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Evaluation of Heat Stress and Strain in Electric
Utility Workers

A dissertation submitted in partial satisfaction of the requirements
for the degree Doctor of Public Health
in Environmental Health Sciences

by

Eric Nicholas Brown

2013

ABSTRACT OF THE DISSERTATION

Evaluation of Heat Stress and Strain in Electric
Utility Workers

by

Eric Nicholas Brown

Doctor of Public Health in Environmental Health Sciences

University of California, Los Angeles, 2013

Professor Richard Jackson, Chair

Heat stress is a known occupational hazard. The purpose of this dissertation was to evaluate industrial hygiene heat exposures in electric utility line workers during work in regions with high ambient temperatures (75-115°F) and low relative humidity (8-37%). Relationships between accepted heat stress and heat strain variables were examined. New variables, namely a modified version of the Physiological Strain Index, and the differences from baseline for the oral temperature and heart rate were examined as well.

The hypotheses tested in this study are as follows:

- (1) Certain tasks and job classes had higher levels of heat stress and heat strain than others;

- (2) The measured and derived independent heat stress variables, such as Wet Bulb Globe Temperature levels, metabolic effort levels, exposure levels differences from applicable guidelines and standards, and personal factors (age, weight, body mass index, acclimatization), influence or predict measured and derived dependent heat strain variables (heart rate, body temperature, and Physiological Strain Index);
- (3) The test variable of the modified Physiological Strain Index offered improvement over the unmodified version;
- (4) The test variables of the difference in heart rate from baseline measurements, and the difference in body temperature from baseline were significant improvements over using the heart rate or body temperatures alone; and
- (5) The level of ambient temperature increase from global warming had an impact on occupational heat stress exposures.

The design of the study was a cross-sectional study. Eighty nine subjects, age 18-64, and 428 individual tasks of one to four hour length were evaluated in two populations. Resultant data were analyzed using univariate comparisons and mixed effects multiple linear and logistic regressions.

Results indicated that workers conducting certain tasks (digging) and working as certain job classes (groundmen and journeyman linemen) represented exposures to higher heat stress levels than others. Results also showed that workers performing certain tasks (digging) and classes (Groundmen and apprentice linemen) exhibited higher levels of heat strain. Personal variables (age, past shift work) were significantly predictive of increased heat strain. Race was not correlated to heat strain. The analysis

of acclimatization status as a variable was removed from this study due to dissimilar populations. Heat exposure standards (ACGIH and NIOSH) appeared to be conservative and protective to the worker, however, this population (utility workers) is a very healthy population and shouldn't necessarily represent the general working population. California OSHA's use of 85°F as a trigger temperature did not correlate well with increased heat strain metrics. The 95°F set-point correlated better.

Oral temperatures, per se, were not correlated to exposure, but the differences in oral temperature from baseline were better heat strain indicators. Heart rate increases were strong indications of heat strain, but the differences in heart rate from baseline were better indicators, especially for tasks with less metabolic load variance. Heart rate set-points of 110 bpm and 120 bpm correlated well with increased exposures. The modified Physiological Strain Index was not an improvement over the non-modified one.

And applying forecasted global warming by the end of the century to the population in this study would increase worker exposures from 33% to 100% of the population being over the recommended limits.

The dissertation of Eric Nicholas Brown is approved

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Richard Jackson, Committee Chair

University of California, Los Angeles

2012

Dedication

This dissertation is dedicated to my father, Dr. H. Wesley Brown.

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I can't express how grateful I am for the help that my committee has given me. Dr. Nola Kennedy has given me so much of her limited time to help with this study and has assisted me at every phase. Dr. Richard Jackson has provided many important insights. Dr. Pamina Gorbach's guidance helped me to research into the statistical side, which was assisted as well by the UCLA Statistical Consulting group. Also, Dr. Thomas Bernard from University of South Florida was critical in the outlining and creation of the research study.

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List of Abbreviations

ACGIH® American Conference of Governmental Industrial Hygienists

AL Action Limit

BLS Bureau of Labor Statistics

BMI Body Mass Index

bpm Beats per minute

Cal/OSHA California Occupational Safety and Health Administration

CBT Core body temperature

°C Celsius

CAF Clothing Adjustment Factor

CDC Centers for Disease Control and Prevention

CET Corrected Effective Temperature

CI Confidence Interval

DHS Department of Health Services

E Evaporative Heat Loss

ESI Environmental Stress Index

ET Effective temperature

°F Fahrenheit

HR Heart rate

HR_{rec} Recovery heart rate

HRI Heat-Related Illness

IQR Inter-Quartile Range

IRB Institutional Review Board

M Metabolism

NET New Effective Temperature

NIOSH National Institute for Occupational Safety and Health
NOAA National Oceanic and Atmospheric Administration
OEL Occupational exposure limit
OSHA Occupational Safety and Health Administration
OTM OSHA Technical Manual
PEL Permissible exposure limit
PPE Personal protective equipment
PSI Physiological Strain Index
PSI_m Modified Physiological Strain Index
R Radiant Heat
RAL Recommended Alert Limit
REL Recommended Exposure Limit
RH Relative Humidity
S Body Heat Content
SR Solar Radiation
T_a Ambient temperature
T_{db} Dry bulb temperature
T_{NWB} Natural wet bulb temperature
T_o Oral temperature
TLV® Threshold limit value
T_{rec} Rectal temperature
TWA Time-weighted average
TWB Wet bulb temperature
WBGT Wet bulb globe temperature
W_{ex} Mechanical Work

WHO World Health Organization

WNA Western Region of North America

List of Equations

Equation 1 - Heat Balance Equation

Equation 2 - Outdoors Wet Bulb Globe Thermometer Equation

Equation 3 - Indoors Wet Bulb Globe Thermometer Equation

Equation 4 - Environmental Stress Index Equation

Equation 5 - Body Mass Index Equation

Equation 6 - ACGIH Threshold Limit Value Equation

Equation 7 - ACGIH Action Level Equation

Equation 8 - NIOSH Ceiling Limit Equation

Equation 9 - Time Weighted Average Equation

Equation 10 - Physiological Strain Index Equation

Equation 11 - Modified Physiological Strain Index Equation

1 INTRODUCTION

Impact of Heat-Related Illness

When the human body is exposed to environmental heat stress, or when the body creates its own metabolic heat internally, the overall heat load on the body will increase. Although thermoregulatory controls exist that will stabilize and reduce this heat load, these controls can fail or simply not be adequate. When this occurs, the body may express this heat strain as a Heat Related Illness (HRI). Examples of HRI's are heat exhaustion and heat stroke.

The impact of Heat-Related Illnesses is significant in the areas of both occupational and public health. The Bureau of Labor Statistics (BLS) shows a large number of reported illnesses and deaths from occupational heat exposures, and these estimates are significantly under-reported by applicable labor reports and statistical briefs (BLS, 2003). Both the Federal and California Occupational Safety and Health Administrations (OSHA and Cal/OSHA, respectively) have placed occupational heat illness on the top of their priority lists within the last three years. (Cal/OSHA, 2007).

Occupational:

When HRIs are discussed in terms of the workplace, there are illnesses and there are deaths. The BLS states that in the five-year period 1999-2003, there were more than 200 deaths and 15,000 cases of days away from work due to "Environmental Heat" in the private sector workforce. The "Environmental Heat" classification is actually a number of combined classifications that include heat illness (US Department of Labor, 1992). The Centers for Disease Control and Prevention (CDC) has higher estimates, stating that an

average of 175 deaths occur annually in the United States, and from 1979 to 2003, excessive heat exposure directly caused 8015 deaths. That is more than from hurricanes, lightning, tornadoes and floods combined (CDC, 2006).

Estimates of the cost of each heat-related illness indicate an average of \$7500 per occurrence (Bureau of Labor Statistics, 2009). Adding this to the \$150/day average wage loss would equate to over \$100 million for the above-described BLS five year period, or over \$20 million per year (US Census Bureau, 2010). This amount is only for acute illnesses, not fatal instances. Since employee deaths have many economic costs (not to mention ethical ones), they serve to illustrate the significance of HRIs.

The cost to the economy is also exacerbated in terms of lost productivity. Figure 1 shows that worker productivity decreases as ambient environmental temperatures increases (Poulton, 1970).

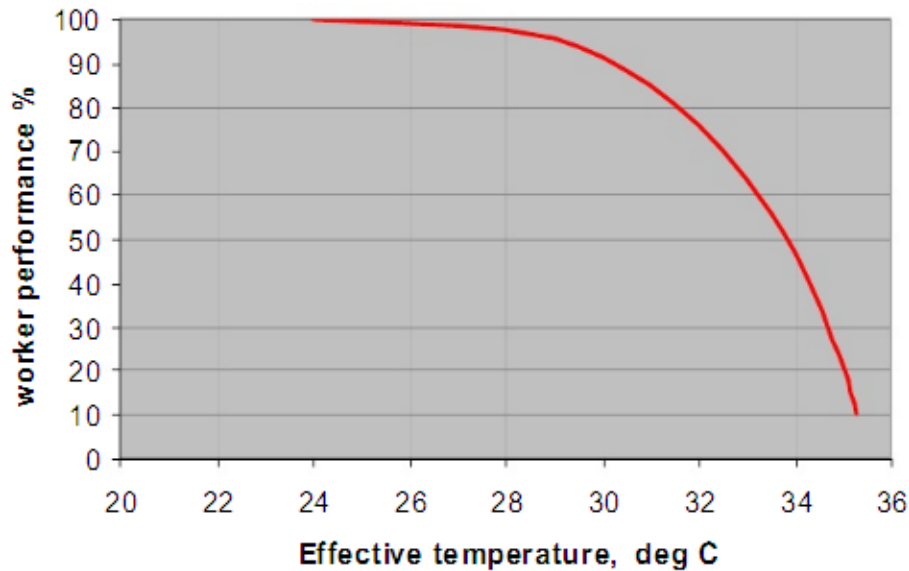


Figure 1: Worker performance in increased temperatures

The CDC has stated that occupational injuries also increase in ambient temperatures over 85°F (CDC, 2006).

Actual deaths which occur due to HRIs are likely underreported. The variety of expressions that HRIs take (heat exhaustion, heat stroke, heat syncope) have a number of underlying causes that could be aggravated by, and aggravate in turn, other existing diseases. “Heat illness is generally underreported, and the true incidence is unknown. Death rates from other causes (e.g. cardiovascular, respiratory) increase during heat waves but are generally not reflected in the morbidity and mortality statistics related to heat illness” (Rampulla, 2012). It was reported by the Center for Disease Control (CDC) that in the military, which is very conscious of heat illness risk, heat stress was documented as either a primary or contributing cause of exercise-related deaths in over 33% of cases (CDC, 2006).

The General Population:

The CDC also reports that, in every year since 1996 (to 2006), more than 6,000 people were seen annually in the ER for HRIs, primarily from outdoor activities. Resultant costs follow these large numbers. For example, in Arizona alone, over ten million dollars were spent in 2008 on treatment for HRIs (Bureau of Public Health Statistics, 2009). There were also, on average from 1992-2006, over 250 non-occupational heat-related deaths in the US per year (CDC, 2006). Again, this number is likely underreported, but still shows the importance of HRIs.

Also, potential global warming may increase the ambient temperatures to which people will be exposed, both publically and occupationally. In turn, the heat stress burden could increase, and therefore so would the risk and occurrence of HRIs. If outdoor temperatures increase due to global warming effects, the numbers of people affected, both occupationally and generally, will also increase.

2 BACKGROUND

The term “Heat Stress” refers to the externally-based heat load created from a summation of factors in the environment. These factors include climatic conditions, metabolic work load, and clothing adjustments (Epstein, 2006). Heat Strain is the expression of the body’s response to the heat stress through various mechanisms. The body’s internal temperature may increase directly, and the heart rate may increase to increase blood flow.

The descriptive basic Heat Balance Equation, as given by the National Institute of Occupational Safety and Health (NIOSH, 1986), is:

$$\Delta S = (M - W_{ex}) \pm (R + C) - E \quad \text{Equation 1}$$

Where:

ΔS = change in body heat content;

$(M - W_{ex})$ = net metabolic heat production from total metabolic, where (M) heat production

W_{ex} = mechanical work;

$(R + C)$ = radiation and convection heat exchange; and,

E=evaporative heat loss.

If there is heat balance between heat stress and evaporative heat loss, $\Delta S=0$, so

$(M - W_{ex}) \pm (R + C)$ would equal E_{req} , which is the evaporation needed to achieve thermal balance (NIOSH, 1986).

2.1 BIOLOGICAL RESPONSES TO HEAT STRESS

When the human body is exposed to thermal stress, either environmental external stress or internal metabolic stress, the body attempts to maintain the above heat balance using a number of thermoregulatory mechanisms. Seen strictly in terms of energy, the body will use every option available to transfer the internal energy to the outside environment. These transfer methods are a body's thermoregulatory response.

There are two basic components for thermoregulation, the core and the peripheral. The core component is regulated by the hypothalamus (McArdle, Katch, and Katch, 2001). It

is either directly stimulated from blood temperature, or it is activated from heat receptors in the skin. When the hypothalamus is activated, it causes an increase in heart rate (HR) and a dilation of blood vessels. It also causes internal organs to divert blood towards the periphery. Blood vessels at the surface of the skin are dilated to increase flow as far towards the skin surface as possible. This is why skin appears flushed during times of increased exertion or in the heat (Brouha et al., 1960).

During physical activity, the muscles themselves will create heat energy, in the form of friction. To reduce this heat energy, blood is moved past the muscles, absorbs the heat energy, and carries it to the skin. The heat can then transfer to the environment from convective contact with the air.

Once the blood reaches the periphery/skin, the peripheral thermoregulatory component activates. This is primarily the activation of the sweat glands. Evaporation of sweat from the surface of the skin to the air is an endothermic reaction, so heat energy is removed from the body as evaporation increases. This has been shown to be the body's primary method for lowering the core temperature (Armstrong and Pandolf, 1988). These thermoregulatory responses are the reason for increased heart rate as one expression of heat strain.

These thermoregulatory components (HR and sweating) keep the body core temperature as stable as possible. However, as environmental and metabolic loads continue to increase, eventually the body temperature will increase.

2.2 METRICS OF HEAT STRESS

Heat Stress is described as the environmental factors affecting the body, typically from the exterior, such as increased temperature and humidity (Ramsey and Bernard, 1994). An increased work load resulting in an increased metabolic rate would also be considered heat stress. The various ways the body responds to the heat stress is typically referred to as heat strain (Ramsey and Bernard, 1994). There are indices (ways to measure and gauge the level) for heat stress as well as for heat strain.

2.2.1 ENVIRONMENTAL TEMPERATURES

Several methods are used to measure environmental heat stress. The first method used to measure heat stress is the use of the dry bulb temperature (T_{db} or T_a). This measurement is the temperature of the air, with no humidity or radiant heat involved. This is typically measured by a mercury or alcohol thermometer that is shielded from radiant sources such as sunlight. Alcohol is typically used at a lower range of temperatures, due to the 70 °C boiling point of alcohol (NIOSH, 1986). The T_a is the easiest and cheapest environmental measurement to collect, but, in terms of heat risk evaluation, typically seen as too simplistic a method of environmental evaluation by itself.

An additional measure is Relative Humidity (RH). Relative humidity is very important for heat stress evaluations, as it affects the rate of sweat evaporation, which is the most effective cooling mechanism. It indicates the rate at which sweat will evaporate from the skin, in other words it shows the rate of overall cooling effectiveness (NIOSH, 1986). The RH can be calculated via the Natural Wet Bulb (T_{NWB}) temperature, which is collected by a

thermometer covered with a wetted wick, or by the Wet Bulb (T_{wb}) temperature which is collected via the use of a sling psychrometer. The wet bulb method acts in a similar manner as the skin when sweat evaporates, and the cooling effect that evaporation has on the thermometer is expressed as a temperature index weighted by humidity. This method is cheap and simple, but depending on the method may not take air velocity completely into consideration and it ignores radiant heat load (Peters, 1991).

Radiant heat from the sun (also from hot machinery) can also be a significant factor (Haldane, 1905). The radiant heat load can be measured either directly or indirectly (NIOSH, 1986). The Globe temperature (T_g), an expression of radiant heat, is measured using a Botts-ball®, a copper globe painted matte black and surrounding a thermometer. Radiation heats the globe and indirectly measures the radiant heat effect. This is inexpensive and simple. A radiometer is required to directly measure radiant heat. This is an expensive and unwieldy piece of equipment, but the thermal radiation is directly shown as an output (Reischl and Reischl, 1977). Much like a photometer that measures visible light intensity, radiometers measure entire spectra of electromagnetic energy including ultraviolet and infrared ranges.

2.2.2 ENVIRONMENTAL INDICES

There are a number of indices and scales used to combine these various environmental measurements into a single workable number that could be more easily applied and examined. These indices were first created in the early 1900s and continue to be developed today. A list of these various indices was created as part of meta-analysis by Epstein and Moran (2006), and is shown in Figure 2. The highlighted indices are those evaluated as part of this current research study.

Table 3. Proposed systems for rating heat stress and strain (heat stress indices)

Year	Index	Author(s)
1905	Wet-bulb temperature (T_w)	Haldane ⁽⁹⁾
1916	Katathermometer	Hill <i>et al.</i> ⁽⁴⁷⁾
1923	Effective temperature (ET)	Houghton & Yaglou ⁽⁵⁰⁾
1929	Equivalent temperature (T_{eq})	Drafton ⁽⁶⁰⁾
1932	Corrected effective temperature (CET)	Vernon & Warner ⁽⁵⁴⁾
1937	Operative temperature (OpT)	Winslow <i>et al.</i> ⁽⁴⁹⁾
1945	Thermal acceptance ratio (TAR)	Ionides <i>et al.</i> ⁽⁵⁶⁾
1945	Index of physiological effect (E_p)	Robinson <i>et al.</i> ⁽⁵⁵⁾
1946	Corrected effective temperature (CET)	Bedford ⁽⁵²⁾
1947	Predicted 4-h sweat rate (P4SR)	McArdel <i>et al.</i> ⁽⁵⁸⁾
1948	Resultant temperature (RT)	Missenard <i>et al.</i> ⁽⁵⁴⁾
1950	Craig index (I)	Craig ⁽⁵³⁾
1955	Heat stress index (HSI)	Belding & Hatch ⁽⁵⁾
1957	Wet-bulb globe temperature (WBGT)	Yaglou & Minard ⁽⁵¹⁾
1957	Oxford index (WD)	Lind & Hellon ⁽⁵⁴⁾
1957	Discomfort index (DI)	Thom ⁽⁵⁶⁾
1958	Thermal strain index (TSI)	Lee & Henschel ⁽⁵⁴⁾
1959	Discomfort index (DI)	Tonnenbaum <i>et al.</i> ⁽⁶⁰⁾
1960	Cumulative discomfort index (CumDI)	Tonnenbaum <i>et al.</i> ⁽⁶⁰⁾
1960	Index of physiological strain (I)	Hall & Polte ⁽⁵⁷⁾
1962	Index of thermal stress (ITS)	Givoni ⁽⁵⁴⁾
1966	Heat strain index (corrected) (HSI)	McEarns & Brief ⁽⁵⁹⁾
1966	Prediction of heart rate (HR)	Fuller & Brouha ⁽⁶⁰⁾
1967	Effective radiant field (ERF)	Gagge <i>et al.</i> ⁽⁶⁰⁾
1970	Predicted mean vote (PMV)	Fanger ⁽⁶⁾
1970	Threshold limit value (TLV)	
1970	Prescriptive zone	Lind ⁽⁶³⁾
1971	New effective temperature (ET [*])	Gagge <i>et al.</i> ⁽⁶⁰⁾
1971	Wet globe temperature (WGT)	Bonford ⁽⁶⁴⁾
1971	Humid operative temperature	Nishi & Gagge ⁽⁶⁵⁾
1972	Predicted body core temperature	Givoni & Goldman ⁽⁶⁶⁾
1972	Skin wettedness	Kerlake ⁽⁶⁷⁾
1973	Standard effective temperature (SET)	Gagge <i>et al.</i> ⁽⁶⁶⁾
1973	Predicted heart rate	Givoni & Goldman ⁽⁶⁶⁾
1978	Skin wettedness	Gonzales <i>et al.</i> ⁽⁷⁰⁾
1979	Fighter index of thermal stress (FITS)	Nunnley & Stribley ⁽⁷¹⁾
1981	Effective heat strain index (EHSI)	Kamon & Ryan ⁽⁷²⁾
1982	Predicted sweat loss (m_{swe})	Shapiro <i>et al.</i> ⁽⁷³⁾
1985	Required sweating (SW_{req})	ISO 7933 ⁽⁶⁾
1986	Predicted mean vote (modified) (PMV [*])	Gagge <i>et al.</i> ⁽⁷⁰⁾
1996	Cumulative heat strain index (CHSI)	Frank <i>et al.</i> ⁽⁶⁸⁾
1998	Physiological strain index (PSI)	Moran <i>et al.</i> ⁽⁷⁷⁾
1999	Modified discomfort index (MDI)	Moran <i>et al.</i> ⁽⁸⁰⁾
2001	Environmental stress index (ESI)	Moran <i>et al.</i> ⁽⁸⁰⁾
2005	Wet-bulb dry temperature (WBDT)	Wallace <i>et al.</i> ⁽⁸⁰⁾
2005	Relative humidity dry temperature (RHDT)	Wallace <i>et al.</i> ⁽⁸⁰⁾

Figure 2: Heat Stress Indices

Effective Temperature/Corrected Effective Temperature

One of the oldest of these indices of heat stress was the Effective Temperature/ET scale, which looked at temperatures and air velocity. The ET is defined as the temperature of still, saturated (with water) air that would give the same instantaneous thermal sensation as the actual environment under consideration. This was created and tested only on sedentary individuals, which limits its usefulness (Vernon and Warner, 1932). It later became the Corrected Effective Temperature/CET scale, which added T_g for radiant heat. And finally, in 1971, it became the New Effective Temperature/NET, which assumes 50% relative humidity (Gagge et al, 1971). This scale was used for years by the military, but is not used as often due to more recent heat indices namely the WBGT, discussed below.

NOAA Heat Index

The National Oceanic and Atmospheric Administration (NOAA) developed a heat index for general public usage, based on temperature and RH. This chart is shown in Figure 3, and is intended for exposures in the shade (no radiant heat) with either prolonged exposures or strenuous work load (NOAA, 2013). This index is not frequently used or recommended for occupational exposures. However, several state and non-profit organizations utilize this index for public health concerns, due to its ease of use.

NOAA's National Weather Service

Heat Index Temperature (°F)

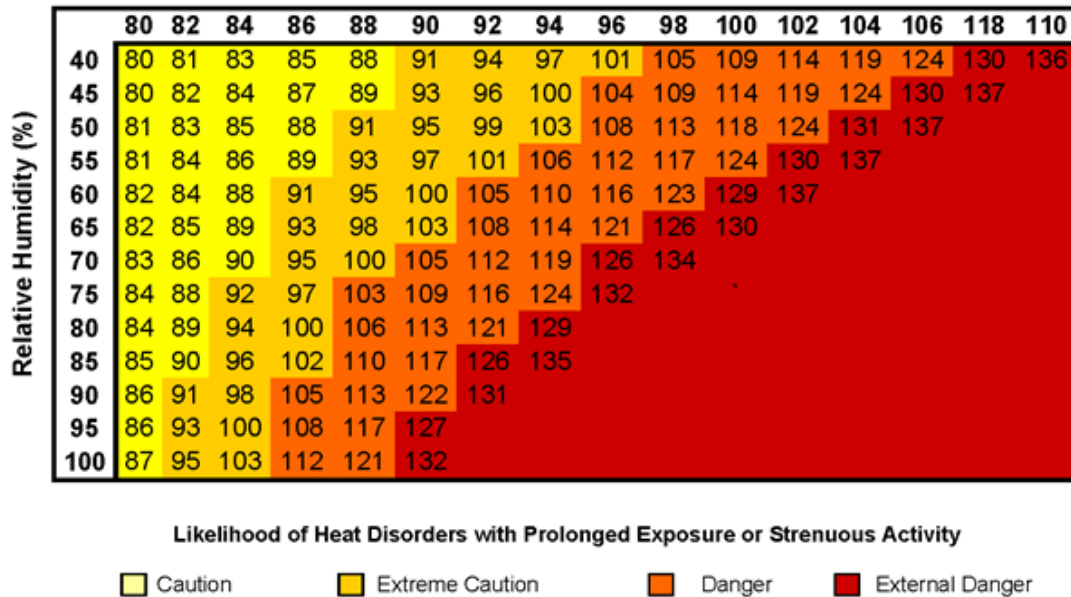


Figure 3: NOAA Heat Index

Wet Bulb Globe Temperature

The Wet Bulb Globe Temperature (WBGT) is the most commonly used index that combines the relevant environmental heat conditions, T_a , RH, and radiant heat, into one number. It was created in 1957 by the Marine Corps (Yaglou and Minard, 1957), and is recommended by governmental agencies in the US, including the military, ACGIH, NIOSH, and OSHA. The WBGT relies upon the T_{NWB} , T_g , and T_a temperatures. This index and weighting have been validated empirically numerous times (CDC, 2006; NIOSH, 1986; ACGIH, 2006). The equation used for the WBGT is simple, and there are separate indoor and outdoor equations.

$$WBGT_{\text{Outdoors}} = 0.7 T_{NWB} + 0.2 T_g + 0.1 T_a \quad \text{Equation 2}$$

and

$$\text{WBGT}_{\text{Indoors}} = 0.7 T_{\text{NWB}} + 0.3 T_g \quad (30) \quad \text{Equation 3}$$

The 70% weighting towards the natural wet bulb temperature highlights the importance of humidity and evaporative cooling. It should be noted that the WBGT is not in itself a complete descriptor of thermal stress. It only looks at the environmental variables, and not the metabolic load or clothing effects, as later, more comprehensive indices do. Nor is there an actual number currently used to detail risk from the WBGT alone. However, when used with other measurement scales, when it comes to environment alone, the WBGT seems to be most highly validated and the lowest cost (Bernard et al. 1994).

There are some valid criticisms of using only the WBGT index. The WBGT may not fully account for differences in air velocity, which can be an important factor in sweat/evaporation rates. Also, the WBGT accounts for neither individual variations nor the many non-environmental factors that can influence thermoregulatory processes. For example, individuals with certain respiratory illnesses and the obese are at higher personal risk using just the WBGT because these personal factors that increase susceptibility to heat stress are not considered (Bashir and Ramsey, 1988). Perhaps most importantly, the WBGT does not consider at all the huge impact that metabolic rate and physical activity have on the total heat load.

There is also the Environmental Stress Index (ESI), which was created as a substitute for the WBGT. The ESI uses the T_a , T_{WB} (with a sling psychrometer rather than a wetted wick for T_{NB} as in the WBGT), and Solar Radiation (SR), again directly measured instead of T_g . This index was validated as being 95% similar to the WBGT, and slightly more accurate in

extreme humidity regions (Moran et al, 1982). This index uses more expensive equipment for direct radiant heat measurements. The equation for the ESI is as follows:

$$ESI = 0.62 T_a - 0.003 RH + 0.002 SR + 0.0054 (T_a * RH) - 0.073 (0.1 + SR)^{-1} \quad \text{Equation 4}$$

This equation illustrates the similarity of environmental parameters (T_a , RH, and SR) in terms of weighting, and also shows the nature of interactions between them, with $T_a * RH$, for example.

2.2.3 METABOLISM

Metabolism (M) is a component of heat stress. To simply survive, the body requires certain internal processes to continue. The summation of these internal processes is expressed as the basal metabolic rate. When the body is subjected to a work load, there is an increased requirement for energy, which translates to a higher metabolic rate to compensate. In the Heat Balance equation (Equation 1), M is considered a stress that is always added to the overall heat load.

Metabolic rates can be measured directly (calorimetry) or indirectly (oxygen consumption) in a laboratory, or by estimation (NIOSH, 1986; ACGIH 2006). ACGIH created a Threshold Limit Value (TLV) for heat stress and included an empirically-derived table of tasks to be converted into metabolic rate (W/hr or Kcal/minute). The three components to consider are (1) the base metabolism value, (2) a value related to body position/movement, and (3) one based on the type of work being performed. The body positions are seated, standing, or kneeling, and the types of work are hand, one-arm, two-arms, or whole body work. These numbers are added, per time unit, and

assigned a category of metabolic rate. This method is derived from the International Standards Organization (ISO, 2004). Basal levels of metabolic rate are always added to the derived number (Metabolic rate is never 0).

Activity	Effort			
	Light	Moderate	Heavy	Very Heavy
None	0	0	0	0
Hand(s) Only	25	55	70	80
One Arm	65	100	135	170
Both Arms	115	155	190	230
Whole Body	225	340	505	700

Table 1: ISO Metabolic Rate Estimation

There are more simple methods for metabolic rate estimation as well. ACGIH provides a chart in the 2006 TLV Handbook that can be used, but it is stated in the chart that the ISO Metabolic Rate Estimation component method is a better alternative (ACGIH, 2006).

Work Demands	Category	Rate	Metabolic Rate [W]
	Rest / Sedentary	115	
Choose a characteristic category and enter rate. Intermediate values are acceptable.	Light Sustainable with ease for 8 h	180	A better alternative is to use the component estimate method.
	Moderate Sustainable for 8 h w/ nominal breaks	300	
	Heavy Breaks required at least every hour †	415	
Values based on average person.	Very Heavy Frequent breaks required †	520	
	† When averaged over an hour, heavy and very heavy work with breaks are usually moderate.		

Table 2: Metabolic Rate Estimation, taken from ACGIH 2006 TLV Handbook

Metabolic rate is also adjusted based on body weight. A multiplier of subject weight divided by 70 kg (154 lbs) is recommended in the TLV. It is unknown whether this simple linear corrective factor adequately adjusts for metabolism.

The duration of the work task is an important factor to consider. Recent research has suggested that the length of time required for a task, or more specifically the work/rest interval, does impact the body's ability to thermoregulate (Gagnon and Kenny, 2011). NIOSH recommends a 1-2 hour task length, as does ACGIH. However, ACGIH states if the work demands and work environments are the same throughout the entire day, a single task estimate for the entire day may be used (ACGIH, 2006).

2.2.4 CLOTHING ADJUSTMENT FACTORS

Additional heat stress load can be added by wearing certain types of clothing, such as fire- or chemical-retardant clothing. Impermeable/coated and other non-woven materials used in protective garments will block evaporation of sweat (and thus reduce the endothermic removal of heat from the body) and will lead to higher levels of heat stress. The ACGIH TLV assumes either normal work clothes (a long sleeve shirt and pants) or cloth overalls. These clothing ensembles do not justify a clothing adjustment factor (CAF).

However, any further clothing, or multiple layers of clothing will impose a Clothing Adjustment Factor to be added to the WBGT measurement for that task. The adjustment ranges from 0°F adjustment for a single layer of normal work clothing, to 20°F additional heat load for impermeable, vapor barrier clothing, such as a chemical-resistant suit

(ACGIH, 2006). The ACHIG Clothing Adjustment Factors chart is given in Table 3, also note the space given for combinations and other clothing ensembles.

Clothing	<i>Ensemble</i>	<i>°F</i>	<i>°C</i>	Clothing Adjustment Factor
Check an Ensemble and Enter Clothing Adjustment Factor.	<input type="checkbox"/> Work Clothes / Cloth Coveralls	0	0	
	<input type="checkbox"/> Double Layer Cloth	5	3	
	<input type="checkbox"/> SMS Polypropylene Coveralls	1	0.5	
	<input type="checkbox"/> Polyolefin Coveralls	2	1	
	<input type="checkbox"/> Limited-Use Vapor-Barrier	20	11	
Space provided for two other ensembles.	<input type="checkbox"/>			°F / °C
	<input type="checkbox"/>			

Table 3: ACGIH Clothing Adjustment Factors

2.2.5 PERSONAL FACTORS

Personal factors can influence an individual’s risk for a HRI. Acclimatization, prescription drugs, past or current illnesses or diseases, age, increased body weight, and even diet can negatively impact an individual’s thermoregulation (Bernard, 1999; Windham, 1974). Race has also been shown to have a potential impact (Carter et al. 2005).

Acclimatization is a physiological adaptation to heat stress. After being exposed repeatedly to heat stress, a person will show lower signs of heat strain (lower body temperature and heart rate). This is shown in Figure 4. Typically, acclimatization starts after five days of successive exposure to heat, when exposures are at least 2 hours per day. Acclimatization drops off within 4 days and can be completely lost by the body within several weeks of non-exposure, but this can last up to 3-4 weeks (NIOSH, 1986).

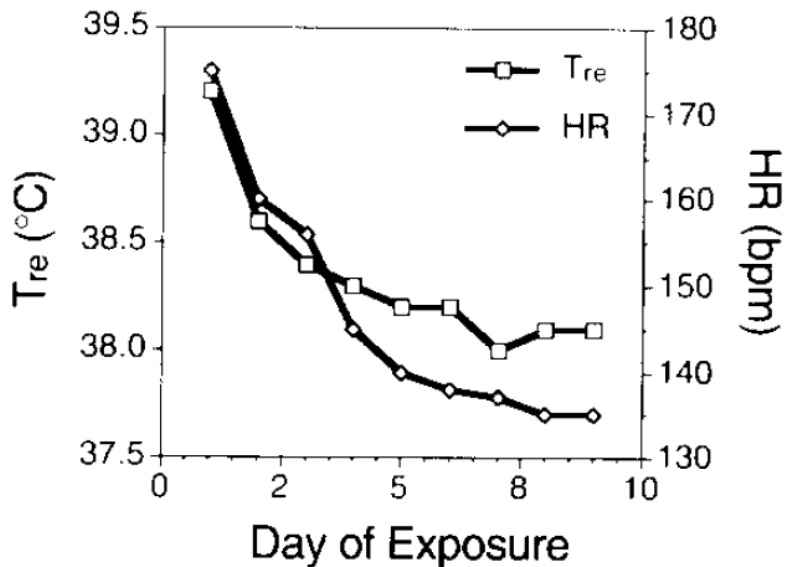


Figure 4: Acclimatization shown as HR and Core Body Temperature per days of exposure (Lind and Bas, 1963).

Drugs that interfere with the thermoregulatory processes include antidepressants and bronchodilators, which can alter the heart rate and reduce sweat rates. High-blood pressure drugs like beta-blockers can decrease blood flow to the skin, reducing convective cooling. Antihistamines can both reduce blood flow to the skin and increase basal body temperature. And of course, diuretic medications or "water pills" will change the fluid balance in the body (Platt, et al., 2010).

If an individual is suffering from a degenerative disease of the cardiovascular system, such as diabetes, their risk for HRI may be increased if their thermoregulatory response is affected. Hypothyroidism affects metabolism and body temperature directly. Anemia,

having a lower red blood cell count, can affect metabolism and cardiovascular (and thermoregulatory) responses (Platt, et al, 2010).

Aging results in lower sweat rates, but increased rates of blood flow to the skin. Given similar environmental and metabolic heat loads, older (over 40 years old) men showed a higher risk for HRI than those under 40. Total amount of body water held in the body decreases with age, which may play a role as well (Brothers, Keller, and Wingo, 2011).

Race been shown to have an effect on the incidence of heat illnesses in the working population. One study showed that Hispanic Americans and African Americans had a lower frequency of heat illness compared with Caucasians (Carter et al., 2005).

Obesity is well-established to predispose individuals to HRIs. (NIOSH, 1986) The lower level of physical fitness, combined with the additional weight, are causes, as is the lower body surface to body weight ratio, which equates to less area for evaporative cooling. The Body Mass Index (BMI) is a useful tool for determining obesity, which follows the following equation. The World Health Organization (WHO) defines obesity as a BMI greater than 30 (WHO, 1995).

$$BMI = \frac{(\text{Mass (lbs)} \times 703)}{\text{Height}^2(\text{inches})} \quad \text{Equation 5}$$

Even a worker's diet can affect the individual's susceptibility to a HRI. Many diets and workout regimens focus on an increased protein intake. However, increased protein intake will result in an increased urine output for nitrogen removal. That worker would therefore be required to drink an additional amount of water to maintain proper

hydration. These diets are very common, so someone on such a diet would have to be monitored more closely for the additional fluid intake.

2.3 METRICS OF HEAT STRAIN

As previously described, the various ways a body responds to heat stress are described as indications of heat strain. The most commonly measured heat strain indicators are body temperature and heart rate.

2.3.1 CORE TEMPERATURE/ORAL TEMPERATURE

Body temperature is perhaps the most important factor to indicate heat strain, as an elevated body core temperature is always present under conditions of severe heat stress (Brouha et al, 1960). There is a traditional two-compartment “core” and “shell” model of body temperature. The body’s deep core temperature is typically measured as rectal temperature (T_{rec}). Since T_{rec} is difficult to obtain in any situation other than the laboratory, surrogate methods have been tested. The shell temperature is collected as skin temperature, but is generally very difficult to collect, and has been found to have a large range, especially since it absorbs radiant heat (Bernard, 1999). Ear canal temperatures showed promise, but they were found to carry too much variability in the field (Fuller and Smith, 1981). They were also observed to be very susceptible to the environment, thus certain insulation was found to be necessary (Muir et al, 2001). Thermometers encapsulated in “pills” can be swallowed (CoreTemp™), and will broadcast via radio frequency the actual core temperature. These are expensive, however, and are invasive by nature. Also, potential complication situations exist with their use, such as if the pill were to break open while inside the subject.

Oral temperatures (T_o) have been validated as a good core temperature surrogate. Both electronic and single-use disposable thermometers can be reliably used. Eating or drinking within 15 minutes of the oral temperature measurement has been shown to have an impact on accuracy, as does mouth-breathing during the measurement. Oral temperatures reliably range from 0.3 to 0.7 degrees °C lower than the core temperature, averaging around 0.5°C lower than core (Bernard, 2001). Core body temperature is recommended to remain below 38°C by NIOSH (NIOSH, 1986), and by the WHO (WHO, 1995). ACGIH recommends that body core temperature not be greater than 38.5 °C for acclimatized workers or greater than 38 °C for un-acclimatized workers (ACGIH, 2006). NIOSH reported that, in populations where core body temperature rose above 39.2 °C, there is an approximately 25% chance of heat exhaustion collapse (NIOSH, 1986).

It should be mentioned that several laboratory-based studies have shown weaknesses in the use of all of the above temperature measurement methods. Direct calorimetry has been observed to be the most accurate method for measuring body temperature, at least by laboratory measurements. This method involves the direct measurement of heat energy released while the body is encased in some sort of device. Indirect calorimetry is also used for the same purpose; it measures the amount of oxygen utilized or carbon dioxide released in the breath. Both methods require extensive machinery in a laboratory setting and so are inappropriate for any field measurement (Reardon et al., 2006; Nettlefold et al., 2007).

2.3.2 HEART RATE

As described above, the body's initial response to increased environmental and metabolic stress is to increase the heart rate. Heart rate has been shown to increase for both a sedentary worker in an environment with increased temperature, and from increased workload with no increased ambient temperatures (Bernard, 1999). The increase in heart rate has virtually no lag (within seconds of exposure or workload increase) (Fuller and Smith, 1981). However, there are variations with heart rate baseline and response time, depending on such factors as level of personal fitness, the presence of certain diseases such as thyroid disease and anemia, and certain medications, like antidepressants and bronchodilators (Bernard and Kenny, 1994).

Typically, this measurement is collected as a baseline and then immediately after a task is completed. NIOSH recommends collecting the heart rate 1 minute after the exertion/task is ended. This is called the recovery heart rate (HR_{rec}). Another study suggested collecting a series of three heart rates after task completion, to show the body's ability to adapt and recover from heat stress (Kamon 1972). However, an important goal of industrial hygiene monitoring is to conduct monitoring in a way that allows the worker to conduct their work activities with as little interruption as possible. The single H_{rec} thus seems to be a better method, if possible.

In terms of upper limits, several recommendations exist. NIOSH states that if the worker is given three minutes to rest after an activity, and the HR is still over 90 bpm after that, observation is prompted. NIOSH also gives a 1 minute limit of 110 bpm (NIOSH, 1986). This limit is used in several other related studies (Bernard and Kenny, 1999). The ACGIH

TLV lists an indication of excessive heat strain as either a sustained HR during work of greater than 180 bpm minus the subject's age (this requires constant monitoring), or a HR_{rec} at one minute after stop of work greater than 120 bpm (ACGIH, 2006).

2.3.3 BLOOD PRESSURE AND SUBJECTIVE MEASUREMENTS

Increased heat stress does affect the worker's blood pressure. However, there is a wide range of variability per individual. Baseline measurements vary a great deal, as do actual rates of change based on a given heat stress (Brothers, Keller, and Wingo, 2011).

The workers themselves can verbally express their level of heat strain. Through verbal interaction during the work, the worker can express the level of comfort and exertion experienced. Subjective estimations of effort and heat exposure have been positively correlated with physiological heat strain indicators. This shows that the worker's self-diagnosing ability may have some utility as an index. However, with HRIs, due to the confusion and mental disorientation from heat syncope, exhaustion, and stroke, this should be not be used as a primary tool for assessing heat strain. Even with proper training and experience, the reliability of subjective reports as a heat strain indicator may be poor (less than 50%) (Honey, 1992).

2.4 STANDARDS AND INDICES

Occupational exposure limits have been proposed by OSHA, NIOSH, and the ACGIH. The purpose is to define a level of heat stress that, if exceeded, will increase the individual's risk of heat illness. The worker's heat stress is monitored using an index of heat stress. As the thermoregulatory responses increase and the resultant heat strain indications increase (such as HR and body temperature), the risk for a heat illness follows. However,

not all of these guidance levels are the same as a strict exposure limit, such as an OSHA Permissible Exposure Limit. Instead, some of them are “conditions at which a heat stress management program should be considered.” (ACGIH, 2006).

2.4.1 OSHA AND CALIFORNIA OSHA

On a federal level, there is no OSHA regulation to specifically address heat stress. The OSHA General Duty Clause states that every employer must furnish a place of employment free from hazards likely to cause death or serious illness for the employee. (41) Exposures to heat have often been cited under this general clause. OSHA did create an advisory committee that made recommendations, contained within the OSHA Technical Manual (OTM) (OSHA, 1994). These recommendations are, for the most part, the same as the ACGIH TLV guidelines, described below.

California OSHA promulgated regulation 3395 in 2010, titled “Heat Illness Prevention” which specifically addresses heat exposures for the worker. It only fully applies to agriculture, construction, transportation, oil and gas, and transportation, although some sections of the regulation apply to all other industries. It also only applies to workers that are working outdoors, so indoor heat stress is not included. The regulation uses two dry bulb (T_a) ambient air temperatures as the only regulating factors. If the outdoor temperature reaches 85 °F (29.4 °C), certain conditions apply, such as for shade and water to be present, and then more stringent conditions at 95 °F (35 °C), namely closer supervision and monitoring (Cal/OSHA 2010).

2.4.2 ACGIH TLV, NIOSH RAL/REL, TWA

The guidelines that seem to be most frequently used by industry are the ACGIH Threshold Limit Value (TLV) and the NIOSH Recommended Alert Level (RAL) and Recommended Exposure Level (REL). Both of these standards provide heat exposure limits for the workers, and like their chemical counterparts, are seen to be somewhat conservative and protective for the worker, as compared to the regulatory standards.

The ACGIH TLV uses the WBGT index as a “useful first-order index” for characterizing the environmental contribution, to heat stress, and includes a component estimate for metabolic load. The TLV assumes every worker is acclimatized, which is considered a weakness by some (Beshir and Ramsey, 1988). It also initially assumed light clothing. However, in 2006 ACGIH added a chart for clothing adjustment factors (CAF) and added an Action Limit (AL) for un-acclimatized workers. With the WBGT on one axis, and the metabolic load on the other, the Action Limit and TLV form a curve of recommended exposures, shown in Figure 5 (ACGIH, 2006).

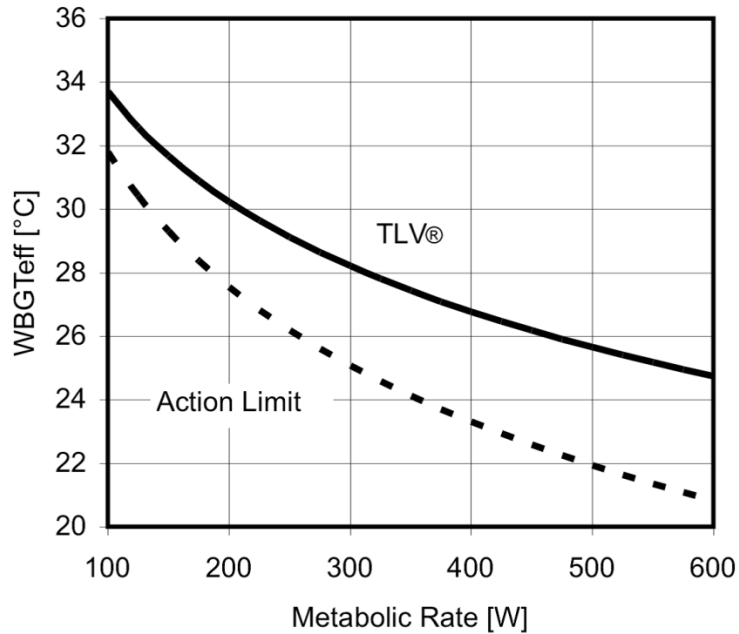


Figure 5: ACGIH Heat Stress Chart

The equation for the TLV is

$$TLV = 56.7 - 11.5 \cdot \log_{10}(\text{Metabolic Rate}) \quad \text{Equation 6}$$

The equation for the Action Limit is

$$AL = 59.9 - 14.1 \cdot \log_{10}(\text{Metabolic Rate}) \quad \text{Equation 7}$$

NIOSH created the Recommended Alert Limit (RAL) and Recommended Exposure Limit (REL) for Heat Stress in 1986. This exposure limit is based on a one-hour time period, but can be applied to a full day Time-Weighted Average (TWA). The RAL applies to un-acclimatized workers, the REL to acclimatized ones. There is a NIOSH Clothing Adjustment Factor that differs slightly from the ACGIH CAF. Both NIOSH and ACGIH also have limits based on work-rest regimens. According to NIOSH, a worker can work in higher WBGT temperatures or have higher metabolic rates if allowed a designated period

of rest. The amount of recommended rest time per hour is related to the WBGT/Metabolic Rate curve, shown in Figure 6. For example, at 300 W/m² metabolic rate and 25°C WBGT, a worker can work the entire 60 minutes without rest. But if the WBGT exposure is increased, then periods of rest are recommended in 15 minute intervals. The Ceiling limit is the level that should never be exceeded.

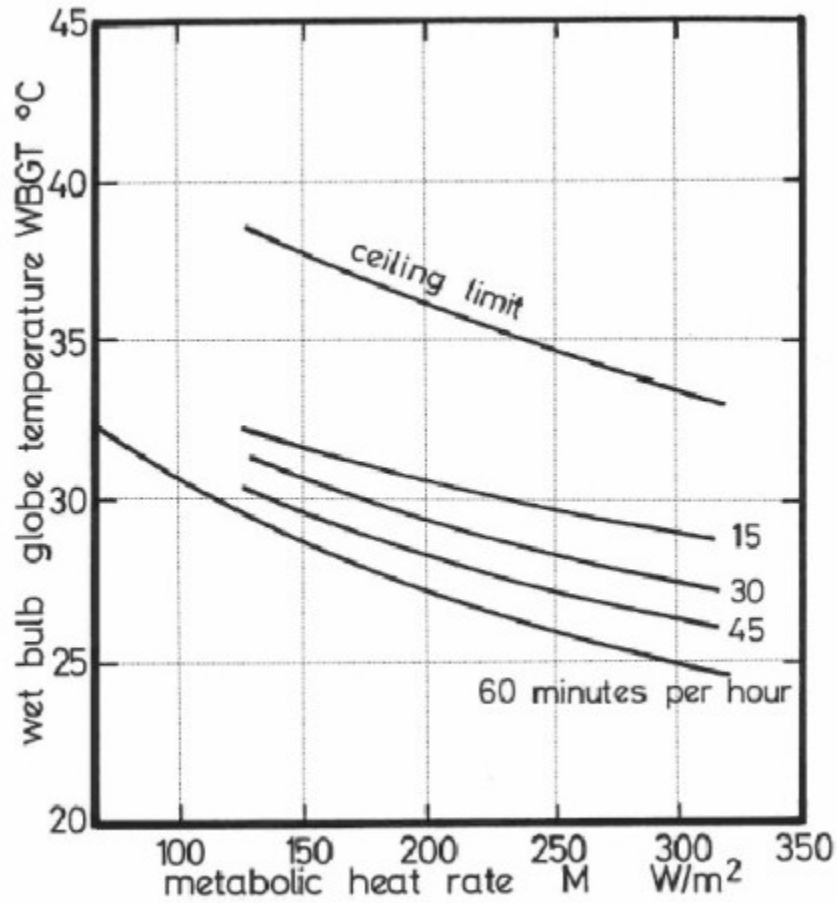


Figure 6: NIOSH REL Chart (17)

The NIOSH REL equation is the same as the ACHIG TLV above, and the RAL equation is the same as the AL.

The NIOSH Ceiling Limit equation shown above is

$$C = 69.9 - 13.4 \cdot \text{LOG}_{10}(\text{Metabolic Rate}) \quad \text{Equation 8}$$

Not shown on the graph, NIOSH also gives an upper limit for T_o of 100.4 °F to be considered reason to terminate exposure even when temperature is being closely monitored.

TWA

For any exposure, heat included, a worker's exposure will be broken down into a variety of tasks of varying exposure for different time periods. These tasks can be looked at from an individual perspective, or averaged over the entire work-day. The averaging of a worker's exposure over a given time period (typically eight hours) is called a Time-Weighted Average, or TWA. The equation for a TWA calculation is as follows:

$$TWA = \frac{\text{Time1(Exposure1)} + \text{Time1(Exposure2)} \dots}{\text{Total Time}} \quad \text{Equation 9}$$

2.4.3 PHYSIOLOGICAL STRAIN INDEX

The Physiological Strain Index (PSI) is a combination of core temperature and HR to show the overall system heat strain. The equation for PSI is:

$$PSI = 5 \times \left(\frac{T_{re} - T_{base}}{39.5 - T_{base}} \right) + 5 \times \left(\frac{HR - HR_{base}}{180 - HR_{base}} \right) \quad \text{Equation 10}$$

The T_{rec} and HR measurements may be collected at any point for an instantaneous heat strain measurement. The 39.5°C and 180 bpm given in the equation show the comparison maximums for body temperature and HR. These set points will be described in later heat strain descriptions. The PSI results in a scale of 0 to 10, with 10

representing the highest amount of strain (Moran, et al, 1997). This index has been validated in a variety of environments, and gives a scale of strain. A PSI of 0 to 2 is listed as “No/Little” strain, 3-4 is “Low” strain, 5-6 “Moderate” strain, 7-8 “High” levels, and 9-10 as “Very High” levels of strain.

2.5 CLIMATE CHANGE

The magnitude of existing HRIs has been shown to be significant. To predict how potential climate change could affect worker HRIs in the future, the potential increase in global and regional temperatures should first be explained. For the purposes of this research, climate estimates have focused on the Western North American Region. Estimates vary significantly as to how much exactly the global temperature could increase. The Finnish Environment Institute has stated that in the Western Region of North America (WNA in Fig 7 below), the average temperature (dry bulb, T_a) could go up by over 9 °C/16 °F by 2099. This is shown in Figure 8. This was an analysis looking at several studies, and most estimates hover around the 5 °C change by 2099 (Ruosteenoja et al, 2003).

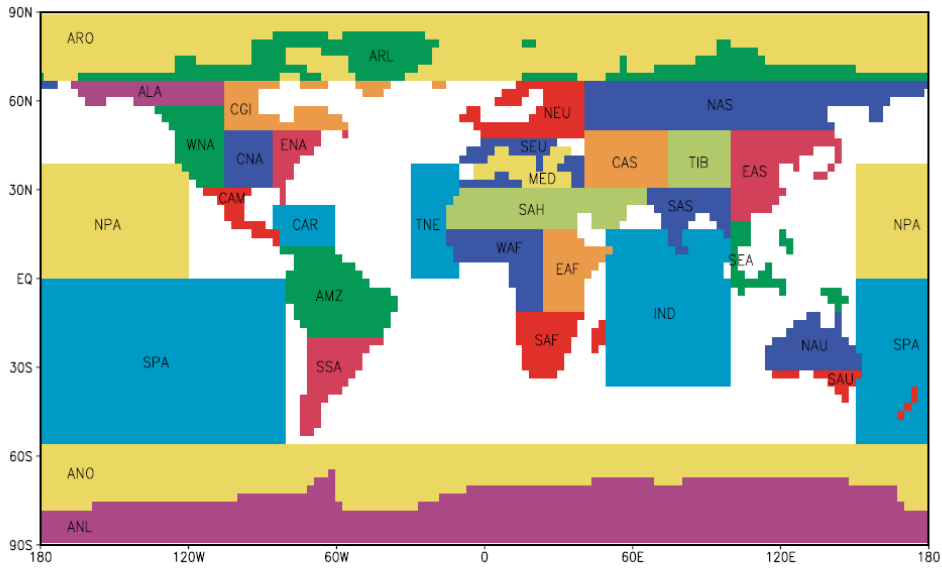


Fig. 2. The 32 world regions defined in Table 2 shown on the ECHAM4 model grid (resolution $2.8^\circ \times 2.8^\circ$).

Figure 7: Listing of Climate Regions

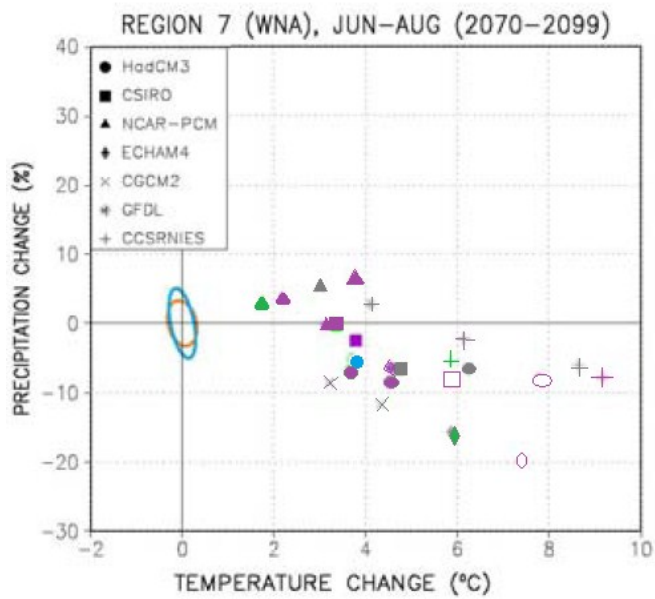


Figure 8: Forecasted Temperature Change for Western North America (44)

As stated in the 2007 Intergovernmental Panel on Climate Change’s (IPCC) Regional Climate Projections, “As a consequence of the temperature dependence of the saturation vapour pressure in the atmosphere, the projected warming is expected to be accompanied by an increase in atmospheric moisture flux and its convergence/divergence intensity.” (Christensen, et al. 2007). The temperature increase estimates are more moderate than the IPCC, with an average increase to around 4 °C by 2100, shown in Figure 9. However, in a detailed explanation in the article, temperatures in summer months could increase by up to 10 °C/18 °F.

Region ^a	Season	Temperature Response (°C)				Precipitation Response (%)					Extreme Seasons (%)					
		Min	25	50	75	Max	T yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
NORTH AMERICA (continued)																
WNA	DJF	1.6	3.1	3.6	4.4	5.8	25	-4	2	7	11	36	>100	80	18	3
	MAM	1.5	2.4	3.1	3.4	6.0	20	-7	2	5	8	14	>100	87	14	
30N,50E to 75N,100E	JJA	2.3	3.2	3.8	4.7	5.7	10	-18	-10	-1	2	10		100	3	
	SON	2.0	2.8	3.1	4.5	5.3	20	-3	3	6	12	18	>100	95	17	2
	Annual	2.1	2.9	3.4	4.1	5.7	15	-3	0	5	9	14	70	100	21	2

Figure 9: Forecasted Temperature Change for Western North America

For the most part, as long as the ambient temperature remains low enough that, combined with the humidity, sweat can evaporate from the skin, survival itself won’t be an issue. However, the wet-bulb temperature, T_{WB} , which typically never goes above 31 degrees C, (46) could potentially increase with the increased T_a and resultant evaporation and increased moisture in the air from a feedback loop with other greenhouse gasses (Sherwood and Huber, 2010).

This increase in rainfall as described above may in turn result in higher ambient RH, which would increase the risk for HRIs. However, the actual impact global warming has

on the regional humidity is too hypothetical for any quantitative estimates. Per Figure 9, change in rainfall also varies significantly. Thus, only dry bulb temperature increase will be considered for this study.

3 METHODS

3.1 EXPERIMENTAL DESIGN

This study was a cross-sectional study. The study environment was typically desert-like with high temperatures and low RH, but at times was more moderate. The region was Southern California, and the study was conducted in the summer months. Subjects were followed throughout their normal work day, with both heat stress and heat strain data collected. Subjects came from a number of job classifications, but all worked within the electric utility field. Subject work days were broken down into tasks, lasting from one to four hours. These tasks were categorized into nine task groups.

Heat strain variables and indices were treated as dependent variables, while the environment, metabolic rate, clothing factors, and personal characteristics were treated as independent variables. Heat stress variables as well as job class and standardized tasks were used to predict the ACGIH TLV/AL, the NIOSH REL/RAL, set Heart Rates, and the PSI/PSI_m.

Hypotheses for this study were as follows:

- (1) Certain tasks and job classes had higher levels of heat stress and heat strain than others;
- (2) Measured and derived independent heat stress variables, such as WBGT levels, metabolic effort levels, ACGIH TLV/AL, NIOSH REL/RALs, as well as personal factors, such as age, weight, BMI, acclimatization, were predictive of measured and derived dependent heat strain variables, such as heart rate, body temperature, PSI, and HR_{rec} >110/120 bpm.

- (3) The PSI_m , ΔHR , and ΔT_o were improvements over the PSI , HR_{rec} , and T_o as heat strain evaluation tools.
- (4) The level of ambient temperature increase from global warming was associated with occupational heat stress exposures.

3.2 PARTICIPANTS

Participants were all male and could be divided into two broad classes: utility line workers/meter technicians who worked in the transmission and distribution sections of an electric utility company, and observers, which were outside consultants or health and safety representatives hired by the parent company. A total of eighty-one worker subjects participated in the study.

Observers also served as participants themselves by recording their own task data, namely the collection of worker data. Observers were not subject to varying metabolic heat loads or clothing factors, but were a population exposed to the same environmental stress as the working population.

Observers were either consultants from the consulting firm Bureau Veritas (Houston, Texas), or employees of the parent company. All Observers completed the required IRB online human research subjects training. Observers were blind to the purpose and aims of the study. A total of eight individual Observers participated in the study. Informed consent was obtained in accordance with the Institutional Review Board (IRB) of the University of California, Los Angeles (Appendix 1).

3.3 EQUIPMENT

Clothing

Clothing worn by the subjects varied. The utility workers typically worked in two-layers of clothing, a fire-resistant, long-sleeve shirt with an undershirt. In the presence of energized equipment, they donned fire-resistant coveralls as well.

The observers typically wore jeans and a short-sleeve shirt.

Wet Bulb Globe Temperature (WBGT):

The WBGT is currently the best index for evaluating environmental heat stress. A data-logging WBGT meter was placed on a tripod to stand at average chest level in the area the subject was working, and was set to collect T_a , T_g , and T_{NWB} readings every minute.

The WBGT meter was factory calibrated annually. The meter used was a QUESTemp™ 32 (Quest/3M, Oconomowoc, Wisconsin), an “intrinsically-safe” meter for use in high-voltage areas. It measures temperatures in the range of 23°F-212°F, accurate to within $\pm 0.9^\circ\text{F}$, as well as relative humidity in the range of 0%-100%, accurate to within $\pm 5\%$. The wick of the bulb was wetted and refilled using de-ionized water.

Software:

QuestSuite Professional™ (Quest/3M, Oconomowoc, WI) was used to manage the logged WBGT data. The data were exported to a usable format in Microsoft Excel 2010

(Microsoft Corp, Redmond, Washington) for data management and analyzed using Stata 12 (StataCorp, College Station, Texas).

Heart Rate:

Due to the clothing restrictions and the number of clothing combinations and changes in the utility worker's day, a watch with a heart rate monitor was chosen over a chest-strap type. High-voltage work will sometimes not allow metal objects like watches or rings to be worn. A Motiva™ (Mio, Fremont, CA) heart rate monitoring watch was either worn by the subject for the entirety of their work day, or (more often) placed on the subject at the end of each task for collection.

Oral Temperature:

Oral temperature was initially collected by the use of single-use, disposable TempaDot™ (3M, Oconomowoc, Wisconsin) thermometers. However, because high ambient temperatures could inflate body temperature readings, an alternate method for collecting body temperature was required. Therefore, SureTemp Plus™ (Welch Allyn, Skaneateles Falls, New York) electronic thermometers were used. These thermometers are accurate to within 0.1 °C and are not affected by high ambient temperatures.

Both types of thermometers were calibrated using a calibration water bath and a calibration hot wax bath, set within 1/100th of a degree F. At least five disposable thermometers from each lot were used at each temperature, going from 95 to 103 °F to generate calibration curves (Figures 10 and 11), which were applied to the final readings.

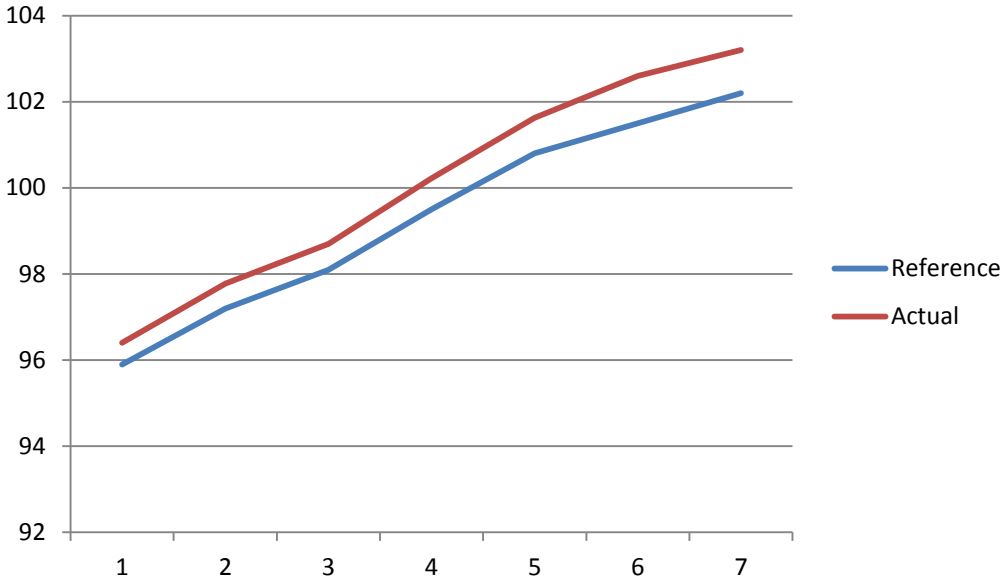


Figure 10: Tempadot™ Calibration Curve. X-axis indicates number of calibration set. Y-axis is temperature in °F.

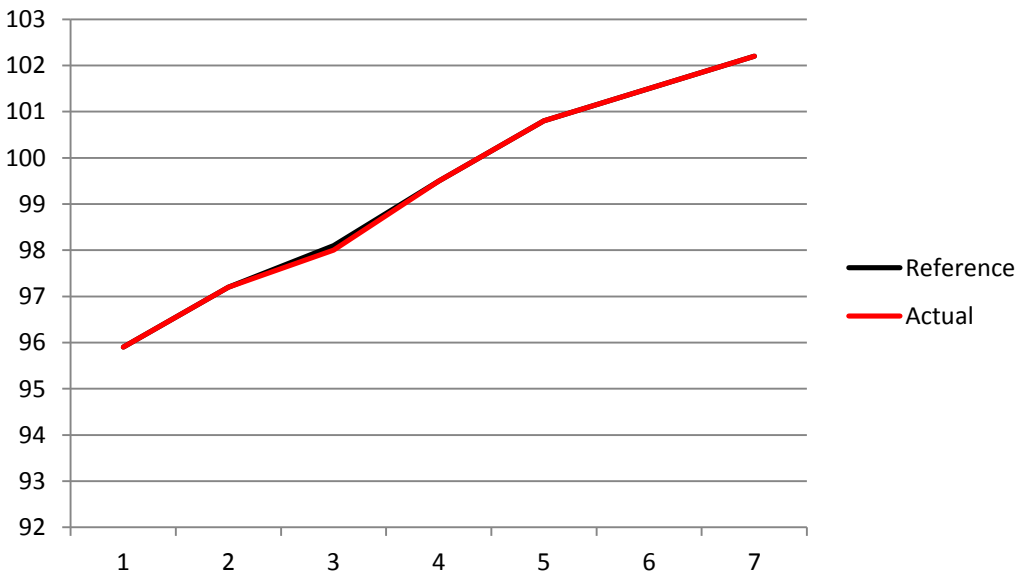


Figure 11: SureTemp Plus™ Calibration Curve . X-axis indicates number of calibration set. Y-axis is temperature in °F.

Two temperatures were collected and the average was calculated. If there was more than a 0.5 degree change in temperature between the two measurements, a third measurement was collected.

3.4 STUDY DESIGN AND PROCEDURES

Each participating subject completed an initial survey prior to being monitored. (Appendix 2) The survey consisted of basic demographic data (age, gender, ethnicity, height, and weight) as well as information to gauge the subject's level of acclimatization, length of past shifts, and clothing worn at the start of the day. Personal identifying data (last names, social security number, personnel number, etc.) were not collected as part of this survey. Subjects were asked to list any prescription drugs currently being taken and any current medical conditions. Subjects were instructed in the procedures and reminded not to drink or eat within 15 minutes of temperature being collected.

Observers were assigned to a field crew in one of several service centers of the parent company. Supervisors were asked to assign a field crew and not a crew working only in the yard. The observers began with one subject observation per day, but this increased to two and sometimes three subjects later in the study. Subjects and observers were randomly matched each day.

Subjects were followed throughout the entirety of their day, which was typically an 8-hour workday. Although reports of longer days were described, none occurred in this study. Some subject days were shorter than 8 hours.

The observers were observed at random points by their supervisor to ensure the study methodology was followed. The author observed each observer several times for verification as well.

The activities of the subject were documented by the observer on the Field Data Entry Form (Appendix 3). Task descriptions were detailed, and the activity was described in term of posture, effort level, and body activity type. After every major task (minimum 45 minutes, maximum 4 hours, target 1 hour), an initial oral temperature was collected by placing the thermometer in the subject's mouth. The subject's HR_{rec} was collected with the HR monitoring watch after one minute, and then a second oral temperature was collected. If the subject changed clothing, this was noted.

Observers were instructed to inform the supervisor immediately if any of the following was observed in the subjects:

- HR_{rec} higher than 180 bpm minus the subject's age, or
- Any obvious signs of heat stress, including flushed skin, significant change in sweat levels (too much or none), fatigue, dizziness, nausea, or lightheadedness.

The instruments were used per manufacturer instructions. The oral thermometers were either discarded (disposable thermometers) or had disposable single-use probe covers (electronic thermometers). The WBGT monitors were activated at the beginning of the day, and kept in the vicinity of the subject being followed. If the worker was inside a vault, the monitor was placed in the vault with them, unless there were specific safety concerns. Observers were not permitted inside vaults. The WBGT monitor was allowed at least 15 minutes to adjust to each new environment.

3.5 UTILITY WORKER JOB CLASS AND TASK DESCRIPTION

CLASS DESCRIPTION

There were six major job classifications monitored for this study. These were:

1. Journeyman Lineman (Lineman)
2. Apprentice Lineman
3. Groundman
4. Cable Splicer
5. Meter Technician
6. Observer

Within the parent company, the Cable Splicers and the Journeyman Lineman are the same job class per Human Resources, however, the subjects labeled themselves differently when asked their job title. At other electrical utility companies, these two job classes are sometimes different in Human Resource coding. In reviewing the list of task descriptions for each job, it was noted that the tasks generally differed from Linemen for those self-titling as Cable Splicer. So it was decided to separate these two groups in the standardized lists. The tasks for Linemen, Apprentice Linemen, and Groundmen are similar. These include such activities as:

- Climbing utility poles or utilizing mounted buckets to gain access to equipment.
- Digging holes to set poles, if needed operating cranes and power equipment.
- Driving vehicles to job sites.
- Replacing or straightening damaged poles.
- Attaching cross-arms to poles before installing them.

- Installing or repairing electrical systems, including such equipment as circuit breakers, transformers, and switches.
- Pulling wire and cables in between poles, towers, and buildings.

As a general rule, it is more typical for the Groundmen and Apprentice Linemen to be assigned the more physically-laborious duties, although the full Journeyman Linemen will also conduct these when necessary.

In some companies, a Cable Splicer is combined to the same job classification as the Journeyman Lineman class. Indeed, a Cable Splicer has the same duties as above, but with more frequent wire and cable-related activities. Cable Splicers tend to spend more time in underground vaults, with such duties as:

- Splicing or soldering cables together or to overhead transmission lines.
- Installing watt-hour meters between power lines and consumers' facilities.
- Laying or stringing underground cable through conduit in the trenches.
- Cutting and peeling lead sheathing and insulation from cables.

The Meter Technicians tend to work with equipment at a lower voltage, and focus their efforts at the residential/commercial side rather than inside vaults or on overhead lines. Their typical activities are:

- Recording meter readings into hand-held computers.
- Disconnecting and/or removing defective or unauthorized meters.
- Mounting and installing meters and other electric equipment.
- Installing, inspecting, and testing electric meters.

- Repairing electric meters and components.

3.6 MEASURED VARIABLES

T_{db} , T_{NWB} , T_G and RH measurements were collected every minute and logged into the WBGT monitor. Task description, posture, effort level and body activity data were collected during each task, defined as a collection of activities of the same general type (see below). The subject's T_o and HR_{rec} were collected after every task. Tasks were narrowed into nine categories once all of the data collection was completed.

The PSI (Equation 11) uses the actual basal temperatures of the subject. However, it was hypothesized that the basal temperature could be assumed at the typically considered levels of 36.5°C (97.7°F) body temperature and the basal limit of 60 Heart Rate.

Therefore, a modified version of the PSI, the PSI_m , was created for examination in this study, incorporating the assumed basal body temperature and HR instead of the assumed ones. The equation for the modified PSI (PSI_m) is shown in Equation 11. The validity of this PSI_m will be examined and compared to the PSI.

$$PSI_m = 5 \times \left(\frac{T(rec) - 36.5^{\circ}C}{39.5^{\circ}C - 36.5^{\circ}C} \right) + 5 \times \left(\frac{HR - 60 \text{ bpm}}{180 \text{ bpm} - 60 \text{ bpm}} \right) \quad \text{Equation 11}$$

The wide range of body temperatures and HR's prompted the creation and evaluation of the ΔT_o and the ΔHR . The baseline measurements for body temperature and heart rate were subtracted from the task measurements to obtain the difference. It didn't follow that an absolute number such as 110 bpm should hold as much weight when the

baseline HR ranged from 54 bpm to 89 bpm. Equations 12 and 13 show these two proposed heat strain measurements.

$$\Delta T_o = T_o(\text{task}) - T_o(\text{baseline}) \quad \text{Equation 12}$$

$$\Delta HR = HR_{\text{rec}}(\text{task}) - HR(\text{baseline}) \quad \text{Equation 13}$$

3.7 TASK CATEGORIES

The specific tasks of each observed subject were collected and documented. As there were obviously a wide range of tasks conducted by the job classes in this study, the job tasks were then grouped into nine categories of task. These task categories are:

1. Vault Work
2. Cable Work
3. Outdoor Mechanical Work
4. Indoor Mechanical Work
5. Transformer Work
6. Pole Work
7. Digging
8. Data Collection
9. No Activity

3.8 DATA PREPARATION AND GENERATION

In preparation for statistical analyses, the following data management was conducted:

1. Tasks were classified into one of the task categories, based on task description.

2. Metabolic rate for each task was calculated using the ACGIH TLV Table given in Figure 4, Metabolic Rate Estimation, and adjusted to the subject's weight with the (subject weight/154 lbs) ratio.
3. The difference between the task HR_{rec} and the baseline initial HR was calculated per task.
4. The average of the two T_o 's collected per task was calculated.
5. The T_o was adjusted per the applicable calibrations curves.
6. The difference between the task T_o average and the baseline T_o was calculated per task.
7. The Clothing Adjustment Factor was estimated per the clothing descriptions per task.
8. If the subject was acclimatized, the ACGIH TLV was calculated per task using Equation 6.
9. If the subject was un-acclimatized, the ACGIH AL was calculated per task using Equation 7.
10. If the subject was acclimatized, the ACGIH TLV TWA was calculated for the entire work day using Equation 9.
11. If the subject was un-acclimatized, the ACGIH AL TWA was calculated for the entire work day using Equation 9.
12. If the subject was acclimatized, the NIOSH REL was calculated per task using Equation 6.
13. If the subject was un-acclimatized, the NIOSH RAL was calculated per task using Equation 7.
14. For both acclimatized and un-acclimatized subjects, the NIOSH C was calculated per task using Equation 8.

15. Using Equation 10, the PSI was calculated per task.
16. A modified version of the PSI was calculated per task (PSI_m), using Equation 11.
17. Using Equation 5, each subject's BMI was calculated.
18. Each task type was evaluated for average metabolic rate, average change in HR_{rec} from baseline, average overall HR_{rec} , average change in T_o , average difference from TLV per task and TWA, RAL/REL, PSI, and PSI_m .
19. Each job class was evaluated for average percentage of time spent at each task, average metabolic rate, average change in HR_{rec} from baseline, average overall HR_{rec} , average change in T_o , average difference from TLV per task and TWA, RAL/REL, PSI, and modified PSI.
20. A hypothesized increase in T_a from global warming was added to the measured exposures, re-estimating the average difference from TLV per task.

4 RESULTS

4.1 DESCRIPTIVE STATISTICS

A total of 81 unique utility-based subjects (non-observers) were followed for a total of 94 full work days, yielding 271 tasks of one to four hours in length.

Eight unique observers recorded task measurements for their own activities for a total of 155 tasks. The number per each standard task is given in Table 3. The highest number of observed tasks was "Cable Work", with only a few tasks labeled as "No Activity". The total number of tasks per job class is given in Table 4.

Table 4: Standard Tasks per Type

Standard Task	# of Tasks
Vault Cable Work	34
Digging	18
Transformer Work	41
Pole Work	52
Cable Work	68
Outside Mechanical Work	30
Inside Mechanical Work	20
No Activity	8
Observing	155
TOTAL	426

Table 5: Number of Observed Tasks per Job Class

ID#	# tasks
Observers	155
Meter Technicians	26
Groundmen	20
Cable Splicers	34
Apprentice Linemen	25
Journeyman Lineman	172

Descriptive statistics of personal characteristics of the subjects are listed in Table 5.

Subjects varied widely among all characteristics.

Table 6: Overall Subject Personal Statistics

Characteristic	Mean	Standard Deviation	Minimum	Maximum
Height (in)	70.1	3.2	64	79
Weight (lbs)	202.7	40.9	125	300
Age (years)	40.5	13.4	20	64
BMI (kg/m ²)	28.2	4.6	17.6	37.9
Base HR (bpm)	77.5	10.4	54	89
Base T _o (°F)	98.4	0.50	96.6	99.8

Means and standard deviations of personal characteristics by job class (height, weight, age, BMI) are listed in Table 6. The oldest group was the observers, with the cable splicers and journeyman linemen close behind. Meter technicians and groundmen were the youngest subject groups.

Groundmen had the highest mean BMI, slightly over the WHO obesity level of 30 kg/m². Apprentice Linemen were close to this level, with a mean of 28.4 kg/m².

Table 7: Personal Characteristics per Job Class

	Height - Mean/S.D. (in)	Weight - Mean/S.D. (lbs)	Age - Mean/S.D. (yrs)	BMI -Mean/SD (kg/m ²)
Combined Average	70.1/3.2	202.7/40.9	40.5/13.4	28.2/4.6
Journeyman Lineman	70.9/3.1	203.5/32.6	38/9.4	28.4/3.6
Apprentice Lineman	67.3/3.3	186.3/24.8	32.8/3.9	29.1/2.5
Cable Splicer	72.3/2.9	208.2/29	39.6/7.5	27.9/2.5
Groundman	68.0/3.7	201.7/24.7	31.1/7.5	30.8/4.0
Meter Technician	68.6/1.7	184.8/31.6	31.1/4.7	27.6/4.1
Observer	68.9/3.3	177.5/48.6	42.1/18.1	26.1/5.7

Job classes varied widely in their daily allotment of time to standard tasks. Figure 12 shows the breakdown of proportion of time spent by each job class at each standardized activity. For example, compared to other job classes, meter technicians spent proportionally more time doing vault work and outdoor cable work.

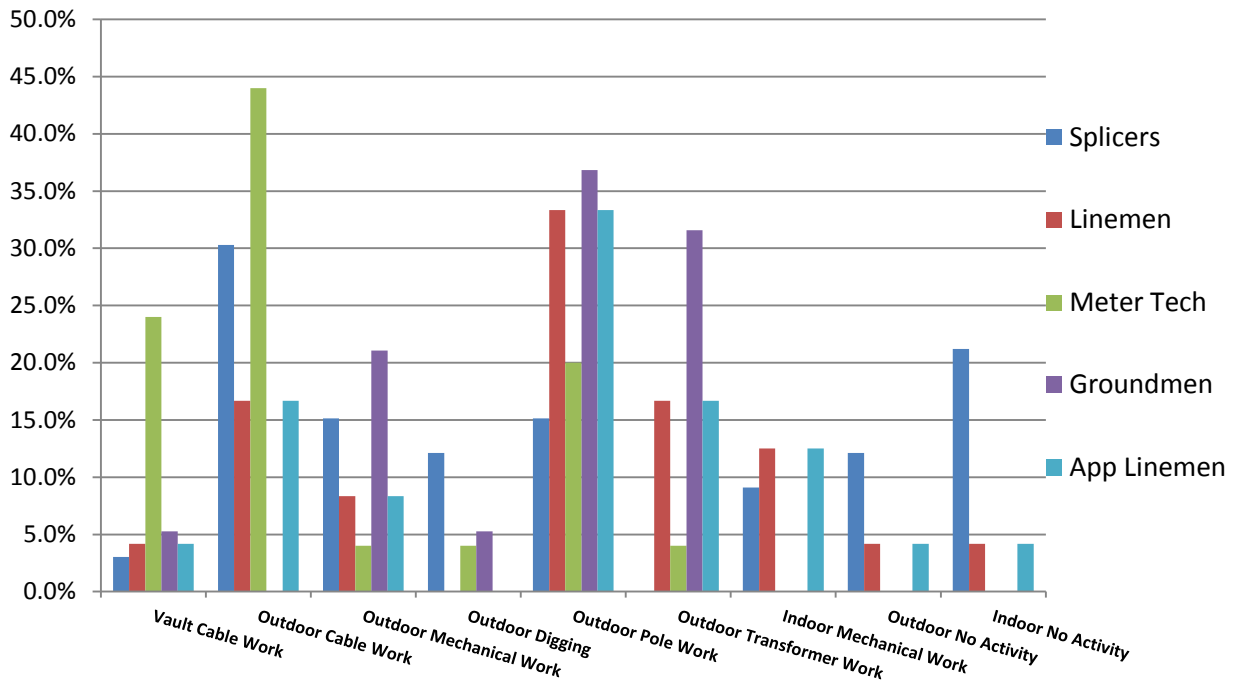


Figure 12: Job Class Percentage by Task.

METABOLIC RATES

Each metabolic rate was individually derived per task using the various task descriptors as shown in Table 1. Distributions of the derived average metabolic rate by task type are displayed in Figure 13. For all boxplots used in this report, the black line in the box is the median, the box ends represent the first and third quartiles, and the whiskers are 1.5 times the Inter-Quartile Range (IQR). The task with the highest median metabolic rate was digging, with transformer work, cable work, and vault cable work showing similarly lower median metabolic rates. No activity yielded, as might be expected, the lowest average metabolic rate.

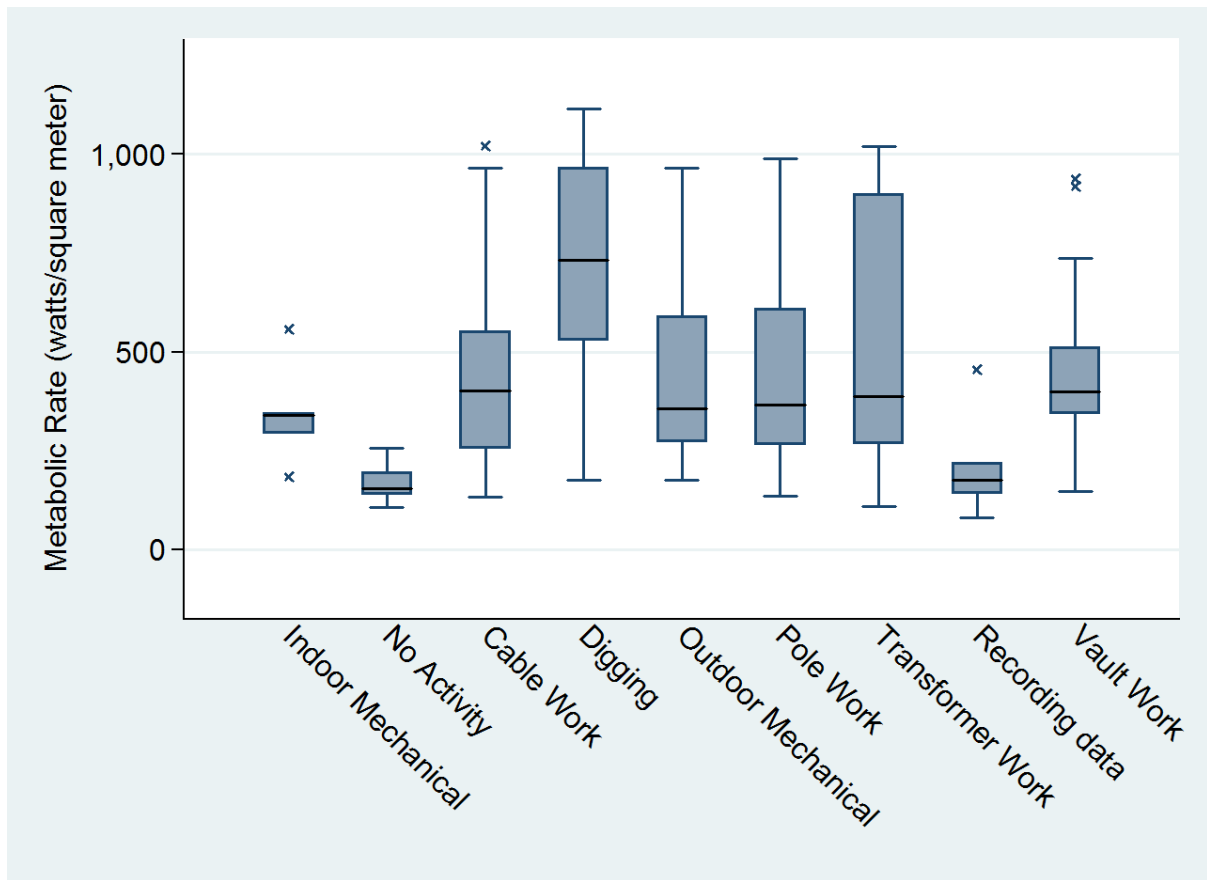


Figure 13: Average Metabolic Rate by Task

Distributions of the average metabolic rate were also examined for each job class, and are plotted in Figure 14. The job class with the highest median metabolic rate average was the groundmen followed by the meter technician.

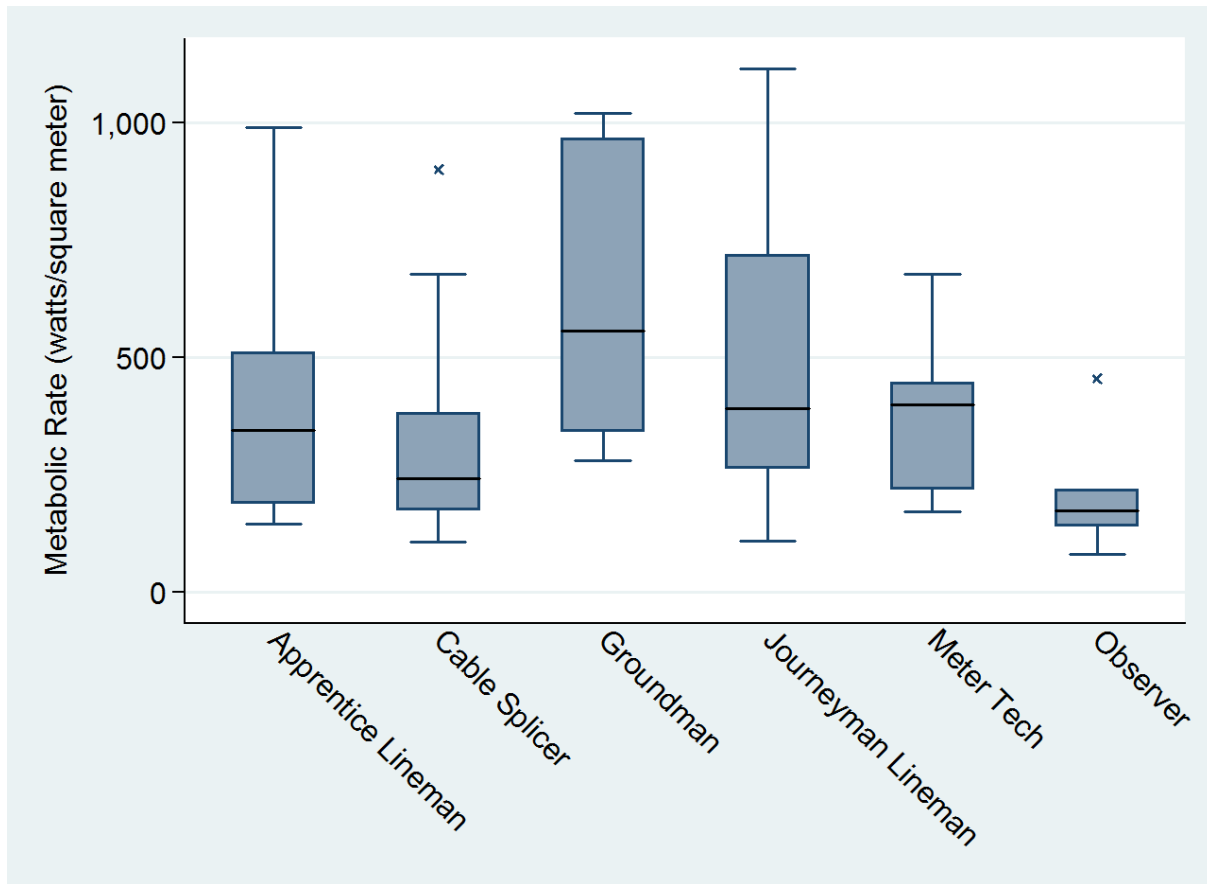


Figure 14: Average Metabolic Rate by Job Class

TLV/RAL/REL/C EXPOSURES

For each standardized job task, exposure levels were compared to several industry exposure standards, the ACGIH TLV, the NIOSH RAL/REL and Ceiling limit. The distributions of differences of worker exposure from these standards by job task are given in Figure 15. That is, the actual exposure of the worker was subtracted from the recommended TLV to get each task's relative exposure.

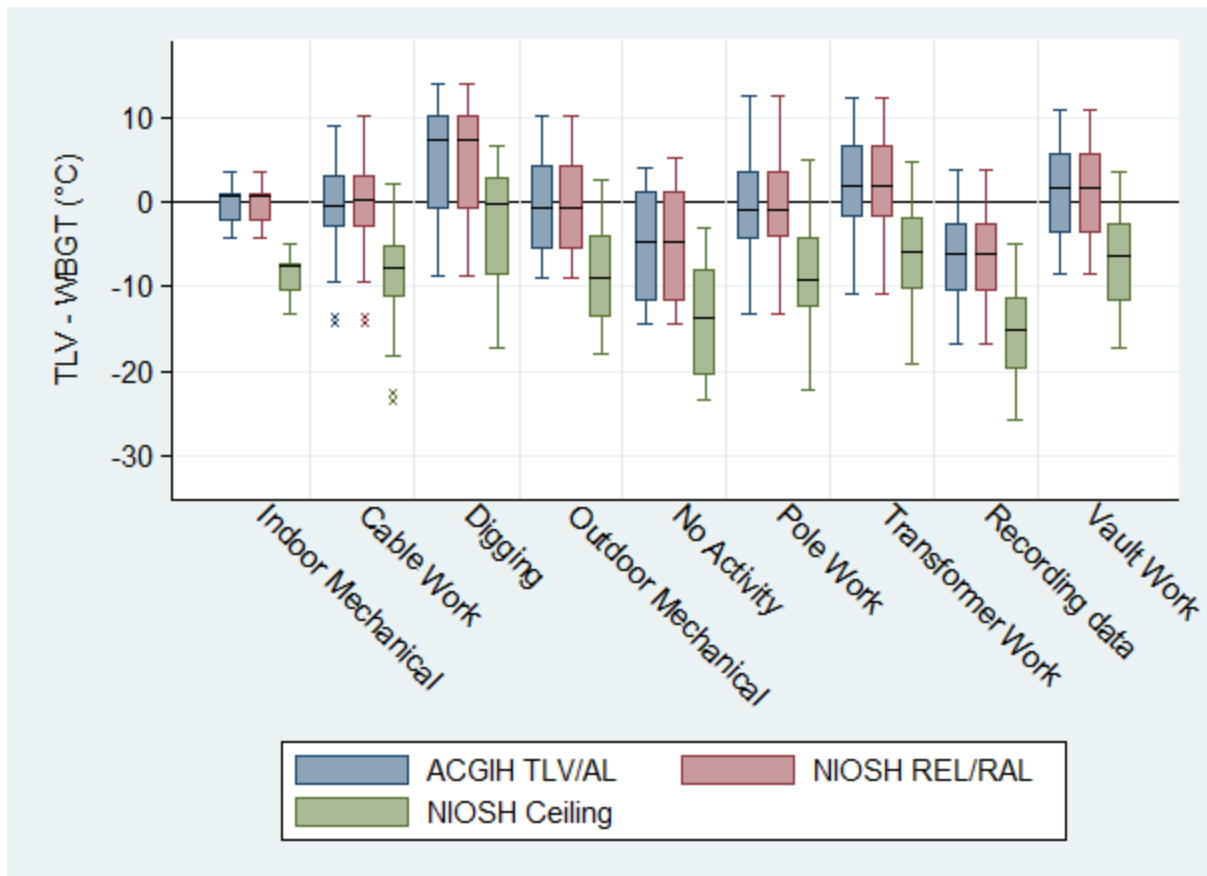


Figure 15. Δ TLV (TLV-WBGT)/AL by Task Type

The task type showing the highest exposure, with almost 75% of workers above the recommended limits of TLV and REL, was digging. However, both transformer work and vault work had median exposure levels above industry standards as well. All median exposure levels were below the NIOSH Ceiling limit. The lowest exposures were from recording data and no activity.

Exposure level comparisons to the same industry standards were made by job class. Distributions of differences from these standards are given in Figure 16. The AL and RAL applied only to the recording data tasks of the observers.

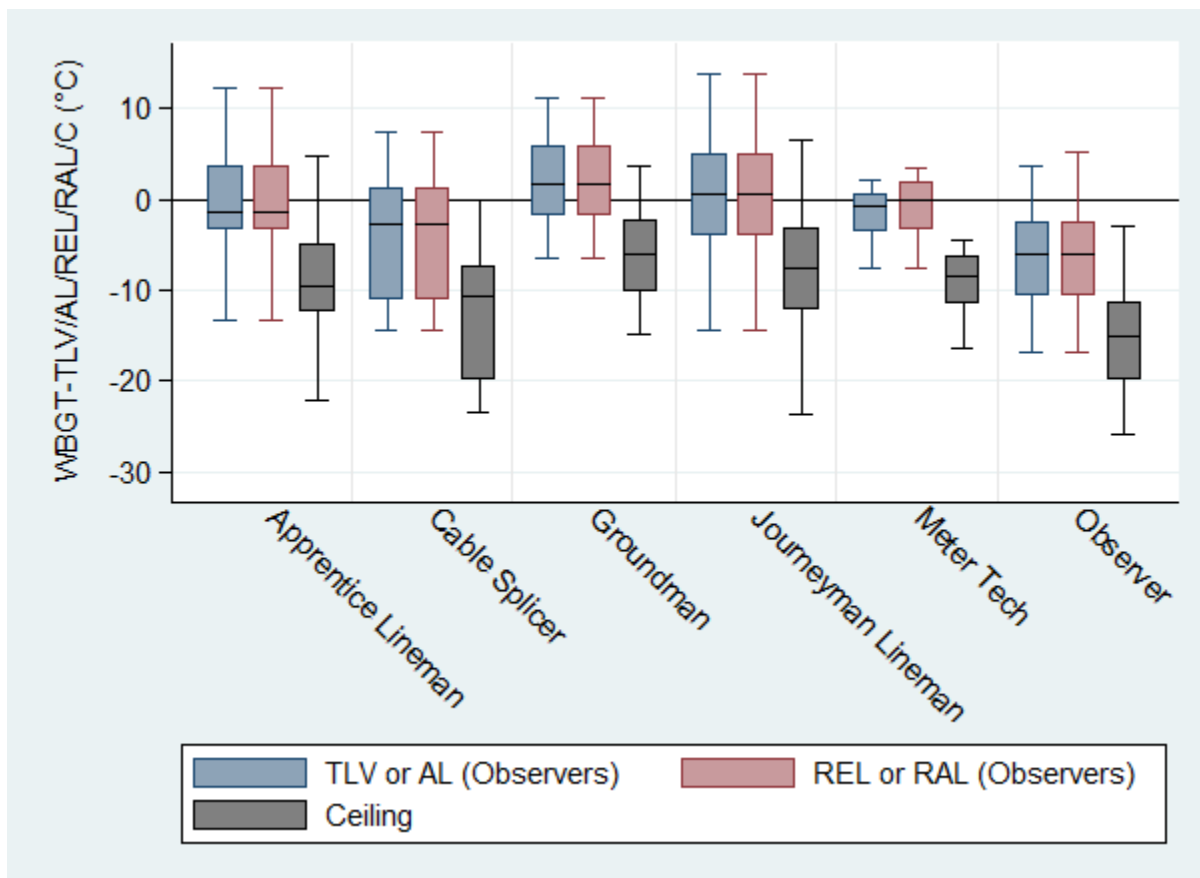


Figure 16. Δ TLV/AL by Job Class (Δ TLV)

The job class with the highest exposures, relative to the ACGIH and NIOSH standards, is groundmen, followed by journeyman linemen. Meter technicians had the next highest median exposure, but the apprentice linemen's had larger variability among exposure levels. Observers and cable splicers had the lowest exposures.

HR_{rec} AND ΔHR

The HR_{rec} was collected one minute after the completion of each task, and the difference compared to the baseline (ΔHR) was examined per standardized task. Distributions of

HR_{rec} at one minute after completion and distributions of (ΔHR) by task are shown in Figure 17.

The highest median HR_{rec} occurred after the task of digging, followed by transformer work and outdoor mechanical work. The highest ΔHR was also associated with digging, followed by outdoor mechanical work.

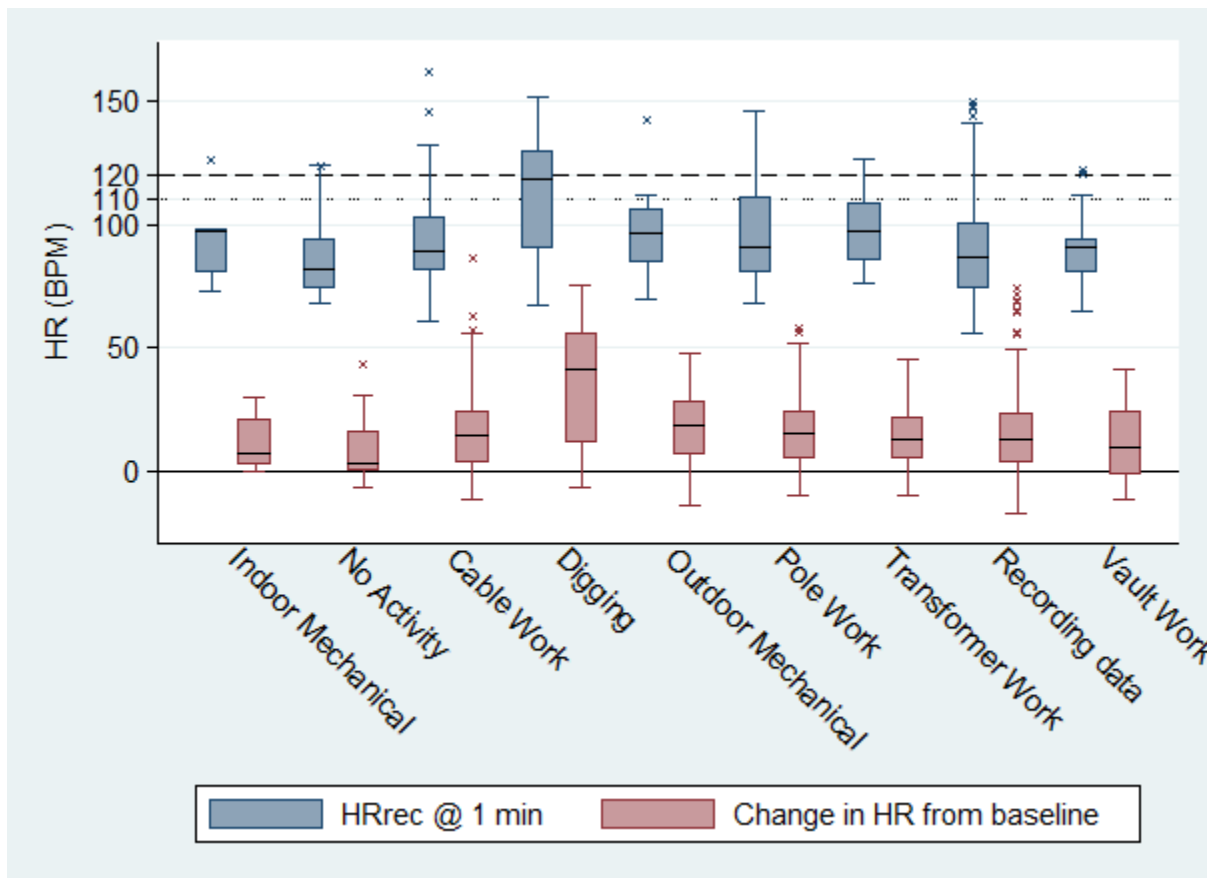


Figure 17. HR_{rec} and Change in HR (ΔHR) by Standardized Task. The dotted line represents the study-derived goal of controlling HR_{rec} to 110 bpm, and the dashed line represents the TLV recommended HR_{rec} limit of 120 bpm.

Figure 18 shows HR_{rec} one minute after the completion of each task and ΔHR were also by job class. The job class with the highest median HR_{rec} was groundmen. The highest ΔHR was recorded for apprentice linemen. No job class had median HR_{rec} above the 110 bpm limit, but the groundmen were close, with a median of 109. However, all classes had some instances of tasks that exceeded the 110 and 120 bpm limits.

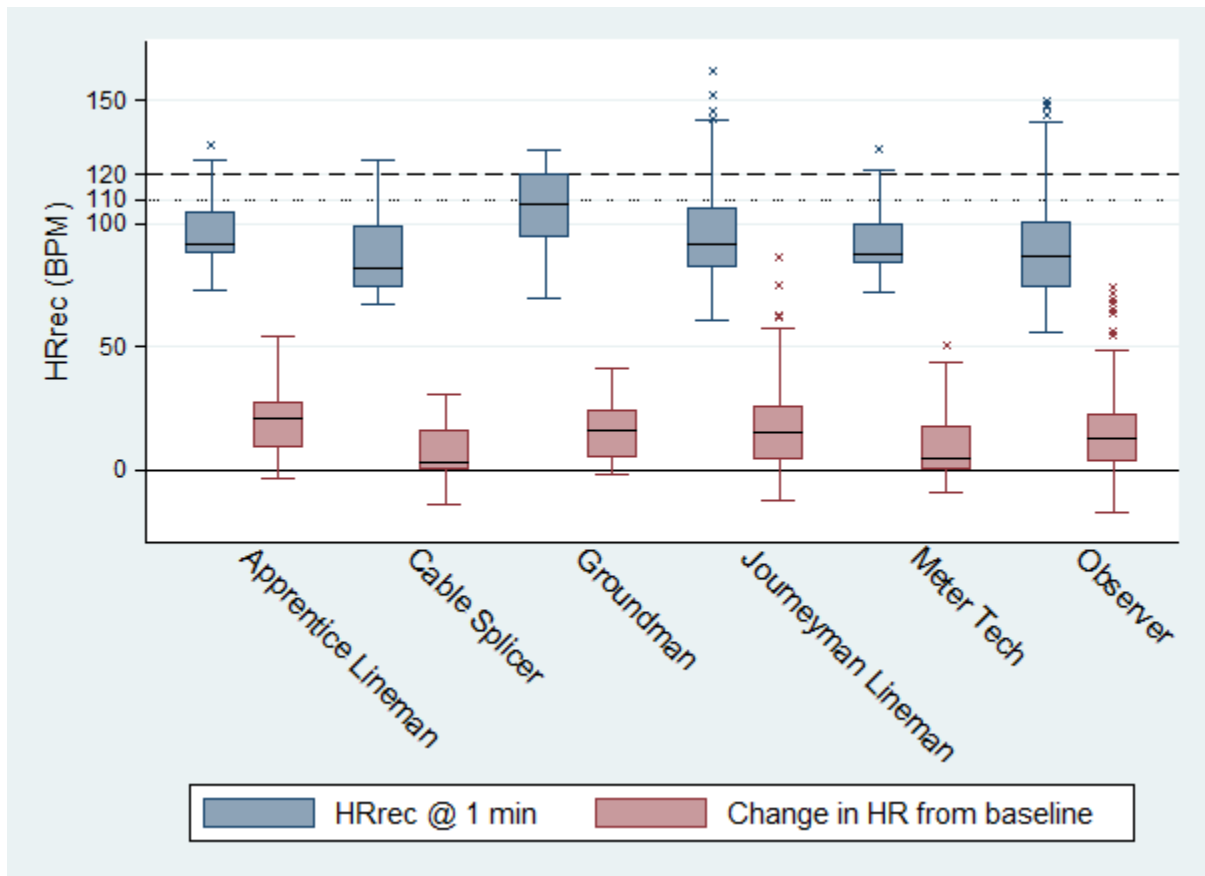


Figure 18. HR_{rec} and Change in HR (ΔHR) by Job Class. The dotted line represents the study-derived goal of controlling HR_{rec} to 110 bpm, and the dashed line represents the TLV recommended HR_{rec} limit of 120 bpm.

T_o and ΔT_o

Two oral temperatures were collected at the conclusion of each task. These two temperatures were averaged, adjusted to calibration curves, and again adjusted to represent T_{rec} . Distributions of oral temperatures by task are shown in Figure 19.

Distributions of oral temperature across tasks were similar in both median location and spread.

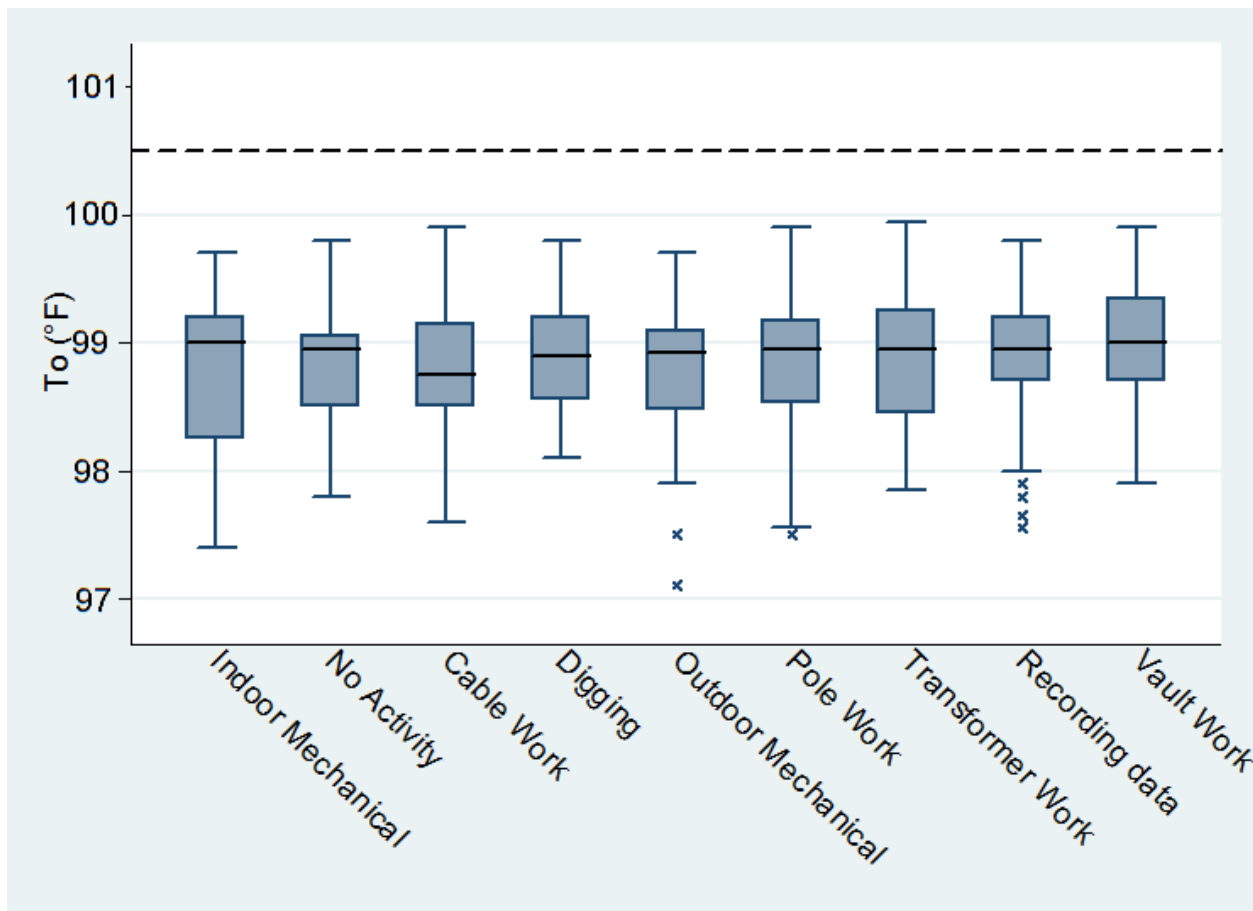


Figure 19. Adjusted T_o by Standardized Task. The dashed line represents the upper temperature limit of 100.5°F.

The oral temperatures were examined by job class as well. There was more variation in the oral temperatures across job classes than across tasks. The job class with the highest median T_o per task was apprentice linemen with observers and journeyman linemen very close behind. These are shown in Figure 20.

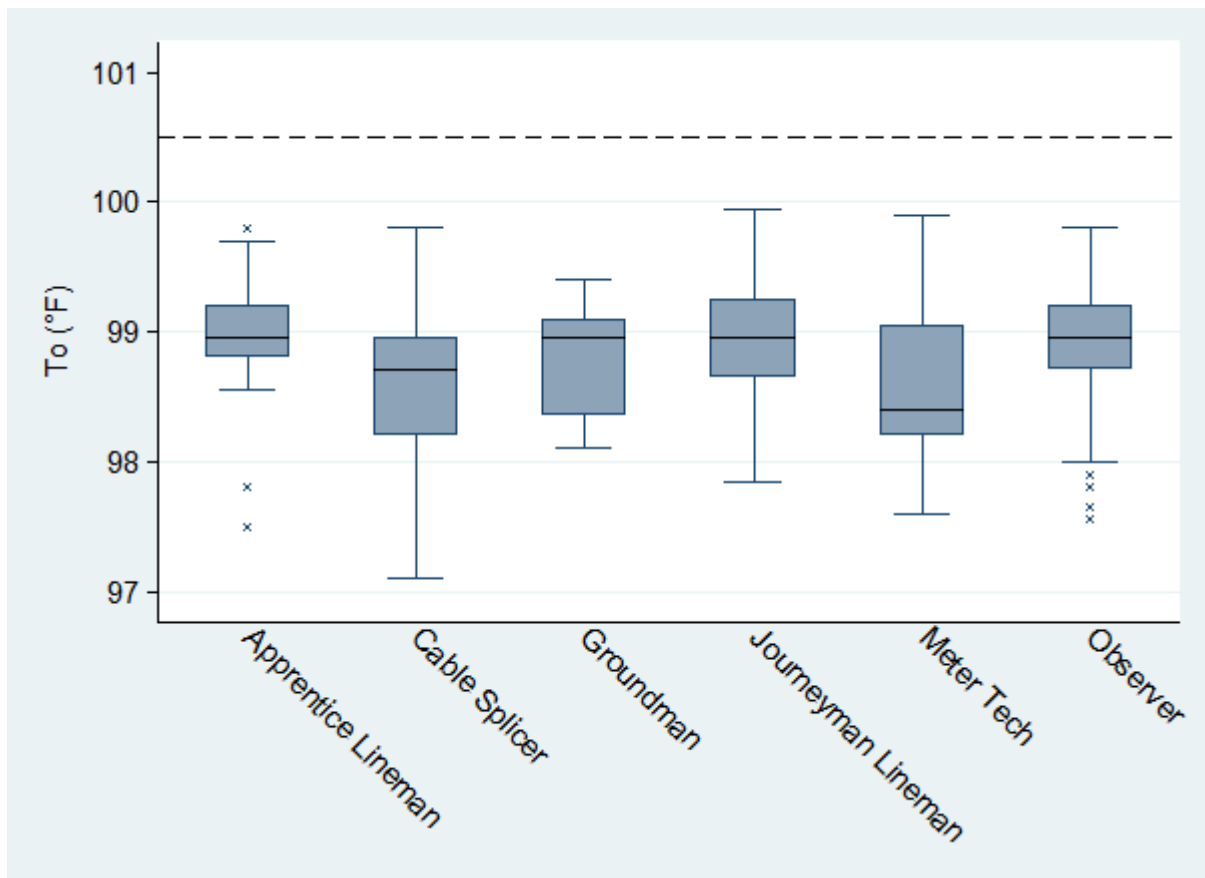


Figure 20. Adjusted T_o by Job Class. The dashed line represents the upper temperature limit of 100.5°F.

The task T_o was subtracted from the baseline T_o to obtain a change in oral temperature (ΔT_o) per task and per job class. Figure 21 shows ΔT_o by task. Indoor mechanical work had the highest positive change in T_o , with digging and vault work following. “No Activity” had the largest negative change, but transformer work also was low.

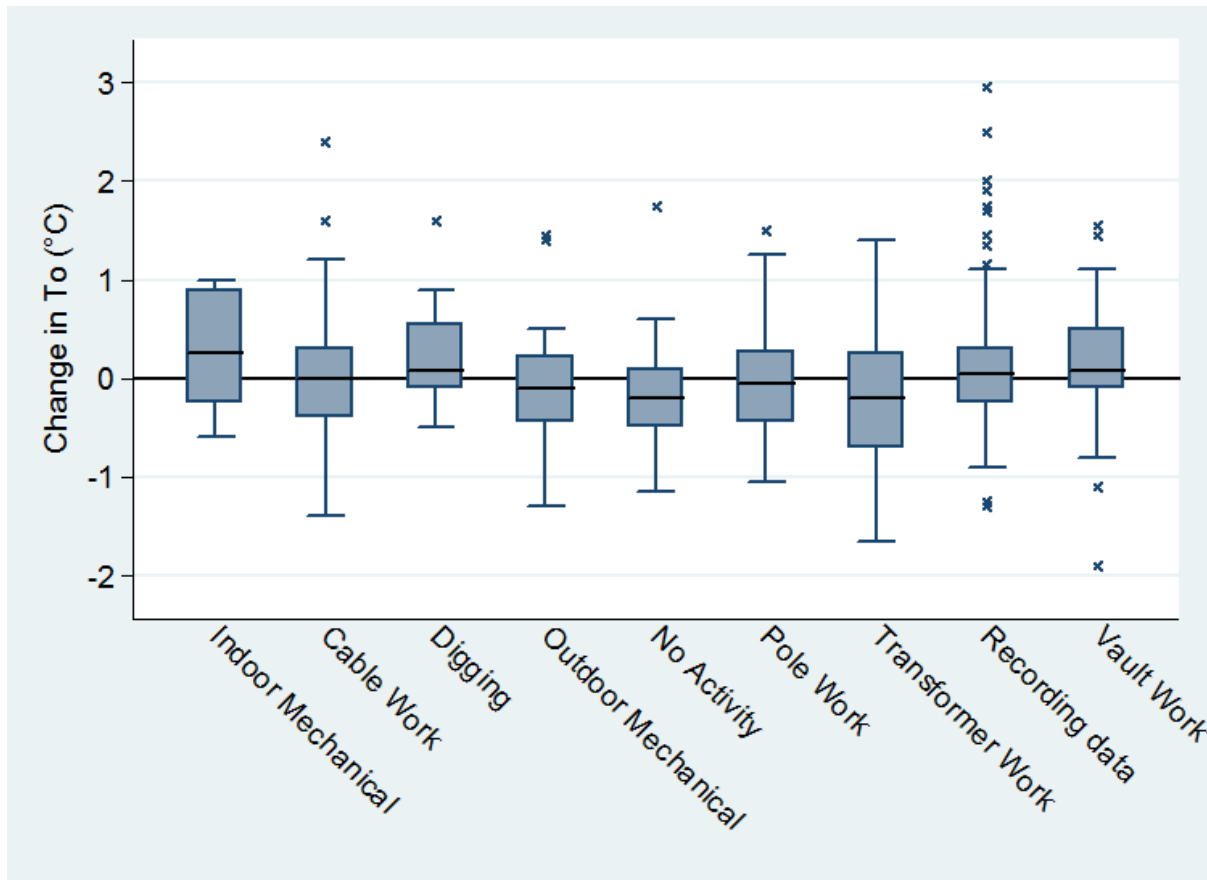


Figure 21. ΔT_o by Standardized Task

Figure 22 shows ΔT_o by job class. The Observers were noted to have the only positive change in oral temperature per task, but the change was very slight. Cable splicers had the largest negative ΔT_o .

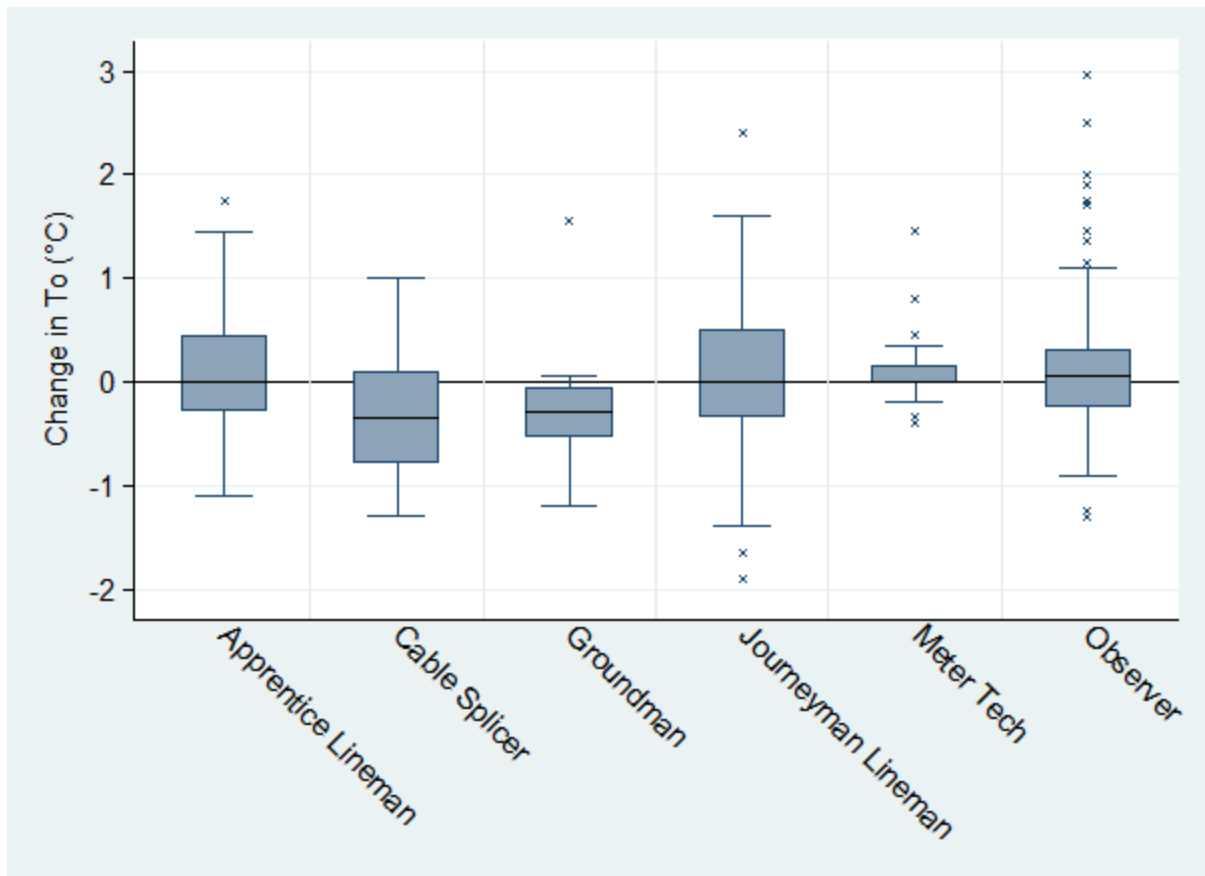


Figure 22. ΔT_o by Job Class

PSI and PSI_m

As previously mentioned, the PSI is a relative scale from 0 to 10 that expresses the total physical heat strain as a combination of body temperature and heart rate. This study examined two PSI measures, the standard PSI and a modified version, PSI_m , which uses observed rather than assumed baseline temperatures and heart rates. Distributions of PSI and PSI_m by task are given in Figure 23. Digging exhibited the highest PSI and PSI_m levels, while no activity had the lowest.

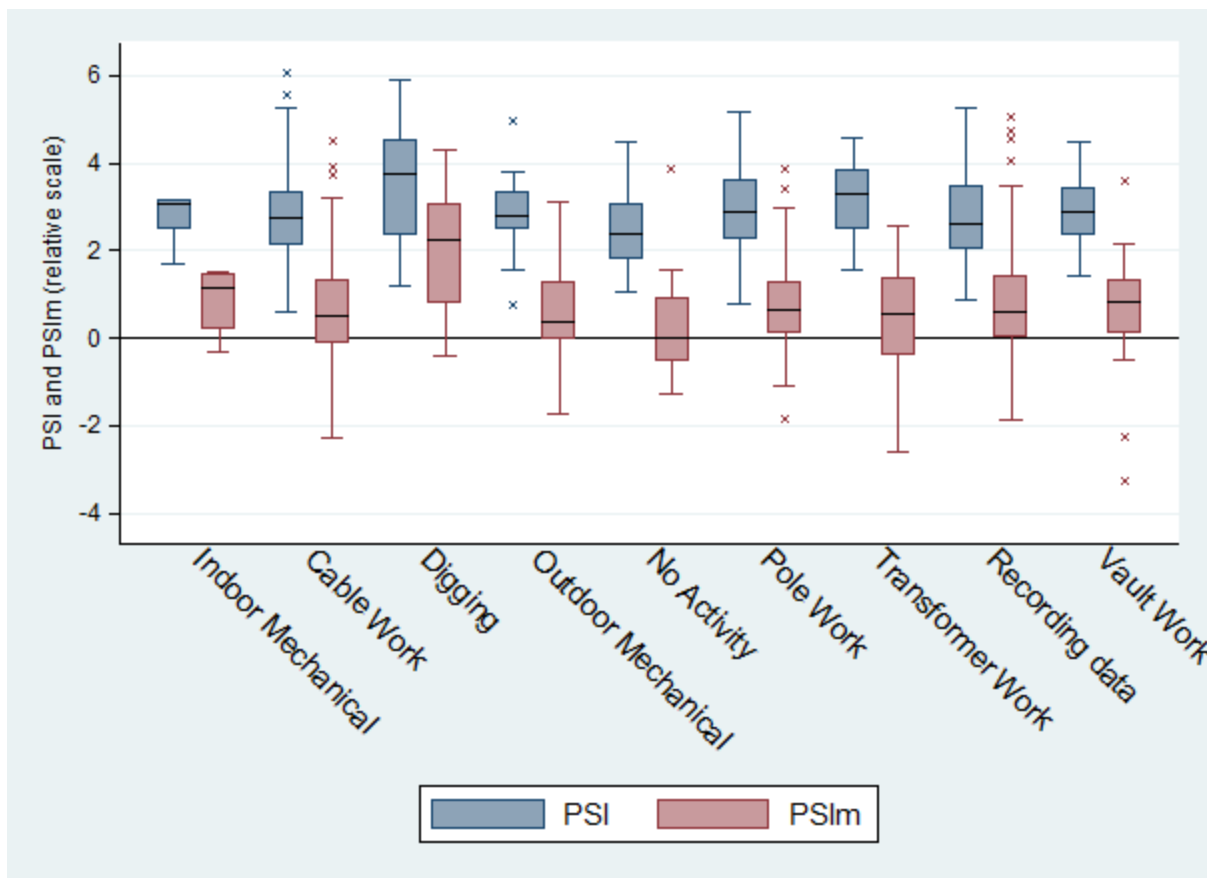


Figure 23. PSI and PSI_m by Standardized Task

PSI and PSI_m levels were also examined by job class (Figure 24). Groundmen showed the highest average PSI levels, while observers showed the lowest. However, PSI_m patterns were slightly different. With PSI_m, the highest levels were the apprentice linemen, and the cable splicers were the lowest.

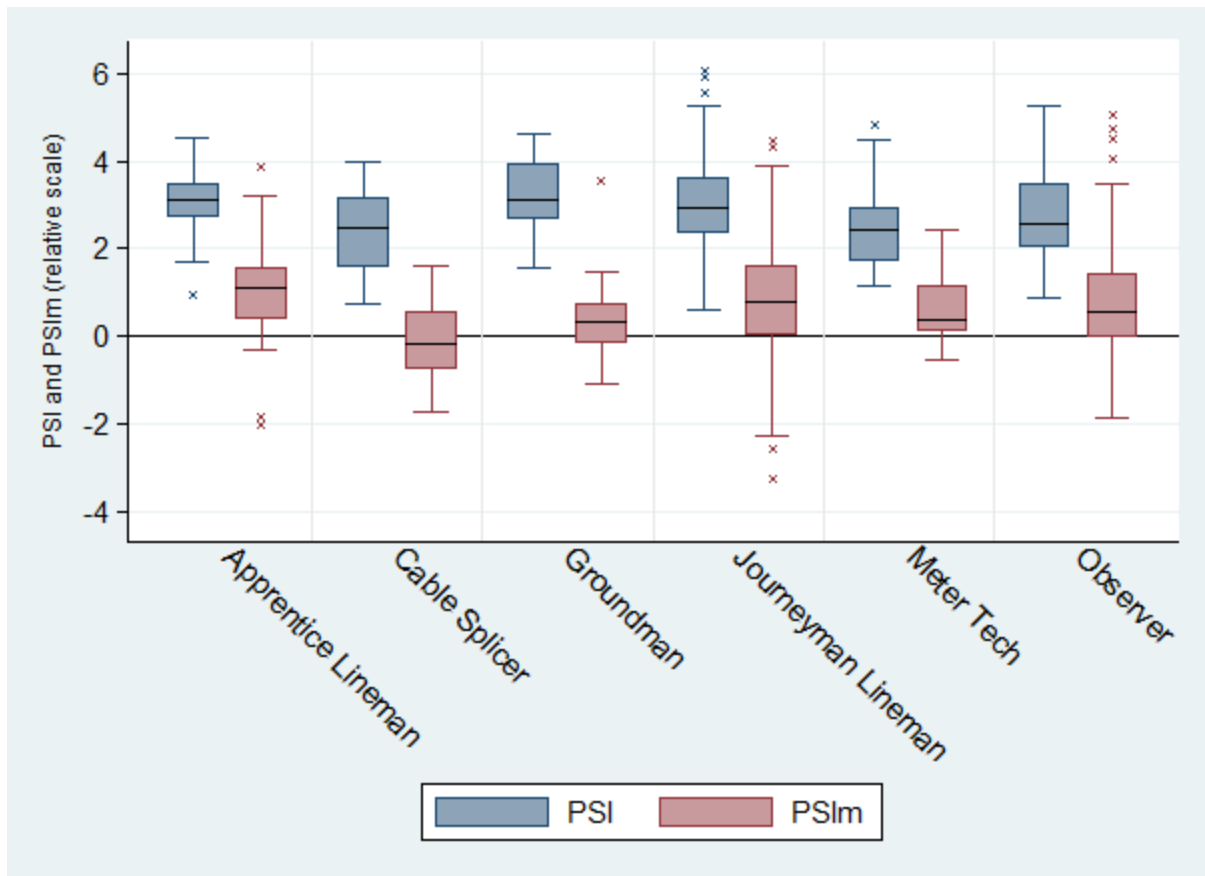


Figure 24. PSI and PSI_m by Job Class

4.2 REGRESSIONS

4.2.1 MIXED EFFECT LINEAR REGRESSIONS

A number of regressions were conducted to evaluate the predictive value of heat stress on heat strain. Since heat strain was measured several times per subject, it was necessary to account for correlation among a subject's scores. Thus, hierarchical (mixed-effects) linear or logistic models with random intercepts, namely intercepts allowed to vary among subjects to account for subject-driven differences, were chosen to control for these dependencies. The Intraclass Correlation (ICC) was calculated for each dependent variable. All ICCs exceeded 0.3, indicating significant within-subject

correlation of scores and justifying the use of random intercepts. For all regressions, a significance level of 0.05 ($p < 0.05$) was used.

Dependent variables in linear regressions were HR_{rec} , ΔHR , T_o , ΔT_o , PSI and PSI_m .

Identifying factors which predict HR_{rec} greater than 110 bpm ($HR > 110$) and greater than 120 bpm ($HR > 120$) were also of interest to this study, so hierarchical logistic regressions were used to model these relationships.

Independent variables included ΔTLV , WBGT, metabolic rate, age, BMI, past shift work (yes or no), race (white and non-white), acclimatization (yes or no), $T_{db} > 85^\circ F$ (yes or no), and $T_{db} > 95^\circ F$ (yes or no). Due to the very high collinearity between some of the independent variables (for example, ΔTLV is inherently related to both WBGT and metabolic rates), some combinations of predictors could not be entered into the same regressions.

Since observers were the only un-acclimatized population, they were compared to different standards, namely the ACGIH AL and NIOSH RAL. Thus, although the same dependent variables were used, observers were analyzed in their own set of mixed-effect regressions. As much as possible, then, each regression was run with 3 different samples: utility line workers/meter technicians, observers, and utility line workers/meter technicians and observers combined (deemed the “overall” group henceforth). Differences in worker characteristics often necessitated the use of separate regression. For example, race was coded either “white” or “non-white”. However, all observers were white, so race could not serve as a predictor for observer heat strain.

Similarly, none of the observer group reported working the previous day, so the past shift variable could not serve as a predictor for observers either.

Race was separated into two categories of “white” and “non-white” which consisted only of Hispanic workers. Four Asian Americans were excluded from the race analysis.

The predictor “acclimatized” coded whether the worker normally worked in the region where they were monitored. All of the workers were acclimatized and all observers were not, so this variable served as a proxy for no heat-stress related differences between utility line workers and observers.

HR_{rec}

The range of HR_{rec} was 61 to 162 bpm for workers with a mean of 93.4 bpm. The observers had a range of 59 to 142 bpm and a mean of 88.2 bpm. Figure 25 illustrates the predictive relationship between the independent variables and HR_{rec}. In the overall group, Δ TLV, Age, Metabolic Rate, and WBGT were significant predictors of HR_{rec}, all with positive relationships. For the workers, Δ TLV, Metabolic Rate and WBGT were all positively related to HR_{rec}. Interestingly, the variable of working in an environment with a $T_{db} > 85$ °F (OSHA > 85 °F) was negatively predictive for HR_{rec}. For observers, only Δ TLV was predictive of HR_{rec}.

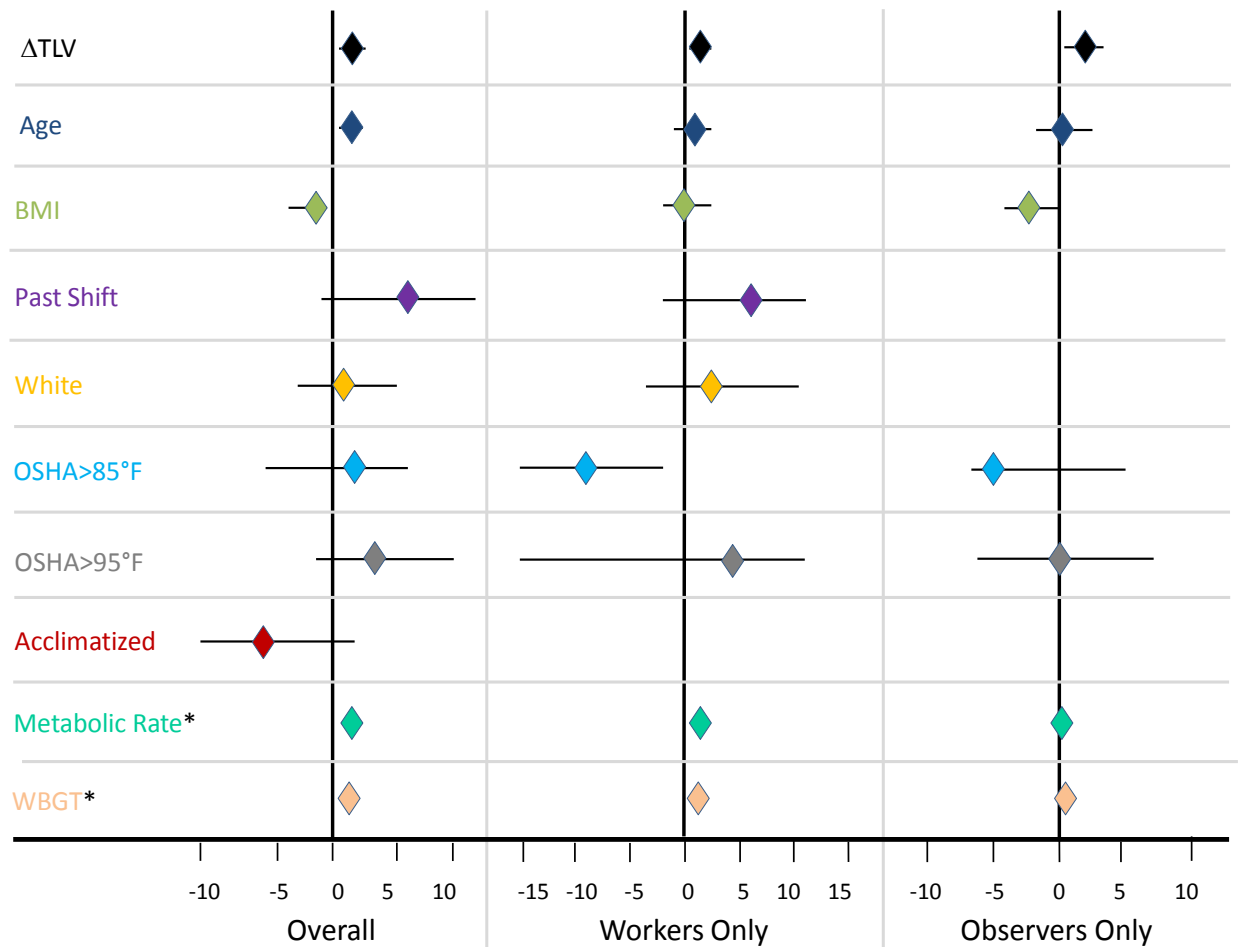


Figure 25. HR_{rec} Regression Coefficients and 95% CI. (* indicates the regression set had to be run separately, replacing the ΔTLV)

ΔHR

The worker's ΔHR ranged from -34 to 75 bpm with a mean of 12.7 bpm, while the observers had a range of -23 to 64 bpm and a mean of 11.1 bpm. Figure 26 displays the results of ΔHR regressions. Overall, ΔTLV , Age, Metabolic Rate, and WBGT were all significantly, positively related to ΔHR . Both BMI and $T_{db} > 85^\circ F$ were negatively related to ΔHR . Workers showed the same significant relationships as the overall group. However, for observers, only ΔTLV and WBGT were predictive.

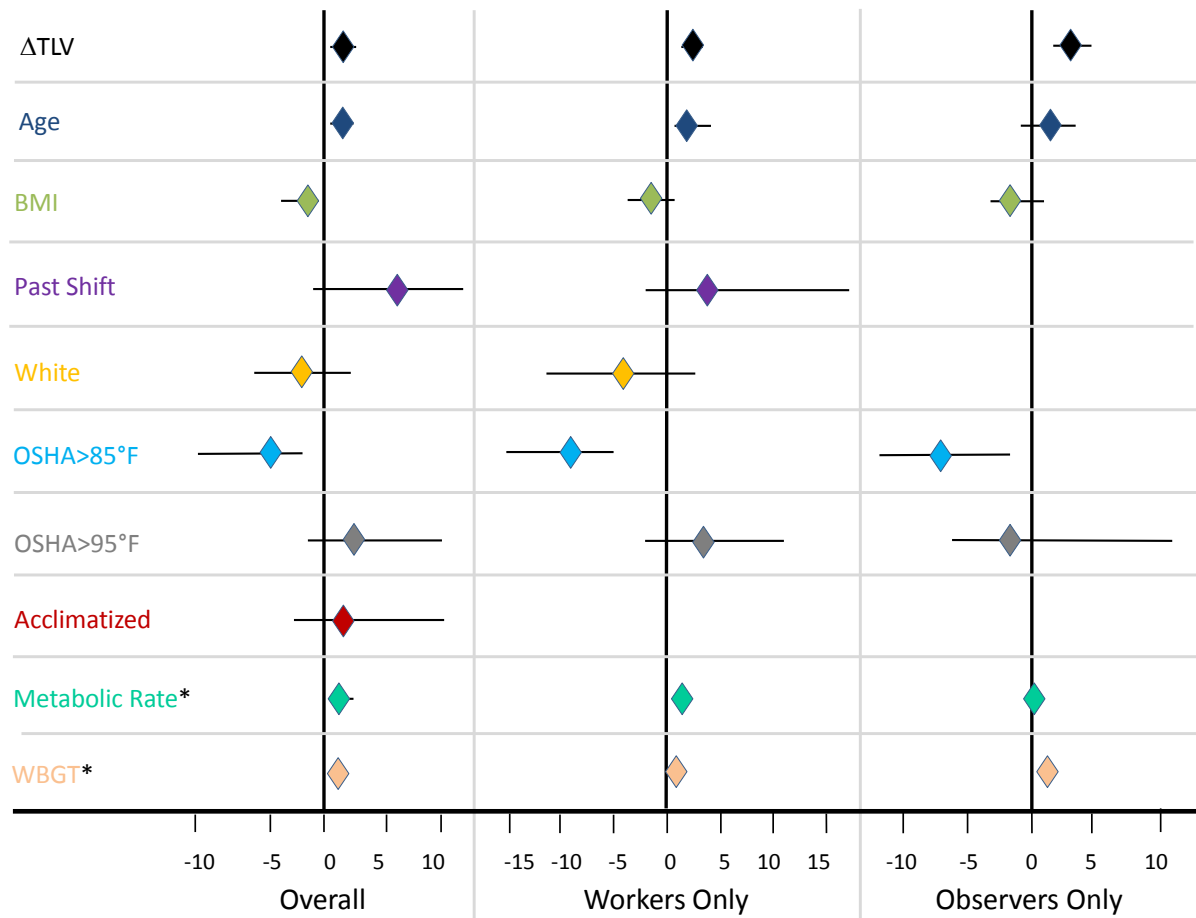


Figure 26. Δ HR Regression Coefficients and 95% CI. (* indicates the regression set had to be run separately, replacing the Δ TLV)

T_o

The T_o for the workers had a range of 96.3 to 99.8°F with a mean of 98.4°F. The observers had a range of 96.2 to 99.3°F and a mean of 98.3°F. Results of the regressions of T_c are given below in Figure 27. Results showed that overall and for utility workers alone, increased Δ TLV, BMI, and WBGT measurements predicted a higher T_o . Being acclimatized predicted higher T_c as well.

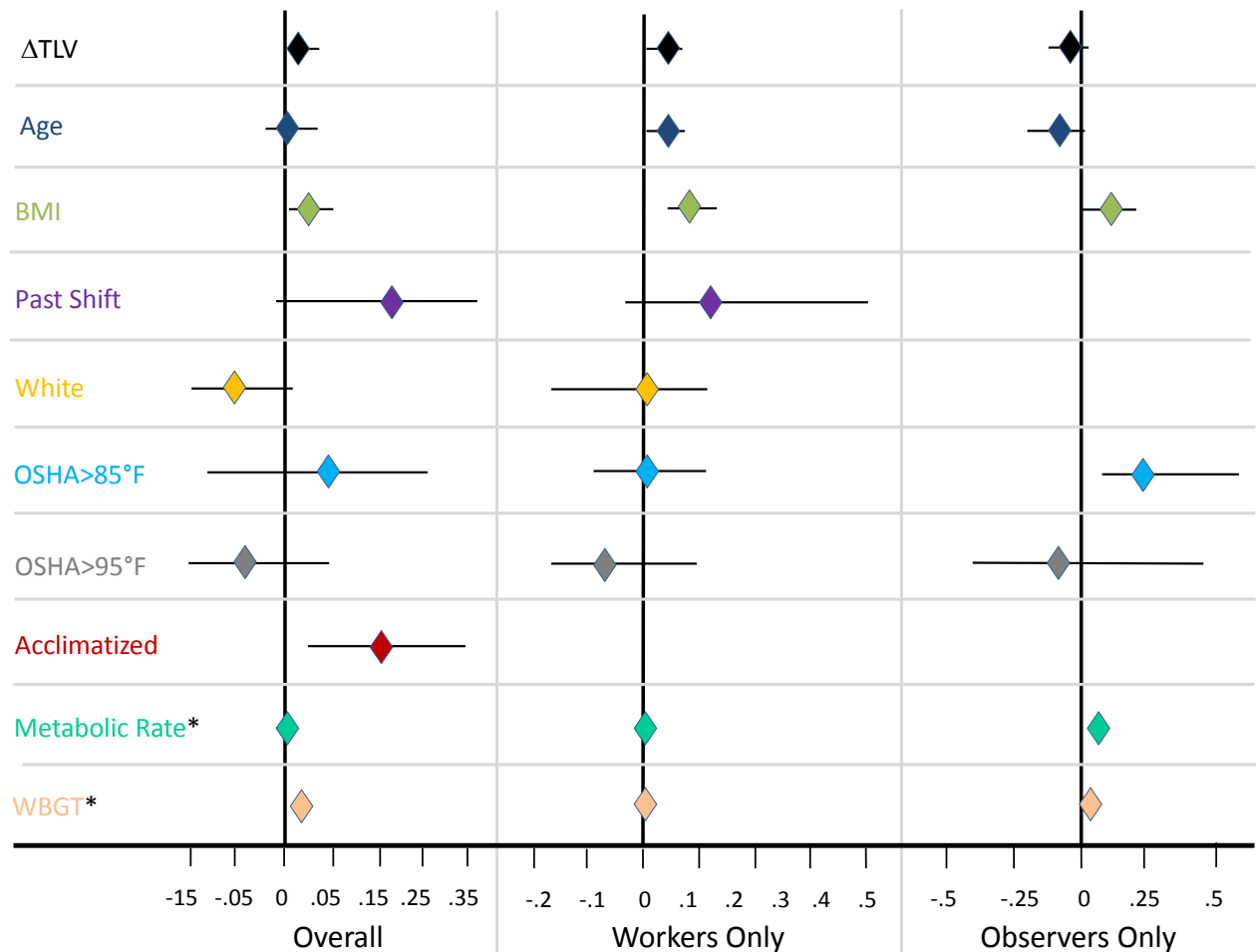


Figure 27. Oral Temperature Regression Coefficients and 95% CI. (* indicates the regression set had to be run separately, replacing the ΔTLV)

ΔT_o

The ΔT_o for the worker population had a range of -2.75 to 2.4°F with a mean of 0.01°F.

The observers had a range of -4.4 to 2.95°F and a mean of 0.1°F. Figure 28 displays relationships between the same set of independent variables and the outcome ΔT_o .

Unlike previous outcomes, having a past shift immediately before the measured shift predictive of higher ΔT_o in the overall and worker regressions. $T_{wb} > 95^\circ F$ (OSHA > 95°F) was predictive of higher ΔT_o overall also. The acclimatized population (utility line workers) had higher ΔT_o , than the unacclimatized population (observers).

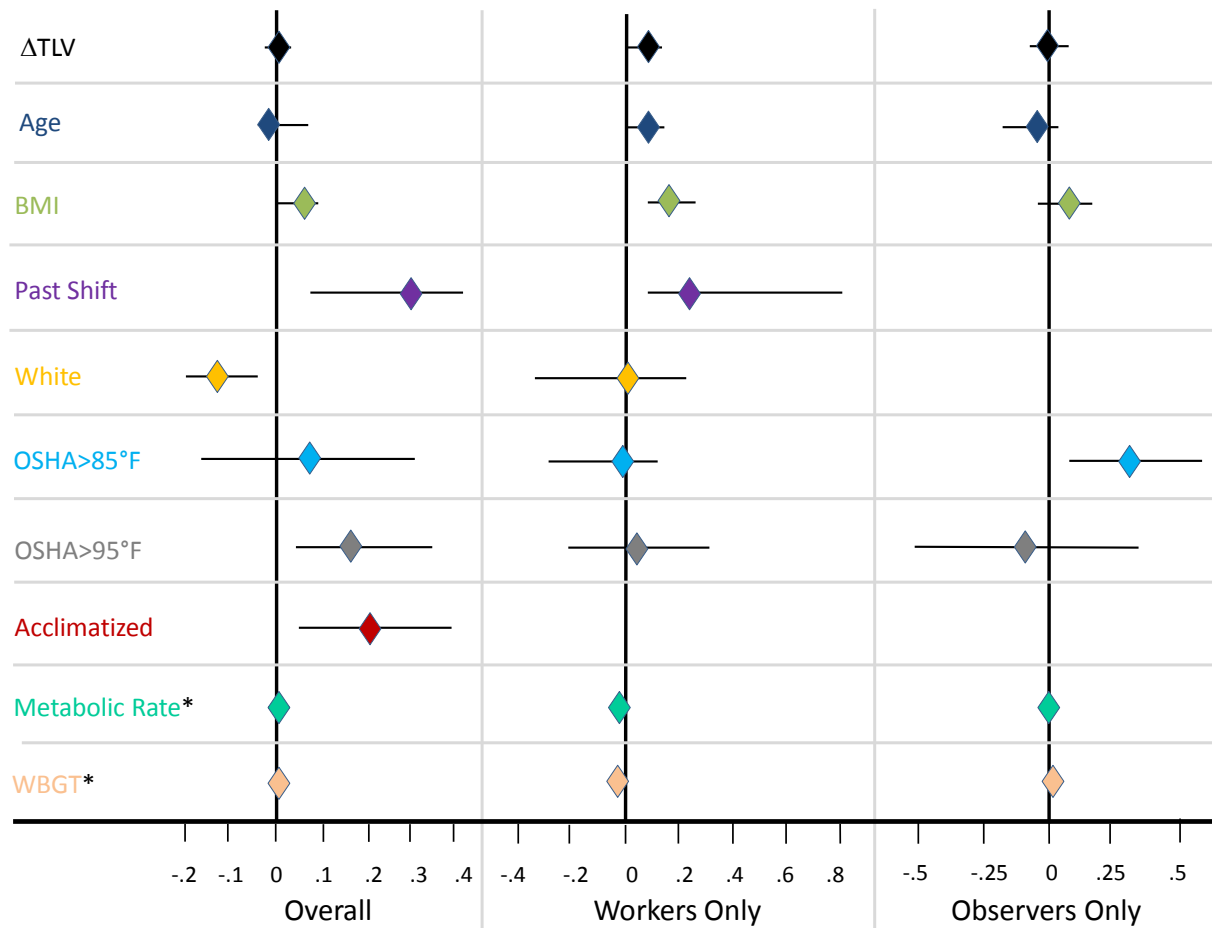


Figure 28. ΔT_0 Regression Coefficients and 95% CI. (* indicates the regression set had to be run separately, replacing the ΔTLV)

PSI

The PSI for the worker population had a range of 0.6 to 6 with a mean of 2.9. The observers had a range of 0.9 to 5.2 and a mean of 2.7. Results of mixed effects regressions of PSI are shown in Figure 29. Overall, ΔTLV , Age, and $T_{db} > 95^\circ F$ (OSHA>95°F) were all positively associated with PSI. In the worker populations, ΔTLV and age were positively associated, while a $T_{db} > 85^\circ F$ (OSHA>85°F) was negatively associated. For observers, only ΔTLV was significantly predictive in the regressions.

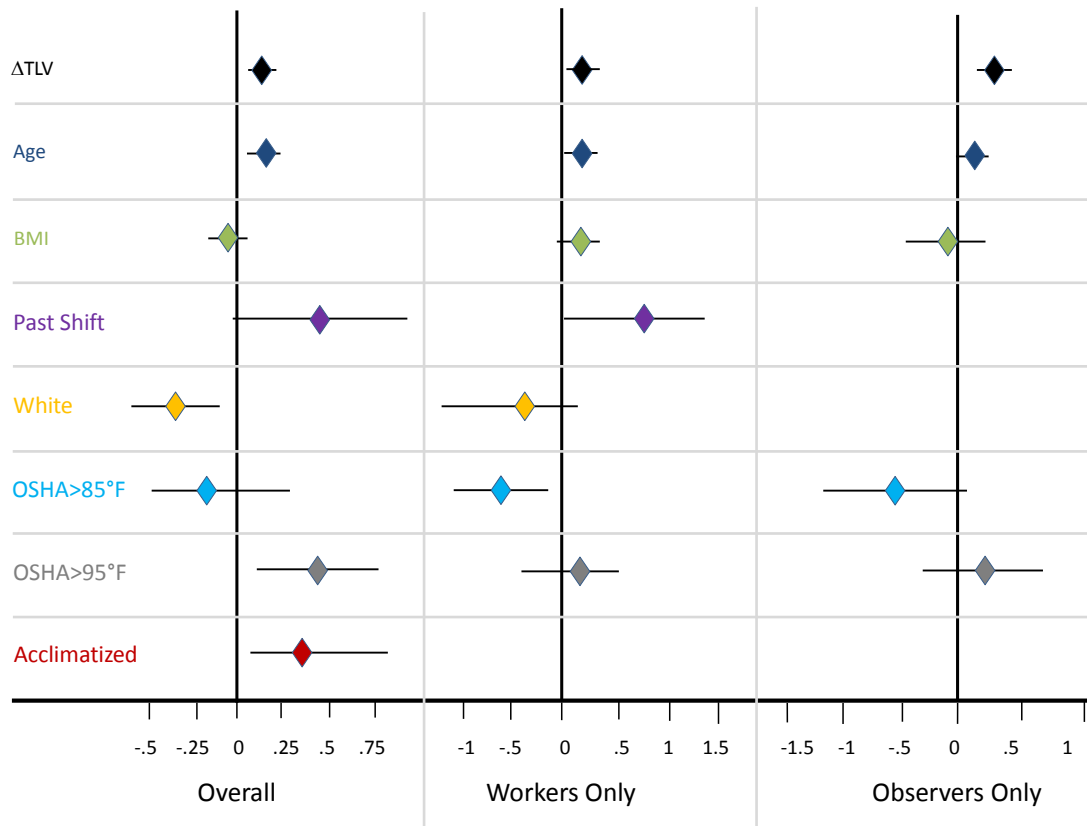


Figure 29. PSI Regression Coefficients and 95% CI.

PSI_m

The worker's PSI_m had a range of -3.2 to 4.2 with a mean of 0.7. The observers had a range of -1.8 to 5.0 and a mean of 2.7. Results of regressions of PSI_m are shown in Figure 30. Δ TLV and age were positively related to PSI_m in all three populations. Past Shift was predictive of an increased PSI_m in the worker population, and again, interestingly, being in an environment with a T_{db} greater than 85°F was negatively associated with PSI_m .

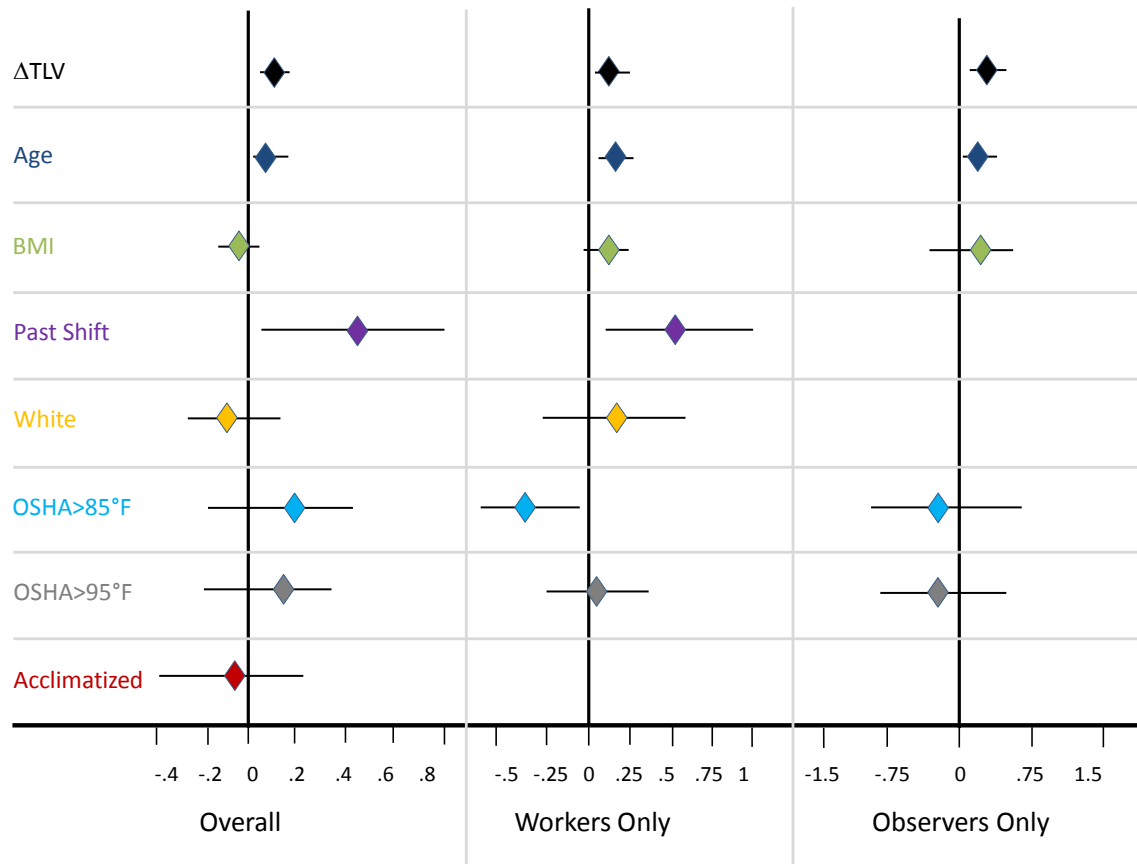


Figure 30. PSI_m Regression Coefficients and 95% CI.

4.2.2 MIXED EFFECT LOGISTIC REGRESSIONS

Mixed effects logistic regressions were conducted where the same set of independent variables was used to predict the probability of exceeding HR_{rec} of 110 or 120, conducted in two sets of regressions (each set tested on three samples: overall, worker only, and observer only). In the same manner as in the mixed effects linear models, intercepts were allowed to vary by subject, accounting for correlations among HR_{rec} measurements within subjects.

HR_{rec} > 110 bpm

Results of mixed effects logistic regressions predicting the probability of HR_{rec} > 110 bpm are shown in Figure 31. Δ TLV and Age were associated with an increased probability of having a HR_{rec} > 110 bpm in the overall and worker only populations. Overall, T_{db} > 85°F was negatively associated with exceeding 110 bpm, but this association did not hold in the individual groups. No variables were significantly predictive of having a HR_{rec} > 110 bpm in the observers only regression.

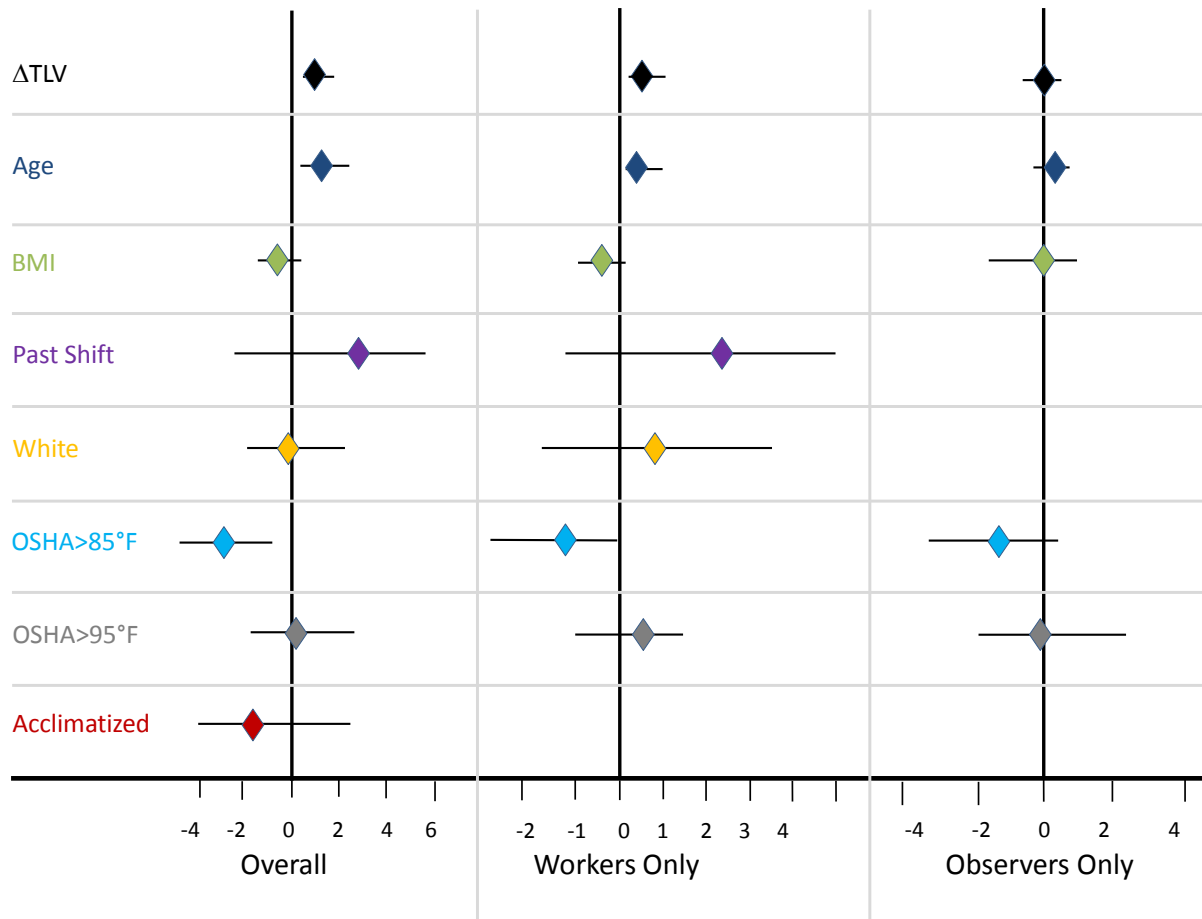


Figure 31. HR_{rec} > 110 bpm Regression Coefficients and 95% CI.

HR_{rec} > 120 bpm

Finally, results of regression of HR_{rec} > 120 bpm are presented in Figure 32. Δ TLV and age were predictive of higher probabilities of HR_{rec} > 110 bpm, both overall and in the workers only population. T_{db} >85°F was negatively related to HR >110 bpm, for the worker population and overall.

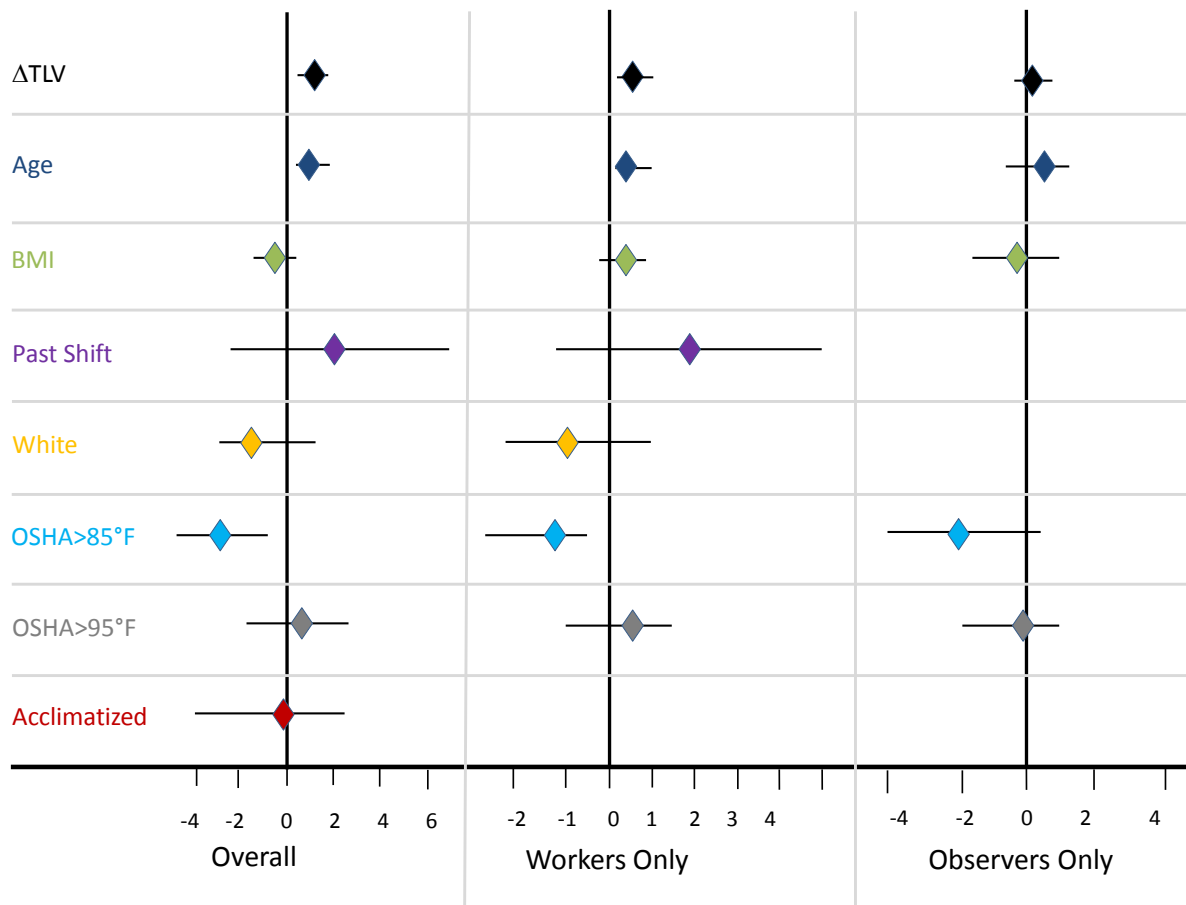


Figure 32. v HR_{rec} > 120 bpm Regression Coefficients and 95% CI.

Global Warming

As stated in the literature review, there is a fair amount of uncertainty in global warming models. Several meta analyses showed average ambient temperature increase estimates

between 4 and 5°C. Differences in precipitation varied to the point that overall there was no overall change.

For the purposes of estimating what effect an increased ambient temperature would have on occupational exposures, 5 degrees Celsius were added to the WBGT measurements. Only the outdoor measurements were increased, as certain tasks were conducted indoors and so would not be affected by increased ambient temperatures. The change in exposures was graphed, as Δ TLV (Δ AL for observers) per job class. The same basic order of risk remained as before, but the median increased above the TLV for almost all job classes, with the observers remaining below the regulatory limit.

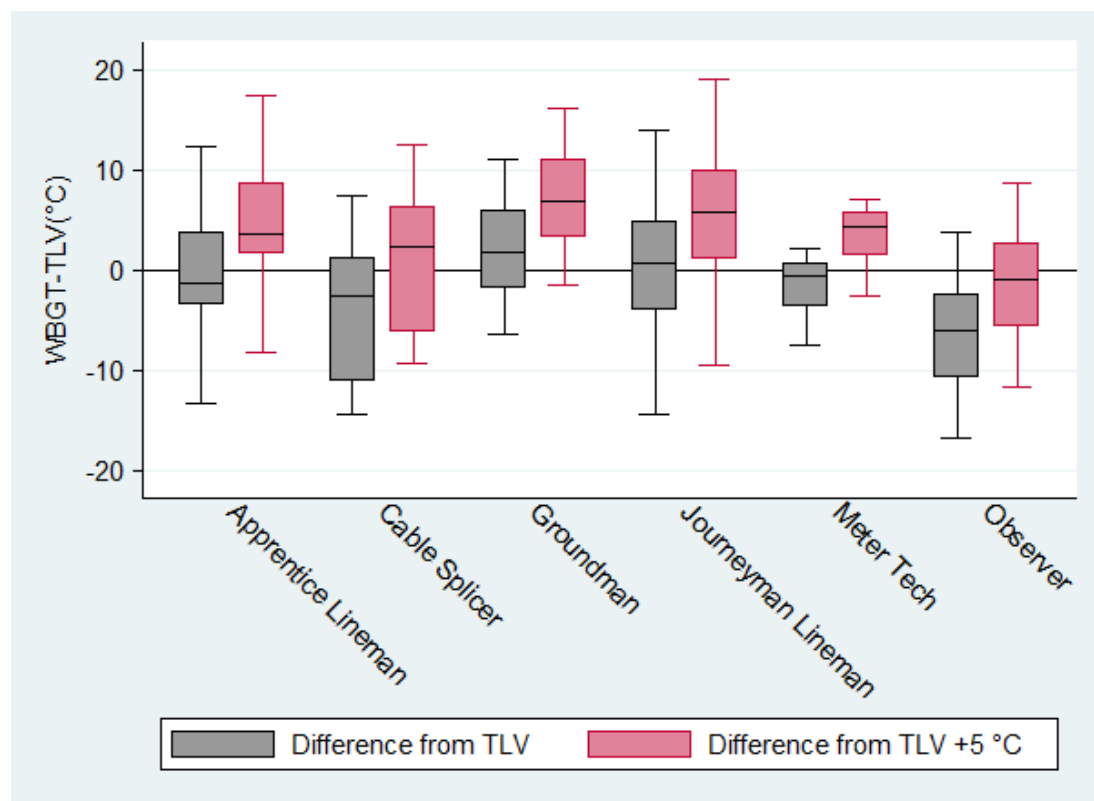


Figure 33. Hypothetical Increase in Exposure, relative to the TLV, from Global Warming

5 DISCUSSION

Task Risk Analysis

One of the goals of the industrial hygienist is the evaluation of occupational hazards. Heat stress hazards for utility workers on both a task and job class basis were evaluated in this dissertation. The methodologies used were (1) a comparison of exposure averages per job and class as compared with standards and guidelines, (2) an evaluation of metabolic stress per job and class, and (3) an evaluation of heat strain expressions per job and class.

The most physically demanding task is digging. Individuals performing this task had the highest average metabolic rate, compared with other tasks. When digging was conducted by subjects, they exhibited the highest calculated combined heat stress exposure as compared with the ACGIH TLV and NIOSH REL. Diggers also had the highest average HR_{rec} per task and the highest change in HR_{rec} from baseline. As a derivation of T_o and HR_{rec} , the PSI indicated the highest relative levels during digging, versus other tasks, and the PSI_m , using actual instead of derived baseline T_o and HR_{rec} , showed the same.

Several other tasks stood out as showing indications of higher risk of HRI. Just based on metabolic rate alone, transformer work, cable work, and vault work were all very high, compared with the other tasks. Subjects performing transformer work and vault work both showed mean exposures above the ACGIH and NIOSH exposure limits. The second highest average HR_{rec} was observed during transformer work.

In terms of heat strain indicators alone, in addition to the above, outdoor mechanical work showed a high average HR_{rec} and the second highest ΔHR from baseline.

Digging was the most physically-demanding of the tasks, and therefore, given the same environments, would pose the highest risk. However, this task was uncommon, with only 20 of the 279 measured tasks. Nor did it last a long time, relative to the other tasks, with an average task length of forty eight minutes, compared to over an hour for all other tasks.

Transformer work and cable work are also tasks with indications of higher heat stress risk. Transformers themselves are often very hot, and working in close proximity to them heats the environment through convection. Also, the transformers can directly heat the worker from conduction when touching the hot surface or from radiation of heat coming from the surface itself. Cables themselves act much in the same way, becoming very hot from resistance to the flow of electric current.

Interestingly, the tasks with the highest average T_o were indoor mechanical work and vault work, and the greatest ΔT_o was during indoor mechanical work. This is not to be expected because both ambient exposures and metabolic load were not highest for these tasks. However, working indoors or inside a vault changes/negates the wind speed, and thus evaporation rates off the skin are slower. This might account for the elevated T_o , relative to those tasks conducted outdoors. Also, there is often heated machinery and/or heated cabling inside the structure or vault which can impact the worker.

Job Class Risk Analysis

The above risk analysis details those singular tasks that carry the highest risk for HRI. The same analysis was conducted looking at job classes as a whole, where workers carry out combinations of tasks, per Figure 12.

The groundmen were of the job class conducting activities with the highest average metabolic rate. Groundmen also were of the job class having the highest actual exposures, relative to the ACGIH TLV and NIOSH REL (Δ TLV). They had the highest average HR_{rec} , and the highest derived PSI levels. The groundmen also had the highest reported BMI, with an average slightly-over-the-WHO obesity limit, and as detailed in Section 2, the BMI can influence the HR_{rec} and T_o .

Journeyman linemen had the second highest actual measured exposures when compared to the TLV and REL. However, heat strain variables did not reflect this, as HR_{rec} and T_o , and their differences from baselines, were mostly below the other job classes.

Apprentice linemen showed the greatest expression of heat strain, with the highest T_o averages and the highest Δ HR. This job class exhibited the second highest BMI levels, with their average of 28.4 kg/m² approaching the 30 kg/m² WHO obesity limit. This may have contributed to the apprentice linemen having the highest in calculated PSI_m .

Based on metabolic activities alone, the second highest were the meter technicians. However, they were among the lowest on every other heat strain measurement.

The observers were also typically the lowest in actual exposure and in most calculated heat strain measurements. However, the observers were the only job class to have a

positive (albeit slightly) average ΔT_o per task. This unexpected observation will be explored during the discussion of ΔT_o .

In terms of overall risk of HRI, the highest risk job classes were the groundmen and apprentice linemen. They both had the highest average heat stress exposure parameters, and most of the elevated heat strain ones. Also, these job classes showed the highest BMI, which is a risk factor for HRIs.

Personal Variables (BMI, Age, Race, Past Shift, Acclimatization)

Based on the data collected in this study, BMI was positively predictive of the task T_o in the worker population. Thus, when the BMI increased, there was a significant possibility of the subject's T_o to increase. This reinforces the literature, which shows a greater incidence of HRI from increased BMI (NIOSH, 1986).

However, in the observer population, BMI was negatively predictive of both HR_{rec} and ΔHR . A lower BMI was associated with both a higher task HR_{rec} and a higher ΔHR compared with baseline. This contradicts the literature, as stated above. The most likely reason for this is that, despite the large number of task measurements (155 tasks) collected from the observers, the number of different individual observers was small (8 individuals). Two of the observers had high BMIs ($>35 \text{ kg/m}^2$) but were active and in seemingly good health. They both had muscular builds and a seemingly thick bone structure. The lack of BMI measurements to take body fat percentage into consideration has been documented as a weakness of this type of measurement (Phan et al., 2012).

The distribution of the BMI with the small number of subjects (each given in a vertical line of observations) can be seen in Figure 24.

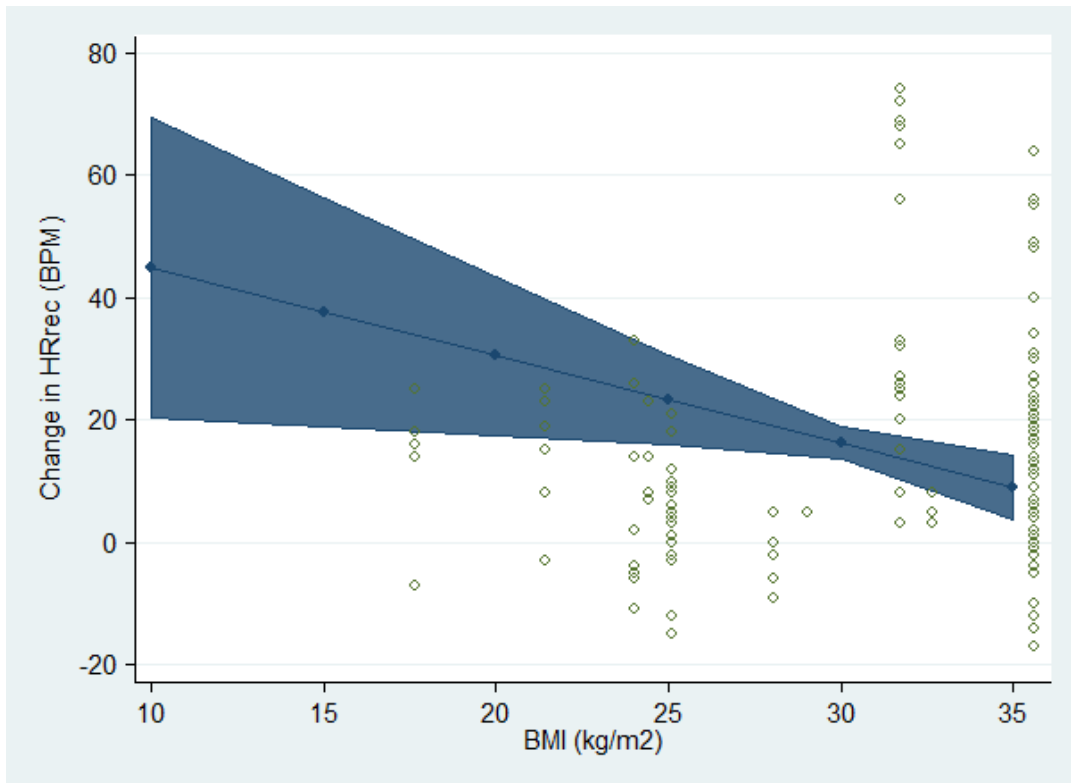


Figure 34. Observers only, ΔHR v BMI regression with 95% CI.

Age was positively predictive of a number of dependent variables. In the worker population, age was related to the ΔHR , the PSI measurements, and a HR_{rec} greater than 110 bpm (compared with measurements under 110 bpm) and $HR_{rec} > 120$ bpm. The PSI is a derived variable from the HR_{rec} and the T_o (via the T_{rec}), both of which are affected by age in the literature, so this was to be expected. However, age was not significantly predictive of the HR_{rec} or the T_o themselves in the worker population, as might be expected from the literature.

Even more dependent variables were positively predicted by age in the observer population. HR_{rec} , ΔHR , ΔT_o , PSI, and PSI_m were all significantly positively predicted using age. Again, this is to be expected, based on literature and understanding how the thermoregulatory system would work with reduced effectiveness as age increased. Based on this study, age is a strong predicting factor of heat strain (Marx et al, 2010).

Race was broken down into two groups, white and non-white, which consisted of only Hispanic workers. Being white as compared to Hispanic was for the most part not significant as a predictor variable. Only in the ΔT_o and the PSI_m was being white significantly predictive, and that was negatively predictive of both. So being Hispanic was predictive of a slightly higher ΔT_o with a regression coefficient of $0.2^\circ C$. The degree of decreased PSI_m (coeff. = -0.38) is at this point irrelevant due to the 0 to 10 scale being undefined.

Whether the subject worked the night before (Past Shift) was significantly predictive of an increased ΔT_o and an increased PSI level. The thermoregulatory mechanisms in the body will fatigue over time, and since work was completed in the same region, continued heat exposures can be expected during that time. Therefore, past shift work is also a good predicting factor of heat strain. It was only possible to analyze the worker population, as no observers worked the previous evening.

Acclimatization presented several issues. The only acclimatized population was the workers and the only un-acclimatized population was the observers. It was attempted to group the two groups into one overall group and analyze them using a logistic regression. However, the results were varied and not expected, and although they are

given in the regression descriptions, the results relating to acclimatization were decided to be removed from this study. The two groups were too dissimilar to simply combine for analysis.

HR_{rec} v Δ HR

The difference in HR_{rec} from baseline (Δ HR) is not a commonly used variable for the assessment of heat strain. However, during the pilot study, a range of basal HRs was noted. Thus it was hypothesized that the HR would be better examined from the standpoint of how far the HR moved from the actual baseline (Δ HR), rather than using a single, number such as 110 bpm or 120 bpm.

In terms of significance of findings in regression analyses, the results seemed to support the use of Δ HR. In the worker population, using exposure (Δ TLV) as the independent variable and adjusting for the other possible variables, the HR_{rec} was predicted to increase by 0.84 bpm (p=0.001). The Δ HR also was predicted by the Δ TLV exposure, and to a higher degree, with a regression coefficient of 0.98 bpm (p=0.001). In the observer population, however, the Δ HR_{rec} was again better predicted by the Δ TLV exposure, with a coefficient of 2.28 bpm (p=0.001), while HR_{rec} had a regression coefficient of only 1.37 bpm (p = 0.001).

The Δ HR seems to be a better fit than the HR_{rec}, for relating to a given heat stress, but slightly less so in the worker population. The workers and observers differed primarily in metabolic load, as observers had a bare minimum of work load, and both groups were exposed to essentially the same environmental heat stress. Clothing adjustments were

slightly less in the observers, but that should have made a minor impact. Therefore, it appears that ΔHR might be better for evaluation of heat strain in work activities that are more stable and repetitive and not largely varying in metabolic load, while HR_{rec} might be better for the opposite activities.

HR_{rec} greater than 110 bpm and 120 bpm

The one-minute recovery heart rate (HR_{rec}) is recommended by NIOSH not to exceed 110 bpm and by ACGIH not to exceed 120 bpm. These numbers were used as set points, and the HR_{rec} for each task was assigned a logistical variable to represent their status relative to the 110/120 bpm points.

The probability of a HR_{rec} being over 110 bpm was predicted by exposure/ ΔTLV with a regression coefficient of 0.185 ($p=0.002$). The HR_{rec} over 120 bpm was slightly more likely, with a coefficient of 0.195 ($p=0.004$). This is to be expected in that as exposure increases, the HR_{rec} will be more likely to exceed the 110/120 bpm set-points. The bivariate logistic regression of $HR_{rec} > 110$ bpm to TLV is given in Figure 35.

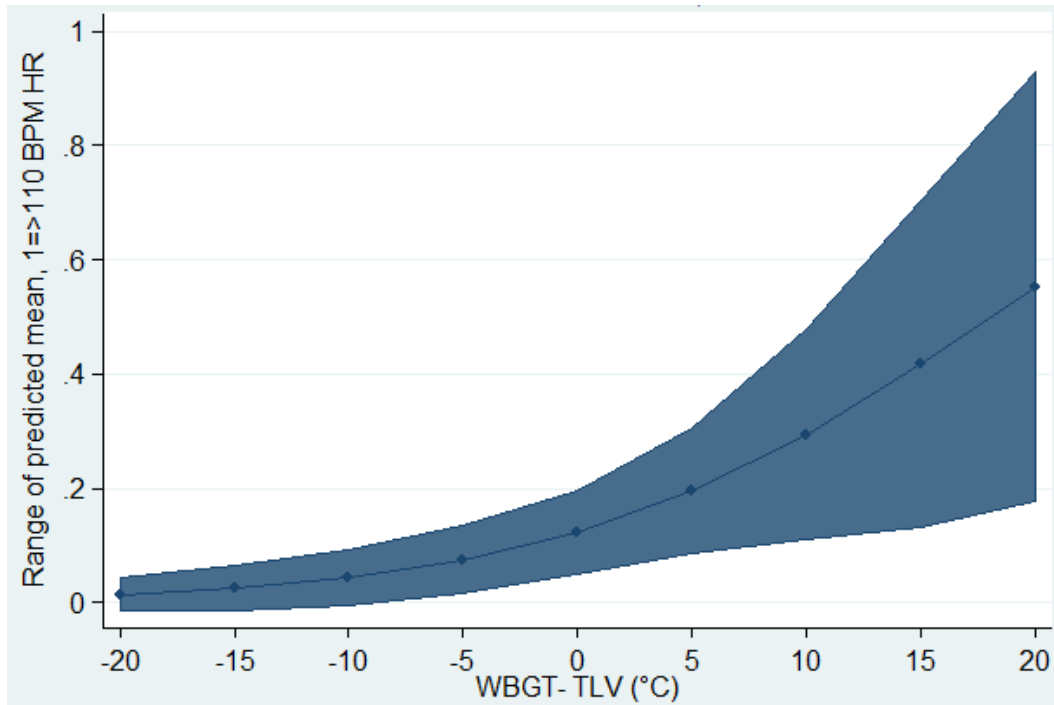


Figure 35. ΔTLV v $HR_{rec} > 110$ bpm regression with 95% CI

HR_{rec} 's of over 110 or over 120 bpm were not significantly predicted by any variable in the observer group. Since the groups were exposed to the same environmental variables, the difference of metabolic effort must have been responsible for the predictive influence.

T_o v ΔT_o

Oral temperature did not appear to be a well-predicted variable in terms of response to given elevated exposures to heat stress. Exposure based on environmental conditions alone (T_{db} , WBGT) did correlate significantly with T_o , but any exposure that included metabolic conditions (ΔTLV , metabolic rate) showed no predictive value with significance. One study mentioned the possibility of a lag effect, where body temperature would take a period of time to increase (Gagnon and Kenny, 2011). Another

mentioned that the body temperature may only increase significantly in those times when the thermoregulatory system fails, which would be in the presence of a HRI. (Nettlefold et al, 2011).

The difference from baseline oral temperature (ΔT_o) was used as a test dependent variable. The ΔT_o had several interesting results. A large number of the T_o measurements collected upon completion of the standardized tasks (34% of measurements) resulted in a negative number, compared to the baseline measurements. In virtually all cases, both environmental and metabolic stressors increased, compared to the beginning of the day's baseline.

There may have been some cases of activities conducted by the subjects prior to collection of baseline measurements, or the consumption of hot drinks in the morning such as coffee, both of which would have falsely elevated the baseline T_o . There may have been some cases of cold drinks consumed prior to task T_o measurements, falsely dropping the task T_o . However, the observers were made aware of these possible confounders, so the incidence of such activities should have been rare.

Although the ΔT_o had a number of insignificant measurements, it was better predicted by independent variables than the T_o alone. In the worker population, the ΔT_o was predicted to be influenced positively by BMI, past shift work, and having a T_{db} greater than the OSHA set-point of 95°F, as compared to the T_o , which was only predicted by BMI. The ΔT_o seems to be a better choice for heat strain measurement than the T_o .

PSI v PSI_m

PSI is an equation that uses the measured basal HR and body temperature. This study created a test variable of an assumed basal HR of 60 bpm and an upper limit of 180 bpm to create the PSI_m.

The PSI and PSI_m had very similar results. Both placed digging as having the highest strain compared to other tasks. Both placed “no activity” as among the lowest, although the PSI placed that lower than the PSI_m. Both were varied on their job class assessment, with the PSI placing observers in the middle of the heat strain levels and groundmen among the lowest. Only the PSI found the Past Shift variable to be significant, while only the PSI_m found being in a $T_{db} > 95F$ and being acclimatized to be so. They both found ΔTLV to be significantly predictive, but with similar very low regression coefficients (.0045 PSI v 0.0050 PSI_m). It appears that the PSI and PSI_m are both effective indices of measuring heat strain, but the index utilizing the actual rather than assumed baselines, the PSI, makes more sense, considering the wide range of basal readings collected from this study.

ACGIH and NIOSH Standards

As mentioned above, there were a large number of tasks, and workdays overall, that had environmental exposures and metabolic loads that were above recommended limits. Being over the ACGIH and NIOSH recommended limits was related by regression to having increased heat strain expressions, but despite being over the regulatory limits, there were no cases, in over 400 tasks measured, of a body temperature over the recommended limit. Only a few tasks (12 of 426) went past the NIOSH Ceiling limit, which may be a reason that no thermoregulatory system failure occurred,. It would

appear that, based upon this research data, the ACGIH and NIOSH limits are very conservative and protective of the worker population.

Cal/OSHA applicability

Cal/OSHA's regulation is based on two simple triggers, whether the ambient T_{db} is above 85°F or above 95°F. The variables of having a $T_{db} > 85^\circ\text{F}$ and $> 95^\circ\text{F}$ were compared to each of the outcome variables. Due to the T_{db} 's inherent relationship to the WBGT measurements and ΔTLV exposures, the regression analyses had to be re-run.

The significance of being over 85°F was varied. For most dependent variables in most populations, there was no significant predictive value of the independent Cal/OSHA heat stress variable (OSHA $> 85^\circ\text{F}$) on the dependent heat strain. There were some examples of having a $T_{db} > 85^\circ\text{F}$ being positively predictive of the outcome variables. T_o and ΔT_o were positively predicted by $T_{db} > 85^\circ\text{F}$ in the observer population.

However, working in an environment over 85°F (compared to less than 85°F) was significantly predictive for a negative effect on many more dependent variables. HR_{rec} was predicted negatively by $T_{db} > 85^\circ\text{F}$ for the worker population. ΔHR was negative in all of the populations, and PSI and PSI_m were negative in the worker populations. Compared to having a $\text{HR}_{rec} > 110$ bpm, a $T_{db} > 85^\circ\text{F}$ was negatively associated with the increased HR_{rec} . The same predictive association exists with a $\text{HR}_{rec} > 120$ bpm.

Based on this study, then, it would seem that the T_{db} set-point of over/under 85°F alone as a predictive factor for heat strain is a weak indicator, and in some cases an inverse predictor of heat strain. Since the body temperature is somewhere around 96-98°F, it

would follow that the environment below 85°F would have a convective cooling effect. Other independent variables, such as the derived ACGIH TLV/AL or NIOSH REL/RAL, or even simple estimations of metabolic load or WBGT would appear to be better suited for the purpose of estimating/predicting heat strain.

Using the $T_{db} > 95^\circ\text{F}$ was slightly different. In two of the six measured dependent variables, ΔT_o and PSI_m , having the worker in an environment with a $T_{db} > 95^\circ\text{F}$ resulted in a significantly positive prediction of those variables. The estimated increase was not large, but it was present. Again, this makes sense, considering the body temperature and the convective heating effect that a T_{db} greater than 95°F would have. It would appear that the 95°F set point is a better general predictive tool, although still not as strong as some other predictive variables.

One issue to consider however is the aim of the Cal/OSHA regulation. As previously stated, this regulation was aimed primarily at agriculture and construction activities. In those work environments, long periods of time are spent doing very heavy physical labor and/or in areas with very high radiant heat loads (with minimal shade). That is not typically the case with utility workers, which might point at reasons why the 85°F set-point was not as predictive for heat strain in this study.

Global Warming

The ambient temperature predictions were averaged to increase by 5°C by 2100. This increase, assuming the same ambient humidity, was added to this study's exposures and graphed. Based on Figure 33, the increase in ambient exposure by 5°C was a significant increase in exposures for the subjects. Where only two of six worker classes (33%) were

averaged over the ACGIH TLV under normal conditions, after the increase every worker class (100%) was significantly over the allowed ACGIH and NIOSH exposure limits.

Since it has been determined from this study that the ACGIH TLV and similar standards are conservative, it is unknown whether this will result in a significantly increased numbers of HRIs. From a public health perspective, a 5°C increase will certainly result in an increased number of deaths, directly and indirectly, from heat exposures. Based on this alone, public health officials and government should focus their efforts on minimizing the global warming trends.

Limitations

Although this study did not show any indications of a HRI, despite very hot ambient temperatures and work exposures above the TLV and REL, it should be noted that the population studied is an extremely fit and strong population. Utility line workers are typically in very good shape, and despite the elevated BMIs described, these are muscular and fit workers. And the exposure limits described are aimed at the general working population, which would not be as in-shape and healthy as this one.

Conclusion

Industrial hygiene is the anticipation, recognition, evaluation and control of occupational hazards. This study was an industrial hygiene heat stress and strain evaluation of electric utility workers while working in high temperature, low humidity regions. The following conclusions were made in this study:

1. The highest heat risk task category was digging, although transformer work and outdoor mechanical work also exhibited higher risk. Indoor work such as indoor mechanical work and vault work both showed signs of higher heat strain, compared to other tasks. The job classes of highest risk were groundmen and apprentice linemen.
2. An increased BMI predicted increased expressions of heat strain, except in the observer population, where it decreased. This illustrated a weakness of using BMI as a predictive tool.
3. Age was a strong predictor of increased heat strain.
4. Race did not correlate well with heat strain variables.
5. Whether the subject worked the night before (past shift work) was a strong predictor for increased heat strain variables.
6. Acclimatization was removed from this study, as the two different populations were unable to be combined.
7. Oral temperature correlated well to exposure and other heat stress variables. The change in oral temperature (ΔT_o) correlated better than T_o .
8. Heart rate was a good predictor of heat strain, but the difference in HR (ΔHR) was better-predicted by those activities with less metabolic load variance.
9. Using HR_{rec} set-points of 110 bpm and 120 bpm both correlate well with increasing exposures.

10. The PSI_m was not a significant improvement on the PSI.
11. The ACGIH and NIOSH standards are conservative and protective of the worker.
12. The Cal/OSHA set-point of 85°F is a weak predictor, and in some cases, inversely predictive of heat strain, although it is designed for different populations than this study.
13. The Cal/OSHA set-point of 95°F is a better and positive predictor of heat strain than 85°F.
14. Global warming would increase occupational exposures for the population in this study from 33% to 100% above recommended limits.

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APPENDIX I – INITIAL INFORMATION SHEET

UNIVERSITY OF CALIFORNIA LOS ANGELES

STUDY INFORMATION SHEET

Evaluation of Heat Stress and Strain in Electric Utility Workers

Eric Nicholas Brown, from the *Environmental Health Sciences Department* at the University of California, Los Angeles (UCLA) is conducting a research study.

You were selected as a possible participant in this study because you are an Electrical Utility Worker. Your participation in this research study is voluntary. Your decision whether to participate will not affect your employment or relationship with SCE in any way.

Why is this study being done?

This study will look at how heat from the environment affects the worker's heart rate and oral body temperature. It will also look at work tasks.

What will happen if I take part in this research study?

If you volunteer to participate in this study, the researcher will ask you to do the following:

- *Allow your heart rate (with a heart rate watch) and oral temperature (sterile medical thermometer) to be collected after every major task.*

- *Complete a brief questionnaire that includes questions about your health and prescription medicines.*
- *Possibly take photos that may be used to help describe a task. These photos will not be shared with the public or your employer.*

How long will I be in the research study?

Participation will take a total time of your normal work day. You may be asked to participate for a series of days throughout the summer months. You may be asked to participate for a series of approximately 50 - 100 full day monitoring sessions throughout the summer. You can end your participation in the study at any time.

Are there any potential risks or discomforts that I can expect from this study?

There are no anticipated risks.

Are there any potential benefits if I participate?

You will not personally benefit from this study. The results of the research may be used to evaluate the heat stress that electric utility workers are exposed to, and help determine the best methods to evaluate this.

Will information about me and my participation be kept confidential?

Any information that is obtained in connection with this study and that can identify you will remain confidential. It will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of random number assignment and a coded

key that links random number to individuals. This coded key will be used only by the observers to link multiple days to the same random number. The coded key will not be shared with the researcher, and will be securely stored separately from the data.

Even though data collectors will be from the company's safety department and a consultant has been hired by the company to oversee the field research, no individual identifying information will be shared with the employer.

What are my rights if I take part in this study?

- You can choose whether or not you want to be in this study, and you may withdraw your consent and discontinue participation at any time.
- Whatever decision you make, there will be no penalty to you, and no loss of benefits to which you were otherwise entitled.
- You may refuse to answer any questions that you do not want to answer and still remain in the study.

Who can I contact if I have questions about this study?

If you have any questions, comments or concerns about the research, you can talk to the one of the researchers. Please contact:

Eric Brown
XXXX East Chapman Ave
Fullerton, CA XXXXX
XXX.XXX.XXXX
XXXXXX@gmail.com

Nola Kennedy
UCLA School of Public Health
1650 Charles E. Young South
Los Angeles, CA 90095
XXX.XXX.XXXX
XXXX@ucla.edu

•UCLA Office of the Human Research Protection Program (OHRPP):

If you have questions about your rights while taking part in this study, or you have concerns or suggestions and you want to talk to someone other than the researchers about the study, please call the OHRPP at (310) 825-7122 or write to:

UCLA Office of the Human Research Protection Program

11000 Kinross Avenue, Suite 211, Box 951694

Los Angeles, CA 90095-1694

APPENDIX II – INITIAL SURVEY FORM

Date:				
Business Unit	District	Job Class	Random #	Instrument Number
Base Clothing				
<p>Self-Reported Data - The information you provide is important to the success of the study. However, you can skip any questions that you are not comfortable with.</p>				
Height	Weight	Age	Race	
			W H AA NA A PI M	
<small>White, Hispanic, African American, Native American, Asian, Pacific Islander, Mixed</small>				
Past Shift Info (Overtime, etc)				
Is this your normal district? If no, where are you normally assigned?				
Are you taking any Prescription Drugs? If Yes, please list:				
Have you been diagnosed by a doctor or nurse with any of the following? High Blood Pressure, Arrhythmia, Heart Condition, Diabetes?				
Note: Do not drink 15 minutes prior to taking temperature! Please notify us if you have.				

APPENDIX III – WBGT FIELD BRIEF



How to turn on the QUESTemp

1. Make sure the wet bulb's wick is clean and its compartment is filled with deionized water.
2. Push the "I/O Enter" button to turn on the unit.
3. **Note:** Each time before datalogging for the day, press the "I/O Enter" button to enter the RESET mode. Clear the memory by holding down the "I/O Enter" while the display counts down from three.
4. Press the "RUN STOP" button to begin datalogging (Note that when data is being collected, an asterisk will be present in the bottom right corner of the screen.)

How to turn off the QuesTemp

1. To turn off the unit, hold down the "I/O Enter" button for 5 seconds. As you hold down the button, a 3 second countdown will be displayed in the lower right corner of the screen. As soon as the countdown is finished, the unit will turn off.

How to attach the QuesTemp to the computer for data entry

1. Attach the designated cable to the QuesTemp and your computer.
2. Turn on the QuesTemp.
3. A screen will pop up with the QuesTemp logo.
4. Click on the download button in the program to retrieve data from the unit.

APPENDIX IV –DATA COLLECTION FORM

Date:	Identification Number:								
Time	Location	Activity - Take Photos per Activity	Posture	Body Activity	Effort Level	HR@ 1min	Toral 1	Toral 2	Notes (e.g. PPE, Radiant Sources)
			Sit Stand	N H 1A 2A WB	L M H VH				
			Sit Stand	N H 1A 2A WB	L M H VH				
			Sit Stand	N H 1A 2A WB	L M H VH				
			Sit Stand	N H 1A 2A WB	L M H VH				
			Sit Stand	N H 1A 2A WB	L M H VH				

N - No movement H - Hands only 1A - One Arm 2A Two Arms WB Whole Body

L - Light Activity, sustainable with ease for 8 hours
M - Moderate - sustainable for 8 h w/ nominal breaks
H - Heavy - breaks required at least every hour
VH - Very Heavy - frequent breaks required

About the Author

.Eric Brown received a Bachelor of Arts degree in Philosophy from the University of Toledo, Ohio in 1995. While employed as an Environmental Health Specialist for a county health department, he enrolled in the Master of Public Health degree program at the Medical College of Ohio. He was the recipient of a full scholarship and graduated in 1999 with a specialization in Occupational Health and Safety.

Mr. Brown has worked as an industrial hygienist for several consulting firms, obtaining both his Certified Industrial Hygienist and Certified Safety Professional certifications. He is currently employed by Southern California Edison's Corporate Health and Safety department.