



Understanding occupational heat exposure in the United States and proposing a quantifying stress index

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Received: 7 December 2020 / Accepted: 9 April 2021 / Published online: 25 May 2021
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Abstract

Purpose Millions of workers exposed to the outdoor environment are extremely susceptible to extreme heat. Although several articles analyzed heat-related illnesses, injuries, fatalities at the country level, few investigated regional and state statistics especially for OSHA Region 4 and the state of Alabama, U.S, which we explored in this study.

Methods We studied the number of heat-days over 90 °F (32.2 °C) heat-index within our study area, analyzed heat-related injury and illnesses to calculate their incidence rate during 2015 to 2019, observed the nature of such incidents, their monthly occurrence, and incidence trend over average air temperature. We conducted a comparative analysis of heat-related fatalities between construction and all industries. The existing heat regulations by OSHA and some state agencies have also been summarized.

Results We observed the highest mean, maximum heat-days and injury-illness rate in the south and southeast part of Region 4; increase in incidence rate from 0.03 in 2017 to 0.28 per 10,000 employees in 2018 for the contiguous U.S; highest injury-illness rate (HIR) in OSHA Region 1, 4 and 6; highest HIR in Lee, Montgomery, Mobile and Madison counties of Alabama; 34.7% (construction) and 31.3% (all industries) of all cases experiencing nonclassifiable heat-light effects; high fatalities in construction industry with a trend of 1 death/5 years; increased mortality in all occupations with 1 death/2.4 years. We also proposed a Heat-Stress Index (HSI) as a routine heat-stress measure on jobsite.

Conclusion The findings from this research and the proposed index can help in understanding heat-related risk at a regional level and implementing workplace interventions.

Keywords Extreme heat days · Heat Index · Heat-stress · Occupational exposure · Risk assessment

Introduction

Exposure to extreme heat poses a significant occupational hazard with a matter of life and death for laborers working in outdoor environments for long hours (Lucas et al. 2014; Lundgren et al. 2013). Extreme heat refers to a hot weather condition exceeding the usual average temperature considered for a certain location and time, which also varies with other weather parameters including cloud coverage and relative humidity (CDC 2021). A high humid condition limits our ability of evaporative cooling that can exacerbate our heat perception. People living in a humid region can experience heat stress related symptoms or illnesses at a temperature below 90 °F (32.2 °C) (Tustin et al. 2018), while dry weather with a high temperature can create an extreme heat condition. The metabolic rate, type of physical activity and clothing of the workers can control their susceptibility to heat stress when the body fails to dissipate heat and

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maintain normal body temperature (98.6 °F (37 °C)) during a heatwave (Cheshire 2016; Lucas et al. 2014; Tustin et al. 2018). These conditions can lead to several heat-related injury or illnesses (HRI) such as heat stroke, heat exhaustion, muscle cramping, and dehydration in the work environment (Gerrard 2020). The level of a worker's physical activity is equally important and should be considered, rather than the work-hours alone while defining an occupational heat-exposure limit (OEL). Additionally, heat exposure has become a concerning matter for human health due to global warming (Fahad et al. 2018; Sabrin et al. 2020), especially for the outdoor workers. On average, excessive heat causes 650 deaths in the U.S. every year (NOAA 2018). Each year, many workers die and become ill working under warm and humid conditions resulting in 49 jobsite fatalities in 2018, which is 2.72 times higher than the occurrence in 2014 (OSHA 2021; BLS and U.S. Department of Labor 2014, 2018). According to data collected by the federal government, exposure to extreme heat killed 783 U.S. workers and seriously injured 69,374 workers from 1992 to 2016 (Public Citizen 2018).

The Occupational Safety and Health Administration (OSHA) does not provide an enforceable permissible exposure limit for heat stress to be followed strictly by all employers. Instead, it relies on the General Duty Clause (GDC), Sect. 5(a)(1) of the Occupational Safety and Health Act. According to the GDC, 'Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees' (OSHA 1970). OSHA cites employers for any heat-related hazards under this clause, which itself is very broad, since it does not state a specific standard to follow. OSHA suggests some precautions categorized in four risk levels (i.e., lower, moderate, high, and very high to extreme) respectively corresponding with the Heat Index (HI) of < 91 °F (32.8 °C), 91 °F to 103 °F (32.8 °C to 39.4 °C), 103 °F to 115 °F (39.4 °C to 46.1 °C), and > 115 °F (46.1 °C), which do not account important factors such as air movement, direct sun, physical activities and clothing types (Tustin et al. 2018; OSHA 2016). Many researchers use a HI index to understand the perceived heat, which is a combined measure of relative humidity and air temperature. However, after reviewing 79 work-heat-related fatalities, a recent study indicated that 5% of heat-related fatalities occurred at temperatures considered as low HI, and an additional 20% occurred on the lowest "Caution" level (Roelofs 2018). Moreover, 6 of 14 deaths studied in a Centers for Disease Control and Prevention (CDC) report occurred with the HI less than 91 °F (32.8 °C) and additional evidence supports the possibility of serious illness when the HI is less than 91 °F (32.8 °C) (Tustin et al. 2018). 14% of moderate to severe HRI at a U.S. military training installation (Armed

Forces Health Surveillance Center 2011) and at least 25% of HRI in Washington agriculture and forestry workers (Spector et al. 2014) happened when the HI was less than 90 °F (32.2 °C). Some reported hospitalizations in OSHA's Severe Injury Reports Database (OSHA 2017) have been associated with a HI < 280 °F (26.7 °C). Employers often fail to provide protections for heat-stress due to confusion, ignorance, or carelessness about their responsibilities towards employees. Few states including California, Minnesota and Washington have started implementing occupational heat-related regulations by providing heat protection for the outdoor workers (California Code of Regulations 2005; Gubernot et al. 2014). However, improving the existing federal and state level heat-related regulations has become essential, since the OEL limit for heat-exposure will greatly vary in regions or even industries depending on the climate pattern, physical condition of the workers, type of works, and workhours. An operational standard in response to heat-stress is in dire need to be developed to protect workers from excessive heat. In addition, understanding the existing risk at a state, county, and local levels is necessary to enforce any standard and limit workers heat exposure at work. Further studies are required to recognize the risks of environmental heat and build a quantitative risk index system as a measure of heat-stress.

The objective of this paper is to: (1) explore heat-related impacts at the state and county level due to occupational exposure, (2) further categorize associated risks experienced by construction workers in comparison to all other industries and (3) propose a suitable index for outdoor workers to detect their heat-related vulnerability before any hazard or accident is triggered due to excessive environmental heat.

Literature review

The global land-ocean temperature index shows a warming trend with a recent spike, whereby 18 out of 19 warmest years on record have occurred since 2001 (NASA 2019). The risk of heat-related mortalities and morbidities has been evidently associated with the rising trend in recent heat events (Sarofim et al. 2016; Lundgren et al. 2013). In the U.S., more deaths have been caused by extreme-heat events than other weather-related exposures (CDC 2019). The Fourth National Climate Assessment (NCA4) forecasts that the average number of heat days will significantly increase across the continent of North America by 2050 and almost all National Climate Assessment (NCA) regions are projected to experience 20–30 more days per year over 89.6 °F (32 °C) and 40–50 more hot days in most of the southeast region by 2050 under RCP8.5 (Representative Concentration Pathway) climate scenario (Vose et al. 2017). A recent study by Dahl et al. (2019) showed that the annual number of days over 100 °F (37.8 °C)

will increase in double and days over 105 °F (40.6 °C) will triple by 2100.

Construction workers in the southern U.S., Latin America, Middle East, Africa, and Asia are frequently subjected to high temperatures for longer hours with limited or no access to drinking water or shade (Xiang et al. 2013). Mostly, roofers and road workers in the U.S. are 13 times more vulnerable in comparison to other industry workers (Bonauto et al. 2007; Calvert et al. 2013; Gubernot et al. 2015). Heavy workloads, unmonitored small businesses, and limited healthcare resources for immigrant workers, further exacerbate workers' HRI vulnerability (Acharya et al. 2018). Construction workers in 133 U.S. cities have been predicted to encounter 35.3 million hot worker-days in 2000 soaring to 76.4 million in 2030, and 95.1 million in 2050. In addition, more than 698,000 construction workers will be working for at least 30 extreme heat days (> 104 °F (40 °C)) a year by 2030 and 872,000 workers by 2050 (Fig. 1) (Public Citizen 2018). Since outdoor workers are more susceptible towards environmental heat, it is important to understand how the health conditions of the workers can remain safe during such extreme events and how to detect any vulnerability leading to fatal health hazards.

Papers regarding occupational exposure to environmental heat have studied topics such as HRI (Bonauto et al. 2007), work-related injuries and fatality rates (Xiang et al. 2013; Petitti et al. 2013; Gubernot et al. 2015), cardiac parameters (Sett and Sahu 2014), perceived risk of excessive heat (Lin and Chan 2009), measuring exposure risk with personal sampling (Wang et al. 2019), heat tolerance time (Yi and Chan 2013), and recovery time in terms of Physiological Strain Index (Chan et al. 2012). Most studies in the U.S. analyzed in the context of country level, while very few

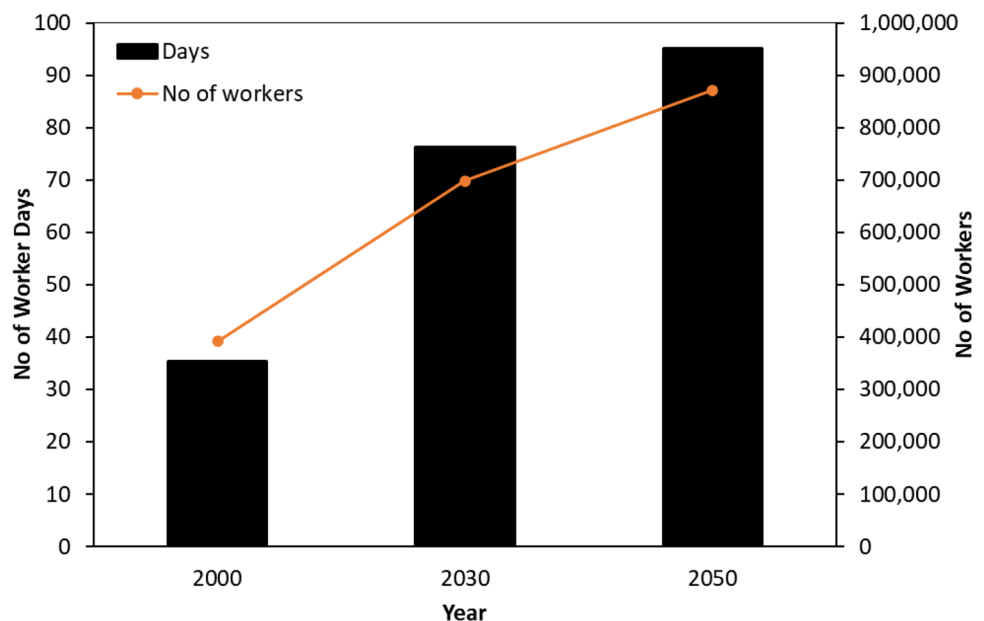
focused on the state, regional, or local level analysis and performed a comparative analysis between construction and all other industries (Bonauto et al. 2007; Crider et al. 2014; Gubernot et al. 2015). Moreover, current occupational health and safety protocols regarding heat exposure lack in efficient measures to protect workers in the extreme summertime temperature, which make this topic a significant one to explore.

Data analysis and observations

Historical heat days in the OSHA Region 4 and the state of Alabama

Spatiotemporal distribution of extreme heat days has been observed for the states included in the OSHA region 4 and the state of Alabama. Since the OSHA Region 4 typically contains high humidity, we have used a threshold of 90 °F (32.2 °C) HI to identify the extreme heat days. The HI index chart provided by the NOAA (National Ocean and Atmospheric Administration) National Weather Service (2016) labels HI values higher than 90 °F (32.2 °C) with 'Extreme caution'. CDC also starts measuring the number of extreme heat days from a 90 °F (32.2 °C) HI threshold. The number of heat days over 90 °F (32.2 °C) HI in the domain of Region 4 was collected from the CDC (CDC 2021). CDC obtained this data from the North American Land Data Assimilation System (NLDA) to measure daily temperature for the period of 1979–2016 and specifically for the warm season (May to September) which mostly captures all heat events across the U.S.

Fig. 1 Number of dangerous heat days for construction workers (in millions of workers-days) and the number of construction workers spending 30 days or more a year in dangerous heat in 133 U.S. cities (Public Citizen 2018)



Moreover, the annual employee numbers and number of severe injuries and illnesses in the work environment due to exposure to environmental heat were collected for 2015 to 2019 to calculate incidence rates along with the mean weekly work hours collected from 2018 five years estimates by the American Community Survey (ACS). The data on the number of annual employments aggregated by all industries and all U.S. counties were collected from the United States Bureau of Labor Statistics (U.S. BLS). Severe injuries and illnesses data provided by the OSHA includes incidents reported by all industries (OSHA 2020). This dataset consists of the reportable severe occupational illnesses and injuries within the federal OSHA jurisdiction, that resulted in in-patient hospitalization, amputation or loss of eye. Since the region of our interest generally falls within a warm climate, we chose to use annual data on employments without accounting for seasonality. Annual heat-related injury or illness rate (*HIR*) was calculated for 2015 to 2019 using Eq. (1), where *N*, *E* and *H* represent the number of heat-related injuries and illnesses per year (*N*), annual employee numbers per county (*E*), and the mean weekly workhours (*H*), respectively. A general equation of

computing incidence rates provided by the U.S. BLS uses 200,000 h, which is based on 100 full-time workers working 40 h/week and 50 weeks/year (BLS 2019). Our *HIR* equation is designed for measuring incidence rate per 10,000 full-time employees to avoid estimating very small incidence rate due to counting only heat-related injuries and illnesses. Number ‘2,500,000’ in the equation comes from calculating total hours (10,000*40 h/week*50 weeks/year) for 10,000 full-time workers, diving it by (4*12) from the total hours worked by all employee per county (*E***H**4 weeks/month *12 months/year) and converting to a rounded figure by multiplying with 6.

$$\text{Heat-related Injury or Illness Rate, HIR} = \frac{N}{6 * E * H} * 2,500,000 \tag{1}$$

Mean *HIR* was calculated using the annual *HIR* estimates from 2015 to 2019. Figure 2 shows measured mean, maximum, minimum heat days per each year, the rate of change per year in the number of heat days over the period of 1979–2016 and the mean heat-stress incidence rate during 2015–2019. *HIR* rates were estimated using the incidence

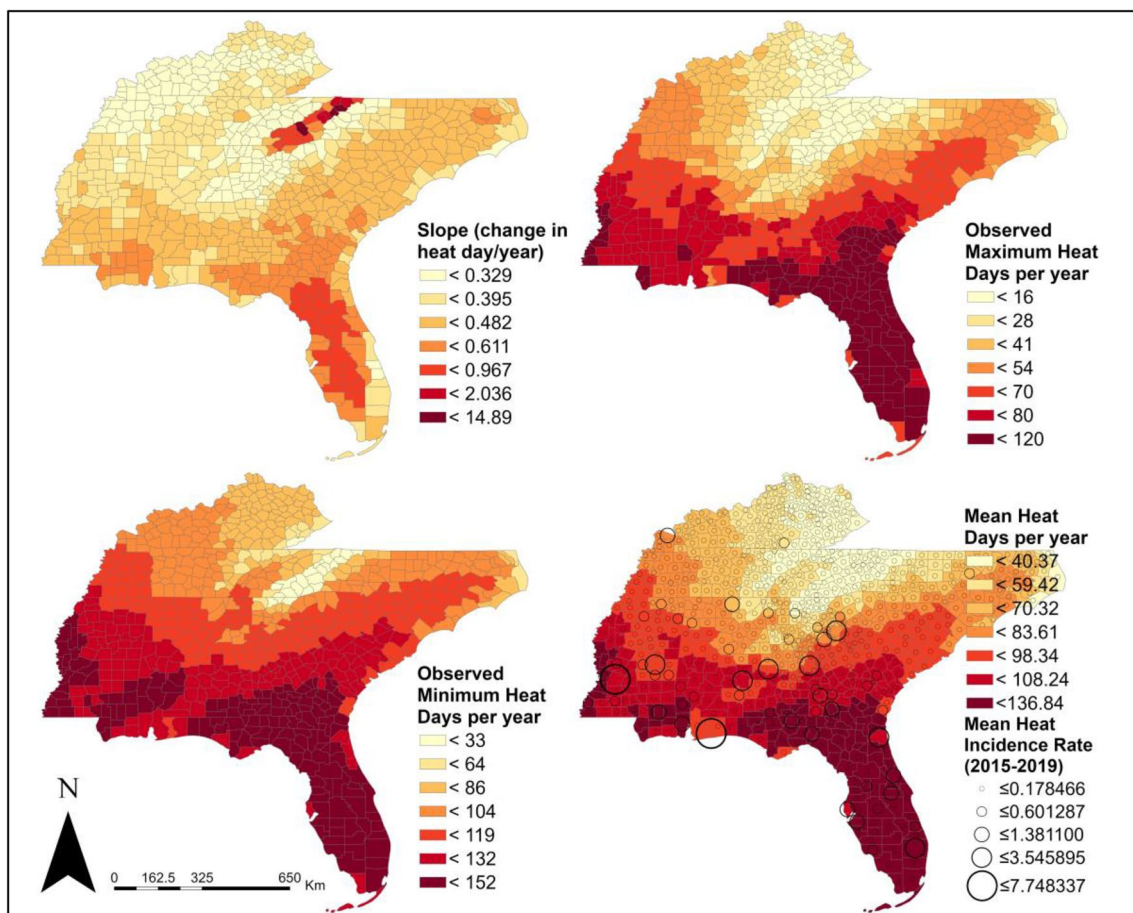


Fig. 2 Measured mean, maximum, and minimum heat days over 90 °F (32.2 °C) HI during 1979–2016 in the OSHA Region 4

numbers aggregated at the county level. It is observed that the south and southeast part of Region 4 (i.e., Mississippi, Alabama, Georgia, Florida, South Carolina) have mostly experienced the highest average and maximum number of heat days per year. Florida experienced the highest minimum number of heat days per year during 38 years study period. The increasing rate of the number of heat days per year, is noticed to be higher in the states of Georgia and Florida. Moreover, the mean *HIR* estimates for the last 5 year (2015–2019) seem to correlate with the mean heat day per year in terms of HI threshold.

Additionally, we explored how Alabama experienced heat events over 38 years' time span during 1979 to 2016. Figure 3 shows spatial distributions of the number of days exceeding 90 °F (32.2 °C) HI in Alabama for 2009 to 2016 as sample maps. It is observed that mostly the counties in the southern region of the state experienced a higher number of hot days. During this timeframe, Geneva county of Alabama experienced the highest with 110.1 average days per year crossing over the HI threshold and DeKalb county of Alabama with the lowest average number of heat days (46.9 days), which are marked in Fig. 3 with blue boundaries accordingly. The majority of the hottest years occurred after 2000. It was observed that 2010 was the warmest year in terms of 90 °F (32.2 °C) HI threshold with a maximum of 139 days in Houston county of Alabama and a minimum of 95 days exceeding 90 °F (32.2 °C) HI in DeKalb county of Alabama. However, 2013 appeared to be a moderately cool year since 2000 with a maximum of 118 heat days in Wilcox county of Alabama and minimum 43 days in DeKalb county of the state.

Occupational heat exposure incidents in U.S. States and OSHA Region 4

OSHA has required all employers under federal OSHA jurisdiction to report every severe work-related injury and illness within 24 h of an incident since January 1, 2015. OSHA organizes these reports by including incident description, employers' name, address of the reported establishment, type of event or exposure, and nature of injury or illnesses. The dataset includes all severe illnesses and injuries that resulted in in-patient hospitalization, loss of eye or amputation. We collected the dataset containing all work-related incidents from all industries during 2015 to 2019 (Data source: OSHA 2020). The BLS Occupational Injury and Illness Classification System (OIICS) categorized all heat-related incidents with the OIICS code 531 referred as 'Exposure to Environmental Heat' (BLS 2012). The occupational heat-related injury and illnesses were separated by using the event or exposure types classified as 'Exposure to Environmental Heat'. We checked the description of all incidents to ensure that every incident is specifically

related to heat-exposure. The dataset seems to underrepresent the number of heat-related incidents due to including the incidents that mostly resulted in hospitalization and not including data for the states that administer their own health and safety programs. Hence, the data did not include any records from the states of Idaho, Iowa, Michigan, Minnesota, Montana, New Hampshire, Vermont, Washington, and Wyoming. It is also possible for some employers not to report all claims regarding heat-related incidents from the employees to escape the cost of reporting. Figure 4 summarized these reported incidents for all the states in the U.S. during 2015 to 2019. Texas and Florida were observed to report high average number of incidents and Alabama ranked 7th with an average of 11.4 incidents reported yearly among the 39 states, shown in the figure.

The heat-stress incidents reported for all industries during the period of 2015 to 2019 have been geolocated and *HIR* values were calculated for all counties. These *HIR* estimates were aggregated at the state level to estimate mean *HIR* rates for the 39 contiguous states. Figure 5 shows the locations of reported incidents grouped by each year from 2015 to 2019 and the estimated average incidence rates for all states. From Fig. 5, it is evident that the majority of workers in the South (i.e., Texas, Florida, Mississippi, Alabama, Georgia, Louisiana, and Arkansas), Midwest (i.e., Oklahoma, Missouri, Illinois, Wisconsin, and Kansas) and some of the Northeast states (i.e., Philadelphia, New York, and Maine) have experienced high occupational heat-stress illnesses in the last 5 years. Figure 5 also shows the states grouped into 10 major regions regulated by OSHA, with the southern states falling under Region 4 and 6.

To identify the regions mostly experiencing occupational heat exposure incidents, Fig. 6 plots yearly incidents categorized by 7 OSHA Regions and does not include Region 5, 8 and 10 due to missing data in most of their states. The plot shows that Region 4 and 6 continued to experience the highest incident rates among the 10 Regions throughout the study period. Though we are missing data in the states of New Hampshire and Vermont, we observed the incidence rates in 2018 significantly increasing for the remaining north-eastern states represented by OSHA Region 1, which consists of Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, and Vermont. Moreover, it is clearly shown that total incidence rate in the U.S. significantly increased from 0.03 in 2017 to 0.28 incident per 10,000 employees in 2018 due to rapid increase in the rates for Region 1, 4, and 6.

Reported occupational HRI in Alabama.

Since this research is focusing on studying heat-exposure events within the extent of OSHA Region 4 and the state of Alabama, all the reported incidents have been geocoded using latitude and longitude information provided in the

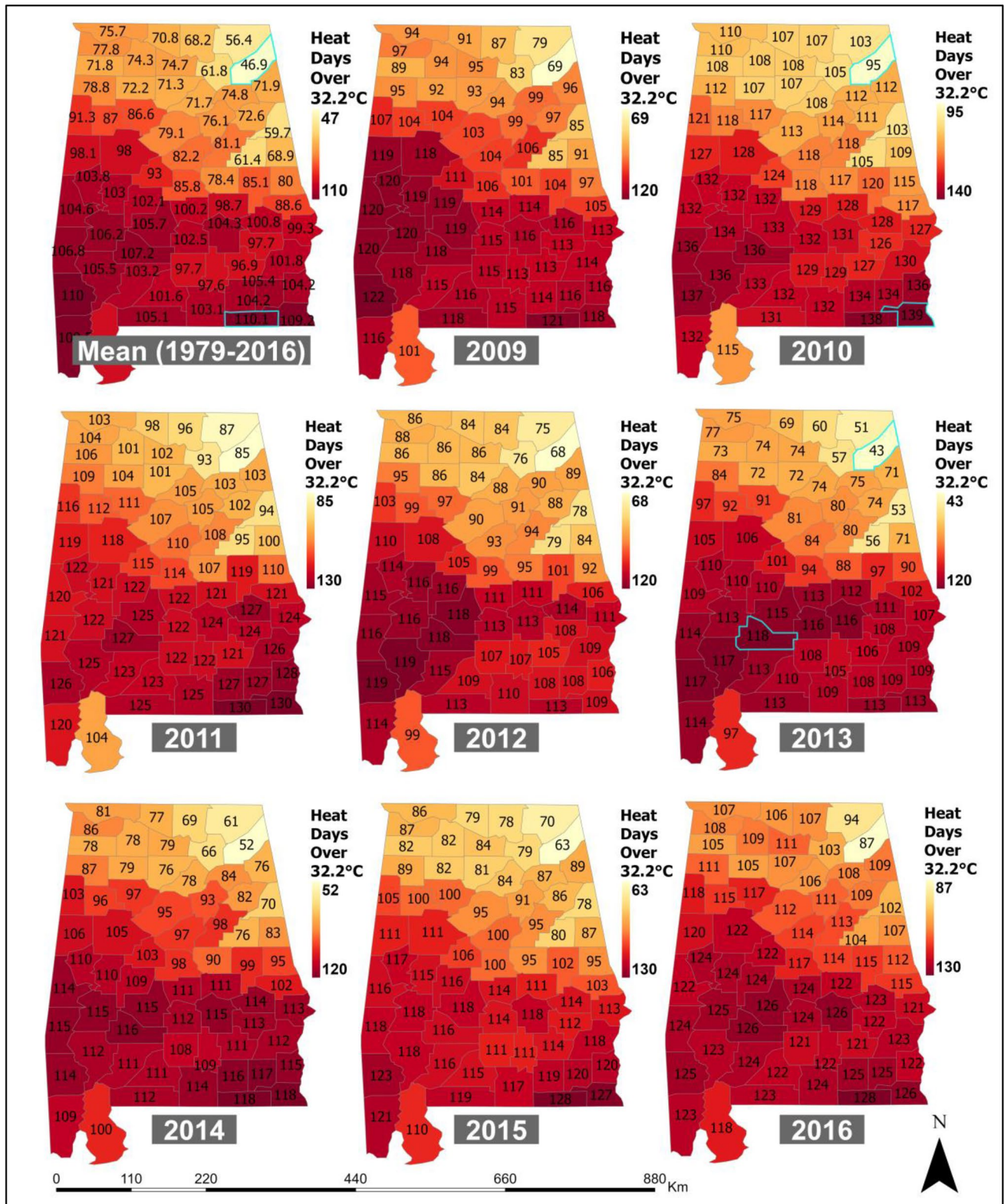


Fig. 3 Days with heat-index > 90 °F (32.2 °C) in Alabama during 2008 to 2016. (note: counties marked with blue boundary in the figure of mean (1979 to 2016), 2011 and 2013, represent maximum and minimum number of days exceeding 90 °F (32.2 °C))

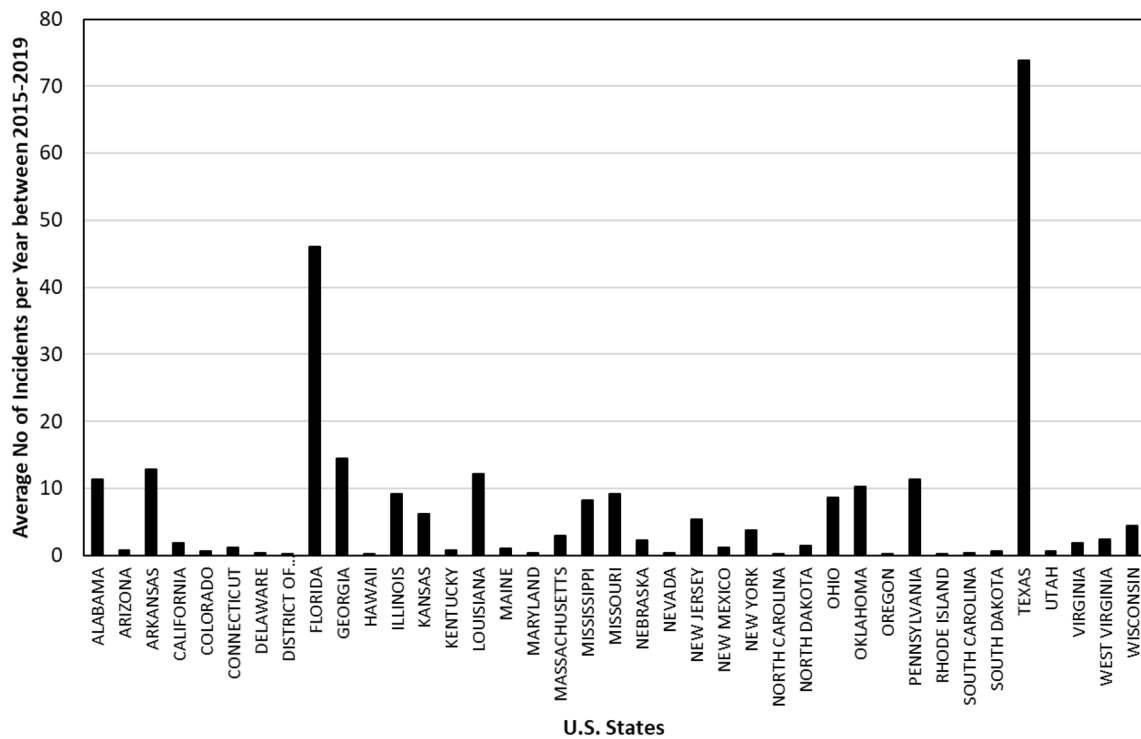


Fig. 4 Reported average heat exposure incidents in US states from 2015 to 2019

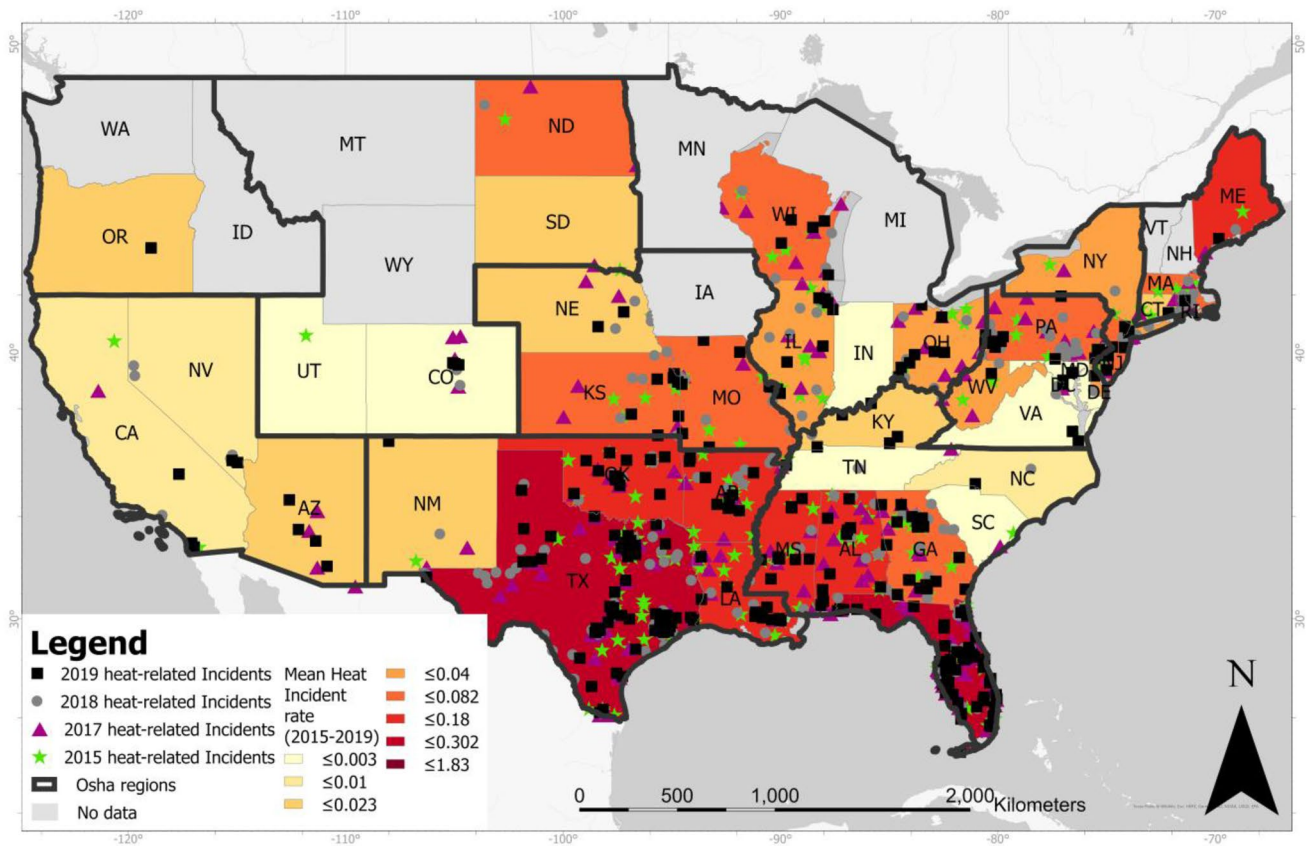


Fig. 5 Locations of reported heat-stress incidents during 2015–2019 and the mean HIR estimated for the US states

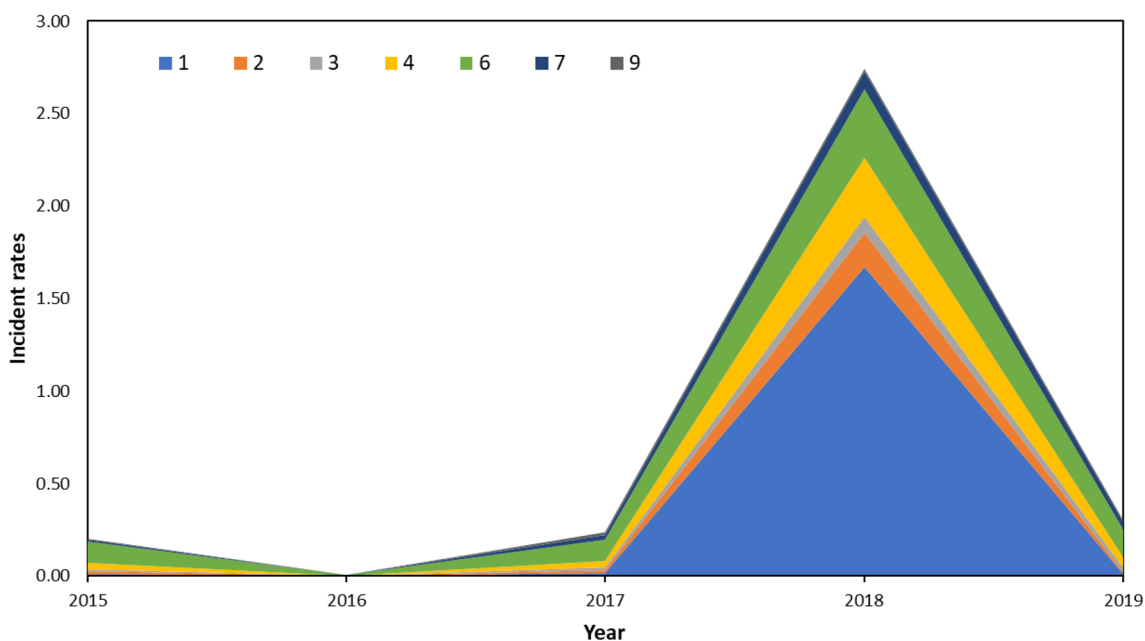


Fig. 6 Heat-stress incidents in the US states from 2015 to 2019 by OSHA Region

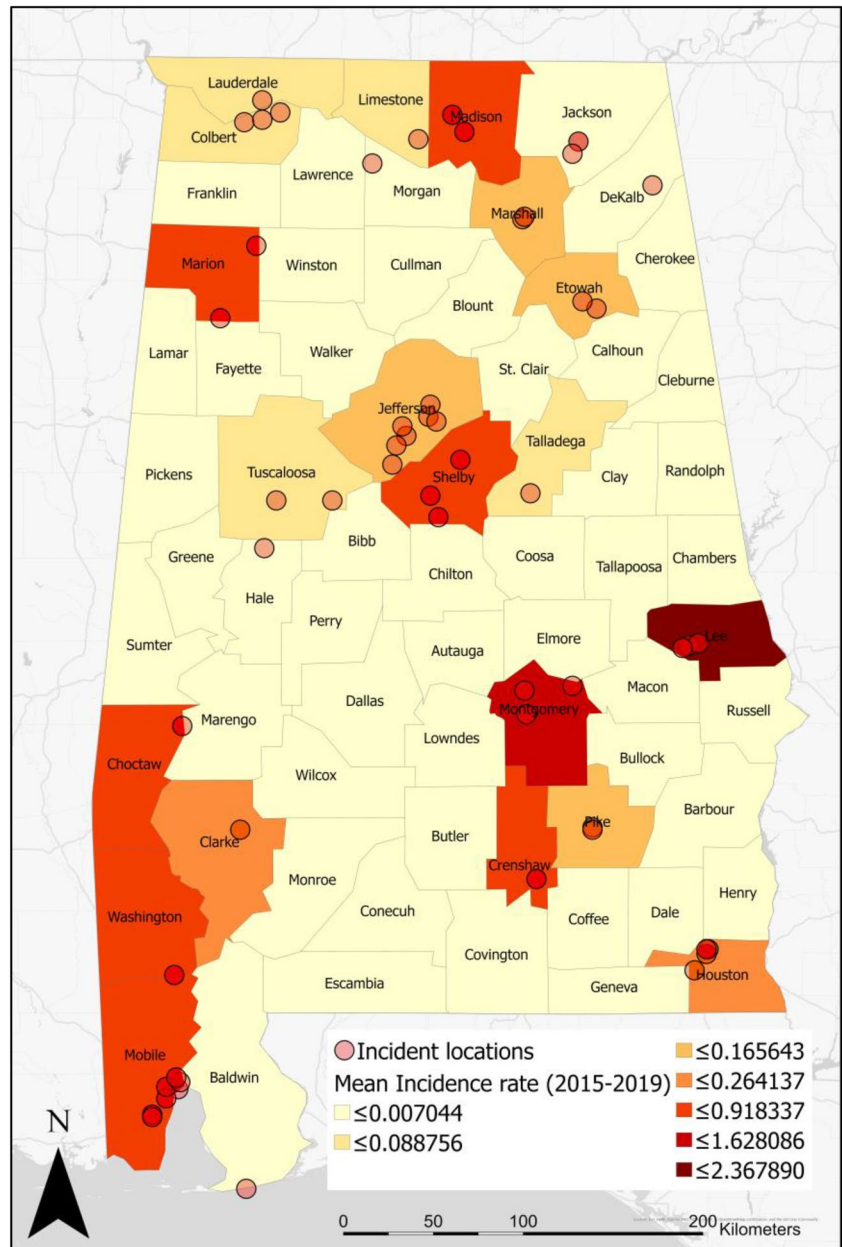
dataset. Figure 7 shows a map with points locating the heat incidents occurring in Alabama. Jefferson County seems to experience 7 reported incidents, which is the highest among all Alabama counties. After this county, 6 incidents were reported in Mobile County, where 5 of them occurred very recently in 2019. The color-coded counties in Fig. 7 also show estimated incidence rates for the counties in Alabama during 2015 to 2019, illustrating the highest rate in Lee county of Alabama followed by Montgomery, Mobile, and Madison county.

Nature of HRI reported in OSHA Region 4

We also assessed the nature of the heat-related injury or illnesses by studying the claims identified with OIICS code 531 (BLS 2012). OSHA has designated the nature of injury or illnesses due to environmental heat exposure (OIICS 531) under the main OIICS classification 172 referred as ‘Effects of heat and light’. This OIICS code 172 is further classified into 8 subcategories: effects of heat and light (unspecified) (code 1720), heat stroke (i.e., heat apoplexy, heat pyrexia, ictus solaris, siriasis, sunstroke, thermoplegia) (code 1721), heat syncope (i.e., loss of consciousness associated with heat) (code 1722), heat fatigue (code 1723), heat edema (code 1724), heat exhaustion, prostration (code 1725), multiple effects of heat and light (code 1728), and effects of heat and light, n.e.c. (not elsewhere classified) (code 1729; example: dehydration resulting from heat exposure) (BLS

2012). This subcategorization is structured in a way so that the first subcategory represents traumatic injuries and disorders (i.e., heat stroke), while the rest of the subcategories represent exposure-related different symptoms, signs (i.e., heat exhaustion), diseases or disorders (i.e., heat syncope) (BLS 2012). Unspecified effects of heat and light (code 1720) are identified for the cases when exposure to heat or light is the only available information. Our dataset listing all heat-exposure incidents in the construction industry and all industries has been categorized in these sub-categories. However, the dataset does not include one of the subcategories: heat edema (OIICS 1724), which might have been grouped with ‘effects of heat and light, n.e.c.’ (OIICS 1729) or ‘effects of heat and light, unspecified’ subcategory (OIICS 1720). Figure 8 summarized the percentage of all counted incidents under each category. In OSHA Region 4, 29.9% of 415 reported heat-related incidents in all industries were received from the construction establishments during 2015 to 2019. 30.8% cases of all industries were observed to be affected by nonclassifiable heat and light effects. Unspecified heat and light effects were observed in 31.3% of the cases, followed by 14.5% cases experiencing exhaustion, 13.3% cases with multiple effects of heat and light. Few other reported cases showed heat syncope, stroke, and fatigue. The construction industry has shown similar percentages, but higher percentages (34.7%) in the traumatic injuries or disorders (i.e., unspecified effects of heat and light) compared to all other industries.

Fig. 7 Locations reporting heat-related incidents and mean incidence rate in the Alabama counties during 2015 to 2019



Comparison in heat-related fatalities (HRF) between construction and all other industries

Data on heat-related fatalities (HRF) for the whole U.S. were collected from BLS OIICS, which characterizes the extreme heat events as ‘Exposure to Environmental Heat’. Overall, 26,739 total fatalities occurred among construction workers between 1992 and 2018, which represents 19% of all occupational fatalities (Fig. 9a). While 285 HRF occurred among construction workers between 1992 and 2018, comprising 36% of heat-related deaths in all industries (Fig. 9b). The number of HRF and all fatalities

in construction fluctuated over time, but the portion of heat-related deaths in construction was steadily higher than its share of all fatalities in the nation. Over this time period, the annual number of heat-related fatalities in the construction industry significantly increased with 1 death every 5 years. A similar trend was observed for all industries HRF; frequency of deaths has significantly increased with 1 death every 1.54 years.

Also, the number of HRF in different occupations have been studied for the years 2003 to 2018 to identify the occupations at most risk due to environmental heat exposure.

Fig. 8 Nature of Heat-related Incidents (in %) (2015 to July 2019)

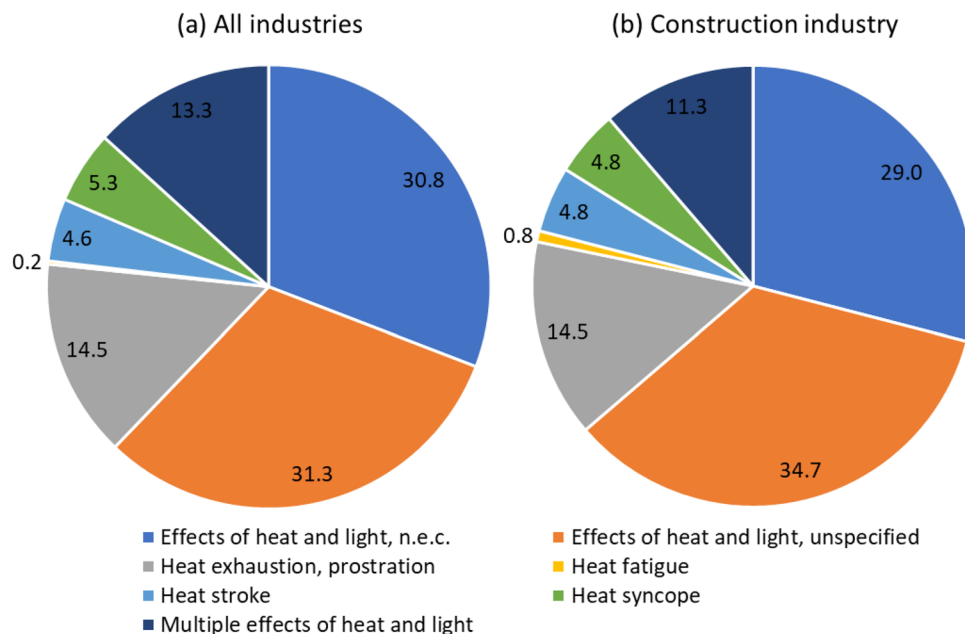


Figure 10 illustrates that the workers involved in construction and extraction occupations (SOCs 47–0000) have continued to experience highest fatalities over the past years, which is followed by the occupations of building and ground cleaning and maintenance (SOCs 37–0000), management (SOCs 11–0000), transportation and material moving occupations (SOCs 53–0000). The numbers within the brackets show the standard Occupational Classification (SOC) codes which are used to classify different occupations by federal agencies (BLS 2021). The current trend in Fig. 10 shows 1 fatality every 2.4 years for all occupations. Hence these occupations require detailed preventive measures to protect heat-related mortalities and morbidities.

We later separated the heat-related injury and illnesses only reported within the construction industry from our collected geocoded severe injury and illnesses dataset provided by OSHA. We utilized the North American Industry Classification System (NAICS) code designated for the construction sector to extract the incident specific to the construction industry. NAICS sector 23 comprises all establishments related to the construction industry (NAICS 2021). These HRI incidents occurred during the study period of 2015 to 2019. Figure 11a shows geographic locations of the reported incidents in the construction industry along with the incidents in all industries, which indicates a substantial number of total incidents reported by the construction industry are located in the OSHA Region 4. Figure 11b compares the reported incidents between the construction industry and all industries for the states included in Region 4. Florida, Georgia and Alabama have the highest percentages of all incidents reported in construction. The analysis proved that

the construction industry is one of the major industries that is highly vulnerable to environmental heat waves.

HRI monthly occurrence and trend over temperature

Data collected for all occupational heat-related incidents from 2015 to 2019 has been summarized to analyze the monthly occurrence of the occupational heat-related incidences. Figure 12a shows the percentage of occupational heat-related incidence in the domain of the U.S and the state of Alabama, by month of the incident. Over the study period, most incidents in the overall U.S occurred during the month of July (38.6%), August (20.8%), and June (19.7%). Whereas the majority of the incidents in Alabama occurred in July (47%), August (21.6%), and September (13.7%). Therefore, necessary preventive measures should be taken during July, August, and September in Alabama. Also, data on the average temperature during the period of (May to September) were collected for the Alabama counties to observe incidence rate over temperature (NOAA 2021). The heat-related incidents have been plotted over the average summer temperature for Alabama counties in Fig. 12b. The figure shows that number of incidents increases at the rate of 1 incidence by 38.1 °F (3.4 °C).

Current scenario

OSHA's response to occupational heat-stress

The actual number of injuries and fatalities from heat stress are greatly understated due to not reporting these

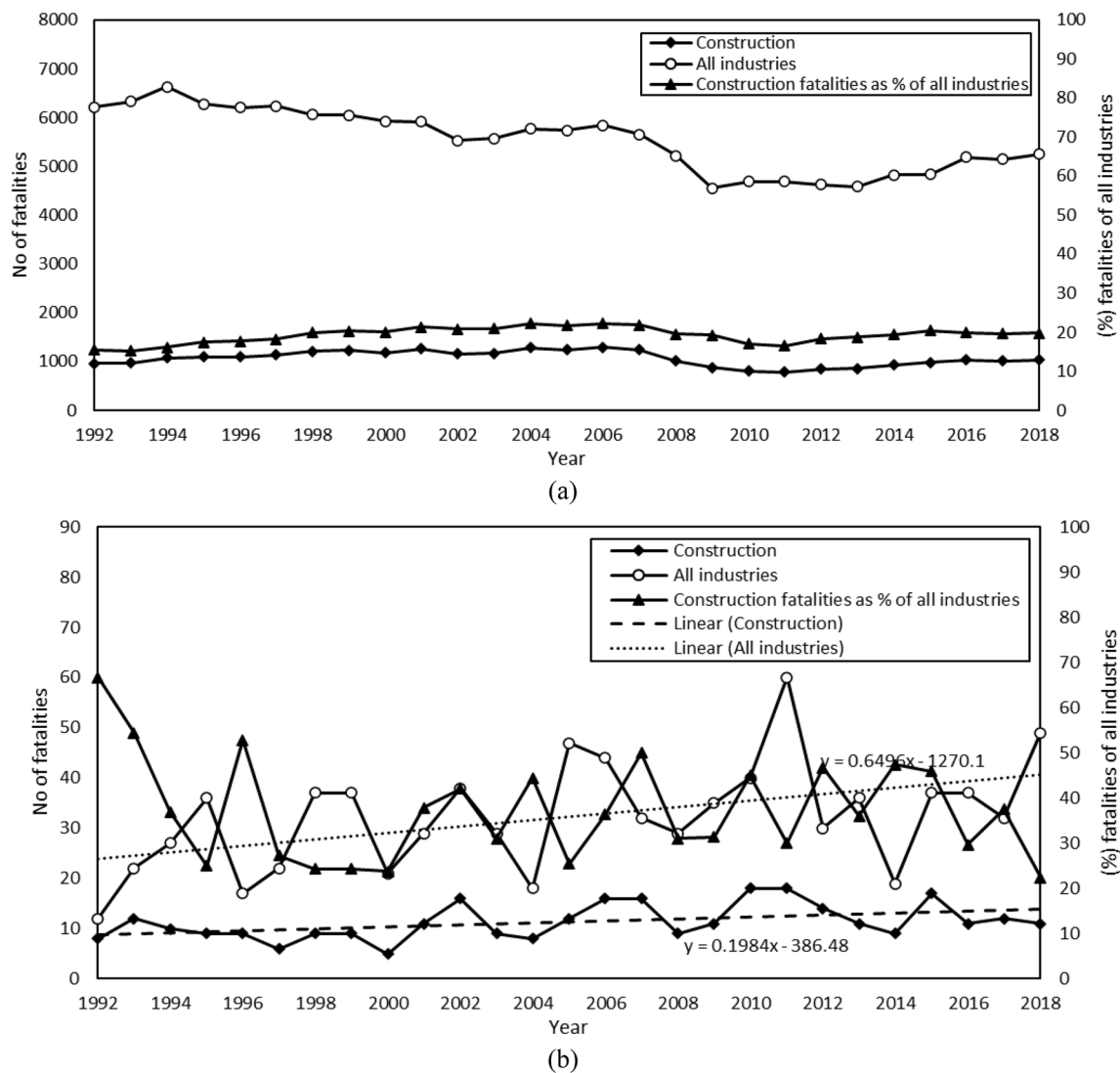


Fig. 9 **a** Fatalities in the Construction Industry compared to all occupational fatalities; **b** Comparing HRF between Construction Industries and all Other Industries (1992 to 2018)

incidents properly (Gubernot et al. 2014; Xiang et al. 2013). Also, OSHA’s reliance on the General Duty Clause as a substitute for a specific standard is insufficient. A recent case of Sturgill Roofing, Inc. being cited under OSHA’s General Duty Clause for failing to provide sufficient heat-related training was criticized by the Occupational Safety and Health Review Commission (OSHRC) for the use of the clause instead of developing a standard (Neuroth 2019). In this particular case, the commission remarked of the levels of the National Weather Service’s (NWS) HI chart to be an impractical tool in defining significant danger (Neuroth 2019). While federal OSHA conducted 142 inspections resulting in at least one heat citation under the General Duty Clause, California completed 7082 inspections resulting in at least one heat standard violation between 2013 and 2017, which indicated that

California conducted 50 times more inspections resulting in a violation for unsafe heat exposure practices as OSHA did nationwide between 2013 and 2017 (Public Citizen 2018). The underreporting of HRI and HRF incidents by the federal OSHA generally occurs due to their fewer inspection rate compared to the state agencies of labor and industries, which applies for all occupational health violations. In a 2016 study, OSHA researchers analyzed the circumstances surrounding all 84 citations the agency issued for unsafe heat exposure under the General Duty Clause in 2012 and 2013, and 23 of the cases involved worker deaths (Arbury et al. 2016). Remarkably, 17 of the 23 fatalities (74%) involved workers who were in their first three days on the job, and eight (35%) victims were on the very first day of work. The same study found that large percentages of employers fail to provide advisable

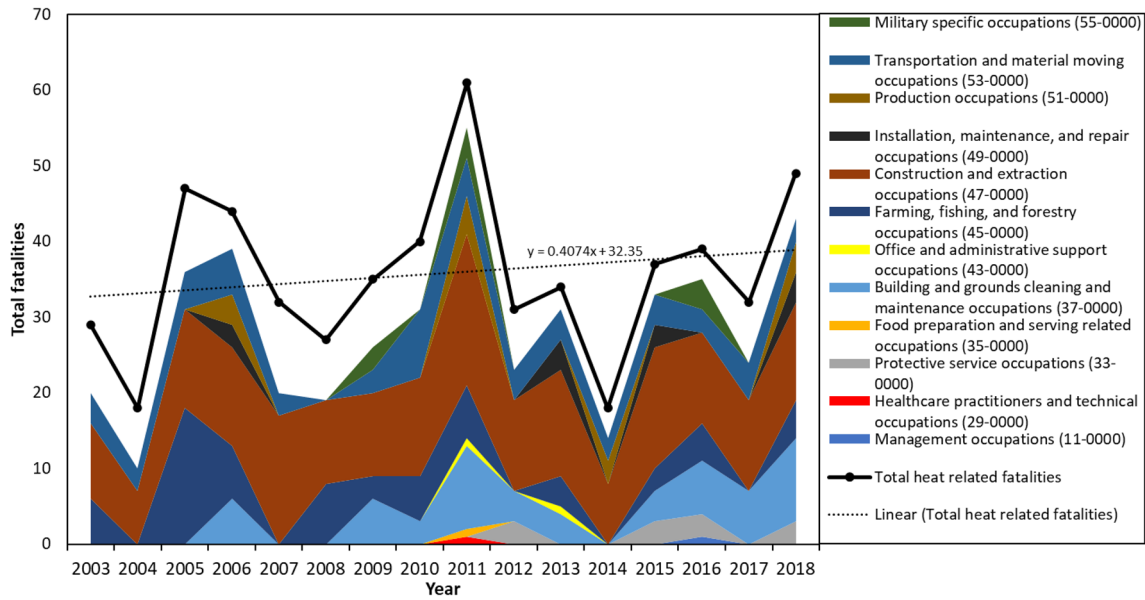


Fig. 10 HRF in different occupations in the U.S. from 2003 to 2018. (Note: value within bracket shows SOC's code for each occupation)

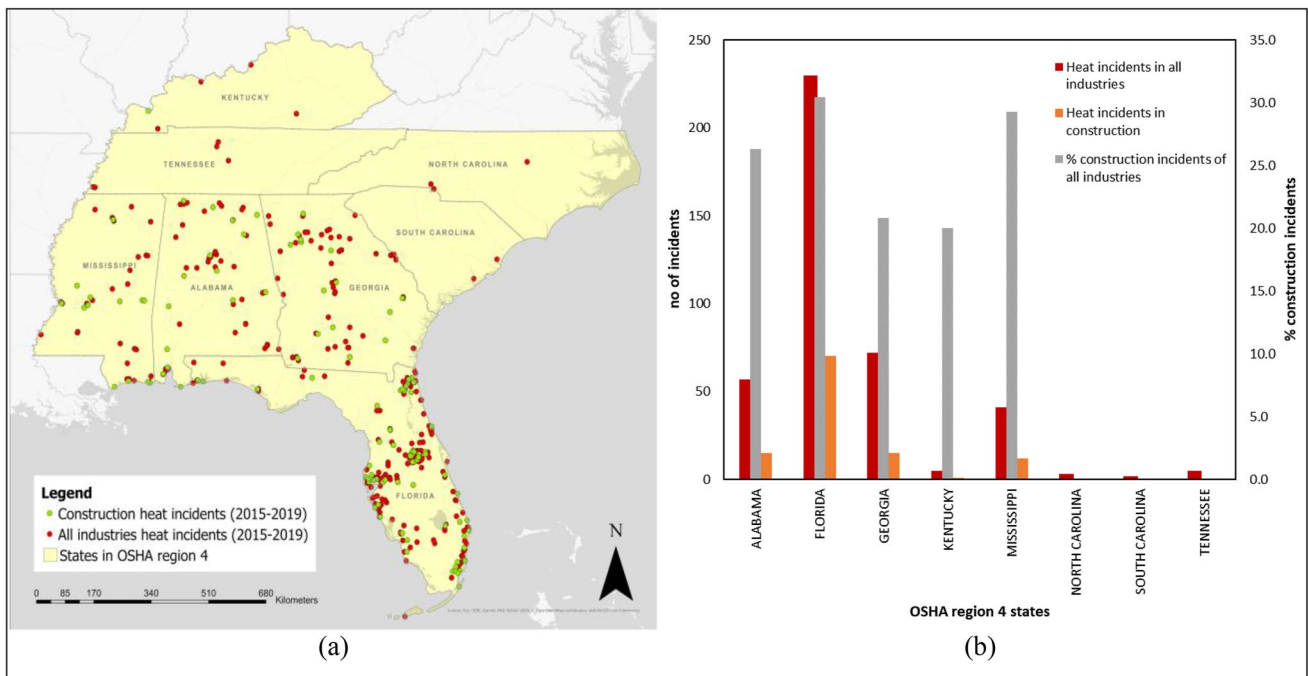


Fig. 11 a Geographic locations of the reported cases, and b comparison of heat incidents between construction industry and all industries in the OSHA region 4 from 2015 to 2019.

safety measures, especially for acclimatization. Only 1% of the cited employers had an acclimatization program for new employees to adjust to working in a hot environment, only 16% considered heat-index in identifying heat-stress risks, 30% provided prevention training, and 20% either failed to provide water or adequate access to it.

Existing policies

Although the National Institute for Occupational Safety and Health (NIOSH) published a document on the criteria for a recommended standard regarding occupational heat stress in 1972 and revised twice in 1986 and 2016 (Coco et al. 2016),

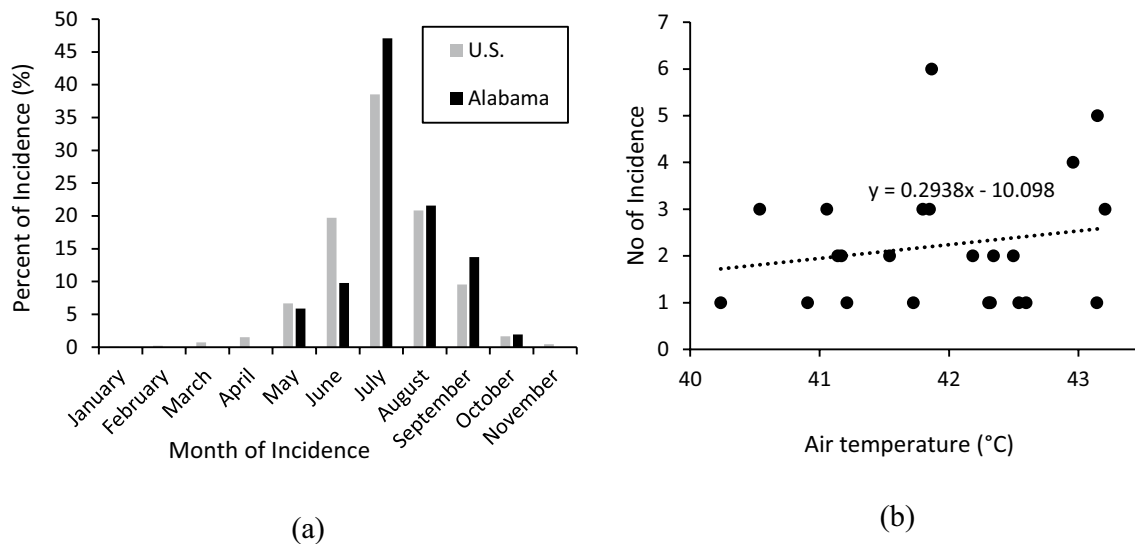


Fig. 12 **a** Percentage of occupational HRI, by month of incident (sum of 2015 – 2019); **b** Change in the number heat-related incidence over average summer temperatures in the Alabama counties (2015–2019).

OSHA has never disseminated a federal standard (Public Citizen 2018). California, Minnesota, and Washington have implemented standards protecting outdoor (i.e., California and Washington) or indoor (i.e., California and Minnesota) workers from heat-stress and demonstrate the feasibility of regulations at the state and federal levels. Although being limited to outdoor workers in 2005, California’s standard was the most comprehensive and detailed state standard, which was implemented as an emergency measure in response to a spike in HRF that year (California Department of Industrial Relations 2005). According to heat-illness prevention standard by California (T8 CCR 3395), every outdoor employee in the construction, landscape, agriculture, oil–gas extraction, transportation industries and those who work for extended hours in the outdoor environment must be protected by providing shading, water-supply, and sufficient break time. The standard requires all employers to develop a written plan for HRI prevention including emergency response procedures in order to implement them effectively and emphasizes on a multilingual outreach-training program.

Required measures for heat-stress standard

Heat in a combination of weather conditions (i.e., temperature, humidity, and the amount of direct sunshine) and people’s physiological condition such as metabolic heat generated through physical labor, worker’s fitness, and clothing types or equipment used by the workers, control the susceptibility to heat-stress (Coco et al. 2016). In 2016, comprehensive recommendations for a heat-stress standard by NIOSH establishes thresholds for constituting risk factors and recommends methods to protect employees’ exposure.

Some of the recommendations for occupational heat-exposure standards by NIOSH include the following components (Coco et al. 2016): (1) surveillance in the workplace: (a) exposure limits for both acclimatized and unacclimatized worker including different clothing insulations, (b) determining heat-exposure events by methods of measuring environmental parameters in order to modify work conditions, and (c) determining individual metabolic heat and screening physiological condition; (2) initiate a medical monitoring program: (a) a comprehensive physical examination along with work and medical history, (b) conduct periodic evaluations, (c) emergency care in case of HRI, and (d) provide information related to worker’s duties and exposure to their healthcare provider; (3) surveillance on distribution and occurrence of adverse health effects; (4) identify heat-stress areas and post warning signs; (5) provide protective clothing and equipment; (6) knowledge on new workers’ condition to initiate training program and maintain safety data sheet for heat-stress; (7) control measures including engineering controls, work modification and hygiene practices, develop heat-alert program; and (8) recordkeeping of the surveillance data including environmental conditions, metabolic heat, medical conditions, sentinel health events and HRI.

Proposed index

Several indices (i.e., direct, single, rational, empirical) have been proposed in the existing literature to evaluate or forecast the heat-stress level in the work environment (i.e., Dry-bulb temperature, wet-bulb temperature, wet-bulb globe temperature, Belding-Hatch heat stress, effective temperature,

universal thermal climate index, physiological strain index, predicted heat strain, etc.) (Roghanchi et al. 2015). Some of the indices use a single environmental parameter as a function of metabolic heat and some were developed in a combination of multiple environmental factors including metabolic heat production. Dry bulb and wet bulb temperature are the examples of single-factor index. The use of dry-bulb temperature in the uncomfortable humid condition is not practical, while wet bulb temperature works best in a hot-humid condition with a low air velocity and radiant heat (Brocherie and Millet 2015; Coco et al. 2016). The wet bulb globe temperature (WBGT) combines the coupled effects of wind movement and humidity, radiation and air temperature and has been a recommended index by NIOSH for its straightforward calculation and simplicity in data collection. The index showed high correlation with the workers' heart rate (Monazzam et al. 2014), but it does not include physiological aspects and may not be appropriate in case of impermeable clothing. A recent study by Wang et al. (2019) measured wet bulb globe temperature (WBGT) using temperature data collected from sample individuals' small thermometers and compared them to WBGT from a nearby weather station. This study showed that the percent of hours exceeding the threshold limit value (TLV) is higher using the personal WBGT than the estimated value using weather station based WBGT. Belding-Hatch Heat Stress Index, a rational index has been widely used in the field

and laboratory studies, which was developed by incorporating heat-balance equation. The index assumes a healthy sweating rate that is unproven in epidemiological studies, fails to capture extreme heat conditions and accurately differentiate between environmental factors and metabolic heat contributing to overall heat-stress (Suma'mur 1979). Effective temperature along with its modified version is an empirical index, which was developed in combination of globe temperature, wet-bulb temperature and wind-speed, was also one of the most widely used heat-stress index. The index showed limitations by overestimating the humidity effects and underestimating the effects of wind-speed (Webber et al. 2003). Universal thermal climate index (UTCI), a most recent thermal stress indicator, incorporates heat balance models containing complex physiological and anatomical properties to predict human thermoregulatory responses (Coco et al. 2016; Zare et al. 2019). The application of UTCI as an occupational heat-stress index was found similar to WBGT and showed significant positive correlation with physiological parameters (Nassiri et al. 2017). More research is required to prove UTCI's effectiveness in capturing heat-stress being a relatively new model as occupational heat-stress index. Besides, most indices described above have certain drawbacks in assessing individual worker's response to environmental heat. The rising trend in global temperature requires a more comprehensive index capable of capturing

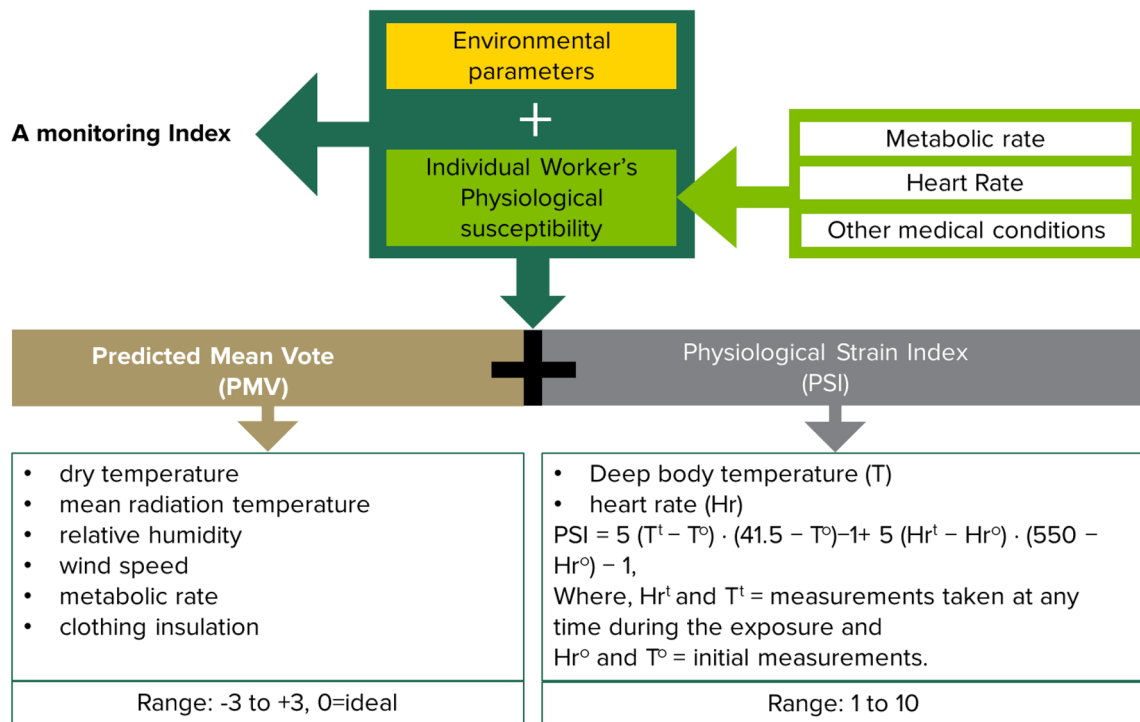


Fig. 13 Proposed Occupational Heat-Stress Index (HSI)

the effects of a combined scenario including weather, physiological factors and thermal insulation.

This study proposes a Heat-Stress Index (HSI) as an alternative comprehensive solution of the existing indices (Fig. 13). The index can be helpful to track both the responsible environmental parameters and the worker's physiological conditions depending on the performed works. HSI can be formulated in a combination of two already established indices, Predicted Mean Vote (PMV) and Physiological Strain Index (PSI). The employers can utilize it as a routine task during the summer days over 85 °F (29.4 °C) heat-index as suggested by CDC (Tustin et al. 2018). Moran et al. (1998) introduced physiological strain index (PSI) considering deep body temperature (T) and heart rate (HR) to be compared between the resting and working condition. PSI has been previously validated and widely used in occupational heat strain assessment (Mac et al. 2021). PSI is measured by collecting real-time heat strain data at individual level. PSI index ranges from 0 to 10 with highest physiological strain represented by a score of 10. It is calculated using Eq. (2) and useful to perform individual-level assessments and respond to individual needs as recommended by NIOSH since people show different physiological response to environmental stimulus. Evaluating individual physiology is not considered in many existing indices. The resting heart rate and core body temperature can be measured before a worker begins his/her daily routine-works, while the parameters during exposure can be measured using the available wearable fitness devices designed to track heart rate and core-body temperature.

$$\text{PSI} = 5(T^t - T^o) \times (41.5 - T^o) - 1 + 5(Hr^t - Hr^o) \times (550 - Hr^o) - 1 \quad (2)$$

where T = Deep body temperature

Hr = Heart rate

Hr^o and T^o = measurements in the resting condition

Hr^t and T^t = measurements taken at any time during the exposure

Additionally, to evaluate the effects of environmental factors on heat stress along with metabolic heat and insulation, we propose to use the Predicted Mean Vote (PMV). Fanger (1972) developed PMV as an empirical fit of human perceived thermal comfort by using the ASHRAE's (American Society of Heating, Refrigerating and Air-Conditioning Engineers) 9-point thermal sensation scale, which was later adopted as an ISO (International Organization of Standardization) standard. PMV has often been used as an occupational thermal index beside its application in the meteorological, urban planning studies (Fang et al. 2017; Ghalhari et al. 2019; Sugiono et al. 2014). PMV primarily developed as an indoor thermal comfort index has been modified to represent an outdoor condition (Thitisawat et al. 2011). The calculation of PMV requires 6 factors (i.e., dry temperature,

mean radiation, temperature, relative humidity, wind speed, metabolic rate, and clothing insulation) as inputs to its complex curve fit equation (Fanger 1972). PMV can predict the collective perception of a group of individuals placed in the same environmental condition. Unlike many indices, PMV represents the workers' thermoregulatory responses similar to UTCI by considering meteorological conditions, workers' metabolic heat production and their clothing insulation level in an energy balance model. Also, the 9-point thermal scale used in PMV makes the index simple to be interpreted in the workplace. The input meteorological parameters can be regularly monitored on the jobsites as recommended by NIOSH. The PMV calculation will require regular monitoring of the environmental conditions as part of the workplace surveillance routine. Some inputs variables including the clothing types and metabolic rate remain constant depending on the job type and performed tasks. Also, some available software programs can be used to automate PMV calculation from the input jobsite data. Finally, the proposed Heat-Stress Index (HSI) can be organized in a risk matrix in a combination of 9-point PMV and 10-point PSI scales. Preserving both scales in a risk matrix will help to differentiate the physiological response to heat-stress between the individual and a group of workers.

Conclusion

In this study, we attempted to understand occupational heat-exposure risks at a regional level and identify the most vulnerable industries and occupations by analyzing the reported jobsite injury-illnesses and fatalities due to environmental heat-exposure. We found the risk of occupational heat-exposure is evident by observing the incidents of injury-illnesses at the state and regional level. Over the 38 years timespan of 1979 to 2016, south and southeast part of OSHA Region 4 experienced highest number of heat days beyond 90 °F (32.2 °C) heat-index. We observed increasing trends in the number of extreme-heat days in most counties of Florida followed by the counties of Georgia. The heat-related injury-illness rate seemed to correlate in the counties with high average number of heat days. The state of Alabama also showed similar pattern in the southern counties with a higher occurrence of heat days. During 2015 to 2019, most incidents of heat-related severe injury-illnesses occurred in the state of Florida and Texas, while Alabama ranked 7th with an average of 11.4 yearly incidents among 39 states, with higher incidence rates in Lee, Montgomery, Mobile, and Madison counties of Alabama. The injury-illness rate in the U.S. significantly increased from 0.03 in 2017 to 0.28 incident per 10,000 employees in 2018 due to rapid increase in the rates for Region 1, 4, and 6. The annual number of fatalities in all industries significantly increased with a trend of 1 death every 1.54 years and 1 death every 5 years in the construction industry

during 2015 to 2019. The workers in construction and extraction occupations have continued to experience highest fatalities over the past years, which is followed by building and ground cleaning and maintenance occupations, management, transportation and material moving occupations. By geolocating the reported injury-illnesses, we found Florida, Georgia and Alabama in the OSHA Region 4 receiving highest incidents in the construction industry. These findings reveal increasing heat-exposure risk due to significant increase in extreme-heat days throughout the country. The risk of heat-related injuries-illnesses and fatalities is expected to increase and worsen in the coming years because of the global climate change.

The workers are not protected enough from being exposed to extreme heat conditions due to the absence of a recognized federal exposure limit regarding workplace heat-stress. The employers do not properly emphasize this matter and fail to follow necessary precautions in the workplace. This results in exposing millions of outdoor workers to extreme heat-stress and additional health effects, further illustrating that the current system is not designed properly to protect workers. The heat-stress incidents can be effectively mitigated in the future by mandating federal guidelines in response to combatting heat exposure. Additionally, surveilling the environmental conditions and workers' physiological response to heat has become necessary to protect them from the increasing heatwaves besides providing shades, water, and training programs. Current heat regulations do not provide the complete picture of the thermal perception of a working individual. The proposed modified index is a combination of a heat-balance model and physiological index and can be a comprehensive surveillance tool on jobsites. The index would be able to capture the workers' heat perception along with their physiological strain level. This scale-based index system is easy to interpret and can be useful in terms of maintaining a regular monitoring system and keeping records of the workers' individual and group response to heat-stress. However, assessing the practical implementation of the index was not included within the scope of this study. In our future studies, we will explore its feasibility of evaluating physiologically stressful conditions.

Acknowledgements We acknowledge Dr. Wesley C. Zech and Dr. Maryam Karimi for their efforts in critically reviewing this article.

Author contributions Conceptualization: Samain Sabrin, Wesley C. Zech; Methodology: Samain Sabrin; Formal analysis and investigation: Samain Sabrin; Writing—original draft preparation: Samain Sabrin; Writing—review and editing: Samain Sabrin, Wesley C. Zech, Rouzbeh Nazari, Maryam Karimi; Supervision: Wesley C. Zech.

Funding No funding was received for conducting this study.

Availability of data and material The occupational injury and illness data is available in the Occupational Injury and Illness Classification System (OIICS) published by the U.S. Bureau of Labor Statistics

(BLS) (OSHA 2020). We collected data on extreme heat days from the National Environment Public Health Tracking Network published by the Centers for Disease Control and Prevention (CDC) (CDC 2021). Also, historical data on heat-related deaths from different industries and occupations were gathered from the Injuries, Illnesses, and Fatalities (IIF) program (<https://www.bls.gov/iif/>) of U.S. BLS.

Declarations

Conflict of interests The authors have no conflicts of interest to declare that are relevant to the content of this article.

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