group admitted to being so hot and tired that, once he completed his rotation on the nozzle and had moved to the RIT, removed his facepiece and opened his coat to cool down. He believed he "got in trouble" for this action and responded that he was, "too hot and they could just kick him out if they didn't like it." An instructor reported that at least two trainees came to their RIT assignment and appeared to need rest. The instructor allowed them to remove their facepieces and open their coats to cool down, although this was not normal procedure.

Following the 70-minute lunch break, the groups reassembled at 1330 hours. Once again, the Blue group was assigned to rehab in the pavilion, and Trainee A volunteered to fluff the excelsior. Following their rehab assignment, the group progressed to the burn building for their interior live-burn evolution.

The interior live-burn rotation took about an hour, after which the Blue group was sent to the dumpster/car fire props at approximately 1600 hours. On the way, the trainees walked through the apparatus building to get a drink but found the Gatorade® jug empty. They drank as much water as possible using the 6-ounce cups provided. Trainees who brought their own bottled water or Gatorade® refilled their bottles at this point with water. This break lasted approximately 20–25 minutes.

The Blue group reported to the dumpster/car fire props which provided no shade. The trainees were required to wear full bunker gear with SCBA and facepieces. At this point, most trainees were reportedly exhausted. Between rotation of the dumpster and car fires, all trainees went to the un-shaded rehab where they doffed their turnout gear and drank fluids for about 5 minutes. Then they donned their gear and moved to the car fire prop. All those present reported that Trainee A appeared to be holding up better than everyone else. Trainee A told an instructor that he "worked outside digging ditches all day and this didn't bother him at all. In fact, he was enjoying it."

Upon completion of the car fire prop, the day's training was completed for the Blue group. They removed their PPE and SCBA, took a short break, drank fluids, and reloaded the equipment and hoses on the fire engine. Shortly thereafter, Trainee A asked a staff member if he could go to the bathroom without his "buddy." Since the training was completed and only clean-up remained, he was allowed to go alone.

Sometime after Trainee A arrived at the apparatus building, he talked to another trainee for a few minutes and they decided to check on another trainee at the burn building. Trainee A and his fellow trainee returned to the apparatus building where Trainee A mentioned changing clothes and went into the bathroom.

As the other two groups concluded their burn building exercise, two instructors entered the bathroom (about 1810 hours), but neither noted Trainee A in the stall. Three trainees came into the bathroom; each trainee reported seeing bunker boots in a normal position under the stall door. They spoke to the person in the stall but received no response. Several minutes later, a staff member checked the bathroom and noted someone's boots and legs sticking out of the stall at an unusual angle. The staff member opened the stall door and found Trainee A unresponsive in the stall. The staff member yelled, "We have a man down in the bathroom" and another staff member called 9-1-1 (about 1815 hours).

The paramedic and two staff members responded and found Trainee A unconscious, not breathing, and without a pulse. They called for the automated external defibrillator (AED) and medical kit and moved Trainee A to the floor and checked for a pulse. Finding no pulse, the paramedic began rescue breathing with a pocket mask; CPR was initiated by a staff member. The medical kit arrived but did not have tubing to provide supplemental oxygen to the pocket mask or bag-valve-mask. The AED arrived seconds later and no shock was advised. CPR continued for 9 additional AED assessments, all with no shock advised.

The ambulance arrived at 1824 hours and the paramedics assumed patient care. A cardiac monitor revealed asystole. An intravenous (IV) line was placed and Trainee A was intubated. Endotracheal tube placement was confirmed by end tidal carbon dioxide testing [AHA 2016]. Cardiac resuscitation medications were administered. Trainee A remained in asystole, CPR continued, and Trainee A was loaded into the ambulance. The ambulance left the scene at 1839 hours and arrived at the hospital at 1847 hours. ED staff immediately took over advanced life support treatment from the ambulance crew. Resuscitation efforts continued for an additional 24 minutes without success. Trainee A was pronounced dead at 1911 hours.

Medical Findings

The death certificate and autopsy (completed on June 2, 2008 by the State Medical Examiner) listed "hyperthermia" as the cause of death, with "hypertensive atherosclerotic cardiovascular disease" and "obesity" as other significant medical conditions. Pertinent findings from the autopsy are listed in Appendix D.

Trainee A was 72 inches tall and weighed 268 pounds, giving him a body mass index (BMI) of 36.3 kilograms per meters squared (kg/m^2) [CDC 2015]. Trainee A had a history of ulcerative colitis and obesity. According to his family and crew members, Trainee A had no complaints of chest pains, unusual shortness of breath on exertion, or any other heart-related illness. The day before his collapse, he worked outdoors at his regular job in Water Department maintenance for a local city.

Fire Department

At the time of the NIOSH investigation, Trainee A's volunteer fire department consisted of 10 full-time uniformed personnel and 10 part-time personnel in training and/or on probation and served a population of 800 in a 15-square-mile area. It had 1 fire station.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Membership and Training

The fire department requires the following of all fire fighter applicants: be at least 18 years of age, pass a fire department vote, and attend meetings and training.

The successful applicant is placed into a training program and scheduled to attend the 136-hour FFI course through State Fire Service Training. Upon completion of this course, the candidate must pass the 8-hour live-fire evaluation to achieve the complete FFI certification. Trainee A had just completed the FFI certification course, was certified in Hazardous Materials Awareness, and had 8 years of firefighting experience.

Medical Evaluations

Pre-placement and annual medical evaluations, medical clearance for respirator use, and annual SCBA fit testing were not required by the fire department.

If a fire fighter is injured on duty, a return-to-duty medical clearance is required from the fire fighter's primary care provider and given to the Fire Chief, who makes the final determination for return-to-duty.

Wellness/Fitness Programs

The fire department does not have a wellness/fitness program. Strength and aerobic equipment is not available at the fire station. An annual physical ability test is not required.

State Fire Service Training Medical Requirement

The State Fire Service Training requires each trainee to identify health problems on their course application, and the information is reviewed by the lead instructor. However, no medical precertification or evaluation is required. In this case, Trainee A identified "ulcerative colitis" on his application.

Discussion

Hyperthermia, Heat Stress/Strain, Tolerance, Fluid Balance, Heat Illness, and Heat Stroke

Hyperthermia is characterized by an uncontrolled increase in body temperature that exceeds the body's ability to lose heat [CDC 2006]. Exertional hyperthermia is defined as a core body temperature above 104°F during activity [Armstrong et al. 2007]. Although, Trainee A's core body temperature was not measured during rehab or in the ED, the death certificate and autopsy completed by the Medical Examiner listed "hyperthermia" as the cause of death based on clinical scenario.

Heat stress/strain. Heat stress refers to the overall heat load on a body from all sources - the environment (e.g., air temperature, humidity), physical activity (produces body heat), and protective clothing/PPE (traps body heat) [NIOSH 2016]. Above a certain threshold of excess heat storage, the body responds with cooling mechanisms to remove the heat and restore balance. The skin is the key site of heat transfer. An increase in blood flow moves heat from the warmer core of the body out to the skin surface (cutaneous dilation), where the excess heat is expelled to the surrounding environment. Greater skin blood flow also facilitates evaporation of sweat from the skin, which is the most effective way for the body to eliminate excess heat.

Heat strain refers to the physiological effects and consequences of heat stress [DOD 2003]. Cardiovascular strain occurs when the heart must pump faster to maintain a higher cardiac output to increase blood flow to the skin. Thermal strain refers to an increase in deep body or "core" temperature as a result of stored heat (excess heat). If the body lacked the ability to sweat and increase skin blood flow to remove stored heat, core temperature would rise quickly and reach an unsafe level after about 15 minutes of moderate exercise [Kenney and Johnson 1992].

Heat tolerance. The ability to tolerate heat stress is highly individual. About half the variation between people is explained by differences in body size and aerobic fitness [Wyndham 1973]. The remainder may involve differences in sweat production, circulatory capacity, hormonal effects on fluid and electrolyte balance, and other factors that are not well understood. Even in the same person, tolerance to the same heat load can vary day to day because of current physiological status, e.g., hydration, underlying illness, medications, sleep, or fatigue [DOD 2003; NIOSH 2016].

Heat acclimatization is the process of developing improved tolerance to work or exercise in the heat, and this develops with repeated episodes of exertion in a hot environment over the course of consecutive days to weeks [DOD 2003; NIOSH 2016]. After becoming acclimatized, work output increases with reduced physiological strain (lowered heart rate and body temperature), which decreases the risk for serious HRI or injury [Casa et al. 2009; DOD 2003; Moseley 1994; NEHC 2007]. A high level of aerobic fitness provides partial acclimatization to heat, as the metabolic heat of exercise confers physiological benefits that are similar to those from environmental heat [Nunneley and Reardon 2002; Tipton et al. 2008].

Fluid balance. The sweating rate is influenced by level of physical activity, environmental heat, clothing/PPE worn, and whether or not a person is acclimatized [DOD 2003]. Once acclimatized to heat, sweating starts earlier and is produced in larger volume. Thus, acclimatization actually increases net body water loss; improved electrolyte retention offsets this somewhat by helping maintain plasma volume (the fluid portion of whole blood). Around 1 liter/hour of sweat is lost during strenuous heat-exertion and around 2 liters/hour if limited permeability PPE is worn, e.g., fire fighters [DOD 2003; Eglin et al. 2004]. Being proactive with fluid replacement is key, as onset of thirst does not begin until about 1%–2% of body water is lost [Hubbard et al. 1990]. (Given that one pound of body weight equates to about 16 ounces of water, sweating in a 200-pound adult which causes 2% weight loss [4 pounds] would yield a fluid deficit of approximately 2 quarts [64 ounces].)

Rehydration is ideally accomplished by drinking small quantities of water at regular, frequent intervals, e.g., every 15–20 minutes, instead of drinking a large volume all at once [McArdle et al. 2010]. The stomach empties at a rate of approximately 1.2 quarts (38 ounces) per hour, which may increase with mild exercise but slows down during maximal exercise [Marzio et al. 1991]. Electrolyte-carbohydrate sports drinks are recommended if prolonged exertion (e.g., ≥ 1–2 hours) with heavy sweating is likely, in order to replace electrolytes lost in sweat and prevent dilutional hyponatremia [Montain and Cheuvront 2008; NFPA 2015a].

Dehydration (reduced total body water) negates the physiological advantages of acclimatization, particularly when fluid losses exceed 2% of body weight [DOD 2003; Greenleaf and Harrison 1986; Taylor et al. 2008]. Progressive dehydration increases physiological strain and impairs the body's ability to cool itself. The production of sweat declines, the contracted blood volume strains the heart to pump faster, and core temperature rises by approximately 0.12°F–0.15°F (~0.2°C–0.3°C) for each 1%

of weight loss [González-Alonso et al. 2008; Grucza et al. 1987; Sawka et al. 1985]. Work/exercise endurance decreases, and fatigue occurs earlier [Buskirk et al. 2000; Cheuvront et al. 2010; DOD 2003; NIOSH 2016]. Thus, dehydration compounds the effects of hyperthermia and the risk of HRI, including heat stroke, increases.

Heat-related illness. Core temperature may become elevated (hyperthermia) but remain steady during strenuous activity, with heat gains balanced by heat losses. Being adequately hydrated, acclimatized, and aerobically fit helps prevent the likelihood of hyperthermia and serious HRI; however, these protective factors do not eliminate the risk [Armstrong et al. 2007; Binkley et al. 2002; DOD 2003; NIOSH 2016]. Core temperature can leave its steady state if the body's ability to compensate for heat gains becomes overwhelmed. For example, if evaporative cooling ability is inhibited by PPE and/or high humidity conditions, core temperature can escalate and HRI becomes more likely [DOD 2003].

Exertional heat exhaustion. Exertional heat exhaustion is the most common HRI among active people. It is characterized by physical exhaustion and the inability to continue work or exercise due to insufficient cardiac output. Heart rate, which largely drives cardiac output, may reach its physiological upper limit while trying to meet the combined demands of increased blood flow to the skin, exercising muscle, and vital organs such as the heart and brain [Armstrong et al. 1997; DOD 2003]. Other signs/symptoms of exertional heat exhaustion may include profuse sweating, headache, irritability, weakness, nausea, feeling dizzy or light headed, tachycardia, etc. If present, hyperthermia with heat exhaustion may be mild to moderate (100.4°F–102.2°F / 38°C–39°C), which some individuals cannot tolerate; others, such as marathon runners or elite soldiers, may perform well at even higher temperatures [Armstrong et al. 2007; Joy and Goldman 1968]. Once core temperature reaches 102.6°F (39.2°C), risk of heat exhaustion collapse is around 25%; as it approaches 104°F (40°C), the majority of people will experience an HRI [NIOSH 2016].

Exertional rhabdomyolysis. Exertional rhabdomyolysis (breakdown of skeletal muscle) can develop during strenuous exertion in the heat as a complication of heat stroke or as a separate injury [DOD 2003; NIOSH 2015]. When muscles die or are injured, their contents can enter the bloodstream and cause damage. Potassium can cause irregular heat rhythyms and seisures while myoglobin, the protein that carries oxgygen inside muscle cells, may cause kidney damange clogging the kidney's filtration systemIn about 25% of cases,myoglobin induced kidney damage is severe enough to cause acute renal failure [NEHC 2007]. Classic symptoms of exertional rhabdomyolysis include localized muscle pain worse than expected for the exetion, swelling of the affected muscle, and new inability to complete previously routine physical tasks; urine may appear very dark or "tea" colored from myoglobinuria [Brown 2004; Sawka et al. 2007]. Hospitalization to receive intravenous fluids to flush out the potassium and restore fluid balance, temporarly dialysis if/until kidney function recovers, and cardiac monitoring may be necessary to ensure recovery from severe cases of rhabdomyolysis.

Heat Stroke. Heat stroke is a life-threatening emergency of failed thermoregulation with severe hyperthermia (> 104.9°F / 40.5°C) and central nervous system (brain) dysfunction, often with loss of consciousness [Armstrong et al. 2007]. The brain is particularly sensitive to hyperthermia and thus shows dysfunction early on; heat stroke may be further complicated by a cascade of damage to other organ systems that resembles the sepsis syndrome [Bouchama et al. 2005; Walter and Carraretto 2016]. Exertional heat stroke primarily strikes young, active people who are usually still sweating at the time of collapse [NIOSH 2016]. This differs from nonexertional or "classic" heat stroke which affects the elderly and chronically ill during heat waves, and in whom sweating has often ceased. Exertional heat stroke is a particular threat to fire fighters, the military, athletes, and others whose work or training involves intense physical effort in the heat while wearing limited permeability PPE or gear that traps body heat [Goforth and Kazman 2015].

Because internally generated heat is its root cause, exertional heat stroke can develop even during cool conditions that may be mistakenly considered “safe” [Armstrong et al. 2007; Giercksky et al. 1999; Stacey et al. 2015]. The time to reach severe hyperthermia can be short, ranging from approximately 30 minutes to several hours [Rav-Acha et al. 2004]. Many cases go unrecognized until collapse. Possible earlier signs or symptoms include headache, nausea, confusion (e.g., failure to follow commands), irrational or out of character behavior, slurred speech, clumsiness, staggering, etc. [DOD 2003; Epstein et al. 1999]. Exertional heat stroke mortality in epidemiological studies (analyses of groups or populations) ranges from about 4% to 22% [Carter et al. 2005; Rav-Acha et al. 2004; Shibolet et al. 1976; Zeller et al. 2011]. Duration of hyperthermia before cooling affects prognosis more so than the peak core temperature reached [Shapiro et al. 1973]. Prompt immersion in ice water has been endorsed by national sports medicine and athletic training associations as the best method to rapidly lower core temperature and improve outcomes [Armstrong et al. 2007; Casa et al. 2015; Leon and Bouchama 2015; McDermott et al. 2009; Smith et al. 2005]. As this case suggests, heatstroke can be the presenting illness. Trainee A probably had heatstroke and ice water immersion was not available at the PSC.

Trainee A’s presentation and clinical course, which followed training in hot environmental conditions, was typical of exertional heatstroke. As noted above, Trainees B and C reported symptoms consistent with mild to moderate HRI during this live-fire training. Trainee C required medical evaluation on-scene, while Trainee B required medical evaluation and treatment at the local ED.

Risk Factors for Heat-Related Illness/Exertional Heat Stroke

Predisposing factors for HRI/exertional heat stroke have been identified, including metabolic heat generation, external factors and internal (personal) factors [Abriat et al. 2014; Armstrong et al. 1990; NEHC 2007; Rav-Acha et al. 2004; USAPHC 2016]. These factors are discussed below as they relate to this incident.

Metabolic Heat Generated During PSC Live-Fire Training

For those engaged in moderate to heavy physical work, metabolic heat is the primary driver of heat stress. Using the descriptions of the training tasks as written in the PSC procedures manual and during NIOSH interviews, the metabolic heat generated could be estimated by task analysis for each training evolution (Example calculations are provided in Appendices E-I). These energy expenditures ranged from light (most exterior fire evolutions) to moderate (hidden wall evolution) to heavy (interior evolution). These estimates are modestly lower than exertion/work estimates obtained during actual and simulated fire suppression in SCBA and turnout gear [Bugajska et al. 2007; Lemon and Hermiston 1977; O’Connell et al. 1986]. However, when the weight adjustment factor for Trainee A is taken into account (see Appendix E-I), his evolution work estimates were in the moderate to heavy exertion ranges.

External Risk Factors

Environment. Environmental heat is determined by four factors: air temperature, humidity, air movement, and radiant heat. The commonly used "heat index" reported by the U.S. National Weather Service accounts for air temperature and humidity, whereas the WBGT index also accounts for radiant heat and wind [NIOSH 2016; Parsons 2006]. Thus, measuring or estimating the WBGT is important for two reasons. First, it is a more accurate index of environmental heat load. Second, it is used in HRI prevention guidelines [ACGIH 2017; Armstrong et al. 2007; NIOSH 2016; Parsons 2006].

In this incident, neither the training facility nor the course instructors had equipment to measure the WBGT. Formulas, however, have been developed that estimate WBGT using routinely collected meteorological data [ABM 2010; Lemke and Kjellstrom 2012; Liljegren et al. 2008]. At 1330 hours, the dry bulb temperature was 89°F, the wet bulb temperature was 78°F, the humidity was 59%, and the wind was 11 Miles per hour (mph) with scattered cloud cover. Under these conditions, the Australian Bureau of Meteorology method would estimate the WBGT to be 90°F (32°C) (Appendix J), although the validity of the Australian Bureau of Meteorology method has been questioned [Lemke and Kjellstrom 2012].

Clothing Adjustment Factor, Fire Fighter Turnout Gear, and PPE. Heat is removed from the body primarily by evaporation of sweat from the skin. Clothing alters the amount and rate of heat exchange between the skin and the ambient air by convection, radiation, and evaporation [NIOSH 2016]. In general, the thicker the garment and the greater the air and vapor impermeability of the clothing, the more it interferes with the body's cooling process. In evaluating heat stress, a "clothing adjustment factor" must be applied to the WBGT [ACGIH 2017; NIOSH 2016]. The turnout gear worn by fire fighters is a multilayer garment (three layers of outer shell, moisture barrier, and thermal liner) with partial air/vapor impermeability [Duffy et al. 2008]. A clothing adjustment factor of 10°F to 20°F (6°C to 11°C) for fire fighter turnout gear has been suggested [Bernard 1999; Duffy et al. 2008; Pennington et al. 1980]. Thus, the effective WBGT in this incident would have been 100°F to 110°F (38°C to 43°C).

On the day of the incident, Trainee A wore the full PPE required for live-fire training for over 3 hours. He collapsed at the end of the 10-hour training.

Exertion. Any protective clothing/equipment will limit heat tolerance to a certain extent by adding weight and altering heat transfer [NIOSH 2016; White and Hodous 1987]. The physiological burden of protective clothing can increase core temperature, cardiovascular strain, and physical fatigue, and lessen the time to reach exhaustion [Armstrong et al. 2010; Barr et al. 2010; NIOSH 2016; Petruzzello et al. 2009]. The features of fire fighter PPE that protect against the hazards of fire fighting are also the characteristics that increase the risk of HRI. The insulating layer of the turnout coat traps body heat and the semi-permeable moisture barrier impedes sweat evaporation [Eglin 2007]. The SCBA increases the work of breathing (metabolic heat) [Jones 1991]. In addition, metabolic workload and thus body heat are increased by the substantial weight of PPE and SCBA (the weight of structural fire fighter protective clothing plus SCBA and tank is approximately 40–50 pounds [Haddam Volunteer Fire Company 2013]). PPE and SCBA contributed to the heat stress experienced by Trainee A.

Based on descriptions of the live-fire prop, the exterior hidden wall fire prop, the exterior fire extinguisher prop, the pallet/dumpster fire prop, and the car fire prop, protective clothing ensemble/SCBA considerations, and workload estimates [NFPA 2015a; NIOSH 2015], the metabolic workload for the live-fire training was estimated to be in the range of 350–740 kilocalories per hour (kcal/hour) (moderate to heavy workload). Since the live-fire training was required for FFI certification, this could have led to its intensity. Prior to Trainee A's collapse, instructors had already treated 2 trainees for heat exhaustion and transported one of them to the hospital for treatment. The exertion and intensity of the live-fire training contributed to the heat stress experienced by Trainee A.

Personal Risk Factors

The literature describes personal risk factors for exertional heatstroke, some of which include increased age, obesity, poor physical fitness, a previous history of exertional heatstroke, and various medical conditions such as heart disease. Some medications and other ingested substances (e.g., alcohol, dietary supplements) can impact the body's ability to regulate heat [Armstrong et al. 2007].

Trainee A was obese and had ulcerative colitis, an inflammatory disorder of the large intestines that can cause diarrhea. Trainee A suffered "flare-ups" of this condition on the morning before, and the morning of, the live-fire training. This may have exacerbated Trainee A's dehydration found at autopsy, but it is unclear what role, if any, it played in Trainee A's sudden death. During the safety briefing and throughout the day, hydration was emphasized. To prevent dehydration, the PSC coordinator reminded the trainees to drink the water and Gatorade® provided at 3 locations: (1) a 10-gallon jug in the rehab pavilion near the burn building, (2) a 5-gallon jug near the car/dumpster fire prop, and (3) two 5-gallon jugs in the apparatus bay near the classroom. Several water jugs and one jug of Gatorade® were reportedly empty throughout the day. Access to drinking water could have been a problem. Trainee A reportedly drank Gatorade® during the training.

Prior to the training, Trainee A was not known to have heart disease. The autopsy, however, revealed moderate coronary artery disease (CAD), left ventricular hypertrophy (LVH), and cardiomegaly. These conditions increase the risk of sudden cardiac death [Levy et al. 1990]. While it is unlikely Trainee A died due to a cardiac event, this cannot be ruled out.

Lack of heat acclimatization is another heatstroke risk factor. With heat acclimatization, physiological changes such as sweating at a lower temperature, more sweating, and less electrolyte loss make the body more efficient in dealing with heat stress. Any exercise program that builds and maintains a high level of aerobic fitness partially adapts the body to heat stress [Nunneley and Reardon 2009]. To fully acclimatize, however, the body needs to experience the actual work conditions in consecutively increasing 1½- to 2-hour increments. Adaptive physiological changes occur within 4 days, but complete acclimatization can take up to 3 weeks [Voltaire et al. 2002]. Once heat stress exposure stops, the body's adaptive mechanisms regress; clinically significant reductions are seen within 4 days [ACGIH 2017].

Exertional heat stroke has been called the "illness of the over-motivated" [Epstein et al. 1999]. High motivation or "overzealousness" has been identified as a risk for heat stroke among military members and athletes [Abriat et al. 2014; DOD 2003; Rav-Acha et al. 2004; USAPHC 2016]. A strong desire to meet or exceed standards to complete a mission causes some soldiers to continue pushing themselves despite early signs or symptoms of exertional heat stroke. Athletes, especially during competition, may ignore early warning signs or symptoms that would normally be protective [Cleary 2007; Lopez et al. 2011]. In other words, in the setting of heat strain, judgment may be impaired among those who are highly motivated to perform well.

Summary of Predisposing Risk Factors. Trainee A had a "flare up" of his ulcerative colitis which can cause diarrhea which can lead to dehydration. Once the training began, Trainee A was exposed to multiple sources of heat stress – environmental heat, physical exertion, heat-trapping protective clothing, SCBA, the overall weight of PPE/SCBA, and high motivation. The autopsy showed he was dehydrated.

Guidelines for Workers/Athletes at Risk for Heat-related Illness and Exertional Heatstroke

Several organizations have developed guidelines for stopping or restricting physical activities on the basis of WBGT, metabolic work requirements, clothing adjustment factors, and acclimatization. For heavy (415 kcal/hour) work among acclimatized individuals, the U.S. Army and Air Force cancel all scheduled physical training in acclimatized individuals when WBGT is above 32.0°C (89.6°F) [Nunneley and Reardon 2009; Pennington et al. 1980]. The American College of Sports Medicine recommends cancelling all scheduled events when WBGT is above 32.3°C (90.14°F) [Armstrong et al. 2007]. NIOSH recommends discontinuing heat exposure (work) for acclimatized workers on moderately physically demanding jobs (300 kcal/hour) when the WBGT is above 32°C (89.6°F) [NIOSH 2016]. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends discontinuing heat exposure (work) for acclimatized workers doing moderately physically demanding work when the WBGT rises above 31.5°C (88.7°F) [ACGIH 2017].

It should be noted that the NIOSH and ACGIH guidelines are based on an 8-hour workday and a 40-hour workweek. The PSC live-fire training lasted 10 hours, however less than half of the time was actually spent doing fire suppression. However, many trainees reported not having enough time between props to doff their turnout gear or were told not to doff their turnout gear due to the safety concerns in the immediate vicinity of the props. In addition, the 10-minute rest periods between props was probably not long enough to effectively lower the fire fighter's core temperature [McLellan and Selkirk 2006].

The National Fire Protection Association (NFPA) also provides guidelines [NFPA 2015a]. In the Annex of NFPA 1584, the organization lists both a "Heat Stress Index" and the HUMIDEX both derived from air temperature and humidity. A footnote under the Heat Stress Index suggests adding 10.0°F when wearing protective clothing and 10.0°F when working in direct sunlight, but a similar correction factor is not included in the HUMIDEX Chart. Using the temperature and humidity measurement at 1330 hours, the HUMIDEX index was 43 which translates to an Alert Level 2 = Extreme Caution. At this level, NFPA recommends the following:

(1) Postpone optional activities or reschedule them to cooler times of the day when possible.
(2) Introduce additional rest breaks for workers performing moderate work.
(3) Further reduce heavy work.
(4) Consider cessation of nonessential operations involving heavy physical activity.
(5) Minimize using bunker suits whenever possible.

NFPA 1584 goes on to recommend postponing all training activities except recruit training. When conducting recruit training within the HUMIDIX 40–45 range, the following is recommended:

(6) Limit recruit live-fire burns to occur between 0700–1200 hours only.
(7) Provide increased rest break for all work loads.

(8) Limit heavy work to less than 15 minutes per hour.
(9) Initiate rehabilitation at the beginning of the incident.
(10) Use active cooling where possible (forearm immersion, misting fan, and/or air conditioning).

Given that two trainees suffered heat exhaustion in the morning, and the estimated WBGT was 90°F (32°C), strong consideration should have been given to cancelling the afternoon training session. In addition, trainees and instructors were not allowed to remove any bunker gear while in the immediate vicinity of the props due to safety concerns. This increased the duration of heat exposure. When the clothing adjustment factor is taken into account [WBGT estimated to be between 100°F–110°F (38°C–43°C)], the training session should have been cancelled according to the U.S. Army, U.S. Air Force, American College of Sports Medicine, NIOSH, and ACGIH. Since the decision was made to continue the training, at least the NFPA recommendations 6–8, and 10 should have been followed (#9 was already in place).

Treatment. Rapid core body temperature reduction is the most important treatment for exertional heatstroke. Its use has resulted in lower exertional heatstroke mortality rates [Bouchama et al. 2007; Costrini 1990; McDermott et al. 2009]. Cold/ice water immersion is the best method and is endorsed by the ACSM and the National Athletic Trainers' Association [Armstrong et al. 2007; Binkley et al. 2002]. Cold/ice water immersion was not available on site.

Rehab Standards for Structural Fire Fighters. NFPA 1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises*, establishes the minimum criteria for developing and implementing a rehab process for fire department members at incident scene operations and training operations [NFPA 2015a]. Components of the rehab should include (1) rest and relief from climate conditions, (2) medical evaluation and treatment, and (3) fluid and food replenishment.

1. Rest and Relief. Rehab was provided, however during rehab, some trainees were required to prepare excelsior fuel for the burn props while wearing bunker pants, boots, gloves, and helmet. In addition, in some situations a group could move from one prop to the next (e.g., Blue group) without an opportunity to cool down in Rehab.

NFPA 1584 also recommends that an adequate area and/or shelter be available during operations and training. For hot environments, this includes shade and/or air conditioning and a place to sit [NFPA 2015a]. One rehab area at the Skills Center did not have shade and the only air-conditioned area at the Skills Center was the classroom.

Members entering rehab for the first time should rest for a minimum of 10 minutes or longer if practical [NFPA 2015a]. Following the use of a second 30-minute SCBA cylinder, a single 45-minute or 60-minute SCBA cylinder, or 40 minutes of intense work without SCBA, a minimum of 20 minutes rest is required [NFPA 2015a]. In this training session, a few of the rehab visits lasted only 5 minutes.

A member must not return to operations if he/she does not feel adequately rested; if emergency medical or supervisory staff see evidence of medical, psychological, or emotional distress; or if the member appears otherwise unable to safely perform his or her duties [NFPA 2015a]. In this case, a culture existed in which instructors believed trainees would come forward when they needed a break; and, conversely, in which trainees believed they were inadequate if they came forward to express this need. This culture included trainee knowledge that if they sought medical attention and/or were transported to the hospital, they would not be allowed to continue the testing process. The SOG stated that if a trainee was transported to the hospital, the trainee could not complete FFI training with his/her class. They would have to return to the Skills Center at a later date to repeat the entire testing process.

2. Medical. NFPA recommends a written standard operating guideline (SOG) [NFPA 2015a]. This guideline should include a medical component. In this training, a lesson plan was written, but it did not include a medical component, and the course application form did not mention rehab, hydration, or medical requirements. Although trainees were observed by instructors, vital signs were not taken as a baseline prior to training, upon entering rehab, or upon leaving rehab.

3. Fluids. The training center emphasized adequate hydration at numerous times prior to, and during training. For scheduled events, pre-hydration should include an additional 16 ounces of fluids within 2 hours prior to the event. Throughout the training exercises fluids (water and Gatorade®) were available, although the jugs were occasionally found to be empty by trainees. These jugs were subsequently refilled.

Live-fire Training Standards for Structural Fire Fighters. NFPA 1403, *Standard on Live-fire Training Evolutions*, contains the minimum requirements for training fire suppression personnel under live-fire conditions [NFPA 2007, 2012]. (The 2007 edition was current when this incident occurred).

As required by NFPA 1403 a pre-burn briefing and a walk-through of the burn building prior to conducting live-fire training were performed [NFPA 2007]. However, in 2005, the State Fire Service Training made some changes. For safety reasons simulated and/or practice burns to the burn building and the car fire/dumpster fire props were added. These changes resulted in a longer training day, which lead to increased heat exposure and physical exertion. Our record review indicated that since 2005, an average of 1 trainee per 3.6 live-burn classes have been transported to the hospital for HRIs. Additionally, the large class size (25 trainees) resulted in a longer training day.

There must be an awareness of weather conditions including the amount of sunshine and wind speed. The training should be modified, postponed, or canceled, as necessary for extreme weather conditions [NFPA 2015a]. The instructors were aware of the weather, including temperature and humidity, but there was no written guideline for shortening or modifying the training in a hot environment, nor were there another correction factors for sunshine or wearing turnout gear.

All State Fire Service Training instructors that participate in live-burn training were trained to comply with NFPA 1403. An NFPA 1403 checklist was completed prior to the training, and the local fire department was notified. However, an ambulance was not available at the PSC.

The lesson plan for conducting live-fire training evolutions included the following: check in and welcome, facilities information, safety briefing, NFPA 1403 compliance plans, walkthrough demonstrations, and exam information. However, there was no guidance requiring medical information.

Emergency medical services (EMS) personnel are required to be available on-site at training activities to handle injuries [NFPA 2007, 2012]. However, the State Fire Service Training did not have an ambulance, and the closest emergency medical transport unit and advanced life support unit were over 9 minutes away. Furthermore, the State Fire Service Training did not operate under the supervision of a Medical Director or have medical protocols other than the State First Responder Protocol. Therefore, a paramedic may be on-site, but can only provide care at the first responder level (check vital signs, administer oxygen through a non-rebreather mask, provide CPR with a pocket mask, and utilize an AED). The lead instructor at the training session was a paramedic, but available emergency medical equipment was only basic life support.

The instructor-in-charge (lead instructor/paramedic in this case) is responsible for coordinating overall live-fire training area fireground activities to ensure proper levels of safety [NFPA 2007, 2012]. While there were an adequate number of instructors to teach and perform other functions, the lead instructor had many responsibilities, including oversight of the entire training session, participating as an instructor, primary emergency medical person on-scene, and completion of all required paperwork.

Recommendations

Recommendation #1: Conduct live-fire training exercises consistent with NFPA 1403, Standard on Live-fire Training Evolutions.

Discussion: Dedicated emergency medical personnel, with a minimum of basic life support capabilities (BLS), must be standing by at all live-fire exercises.

The lead instructor should be free to oversee the live-fire training without the added responsibilities of instruction and medical treatment. While the lead instructor is performing one task, other areas of training, including rehab, may not receive adequate oversight.

Consider revising the live-fire training standard to give credit for completed blocks of training. Due to trainee/instructor relations and perceptions, trainees may be intimidated by instructors. Trainees may continue intense physically-exerting training in order to complete a course or block of training, even though they are at increased risk of a serious/life-threatening health event. If the training standard allowed for credit to be given for completed blocks of training, trainees would only have to complete the portions they missed. Since the live-fire training had several portions, each portion could count as a separate block.

Another option to consider is to lengthen the live-fire exercises to a two- or three-day event with adequate down time during periods of elevated environmental conditions.

A third option to consider is to conduct the live-fire classes in the spring or fall.

Recommendation #2: Formulate and institute a heat stress prevention program. Minimize disincentives to reporting of symptoms. For example, reconsider policy of not allowing trainees to return to their training course once medically cleared if they left training to seek care for possible HRI and/or rhabodmyolysis. Such a policy creates a disincentive for seeking prompt medical care which may place trainees at an increased risk.

Discussion: A number of guides recommend measures and standards for protection from heat stress injuries. A list can be found in the NIOSH Criteria for a recommended standard, *Occupational Exposure to Hot Environments* [NIOSH 2016]. This criteria document contains standards and recommendations from ACGIH, Occupational Safety and Health Administration (OSHA), American Industrial Hygiene Association, the Armed Forces, American College of Sports Medicine, and the International Organization for Standardization. Although there are occupation/industry-specific components found in each group’s documents, the State Fire Service Training should examine all the guides in their updated form to identify policies that fit their unique situation. A program should include heat casualty risk management (identify and assess hazards; develop and implement controls;

and supervise and evaluate the program) [Department of the Army Training and Doctrine Command 2005], education, a surveillance system for early detection, and compliance monitoring.

When to restrict/cancel live-fire training should be determined based on the heat stress index. When protective clothing is worn, 10°F is added to the index. When in direct sunlight, 10°F is added to the index. Based on available information, training should be monitored carefully when apparent temperature exceeds 90°F; modified or suspended when apparent temperature exceeds 105°F. At 1540 hours on the date of this incident, the basic heat index was 98°F. However, since Trainee A was wearing full bunker gear, the heat stress index was 108°F (the danger zone). Heat cramps or exhaustion is likely, and heat stroke is possible, if exposure is prolonged and there is physical activity. According to the Canadian index, the Humidex, the heat index (including the gear) was 115°F during this incident (danger zone) [NFPA 2015a]. Therefore, in high-heat environments, it is recommended to: (1) significantly reduce both heavy and moderate work, (2) minimize using bunker suits whenever possible, (3) consider cessation of non-essential operations involving moderate physical activity, and (4) cease all non-essential operations involving heavy physical activity [NFPA 2015a].

Consider the following program elements taking place before, during, and after all training courses:

BEFORE TRAINING

- Ensure onsite EMS personnel assess trainee risk for heat illness prior to participation in strenuous training (to include any training in full turnout gear); consider use of a checklist or other screening tool for this purpose.

DURING TRAINING

- Ensure onsite EMS personnel regularly monitor trainees for early signs and symptoms of HRI (e.g., overall appearance, mental status, pulse, temperature) at a frequency based on training duration, intensity, and other factors relevant to heat stress. Ensure instructors brief trainees on the process for promptly reporting suspected HRI in themselves or fellow trainees.
- Ensure trainees are hydrated at all phases of physically demanding tasks.

AFTER TRAINING

- Ensure trainees rehydrate during rehab to fully replace fluid losses from sweating. For multi-day training exercises, encourage trainees to increase fluid intake during time away from training (off-duty hours, rest days) to reduce the risk of dehydration on subsequent training days [NIOSH 2015].
- Seek input from trainees and instructors about removing barriers, real and perceived, to reporting or seeking medical attention for signs/symptoms of possible HRI.

Recommendation #3: Institute a rehabilitation (rehab) program consistent with NFPA 1584, Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises.

Discussion: SOGs should be written that include such rehab components as the following:

- relief from climatic conditions
- rest and recovery
- active and/or passive cooling or warming as needed for incident type and climate conditions

- rehydration (fluid replacement)
- calorie and electrolyte replacement
- medical monitoring
- EMS treatment in accordance with local protocol
- member accountability
- release

SOGs should be distributed to each instructor prior to commencement of live-fire exercises.

Adequate food and fluid replacement should be available. When hydration is taken with a meal, water is appropriate. However, although water can quench thirst, it does not provide needed carbohydrates and electrolytes. Sports drinks should be considered for rehydration and calorie and electrolyte replacement when scheduled activities are of moderate to high intensity and last 1 hour or longer. Drinks with caffeine and alcohol are discouraged, as these interfere with hydration by increasing urine production [USFA 2008].

Expected trainees should be provided with written information on pre-hydration and appropriate clothing requirements at least 2 days prior to live-fire training. By receiving timely, adequate information, prospective trainees could properly prepare for strenuous training in a warmer environment. Maintaining adequate hydration at least 2 days prior to training allows the trainee to be better physiologically prepared for the physically demanding training. Documentation should include information on monitoring urine output, avoiding excessive caffeine and alcohol intake, and drinking adequate fluids. A minimum of 6–8 ounces of fluids every 6 hours is recommended.

The PSC should provide shade in all rehab areas and medical monitoring of all trainees. At the start of training, take vital signs of each trainee and document pertinent medical information such as history, complaints, or symptoms. Predetermined vital sign criteria should be established for admittance to training, assignment to rehab, discharge from rehab, and transport to the hospital. Emergency medical personnel should evaluate trainees arriving at rehab and prior to release for symptoms of a health and/or safety concern. The evaluation should include a set of vital signs. Symptomatic members or members with abnormal findings should receive additional monitoring. Members suffering from heat stress should be removed from active duties. If medical care is given, a medical report should be completed and maintained [NFPA 2015a].

Rehab time should be dedicated, uninterrupted time. In this case, trainees were required to break apart, fluff, and place excelsior in preparation for the live-burns while wearing bunker pants, boots, gloves, and helmets. Rehab time should last at least 10–20 minutes after each hour in full bunker gear. If adequate rehab time causes the training time to be longer, perhaps the training could be extended over 2–3 days. Trainees must be directed by instructors and EMS personnel to completely remove all bunker clothing, including helmets, gloves, and bunker pants prior to entering the rehab area. Instructors must also comply with rehab protocols. Active cooling methods must be provided (i.e., cold and wet towels, forearm immersion, misting, etc.).

Recommendation #4: **Ensure that all fire fighters receive an annual medical evaluation consistent with NFPA 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments.**

Discussion: Guidance regarding the content and frequency of these medical evaluations can be found in NFPA 1582 [NFPA 2013a]. These evaluations are performed to determine a fire fighter's medical ability to perform duties without presenting a significant risk to the safety and health of themselves or others. This medical evaluation should be consistent with the requirements of NFPA 1582.

Recommendation #5: Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of fire fighting, the personal protective equipment used by fire fighters, and the various components of NFPA 1582.

Discussion: According to NFPA 1582, the FD should require that physicians are familiar with the physical demands of fire fighting and the risks that fire fighters encounter and should guide, direct, and advise members with regard to their health, fitness, and suitability for duty [NFPA 2013a]. The physician should review job descriptions and essential job tasks required for all FD positions to understand the physiological and psychological demands of fire fighting and the environmental conditions under which fire fighters perform, as well as the personal protective equipment they must wear during various types of emergency operations.

Recommendation #6: Phase in a mandatory comprehensive wellness and fitness program for fire fighters.

Discussion: Guidance for fire department wellness/fitness programs to reduce risk factors for cardiovascular disease and improve cardiovascular capacity is found in NFPA 1583, Standard on Health-Related Fitness Programs for Fire Fighters, the IAFF/IAFC Fire Service Joint Labor Management Wellness/Fitness Initiative, the U.S. Fire Administration Health and Wellness Guide for the Volunteer Fire and Emergency Services, and in Firefighter Fitness: A Health and Wellness Guide [IAFF, IAFC 2008; NFPA 2015; Schneider 2010; USFA 2004]. Worksite health promotion programs have been shown to be cost effective by increasing productivity, reducing absenteeism, and reducing the number of work-related injuries and lost work days [Aldana 2001; Stein et al. 2000]. Health promotion programs for fire fighters have been shown to reduce coronary heart disease risk factors and improve fitness levels, with mandatory programs showing the most benefit [Blevins et al. 2006; Dempsey et al. 2002; Womack et al. 2005].

The FD has does not have exercise equipment available to members and does not have a wellness/fitness program. Given the FD's structure and budget limitations, helpful resources for starting a program may include the Heart-Healthy Firefighter Program developed by the National Volunteer Fire Council [NVFC, no date] and the Health and Wellness Guide for the Volunteer Fire and Emergency Services [USFA 2004].

Recommendation #7: Perform an annual physical performance (physical ability) evaluation.

Discussion: NFPA 1500 recommends fire department members who engage in emergency operations be annually evaluated and certified by the FD as having met the physical performance requirements identified in paragraph 10.2.3 of the standard [NFPA 2013b]. This is recommended to ensure fire fighters are physically capable of performing the essential job tasks of structural fire fighting. The physical ability test could be incorporated into the FD's training program.

Recommendation #8: Ensure treatment guidelines are followed for a heat-related illness.

Discussion: First aid measures are summarized on the NIOSH "Heat Stress" website https://www.cdc.gov/niosh/topics/heatstress/default.html and in many other resources. Transfer to acute medical care should be accomplished as the clinical condition warrants [Danzl 2015; Kraska 2018].

References

ABM [2010]. Thermal comfort observations – wet bulb globe temperature. Australian government. Australian Bureau of Meteorology, http://www.bom.gov.au/info/thermal_stress/#wbgt.

Abriat A, Brosset C, Brégigeon M, Sagui E [2014]. Report of 182 cases of exertional heatstroke in the French Armed Forces. Mil Med *179*(3):309–314, https://dx.doi.org/10.7205/MILMED-D-13-00315.

ACGIH [2017]. Documentation of the threshold limit values® and biological exposure indices®, 7th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AHA [2016]. Part 7: Adult advanced cardiovascular life support. 2015 American Heart Association Guidelines Update for cardiopulmonary resuscitation and emergency cardiovascular care. Dallas, TX: American Heart Association, https://eccguidelines.heart.org/index.php/circulation/cpr-ecc-guidelines-2/part-7-adult-advanced-cardiovascular-life-support/.

Aldana SG [2001]. Financial impact of health promotion programs: a comprehensive review of the literature. Am J Health Promot *15*(5):296–320, http://dx.doi.org/10.4278/0890-1171-15.5.296.

Armstrong LE, De Luca JP, Hubbard RW [1990]. Time course of recovery and heat acclimation ability of prior exertional heatstroke patients. Med Sci Sports Exerc *22*(1):36–48, PMID: 2406545.

Armstrong LE, Maresh CM, Gabaree CV, Hoffman JR, Kavouras SA, Kenefick RW, Castellani JW, Ahlquist LE [1997]. Thermal and circulatory responses during exercise: effects of hypohydration, dehydration, and water intake. J Appl Physiol (1985) *82*(6):2028–2035, https://doi.org/10.1152/jappl.1997.82.6.2028.

Armstrong LE, Casa DJ, Millard-Stafford D, Moran D, Pyne SW, Roberts WO [2007]. Exertional heat-related illnesses during training and competition - ACSM position stand. Med Sci Sports Exerc *39*(3):556–572, https://dx.doi.org/10.1249/MSS.0b013e31802fa199.

Armstrong LE, Johnson EC, Casa DJ, Ganio MS, McDermott BP, Yamamoto LM, Lopez RM, Emmanuel H [2010]. The American football uniform: uncompensable heat stress and hyperthermic exhaustion. J Athl Train *45*(2):117–127, http://dx.doi.org/10.4085/1062-6050-45.2.117.

Barr D, Gregson W, Reilly T [2010]. The thermal ergonomics of firefighting reviewed. Appl Ergon *41*(1):161–172, http://dx.doi.org/10.1016/j.apergo.2009.07.001.

Bernard TE [1999]. Heat stress and protective clothing – an emerging approach from the United States. Ann Occup Hyg *43*(5):321–327, https://doi.org/10.1016/S0003-4878(99)00058-7.

Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE [2002]. Exertional heat-related illnesses - National Athletic Trainers' Position Statement. J Athl Train *37*(3):329–343, http://dx.doi.org/10.4085/1062-6050-50-9-07.

Blevins JS, Bounds R, Armstrong E, Coast JR [2006]. Health and fitness programming for fire fighters: does it produce results? Med Sci Sports Exerc *38*(Suppl 5):S454.

Bouchama A, Ollivier V, Roberts G, Al Mohanna F, de Prost D, Eldali A, Saussereau E, El-Sayed R, Chollet-Martin S [2005]. Experimental heatstroke in baboon: analysis of the systemic inflammatory response. Shock *24*(4):332–335, https://doi.org/10.1097/01.shk.0000180620.44435.9c.

Bouchama A, Dehbi M, Chaves-Carballo E [2007]. Cooling and hemodynamic management in heatstroke: practical recommendations. Crit Care *11*(3):R54, https://doi.org/10.1186/cc5910.

Brown TP [2004]. Exertional rhabdomyolysis. Early recognition is the key. Phys Sportsmed *32*(4):15–20, http://dx.doi.org/10.3810/psm.2004.04.197.

Bugajska J, Zużewicz K, Szmauz-Dybko M, Konarska M [2007]. Cardiovascular stress, energy expenditure and subjective perceived ratings of fire fighters during typical fire suppression and rescue tasks. Int J Occup Saf Ergon *13*(3):323–331, https://doi.org/10.1080/10803548.2007.11076730.

Buskirk ER, Iampietro PF, Bass DE [2000]. Work performance after dehydration: effects of physical conditioning and heat acclimatization. Wilderness Environ Med *11*(3):204–208, https://doi.org/10.1580/1080-6032(2000)011[0204:WPADEO]2.3.CO;2.

Carter R 3rd, Cheuvront SN, Williams JO, Kolka MA, Stephenson LA, Sawka MN, Amoroso PJ [2005]. Epidemiology of hospitalizations and deaths from heat illness in soldiers. Med Sci Sports Exerc *37*(8):1338–1344, https://doi.org/10.1249/01.mss.0000174895.19639.ed.

Casa DJ, Csillan D, Armstrong LE, Baker LB, Bergeron MF, Buchanan VM, Carroll MJ, Cleary MA, Eichner ER, Ferrara MS, Fitzpatrick TD, Hoffman JR, Kenefick RW, Klossner DA, Knight JC, Lennon SA, Lopez RM, Matava MJ, O'Connor FG, Peterson BC, Rice SG, Robinson BK, Shriner RJ, West MS, Yeargin SW [2009]. Preseason heat acclimatization guidelines for secondary school athletics. J Athl Train *44*(3):332–333, http://dx.doi.org/10.4085/1062-6050-44.3.332.

Casa DJ, DeMartini JK, Bergeron MF, Csillan D, Eichner ER, Lopez RM, Ferrara MS, Miller KC, O'Connor F, Sawka MN, Yeargin SW [2015]. National Athletic Trainers' Association position statement: exertional heat illnesses. J Athl Train *50*(9):986–1000, http://dx.doi.org/10.4085/1062-6050-50.9.07.

CDC (Centers for Disease Control and Prevention) [2006]. Heat-related deaths--- United States, 1999–2003. MMWR *55*(29):796–798.

CDC (Centers for Disease Control and Prevention) [2015]. BMI – body mass index. https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_mi_calculator/BMI_calculator.html.

Cheuvront SN, Kenefick RW, Montain SJ, Sawka MN [2010]. Mechanisms of aerobic performance impairment with heat stress and dehydration. J Appl Physiol (1985), *109*(6):1989–1995, http://dx.doi.org/10.1152/japplphysiol.00367.2010.

Cleary M [2007]. Predisposing risk factors on susceptibility to exertional heat-related illness: clinical decision-making considerations. J Sport Rehabil *16*(3):204–214, https://doi.org/10.1123/jsr.16.3.204.

Costrini A [1990]. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. Med Sci Sports Exerc *22*(1):15–18, PMID: 2406541.

Danzl DF [2015]. Heat-related illnesses. In: Kasper DL, Hauser SL, Jameson JL, Fauci AS, Longo DL, Loscalzo J, eds. Harrison's principles of internal medicine. 19th ed. New York: McGraw-Hill, pp. 479e-1-479e-4.

Dempsey WL, Stevens SR, Snell CR [2002]. Changes in physical performance and medical measures following a mandatory firefighter wellness program. Med Sci Sports Exerc *34*(5):S258, https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1097%2F00005768-200205001-01445.

Department of the Army Training and Doctrine Command [2005]. Enlisted initial entry training policies and administration. Fort Monroe, VA: Department of the Army. Regulation 350-6.

DOD [2003]. Technical bulletin: heat stress control and heat casualty management. TB MED 507/AFPAM 48-152 (I). Washington, DC: Departments of the U.S. Army, Navy, and Air Force, http://www.apd.army.mil/epubs/DR_pubs/DR_a/pdf/web/tbmed507.pdf.

Duffy RM, Roche K, Weider M, Stull J [2008]. Emergency incident rehabilitation. Washington, DC: Federal Emergency Management Agency, http://iaff.org/hs/EIRP/index.html.

Eglin CM [2007]. Physiological responses to fire-fighting: thermal and metabolic considerations. J Human-environ System *10*(1):7–18, http://dx.doi.org/10.1618/jhes.10.7.

Eglin CM, Coles S, Tipton MJ [2004]. Physiological responses of fire-fighter instructors during training exercises. Ergonomics *47*(5):483–494, http://dx.doi.org/10.1080/0014013031000107568.

Epstein Y, Moran DS, Shapiro Y, Sohar E, Shemer J [1999]. Exertional heat stroke: a case series. Med Sci Sports Exerc *31*(2):224–228, https://doi.org/10.1097/00005768-199902000-00004.

Giercksky T, Boberg KM, Farstad IN, Halvorsen S, Schrumpf E [1999]. Severe liver failure in exertional heat stroke. Scand J Gastroenterol *34*(8):824–827, https://doi.org/10.1080/003655299750025778.

Goforth CW, Kazman JB [2015]. Exertional heat stroke in navy and marine personnel: a hot topic. Crit Care Nurse *35*(1):52–59, http://dx.doi.org/10.4037/ccn2015257.

González-Alonso J, Crandall CG, Johnson JM [2008]. The cardiovascular challenge of exercising in the heat. J Physiol *586*(1):45–53, http://dx.doi.org/10.1113/jphysiol.2007.142158.

Greenleaf JE, Harrison MH [1986]. Water and electrolytes. ACS Symp Series *294*:107–124, http://dx.doi.org/10.1021/bk-1986-0294.ch008.

Grucza R, Lecroart JL, Carette G, Hauser JJ, Houdas Y [1987]. Effect of voluntary dehydration on thermoregulatory responses to heat in men and women. Eur J Appl Physiol Occup Physiol *56*(3):317–322, https://doi.org/10.1007/bf00690899.

Haddam Volunteer Fire Department (VFD) [2013]. What's it weigh? Firefighter gear, piece by piece. The Haddams Patch, January 1, https://patch.com/connecticut/thehaddams-killingworth/bp--whats-it-weigh-firefighter-gear-piece-by-piece.

Hubbard RW, Szlyk PC, Armstrong LE [1990]. Influence of thirst and fluid palatability on fluid ingestion during exercise. In: Lamb DR, Gisolfi CV, eds. Perspectives in exercise science and sports medicine: fluid homeostasis during exercise. Indianapolis: Benchmark Press.

IAFF, IAFC [2008]. The fire service joint labor management wellness/fitness initiative. 3rd ed. Washington, DC: International Association of Fire Fighters, International Association of Fire Chiefs.

Jones JG [1991]. The physiological cost of wearing a disposable respirator. Am Ind Hyg Assoc J *52*(6):219–225, http://dx.doi.org/10.1080/15298669191364631.

Joy RJ, Goldman RF [1968]. A method of relating physiology and military performance. A study of some effects of vapor barrier clothing in a hot climate. Mil Med *133*(6):458–470, PMID: 4988425.

Kenney WL, Johnson JM [1992]. Control of skin blood flow during exercise. Med Sci Sports Exerc *24*(3):303–312, PMID: 1549024.

Kraska E [2018]. Heat emergencies. In: Cydulka RK, Fitch MT, Joing SA, Wang VJ, Cline DM, Ma O, eds. Tintinalli's Emergency Medicine Manual, 8th ed. New York, NY: McGraw-Hill. http://accessemergencymedicine.mhmedical.com/content.aspx?bookid=2158&sectionid=162272869.

Lemke B, Kjellstrom T [2012]. Calculating workplace WBGT from meteorological data – a tool for climate change assessment. Ind Health *50*(4):267–278, https://www.jstage.jst.go.jp/article/indhealth/50/4/50_MS1352/_pdf.

Lemon PWR, Hermiston RT [1977]. The human energy cost of fire fighting. J Occup Med *19*(8):558–562, PMID: 894379.

Leon LR, Bouchama A [2015]. Heat stroke. Compr Physiol *5*(2):611–647, http://dx.doi.org/10.1002/cphy.c140017.

Levy D, Garrison RJ, Savage DD, Kannel WB, Castelli WP [1990]. Prognostic implications of echocardiographically determined left ventricular mass in the Framingham Heart Study. N Engl J Med *323*(24):1706–1707, https://search.proquest.com/docview/1282630640/fulltextPDF/CD0E42D46A6147B0PQ/1?accountid=26724.

Liljegren JC, Carhart RA, Lawday P, Tschopp S, Sharp R [2008]. Modeling the WBGT using standard meteorological measurements. J Occup Environ Hyg *5*(10):645–655, http://dx.doi.org/10.1080/15459620802310770.

Lopez R, Casa D, McDermott B, Stearns R, Armstrong L, Maresh C [2011]. Exertional heat stroke in the athletic setting: a review of the literature. Athl Train Sports Health Care *3*(4):189–200, http://dx.doi.org/10.3928/19425864-20101230-06.

Lugo-Amador NM, Rothenhaus T, Moyer P [2004]. Heat-related illness. Emerg Med Clin North Am *22*(2):315–327, https://doi.org/10.1016/j.emc.2004.01.004.

Marzio L, Formica P, Fabiani F, LaPenna D, Vecchiett L, Cuccurullo F [1991]. Influence of physical activity on gastric emptying of liquids in normal human subjects. Am J Gastroenterol *86*(10):1433–1436, PMID: 1928033.

McArdle WD, McArdle FL, Klatch VL [2010]. Exercise physiology. In: McArdle WD, McArdle FL, Klatch VL, eds. Exercise physiology: nutrition, energy, and human performance. 7th ed. Philadelphia: Lippincott Williams and Wilkins.

McDermott BP, Casa DJ, Ganio MS, Lopez MR, Yeargin SW, Armstrong LE, Maresh CM [2009]. Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. J Athl Train *44*(1):84–93, http://dx.doi.org/10.4085/1062-6050-44.1.84.

McLellan TM, Selkirk GA [2006]. The management of heat stress for the firefighter: a review of work conducted on behalf of the Toronto Fire Service. Ind Health *44*(3):414–426, https://www.jstage.jst.go.jp/article/indhealth/44/3/44_3_414/_pdf.

Montain SJ, Cheuvront SN [2008]. Fluid, electrolyte and carbohydrate requirements for exercise. In: Taylor NAS, Groeller H, eds. Physiological bases for human performance during work and exercise. Edinburgh: Churchill Livingstone Elsevier.

Moseley PL [1994]. Mechanisms of heat adaptation: thermotolerance and acclimatization. J Lab Clin Med *123*(1):48–52, PMID: 8288960.

NEHC [2007]. Prevention and treatment of heat and cold stress injuries. Technical Manual NEHC-TM-OEM 6260.6A. Portsmouth, VA: Navy Environmental Health Center, Bureau of Medicine and Surgery, http://www.med.navy.mil/sites/nmcphc/Documents/oem/Heat_and_Cold_final_June07.pdf.

NFPA [2007]. Standard on live fire training evolutions. Quincy, MA: National Fire Protection Association. NFPA 1403.

NFPA [2012]. Standard on live fire training evolutions. Quincy, MA: National Fire Protection Association. NFPA 1403.

NFPA [2013a]. Standard on comprehensive occupational medical program for fire departments. Quincy, MA: National Fire Protection Association. NFPA 1582.

NFPA [2013b]. Standard on fire department occupational safety and health program. Quincy, MA: National Fire Protection Association. NFPA 1500.

NFPA [2015a]. Standard on the rehabilitation process for members during emergency operations and training exercises. Quincy, MA: National Fire Protection Association. NFPA 1584.

NFPA [2015b]. Standard on health-related fitness programs for fire fighters. Quincy, MA: National Fire Protection Association. NFPA 1583.

NIOSH [2015]. Evaluation of heat stress, heat strain, and rhabdomyolysis during structural fire fighter training. By Eisenberg J, Methner M, Dowell CH, Mueller C. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 2012-0039-3242, https://www.cdc.gov/niosh/hhe/reports/pdfs/2012-0039-3242.pdf.

NIOSH [2016]. Criteria for a recommended standard: occupational exposure to heat and hot environments, revised criteria 2016. By Jacklitsch B, Williams WJ, Musolin K, Coca A, Kim J-H, Turner N. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2016-106, https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf.

Nunneley SA, Reardon MJ [2002]. Prevention of heat-related illness. In: Wenger CB, ed. Medical aspects of harsh environments, Vol 1, Section I: Hot environments. Washington, DC: Office of The Surgeon General, Department of the Army, http://www.bordeninstitute.army.mil/published_volumes/harshEnv1/harshEnv1.html.

Nunneley SA, Reardon MJ [2009]. Prevention of heat illness. In: Wenger CB, ed. Medical aspects of harsh environments, https://ke.army.mil/bordeninstitute/published_volumes/harshEnv1/Ch6-PreventionofHeatIllness.pdf.

National Volunteer Fire Council (NVFC). Heart-Healthy Firefighter Program. https://www.nvfc.org/programs/heart-healthy-firefighter-program/.

O'Connell ER, Thomas PC, Cady LD, Karwasky RJ [1986]. Energy cost of simulated stair climbing as a job-related task in fire fighting. J Occup Med *28*(4):282–284, PMID: 3701477.

Parsons K [2006]. Heat stress standard ISO 7243 and its global application. Ind Health *44*(3):368–379, http://dx.doi.org/10.2486/indhealth.44.368.

Pennington JD, Crawford DL, Meyer EC, Arentzen WP, Allen L Jr [1980]. Occupational and environmental health – prevention, treatment, and control of heat injury. TB MED 507, NAVMED P-5052-5, AFP 160-1, Headquarters, Departments of Army, Navy, and Air Force, http://www.med.navy.mil/directives/Pub/5052-5.pdf.

Petruzzello SJ, Gapin JI, Snook E, Smith DL [2009]. Perceptual and physiological heat strain: examination in firefighters in laboratory- and field-based studies. Ergonomics *52*(6):747–754, http://dx.doi.org/10.1080/00140130802550216.

Rav-Acha M, Hadad E, Epstein Y, Heled Y, Moran DS [2004]. Fatal exertional heat stroke: a case series. Am J Med Sci *328*(2):84–87, https://doi.org/10.1097/00000441-200408000-00003.

Sawka MN, Young AJ, Francesconi RP, Muza SR, Pandolf KB [1985]. Thermoregulatory and blood responses during exercise at graded hypohydration levels. J Appl Physiol *59*(5):1394–1401, https://doi.org/10.1152/jappl.1985.59.5.1394.

Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS [2007]. American College of Sports Medicine position stand: exercise and fluid replacement.Med Sci Sports Exerc *39*(2):377–390, http:/dx.doi.org/10.1249/mss.0b013e31802ca597.

Schneider EL [2010]. Firefighter fitness: a health and wellness guide. New York: Nova Science Publishers.

Shapiro Y, Rosenthal T, Sohar E [1973]. Experimental heat-stroke: a model in dogs. Arch Int Med *131*(5):688–691, http://dx.doi.org/10.1001/archinte.1973.00320110072010.

Shibolet S, Lancaster MC, Danon Y [1976]. Heat stroke: a review. Aviat Space Environ Med *47*(3):280–301, PMID: 769777.

Smith DL, Petruzzello SJ, Chludzinski MA, Reed JJ, Woods JA [2005]. Selected hormonal and immunological responses to strenuous live-fire firefighting drills. Ergonomics *48*(1):55–65, http://dx.doi.org/10.1080/00140130412331303911.

Stacey MJ, Parsons IT, Woods DR, Taylor PN, Ross D, J Brett S [2015]. Susceptibility to exertional heat illness and hospitalisation risk in UK military personnel. BMJ Open Sport Exerc Med *1*(1):e000055, http://dx.doi.org/10.1136/bmjsem-2015-000055.

Stein AD, Shakour SK, Zuidema RA [2000]. Financial incentives, participation in employer sponsored health promotion, and changes in employee health and productivity: HealthPlus health quotient program. J Occup Environ Med *42*(12):1148–1155, https://doi.org/10.1097/00043764-200012000-00005.

Taylor NAS, Kondo N, Kenny WL [2008]. The physiology of acute heat exposure, with implications for human performance in the heat. In: Taylor NAS, Groeller H, eds. Physiological bases of human performance during work and exercise. 1st ed. Edinburgh: Elsevier.

Tipton M, Pandolf K, Sawka M, Werner J, Taylor N [2008]. Physiological adaptation to hot and cold environments. In: Taylor N, Groeller H, eds. Physiological bases of human performance during work and exercise. Edinburgh: Churchill Livingstone Elsevier.

USAPHC [2016]. Heat-related illness risk management slides for unit/installation training applications. Aberdeen Proving Ground, MD: U.S. Army Medical Department, U.S. Army Public Health Center, http://phc.amedd.army.mil/topics/discond/hipss/Pages/HeatInjuryPrevention.aspx.

USFA [2004]. Health and wellness guide. Emmitsburg, MD: Federal Emergency Management Agency; United States Fire Administration. Publication No. FA-267.

USFA [2008]. Emergency incident rehabilitation. Emmitsburg, MD: Federal Emergency Management Agency; United States Fire Administration.

Voltaire B, Galy O, Coste O, Racinais S, Callis A, Blonc S, Hertogh C, Hue O [2002]. Effect of fourteen days of acclimatization on athletic performance in tropical climate. Can J Appl Physiol *27*(6):551–562, https://doi.org/10.1139/h02-031.

Walter EJ, Carraretto M [2016]. The neurological and cognitive consequences of hyperthermia. Crit Care *20*(1):199, http://dx.doi.org/10.1186/s13054-016-1376-4.

White MK, Hodous TK [1987]. Reduced work tolerance associated with wearing protective clothing and respirators. Am Ind Hyg Assoc J *48*(4):304–310, PMID: 3591644.

Womack JW, Humbarger CD, Green JS, Crouse SF [2005]. Coronary artery disease risk factors in firefighters: effectiveness of a one-year voluntary health and wellness program. Med Sci Sports Exerc *37*(Suppl 5):S385.

Wyndham CH [1973]. The physiology of exercise under heat stress. Annu Rev Physiol *35*:193–220, http://dx.doi.org/10.1146/annurev.ph.35.030173.001205.

Zeller L, Novack V, Barski L, Jotkowitz A, Almog Y [2011]. Exertional heatstroke: clinical characteristics, diagnostic and therapeutic considerations. Eur J Intern Med *22*(3):296–299, http://dx.doi.org/10.1016/j.ejim.2010.12.013.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Investigator Information

This incident was investigated by the NIOSH Fire Fighter Fatality Investigation and Prevention Program, Cardiac and Medical Line of Duty Deaths (LODD) Investigations Team in Cincinnati, Ohio, Mr. Tommy Baldwin (MS) led the investigation and co-authored the report. Mr. Baldwin is a Safety and Occupational Health Specialist, a National Association of Fire Investigators (NAFI) Certified Fire and Explosion Investigator, an International Fire Service Accreditation Congress (IFSAC) Certified Fire Officer I, and a former Fire Chief and Emergency Medical Technician. Drs. Judith Eisenberg and Wendi Dick, current and former Team Leads for Cardiac and Medical LODD Investigations respectively, provided medical consultation and contributed to the report. The team's current investigator, Robert Saunders, a current fire chief and EMT, also contributed to this report.

Additional Information

A number of fire departments across the country have SCBA training props and maze facilities. Physiological strain from exertion or heat stress has been involved in medically-related line-of-duty deaths that have occurred in SCBA maze trailers. Below are links to other NIOSH fire fighter fatality investigation reports involving SCBA maze training.

Fire Fighter Trainee Suffers Sudden Cardiac Death During Maze Training – Virginia (2008), https://www.cdc.gov/niosh/fire/pdfs/face200902.pdf

Captain Dies from Hyperthermia and Exertional Heat Stroke While Performing Advanced Survival Training – Texas (2012), https://www.cdc.gov/niosh/fire/pdfs/face201227.pdf

Disclaimer

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Photo 1. Burn building. PSC photo.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Photo 2. Hidden wall fire prop. PSC photo.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Photo 3. Fire extinguisher prop. PSC photo.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Photo 4. Pallet/dumpster fire and car fire props. PSC photo.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Photo 5. Rehab pavilion. PSC photo.

Table 1

Dry and Wet Bulb Temperature, Relative Humidity, and Heat Indices

Nearby Local Airport*

May 31, 2008

Hour	Dry Bulb Temperature	Wet Bulb Temperature	Relative Humidity	Wind (mph)^	Cloud Cover	Heat Index**	Estimated WGBT***
0800	76°F	69°F	69%	8	Partly	77°F	79°F
1100	82°F	74°F	67%	8	Scattered	85°F	84°F
1330	89°F	78°F	59%	11	Scattered	97°F	90°F
1540	88°F	76°F	57%	11	Mostly	93°F	88°F
1600	88°F	76°F	57%	11	Mostly	93°F	88°F

°F = degrees Fahrenheit

^ = miles per hour

*NOAA [2008]. Quality controlled local climatological data. National Oceanic and Atmospheric Administration, http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N.

**NOAA [2011]. Heat index calculator. National Weather Service, National Oceanic and Atmospheric Administration, http://www.srh.noaa.gov/epz/?n=wxcalc_heatindex.

***Bureau of Meteorology [2010]. Thermal comfort observations - web bulb globe temperature (WBGT). Australian Government, http://www.bom.gov.au/info/thermal_stress/#wbgt.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Appendix A

Live-fire Exercises: Interior and Exterior Evolutions

Interior Evolutions - Burn Building

The two-story burn building is located in the south east portion of the main building. It is constructed of steel with a concrete floor and measures 16 feet by 33 feet. There are 2 burn rooms downstairs and 1 burn room upstairs along with attic space and a panel chop out on the roof. The building is equipped with a 10-foot by 10-foot exterior platform and stairway. The interior of the burn building is composed of 1-inch thick panels of Padgenite (crushed/milled calcium silicate).

The burn building fires is fueled by Excelsior. Excelsior is a shredded wood material that needs to be "fluffed" from its' storage bales. Approximately one-fourth of a bale is used for each burn evolution. No other fuel (pallets or propane) was used.

During the burn building exercises, the instructors utilized an incident management system. Instructors rotate between the roles of Incident Commander, fire attack, RIT, and rehab. A staff member is assigned as pump operator while another instructor serves as proctor and evaluates the trainees' performance.

The burn building training was broken into two components: (1) a guided walkthrough portion with no actual trainee fire fighting in the morning (the instructors performed the fire fighting as an example), and (2) afternoon rotation allowing the trainees to perform the live-fire suppression.

In general, trainees were divided into groups of 6, and then further divided into 2-person teams. Each team would rotate between the following 3 assignments: entry/attack, backup/ventilation, and RIT. All teams worked two separate fires; one downstairs and one upstairs. The assigned entry/attack team advanced the hoseline to the fire and perform either direct or indirect attacks as instructed. Although all teams wore wear full bunker gear with SCBA, only the entry/attack team was "on air." The entry teams would rotate the nozzle person between the two (upstairs and downstairs) fires. During team assignment changes, short breaks of about 10 minutes were allowed, but PPE was not allowed to be doffed.

Before starting the live-fire training, coordination was established between the command, fire attack leader, RIT leader, interior safety, and ignition officer. At the appropriate time the fire would be lit by the ignition officer and the two-person fire attack team would enter the building.

If any problem is experienced, the evacuation signal would be sounded (3 blasts on the engine's airhorn). At that point, all personnel inside the building would be instructed to evacuate the building and the staff would determine what action is required to correct the problem.

Appendix A cont.

Exterior Evolutions

Hidden Wall Fire: The hidden wall prop consisted of an approximate 4-foot wall constructed of metal studs and a method of sliding sheetrock panels in front of the studs. Excelsior or hay was placed behind the sheetrock and ignited to produce a small, smoldering fire. For this rotation, the trainees were placed in teams of three. One trainee would carry the hoseline, another would carry a forcible entry tool (a Halligan® bar), and the third would carry salvage tools (a tub and a salvage cover). To complete this rotation, the fire had to be located, the salvage cover placed, the wall opened up, and the fire extinguished. While the group's 1st team was participating, the second team of three was staged on the RIT hoseline wearing full bunker gear and SCBA and mask but not "on air."

Fire Extinguisher Prop: The fire extinguisher prop consisted of an electrical box with a switch and a trough for flammable liquids. Once the trough liquid was ignited, the trainees sprayed the extinguisher on the electrical panel, flipped the switch to the "off" position, then continued to the trough and directed the extinguisher onto the fuel until the fire was extinguished. The group would work in teams of two for this exercise, and the remaining members would be on the RIT hoseline. All trainees would remain in full bunker gear and SCBA (mask in place but not on air) throughout this rotation.

Pallet/Dumpster Fire: At the pallet/dumpster fire rotation, trainees in two-person teams would wear full bunker gear with SCBA (mask in place but not on air). One team (mask in place and on air) would be on the nozzle, the second team (mask in place but not on air) would back them up, pulling slack, and the third team (mask in place but not on air) would be on the RIT hoseline. Each team would practice a "dry run" on extinguishing the simulated burning pallets and would move over to open the dumpster, stir the contents, and extinguish the dumpster fire. The teams would rotate positions until all teams completed this exercise. After practicing a "dry run," each team would participate in actual live-fire training, taking approximately 40 minutes per team rotation.

Car Fire Prop: The car fire consisted of a mockup of a car on fire. Trainees would wear full bunker gear and SCBA (mask in place and on air). Two-person teams would be formed, and each team would rotate personnel until each person had handled the hose nozzle. After practicing a "dry run" of this prop, teams would participate in actual live-fire training, taking approximately 40 minutes per team rotation.

Appendix B

Instructor Positions, Responsibilities, and Qualifications

PSC coordinator is responsible for the following:

- plan and coordinate the entire training event
- ensure compliance with NFPA 1403 and other pertinent safety procedures
- coordinate instructors, assistants, and safety officer(s)
- verify training levels and competencies of instructors, assistants, and safety officers
- order consumables such as excelsior, propane, etc.
- ensure that training records are completed

Qualifications of the coordinator include: (1) Instructor I; (2) FFI or equivalent; (3) FFII if teaching any of the following: (a) FFII, (b) flammable liquids and gas firefighting [FLAG], or (c) liquefied petroleum gas [LPG] courses; and (4) Live-fire Train-the-Trainer certification.

Live-fire instructors are responsible for the following:

- present the classroom/skills training session
- pre-fire safety briefing
- ensure compliance with safety procedures

Qualifications for the live-fire instructors include: (1) Instructor I; (2) FFI or equivalent; (3) FFII if teaching any of the following: (a) FFII, (b) FLAG, or (c) LPG courses; and (4) Live-fire Train the Trainer certification.

Live-fire assistants (assigned by the live-fire coordinator) were responsible for the following:

- assist with live-fire training which could include water supply, igniter, prop assistant, etc.

Qualifications for a live-fire assistant included: (1) Structural Fire Fighter, FFI, or equivalent; (2) Live-fire Train the Trainer certification; and (3) Ignition officers and igniters must also demonstrate their ability to the lead instructor.

Safety officers were assigned by the live-fire coordinator and were responsible for the following:

- ensure compliance with safety procedures
- ensure all instructors, assistants, and trainees have and wear NFPA compliant personal protective equipment and SCBA during training sessions
- establish "hot" zones with cones or other visible indicators
- intervene and stop operations when, in their judgment, a dangerous or unsafe condition exists

Qualifications for the safety officer were based on training, experience, and knowledge of NFPA 1500 and NFPA 1403 as determined by the State Fire Service Training office.

Appendix C

Incident Timeline Estimates for Members of the Blue Group

Hours:

0700: Instructors, staff, and trainees arrived at the State Fire Service Training PSC

0800: Introductions, Safety Briefing

0900: Reports to Rehab

1000: Walk-through and observation of interior live-fire suppression at burn building

1100: Hidden wall prop live-fire
Blue group trainee (Trainee B) suffers heat-related illness and transported to ED

1120: Second Blue group trainee (Trainee C) suffers heat-related illness (managed on-scene)

1130: Dumpster fire prop walkthrough

1200: Car fire prop walkthrough

1220: Lunch break

1330: Training resumes; assigned to Rehab

1445: Interior live-fire suppression at burn building

1600: Rest in rehab

1630: Pallet/dumpster prop live-fire

1700: Car prop live-fire

1725: Training completed; trainees and instructors pick up hose and equipment

1815: Trainee A found in unconscious in bathroom stall

Appendix D

Autopsy Findings

- Hyperthermia
    - History of exercising in a hot environment
    - "Vitreous electrolytes consistent with dehydration" (values not reported)
        - Normal vitreous sodium 135–150 milliequivalents per liter
        - Normal vitreous urea nitrogen 8–20 milligrams per deciliter [Rose and Collins 2008]
    - Generalized brain edema
- Hypertensive atherosclerotic cardiovascular disease (CVD) [Weiner and Baggish 2012]
    - Cardiomegaly (enlarged heart) (heart weighed 560 grams [g]; predicted normal weight is between 327 g and 570 g as a function of gender, age, and body weight) [Kitzman et al. 1988; Silver and Silver 2001]
    - Left ventricular hypertrophy (LVH) - Left ventricle and interventricular septum walls thickened (1.8 centimeters [cm] and 2.2 cm, respectively;
        - Normal at autopsy is 0.76–0.88 cm [Colucci and Braunwald 1997];
        - Normal by echocardiographic measurement is 0.6–1.1 cm) [Armstrong an Feigenbaum 2001]
- Coronary artery disease
    - Moderate (75%) focal narrowing of the left anterior descending coronary artery
    - Mild (50%) focal narrowing of the right coronary artery
    - No evidence of recent thrombus (blood clot in the coronary arteries)
- Normal cardiac valves
- No evidence of a pulmonary embolus (blood clot in the lung arteries)
- Obesity
- Blood tests for drugs and alcohol were negative

REFERENCES

Armstrong WF, Feigenbaum H [2001]. Echocardiography. In: Braunwald E, Zipes DP, Libby P, eds. Heart disease: a text of cardiovascular medicine. 6th ed. Vol. 1. Philadelphia, PA: W.B. Saunders Company, p. 167.

Colucci WS, Braunwald E [1997]. Pathophysiology of heart failure. In: Braunwald, ed. Heart disease. 5th ed. Philadelphia, PA: W.B. Saunders Company, p. 401.

Kitzman DW, Scholz DG, Hagen PT, Ilstrup DM, Edwards WD [1988]. Age-related changes in normal human hearts during the first 10 decades of life. Part II (maturity): a quantitative anatomic study of 765 specimens from subjects 20 to 99 years old. Mayo Clin Proc *63*(2):137–146, http://dx.doi.org/10.1016/S0025-6196(12)64946-5.

Rose KL, Collins KA [2008]. Vitreous postmortem chemical analysis. College of American Pathologists, NewsPath: News for the Pathology Community, December 2008, http://www.cap.org/apps/docs/newspath/0812/vitreous_postmortem_chemical_analysis.pdf.

Silver MM, Silver MD [2001]. Examination of the heart and of cardiovascular specimens in surgical pathology. In: Silver MD, Gotleib AI, Schoen FJ, eds. Cardiovascular pathology. 3rd ed. Philadelphia, PA: Churchill Livingstone, pp. 8-9.

Weiner RB, Baggish AL [2012]. Exercise-induced cardiac remodeling. Progress in Cardiovascular Diseases *54*(5):380–386, http://dx.doi.org/10.1016/j.pcad.2012.01.006.

Appendix E

Estimated Metabolic Heat Production (in kilocalories per minute) by Task Analysis during Interior Live Fire Prop, State Fire Service Training's Professional Skills Center, OK [ACGIH 2015; ISO 2004; NIOSH 1986]

Various Fire Fighter Positions	kcal/min*
A. Body position and movement	
Intermittent walking up/down/crawling	2.0 kcal/min
B. Type of work –	
Both hands – heavy	3.5 kcal/min
C. Basal metabolism	1.0 kcal/min
Metabolic rate per minute	6.5 kcal/min
Metabolic rate per hour	390 kcal/hr

D. Multiply by the weight correction factor**: 390 kcal/hr x 1.9 = 741 kcal/hr

Total estimated metabolic rate = 741 kcal/hour

Appendix F

Estimated Metabolic Heat Production (in kilocalories per minute) by Task Analysis during Exterior Hidden Wall Fire Prop, State Fire Service Training's Professional Skills Center, OK [ACGIH 2015; ISO 2004; NIOSH 1986]

Various Fire Fighter Positions	kcal/min*
A. Body position and movement	
Standing	0.6 kcal/min
B. Type of work –	
Both hands – heavy	3.5 kcal/min
C. Basal metabolism	1.0 kcal/min
Metabolic rate per minute	5.1kcal/min
Metabolic rate per hour	306 kcal/hr

D. Multiply by the weight correction factor**: 306 kcal/hr x 1.9 = 581 kcal/hr

Total estimated metabolic rate = 581 kcal/hour

Appendix G

Estimated Metabolic Heat Production (in kilocalories per minute) by Task Analysis during Exterior Fire Extinguisher Prop, State Fire Service Training's Professional Skills Center, OK [ACGIH 2015; ISO 2004; NIOSH 1986]

Various Fire Fighter Positions	kcal/min*
A. Body position and movement	
Standing	0.6 kcal/min
B. Type of work –	
Both hands – light	1.5 kcal/min
C. Basal metabolism	1.0 kcal/min
Metabolic rate per minute	3.1 kcal/min
Metabolic rate per hour	186 kcal/hr

D. Multiply by the weight correction factor**: 186 kcal/hr x 1.9 = 353 kcal/hr

Total estimated metabolic rate = 353 kcal/hour

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Appendix H

Estimated Metabolic Heat Production (in kilocalories per minute) by Task Analysis during Pallet/Dumpster Fire Prop, State Fire Service Training's Professional Skills Center, OK [ACGIH 2015; ISO 2004; NIOSH 1986]

Various Fire Fighter Positions	kcal/min*
A. Body position and movement	
Standing	0.6 kcal/min
B. Type of work –	
Both hands – light	1.5 kcal/min
C. Basal metabolism	1.0 kcal/min
Metabolic rate per minute	3.1 kcal/min
Metabolic rate per hour	186 kcal/hr

D. Multiply by the weight correction factor**: 186 kcal/hr x 1.9 = 353 kcal/hr

Total estimated metabolic rate = 353 kcal/hour

Appendix I

Estimated Metabolic Heat Production (in kilocalories per minute) by Task Analysis during Car Fire Prop, State Fire Service Training's Professional Skills Center, OK [ACGIH 2015; ISO 2004; NIOSH 1986]

Various Fire Fighter Positions	kcal/min*
A. Body position and movement	
Standing	0.6 kcal/min
B. Type of work –	
Both hands – light	1.5 kcal/min
C. Basal metabolism	1.0 kcal/min
Metabolic rate per minute	3.1 kcal/min
Metabolic rate per hour	186 kcal/hr

D. Multiply by the weight correction factor**: 186 kcal/hr x 1.9 = 353 kcal/hr

Total estimated metabolic rate = 353 kcal/hour

FOOTNOTES AND REFERENCES – APPENDICES E–I

*For a standard male worker of 70 kilograms (kg) (154 pounds) body weight and 1.8 m^2 (19.4 ft^2) body surface [NIOSH 1986].

**The weight correction factor (WCF) is used when employee weight plus personal protection ensemble and equipment weigh more than 154 pounds (lbs). The WCF is calculated by dividing the sum of the employee's current body weight (BW) and the PPE plus equipment weight (EW) by 154 lbs [WCF = (BW + EW) ÷ 154 lbs]. Trainee A's correction factor on May 31, 2008, was estimated to be (268 lbs + 30 lbs) ÷ 154 lbs = 1.9.

ACGIH [2015]. Documentation of the threshold limit values® and biological exposure indices®, 7th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

International Organization for Standardization (ISO) 8996 [2004]. Ergonomics of the thermal environment – determination of metabolic rate. Geneva, Switzerland.

NIOSH [1986]. Criteria for a recommended standard: occupational exposure to hot environments, rev. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 86-113.

Fire Fighter Trainee Dies from Hyperthermia After Live-Fire Training—Oklahoma

Appendix J

Estimating Wet Globe Bulb Temperature (WBGT)

From Temperature and Relative Humidity*

Wet Bulb Globe Temperature (WBGT) from Temperature and Relative Humidity

Relative Humidity (%) \ Temperature (°C)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	15	16	16	17	18	18	19	19	20	20	21	22	22	23	23	24	24	25	25	26	27	27	28	28	29	29	30	31	31	32	32
5	16	16	17	18	18	19	19	20	21	21	22	22	23	24	24	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35
10	16	17	17	18	19	19	20	21	21	22	23	23	24	25	25	26	27	27	28	29	30	30	31	32	32	33	34	35	36	36	37
15	17	17	18	19	19	20	21	21	22	23	23	24	25	26	26	27	28	29	29	30	31	32	33	33	34	35	36	37	38	39	
20	17	18	18	19	20	21	21	22	23	24	24	25	26	27	27	28	29	30	31	32	32	33	34	35	36	37	38	39			
25	18	18	19	20	20	21	22	23	24	24	25	26	27	28	28	29	30	31	32	33	34	35	36	37	38	39					
30	18	19	20	20	21	22	23	23	24	25	26	27	28	29	29	30	31	32	33	34	35	36	37	39							
35	18	19	20	21	22	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39								
40	19	20	21	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39									
45	19	20	21	22	23	24	25	26	27	27	28	29	30	32	33	34	35	36	37	38											
50	20	21	22	23	23	24	25	26	27	28	29	30	31	33	34	35	36	37	39												
55	20	21	22	23	24	25	26	27	28	29	30	31	32	34	35	36	37	38													
60	21	22	23	24	25	26	27	28	29	30	31	32	33	35	36	37	38														
65	21	22	23	24	25	26	27	28	29	31	32	33	34	36	37	38															
70	22	23	24	25	26	27	28	29	30	31	33	34	35	36	38	39								WBGT > 40							
75	22	23	24	25	26	27	29	30	31	32	33	35	36	37	39																
80	23	24	25	26	27	28	29	30	32	33	34	36	37	38																	
85	23	24	25	26	28	29	30	31	32	34	35	37	38	39																	
90	24	25	26	27	28	29	31	32	33	35	36	37	39																		
95	24	25	26	27	29	30	31	33	34	35	37	38																			
100	24	26	27	28	29	31	32	33	35	36	38	39																			

Note: This table is compiled from an approximate formula which only depends on temperature and humidity. The formula is valid for full sunshine and a light wind

*Source: Bureau of Meteorology [2010]. Thermal comfort observations - web bulb globe temperature (WBGT). Australian Government, http://www.bom.gov.au/info/thermal_stress/#wbgt.