UNIVERSITY OF CALIFORNIA

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A critical review of the scientific and empirical literature

on indoor heat illness prevention standards

A thesis submitted in partial satisfaction

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in Environmental Health Sciences

by

Nan Jiao

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ABSTRACT OF THE THESIS

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Professor Shane S. Que Hee, Committee Chair

Heat stress has been a longstanding hazard for workers across many industries. Climate change creates new environmental issues for the workplace. Cal/OSHA is preparing a draft standard to minimize heat-related illness and injury among indoor workers. Indoor heat stress could lead to morbidity and mortality of workers as well as economic burdens and impacted productivity to industries. The goal of this research was to identify the existing literature (standards/guidelines and research articles) and discuss if there were sufficient research data available to implement an indoor workplace heat stress prevention standard in California. Existing national and local enforceable standards and recommended guidelines have been collected. Each standard/guideline was evaluated with the metrics of the originating agency, workplace coverage (indoor/outdoor), year established, measurements, and control methods. A comprehensive search of Pubmed and SciFinder databases was conducted for evidence of measurements and control methods to identify, classify, and evaluate them. In conclusion, a Cal/OSHA standard is feasible because the scientific database is adequate. Weather it is practical depends on cost, ease of field management, stake-holder buy-in, and factors outside of the scientific arena. An indoor heat standard should cover all indoor workplaces. American Conference of Governmental Industrial Hygienists (ACGIH) provided the most accurate and precise measurement method, however, required a Wet Bulb Globe Temperature device and several steps to make determination. The control hierarchy with an emphasize on engineering controls should be implemented at all hot workplace. Administrative controls, such as training, work-rest schedule, hydration, and acclimatization, are bottom lines if engineering controls are not feasible. Cooling vest is effective in preventing heat accumulation, however, may not fit other personal protective equipment. Future studies should focus on effectiveness evaluation of existing standards, cost-benefit of measurement and control methods and identification of impacted industries.

The thesis of Nan Jiao is approved.

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DEDICATION

I dedicate my dissertation work to my family, my faculty advisor and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my faculty advisor, Dr. Shane Que Hee, who has supported me throughout the process.

I dedicate this work and give special thanks to my friends for being there for me throughout the entire master program.

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1. INTRODUCTION

Heat-related illness in the workplace has long been recognized as an occupational health concern. A literature review of the epidemiology of occupational heat exposure showed that studies and reports had described demographic characteristics of populations with heat illness. However, the contribution of age, fitness level, and other risk factors to heat-related illnesses varied. Few studies analyzed mortality and morbidity incidence. The most impacted workers studied are construction workers, cooks, farmers, fire fighters, airport ground servicers, manufacturing workers, miners, mixed manual workers, and steel workers. [1] Underreporting is a major issue when assessing severity of heat stress prevalence. Possible reasons for employees not reporting heat-related illnesses are unawareness of heat-related illnesses, fear of being labeled as problematic and of losing their jobs, no economic incentive, and undocumented immigration status [2]. In a study, 79% of underground mine workers experienced heat illness, among whom the majority have mild symptoms. Most workers reported more than one experience of heat-related illness. [3] This implies that heat related illness could be universal, but is discounted due to mild symptoms.

Industrial hygienists have shown concerns about workplace heat exposure. Barriers recognized by occupational hygienists in a national occupational hygiene conference in Australia in 2012 were lack of awareness, insufficient training, unsatisfactory management commitment, and low compliance with preventative standards. [4]

Heat stress accumulates in the human body through several pathways. The biophysics of heat balance [5] are:

- Metabolic heat production is a byproduct of the process that metabolic energy converts to mechanical energy for external work.

- Heat conduction is the heat exchange between direct contact of two solid surfaces. Temperature difference between surfaces, material thermal conductivity, thickness and contact area are factors impacting heat conduction. In workplaces, heat conduction is neglected unless the skin is in contact with a hot solid surface such as a warm blanket.
- Thermal radiation is a type of electromagnetic wave in the infrared region generated between two surfaces with different temperature. The intensity of heat exchange through thermal radiation depends on surrounding subjects and body surface temperature and emissivity, clothing insulation, and effective radiant surface area. Some examples of heat radiation sources are radiant warming lamps, furnaces, and boilers.
- Convection is a form of heat transfer between a solid surface and a surrounding fluid medium. The convection rate between a body surface and its surrounding fluid depends on temperature difference, clothing insulation, fluid density, heat capacity, thermal conductivity, velocity of the fluid, and type of fluid flow. Cold water immersion is an example of reducing body heat load through convection.
- Skin sweat evaporation is the major route of heat loss through the body during exercise. The two steps of sweat evaporation are phase transformation of sweat from liquid to vapor, and diffusion of vapor into the surrounding atmosphere.
- Respiratory heat loss happens between the respiratory tract and the surrounding environment during pulmonary ventilation. Dry cool air is inhaled and saturated and warm air is exhaled if the surrounding temperature is cooler than the body temperature.

Convection and evaporation happen during breathing.

Types of heat-related illness are [6] [7]:

- “Heat edema: extremity swelling caused by peripheral vasodilation and interstitial pooling
- Heat cramp: activity-associated muscle spasms during or immediately after activity
- Heat syncope: a transient loss of consciousness due to pooling of blood in the extremities, usually after ending activity suddenly
- Heat exhaustion: the inability to continue activity in heat due to exertional heat stress and low central blood volume impairing heat dissipation
- Exertional heat stroke: extreme activity-induced hyperthermia, thermoregulatory failure, and profound central nervous system dysfunction.”

Some populations are more vulnerable to heat stress. Screening personal risk factors are: [6] [8] [9] [10]

- Gender: the lower aerobic power of women leads to higher risk of exertional heat illness. Extreme heat stress endangers pregnancy
- Age: aging reduces sweating ability and cardiovascular efficiency in distributing heat
- Fitness and obesity: excessive body fat and lower physical fitness lead to higher risk of heat illness. The combination of both significantly increased the risk. [11]
- History of diseases: Past history of heat illness is the greatest risk of future exertional heat illness.
- Temporary unfit: workers who feel unwell, e.g. vomiting or diarrhea, have infection, dehydration, loss of sleep, or on low sodium diet have higher risk of heat illness.

Other factors include cardiopulmonary fitness, body temperature, experience and skills, high blood pressure, diabetes, impaired mental capacity, myocardial infarction, cardiac bypass, and heat perception. Predictive factors for hospitalization of patients with heat illness are age over 65 years, hyperthermia, disturbance of consciousness, and increased serum creatinine above its upper reference threshold. [12]

To write this literature review, the author used two types of search methods: existing national and local enforceable standards and recommended guidelines and the scientific literatures.

Standards are enforceable by regulators, and can be established on a national level, such as federal standard, or at local level, such as state standards. Guidelines can be published by independent institutions. Each standard/guideline was evaluated with metrics of its originating agency, workplace coverage (indoor/outdoor), establishment year, measurements, and control methods. The author collected standards and guidelines through all following ways:

- The author conducted the search on Google with key words, such as “heat,” “heat stress,” “heat illness” “standard” and “guideline.”
- The author consulted UCLA faculty and professionals with an international background who have worked and are working in the environmental health sciences field. The author asked if they had heard about heat prevention standards/guidelines in their country of origin, and which agencies/website published such standards and guidelines.
- The author searched for standards in every state in the US.
- The author included standards and guidelines in English and Chinese only.

The author also conducted a comprehensive scientific research database search (PubMed and SciFinder) for published measurements and control methods to identify, classify, and evaluate each method. Search criteria were:

- The cut-off dates of Pubmed searches were January 1900 to March 2017, and of Scifinder were January 1986 to March 2017.
- Pubmed database searching criteria was “((prevention & control[MeSH Terms]) AND heat stress[Title/Abstract]) OR heat illness[Title/Abstract]”.
- Scifinder database research topic input was “workplace heat stress prevention”.
- The author filtered all articles by abstract and title, and divided qualified articles into subsections of measurement, control, and others but important.
- Only articles written in English were included.

2. IDENTIFICATION AND EVALUATION OF AVAILABLE MEASUREMENTS

2.1 Objective Measurements

2.1.1 Heat Stress Indices

2.1.1.1 Wet Bulb Globe Temperature

Wet Bulb Globe Temperature (WBGT) is the most widely used heat stress measurement. The WBGT takes into account four environmental factors leading to heat stress: air temperature, humidity, air velocity, and radiant heat by dry bulb (T_{db}), natural wet bulb (T_{nwb}), and globe (T_g) temperatures, respectively. For indoor conditions, the calculation of WBGT is: $WBGT = 0.7T_{nbt} + 0.3\ T_g$, and for outdoor conditions, solar radiation is considered: $WBGT = 0.7T_{nwb} + 0.2T_g + 0.1T_{db}$. [13]

Since traditional WGBT area measurement does not consider personal factors, adjusted clothing factors were provided in several studies to satisfy heat stress from wearing different personal protective equipment (PPE). Not only texture and coverage of clothing, but also hoods could make a difference by decreasing WBGT threshold value by 1-11°C [14] [15] [16].

Studies also focus on estimation of WBGT from standard meteorological measurements, such as air temperature, relative humidity, wind speed, and solar radiation. The method of Liljegren [17] is better for estimation of indoor WBGT, and the Bernard method [18] describes outdoor WBGT better [19] [20].

Though adopted by various standards and guidelines, the limitations of WBGT have been clearly studied: 1. WBGT does not reflect heat stress in an environment where heat evaporation is limited; 2 Inaccuracy could be caused by omission of the globe temperature, non-standard measurement, and unsatisfactory calibration. [21] [22] [23]

The development of adjusted clothing factors resolved the first limitation of sweat evaporation. At the same time, work activity level and work-rest cycle have also been taken into account when setting upWBGT thresholds by ACGIH [24].

2.1.1.2 Heat Stress Index (HSI) and Predicted Heat Strain (PHS)

In the Heat Stress Index (HSI) model, heat stress can be expressed by the ratio of evaporative heat required by the human body to maintain heat equilibrium to the maximum evaporative capacity of climate. [25] The numerator and denominator can be determined by nomograms. [26]

The Predicted Heat Strain (PHS) model is recommended by ISO 7933 Ergonomics of the thermal environment -- Analytical determination and interpretation of heat stress using calculation of the predicted heat strain. Since its initial publication in ISO 7933 (1989), several studies reviewed its limitations in terms of the required sweat rate model and developed the predicted heat strain model. [27] [28] [29] The updated ISO 7933 (2004) method is based on a larger database and has been tested by more laboratories.

HSI and PHS are useful for extremely hot environments [13]. However, like other heat stress indices below, the methods are calculation heavy, and require well-educated specialists to use and interpret the data.

2.1.1.3 Effective Temperature (CT) and Corrective Effective Temperature (CET)

The effective temperature (ET) is a comfort parameter that considers temperature, humidity, and air-movement. The corrective effective temperature (CET) updated the ET by including the globe thermometer reading instead of air temperature. [30]

The scale value determined by both methods can be found in a specific nomogram with ease.

However, physical activity level and clothing factors were not considered. The ET may underestimate heat stress in severe conditions. [13]

2.1.2 Biomarkers

Several types of biomarkers have been utilized since the 1990s. Biomarkers are personal physiological measurements within the human body. Core body temperature is considered as the most accurate and direct physiological indicator of heat stress. For example, ACGIH claimed that its TLV allowed healthy workers to keep within 1°C of normal core body temperature. [24] However, this is also expensive (ingestible pill) and impractical for active workers (rectal probe). Other biomarkers are measurable physiological responses to heat stress, including heat shock protein 72, urine specific gravity, aural canal temperature, skin temperature, metabolic rate, blood pressure, and blood volume.

2.1.2.1 Core Body Temperature

Human core body temperature (CBT) is represented by rectal and gastrointestinal temperature. Rectal temperature can be measured by a flexible rectal probe inserted 12 centimeters past the anal sphincter [31]. The miniaturized radio-transmitter, which is capable of measuring gastrointestinal tract tissue temperature is composed of an ingestable temperature sensing pill and a data receiver. The pills measure surrounding tissue temperature during its transit in the gastrointestinal tract, typically 24-48 hours [32].

Considering the difficulty of obtaining CBT, several studies tried to estimate it by different physiological factors. A temperature sensor inside protective headgear could estimate the rectal temperature within 0.5 °C or less [31]. Insulated skin temperature combined with microclimate temperature predicted rectal temperature of emergency providers wearing fully encapsulated impermeable PPE [33]. Studies have shown that CBT is predictable: a real-time estimation of CBD in 20 min ahead of time is available by using current CBT as reference [34] [35]. Though promising as it may seem, conflicting study results exist. For example, one study showed that 5 external thermometers failed to predict CBT of firefighters with thermal protective clothing [36].

The rectal probe is affordable. Rectal temperature can be measured by a non-specialist and is considered as the gold standard in studies [31] [33] [36]. However, the biggest issue is that it is invasive and uncomfortable to wear over a long time period. In a workplace, workers might refuse to wear the rectal probe while working.

The miniaturized radio-transmitter ("pill") is also accurate and reliable. It is designed to give real-time temperature every 0.5-2 min after ingestion. [32] However, it is also costly, and requires specialists to set up the devices as well as monitor the process. There is also a possibility that workers could be unwilling to swallow the pill.

External thermometers have the potential to estimate the CBT easily and cheaply, but more research needs to be done to validate the methods [31] [36]. Insulated skin temperature is as impractical to measure as rectal temperature and pill ingestion [33].

2.1.2.2 Tympanic Temperature

Tympanic temperature can be measured by a thermistor probe and an infrared-radiation-type tympanic thermometer. A study showed that both thermister probes and infrared detectors had good agreement with rectal temperature for car racers [37].

Although both measurements mentioned above showed good agreement with rectal temperature, the easier-to-measure aural canal temperature did not show similar results [38].

Further validation of tympanic measurement under different workplaces should be conducted. Compared to the aural canal, measurement of tympanic temperature requires more invasive devices. However, development of infrared detectors may provide a new future of core temperature measurement.

2.1.2.3 Heat Shock Protein 72

Heat illnesses are physiological responses of cells, tissues and the whole organism. Thus, a family of heat shock protein 72 (Hsp 72) can be a biomarker due to its rapid response to elevated body temperature. Many studies have shown correlations between heat stress and Hsp 72 release. Studies have shown that heat acclimatization could lead to elevated Hsp 72 level in peripheral blood mononuclear cells [39] [40]. This is consistent with another study on athletes with prior exertional heat illness not having reduced plasma Hsp 72 level during exercise [41]. One study further indicated that heat stress could lead to alteration of circulating metabolites in animals [42].

Hsp 72 has potential to be a biomarker of early diagnosis of heat stress. However, more study needs to be done to identify its role in the heat stress reaction and give a threshold quantitatively or qualitatively. The biomarker is expensive to measure.

2.1.2.4 Urine Specific Gravity

Urinary specific gravity (USG) is a measurement of the concentration of solutes in the urine and fluid intake. It measures the ratio of urine density to pure water density at the same temperature. The first urine void has been shown to best indicate hydration status. Studies have tested USG of athletes and workers, such as construction workers.[44] There is no study reporting any serious issues on sample collection and analysis procedures.

Urine specific gravity has been shown to be a reliable biomarker indicating dehydration status of the human body. It is non-invasive and easy and quick to collect samples [43] [44]. However, there is no clear relationship between dehydration and USG. Studies adopted different criteria defining hydration status by USG: 1.015 [43] [45] and 1.020 [45] [46]. Below the cut-off point is considered as well-hydrated, with pure water capacity of 1.000 as the reference.

2.1.2.5 Heart Rate

Heart rate (HR) could be a physiological biomarker of heat stress through two physiological phases: 1. Elevated oxygen replacement coupled with increased blood flow to the skin to dissipate heat could increase HR, 2. fluid loss though sweat evaporation also increases HR. A study has shown that there is a relationship between HR and rectal temperature [47].

A heat strain personal monitor with measurement of HR was tested. However, the results showed that the monitor underestimated the rectal temperature for both vapor permeable and vapor barrier encapsulating PPE suits [48]. This monitor provides a new option to measure heat stress, but further research and development is needed.

2.1.2.6 Metabolic Rate

Metabolic rate (MR) is hard to measure directly but is an essential factor to set WBGT thresholds. A combination of HR, body weight, and body fat could comprise an estimate of metabolic rate [49].

The study showed that predictors of HR increased the accuracy of MR estimation in terms of percent of HR reserve by taking into account the subject's fitness level, and net HR. The inclusion of body weight and body fat variables also increased the precision of estimation of MR [49].

2.2 Subjective Measurements

Previous studies have reviewed signs and symptoms of heat illness [50]. Signs and symptoms of heat cramp are elevated body temperature, thirst, muscle cramps, sweating, and tachycardia. Heat exhaustion has the same signs plus nausea/vomiting, headache, malaise/myalgias, hypotension, lightheadedness/syncope, oliguria, uncoordination, confusion, and irritability. Heat stroke has the previous ones plus anhydrosis, delirium/seizure/core, renal failure, hepatocellular necrosis, hyperventilation, pulmonary edema, arrhythmia, rhabdomyolysis, and shock.

Signs and symptoms of heat stress illness are clear to medical professionals. Some may be easily recognized by normal people with common sense, such as thirst, nausea, and shortness of breath. However, it might be hard for people with non-medical backgrounds to understand and recognize all of them. Education about the basic signs and symptoms is essential in the workplace especially with poor control methods. Signs and symptoms should be considered as alert screening rather than a measurement of heat stress due to the possibility of incorrect identification.

Table 2.1 summarizes the available methods of heat stress evaluation.

Table 2.1 Evaluation of Measurements

	Direct reading	Accuracy and reliability	Ease of use	Cost
WBGT with corresponding personal factors	Yes	High	Easy. Basic calculation.	~200 USD [51] for WBGT device
Heat Stress Index	No	Reduced accuracy	Not practical in workplace: Calculation heavy, measurement of radiant heat and convective heat exchange	Unable to estimate devices costs in a laboratory setting.
Predicted Heat Strain	No	ISO 7933 (2004) has been tested in large databases	Not practical in workplace: Calculation heavy, measurement of radiant heat and convective heat exchange	Unable to estimate devices costs in a laboratory setting.
Effective Temperature	No	Unable to measure radiant heat. Unable to measure personal factors.	Easy. Two types of scale tables.	~100 USD for dry bulb + wet bulb thermometers [52]
Corrective Effective Temperature	No	Unable to measure personal factors.	Easy. A scale table	Can be determined by WBGT device with globe temperature and dry wet bulb temperature readings.

Core Body Temperature	Yes	“gold standard”	Hard and impractical for workers Need specialists to measure both rectal temperature and gastrointestinal temperature.	~400 USD for a rectal probe thermometer. [53] More information is needed for miniature radio-transporter price.
Heat Stroke Protein 72	No	Conflicting research results	Requires blood and is invasive	Expensive
Urine Specific Gravity	No	High	Easy to collect urine sample, but hard to analyze outside laboratory.	10 USD per sample. [54]
Tympanic Temperature	Yes	Conflicting research results The method should be tested in different workplaces to be validated.	Invasive. The thermometer needs to contact the tympanic membrane.	50-250 USD. [55]
Heat Rate	Yes	The HR monitoring device underestimates the rectal temperature.	Easy to use.	More product information is needed to determine price.
Metabolic Rate	Yes	A reliable and accurate relationship between HR and MR.	This method is still under study.	More product information is needed to determine price.
Subjective Measurements	Yes	Early signs and symptoms resemble other illnesses.	Education on heat-related illness can be done by industries.	The price of hiring instructors need more information to determine.

3. HEAT STRESS PREVENTION AND TREATMENT

3.1 Heat stress prevention

3.1.1 Engineering controls

There are few references on the effectiveness of engineering controls, possibly due to low report rates of heat-related illness and lack of money/incentives for industries to install heat-eliminating equipment. Some engineering controls were summarized in Table 3.1.[23] [56] [57] [58]

Table 3.1 Engineering controls of heat stress

Environmental factor contributing to heat stress	Engineering controls reducing heat stress by the environmental factor
Air temperature	Install air-conditioners or evaporative coolers to lower air temperature
Humidity	Mechanical cooling of workplace
	Spot cooling of cool dehumidified air
	Air dehumification
Air flow	Increase air movement using fans in cases where the ambient temperature is no higher than the skin temperature Increase blower power on ventilation systems
Heat source	Isolate workers from indoor heat sources, for example by insulating plant, pipes and walls
	Remove heated air or steam from hot processes using local exhaust ventilation Provide radiant shielding

Installing engineering controls can be expensive and may not be applicable to certain industrial setting. In addition to industrial hygienists and safety specialists, mechanical and civil engineers need to get involved in the design process of engineering controls as well. Once established, engineering controls listed above should play a critical role in reducing environmental factors leading to heat stress among workers. With improper installation, it is possible that the engineering controls would fail and introduce new health and safety hazards, such as noise, ergonomic concerns, trip and falls, et al.

3.1.2 Administrative controls

3.1.2.2 Worker training

Studies showed that awareness of health impacts of working in the hot environment by both employers and employees helped lower heat-related illness among workers. [59] [60] [61] Workers with previous education of heat stress often keep hydrated compared to uneducated workers who usually experience “involuntary dehydration.”

Worker training does not require industry to spend much money compared to engineering controls. The key points of education should include signs and symptoms of heat illnesses, prevention methods, and the channel of reporting heat illness. To be an instructor, the person does not need high-level education. Instructors can be healthcare professionals, industrial hygienists, and safety specialists. Non-profit institutes like the UCLA Labor Occupational Safety and Health program also provide heat stress prevention classes.

3.1.2.4 Work-rest intervals

In a hot workplace, a repetitive work mode leads to the limit of tolerance faster and requires a longer recovery time while favorable heat balance can be maintained with a non-repetitive work mode in the same situation. Self-pacing should be encouraged in the hot workplace where no guideline of work-rest cycle exists. For workers conducting long time work with extreme workload, mandatory rest stops could ensure safety. [62] [63] [64]

Required rest and self-pacing may appear to be obstacles to industry productivity. However, with a proper work rate, a worker could make fewer mistakes and the rate of heat illness could be maintained at a low level. Other accidents related to fatigue and discomfort could be prevented as well. Altering work schedules so that work is done at cooler times is another related administrative strategy.

3.1.2.5 Acclimatization

Heat acclimatized workers have better performance in conducting endurance work. In a survey identifying risk factors of heat illness among British soldiers, the two risks with highest report rate were "acclimatization programme <7 days" and "no acclimatization programme" [65]. Long term aerobic exercise is the best way to reach heat acclimation by adjusting sweat rate, skin blood flow, fluid balance and cardiovascular stability [66]. However, a study also claimed that 4 days of low intensity work with protective clothing on could not improve workers' physiological responses while doing actual work in the same environment and protective clothing [67].

An acclimation program should be a part of new worker training. During the acclimation process, supervisors should conduct close obervation of workers. Workers with different health backgrounds may present different abilities to get acclimatized. However, effectiveness of the acclimation program can vary under more extreme work types. The longer the acclimation period, the more productivity loss of the industry.

3.1.2.6 Hydration

Ensuring enough water consumption by workers during work is very important. Temperature and flavor of beverage can impact how much water is consumed by workers [68]. A cool beverage (<22 °C) increases palatability, fluid consumption and hydration compared to an ambient temperature beverage (>22 °C) [63]. A study on underground miners showed that workers did not drink more water during lunch break than during work, which was opposite to the usual expectation that workers drank more water during breaks. This may due to limited break time. Also, workers with better awareness of health impacts of heat stress tend to drink more water than uneducated workers. When comparing the effects of ambient temperature beverages with chilled water, a study showed that both resulted in similar fluid consumption [69]. Hydration status can be directly and easily assessed by urinary specific gravity as discussed in the measurement section.

Studies have provided several alternatives of fluid for intake, which could be adopted by industries with different budgets. In order to keep workers hydrated, education of the importance of hydration should also be provided.

3.1.2.7 Supplements

Supplements have been under discussion in sports as to if these supplements could keep athletes free from heat stress. These include caffeine, protein, carbohydrates, creatine, glycerol, ephedra, Na^+, K+, and Ca^{2+}. Even though these supplements are widely believed to be effective, the evidence supports only some of them. In addition, athletes are different from other traditional working populations in fitness level, age, type of physical work, and health care monitoring frequency, it is irresponsible to apply same type and dose of supplements to general worker populations due to possible different physiological responses.

Caffeine serves as mild diuretic at rest, and a dose of 9 mg/kg caffeine increased core body temperature by 1 °C in a study with ten healthy males. [70]. However, there is no evidence shows that this dose altered heat balance or increased heat strain.

One literature review summarized that creatine increased body mass, but no evidence supported that this would lead to dehydration or heat-related illnesses [71].

Glycerol improves an athlete's body ability to retain fluid during aerobic activity. No evidence supports any "rumors" about Ephedra [72].

Supplementation of protein and glucose increases plasma volume which leads to better thermal adaptation of old men with or without hypertension [73].

Fluid-electrolytes loss during endurance exercise at hot temperature is countered by supplementation with fluid and electrolytes like Na^{+}, and Ca^{2+} in 6-hour or longer periods of treadmill exercise [74].

Although research has confirmed some physiological functions of supplements, care should be advised before generally recommending supplements to workers due to different exercise and health backgrounds from athletes

3.1.3 Personal protective equipment and clothing

3.1.3.1 Cooling vest

The cooling vest is the most popular protective clothing. Three types of cooling garments are currently used by industry workers and athletes: liquid cooled garment, phase changing garment, and ice garment. The liquid garment reduces heat stress by circulating cool water though the garment. The change of phase from solid to liquid gives the phase cooling materials the ability to absorb heat from the surrounding skin. The ice vest cools down the body by ice melting.

Studies show that the phase changing pack is effective in reducing skin temperature but less so for core body temperature. It is less effective than an ice vest, and loses its cooling effects more quickly. The cooling vest with circulating cold water can reduce heat stress, but is less effective than the chilled air cooling system. The limitation of a liquid cooling vest is that the design of the garment limits worker range of action. Ice vests worn by long distance runners before competition produced lower rectal temperature before and after exercise than athletes without vests. [75] [76] [77] [78] [79]

In general, cooling vests are effective in reducing overall heat accumulation along with heat perception. However, cooling vests also have limited cooling time and might also prohibit worker mobility. [80] [81]

3.1.3.2 Impermeable protective clothing

Though different types of impermeable protective clothing are available, all have long been recognized as contributing to heat stress. [82] [83] A military chemical suit shows similar physiological impacts to an industrial usage vapor barrier [84]. It generally adds 10 °C to the WBGT reading and could cause actual heat stress [85]. The US. Air Force underestimated work tolerance in a study testing maximal work ability of soldiers under chemical defense ensembles [86].

Potential cooling methods of workers wearing impermeable protective clothing during rest are cranial and neck cooling by liquid hoods, air, and ice cooling. [87] [79]

3.2 Heat stress treatments

Heat stress treatments are cooling methods after work in the hot environment. Medical providers in emergency departments and clinical settings have been developing and utilizing effective treatments for heat illnesses from mild to severe. Treatments for mild heat related illness, like heat rash, will be identified and discussed below. Treatments for severe and fatal heat illnesses will not be discussed considering the complexity and difficulty of methods. Healthcare professionals should be on-site and lead the treatments.

3.2.1 Body immersion in water

Water immersion is an effective way to reduce heat accumulation in both military and industry settings. Different types of water immersion have been tested. A study recording time for core temperature to drop to 37.5 ° C from 39.5 °C showed that cold water immersion was the best cooling technique, followed by room temperature water immersion, and air cooling [88]. Studies showed that cold water has a better body cooling effect in the first several minutes [89], but eventually both cold and warm water lowered body temperature to normal in a similar time of approximately 22 min with a cooling rate of approximately 0.22 °C/min [90]. Hot water immersion after exercise induced heat acclimation [91]. [92]

When whole-body immersion is not applicable, water immersion of the partial body is also effective in cooling. Hand/arm cooling for 10-18 minutes has better cooling effects than passive cooling [93]. Considering special restrictions and remote workplaces, a trap-assisted cold water immersion technique has also been tested to effectively reduce heat load [94]. [95] [96] [97]

Studies discussed above proved that water immersion can be an effective cooling technique in industry. Although options are available, such as water temperature and partial body immersion, the equipment requires space and could be time consuming. Also, cold-water immersion should be monitored by professionals considering a case study showed that an athlete experienced severe leg cramping after cold water immersion [98].

3.2.2 Other cooling methods

Ingestion of crushed/slurry ice has been proved to be a feasible, applicable, and affordable cooling method in the workplace. This cooling method requires an ice shaver and access to power. A study showed that ice slurry ingestion of athletes prolonged exercise time, decreased core body temperature during exercise, and increased core body temperature near exhaustion. A consumption rate of 4-5 ml/kg body weight is recommended during rest. However, some workers may be unwilling to do so due to personal habits. [96] [97] [99]

Whole body fanning after exercise showed a better effect than a phase-changing garment in a laboratory setting where subjects sat in front of a fan blowing ambient air on the whole body. This could be a technique for industry with limited budget that cannot afford air-conditioners, however, this technique also limits the available working area and can be difficult to provide air flow to a large number of workers at the same time. [100]

Chilled air of 15-20 °C showed cooling effects with or without encapsulating personal protective clothing. Though effective, air conditioners may not be affordable to some small business and need installation by professionals. [76]

Passive cooling should be a bottom line when all the above cooling methods are not present. It showed a cooling effect, but less effective than all the above methods. [79] [87] [95] [93] [94].

A summary evaluation of the above control methods is presented in Table 3.2.

Table 3.2 Evaluation of Control Methods.

	Cost	Ease of use	Effectiveness	New H&S hazards
Engineering Controls	High	Need engineers to design and install engineering controls. Once finalized, the controls should be easy to use.	Best control methods	Improper installation may introduce new hazards
Worker training -administrative	Price of instructors	Need employer support. Need instructors.	Educated workers tend to keep more hydrated than uneducated workers.	No
Work-rest interval -administrative	Rest should be paid. Industry productivity may be reduced with longer rest time, but workers make fewer mistakes and have low heat-related illness incidents.	Need employer support.	Workers with proper rest have lower heat stress incidents.	No
Acclimatization -administrative	Industry productivity may be reduced with longer rest time, but workers make fewer mistakes and have low heat-related illness incidents.	Need employer support.	Acclimatized workers are more resistant to hot workplace.	No
Hydration – personal protection and administrative	Bottled water.	Water should be accessible to employees.	Dehydration is a major factor leading to heat stress illness.	No
Supplements -administrative	Varied. Some are prescription drugs.	Follow instructions.	More research is needed to validate dose and response.	Possible unexpected physiological reactions.
Cooling vest – personal protection	<200 USD [101]	Easy to wear. Might not fit workers with other PPEs.	Cooling vest reduces heat accumulation.	Ergonomic concerns; may cause safety problems if too bulky
Heat stress treatment -administrative	Clinical/emergency service and may be expensive	Need healthcare professionals to provide treatments.	Medical treatment, not prevention.	Possible.

4. EXISTING STANDARDS/GUIDELINES

As shown in Table 4.1, the majority of the standards and guidelines share similar elements, such as title, scope and application, definitions, measurement, and control (includes health monitoring and training). Measurements can be further divided into two sections: subjective and objective. Subjective measurements are signs and symptoms of heat stress, and objective measurements could be measurement of temperature, humidity, radiation heat, clothing, workload, work-rest cycle, and acclimatization.

Standards and guidelines have different target audiences. The state of Minnesota, Japan, and ASHRAE have standards/guidelines for the indoor workplace; the states of California and of Washington have standards for the outdoor workplace, and the rest standards and guidelines cover both the indoor and outdoor environment. The following section discussed strengths and limitations of each standard.

4.1 Minnesota rules 5205.0110, subp. 2a: heat stress [102]

This standard adopted a combination of WBGT and workload to assess heat stress among indoor workers, and required training programs to provide education on heat stress protection and prevention.

In the standard's definition section, WBGT and its component factors, such as globe temperature and natural wet-bulb temperature, were defined with the basic application and calculation. Workload levels, such as heavy, moderate and light work, were defined by caloric expenditure and example activities. The standard adopted a combination of WGBT and workload as thresholds of heat stress. Each threshold should be measured in a 2-hour time weighted average. An assumption was that the thresholds apply to “fully clothed acclimatized workers.” The term was not explained in the definition section.

The standard was clear about the goal: employees should not be exposed to the indoor workplace with values above thresholds indicated in the measurements. However, the standard did not mention any controls that could be adopted to eliminate heat exposure if over the threshold. The only requirement was a training program referred to the 5206.0700 standard. Some essential elements in the training programs were name of the agent, exposure level restriction, acute/chronic effects, symptoms, emergency treatment, proper conditions, contact information of generators, and a written results copy with all prior information.

4.2 Chapter V Temperature and Humidity, Part III Health Standards, Ordinance on Industrial Safety and Health. Japan. [103]

This Japanese standard enphasized the importance of temperature, humidity and radiative heat to evaluate heat stress and gave example controls to eliminate heat stress in indoor workships and workshops in pits. The language was in English. Required measurements for an indoor workshop were temperature, humidity and radiative heat; and, for a workshop in a pit, temperature. However, there was no definitions of “an indoor workshop” and “a workshop in a pit,” nor exposure limits for businesses to follow.

The Japanese standard indicated specific control methods for various situations and environments, such as radiative heat, repair of heating furnaces, humidification and pit. Engineering control and administrative control methods were included.

4.3 ANSI/ASHARE Standard 55-2013. Thermal Environmental Conditions for Human Occupancy. United States. [104]

This guideline provided six measurement models to determine indoor operative temperatures with considerations of metabolic rate, clothing, air speed, humidity, and radiation. That is, this guideline is not only applicable to workplace but also resident buildings. The six models to determine thermal conditions were graphic comfort zone, analytical comfort zone, elevated air speed, local thermal discomfort, temperature variance with time and determining acceptable thermal conditions in controlled naturally conditioned spaces.

All models had very stringent criteria, usually with requirements of low metabolic rate, low clothing factors, and with or without cooling/heating system, to be able to apply to the site of human occupancy. None of the models could be used with workload over 2 met. The met is the rate at which the body expends energy relative to sitting at rest. One met is equal to 3.5 milliliters of oxygen per kilogram of body weight per minute and is also called the metabolic equivalent. According to an example with metabolic rates of various activities in the standard, most miscellaneous occupational activities, such as house cleaning, being seated, heavy limb movement, light and heavy machine work, handling 50 kg bag and pick and shovel work, required caloric expenditure over 2 met. Example activities in the occupational setting with metabolic rate below 2 met were cooking and office activities. This could raise a problem: this standard may not be applicable to most of the workers with middle and heavy workloads. Architects and civil engineers consult this standard in designing heating, ventilation and air conditioning (HVAC) systems and assessing thermal comfort in residential and office buildings.

4.4 ISO 7933: 2004. Ergonomics of the thermal environment: analytical determination and interpretation of heat stress using calculation of the predictable heat strain. European Community. [105]

Published in 2004, this ISO guideline was to evaluate thermal stress and determine the maximum exposure time for workers in the workplace. Unlike other standards and guidelines, this guideline served as a supporting document for validating measurements used in the ACGIH and possibly other standards/guidelines. Data and calculations were provided for the thermal balance computation and exposure time estimation.

The heat balance equation includes metabolic rate; effective mechanical power; heat exchange in the respiratory tract by convection and evaporation; heat exchange from the skin by conduction, convection, radiation and evaporation; and body accumulated heat storage. A worker would experience- heat stress if the heat load caused by activity is larger than the total amount of heat exchange.

In annex C, the guideline adopted methods for metabolic rate determination from ISO 8996. ACGIH adopted and further simplified table C.1 – classification fo metabolic rate for kinds of activities. That is, a person could classify levels of workload by average metabolic rate and example activities. The other two methods were metabolic rate as a function of area of body involved and the intensity of the work with that part of the body, and metabolic rates for specific activities that are inconsistent with ANSI/ASHRAE 55.

No control methods were provided in this guideline. This method though accurate may not be practical or feasible in the workplace due to confidentiality and the very complex measurement methods.

4.5 Heat and cold. Managing the work environment and facilities. Code of practice. Australia. [106]

This Australian standard provided several heat stress controls, but no heat stress exposure limit. Although applicable to both indoor and outdoor occupations, the only quantitative limits mentioned in the standard was the optimum comfort temperaeture (68°F - 78.8°F) for sedentary work. No other environmental or personal factors were mentioned in the standard to set exposure limits. This could lead to a gray area where employers refuse to control or eliminate heat stress exposure due to unclear exposure limits.

The standard did provide 11 control methods that could be used as example control techniques under job specific controls:

- “increase air movement using fans;
- Install air-conditioners or evaporative coolers to lower air temperature;
- Isolate workers from indoor heat sources. For example by insulating plant, pipes and walls;
- Remove heated air or steam from hot processes using local exhaust ventilation;
- Use mechanical aids to assist in carrying out manual tasks;
- Alter work schedules so that work is done at cooler times.

4.6 2016 ACGIH TLVs and BEIs. Heat stress and heat strain. United States [107]

ACGIH heat stress and heat strain might be the most applicable and accurate guideline to be followed by a government agency. Under the goal of maintaining body core temperature within ±1°C of normal (37°C) for the average healthy worker, ACGIH adopted a comprehensive measurement process to determine heat stress with thermal environmental factors (temperature, humidity, and radiative heat) and personal factors (clothing, work-rest schedule, workload, and acclimatization). Proper controls under each situation were also listed after the measurement.

Clothing adjustment factors were listed in the standard. The heavier the clothing ensemble is, the greater the clothing adjustment factor is. The exposure limit is the result of a WBGT value minus the clothing factor. For example, work clothes with long sleeve shirts and pants were typical clothing used to measure heat stress originally, thus these have a coresponding clothing adjustment of 0°C. On the other hand, limited-use vapor-barrier coveralls had a factor of 11°C that is subtracted from the WBGT TLV temperature in °C at a given physical activity.

Workload could be determined by metabolic rate level and specific activities in the third table in the standard, consistent also with ISO 7933:2004. Values under TLV thresholds can be applied to acclimatized workers and an "action limit" applied to unacclimatized workers that ranges froom 2.5 to 3.5 °C lower than the TLV depending on physical activity level.

For a specific work-rest cycle, acclimatization and workload, the WBGT TLV can be determined in the second table in the guideline.

For example, if an acclimatized worker whose job requires sitting is involved in light manual work with the hands for 45 min every hour and wearing double layer woven clothing, the workload is light, the work-rest schedule is 75%, and the clothing factor is 3°C. Thus, a WBGT TLV value of 31°C can be located. Considering the worker has a clothing adjustment factor, the actual exposure limit TLV should be 28°C in WBGT (31°C - 3°C = 28°C).

Instead of measurement of net heat load with consideration of environmental factors and personal factors, the other method is to determine the overall personal physiological response of workers. Personal monitoring threshouolds of heat strain were also listed, including heart rate

(180 minus age in years beats per min), core body temperature (38.5^{o}C for acclimatized workers; 38.0^{o}C for unacclimatized ones), recovery heart rate (>120 beats per minute one minute after a peak work effort), symptoms(sudden fatigue, nausea, dizziness, or lightheadeness), profuse sweating over hours, weight loss over a dhift is greater than 1.5% of body weight, and urinary sodium excretion (<50 mmoles in 24 hours).

The ultimate goal of the program is to stop heat stroke where core body temperature exceeds 40^{o}C and is life-threatening. Fetal death has been known to occur after sustained core temperatures greater than 39^{o}C during the first trimesterof pregnancy.

Control methods were divided into general and job specific controls. General controls included training/monitoring program, water consumption, water intake, resporting process, self-limitation of exposure, buddy system, counsel and monitor people on drugs, and medical screening tests.

Job specific controls were more about goals rather than techniques and measures could be directly followed by businesses. Although engineering controls, administrative controls and personal protective clothing were pointed out, details like how to provide air movement or to reduce process heat were not specified. By borrowing the control methods in the Australian standard to support the job specific controls, this section in the guideline may be improved.

Several Canadian provinces have adopted part or all of the ACGIH guidelines.

4.7 NIOSH Criteria for a Recommanded Standard. United States [108]

Similar to the ACGIH Heat Stress and Strain guideline, the NIOSH guideline set recommaended heat stress alert limits (RALs) and recommended heat stress exposure limits (RELs) by taking workload, work-rest schedule, and environmental heat into account. Clothing adjustment factors were not mentioned. The Recommended Alert Limit (RAL) values were applicable to unacclimatized workers, and recommended exposure limits (RELs) were applied for acclimatized workers. The NIOSH standard adopted a Cartesian coordinate system with X axis as workload and Y axis as WBGT tempreture, this differing from the ACGIH method. The thresholds in both guidelines were consistant with each other, excluding the clothing adjustment factor.

Control methods were listed in categories of engineering control, administrative controls and PPE. Engineering controls were separated into body heat production of task, radiative load, convection load, and maximum ~~e~~evaporative cooling by sweating. However, similar to ACGIH guideline, the NIOSH guideline did not give sample techniques, such as how to reduce air temperature. Administrative controls included acclimatization, work schedule, hydration, rest and recovery, extreme heat event, and other considerations (e.g. worker medical evaluation). PPEs were conditioned clothing, reflective clothing and aprons.

4.8 Guidelines for heat stress at work. United Arab Emirates [109]

This is an enforceable standard in Dubai, United Arab Emirates despite the word “guideline” in the title. The standard had no scope and application definition, or heat stress measurement, and its controls were simple: water, rest, PPE, acclimatization and medical facility referral..

The standard provides signs and symptoms, and treatment of heat illnesses. Heat cramps, heat exhaustion, and heat stroke were also listed. This makes the standard more applicable to heat illness recognition and treatment rather than heat stress prevention. Accumulated heat stress could lead to heat illness. Recognition of illness and treatment is supposed to be the last step in the worker protection chain. The only situation in which such a standard should be applied is an a occupational workplace with severe heat exposure and very little funding/effort to adopt control methods.

4.9 Guideline of heat illness prevention and temperature reduction. China [110]

This is a enforceable standard issued by the State Administration of Work Safety in China. The standard is in Chinese and was translated into English by the author. The standard is short and focused on controls. Required measurements are referred to a standard called occupational exposure limits for hazardous agents in the workplace. Measurements took into account WBGT, workload and work-rest schedule. Controls include engineering controls, such as heat reduction from sources and facility design, and administrative controls~~,~~ such as medical monitoring, special consideration of children and pregnant women, rest, hydration, training, and emergency plan. Two special controls worth discussing were: special consideration of children and preg~~a~~nant women, and worker unions having the right to add heat stress prevention in the worker contract. Children and preg~~a~~nant women are two vulnerable populations that none of other standards or guidelines mention. Giving worker unions the right to modify worker contract is also unique. Though some unions in the US. are adding preventative methods to worker contracts, this action would be easier if mandated by the government.

4.10 3395 Heat illness prevention. California, United States. [111]

This is the Cal/OSHA's outdoor heat illness prevention standard. It applies to all outdoor places of employment with emphasis–on industries with high-heat procedures. This California standard took temperature alone into account and set 80°F and 95°F as action level and exposure limit, respectively. Control methods were hydration, rest, shade, emergency response, training program and "high-heat procedures". The last term was unique, with no other standard/guideline separating industries with high-heat procedure or not as a criterion since all industries could be measured and controlled in the same system, such as for the ACGIH and NIOSH guidelines.

4.11 WAC 296-307-097 and WAC 296-62-095 Outdoor heat exposure.Washington State, United States [112] [113]

Both standards were issued by the state of Washington in 2008 and 2009 under its general occupational standard and safety standards for agriculture separate~~l~~y. These two standards are discussed together because both standards have similar measurements and controls. The measurement took into account temperature and clothing., However exposure limits were generated from regional data, and were indicated as not applicable to other states.

Control methods include training, self-monitoring, emergency response and water. By putting employee self-monitor~~o~~ing into the standard, employees are legally responsible for their own health and safety. This could help workers understand the heat stress standard and increase workers' involvement in compliance. However, this standard did not mention shade and rest as control methods.

4.12 WAC 296-305-05004 Occupational exposure to heat and cold stress. Washington State, United States [114]

This is a firefighter's safety standard regarding heat exposure in the state of Washington. The measurement in the standard is consistent with 296-307-097 and 296-62-095 Outdoor heat exposure with combination of ambient temperature and clothing. The controls for firefighters are very different from other occupations. The standard included written guidelines of rehabilitation, employee~~ss~~ and supervisor training, rotation of rehabilitation, the department's operational guideline, rehabilitation area, and medical monitoring. The standard used NFPA 1584 as reference. National Fire Protection Association (NFPA) standards are recommended guideliens specific for firefighters. The Los Angeles City Fire Department use NFPA guidelines for their major activities and training sessions.

Table 4.1 summarizes the major features of the existing standards and guidelines for heat stress.

Table 4.1 Current State and National Heat Stress Standards and Guidelines

Source	Standard/ guideline	Indoor/ outdoor	Year established	What workers are covered?	Objective measures	Subjective measures	Control methods
ACGIH	Guideline	Outdoor & indoor	1974	Any workers exposed to heat stress	Heat stress is measured with combination of 1. WBGT* (temperature, air movement and humidity). 2. Clothing 3. Work-rest schedule 4. Workload 5. Acclimatization Threshold temperature range: 75.6-90.2°F with work clothes.	Signs and symptoms of heat strain	1. General controls 2. Job-specific controls a) Engineering b) Administrative c) PPE *Note: more detailed controls in the guideline.*
NIOSH	Guideline	Outdoor & indoor	1986	Any workers exposed to heat stress ("Worker exposure to heat stress in the workplace")	Heat stress is measured with combination of 1. WBGT* (temperature, air movement and humidity) 2. Work-rest schedule 3. Workload 4. Acclimatization Threshold temperature range: same as ACGIH.	None	1. Engineering 2. Administrative 3. PPE *Note: more detailed controls in the guideline.*
MN, US	Standard	Indoor	2014	Any workers exposed to "indoor environmental heat conditions"	Heat stress is measured with combination of 1. WBGT* (temperature, air movement and humidity) 2. Workload Threshold temperature range: 77-86°F.	None	1. Control indoor temperatures to below thresholds 2. Training

Japan	Standard	Indoor	2005	Any workers exposed to indoor heat stress and heat stress in underground workplaces ("Indoor workshop" and "workshop in pit")	Heat stress is measured (separately) by 1. Temperature 2. Humidity 3. Radiative heat No threshold provided.	None	Separate controls required for 1. Radiation heat 2. Repair of heated furnaces 3. Humidification
Australia	Standard	Outdoor & indoor	2011	Any workers exposed to heat stress ("Workers carrying out work in extreme heat or cold")	Heat stress is measured by temperature for sedentary work Optimum temperature: 20-26°C (68-78.8°F).	None	1. General controls 2. Job-specific controls *Note: more detailed controls in the standard.*
Dubai, United Arab Emirates	Standard	Outdoor & indoor	2010	Any workers exposed to heat stress	No measurement.	Symptoms of heat illness	1. Water 2. Rest 3. PPE 4. Acclimatization 5. Fitness 6. Medical facility
China	Standard	Outdoor & indoor	2012	Any workers exposed to heat stress	Heat stress is measured with combination of 1. WBGT* (temperature, air movement and humidity) 2. Workload 3. Work-rest schedule Threshold temperature range: 25-33°C (77-91.4°F)	Symptom of heat illnesses	Unique controls for worker subgroups: 1. Pregnant and young workers not allowed to work in certain environments 2. Work unions provide contract

							between workers and industries *Note: more detailed controls in the standard.*
CA, US	Standard	Outdoor	2005	Any workers exposed to outdoor stress (Standard refers specifically to "All outdoor places of employment" and "Industries with high-heat procedures")	Heat stress is measured by 1. Temperature Threshold temperatures: 80 & 95°F (separate measures required at each threshold).	Subjective feeling; Symptoms of heat illnesses	1. Heat illness prevention plan 2. Administrative (water, shade, rest breaks, shade structures) 3. High-heat procedures 4. Acclimatization 5. Training
WA, US	Standard	Outdoor	2008	"All employers with employees performing work in an outdoor environment"	Heat stress is measured with combination of 1. Temperature 2. Clothing Threshold temperature range: 52 & 89°F.	None	1. Outdoor heat exposure safety program 2. Drinking water 3. Responding to signs and symptom of heat related illness 4. Information and training

5. DISCUSSION

Cal/OSHA has held two advisory meetings on Heat Illness Prevention in Indoor Places of Employment as of June, 2017 [1]. In this section, the author discussed the second revision of Cal/OSHA's draft standard and recommended a standard based on this literature review and.

5.1 Scope and application

The standard should apply to all indoor workplaces. Cal/OSHA proposes a trigger value of 85°F dry bulb temperature, which changed from 80°F in the first draft standard. Although no evidence supports any trigger temperature, several obvious limitations of setting a dry bulb threshold temperature of 85°F are: 1. Dry bulb temperature of 80°F was not consistent with the required Heat Index measurement in the standard; 2. working in an indoor place of 85°F has been perceived to be hot for most union representatives and workers; 3. the Cal-OSHA outdoor heat prevention standard adopted 80°F as the trigger value for shade. Thus in the second advisory meeting, union representatives and workers in the most impacted industries, such as warehouses and garment factories, recommended a trigger value of Heat Index 80°F. Heat index was used to be consistent with the measurement section in the second draft standard.

5.2 Terms used in the CAL-OSHA draft standard

Acclimatization, cool-down area, dry-bulb temperature, environmental risk factors for heat illness, globe temperature, heat illness, heat index, heat wave, high-radiant heat work area, indoor, personal risk factors for heat illness, preventative cool-down rest, and radiant heat were defined in the second draft. Among them, heat index (HI) was divided into three levels, and each level was assigned with different control methods from least to the complete control hierarchy. In the literature review, the author found no journal articles adopting HI as the indoor heat stress measurement. Since the national weather service applies the heat index in an outdoor environment, it is unknown if the HI also applies to an indoor environment when air flow and radiation sources are different from outdoor places.

5.3 Assessment of heat illness risk

WBGT is the most accurate, precise, and applicable measurement compared to other heat stress indices, such as HSI, PHS, ET, and CET. Studies have proven the accuracy of WBGT values with corresponding personal factors, such as clothing, workload, and rest schedule. The first Cal/OSHA draft standard simplified and adopted the ACGIH WBGT measurement, but later changed to a heat index due to the complexity of following ACGIH recommendations, and the reality that WBGT devices may not be affordable by many small businesses.

One big issue about measuring heat index in indoor settings is the uncertainty of the relationship between HI and actual heat stress. Though one study gave a correlation between HI and WBGT [2], HI still could not account for personal factors.

5.4 Control

All alternatives discussed in the control section should be implemented in the indoor workplace to prevent heat stress. In the Cal/OSHA second draft, rest and hydration, acclimation, training, record keeping, and emergency response were included. However, engineering and administrative controls were required only by level III: workplace with

HI > 100°F for general industry and HI> 95°F for high radiant industry. According to the control hierarchy, engineering control should always be considered before administrative controls and PPE. The same control methods should apply to all workplaces with HI over the threshold. The emergency response section should refer to the Cal/OSHA outdoor standard, so that the responsibilities and instructions for employers and supervisors are clear.

5.5 Conclusions

The three sections of this literature review summarized and evaluated measurements and control methods from the scientific database, and indoor heat stress standards and guidelines from a legislation perspective. Similar subdivisions of heat stress standards are scope and application, definition, measurements, and control methods (hierarchy of control, training, rest, hydration, and emergency response). The most impacted industries were not apparent through the literature review, however. Some impacted workers attending the Cal/OSHA advisory meeting were warehouse workers, garment workers, restaurant workers, hospitality workers, and drivers. Industries under indoor heat stress study are cooks, manufacturing workers, miners, mixed manual workers, and steel workers [1].

An effective heat stress measurement should be timely, accurate, reliable, easy to use, affordable and enforceable. ACGIH recommended WBGT measurement is of great advance by its ability to measure both environmental and personal factors. An effective heat stress control method is an engineering control, which is affordable, easy to use, practical, and able to reduce heat stress while not introducing new health and safety hazards. Administrative controls, such as training, work-rest schedule, hydration, and acclimatization, are bottom lines if engineering controls are not feasible. Personal protective equipment controls are less effective. For example, cooling vest is effective in preventing heat accumulation, but may not fit other bulky personal protective clothing.

A Cal/OSHA standard is feasible because the scientific database is adequate. Weather it is practical depends on cost, ease of field management, stake-holder buy-in, and factors outside of the scientific arena.

5.6 Recommendations for future studies

Future studies should focus on the cost-benefits of measurement and control methods. A method can be effectively used when it has been proven to be effective in both laboratory and industrial settings. Most methods are effective in a controlled environment, but not in a workplace. Effectiveness evaluation of existing standards should also be studied. Sociological characteristics, such as demographics of working populations and economic status can impact how enforceable a standard is. Implementation of standards is another variable often susceptible to the current political climate. Impacted industries should also be identified and studied, so a standard can be tailor on these industries.

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