Evaluation of Heat Stress, Heat Strain, and Rhabdomyolysis in Park Employees

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from the safety manager at a national park in California. The safety manager asked NIOSH to evaluate park employees working in extreme heat, review the park's current and proposed heat stress management policies, and recommend ways to prevent heat-related illnesses.

What We Did

- We asked employees to fill out a questionnaire about their work history, medical history, and health symptoms.
- We measured core body temperature and heart rate in nine employees on 4 days in July 2013.
- We analyzed employees' blood each day for markers of muscle breakdown and dehydration during 4 workdays and the following 3 rest days.
- We asked about symptoms of heat-related illness and muscle breakdown each workday.
- We estimated how hard the employees were working.
- We measured temperature and humidity each day while employees worked outdoors.
- We reviewed the park's current and proposed heat stress policies.
- We looked at park records of work-related injuries and illness.

What We Found

- One employee had a core body temperature over our defined heat strain criteria.
- No employees were dehydrated or had significant muscle breakdown at work.
- Several employees had sustained maximum heart rates consistent with heat strain.
- Environmental conditions were often above limits for heat stress at work.
- The heat stress policy did not follow NIOSH's heat stress recommendations for work and rest times.
- Employees were not consistent in following the park's heat stress policy. For example, employees did not always observe the "buddy system" rule.
- Employees did not always carry radios nor use them properly.

We evaluated nine park employees who were working in extreme heat. Some employees had signs of heat strain although none of the nine employees had dehydration, clinically significant muscle breakdown, or heat-related illnesses. We recommend scheduling strenuous outdoor work during cooler months, at night, or early in the morning. We also recommend forming a work group of employees, the safety manager, and a physician medical advisor to develop standard operating procedures for self-monitoring when working in the heat, additional training, and changes to the heat stress policy.

What the Employer Can Do

- Avoid moderate to very heavy outdoor work tasks during summer months. If it is necessary to perform these tasks during summer months, work at night.
- Reduce the amount of time employees work in extremely hot weather.
- Revise the park's heat stress policy to include work/rest periods based on NIOSH wet bulb globe temperature and workload.
- Require employee self-monitoring as part of the heat stress policy.
- Develop a workgroup of employees, a physician medical advisor, and the safety manager to make decisions on self-monitoring options and standard operating procedures.
- Stop work when the NIOSH wet bulb globe temperature heat stress ceiling limit is exceeded or provide employees with adequate protective clothing and equipment.

What Employees Can Do

- Follow the heat stress policy at all times.
- Carry a radio at all times.
- Avoid working alone. Use the buddy system.
- Learn the signs and symptoms of excessive heat strain.
- Self-monitor and document signs and symptoms of heat strain.
- Tell your supervisor immediately if you have symptoms of heat-related illness or if you note these symptoms in a coworker.
- Drink plenty of fluids, and take rest breaks as needed.
- Volunteer to be on the work group to develop self-monitoring guidance for working in the heat.

Abbreviations

AC	Air-conditioning
ACGIH®	American Conference of Governmental Industrial Hygienists
bpm	Beats per minute
BUN	Blood urea nitrogen
CBT	Core body temperature
CFR	Code of Federal Regulations
CK	Creatine kinase
F	Fahrenheit
HR	Heart rate
HRI	Heat-related illness
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
REL	Recommended exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
WBGT	Wet bulb globe temperature

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Introduction

The Health Hazard Evaluation Program received a request from the safety manager at a park in California about the potential for heat-related illness (HRI) in employees who work outdoors in extreme heat. We conducted our on-site evaluation in July 2013. This request followed a previous health hazard evaluation request in November 2012, in which general recommendations were made to improve the heat stress policy, but no on-site evaluation was done.

The park covers 3.4 million acres with elevations ranging from 282 feet below sea level to 11,049 feet above sea level. The lower areas of the park are approximately 20° Fahrenheit (°F) warmer than higher elevations. July is the hottest month in the park, when average daily temperatures are 88°F–116°F. The park had a stargazing program that discouraged night-time activities (including maintenance work) requiring the use of artificial lighting. Park maintenance activities were scheduled as funding became available without regard to the season.

The park employed approximately 100 people. Our evaluation focused on the following:

- At a higher elevation in the park, five maintenance employees removed about 10,000 square feet of asphalt from a parking lot. After removing the asphalt, employees prepared the surface for repaving using a grader, Bobcat®, backhoe, shovels, and rakes.
- At a lower elevation in the park, one employee installed exterior bricks on a campground kiosk, and two other employees repaired housing and maintained the grounds.
- At multiple locations within the park, an archaeologist surveyed sites.

Heat-Related Illness and Rhabdomyolysis

Heat stress is the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment [NIOSH 2013]. Many bodily responses to heat stress are desirable and beneficial; however, at some stage of heat stress, the body's compensatory measures cannot maintain internal body temperature at the level required for normal functioning. As a result, the risk of HRI and accidents occurring as a result of HRI-related impaired mental status increase.

The body's response to heat stress is called heat strain. Heat strain is dependent upon a number of factors and cannot be predicted on the basis of environmental heat stress measurements alone. As a result of working in a hot environment, HRI may develop. HRI includes disorders such as:

- Heat stroke – An acute medical emergency arising during exposure to heat resulting in an excessive rise in body temperature and failure of the temperature regulating mechanism. It is characterized by a change in mental status, which can range from confusion or bizarre behavior to seizures and loss of consciousness. It is often preceded by signs and symptoms of heat exhaustion as described below. Body temperature may be in excess of 106°F, but there is no specific temperature used to make the diagnosis. Heat stroke can be fatal if not immediately treated.
- Heat exhaustion – A heat-related illness characterized by muscular weakness, distress, nausea, vomiting, dizziness, pale clammy skin, and fainting; usually associated with

lack of heat acclimatization and physical fitness, poor health status, and inadequate water intake.

- Heat rash – Skin irritation that occurs most often in hot environments and causes skin to become red and itchy. The rash usually appears in areas where clothing is restrictive.
- Heat cramps – Muscle pains or spasms that can happen during prolonged work or exercise in high temperatures.

Rhabdomyolysis, or muscle tissue breakdown, is the result of any process that causes injury to or death of muscle tissue. When muscle cells die, their contents of electrolytes and proteins are released into the bloodstream, which can result in potentially life-threatening conditions affecting the heart and kidneys [Khan 2009]. There is a well-known association between heat stroke and rhabdomyolysis [Department of the Army and Air Force 2003; Bontempo and Kaji 2010; O'Connor and Duester 2011; ACGIH 2014]. Rhabdomyolysis and acute kidney failure often occur together in people with exertional heat stroke [Bontempo and Kaji 2010]. Rhabdomyolysis is serious; up to 8% of documented rhabdomyolysis cases are fatal [Cervellin et al. 2010]. Muscle tissue can be damaged by overheating, overexertion, crush injury, some medications or supplements, or certain medical conditions. More information about heat stress, heat strain, and rhabdomyolysis is in Appendix A.

Methods

The objectives of this HHE were to:

1. Determine if employees had excessive heat strain, signs and symptoms of HRI, or rhabdomyolysis.
2. Identify personal and work-related risk factors for excessive heat strain, HRI, and rhabdomyolysis.
3. Determine if employees had evidence of dehydration after their work shifts.
4. Review the park's current and proposed heat stress policies.
5. Observe how the park's current heat stress policy is being implemented.

The 15 park employees scheduled to work outdoors during the week of the evaluation were invited to participate. We obtained informed consent from nine of the 15 employees, and ensured they had no medical reasons that would exclude them from participating such as digestive problems, having a pacemaker, or pregnancy. Our methods included (1) administering a questionnaire to employees, (2) obtaining twice daily symptom surveys from employees during workdays, (3) testing employees' blood before and after each work shift and once a day on rest days for markers of rhabdomyolysis and dehydration, (4) measuring employees' body weight before and after each work shift, (5) measuring employees core body temperature and heart rate during workdays, (6) assessing environmental conditions on workdays, (7) observing work practices, and (8) reviewing the park's injury and illness records and written heat stress policies (current and proposed).

Questionnaire

Employees completed a questionnaire on work and medical history, including risk factors for and previous diagnoses of HRI or rhabdomyolysis. We asked about recent use (past 2 weeks) of medications, supplements, and beverages that could be associated with rhabdomyolysis and HRI. We also asked about possible HRI signs and symptoms experienced in the week prior to our evaluation.

Daily Symptom Surveys

We asked employees about HRI symptoms (lightheadedness/dizziness, feeling faint, headache, nausea, sudden or severe fatigue, weakness, and heat rash) at lunchtime and at the end of each workday. At the end of each workday we also asked employees about symptoms associated with rhabdomyolysis (unusual soreness in the arms, legs, or back, or darker than normal urine) and to estimate their total fluid intake over that shift.

Blood Analysis for Markers of Rhabdomyolysis and Dehydration

We collected blood samples preshift and post-shift during the workweek and once a day on rest days. Approximately three to six drops of whole blood were collected via fingerstick and analyzed using the Abaxis Piccolo® Metlyte 8 Reagent Disc in a Piccolo Xpress™ Analyzer. To estimate the potential for rhabdomyolysis, we measured the amount of creatine kinase (CK), an enzyme that serves as a marker for muscle breakdown. We used a standard definition of rhabdomyolysis of a CK level five times the upper limit of the reference range of the assay used to analyze the samples [O'Connor and Duester 2011]. Using the Piccolo® Metlyte 8 Reagent Disc in the Piccolo Xpress™ Analyzer, these values were > 1,900 international units/liter for males and 950 international units/liter for females [Abaxis 2011]. We stopped testing individual employees when results showed two successively declining CK levels on rest days. If CK values rose to the level of our case definition (in this evaluation, none did), those employees would have been instructed to seek immediate medical attention. Employees whose CK values did not demonstrate two successively declining levels before the end of our testing were instructed to follow-up with their healthcare provider within 1 week.

We measured blood urea nitrogen (BUN) to creatinine ratios and calculated serum osmolarity to determine the level of dehydration. We defined dehydration as either a BUN to creatinine ratio > 20:1 or a calculated serum osmolarity > 290 milliosmoles/liter [Singer and Brenner 2008]. All blood samples were collected following the standard precautions for prevention of exposure to bloodborne pathogens as specified by the Centers for Disease Control and Prevention and the Occupational Safety and Health Administration (OSHA) [CDC 1998; 29 CFR 1910.1000]. All blood test results were available within 30 minutes of collection. Any employee with a clinically significant abnormal test result was contacted immediately. At the completion of the testing week, all participants received a letter containing their results of all of their blood tests.

Heat Strain Assessment

We classified an employee as having excessive heat strain if he or she had one or more of the following:

- A core body temperature (CBT) > 101.3°F. This is in accordance with the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) heat stress guidelines for acclimatized individuals [ACGIH 2014].
- A heart rate > 180 beats per minute (bpm) minus the age of the employee sustained for at least 3 minutes [ACGIH 2014].
- A body weight loss over a shift greater than 1.5% [ACGIH 2014].
- Symptoms of sudden and severe fatigue, nausea, headache, dizziness, feeling faint, or lightheadedness.

Core Body Temperature

Prior to participating in the evaluation, all employees were screened for medical conditions that would preclude them from safely ingesting a Philips Respironics CBT sensor. The single use CBT sensor is about the size of a multivitamin, is biologically inert, and exits the body with a bowel movement. It takes temperature measurements as it passes through the digestive system and transmits this data to a receiver called a datalogger worn outside the body. Using a CBT sensor is considered the most accurate way to measure internal body temperature [Sawka and Pandolf 2001; McKenzie and Osgood 2004; Byrne and Lim 2007].

Each CBT sensor transmitted data to the datalogger every 15 seconds. Employees swallowed a new CBT sensor before starting work each morning. Each employee then drank about 16 ounces of water and ate 5–10 saltine crackers to help move the sensor from the stomach into the small intestine where the most accurate CBTs are measured. At the end of each workday, we downloaded and stored the CBT data. Employees were not asked to take the CBT sensor on rest days. All employees were considered acclimatized because they worked in this hot environment during the 2 weeks prior to our evaluation.

Heart Rate

We used the Equivital LifeMonitor EQ02 physiological monitoring system to measure and store employee heart rate data every 15 seconds for each workday. This system consists of a chest strap containing a sensor that contacts the skin and determines the heart rate. All heart rate data were transmitted and stored on the same datalogger used to collect the CBT data. Employees were not asked to wear the heart rate sensor on rest days.

Body Weight

We measured preshift and postshift body weight to assess fluid losses over a work shift. We also used participants' body weight changes as one of the criteria to assess their risk for excessive heat strain. Employees who have a weight loss over a work shift of more than 1.5% body weight have been shown to be at increased risk for HRI [ACGIH 2014]. Employees were weighed before and after each work shift on a Seca Travelite™ Model 803 digital scale. Employees were not weighed on rest days.

Heat Stress Assessment

To measure the environmental conditions that contribute to heat stress, we used a Quest Technologies QUESTemp°36 instrument to obtain the wet bulb globe temperature (WBGT) at each work location and in cooling areas. The WBGT measurements were datalogged at 1-minute intervals during the entire workday and also manually recorded by National Institute for Occupational Safety and Health (NIOSH) investigators on a daily activity log for each task. The daily activity log was also used to describe each work task, its duration, and its estimated metabolic load (exertion level), and rest breaks. We classified metabolic loads as rest, light, moderate, heavy, and very heavy on the basis of NIOSH and ACGIH heat stress criteria, which are the same [NIOSH 2013; ACGIH 2014]. Because heat stress occupational exposure limits (OELs) are based on 1-hour averages, we selected three employees whose results (on day 1) showed three different exposure scenarios: (1) CBT and heart rate above the excessive heat strain criteria, (2) heart rate above the excessive heat strain criteria, and (3) no CBT or heart rate above the excessive heat strain criteria. We grouped their work tasks into approximately 1-hour time periods over 1 day. We then calculated time-weighted average (TWA) exposures for the duration of each task and the average estimated metabolic rate, and compared it to work and rest schedules recommended by NIOSH and ACGIH for acclimatized employees. All employees wore cotton work uniforms, so no clothing adjustment to the WBGT was necessary [ACGIH 2014].

Records Review

We reviewed the park's current and proposed heat stress policies and OSHA's Form 300 Log of Work-Related Injuries and Illnesses from 2008–2012.

Results and Discussion

Questionnaire

Nine employees (eight male and one female) participated in our evaluation. Their average age was 46 years (range: 28–59 years). The average duration of employment at this park was 8 years (range: 2–23 years). Participants included 5 of 10 road maintenance employees, 1 of 2 bricklayers, 2 of 2 housing maintenance employees, and 1 of 1 archaeologist.

Two employees reported taking an unscheduled break or leaving work early in the last year because they felt sick from the heat, but neither employee reported seeking medical care. None of the employees reported ever having been diagnosed with rhabdomyolysis. No employee reported leaving work for HRI symptoms in the past year working at this park. No employee reported being treated at an emergency department for HRI since they started work at this park. One employee reported headache, dark urine, decreased urine production, and feeling like he had a fever during the week prior to our evaluation. No other symptoms consistent with HRI or rhabdomyolysis were reported in the week prior to our evaluation.

Employees were asked about their use of medications, supplements, or beverages that could increase risk of HRI or rhabdomyolysis in the 2 weeks prior to our evaluation. One employee reported taking creatine supplements, one reported taking antihistamines, and two reported taking decongestants. Eight of the nine employees reported having a caffeinated beverage within the previous 2 weeks. Six employees reported drinking caffeinated soda, with an average daily intake of 1.5 cans of soda. Five reported drinking coffee, with an average daily intake of 1.8 cups of coffee. Two employees reported drinking energy drinks, with an average daily intake of 1.75 cans. Five employees reported engaging in intense recreational physical activity including weight lifting, circuit training, swimming, and working at a gym.

All employees reported adequate access to water or other hydration fluids during the workday. Although employees were given a trial use of cooling vests, none reported routine use of them after the trial. Reasons given for not continuing use of cooling vests included: too heavy (seven employees); caused a decrease in range of motion (three employees); not available or not offered after the initial trial (three employees); or not effective (two employees). Write-in responses for this question included: "uncomfortable," "have other means of cooling body," "was driving all day," and "never really wanted to." "Driving all day" meant that the employee spent the day in a vehicle equipped with air-conditioning.

Daily Symptom Surveys

One employee reported headache on 3 days; no other employees reported symptoms consistent with HRI. One employee reported unusual soreness in the legs on one day and one reported darker than normal urine on one day; no other employees reported symptoms consistent with rhabdomyolysis.

The post-shift symptom survey also asked employees to estimate their total fluid intake over that day's work shift. Employees reported an average intake of 135 ounces or more per day, but intake as low as 67 ounces was reported. The parks current heat stress management policy advised employees to drink "approximately 24 to 32 ounces of cool water/electrolyte drink every hour." The policy did not differentiate between office workers and those engaged in strenuous outdoor tasks. We did not include office workers or other park employees that worked primarily indoors as part of our evaluation.

Blood Analysis for Markers of Rhabdomyolysis and Dehydration

No employee met our criteria for rhabdomyolysis or dehydration during our evaluation. One employee had brief elevations of CK above the normal range but below the cut-off for rhabdomyolysis. We referred two employees to their personal healthcare provider because they did not have two successively declining CK values on the rest days, although their values were within the normal reference range. These two employees did not follow up on our referral.

Heat Strain

Table 1 summarizes the number of employees identified as having excessive heat strain according to our criteria. Peak CBTs were 97.1°F to 101.6°F, and all but one employee were below our criterion for excessive heat strain (101.3°F) (Appendix B, Table B1). However, five of the nine employees had a heart rate exceeding the excessive heat strain criterion during our 4-day evaluation (Appendix B, Tables B1–B9). One employee had weight loss over the shift exceeding 1.5% of their body weight on 2 days.

Table 1. Employees meeting our evaluation criteria for excessive heat strain

Heat strain criterion	Employees who met criteria at any time during testing (n = 9)
Heart rate > 180 minus age in years for 3 or more minutes	5
CBT > 101.3°F	1
Symptoms of sudden and severe fatigue, nausea, headache, dizziness, rash, feeling faint, or lightheadedness	3
Weight loss over a shift > 1.5% of body weight	1

Heat Stress

The WBGT measured over the 4 workdays ranged from 56.3°F to 101.6°F. The WBGT value is not the same as the measured air temperature. This is because the WBGT value includes humidity, radiant heat, and wind speed to provide an index of the environmental conditions in which a person works. Appendix B, Tables B1–B9 present the WBGT, estimated metabolic rate, CBT, and maximum sustained heart rate (for 3 or more minutes) for each employee by task over the 4 days of our evaluation. Because these tasks varied, we calculated time-weighted averages for WBGT and metabolic rates and compared these results to 1-hour work and rest schedules recommended by NIOSH and ACGIH (both are the same) [NIOSH 2013; ACGIH 2014]. Examples of these task-based, time-weighted averages for day 1 for three employees are shown in Tables 2–4.

On multiple occasions within and across workdays, some employees exceeded the excessive heat strain criteria (Appendix B, Tables B1–B5). This usually happened at lower elevation work sites where the WBGT was high (e.g., WBGT > 85°F) or when employees engaged in moderate to heavy work (e.g., extended walking, bricklaying, tree trimming, shoveling/handling rocks and asphalt). In some of these instances (Tables 2–4), these tasks were performed longer than the NIOSH recommended exposure limit (REL) work/rest schedule (Appendix C, Figure C1). However, other employees performed moderate to heavy tasks under elevated WBGT conditions and did not follow the NIOSH recommended work/rest schedule, yet they did not exceed either the CBT or heart rate criterion (Appendix B, Tables B6–B9). One employee exceeded the NIOSH heat stress ceiling limit (Appendix C, Figure C1) during mortar mixing and bricklaying on day 3 when the WBGT was 97.8°F but did not exceed the excessive heat strain criteria used for this evaluation (Appendix B, Table B8).

Table 2. Heat stress and strain by task* for employee A, day 1

Description of task	Duration (minutes)	Average		Exceed (Yes/No)		Recommended 1-hour work/rest schedule (minutes)
		Metabolic rate† (watts)	WBGT (°F)	Max CBT‡	Max HR§	
Drive to worksite with AC on, walk to worksite	50	197	79.2	No	No	60/0
Walk around worksite, walk to 2nd worksite	**60¶**	228	87	No	No	**45/15¶**
Break; walk to worksite, walk back to vehicle	**55¶**	253	91.9	Yes	Yes	**15/45¶**
Drive to 3rd worksite with AC on, walk to worksite, walk around worksite	78	171	87.5	No	No	60/0
Lunch in AC, drive to 4th worksite, walk to/from worksite	80	230	86.2	Yes	Yes	60/0
Drive back to staging area	50	109	68.4	No	No	60/0

AC = Air-conditioning

*Individual tasks (from Appendix B, Table B1) were grouped into approximately 1-hour periods.

†Metabolic rate adjusted by the weight of the employee

‡101.3°F

§Sustained heart rate for 3 or more minutes during task > 180 minus age in years

¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines for working and resting over a 1-hour period (Appendix C, Figure C1).

Table 3. Heat stress and strain by task* for employee C, day 1

Description of task	Duration (minutes)	Average		Exceed (Yes/No)		Recommended 1-hour work/rest schedule (minutes)
		Metabolic rate† (watts)	WBGT (°F)	Max CBT‡	Max HR§	
Drive to worksite with AC on, walk to worksite	24	174	79	No	No	60/0
Raking, trimming brush/trees	**60¶**	453	85.4	No	Yes	**30/30¶**
Take break outdoors, rake, trim brush/trees	**70¶**	293	90.1	No	Yes	**15/45¶**
Take break outdoors, rake, trim brush/trees	**30¶**	221	93.8	No	Yes	**15/45¶**
Take break outdoors, rake, trim brush/trees	**60¶**	290	91.4	No	Yes	**15/45¶**
Lunch outdoors	**60¶**	174	92.1	No	No	**15/45¶**
Rake, trim brush/trees, take break outdoors	**65¶**	421	90.3	No	Yes	**15/45¶**
Take break outdoors	75	174	84.5	No	No	60/0
Drive to staging area with AC on	20	174	68.4	No	No	60/0

*Individual tasks (from Appendix B, Table B3) were grouped into approximately 1-hour periods.

†Metabolic rate adjusted by the weight of the employee

‡101.3°F

§Sustained heart rate for 3 or more minutes during task > 180 minus age in years

¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines for working and resting over a 1-hour period (Appendix C, Figure C1).

Table 4. Heat stress and strain by task* for employee H, day 1

Description of task	Duration (minutes)	Average		Exceed (Yes/No)		Recommended 1-hour work/rest schedule (minutes)
		Metabolic rate† (watts)	WBGT (°F)	Max CBT‡	Max HR§	
Drive to worksite with AC on, move equipment, mix mortar, lay bricks	**60¶**	401	86.4	No	No	**30/30¶**
Take break indoors with AC on, mix mortar, lay bricks	**75¶**	392	86.6	No	No	**30/30¶**
Take break indoors with AC on, mix mortar, lay bricks	**70¶**	392	89.2	No	No	**15/45¶**
Lay brick, light shoveling, move brick, lunch indoors with AC on	60	220	82.4	No	No	60/0
Lay brick, cut brick, take break indoors with AC on	**145¶**	428	87	No	No	**15/45¶**
Lay brick, move equipment, drive to staging area with AC on	**70¶**	408	86.7	No	No	**30/30¶**

*Individual tasks (from Appendix B, Table B8) were grouped into approximately 1-hour periods.

†Metabolic rate adjusted by the weight of the employee

‡101.3°F

§Sustained heart rate for 3 or more minutes during task > 180 minus age in years

¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines for working and resting over a 1-hour period (Appendix C, Figure C1).

OSHA Injury and Illness Logs

We reviewed the OSHA Logs from 2008–2012. The entries were primarily sprains, strains, lacerations, and bruises. We found one case of HRI in 2012 in which a park ranger suffered heat stroke. There were no cases of rhabdomyolysis.

After our on-site evaluation, we received a report about a park employee working as a heavy equipment operator who died on duty on September 19, 2013. Park officials confirmed that the autopsy listed "heat-related illness" as a primary factor in this fatality. This employee was reportedly working alone on the date of death. Meteorological records showed a high temperature of 107°F in the park on the day of the incident and daily high temperatures of 115°F on 3 of the 4 days prior to the incident. This employee had not participated in our evaluation.

Heat Stress Policy Review

We reviewed the park's current and proposed heat stress policies. The policies were similar in content. However, new sections of the draft policy included the following requirements:

1. Hydration fluid intake rate: the rate was changed from 24–32 ounces per hour to 5–7 ounces every 15–20 minutes. Neither policy recommends a scaled increased of fluid intake based on work tasks or on expected metabolic rates during a given time period.

2. Assignment of work/rest cycles: supervisors are instructed to use "resting, light, moderate, heavy, and very heavy" work levels to assign work/rest cycles in various environmental conditions, as is stated in the ACGIH Heat Stress Monitoring Criteria [ACGIH 2014].

3. Use of vehicles as cooling stations during extreme heat: the policy recommends at least one air-conditioned vehicle remain running during extreme heat to allow employees with signs or symptoms of excessive heat strain to sit in until symptoms diminish. Cooling vehicles were also recommended for Emergency Medical Service/Fire personnel wearing turnout gear or Hazmat suits responding to incidents in the park.

4. Acclimatization criteria: the policy states that employees who have been off work for 4 or more days would not need to reacclimatize "if they remained in a similar heat environment."

The current and proposed policies contain the following elements:

1. Use of a WBGT instrument to determine risk to employees and visitors. Three risk levels are defined using the heat index measurement obtained from the WBGT. These risk levels guide the frequency of employee "self-monitoring" as follows:

   Level One: WBGT heat index > 76°F — Risk of heat-related illness present → employees should self-monitor every hour.
   Level Two: WBGT heat index > 82°F — High risk of heat-related illness present → employees should self-monitor every half hour.
   Level Three: WBGT heat index > 90°F — Extreme risk of heat-related illness present → employees should self-monitor every quarter hour.

2. "Self-monitoring" is not clearly defined in either policy. Both policies contain identical sections titled "Heat Strain Monitoring" in which signs and symptoms of HRI are reviewed, weight change monitoring is discussed, and heart rate monitoring using two parameters, peak sustained heart rate defined as 180 minus age, and a resting heart rate determined after 1 minute of sitting at rest, are described. The policies state that a resting heart rate of greater than 110 bpm is considered elevated and that the employee should remain at rest until their heart rate is less than 90 bpm. At that time, the policy states they may resume work "at a reduced rate/speed." In both policy documents, Appendix A describes a third heart rate parameter, denoted as "recovery heart rate," which recommends that following a "normal work cycle" employees should compare their heart rate taken after 3 minutes of "seated rest" to

their heart rate after resting for 1 minute. However, the policy doesn't explain how to interpret the recovery heart rate, or what to do if that number is greater than a specific value. Finally, no recommendation to seek medical attention is mentioned for any specific heart rate value.

3. Weight change monitoring is also described in the Heat Strain Monitoring sections, which state that "daily and work shift weight changes are measured" and that scales should be available at the maintenance center and three other park offices for employees to use.

4. In Appendix A of both policy documents, "Additional Heat Strain Monitoring Criteria," it states that "accurate temperature measurement in the field is somewhat impractical." Neither policy specifies which self-monitoring parameter (heart rate vs. oral temperature vs. weight or which of the three heart rate parameters mentioned) employees should use to self-monitor under each of the defined heat risk levels.

5. In addition, the policies state that supervisors are responsible for "monitoring employees to determine if they are properly self-monitoring and mitigating for heat stress." As worded, this provision raises several issues of concern that are not addressed such as:

   - No indication of how often the WBGT measurement should be made, who should be making the measurement (employee, safety manager, or supervisor), or where the records of these measurements are to be kept.
   - No recommendation for a medical evaluation for employees with elevated heart rate parameters (peak, resting, or recovery).
   - No indication of where to keep digital thermometers.
   - Conflicting recommendations for frequency of oral temperature checks – for self-monitoring parameter to assess heat risk levels, the policies recommend every 15, 30, or 60 minutes *during work* depending on the heat risk level; Appendix A of the policy documents states employees should "use a digital thermometer right *after stopping work* but before drinking anything."
   - No discussion of metabolic workload associated with different tasks (e.g., shoveling is considered a "heavy" workload) or the relationship between WBGT and metabolic workload. Use of an alternative risk assessment method based on the National Weather Service forecasted high temperatures for the day, when no WBGT is available. The use of the forecasted high temperature provided by the National Weather Service can be helpful to the safety manager to alert employees of potentially hazardous heat stress conditions. Such information could be used to inform employees working outdoors, every day prior to beginning their shift.
   - "Use of the buddy system at all times." Working in pairs, or in a group, is an important aspect of employee safety in hot environments.
   - Adaptable work/rest cycles, adjusted to the heat and the workload. This portion of the policy is critical to reducing the heat stress burden on the employee and should be reinforced during pre-shift meetings. As a guideline, the NIOSH criteria

document provides a chart that suggests appropriate work/rest schedules on the basis of metabolic workload and the WBGT (Appendix C, Figure C1).

- "Adjust work schedules so that moderate to very heavy work is performed during the cooler parts of the day or in the evening."

6. Appendix B of both policies is titled "Personal Risk Factors Evaluation Checklist" which contains a list of "personal risk factors that may affect [employees'] heat tolerance." Several issues of concern are noted here:
   - In this section employees who work in "hot conditions" are "recommended" to consult their physician. Neither version of the appendix specifies what criteria are used to define "hot conditions" so it may not be clear to employees if they fall under this category.
   - Although the policies recognize that "short and long-term health factors that may affect heat tolerance", no guidance is given regarding implementation of initial and periodic examinations by a physician for employees who work outdoor during extreme heat conditions. A helpful example of a medical pre-placement evaluation form which was used during NIOSH's response to DeepWater Horizon Oil Spill Disaster can be found at http://www.cdc.gov/niosh/topics/oilspillresponse/preplacement.html.

Observations

During our visit, we observed little compliance with the current heat stress policy among employees and supervisors. We did not observe any employee self-monitoring (checking their pulse or taking their own temperature) nor any supervisor determining if the employees were self-monitoring. We did not see any weighing scales, or hear reports that employees were routinely monitoring their cross-shift weight changes. We did note that in every restroom there was a poster urging employees and visitors to compare their urine color to a color chart to determine if they were dehydrated. The chart also encouraged additional fluid intake. We observed outdoor maintenance work and archeological assessments occurring under "environmental conditions deemed unacceptable" (e.g., air temperatures greater than 120°F) by both the current and proposed heat stress policies. We also observed employees working alone. None of the employees we observed was following a set work/rest cycle (e.g., work 45 minutes then rest 15 minutes) on the basis of environmental conditions as noted in the current policy, which uses NIOSH heat stress guidelines [NIOSH 2013]. All of the observed employees took rest breaks and drank fluids at their own discretion.

We observed employees shoveling rocks, laying brick, and trimming trees regardless of the hour of the day or the environmental conditions. No vehicles were left running to provide employees access to a cool environment to rest and recover. When a vehicle that had been parked in a shaded area was started, we noted that it took about 30 minutes for the interior to cool.

Neither the current nor proposed heat stress policy explicitly states that an employee or groups of employees must have a radio within reach during working hours to call for assistance or to hear calls from other employees. We saw radios being shared and stored out of hearing range.

Communication between employees and the safety manager needs to be improved. We saw instances where work locations were changed without notifying the safety manager, despite the requirement to do so in the heat stress policy. We observed multiple instances of park employees working alone, despite the mandatory "buddy system" policy. Employees who routinely worked alone were not required to submit the location(s) of work sites and no preset radio "welfare checks" occurred during the workday. If individuals working alone had become incapacitated, no one would know that individual was having a problem until they failed to report at the end of the workday or know where to look for them. Soon after our site visit, a heat-related death occurred in an employee who died while working alone.

Evaluation Limitations

This evaluation has the following limitations. We assessed a small number of employees (nine) over 4 days. We did not evaluate all job titles in the park. We may not have evaluated worst-case environmental conditions because a storm that occurred on two of the four testing days resulted in cooler than normal daily temperatures.

Conclusions

The potential exists for heat stress and excessive heat strain in employees at this park. Employees performed moderate to heavy tasks in elevated WBGT conditions for longer periods of time than are recommended by NIOSH (Appendix C, Figure C1). In one instance the NIOSH ceiling limit for heat stress was exceeded. We found employees who met criteria for excessive heat strain. However, despite working in extreme environmental conditions, some employees were able to perform tasks without showing signs of excessive heat strain. No employee we evaluated developed dehydration, rhabdomyolysis, or significant HRI.

The current and proposed heat stress policies are in need of adjustments such as improving access to and use of radios, notifying the safety manager of changing work locations, and using the buddy system. The heat stress management policies should be written in plain language. Park managers should work with employees to develop a workgroup to make decisions on employee self-monitoring options, as well as develop standard operating procedures for heat stress and heat strain monitoring, including a method for daily documentation and review of employees' self-monitoring. Preventing excessive heat strain and HRI will require a combination of risk management approaches such as avoiding moderate to heavy work during hot summer months, and if this work is necessary, having it performed only during the cooler nighttime hours.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this park to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan to address heat stress and strain. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at this park. The next version of the heat stress policy should include standard operating procedures for monitoring for heat stress, including a method for daily documentation and review of employees' self-monitoring and actual work practices and metabolic workloads. Additional recommendations can be found in the NIOSH document "Preventing Heat-related Illness or Death of Outdoor Workers" at http://www.cdc.gov/niosh/docs/wp-solutions/2013-143/pdfs/2013-143.pdf and on OSHA's website which gives guidance on heat stress prevention in outdoor workers at https://www.osha.gov/SLTC/heatstress/.

Our recommendations include administrative controls, which refer to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Provide WBGT measuring instruments to those employees, or groups of employees who will be working outdoors during periods of extreme heat. These employees should be trained on the instrument operation and the interpretation of results. The instrument should operate continuously during the work shift and be checked hourly when forecasted temperatures exceed those outlined in the heat stress policy. Using the WBGT and estimated metabolic heat load, consult the NIOSH guidance on appropriate work/rest cycles (Appendix C, Figure C1). Reduce the duration of work, and enforce mandatory rest breaks if moderate to heavy work under extreme WBGT conditions must be performed. NIOSH recommends that protective clothing and equipment should be provided to the employees when the total heat stress exceeds the ceiling limit.
2. Develop a workgroup of employees, the safety manager, and a medical advisor to decide among options and develop standard operating procedures for self-monitoring during periods of extreme heat. Several options are available which may improve compliance and accuracy, each with their own strengths and limitations. Wearing heart rate monitors (such as those worn on the wrist by runners), using oral or tympanic thermometers periodically to monitor body temperatures, measuring pre-and post-shift weight, are options to consider.
3. Schedule strenuous outdoor work such as road repair/replacement, bricklaying, and tree-trimming for cooler months. If these activities must occur during the summer, then they should be performed at night or early in the morning.
4. If possible, stop work outdoors and inside buildings without air-conditioning during extreme heat advisories and apply this policy consistently to all park employees.
5. Continue to train employees to recognize early signs and symptoms of HRI in themselves and their coworkers. Instruct employees to tell their supervisor immediately if they develop any symptoms or if they notice any signs or symptoms in their coworkers. (This practice illustrates the importance of using the buddy system.)
6. Continue to allow employees to take rest breaks and fluid intake as needed. Update the heat stress policy to allow for these unscheduled breaks by clarifying that that work/rest cycle guidelines should be adjusted as needed.
7. Enforce the heat stress policy of having at least one vehicle equipped with air-conditioning running at all times. This vehicle will provide a cooling area for

employees who do not have immediate access to an air-conditioned space at their work location during periods of extreme heat (ambient air temperature > 100°F). Ensure that carbon monoxide from vehicle exhaust does not pose a hazard inside the vehicle or in an unventilated building near the idling vehicle.

8. Supply additional water to employees so they can wet their work clothes during the workday when temperatures are high. Wetting clothing aids evaporative cooling and should be done frequently in low relative humidity environments.

9. Establish a procedure for communication between the safety manager and employees or work crew supervisors so that work locations are known. If changes are made, the safety manager should be notified so that she or he can make an informed decision regarding potential work stoppages.

10. Enforce the buddy system as outlined in the heat stress policy. If solitary work is unavoidable, ensure employees have a radio with them at all times, submit their work schedule/locations to their supervisor and safety manager, and arrange for periodic welfare checks over the radio. Other park employees should keep radios within hearing distance so that a call for assistance can be heard and responded to without delay.

11. Discourage employees from hydrating with drinks containing large amounts of caffeine (totaling more than the equivalent of 6 cups of coffee per day) or large amounts of sugar during work. This may worsen dehydration and increase rhabdomyolysis risk.

12. Implement a mandatory initial and periodic medical examination performed by a physician for employees who work outdoor during extreme heat conditions.

Appendix A: Occupational Exposure Limits and Health Effects

Heat Stress

NIOSH defines heat stress as the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment, primarily through evaporation [NIOSH 2013]. Many bodily responses to heat stress are desirable and beneficial because they help regulate internal temperature and, in situations of appropriate repeated exposure, help the body adapt (acclimatize) to the work environment. However, at some stage of heat stress, the body's compensatory measures cannot maintain internal body temperature at the level required for normal functioning. As a result, the risk of heat-related illnesses, disorders, and accidents substantially increases. Increases in unsafe behavior, which may lead to accidents, are also seen as the level of physical work of the job increases [NIOSH 1986].

Many heat stress guidelines have been developed to protect people against heat-related illnesses. The objective of any heat stress index is to prevent a person's CBT from rising excessively. The World Health Organization concluded that, "it is inadvisable for CBT to exceed 100.4°F or for oral temperature to exceed 99.5°F in prolonged daily exposure to heavy work and/or heat." Additionally, a CBT of 102.2°F should be considered reason to terminate exposure even when CBT is being monitored [NIOSH 1986]. This does not mean that an employee with a CBT exceeding those levels will necessarily experience adverse health effects; however, the number of unsafe acts increases as does the risk of developing heat stress illnesses [NIOSH 1986].

NIOSH recommends controlling total heat exposure so that unprotected healthy employees are not exposed to metabolic and environmental heat combinations that exceed the applicable NIOSH criteria. These criteria state that most healthy employees who work in hot environments and are exposed to combinations of environmental and metabolic heat below the NIOSH recommended action limit for non-acclimatized employees or the NIOSH REL for acclimatized employees should be able to tolerate total heat stress without substantially increasing their risk of incurring acute adverse health effects. Also, no employee should be exposed to metabolic and environmental heat combinations that exceed applicable ceiling limits without being provided with and properly using appropriate and adequate heat-protective clothing and equipment [NIOSH 1986].

The 1986 NIOSH heat stress criteria document referenced above is being updated. A draft document was released for public comment as part of a notice placed in the Federal Register in December 2013 which can be viewed at http://www.gpo.gov/fdsys/pkg/FR-2013-12-27/pdf/2013-31066.pdf. It describes five basic preventive practices that should be followed to control heat stress among employees working in hot environments. These are: (1) limiting or modifying the duration of exposure time; (2) reducing the metabolic component of the total heat load; (3) enhancing the heat tolerance of the workers by heat acclimatization, physical conditioning, etc.; (4) training the workers in safety and health procedures for work in hot environments; and (5) initial and periodic medical examination of workers to determine whether an individual can meet the total demands and physical stresses of the job with reasonable assurances the health and safety of the worker and/or fellow workers will not be placed at risk [NIOSH 2013].

The ACGIH heat stress guidelines use a decision-making process that provides step-by-step situation-dependent instructions that factor in clothing insulation values and physiological evaluation of heat strain [ACGIH 2014]. ACGIH WBGT screening criteria factor in the ability of the body to cool itself (clothing insulation value, humidity, and wind) and, like the NIOSH criteria, can be used to develop work/rest regimens for acclimatized and unacclimatized employees. The ACGIH WBGT-based heat exposure assessment was developed for a traditional work uniform of long-sleeved shirt and pants, and represents conditions under which it is believed that nearly all adequately hydrated, unmedicated, healthy employees may be repeatedly exposed without adverse health effects. Clothing insulation values and the appropriate WBGT adjustments, as well as descriptors of the other decision-making process components can be found in the ACGIH document "Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices" [ACGIH 2014]. The ACGIH TLV for heat stress provides a framework for the control of heat-related illnesses only. Although accidents and injuries can increase with increasing levels of heat stress, it is important to note that the TLVs are not directed toward controlling these outcomes [ACGIH 2014].

NIOSH and ACGIH criteria can only be used when WBGT data for the immediate work area are available and must not be used when employees wear encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement. Further assumptions regarding work demands include an 8-hour workday, 5-day workweek, two 15-minute breaks, and a 30-minute lunch break, with rest area temperatures the same as, or less than, those in work areas, and at least some air movement. While NIOSH and ACGIH guidelines distinguish between safe and dangerous levels, professional judgment must be used in administering a heat stress management program to ensure adequate protection. OSHA does not have an exposure limit for heat stress. However, the OSHA technical manual's section on heat stress refers to the ACGIH document for guidelines to evaluate employee heat stress and how to investigate the workplace [OSHA 1999].

Heat Strain

The body's response to heat stress is called heat strain. Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, and strenuous physical activities have a high potential for inducing heat strain in employees. Heat strain is highly individual and cannot be predicted on the basis of environmental heat stress measurements alone. Physiological monitoring for heat strain becomes necessary when impermeable clothing is worn, when heat stress screening criteria are exceeded, or when data from a detailed analysis (such as the International Standards Organization required sweat rate index) show excess heat stress.

The draft revised NIOSH heat stress criteria document recommends during a heat alert (area weather forecast for the next day predicts a maximum air temperature of at least 95°F or if a maximum of 90°F is predicted and is 9°F higher than the temperature reached on any of the preceding 3 days), that personal monitoring be done via checking oral temperatures rather than heart rate. Although no specific oral temperature is cited, this document refers to the World Health Organization recommendation that "the deep body temperature should not, under conditions of prolonged daily work and heat, be permitted to exceed 100.4°F or oral temperature of 99.5°F." It is noted that the oral temperature is usually 0.8°F lower than deep body temperature [NIOSH 1986].

ACGIH considers one indicator of physiological strain, sustained peak heart rate, to be a useful measure of acute, high-level exposure to heat stress. Sustained peak heart rate, defined by ACGIH as 180 bpm minus an individual's age over several minutes, is a leading indicator that thermal regulatory control may not be adequate and that increases in CBTs have occurred or will soon occur [ACGIH 2014]. According to ACGIH, an individual's heat stress exposure should be discontinued when any of the following heat strain indicators occur:

- Sustained (over several minutes) heart rate exceeds 180 bpm minus the individual's age in years for those with normal cardiac performance.
- CBT is greater than 100.4°F for unselected, unacclimatized personnel and greater than 101.3°F for medically fit, heat-acclimatized personnel.
- Recovery heart rate at 1 minute after a peak work effort exceeds 110 bpm.
- Presence of symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

In addition, the ACGIH states than an individual may be at greater risk of heat strain if:

- Profuse sweating is sustained over several hours.
- Weight loss over a shift is greater than 1.5% of body weight.
- 24-hour urinary sodium excretion is less than 55 millimoles.

Acclimatization

When employees are first exposed to a hot environment they may show signs of distress and discomfort, experience increased CBTs and heart rates, and may have headache or nausea. However, following repeated exposure, employees can adapt to the hot environment. This adaptation is called acclimatization.

Employees begin to lose acclimatization when they stop working in the heat stress conditions, and a noticeable loss occurs after 4 days. However, this loss is usually rapidly made up. Chronic illness, a short episode of mild illness (e.g., gastroenteritis), the use or misuse of pharmacologic agents, a sleep deficit, poor nutrition, or a disturbed water and electrolyte balance may reduce an employee's capacity to acclimatize [ACGIH 2014].

Rhabdomyolysis

Rhabdomyolysis is a medical condition associated with heat stress and prolonged physical exertion, resulting in the rapid breakdown of muscle which can damage the kidneys. Classic symptoms of rhabdomyolysis are muscle pain, cramping, swelling, weakness, and decreased range-of-motion of joints. One of the signs of rhabdomyolysis is dark or tea-colored urine [Brudvig and Fitzgerald 2007; Khan 2009; Cervellin et al. 2010]. However, symptoms vary between individuals and some might not have any symptoms at all [Huerta-Alardin et al. 2005; Brudvig and Fitzgerald 2007].

Rhabdomyolysis is diagnosed by measurement of CK, also known as creatine phosphokinase, in the blood by a licensed health care provider. The severity of rhabdomyolysis depends upon damage to other organ systems and the peak CK level. Mild rhabdomyolysis can be treated by drinking lots of fluids [George et al. 2010]. Severe cases require hospitalization as the kidneys may fail and immediate dialysis is needed [Bosch et al. 2009].

It is not uncommon for individuals who engage in exertional activities higher than their baseline level of fitness to develop exertional rhabdomyolysis. However, it also occurs in highly-conditioned individuals who may engage in supramaximal exercise or who have other risk factors along with an exertional activity [Walsh and Page 2006].

Dehydration, Volume Depletion, and Fluid Replacement

When working in hot environments it can be difficult to completely replace lost fluids as the day's work proceeds. Sweat contains water and salt, and excessive sweating can cause dehydration, volume depletion, and electrolyte imbalances. Volume depletion is different from pure dehydration and occurs when loss of both water and salt/sodium results in a reduced circulatory blood volume [Mange 1997]. Volume depletion also negates the advantage granted by high levels of aerobic fitness and heat acclimatization. Several studies have shown that volume depletion or dehydration increases CBT during exercise in temperate and hot environments. Therefore, maintaining enough water improves the body's overall function.

Drinking fluids is important to ensure adequate rehydration, and evidence shows that having drinks that taste good leads to increased consumption. Glucose-electrolyte solutions like Gatorade® can increase sodium and water absorption, and the glucose in these drinks provides energy for muscular activity [Rolls et al. 1990]. However, employees should avoid drinking large amounts of sugar-laden beverages in hot climates as this causes increased urine production that increases fluid loss through urination. Intake of caffeinated beverages and alcohol also increases urinary fluid loss and should be avoided. Because average Americans consume adequate, if not excessive, amounts of sodium in their diet, oftentimes only water replacement is needed. Oral electrolyte replacement formulas such as Gatorade® can be used for moderate volume depletion or for situations involving prolonged sweating. Salt tablets are not recommended. More information on heat stress and strain is available at http://www.cdc.gov/niosh/topics/heatstress/.

Appendix B: Tables

Table B1. Heat stress and strain measurements for employee A, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to worksite with AC on	25	109	74	—	—
	Walk to worksite	25	285	84.4	—	—
	Walk around worksite	30	171	87	—	—
	Walk to worksite	30	285	87	—	—
	Took break, outdoors	10	109	87	—	—
	Walk to worksite	10	285	87	—	—
	Walk back to vehicle	35	285	94.7	E	E
	Drive to worksite with AC on	18	109	77	—	—
	Walk to worksite	10	285	90.6	—	—
	Walk around worksite	50	171	90.6	—	—
	Lunch in car with AC on	25	109	79	—	—
	Walk to worksite	55	285	89.5	E	E
	Drive back to staging area with AC on	50	109	68.4	—	—
2	Drive to worksite with AC on	65	109	72	—	—
	Walk to worksite	65	285	79.2	—	—
	Note-taking, sitting outside truck	30	109	80.3	—	—
	Walking around worksite	20	285	79.1	—	—
	Took break, outside	15	109	80.8	—	—
	Walking around worksite	40	171	80.4	—	—
	Took break, outside	15	109	80.5	—	—
	Walking around worksite	90	171	81.5	—	—
	Took break, outside, download data	30	109	81.2	—	—
	Drive back to staging area with AC on	65	109	63.9	—	—
3	Drive to worksite with AC on	25	109	61.9	—	—
	Walk to worksite	20	285	87.5	—	—
	Walking around worksite	30	285	87.5	—	—
	Walking around worksite	50	394	87.5	—	—
	Walking around worksite	15	394	89.5	—	—
	Drive to next worksite with AC on	20	109	69	—	—
	Walking around worksite	60	285	93.5	—	—
	Drive to next worksite with AC on	10	109	69	—	—
	Lunch, inside with AC on	30	109	73	—	—
	Drive to next worksite with AC on	10	109	67	—	—
	Walking around worksite	40	285	93	—	—
	Took break, outside	10	109	89.9	—	—
	Drive to next worksite with AC on	45	109	65	—	—
	Survey hot buildings, no AC	30	285	94	—	—
	Drive back to staging area with AC on	65	109	64	—	—
4	Drive to worksite with AC on	60	109	66.4	—	—
	Discuss work plan with assistant	20	109	75.9	—	—
	Walking around worksite	70	285	84.4	—	—
	Drive to next worksite with AC on	70	109	74.5	—	—
	Walking around worksite	105	285	94.3	—	E
	Drive to next worksite with AC on	25	109	74.1	—	—
	Lunch, indoors with AC on	25	109	72.1	—	—
	Work in office with AC on	45	109	68.3	—	—
	Drive to next worksite with AC on	20	109	67.3	—	—
	Walking around worksite	25	285	94.3	—	—
	Drive back to staging area	65	109	64	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

E = Above CBT of 101.3°F, or maximum sustained heart rate over a 3-minute period (125 bpm)

Table B2. Heat stress and strain measurements for employee B, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to worksite, AC on	60	136	66.4	—	—
	Measure grading, walking worksite	155	212	82	—	—
	Lunch outdoors	45	136	87.6	—	—
	Measure grading, walking worksite	175	212	86	—	E
	Drive back to staging area with AC on	65	136	64	—	—
2	Drive to worksite with AC on	60	136	66.4	—	—
	Walking worksite, some shoveling	110	212	82	—	E
	Lunch, outdoors	50	136	85.5	—	—
	Walking/inspecting site	10	136	85.6	—	—
	Manual loading debris	20	490	86	—	E
	Walking/inspecting site	70	212	87.1	—	E
	Took break, outdoors	40	136	87.7	—	—
	Walking/inspecting site	40	212	88.2	—	—
	Drive back to staging area with AC on	65	136	64	—	—
3	Drive to worksite AC on	60	136	66.4	—	—
	Walking worksite, checking grade	110	212	71.1	—	—
	Took break, outdoors	10	136	87.1	—	—
	Walking, inspecting site	45	212	86.4	—	—
	Lunch, outdoors	50	136	88.6	—	—
	Manual loading debris into bucket	35	354	89.9	—	E
	Walking/inspecting site	70	212	89.5	—	E
	Supervise demolition of small building	40	136	89.8	—	—
	Took break, outdoors	45	136	90	—	—
	Drive back to staging area with AC on	65	136	70	—	—
4	Drive to worksite with AC on	60	136	66.4	—	—
	Supervise demolition, light shoveling	70	212	76	—	—
	Took break, outdoors	30	136	86	—	—
	Walking, inspecting site, light shoveling	15	212	88.9	—	—
	Lunch, outdoors	60	136	88.6	—	—
	Supervise installation of pipe	30	212	89	—	E
	Supervise demolition of small building	140	212	89.8	—	E
	Drive back to staging area with AC on	65	136	70	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

E = Above CBT of 101.3°F, or maximum sustained heart rate over a 3-minute period (121 bpm)

Table B3. Heat stress and strain measurements for employee C, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to worksite with AC on	24	174	79	—	—
	Raking, trimming brush/trees	60	453	85.4	—	E
	Took break, outdoors	40	174	87.1	—	E
	Raking, trimming brush/trees	30	453	94.1	—	E
	Took break, outdoors	25	174	93.7	—	—
	Raking, trimming brush/trees	5	453	93.9	—	E
	Took break, outdoors	35	174	89.4	—	—
	Raking, trimming brush/trees	25	453	94.2	—	E
	Lunch, outdoors	60	174	92.1	—	—
	Raking, trimming brush/trees	30	453	88.8	—	E
	Took break, outdoors	15	174	91.3	—	—
	Raking, trimming brush/trees	20	453	91.8	—	E
	Took break, outdoors	75	174	84.5	—	—
	Drive back to staging area with AC on	20	174	68.4	—	—
2	Drive to worksite with AC on	24	174	72	—	—
	Raking, trimming brush/trees	35	453	75.8	—	—
	Took break, outdoors	25	174	79.5	—	—
	Raking, trimming brush/trees	46	453	79.7	—	—
	Took break, outdoors	35	174	85.9	—	—
	Raking, trimming brush/trees	40	453	88.3	—	—
	Took break, outdoors	11	174	89.4	—	—
	Lunch, indoors	100	174	80	—	—
	Raking, trimming trees, drive Bobcat	35	453	91.3	—	—
	Took break, outdoors	45	174	91.6	—	—
	Pickup/transport/unload material	30	272	93	—	—
	Raking, trimming brush/trees	18	453	94.7	—	—
	Drive back to staging area with AC on	5	174	68.4	—	—
3	Drive to worksite with AC on	5	174	72	—	—
	Raking, trimming trees, drive Bobcat	29	272	88.9	—	—
	Took break, outdoors	60	174	83.1	—	—
	Raking, trimming trees, driving Bobcat	30	453	87.9	—	E
	Raking, trimming brush/trees	35	453	90	—	E
	Lunch, outdoors	44	174	88.3	—	—
	Gather tools, shovel, dig	37	174	82	—	—
	Took break, outdoors	20	174	88	—	—
	Drive Bobcat, push brush, shovel brush	12	627	92	—	E
	Took break, outdoors	60	174	90.5	—	—
	Raking, trimming brush/trees	12	453	91	—	—
	Took break, outdoors	55	174	91.3	—	—
	Drive back to staging area with AC on	5	174	68.4	—	—
4	Drive to worksite	5	174	72	—	—
	General house cleaning/wiping	75	272	79.3	—	—
	Took break, outdoors	45	174	91.2	—	—
	Pick up materials with truck AC on	60	174	76.5	—	—
	Cleaning house	60	272	76	—	—
	Lunch, indoors	60	174	70.2	—	—
	Paperwork	34	174	96.9	—	—
	Took break, outdoors	10	174	68.1	—	—
	Drive back to staging area, office work	56	174	72.6	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

E = Above CBT of 101.3°F, or maximum sustained heart rate over a 3-minute period (131 bpm)

Table B4. Heat stress and strain measurements for employee D, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Did not work		No data collected			
2	Drive to worksite with AC on	17	162	76.2	—	—
	Install window blinds indoors	75	254	77.8	—	—
	Took break, indoors	40	162	79	—	—
	Raking branches, debris	160	254	90.5	—	E
	Lunch, outdoors	40	162	90.4	—	—
	Raking branches, debris	40	254	91.9	—	—
	Took break, outdoors	20	162	91.8	—	—
	Loading material onto truck	18	585	90	—	E
	Unloading material from truck	15	585	90.6	—	—
	Sweeping up debris	20	254	91	—	—
	Drive back to staging area with AC on	10	162	68.4	—	—
3	Drive to worksite with AC on	10	162	76.2	—	—
	Sweeping, raking, loading brush	25	423	82	—	—
	Took break, outdoors	30	162	82.4	—	—
	Raking branches, debris	45	423	83.1	—	—
	Took break, indoors	60	162	83.1	—	—
	Sweeping, installing blinds	40	254	86.1	—	—
	Drive truck to get supplies	30	162	75	—	—
	Took break, outdoors	40	162	88.3	—	—
	Sweeping	10	254	88.3	—	—
	Lunch, outdoors	44	162	88.3	—	—
	Hang blinds, caulk, paint	45	254	89.9	—	—
	Took break, outdoors	12	162	91	—	—
	Refinishing bathtub	20	254	89.9	—	—
	Took break, outdoors	25	162	91.2	—	—
	Drive back to staging area with AC on	10	162	68.4	—	—
4	Drive to worksite with AC on	10	162	76.2	—	—
	Sweeping, raking, loading brush	20	254	80	—	—
	Took break, outdoors	10	162	82.4	—	—
	Loading materials	30	254	85.6	—	—
	Took break, outdoors	45	162	91.2	—	—
	Unload materials, install ceiling fan	40	254	82.3	—	—
	Painting, sweeping floor	60	254	68.8	—	—
	Lunch, indoors	60	162	70.3	—	—
	Fill out paperwork outdoors in shade	40	162	96.9	—	—
	Cleaning, vacuuming	45	254	68.1	—	—
	Checking swamp coolers	60	254	94.2	—	—
	Checking sprinkler systems	30	254	98.3	—	—
	Drive back to staging area with AC on	10	162	68.4	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

E = Above CBT of 101.3°F, or maximum sustained heart rate over a 3-minute period (132 bpm)

Table B5. Heat stress and strain measurements for employee E, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to worksite with AC on	60	129	73	—	—
	Manual shoveling, removing debris	95	336	79.9	—	—
	Lunch, outdoors	45	129	87.5	—	—
	Manual shoveling, removing debris	55	336	86	—	E
	Equipment maintenance	25	202	82	—	—
	Manual shoveling, removing debris	100	465	81.5	—	—
	Drive back to staging area with AC on	60	129	68.4	—	—
2	Did not work		No data collected			
3	Drive to worksite	60	129	73	—	—
	Unloading materials	5	336	84.9	—	—
	Shovel dry sand	75	336	87	—	E
	Lunch, outdoors	50	129	87.1	—	—
	Shovel rake sand and stone	75	465	84.9	—	—
	Load debris into Bobcat bucket	25	336	89.1	—	—
	Install drain pipe, shoveling sand	45	336	89.6	—	—
	Took break, outdoors	45	129	89.6	—	—
	Drive back to staging area with AC on	60	129	68.4	—	—
4	Drive to worksite with AC on	60	129	73	—	—
	Unloading materials	10	336	76	—	—
	Took break, outdoors	60	129	82.1	—	—
	Manually dig trench, install drainpipe	20	336	85.3	—	—
	Took break, outdoors	35	129	87.8	—	—
	Lunch, outdoors	55	129	89.6	—	—
	Install drain pipe, shoveling sand	25	336	89.8	—	—
	Took break, outdoors	25	129	90.1	—	—
	Installing drainpipe	95	336	90	—	E
	Took break, outdoors	35	129	92.9	—	—
	Drive back to staging area with AC on	60	129	68.4	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

E = Above CBT of 101.3°F, or maximum sustained heart rate over a 3-minute period (127 bpm)

Table B6. Heat stress and strain measurements for employee F, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Did not work		No data collected			
2	Drive to jobsite with AC on	60	129	73	—	—
	Operate Bobcat, some heavy shoveling	110	202	82	—	—
	Lunch, outdoors	50	129	85.5	—	—
	Operate Bobcat, some light shoveling	110	202	85.7	—	—
	Took break, outdoors	15	129	85.7	—	—
	Operate Bobcat	55	202	87.3	—	—
	Ride back to staging area with AC on	60	129	77	—	—
3	Drive to jobsite with AC on	60	129	73	—	—
	Operate Bobcat	110	202	71.2	—	—
	Took break, outdoors	15	129	87.4	—	—
	Operate Bobcat	45	202	87.8	—	—
	Lunch, outdoors	55	129	87.7	—	—
	Operate Bobcat	60	202	89.6	—	—
	Ride back to staging area with AC on	60	129	74	—	—
4	Drive to jobsite with AC on	60	129	73	—	—
	Unload material, digging, handling debris	70	336	76	—	—
	Operate Bobcat	20	202	85.6	—	—
	Took break, outdoors	35	129	87.6	—	—
	Lunch, outdoors	55	129	89.3	—	—
	Laying pipe, shoveling	35	336	89.9	—	—
	Took break, outdoors	30	129	88.9	—	—
	Operate Bobcat	115	202	89.9	—	—
	Drive back to staging area with AC on	60	129	74	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

Table B7. Heat stress and strain measurements for employee G, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to jobsite with AC on	60	154	73.0	—	—
	Shovel, manual handling pieces of asphalt	33	556	77.4	—	—
	Shoveling dry sand, debris removal	85	556	83.3	—	—
	Lunch, outdoors	45	154	87.8	—	—
	Shovel, manual handling pieces of asphalt	115	556	86.0	—	—
	Manual handling pieces of asphalt	45	241	82.4	—	—
	Drive back to staging area with AC on	60	154	74.0	—	—
2	Drive to jobsite with AC on	60	154	73	—	—
	Shovel, manual handling pieces of asphalt	110	402	79.5	—	—
	Lunch, outdoors	50	154	85.5	—	—
	Manual hauling debris, load dumpster	40	402	87.8	—	—
	Shovel, manual handling pieces of asphalt	40	556	85.2	—	—
	Took break, outdoors	20	154	87.2	—	—
	Manual hauling debris, load dumpster	15	556	86	—	—
	Shoveling heavy rocks/pieces of asphalt	55	556	87.7	—	—
	Ride back to shop in AC truck	60	154	78	—	—
3	Did not work		No data collected			
4	Drive to jobsite with AC on	60	154	73	—	—
	Unload material, shovel rock/sand	20	402	76	—	—
	Shoveling, installing plywood	15	402	82.3	—	—
	Shovel, dig trench, install drain pipe	25	402	85.6	—	—
	Took break, outdoors	40	154	87.7	—	—
	Lunch, outdoors	55	154	89.2	—	—
	Shovel, dig trench, install drain pipe	15	402	89.8	—	—
	Pull fire hose, flush out pipes	15	241	89.2	—	—
	Shoveling, raking, walking around site	140	241	89.9	—	—
	Ride back to staging area with AC on	60	154	78	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

Table B8. Heat stress and strain measurements for employee H, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to jobsite with AC on	10	171	73	—	—
	Moving equipment, laying bricks	14	447	83.9	—	—
	Mixing mortar, laying brick	36	447	91	—	—
	Took break, indoors with AC on	15	171	77	—	—
	Mixing mortar, laying brick	60	447	89	—	—
	Mixing mortar, laying brick	60	447	92.8	—	—
	Took break, indoors with AC on	15	171	74.6	—	—
	Laying brick, light shoveling, moving brick	30	268	90.1	—	—
	Lunch	30	171	74.6	—	—
	Laying brick, wet sawing brick,	135	447	88	—	—
	Took break, indoors with AC on	10	171	73.6	—	—
	Lay bricks, cleanup, move equipment	60	447	88.8	—	—
	Drive back to staging area with AC on	10	171	74	—	—
2	Drive to jobsite with AC on	10	171	73	—	—
	Moving equipment, laying bricks	36	447	84	—	—
	Mixing mortar, laying brick	150	447	89	—	—
	Lunch, outdoors	30	171	90.5	—	—
	Mixing mortar, laying brick	75	447	90.8	—	—
	Took break, outdoors	25	171	91.4	—	—
	Mixing mortar, laying brick	60	447	93.2	—	—
	Took break, outdoors	30	171	95.9	—	—
	Cleanup	20	268	96	—	—
	Drive back to staging area with AC on	10	171	74	—	—
3	Drive to jobsite with AC on	10	171	73	—	—
	Moving equip, laying bricks	60	618	85	—	—
	Mixing mortar, laying brick	60	447	88.1	—	—
	Took break, indoors with AC on	15	171	73	—	—
	Mixing mortar, laying brick	90	447	89.1	—	—
	Took break, outdoors	22	171	93.8	—	—
	Mixing mortar, laying brick	41	447	93	—	—
	Lunch, indoors with AC on	45	171	78	—	—
	Mixing mortar, laying brick	79	447	93.9	—	—
	Took break, outdoors	15	171	93.9	—	—
	Mixing mortar, laying brick	90	447	97.8	—	—
	Drive back to staging area with AC on	10	171	74	—	—
4	Did not work		No data collected			

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

Table B9. Heat stress and strain measurements for employee I, by task

Day	Task	Duration (minutes)	Metabolic rate* (watts)	WBGT (°F)	Max CBT† (°F)	Max HR‡ (bpm)
1	Drive to jobsite with AC on	60	184	74	—	—
	Drive truck with AC on	28	184	80.4	—	—
	Waiting in parking lot outside truck	4	184	81.2	—	—
	Drive truck with AC on	17	184	81	—	—
	Waiting in parking lot outside truck	8	184	82	—	—
	Drive truck with AC on	17	184	81.5	—	—
	Waiting in parking lot outside truck	4	184	82.5	—	—
	Drive truck with AC on	14	184	81.2	—	—
	Lunch, outdoors	45	184	85.5	—	—
	Drive truck with AC on	20	184	82.1	—	—
	Waiting in parking lot outside truck	5	184	88.1	—	—
	Drive truck with AC on	15	184	82	—	—
	Waiting in parking lot outside truck	8	184	84.2	—	—
	Drive truck with AC on	18	184	82	—	—
	Waiting in parking lot outside truck	5	184	80	—	—
	Drive truck with AC on	14	184	80	—	—
	Waiting in parking lot outside truck	4	184	80.9	—	—
	Drive truck with AC on	22	184	80.8	—	—
	Waiting in parking lot outside truck	5	184	79	—	—
	Drive truck with AC on	15	184	79	—	—
	Drive back to staging area with AC on	60	184	74	—	—
2	Did not work		No data collected			
3	Drive to jobsite with AC on	60	184	74	—	—
	Drive truck with AC on	165	184	72	—	—
	Lunch, outdoors	30	184	87	—	—
	Drive truck with AC on	75	184	72	—	—
	Assisting with building demolition	75	664	89.8	—	—
	Drive truck with AC on	60	184	72	—	—
	Manual pickup of residential trash cans	60	480	88	—	—
4	Drive to jobsite with AC on	60	184	74	—	—
	Walking, standing, inspecting	70	184	76	—	—
	Shovel, install drain pipe	25	480	85.6	—	—
	Took break, outdoors	35	184	88	—	—
	Lunch, outdoors	55	184	89.3	—	—
	Digging with shovel, laying pipe	15	480	89.8	—	—
	Handling debris, loading dumpster	30	480	89.4	—	—
	Standing around	20	184	89.3	—	—
	Took break, outdoors	65	184	90	—	—
	Shoveling	45	480	90.9	—	—
	Drive to shop with AC on	60	184	74	—	—

*Adjusted for the weight of the employee

†Maximum core body temperature of 101.3°F

‡Maximum heart rate > 180 minus age in years for 3 or more minutes during task

— = Value was below excessive heat strain criteria

Appendix C: Figures

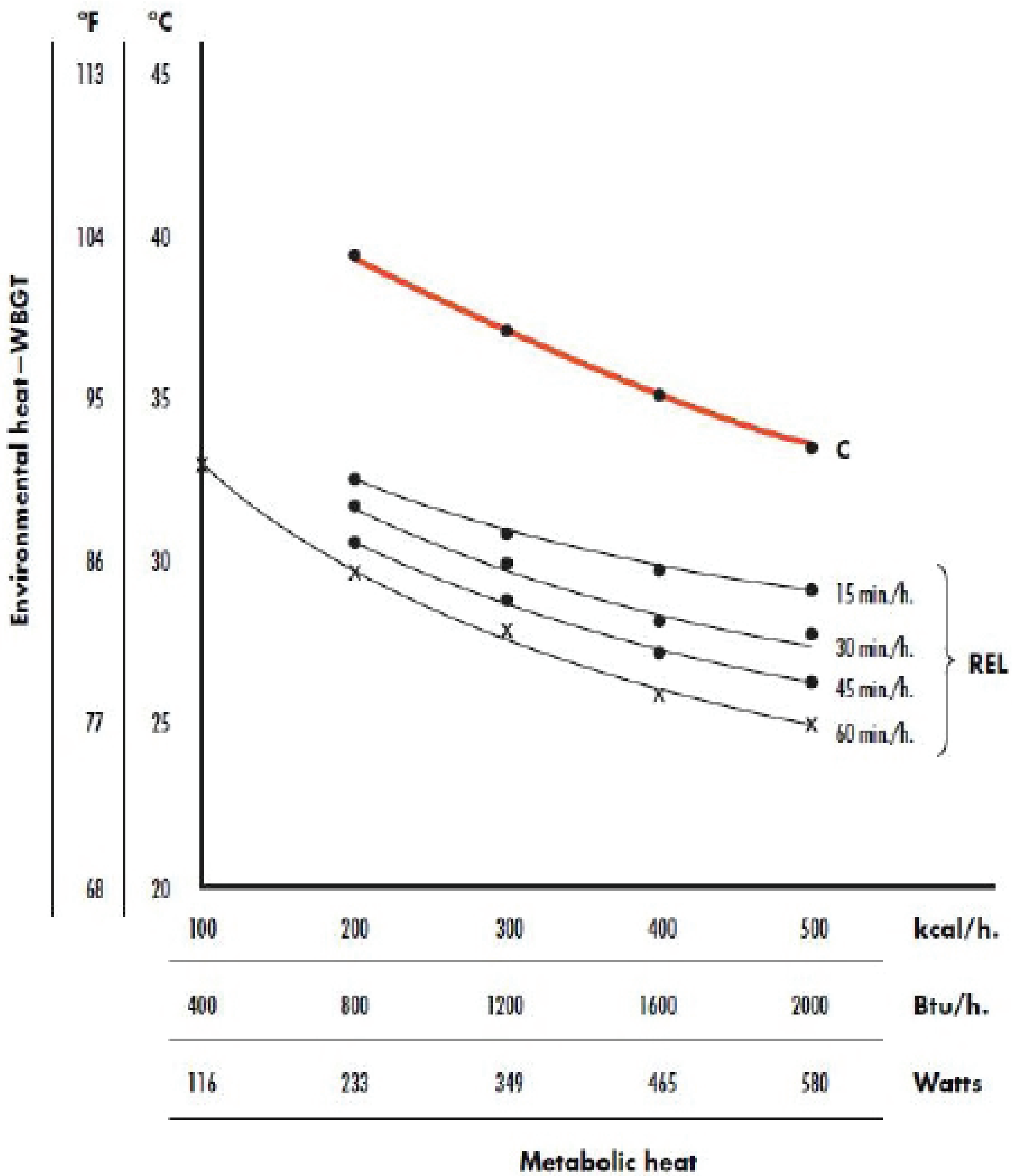

Figure C1. NIOSH-recommended heat stress exposure and ceiling limits for acclimatized workers.

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