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Heat-related deaths among construction workers in the United States

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Abstract

Background: Heat is a severe hazard for construction workers and may be worsening with global warming. This study sought to explore heat-related deaths among U.S. construction workers and a possible association with climate change.

Methods: Heat-related deaths in the Census of Fatal Occupational Injuries from 1992 to 2016 were analyzed. Denominators estimated from the Current Population Survey were matched with demographic and occupational categories in rate calculations. Statistical tests were used to examine heat-related deaths in relation to time, geographic region, and temperature.

Results: Construction workers, comprising 6% of the total workforce, accounted for 36% ($n = 285$) of all occupational heat-related deaths from 1992 to 2016 in the U.S. Mean temperatures from June to August increased gradually over the study period. Increasing summer temperatures from 1997 to 2016 were associated with higher heat-related death rates ($r = 0.649$; 95% confidence interval: 0.290, 0.848). Compared to all construction workers (risk index = 1), statistically significant elevated risk of heat-related death was found among Hispanics (1.21), in particular workers born in Mexico (1.91). Occupations with a high risk index included cement masons (10.80), roofers (6.93), helpers (6.87), brick masons (3.33), construction laborers (1.93) and heating, air conditioning, and refrigeration mechanics (1.60).

Conclusions: U.S. construction workers are at a high risk of heat-related death, and this risk has increased with climate change over time. Effective workplace interventions, enhanced surveillance, and improved regulations and enforcement should accompany broader efforts to combat global warming. The construction industry can help reduce global warming through increased implementation of green building principles.

KEYWORDS
climate change, fatal heat stroke, global warming, heat exposure, occupational health, outdoor workers, workplace intervention

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1 | INTRODUCTION

Global climate change impacts human health through a wide range of effects, from frequent extreme weather events and worsened air quality to changes in vector-borne disease distribution. However, the most evident relationship is between increased temperatures and heat-related illnesses (HRI).[1-5] Numerous studies indicate that at least 97% of actively publishing climate scientists are in agreement that human activities are most likely to be the cause of global warming trends observed over the past century.[6] NASA's global land-ocean temperature index provides a visual representation of this warming trend and also illustrates a recent spike, whereby 18 of the 19 warmest years on record have occurred since 2001.[7]

Occupational heat exposure is of growing concern internationally, particularly for construction workers, who perform strenuous work outdoors, respond to remediate climate disasters, and experience outdoor pollution and vector-borne diseases directly.[8] Using data from the U.S. Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries, Gubernot et al[9] reviewed 359 heat-related deaths that occurred between 2000 and 2010 and found that the rate of heat-related death among construction workers was 1.13 per million, more than five times the rate of 0.22 per million for all workers. That study also found higher rates among workers who were male, Hispanic, or African American; in small establishments with 10 or fewer workers; and in southern states. An earlier study reviewed 480 workers' compensation claims for HRI filed between 1995 and 2005 in Washington state and found that construction had the highest rate of HRI (12.1 per 100 000 workers) among major industries, with subsector rates of 59.0 per 100 000 for roofing and 48.8 per 100 000 for highway, street, and bridge construction.[10] Excluding indoor workers and fire service workers, the study also found significant differences in the average maximum reported temperature for days in which a single HRI claim was filed compared with days when multiple HRI claims were filed (80.4°F vs 88.5°F, $P < .001$). A recent review of 79 work- and heat-related fatalities found that 5% occurred at temperatures below those generating any heat index warning, and an additional 20% occurred on days rating only the lowest level of "Caution," highlighting the importance of occupational factors such as exertion and solar load that are not included in population warnings.[11]

To protect workers, the U.S. Occupational Safety and Health Administration (OSHA) initiated a heat illness prevention campaign in 2011 that is ongoing and consists primarily of educational outreach to workers and employers, including resources such as smart phone heat applications and educational materials.[12] The agency has been petitioned to issue an enforceable standard to prevent HRI, and the National Institute for Occupational Safety and Health (NIOSH) has updated its 1986 criteria document addressing occupational exposure to heat, recommending adoption of a standard with specific criteria for prevention.[13,14] Standards to protect workers from excessive heat have been adopted by several OSHA State Plan States, although none of these contain all the elements recommended by NIOSH.

Despite the absence of a federal standard to prevent HRI, OSHA investigations of reported HRI take place under the General Duty Clause of the Occupational Safety and Health Act, which requires employers to maintain a workplace free from recognized hazards likely to cause death or serious physical harm.[15] A review of 84 heat-related OSHA enforcement cases conducted from 2012 to 2013 identified a set of repeated risk factors that included failure to provide acclimatization periods, lack of heat index monitoring, and no modified work rest cycles.[16] A subsequent review[17] of 38 investigations involving 66 workers whose HRI triggered OSHA enforcement through 2016 confirmed that the majority of cases were among outdoor workers, who comprised 52.3% of affected workers and 79.2% of fatalities. In addition, among those whose work characteristics were known, 95% of the workers who died were reportedly performing work of moderate, heavy, or very heavy intensity. Ten of the 24 deaths (45.5%) occurred on the first day on the job; none of the employers offered an acclimatization program, and none required mandatory rest breaks.

The construction industry is recognized globally as severely affected by heat stress.[18] HRI and preventive measures among construction workers have been studied among workers in Australia,[19,20] India,[21] Hong Kong,[22] and the Middle East.[23] In an international review of 55 epidemiologic studies published between 1997 and 2012 that addressed heat exposure and work, only 13% focused on construction workers.[24] Studies of construction workers in the United States are also limited. Apart from studies of fatal HRI among all groups of workers,[9,11] studies of HRI among U.S. workers have focused specifically on other groups of workers, such as agricultural workers,[25,26] have been conducted among workers in a single state or county,[10,27-29] or have addressed general population mortality.[2] More targeted studies of the impact of heat on U.S. construction workers are warranted. To identify high risk groups for targeted interventions, this study used the most recent data available to evaluate trends and patterns of heat-related fatalities at worksites among U.S. construction workers, including the potential effects of climate change.

2 | MATERIALS AND METHODS

2.1 | Data sources

Fatality numbers were generated from the 1992-2016 Census of Fatal Occupational Injuries research files collected by the U.S. BLS through a data access agreement with the BLS. The Census of Fatal Occupational Injuries is a comprehensive data source of all work-related fatal injuries in the United States, including fatalities among private and government wage-and-salary workers, as well as self-employed workers. The deaths and work-relatedness were verified from death certificates, workers' compensation reports, OSHA reports, medical examiner reports, newspaper articles, and other sources. The Census of Fatal Occupational Injuries data include employment and demographic information on injured workers, nature of the injury, source of the injury, event or exposure, secondary source of injury, and so forth.[30] Denominator estimates for rate tabulations were obtained from the Current Population Survey (CPS), a monthly household survey of employed individuals aged 16 years or older. Climate and temperature data were obtained from the National Oceanic and Atmospheric Administration.[31] Institutional Review Board (IRB) approval was not required for this study since it used previously collected data.

2.2 | Definitions

Heat-related deaths were defined using BLS Occupational Injury and Illness Classification System (OIICS) nature of injury codes for exposure to environmental heat (072*x* before 2011 in the 2007 version, and 172*x* from 2011 to 2016 in version 2.01). Other variables analyzed included the month and time of day when the incident occurred, as well as the geographic region (Northeast, Midwest, West, and the South) where the incident took place. Demographic categorical variables included age group, sex, race, and ethnicity (eg, Hispanic, white non-Hispanic, and black non-Hispanic), and birthplace (the United States or other countries).

The construction industry was defined based on the North American Industry Classification System codes (NAICS 23) for the data between 2003 and 2016, and the Standard Industrial Classification Industry Group codes (SIC 15, 16, and 17) before 2003. Additional employment-related variables included occupation (Standard Occupational Classification), establishment size (category), job tenure (years), ownership type (private or public), and employee status (eg, wage-and-salary or self-employed). Employment and fatalities in both public and private sectors as well as self-employed workers in construction were included in the data analyses.

2.3 | Statistical analysis

The number of heat-related deaths in the construction industry by year was calculated and compared with all-cause fatalities in construction and heat-related deaths in all industries during the same period. Considering potential effects from economic cycles and changes in the industry and injury classification systems over time, the years were grouped into four periods: (a) 1992 to 2002, the period before the North American Industry Classification System; (b) 2003 to 2007, the period of the housing boom; (c) 2008 to 2010, the recession period; and (d) 2011 to 2016, the postrecession period when OIICS version 2.01 was applied. Pearson's correlation and linear regression were used to examine the relationship between heat-related deaths among construction workers and mean summer temperatures in the contiguous United States for the entire duration of the study period, and during the most recent 20-year period that includes a high number of record-breaking temperatures, as described above. The Cochran-Armitage test was applied to examine whether changes in heat-related deaths over time were statistically significant. Statistical significance for this and other tests in the study was determined at the $\alpha = .05$ level.

To increase data comparability, detailed analyses focused on the period between 2011 and 2016 when the BLS OIICS version 2.01 was applied to the Census of Fatal Occupational Injuries data. Combined data from 2011 to 2016 were stratified by demographics, employment status, construction subsector, establishment size, occupation, and time of incident. Denominators were estimated from the CPS and matched with the categories from the Census of Fatal Occupational Injuries. Heat-related death rates with 95% confidence intervals (CIs) were estimated for major demographics, employment status, and major occupations; and adjusted by hours worked from the CPS as number of deaths per 100 000 full-time equivalent workers, assuming a full-time worker works 2000 hours in a year. A risk index was created to identify worker groups with the highest risk, using the 2011 to 2016 average risk of heat-related death for the entire construction industry as the reference (average risk = 1). χ^2 tests and analysis of variance were conducted to test whether differences among subgroups were statistically significant. Distribution of heat-related deaths by month, time of day, and place (region) of heat exposure were tabulated. Months with fewer heat-related deaths were grouped together as needed to meet BLS data reporting criteria. All data analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC).

3 | RESULTS

Overall, 285 heat-related deaths occurred among construction workers between 1992 and 2016, comprising 36% of heat-related deaths in all industries (Table 1). The number of heat-related deaths and all-cause fatalities in construction fluctuated over time, but the share of heat-related deaths in construction was steadily higher than its share of all fatalities in the nation. The annual number of heat-related deaths in construction significantly increased over time ($r = 0.517$; 95% CI: 0.289, 0.745), while the decreasing trend in the number of all-cause construction fatalities was not statistically significant ($r = -0.445$; 95% CI: −0.704, 0.186). Similar trends were observed for all industries; frequency of heat-related deaths significantly increased ($r = 0.575$; 95% CI: 0.386, 0.764), whereas the number of all-cause fatalities significantly decreased ($r = -0.898$; 95% CI: −0.959, −0.838) over the 25-year study period.

The average annual number of heat-related deaths in construction increased steadily across the four time periods from 9.5 deaths per year in the baseline period of 1992-2002 to 13.7 deaths per year in the period of 2011-2016, about a 44% increase ($P < .05$; Table 2). Similar patterns were found in all industries, as the average annual number of heat-related deaths increased from 27.1 deaths in the baseline period to 36.5 in the most recent period, a 35% increase, but not statistically significant.

During the most recent period from 2011 to 2016, 82 heat-related construction deaths accounted for 37.4% of the total heat-related deaths in all industries (219 deaths); more than any other major industry sector (Figure 1). There was significant variation by month ($P < .001$), with the largest proportion of heat-related deaths in construction occurring in July (32.9%; Figure 2). More than three-

TABLE 1 Number of fatalities in construction and all industries, heat-related deaths vs all fatalities, 1992 to 2016

	Heat-related deaths			All fatalities		
Year	Construction[a]	All industries[a]	Construction as % of all industries	Construction	All industries[a]	Construction as % of all industries
1992	8	12	66.7	963	6217	15.5
1993	12	22	54.5	971	6331	15.3
1994	10	27	37.0	1077	6632	16.2
1995	9	36	25.0	1098	6275	17.5
1996	9	17	52.9	1095	6202	17.7
1997	6	22	27.3	1136	6238	18.2
1998	9	37	24.3	1207	6055	19.9
1999	9	37	24.3	1228	6054	20.3
2000	5	21	23.8	1183	5920	20.0
2001	11	29	37.9	1265	5915	21.4
2002	16	38	42.1	1153	5534	20.8
2003	9	29	31.0	1171	5575	21.0
2004	8	18	44.4	1278	5764	22.2
2005	12	47	25.5	1243	5734	21.7
2006	16	44	36.4	1297	5840	22.2
2007	16	32	50.0	1239	5657	21.9
2008	9	29	31.0	1016	5214	19.5
2009	11	35	31.4	879	4551	19.3
2010	18	40	45.0	802	4690	17.1
2011	18	60	30.0	781	4693	16.6
2012	14	30	46.7	849	4628	18.3
2013	13	36	36.1	856	4585	18.7
2014	9	19	47.4	933	4821	19.4
2015	17	37	45.9	985	4836	20.4
2016	11	37	29.7	1034	5190	19.9
Total	285	791	36.0	26 739	139 151	19.2

Note: Heat-related deaths/illnesses in this study include "effects of heat and light" (Nature codes 172*x* in OIICS 2.01 and Nature codes 072*x* in OIICS 1.01).

[a]Denotes that the trend over time is statistically significant at the $\alpha = .05$ level.

TABLE 2 Number of fatalities and changes over time, heat-related deaths vs all fatalities, 1992 to 2016

	Heat-related deaths						All fatalities					
	Construction			All industries			Construction			All industries		
Time period	Sum	Annual average	Change	Sum	Annual average	Change	Sum	Annual average	Change	Sum	Annual average	Change[a]
1992-2002 (baseline period)	104	9.45	1	298	27.09	1	12,376	1125.09	1	67,373	6124.82	1
2003-2007	61	12.20	1.29	170	34.00	1.26	6,228	1245.60	1.11	28,570	5714.00	0.93
2008-2010	38	12.67	1.34	104	34.67	1.28	2,697	899.00	0.80[a]	14,455	4818.33	0.79[a]
2011-2016	82	13.67	1.45[a]	219	36.50	1.35	5,438	906.33	0.81[a]	28,753	4792.17	0.78[a]

Note: Heat-related deaths/illnesses in this study include "effects of heat and light" (Nature codes 172*x* in OIICS 2.01 and Nature codes 072*x* in OIICS 1.01).

[a]Denotes significant differences compared to the baseline period at the $\alpha = .05$ level.

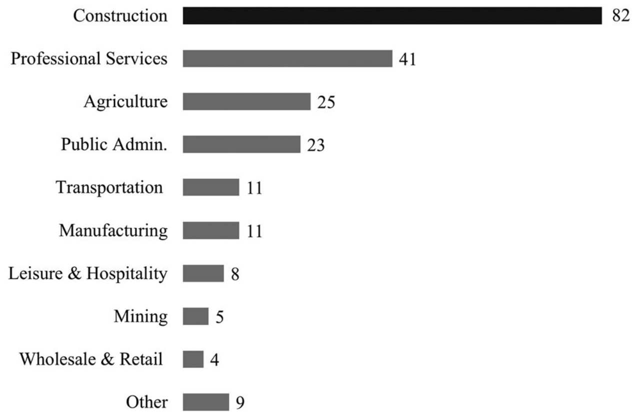


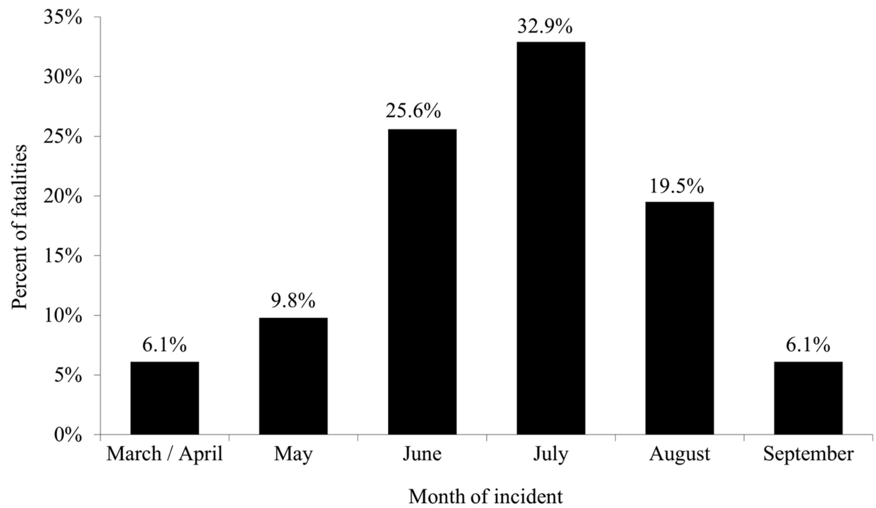
FIGURE 1 Number of heat-related deaths, by major industry, 2011 to 2016 (all employment)

fourths of heat-related fatalities in construction occurred in June, July, and August. There were also significant differences in fatality patterns by time of incident between heat-related deaths and other fatal traumatic injuries ($P < .001$). Heat-related deaths were more common in the middle of the day, with 37.3% occurring from 2:00 to 3:59 PM, more than double the proportion of fatalities from other causes during that time (17.2%; Figure 3).

Over the entire duration of the study period, increasing summer temperatures in the contiguous United States correlated positively with the annual number of heat-related deaths in construction ($r = 0.609$; 95% CI: 0.282, 0.810) and with the rate of heat-related death ($r = 0.414$; 95% CI: 0.022, 0.695). Figure 4 depicts gradual increases over time with regard to temperature and frequency of heat-related deaths in construction. The Figure 4 regression equations model linear increases of 0.26 deaths and 0.08 degrees (F) per calendar year ($\beta = 0.261$; 95% CI: 0.076, 0.446; $\beta = 0.081$; 95% CI: 0.028, 0.135, respectively).

During the most recent 20-year period that includes many of the warmest years on record, mean summer temperatures ranging from 69.5°F to 73.7°F accounted for 42.2% of the observed variability in heat-related death rates among construction workers ($\beta = 0.026$; 95% CI: 0.012, 0.046; Figure 5). Increasing mean summer temperatures during this period were significantly correlated with higher annual heat-related death rates among construction workers ($r = 0.649$; 95%

FIGURE 2 Percentage of heat-related fatalities in construction, by month of incident, sum of 2011 to 2016



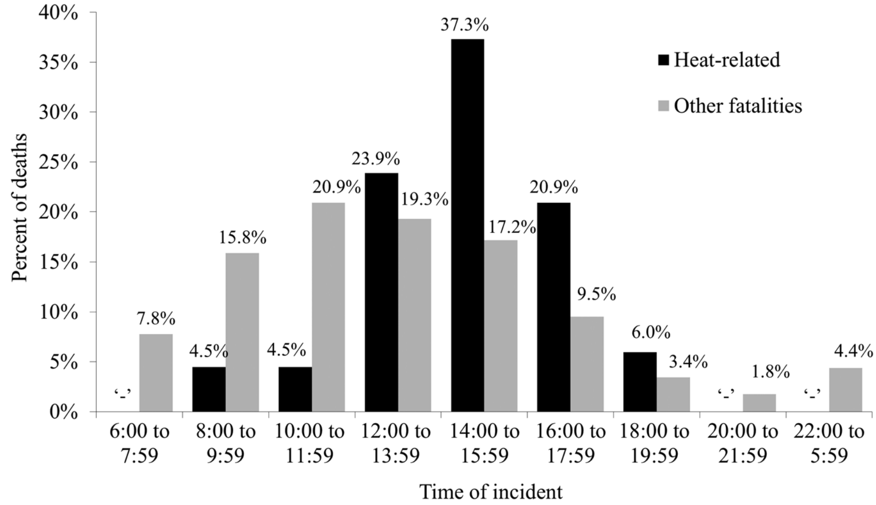


FIGURE 3 Percentage of fatalities in construction, by time of incident, heat-related vs other fatalities, sum of 2011 to 2016. Other fatalities are nonheat-related fatalities. '-' Indicates no data reported or data that do not meet publication criteria. Cases without time information were excluded. The differences between heat-related and other fatalities are significant at $P < .001$

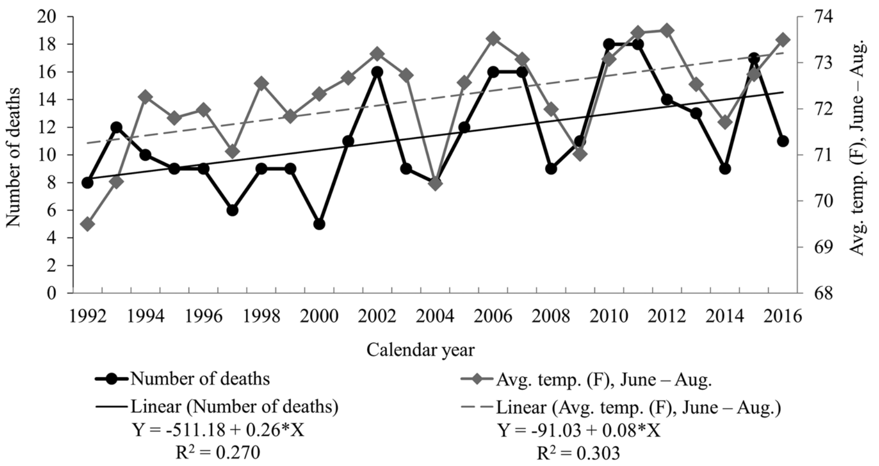


FIGURE 4 Change over time in the number heat-related construction deaths and average summer temperatures in the contiguous United States, 1992 to 2016. R^2 = coefficient of determination

CI: 0.290, 0.848). Consistent with the associations between heat-related deaths and increasing temperatures, over 60% of heat-related deaths occurred in southern states.

When stratifying heat-related deaths between 2011 and 2016 by major demographic and employment characteristics using the combined data, the risk index of heat-related death did not differ significantly by age group (Table 3). Significantly elevated risk indices were observed for workers of race/ethnicity other than white, non-Hispanic. The risk index among construction workers who were born in Mexico was 91% higher than the average for all construction workers. With regard to employment status, the heat-related death risk index for wage-and-salary workers was significantly elevated. The risk of heat-related death also varied by occupation. Compared with all construction workers on average, the risk index of heat-related death was more than 10 times higher among cement masons, and nearly seven times higher among roofers and helpers. Brick masons, construction laborers, and heating, air conditioning, and refrigeration mechanics also had an elevated risk index.

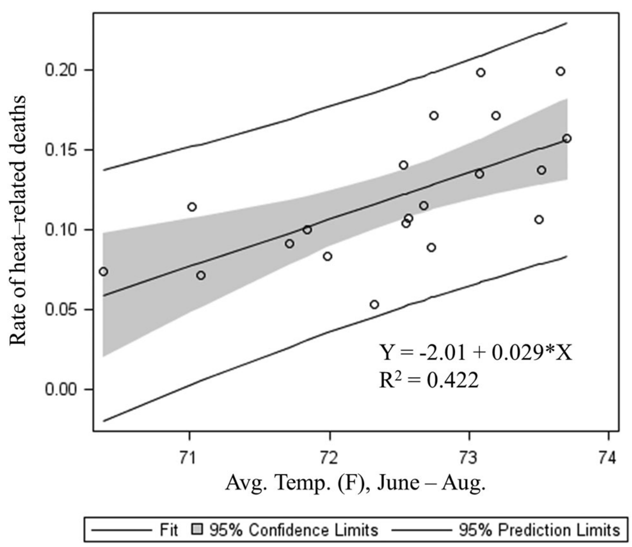


FIGURE 5 Scatter plot and corresponding regression line illustrating the relationship between annual rates of heat-related construction deaths and average summer temperatures in the contiguous United States, 1997 to 2016. Death rates shown per 100 000 construction workers. R^2 = coefficient of determination

4 | DISCUSSION

Construction workers consistently experienced a higher risk of occupational heat-related death compared to all workers during the study period. Between 1992 and 2016, construction workers, who represent roughly 6% of the workforce on average, sustained 19% of all work-related fatal traumatic injuries, while accounting for 36% of the total work-related heat-related deaths in the United States. Moreover, despite a decline in overall fatalities, the risk of heat-related death has significantly increased in recent years in the construction industry.

The positive correlation between rising temperatures and heat-related mortality supports concerns that climate change is already causing increased fatalities among construction workers. Heat waves over areas in North America and Europe are expected to increase in intensity, frequency, and duration over the course of this century, with projected increases in mortality for the general population and for outdoor workers.[32-34]

In addition to disproportionate risk for heat-related death, construction workers may also be at risk for other adverse effects of climate change. Extremely high temperatures and heat stress have been associated with increased workers' compensation injury claims and occupational injuries, respectively.[35,36] Higher temperatures may increase some routes of chemical exposure, and heat stress may affect absorption or exacerbate toxicity from solvents and other chemicals to which construction workers are exposed regularly.[8,37] As outdoor workers, they are at increased risk from the changed distribution of insect disease vectors and from expanded habitat ranges for plant allergens and stinging insects.[5]

High temperatures have also been associated with loss of productivity,[38] estimated to reduce global GDP by up to 2.4 trillion U.S. dollars annually by the year 2030.[39] A recent systematic review of international studies including more than 40 occupations and close to 450 million workers in 30 countries estimated that 30% of workers who experience the physiologic effects of heat exposure

TABLE 3 Number and rate of heat-related deaths among construction workers, selected characteristics, sum of 2011 to 2016

Characteristic	Number of heat-related deaths: 2011-2016 total	%	Incidence rate of heat-related deaths: 2011-2016 average rate[a]	95% confidence interval: Lower	Upper	Risk index[b]
Age group, y						
16-24	5	6.1	0.11	0.10	0.12	0.74
25-34	19	23.2	0.14	0.14	0.15	0.98
35-44	22	26.8	0.16	0.15	0.16	1.07
45-54	21	25.6	0.15	0.14	0.16	1.04
55+	15	18.3	0.14	0.14	0.15	0.99
Race/Ethnicity						
Hispanic	26	31.7	0.18	0.17	0.18	1.21*
White, non-Hispanic	46	56.1	0.12	0.12	0.13	0.85
Black, non-Hispanic	6	7.3	0.22	0.20	0.24	1.51[d]
Other	4	4.9	0.21	0.19	0.24	1.46[d]
Birth place						
Mexico	21	25.6	0.28	0.30	0.27	1.91[d]
Other	5	6.1	0.07	0.08	0.07	0.52
United States	56	68.3	0.13	0.14	0.13	0.91
Region						
Northeast	9	11.0	0.10	0.09	0.10	0.66
Midwest	13	15.9	0.12	0.11	0.12	0.81
South	51	62.2	0.22	0.21	0.23	1.53[d]
West	9	11.0	0.07	0.07	0.07	0.48
Employee status						
Self-employed	7	8.6	0.06	0.06	0.06	0.41
Wage-and-salary	74	91.4	0.17	0.17	0.17	1.18[d]
Occupation						
Laborer	24	29.3	0.29	0.27	0.30	1.93[d]
Roofer	11	13.4	1.04	0.90	1.23	6.93[d]
Carpenter	8	9.8	0.13	0.12	0.13	0.87
Cement mason	5	6.1	1.62	1.27	2.24	10.80[d]
Brick mason	4	4.9	0.50	0.43	0.62	3.33[d]
Electrician	4	4.9	0.13	0.12	0.14	0.87
Plumber	4	4.9	0.15	0.14	0.17	1.00
Heating A/C mech	4	4.9	0.24	0.21	0.27	1.60[d]
Foreman	3	3.7	0.08	0.08	0.09	0.57
Helper	3	3.7	1.03	0.79	1.48	6.87[d]
All construction (Reference group)	82	100.0	0.15	0.14	0.15	1.00

[a]Rate = number of deaths per 100 000 full-time workers.
[b]The average risk of heat-related deaths between 2011 and 2016 was used as the reference (risk index = 1).
[c]Includes Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.
[d]Denotes higher average rates than the reference group at the $\alpha = .05$ level (the numbers reported were rounded).

(such as alterations in core temperature, sustained peak heart rate, electrolytes, or urine specific gravity) report productivity losses[40] that disproportionately impact outdoor work involving heavy manual labor.

The highest risk of heat-related death in the current study was found among cement masons, roofers, construction helpers, and brick masons. Workers in these occupations are typically involved in heavy outdoor labor. For example, cement masons (who had the highest risk of heat-related death in this study) perform difficult labor involving the placement and finishing of concrete. A case study of a concrete slab placing and finishing crew found that the crew members routinely exceeded published guidelines for acceptable levels of heart rate, oxygen consumption, and energy expenditure.[41] It is also common for a bricklayer to lay 200 concrete masonry unit blocks in a single 8-hour shift, totaling more than 3440 kg.[42] Similarly, construction helpers are more likely to perform heavy labor such as site cleanup, digging trenches, loading and unloading materials, disassembling scaffolding, and so forth.

Workplace interventions are essential and should account for personal susceptibilities (eg, acclimatization), environmental factors, and workload intensity.[19] In addition to standard approaches such as acclimatization and heat illness prevention programs, additional measures such as work rotations, physiological monitoring, and ergonomic solutions should be adopted. Altering work hours to limit work time in the hottest hours of the day offers some relief if feasible.[22] In low resource settings, including small enterprises in the United States, basic elements of any HRI prevention program should include ready access to water, active encouragement to drink, and appropriate rest breaks in shade or cool areas, as well as training workers to recognize, prevent, and administer first aid for HRI.[25]

As an adjunct to formal work/rest cycles, researchers have suggested the need to conduct intervention effectiveness research to include self-pacing in addition to standard prevention measures.[19,24] In addition to work practice controls, personal protective equipment to reduce heat exposure is needed. Loose, lightweight, and light-colored clothing can reduce heat absorption and increase air flow and ventilation. The OSHA-NIOSH Heat Safety Tool App is a useful resource for planning outdoor work activities, providing a real-time heat index and hourly forecast specific to worksites, and safety and health recommendations from OSHA and NIOSH.[43]

Beyond known interventions, the specific challenges experienced in the construction industry require new approaches to be developed, evaluated for effectiveness, and implemented widely.[20] Technological advances to reduce both physical exertion and heat load may provide solutions in higher resource settings, such as large enterprises. Clothing developed specifically for construction, such as cooling vests, may prove useful, although such clothing has yet to be evaluated for many of the task requirements encountered in construction.[44-46]

Regulatory intervention is needed urgently. Despite existing OSHA guidance and general duty clause citations for work-related HRI, the recent failure of the Occupational Safety and Health Review Commission to uphold an OSHA general Duty Clause citation in the death of a roofer from heat stroke demonstrates how severely the absence of an HRI prevention standard limits OSHA's enforcement ability.[47] Such a standard is essential to enable OSHA to conduct inspections to identify hazards and enforce abatement. Municipal ordinances requiring rest breaks are a step in the right direction, but fail to address important factors such as acclimatization.[12]

Construction workers will also benefit from broader societal efforts to address the root causes of anthropogenic climate change. The construction industry is well positioned to play a role in this effort. For example, an estimated 6% to 7% of global CO_2 emissions stem from the production of concrete.[48,49] Emerging applications of technology in the construction sector, such as more durable concrete containing engineered nanomaterials, may help to mitigate climate change without harming workers, if risks to workers are anticipated and addressed.[50]

This study has several limitations. It may underestimate the risk of heat-related death in the construction industry, in particular for those workers who experience high heat exposure. The cases of heat-related fatalities were identified based on the Census of Fatal Occupational Injuries classifications. However, heat-related death may be unrecognized or misclassified if heat exposure is not specifically included in the death certificate or other supporting documents used by the Census of Fatal Occupational Injuries.[9] For example, heat exposure as a contributing factor in cardiac deaths or fatal falls could be unrecognized by medical examiners and absent from death certificates. Moreover, information on the number of workers exposed to environmental heat is unavailable. Using total employment as denominators in rate calculations is likely to underestimate risks among workers with high heat exposure.

The study lacked access to more specific geographic information for heat-related deaths, due to confidentiality concerns. Day laborers and temporary workers are within the scope of the Census of Fatal Occupational Injuries but are not specifically categorized as such. The elevated heat-related death rate among immigrant construction workers from Mexico is striking and likely to be linked to employment characteristics, since immigrant workers tend to take high physical demand outdoor jobs, work as day laborers or temporary workers in informal settings, and be unaware of basic rights.[51-53] Research suggests these workers have a high risk of injury and may not be provided adequate training and protective equipment.[52,53] Self-employed workers may work alone or in informal settings where unwitnessed events may make causality determinations more difficult. Lastly, heat-related death is the most severe outcome of heat exposure, but HRI are more prevalent. Research on HRI is needed to provide a more complete assessment of the impacts of heat exposure among construction workers.

5 | CONCLUSIONS

The risk of heat-related death is high among construction workers and appears to be increasing in response to global warming. By analyzing nationally representative data sources, this study explores heat-related fatality trends and patterns in the U.S. construction industry. Although interventions are needed for construction workers as a whole, additional focus is warranted for those in the highest risk groups, such as cement masons, helpers, and immigrant Hispanic workers. Improved surveillance, dissemination, and intervention research, coupled with enhanced regulations and enforcement, are all needed to protect the health and productivity of workers exposed to heat. Other interventions could seek to reduce global warming through increased use of green building principles in construction. Efforts to reduce heat-related health outcomes should accompany broader efforts to promote environmental sustainability and combat global warming.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DISCLOSURE BY AJIM EDITOR OF RECORD

Rodney Ehrlich declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS

XSD designed the study, acquired and analyzed the data, interpreted the results, drafted and revised the manuscript critically for important intellectual content, approved the final version before submission, and agreed to be accountable for all aspects of the work. GHW analyzed and interpreted data related to climate change, helped draft and revise the manuscript, approved the final version, and agreed to be accountable for all aspects of the work. AH-B analyzed the data and interpreted the results, helped draft and revise the manuscript, approved the final version, and agreed to be accountable for all aspects of the work. XW participated in acquisition and analysis of the data. RKS participated in study design and interpretation of results, drafted and revised the manuscript critically for important intellectual content, approved the final version before submission, and agreed to be accountable for all aspects of the work.

ETHICS APPROVAL AND INFORMED CONSENT

Institutional Review Board (IRB) approval was not required for this study since it leveraged pre-existing data. Fatality numbers presented in this study were generated from the 1992-2016 Census of Fatal Occupational Injuries research files collected by the U.S. Bureau of Labor Statistics (BLS) through a data access agreement with the BLS, but the views expressed here do not necessarily reflect the views of the BLS. In accordance with BLS requirements, the declaration is attached to tables and figures where BLS data are cited.

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REFERENCES

1. Lundgren K, Kuklane K, Gao C, Holmer I. Effects of heat stress on working populations when facing climate change. *Ind Health*. 2013;51(1):3-15. https://doi.org/10.2486/indhealth.2012-0089
2. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environ Health Perspect*. 2011;119(2):210-218. https://doi.org/10.1289/ehp.1002313
3. Gasparrini A, Armstrong B. The impact of heat waves on mortality. *Epidemiology*. 2011;22(1):68-73. https://doi.org/10.1097%2FEDE.0b013e3181fdcd99
4. Lippmann SJ, Fuhrmann CM, Waller AE, Richardson DB. Ambient temperature and emergency department visits for heat-related illness in North Carolina, 2007-2008. *Environ Res*. 2013;124:35-42. https://doi.org/10.1016/j.envres.2013.03.009
5. U.S. Global Change Research Program, 2016. The impacts of climate change on human health in the United States: a scientific assessment. https://doi.org/10.7930/J0R49NQX Accessed December 31, 2018.
6. Cook J, Oreskes N, Doran PT, et al. Consensus on consensus: a synthesis of consensus estimates on human-caused global warming. *Environ Res Lett*. 2016;11(4):048002. https://doi.org/10.1088/1748-9326/11/4/048002
7. NASA's Goddard Institute for Space Studies. Global Land-Ocean Temperature Index. https://climate.nasa.gov/vital-signs/global-temperature/. Updated February 7, 2019.
8. Applebaum KM, Graham J, Gray GM, et al. An overview of occupational risks from climate change. *Curr Environ Health Rep*. 2016;3(1):13-22. https://doi.org/10.1007/s40572-016-0081-4
9. Gubernot DM, Anderson GB, Hunting KL. Characterizing occupational heat-related mortality in the United States, 2000-2010: an analysis using the Census of Fatal Occupational Injuries database. *Am J Ind Med*. 2015;58(2):203-211. https://doi.org/10.1002/ajim.22381
10. Bonauto D, Anderson R, Rauser E, Burke B. Occupational heat illness in Washington State, 1995-2005. *Am J Ind Med*. 2007;50(12):940-950. https://doi.org/10.1002/ajim.20517
11. Roelofs C. Without warning: worker deaths from heat 2014-2016. *New Solut*. 2018;28(2):344-357. https://doi.org/10.1177%2F1048291118777874
12. Occupational Safety and Health Administration. Heat Illness Prevention Campaign. https://www.osha.gov/heat/index.html. Accessed May 24, 2019.
13. Public Citizen, et al. Petition to OSHA for a heat standard, July 17, 2018. Washington, D.C. https://www.citizenvox.org/wp-content/uploads/2018/07/180717_Petition-to-OSHA-on-Heat-Stress-Signed_FINAL.pdf. Accessed December 31, 2018.
14. Jacklitsch B, Williams WJ, Musolin K, Coca A, Kim J-H, Turner N. NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2016-106; 2016. https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf?id=10.26616/NIOSHPUB2016106
15. Occupational Safety and Health Administration. OSH Act of 1970, Section 5 (a) 1. https://www.osha.gov/laws-regs/oshact/section5-duties/. Accessed December 31, 2018.

16. Arbury S, Jacklitsch B, Farquah O, et al. Heat illness and death among workers—United States, 2012-2013. *MMWR Morb Mortal Wkly Rep*. 2014;63(31):661-665. https://www.cdc.gov/mmwr/pdf/wk/mm6331.pdf Accessed December 31, 2018.
17. Tustin AW, Cannon DL, Arbury SB, Thomas RJ, Hodgson MJ. Risk factors for heat-related illness in U.S. workers: an OSHA case series. *J Occup Environ Med*. 2018;60(8):e383-e389. https://doi.org/10.1097/JOM.0000000000001365
18. Acharya P, Boggess B, Zhang K. Assessing heat stress and health among construction workers in a changing climate: a review. *Int J Environ Res Public Health*. 2018;15(2):247. https://doi.org/10.3390/ijerph15020247
19. Jay O, Brotherhood JR. Occupational heat stress in Australian workplaces. *Temperature (Austin)*. 2016;3(3):394-411. https://doi.org/10.1080/23328940.2016.1216256
20. Jia YA, Rowlinson S, Ciccarelli M. Climatic and psychosocial risks of heat illness incidents on construction site. *Appl Ergon*. 2016; 53(Pt A):25-35. https://doi.org/10.1016/j.apergo.2015.08.008
21. Dutta P, Rajiva A, Andhare D, Azhar GS, Tiwari A, Sheffield P. Perceived heat stress and health effects on construction workers. *Indian J Occup Environ Med*. 2015;19(3):151-158. https://doi.org/10.4103/0019-5278.174002
22. Rowlinson S, Jia YA. Application of the predicted heat strain model in development of localized, threshold-based heat stress management guidelines for the construction industry. *Ann Occup Hyg*. 2014;58(3):326-339. https://doi.org/10.1093/annhyg/met070
23. Miller V, Bates G, Schneider JD, Thomsen J. Self-pacing as a protective mechanism against the effects of heat stress. *Ann Occup Hyg*. 2011;55(5):548-555. https://doi.org/10.1093/annhyg/mer012
24. Xiang J, Bi P, Pisaniello D, Hansen A. Health impacts of workplace heat exposure: an epidemiological review. *Ind Health*. 2014;52(2): 91-101. https://doi.org/10.2486/indhealth.2012-0145
25. Bethel JW, Spector JT, Krenz J. Hydration and cooling practices among farmworkers in Oregon and Washington. *J Agromedicine*. 2017;22(3): 222-228. https://doi.org/10.1080/1059924X.2017.1318100
26. Mac VVT, McCauley LA. Farmworker vulnerability to heat hazards: a conceptual framework. *J Nurs Scholarsh*. 2017;49(6):617-624. https://doi.org/10.1111/jnu.12327
27. Mirabelli MC, Richardson DB. Heat-related fatalities in North Carolina. *Am J Public Health*. 2005;95(4):635-637. https://doi.org/10.2105/AJPH.2004.042630
28. Petitti DB, Harlan SL, Chowell-Puente G, Ruddell D. Occupation and environmental heat-associated deaths in Maricopa County, Arizona: a case-control study. *PLoS One*. 2013;8(5):e62596. https://doi.org/10.1371/journal.pone.0062596
29. Riley K, Wilhalme H, Delp L, Eisenman DP. Mortality and morbidity during extreme heat events and prevalence of outdoor work: an analysis of community-level data from Los Angeles County, California. *Int J Environ Res Public Health*. 2018;15(4):580. https://doi.org/10.3390/ijerph15040580
30. Bureau of Labor Statistics. Handbook of Methods: Census of Fatal Occupational Injuries. https://www.bls.gov/opub/hom/cfoi/pdf/cfoi.pdf. Accessed February 22, 2019.
31. NOAA National Centers for Environmental Information. Climate at a Glance: National Time Series. https://www.ncdc.noaa.gov/cag/national/time-series. Accessed September 11, 2018.
32. Guo Y, Gasparrini A, Li S, et al. Quantifying excess deaths related to heatwaves under climate change scenarios: a multicountry time series modelling study. *PLoS Med*. 2018;15(7):e1002629. https://doi.org/10.1371/journal.pmed.1002629
33. Meehl GA, Tebaldi C. More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*. 2004;305(5686):994-997. https://doi.org/10.1126/science.1098704
34. Xiang J, Bi P, Pisaniello D, Hansen A. Health impacts of workplace heat exposure: an epidemiological review. *Ind Health*. 2013;52(2):91-101. https://doi.org/10.2486/indhealth.2012-0145.
35. Calkins MM, Bonauto D, Hajat A, et al. A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington State. *Scand J Work Environ Health*. 2019;43(1):86-94. https://doi.org/10.5271/sjweh.3814.
36. Varghese BM, Barnett AG, Hansen AL, et al. The effects of ambient temperatures on the risk of work-related injuries and illnesses: evidence from Adelaide, Australia 2003-2013. *Environ Res*. 2018;170:101-109. https://doi.org/10.1016/j.envres.2018.12.024
37. CPWR – The Center for Construction Research and Training. Respiratory and other health hazards in construction. *The Construction Chart Book: The U.S. Construction Industry and Its Workers*. 5th ed. Silver Spring, MD: CPWR; 2013. https://www.cpwr.com/sites/default/files/publications/5th-Edition-Chart-Book-Final.pdf Accessed February 22, 2019
38. Yi W, Chan APC. Effects of heat stress on construction labor productivity in Hong Kong: a case study of rebar workers. *Int J Environ Res Public Health*. 2017;14(9):1055. https://doi.org/10.3390/ijerph14091055.
39. Kjellstrom T, Lemke B, Otto M, Hyatt O, Dear K Occupational Heat Stress Contribution to WHO project on "Global assessment of the health impacts of climate change", which started in 2009: Climate Change Health Impact & Prevention Technical Report 2014. http://climatechip.org/sites/default/files/publications/TP2014_4_Occupational_Heat_Stress_WHO.pdf. Accessed February 15, 2019.
40. Flouris AD, Dinas PC, Ioannou LG, et al. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *Lancet Planet Health*. 2018;2(12):e521-e531. https://doi.org/10.1016/S2542-5196(18)30237-7
41. Abdelhamid TS, Everett JG. Physiological demands of concrete slab placing and finishing work. *J Constr Eng Manag*. 1999;125(1):47-52. https://doi.org/10.1061/(ASCE)0733-9364(1999)125:1(47)
42. Hess J, Weinstein M, Welch L. Ergonomic best practices in masonry: regional differences, benefits, barriers, and recommendations for dissemination. *J Occup Environ Hyg*. 2010;7(8):446-455. https://doi.org/10.1080/15459624.2010.484795
43. National Institute for Occupational Safety and Health. OSHA-NIOSH Heat Safety Tool App. https://www.cdc.gov/niosh/topics/heatstress/heatapp.html. Updated June 6, 2018. Accessed December 31, 2018.
44. Centers for Disease Control and Prevention. Heat and Outdoor Workers. https://www.cdc.gov/disasters/extremeheat/workers.html. Updated June 19, 2017. Accessed December 31, 2018.
45. Chan AP, Guo YP, Wong FK, Li Y, Sun S, Han X. The development of anti-heat stress clothing for construction workers in hot and humid weather. *Ergonomics*. 2016;59(4):479-495. https://doi.org/10.1080/00140139.2015.1098733
46. Lumley SH, Story DL, Thomas NT. Clothing ventilation—update and applications. *Appl Ergon*. 1991;22(6):390-394. https://doi.org/10.1016/0003-6870(91)90081-r
47. Occupational Safety and Health Review Commission. Secretary of Labor v. AH Sturgill Roofing Inc. OSHRC Docket No. 13-0224. February 28, 2019. https://www.oshrc.gov/assets/1/18/A.H._Sturgill_Roofing_Inc.%5E13-0224%5EComplete_Decision_signed%5E022819%5EFINAL.pdf?8324. Accessed March 23, 2019.
48. Habert G. Environmental impact of Portland cement production. In: Pacheco-Torgal F, Jalali S, Labrincha J, John VM, eds. *Eco-Efficient Concrete*. Cambridge: Woodhead Publishing Limited; 2013:3-25.
49. Shi C, Fernández-Jiménez A, Palomo A. New cements for the 21st century: the pursuit of an alternative to Portland cement. *Cement Concrete Res*. 2011;41(7):750-763. https://doi.org/10.1016/j.cemconres.2011.03.016
50. West GH, Lippy BE, Cooper MR, et al. Toward responsible development and effective risk management of nano-enabled

products in the U.S. construction industry. *J Nanopart Res*. 2016;18(2):49. https://doi.org/10.1007/s11051-016-3352-y
51. CPWR – The Center for Construction Research and Training. Temporary workers in construction and other Industries. *The Construction Chart Book: The U.S. Construction Industry and Its Workers*. 6th ed. MD: CPWR: Silver Spring; 2018. https://www.cpwr.com/publications/research-findings-articles/construction-chart-book
52. Rathod JM. Danger and dignity: immigrant day laborers and occupational risk. *Seton Hall Law Rev*. 2016;46(3):813-882.
53. Buchanan SN, Nickels L, Morello J. Occupational health among Chicago day laborers: an exploratory study. *Arch Environ Occup Health*. 2005;60(5):276-280. https://doi.org/10.3200/AEOH.60.5.276-280 Sep-Oct

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