Impact of Excessive Heat on the Frequency of Work-Related Injuries

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WCRI

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Any errors in the report are the responsibility of the authors.

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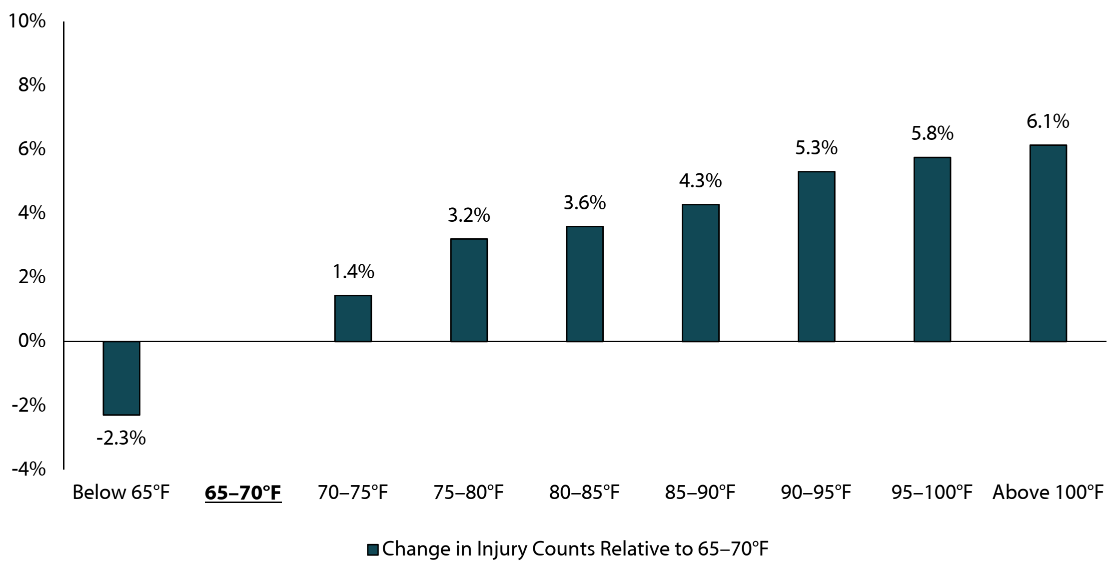
EXECUTIVE SUMMARY

Many locations throughout the United States have been increasingly experiencing higher temperatures. In this study, we examine how excessive heat affects the incidence of injuries in the workplace.

We consider two types of work-related injuries caused by heat: direct and indirect. Direct heat-related injuries are of a physiological nature, where the effect of heat on one's body leads to heat exhaustion, syncope, or cramps. Indirect heat-related injuries occur when heat impairs the perceptual, motor, or cognitive abilities of workers, leading to accidents (like falling off a ladder on a hot day).

Using claim-level data and temperature data from May to October over the 2016–2021 period, we found important effects of excessive heat on the incidence of occupational injuries. As shown in Figure ES.1, the probability of work-related accidents increases by 5 to 6 percent when the maximum daily temperature rises above 90°F, relative to a day with temperatures in the 65–70°F range.

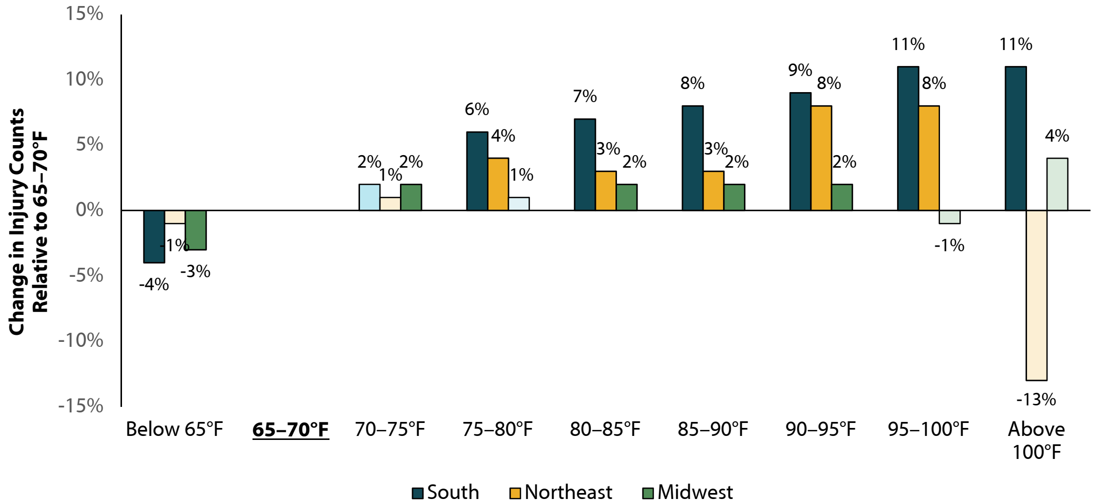
Figure ES.1 Estimated Percentage Change in Injury Incidence Due to Excessive Heat



Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

We found the effect is stronger in the South (Figure ES.2) and for construction workers (Figure ES.3). Also, the effect of excessive heat is larger on traumatic injuries, including fractures, dislocations, and contusions and lacerations.

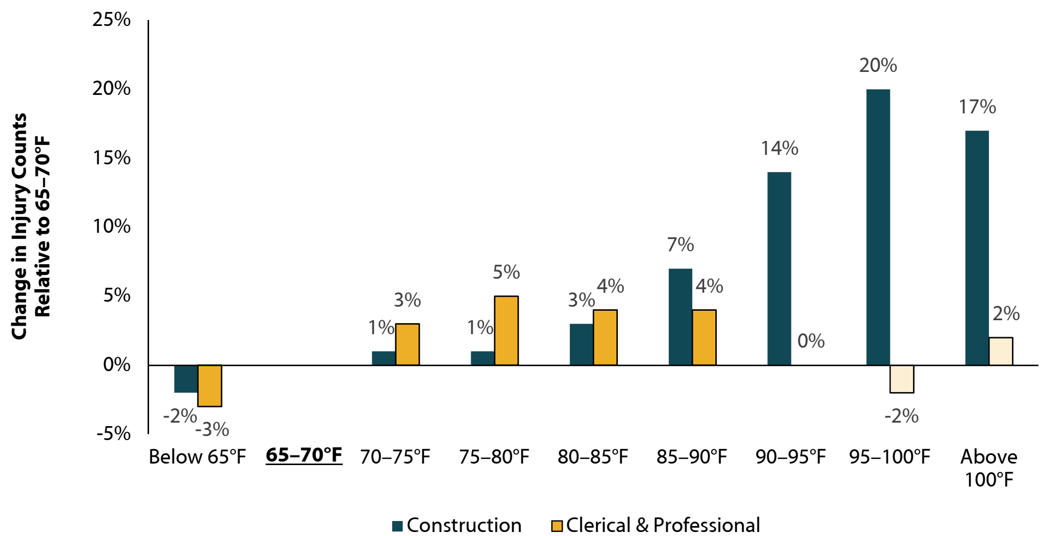
Figure ES.2 Estimated Percentage Change in Injury Incidence Due to Excessive Heat, by Region



Light-shaded bars indicate statistically insignificant estimates (at 10 percent).

Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

Figure ES.3 Estimated Percentage Change in Injury Incidence Due to Excessive Heat for Construction and Clerical & Professional Workers



Light-shaded bars indicate statistically insignificant estimates (at 10 percent).

Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

This study contributes to the literature by examining the overall impact of excessive heat on workers' compensation claims using recent data from 24 states across the United States. The report's findings can inform the public policy debate on the importance of preventing the effects of excessive heat, a growing concern as extreme temperatures become more frequent.

1

INTRODUCTION

Many locations throughout the United States have been increasingly experiencing excessive levels of heat in recent years. There have also been more frequent and more severe heat waves, hurricanes, floods, or wildfires. These phenomena have already been shown to lower economic activities (e.g., Behrer and Park, 2017), leading to reduced hours of work (Deryugina and Hsiang, 2014; Graff Zivin and Neidell, 2014) or increases in the frequency of work-related accidents (Dillender, 2021; Park et al., 2021). In this study, we expand on this literature by focusing on how excessive heat affects the incidence of injuries among workers in the United States.

We consider two types of injuries caused by excessive heat: direct and indirect. Direct heat-related injuries are of a physiological nature, whereby heat's impact on internal organs leads to heat exhaustion, syncope, or cramps. Indirect heat-related injuries occur when heat impairs the perceptual, motor, or cognitive abilities of workers, ultimately leading to accidents (like falling off a ladder on a hot day). Most of the extant research focuses on measuring the extent to which heat-related injuries increase during excessive heat weather in various areas of the country, in states like Washington or California (Bonauto et al., 2007; Heinzerling et al., 2020; Hesketh et al., 2020). In administrative claims databases, these injuries are recorded using codes that directly point to heat as being the primary cause of injury, e.g., heat exhaustion. Several recent studies (e.g., Dillender [2021] and Park et al. [2019], using data from Texas and California, respectively) attempted to measure overall effects of heat on work injuries, occupational health, and other related outcomes by considering all injuries that are attributable to excessive heat. Our study builds and expands on the latter strand of literature by using more recent workers' compensation data and by extending the areas of the country included in the analysis.

It is important to note that workers can adapt, or acclimatize, to excessive heat, which could reduce the incidence of heat-related work accidents. Workers can cope with excessive heat when body cooling is available in the form of air conditioning, ventilation, or access to shaded areas. While air conditioning is more available in indoor workplaces, or shaded areas for some outside jobs, it is not always feasible to ensure body cooling for workers exposed to excessive heat, especially in many outdoor occupations. Moreover, some state and federal work safety agencies recommend employers put in place measures to protect their workforce from the negative impacts of excessive heat (such as recommendations from the U.S. Occupational Safety and Health Administration [OSHA], discussed below). It may be optimal for employers to ensure their workers are protected against excessive heat risks in order to avoid increases in their workers' compensation insurance premiums and to ensure a continuous flow of their economic activities. To recruit and retain a qualified workforce, employers may tend to pay competitive wages to their employees, wages that would in theory compensate for the risks taken by workers performing jobs requiring exposure to risks such as excessive heat.

However, despite workers' acclimatization to heat, the various safety precautions considered in light of public agencies' standards or recommendations, and the incentives employers may have to protect their employees, there are several reasons—discussed in more detail below—for why workers might still be exposed to work-related injuries caused by heat.

The main goal of this study is to measure the extent to which excessive heat increases the incidence of work-related injuries in recent years, by taking into account both direct and indirect heat-related injuries. We also answer the question of whether there is variation in how excessive heat increases the frequency of work-related accidents in various regions of the country. This helps gain a more comprehensive understanding of how excessive heat affects worker populations in a more diverse set of climates, rather than in just a specific state. We also answer the question of whether the effect of excessive heat on the frequency of injuries is larger in certain industries, and on certain injury types.

This study is the first in a series of studies in which WCRI will analyze the impact of excessive heat on other relevant dimensions and outcomes in workers' compensation, such as medical payments, indemnity payments, or disability duration. Other extensions, or venues for future research, could include the measurement of how other instances of weather events (such as low air quality, wildfires, hurricanes, floods, and excessive cold) impact the frequency of work-related injuries and workers' compensation outcomes.

2

EXCESSIVE HEAT AND WORK-RELATED INJURIES

In this chapter we review the mechanisms that have been documented to lead to injuries attributable to excessive heat, summarize the extent of current protection recommendations and standards against excessive heat, and provide a more in-depth literature review on the magnitude of the effects of heat on worker outcomes.

HOW DO HEAT-RELATED INJURIES OCCUR AT WORK?

There is ample literature pointing to the deleterious effects of excessive heat on the human body. Heat exposure above normal limits can reduce the body's ability to regulate physiological processes and can result in heat-related injury or illness, heat stroke, or death (OSHA, 2016). Typically, excessive heat acts on the human body by increasing body temperature above normal levels, with detrimental effects on heart rates, respiratory rates, or blood pressure, which ultimately can lead to heat exhaustion, syncope, fatigue, or cramps. Other negative consequences of excessive heat include cardiovascular, kidney, or respiratory failure (e.g., Seltenrich, 2015; Lee et al., 2019). In work-related circumstances, these heat-related injuries can be traced in the data as injuries that are directly caused by heat. They are often coded using the ICD-9 code 992 or ICD-10 codes T67.0–T67.9. There is substantial epidemiological literature documenting the ways in which high temperatures and heat waves affect workers' health and productivity (Borg et al., 2021; Kjellstrom, Holmer, and Bruno, 2009; LoPalo, 2023). Most of this literature was focused on direct heat-related injuries (e.g., Levi, Kjellstrom, and Baldasseroni, 2018).

In addition, excessive heat can reduce workers' ability to conduct perceptual, psychomotor, or cognitive tasks (Donnan, Williams, and Stanger, 2021; Hancock, Ross, and Szalma, 2007; Hancock and Vasmatzidis, 2003; Martin et al., 2019; Pilcher, Nadler, and Busch, 2002). In such situations, workers' attention and speed of reaction are negatively affected, leading to a higher probability of work-related injuries. In addition, as fatigue often sets in because of exposure to excessive heat, the incidence of work-related injuries increases too. Examples of such injuries include falling off a ladder on a hot day, or being hit by a vehicle or moving machine at work, as workers' perception of their surroundings may be impaired on an extreme heat day. These injuries are ultimately attributable to excessive heat but are likely to be recorded in data as having causes other than excessive heat.

Moreover, excessive heat exacerbates existing health problems like asthma, kidney failure, and heart disease, and can cause heat stroke and even death if not treated properly and promptly. The effect of excessive heat on individual-level factors such as age, pharmaceutical use, comorbid health conditions, and the ability to cool at night (during heat waves, for example) could further exacerbate the negative effects of excessive heat (Kilbourne, 1997; Levi, Kjellstrom, and Baldasseroni, 2018; OSHA, 2021a; Quandt et al., 2013).

The effects of excessive heat can be mitigated by acclimatization—when workers have the opportunity to adapt to heat—and by body cooling techniques (such as air conditioning) (Douma et al., 2020; Foster et al., 2020). Acclimatization consists of changes in the body that occur during repeated exposure to heat. These changes, including increased efficiency or increased skin blood, allow the body to better endure working in hot conditions (e.g., Chong and Zhu, 2017; Fox et al., 1963; Strydom et al., 1966).

In addition to the mechanisms through which excessive heat can affect workers, the frequency of injuries attributable to heat vary substantially by the worker's industry and occupation. Some industries and occupations expose workers to a higher risk of injuries attributable to extreme heat. For instance, OSHA identifies several industries with a higher risk of heat injuries or illnesses—mining, quarrying, oil and gas, construction, manufacturing, administrative and support and waste management and remediation services, and transportation and warehousing (OSHA, 2021a). Agriculture, construction, transportation and warehousing, and administrative and support and waste management and remediation services experience the highest rates of heat-related mortality rates (Gubernot, Anderson, and Hunting, 2014; Tustin et al., 2018).

There are industry or workplace classifications based on the type of exposure to excessive heat: outdoor exposure, indoor exposure, and a combination of indoor and outdoor exposure (Metz, Prier, and Miller, 2021). Sources of excessive indoor heat include furnaces, kilns, stoves, or greenhouses, and they affect workers in foundries, brick-firing and ceramic plants, glass production facilities, rubber products factories, electrical utilities (particularly boiler rooms), bakeries, confectioneries, commercial kitchens, laundries, food canneries, warehouses without adequate climate control, chemical plants, and smelters. Exposure to outdoor excessive heat is likely to occur for occupations in agriculture, landscaping, construction operations, refining gas/oil and well operations, asbestos and lead removal, waste collection activities, package and mail delivery, and any other activities requiring moderate to high physical exertions or the wearing of heavy or bulky clothing or equipment on a hot day (OSHA, 2021a). Moreover, for some occupations in which workers are already exposed to indoor sources of heat, outdoor excessive heat can combine with indoor heat and thus intensify workers' heat exposure and risk of injuries, such as working near a hot furnace or stove on a hot day. Not least, even workers who perform their activities indoors (without exposure to indoor heat) can be affected by excessive outdoor heat if their work environment does not cool properly during periods of high outdoor heat.

Currently, there are several thresholds and classifications used to assess exposure to excessive heat based on the wet bulb globe temperature (WBGT),[1] which considers radiant effects of the sun, air temperature, relative humidity, wind speed, and barometric pressure; the heat index (HI), which considers the temperature and the relative humidity; or the humidity index (humidex), which considers temperature and dew point.[2] OSHA provides guidance according to which temperatures below 70°F (WBGT) pose a low risk of heat-related illness for both acclimatized and unacclimatized workers.[3] When the temperatures reach 70°F (WBGT), strenuous work is possibly unsafe for unacclimatized workers, while when temperatures rise above 77°F (WBGT), there is a high risk of heat-related illness for unacclimatized workers when doing strenuous work. The National Weather Service (NWS) uses the heat index to classify environmental heat into four categories: caution (80°F–90°F HI), extreme caution (91°F–103°F HI), danger (103°F– 124°F HI), and extreme danger (126°F or higher HI). Also, the concept of "heat priority days" is used to determine the days in which a maximum heat temperature can result in an increased risk of heat-related illnesses, that is, above 80°F (OSHA, 2021a). Criteria for heat priority days vary across the country. It is important to note in areas of the United

[1] https://www.osha.gov/heat-exposure/wbgt-calculator

[2] https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml

[3] https://www.osha.gov/heat-exposure/hazards

States not usually subject to elevated dangerous heat conditions, unacclimatized workers may suffer serious heat-related illnesses even when the heat index does not exceed the NWS's heat advisories or warnings. Other ways to assess extreme heat exposure rely on heat hazard frequency measures, such as extreme heat days by county, state, or region (i.e., the number of days exceeding 90°F [Metz, Prier, and Miller, 2021]), or the number of heat waves.

PROTECTIVE MEASURES AGAINST EXCESSIVE HEAT

Currently, there is no federal occupational health and safety standard in effect to protect workers from heat exposure. OSHA has been taking steps toward the creation of a federal standard protecting workers against excessive heat that would more clearly and uniformly set forth employer obligations and measures required to prevent and reduce the incidence of work-related injuries, illnesses, and fatalities caused by excessive heat.[4]

Under the existing Occupational Safety and Health Act, employers are responsible for providing workplaces free of known safety and health hazards (also known as the "general duty" clause), including protecting workers from heat-related hazards. OSHA already outlined several recommendations for employers to ensure workers are protected against excessive heat, such as ensuring that workers follow the "20 percent rule" for new workers (i.e., start with 20 percent of the typical duration of a normal shift and gradually increase by 20 percent each additional day), drink cool water often, take rest breaks, take shelter in cool or shaded areas, dress for the heat, watch out for fellow workers, and so on. In case of a heat-related injury, signs of a heat-related medical emergency include abnormal thinking or behavior, slurred speech, seizures, or loss of consciousness; first aid measures include calling 911, cooling the worker right away, and staying with the worker until help arrives. Other signs potentially leading to a medical emergency include headache or nausea; weakness or dizziness; heavy sweating or hot, dry skin; thirst; and decreased urine output.[5]

Several states currently have occupational heat stress standards. These are OSHA-approved state plans that cover hazards not addressed by federal OSHA standards. These states are California and Washington, with standards for outdoor workplaces (adopted in 2005 and 2008, respectively), Oregon for indoor and outdoor workplaces (adopted in 2022), Colorado for agricultural workers (adopted in 2022), and Minnesota for indoor workplaces (adopted in 2014). For instance, California's standard stipulates that protection requirements are triggered at 80°F and requires that workers drink one quart of water per hour. Employers are required to put in place an acclimatization plan, a heat illness prevention plan, and an emergency response plan. Work breaks are encouraged in general and are mandatory if workers show symptoms of excessive heat exposure. Other standards and regulations are in development in California (for indoor workplaces), Nevada, and Maryland (Natural Resources Defense Council [NRDC], 2024).[6] Table TA.1 in the technical appendix provides more details on these standards, temperature thresholds when they go into effect, and other features. Conversely, in Texas, a recent bill (House Bill 2127, adopted in May 2023) limits cities and counties from creating additional

[4] OSHA published an Advance Notice of Proposed Rulemaking for heat in October 2021 (OSHA, 2021b) and concluded the Small Business Regulatory Enforcement Fairness Act (SBREFA) process on November 3, 2023. This step in the rulemaking process also included the convening of a panel to gain input from small entity representatives on the potential impacts of a heat-specific standard.

[5] https://www.osha.gov/sites/default/files/publications/3431_wksiteposter_en.pdf
https://www.osha.gov/heat/employer-responsibility

[6] Natural Resources Defense Council, "Occupational Heat Safety Standards in the United States," updated March 12, 2024: https://www.nrdc.org/resources/occupational-heat-safety-standards-united-states.

rules to the state's legal requirements on labor, agriculture, and natural resources.[7] More recently, Florida enacted legislation effective July 1, 2024, limiting local governments from creating heat exposure requirements that are not required under the state or federal law.[8]

Employers might take steps to ensure that workers are protected against the risks of excessive heat to ensure a continuous flow of their economic activities. Moreover, to attract and retain qualified employees in competitive labor markets, employers offer competitive wages, which in theory compensate for the risks taken by workers when taking up jobs with exposure to risks such as excessive heat. Employers might also find it in their interest to protect workers against excessive heat as the reduction of risks could help them avoid increases in their workers' compensation insurance premiums. On the other hand, behaviors workers might take to avoid excessive heat might be discouraged by employers, especially when they extend over longer periods of time. There are therefore several reasons why employers' optimal level of heat protection against excessive heat could be lower than the workers' optimal level of protection (Dillender, 2021). Park et al. (2021) discussed additional conditions (such as conditions of wage inequality or imperfectly competitive labor markets) under which the compensating wage differentials may not fully cover the workers' inherent risk of exposure to heat.

THE EFFECT OF EXCESSIVE HEAT

A substantial number of studies measured the impact of excessive heat by assessing the extent to which heat-related injuries (HRI) increase on a hot day, or during a heat wave. For instance, Spector et al. (2023) found that during a "heat dome" event experienced by Washington State in the summer of 2021, among all HRI workers' compensation claims, 76 percent occurred on days with a maximum temperature at or above 80°F, and 29 percent occurred when the temperature suddenly increased relative to the past five days by 10°F, a finding that points to a lack of acclimatization by workers when temperatures increase suddenly. Also, Hesketh et al. (2020) found in the third calendar quarter over the 2006 to 2017 period, public administration workers had the highest rate of heat-related injuries in Washington State (131.3 per 100,000 full-time employees), followed by agriculture, forestry, fishing, and hunting sector workers, with 102.6 injuries per 100,000 full-time employees. Spector et al. (2016) examined the association between heat exposure (as measured by the maximum daily humidex) and traumatic injuries in outdoor agricultural workers, finding that the risk of traumatic injuries increases as a result of heat exposure and internal heat generated by physical effort (e.g., estimating an odds ratio of 1.14). Calkins et al. (2019) also found a nearly linear association of the humidity index with the probability of a traumatic injury among construction workers. Effect estimates were higher among younger (18–24 years) and older (>54 years) workers, workers with lower extremity injuries, workers with less job experience, and smaller employers. Between 1995 and 2005, Bonauto et al. (2007) found the industries with the highest HRI incidence in Washington State during periods of high outdoor ambient temperatures were fire protection; roofing; construction; and highway, bridge, and street construction.

Excessive heat has been shown to be associated with other workers' compensation outcomes as well. Using data from North Carolina, Bradford et al. (2023) identified a correlation between the annual hours above a heat index of 90°F and the costs of workers' compensation claims.

In addition to papers capturing the direct impact of excessive heat on work-related injuries, several recent

[7] https://capitol.texas.gov/tlodocs/88R/billtext/pdf/HB02127F.pdf

[8] https://www.flsenate.gov/Session/Bill/2024/1492/BillText/Filed/PDF

studies expanded the scope of measuring the effects of excessive heat to the overall counts of injuries that are ultimately attributable to excessive heat. In other words, these studies attempted to provide estimates of the overall impact of excessive heat.

In an influential 2021 paper, Dillender estimated empirical models in which, using administrative data on workers' compensation claims from Texas, the injury rates at the metropolitan statistical area (MSA) level were modeled as a function of indicator variables controlling for the possibility that the incidence of injuries can vary by the day of the week, by the day of the month, and by the year in the time frame considered (2006–2014). He identified the effect of excessive temperature on claim rates, accounting for local area specific factors. Other controls included information on the day's precipitation as well as the temperature and precipitation surrounding the day of observation. Some of the major findings are that same-day claim rates increase by 5 percent on a day with temperatures of 86–88°F, and by about 8 percent on a day with a temperature over 100°F, relative to days with temperatures of 59–61°F.

Using workers' compensation claims data from California over the 2001–2018 period, linked to zip code-day level weather data from PRISM Climate Group, Park et al. (2021) followed a similar approach to Dillender (2021) and estimated a residual risk of injury that is attributable to excessive heat. In other words, they examined whether realized injuries are higher on a hotter-than-average day within a given zip code-month-year cell using models with zip-month indicators, accounting for local area-specific injury risk and seasonality, and month-year indicators, to control for California's economic shocks or macroeconomic trends. They also found that higher temperatures increase the likelihood of injuries at work, in proportions similar to the ones from Dillender (2021).

Also relevant to this discussion is the disproportionate impact of excessive heat by the sociodemographic and economic status of workers. Lower-wage workers tend to live and work in areas with greater exposure to excessive heat and potentially with limited access to air conditioning. Park et al. (2021) estimated that for a worker from the bottom quintile of the income distribution, the effect was approximately five times larger than for a worker from the top quintile of the income distribution. They also found that the effect of heat on injuries was significantly larger for men relative to women, and for younger workers relative to older ones. Other studies also point to inequities. Gubernot, Anderson, and Hunting (2014) found that Black and Hispanic workers had higher relative risks of heat-related fatalities compared with White workers over the 2000–2010 period.

3

DATA AND METHODS

In this chapter, we provide a discussion of the data used for this study, the metrics we constructed, and the empirical approach we implemented to measure how excessive heat increases the frequency of work-related accidents in recent years.

DATA

Our empirical analyses rely on two data sources. The first data source is the WCRI Detailed Benchmark/Evaluation (DBE) database, covering all workers' compensation market segments (self-insurance, residual market, voluntary insurance, and state funds). The DBE database is one of the most complete workers' compensation claims databases, and it contains information on the day and zip code when a given work-related injury occurs.[1] The second database contains information on the maximum daily temperature by zip code from May 1 to October 30 over the 2016–2021 period.[2] This data source contains information collected by the National Oceanic and Atmospheric Administration (NOAA) from local weather stations. The temperature values come from the weather station that is closest to a given zip code. The daily maximum temperature for the zip code is set to the value from the weather station that is closest to a given zip code. We collapsed the zip code-day level information to the county-day level, with the maximum daily temperature at the county level determined as the weighted average of maximum temperatures from the zip code level, where the weights are based on the employed population in each zip code. Zip code-level employment data within each county for the years 2016 through 2021 was obtained from the County Business Patterns, a U.S. Census Bureau annual series that provides local area economic data.[3]

We merged the daily maximum temperatures to the daily injury counts and injury rates per 100,000 workers at the county-day level. Our combined data include per county per day information on temperature and the count of injuries from a total of 24 states.[4] These 24 states represent about half of the workers' compensation benefits paid in the United States (Boden et al., 2021). We also kept in the data only the typical working days, i.e., Monday to Friday. Our total number of county-day observations over the 36 months in our

[1] While the DBE database is comprehensive, it is important to note that it does not reflect the entire universe of workers' compensation claims. Coverage of claims in each of the states included ranges between 40 and 80 percent.

[2] This data was organized based on daily data extracts from NOAA by Commenda, LLC.

[3] U.S. Census Bureau, County Business Patterns: https://www.census.gov/programs-surveys/cbp.html.

[4] The 24 states are Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Minnesota, Missouri, New Jersey, New York, North Carolina, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, and Wisconsin.

time frame was around 1.1 million.[5]

We measured the effect of excessive heat using the daily maximum temperature. We classified the maximum daily temperatures into nine categories: below 65°F, 65–70°F, 70–75°F, 75–80°F, 80–85°F, 85–90°F, 90–95°F, 95–100°F, and above 100°F. Using OSHA's recommendations discussed above, we used the range of temperatures between 65 and 70°F as the reference category.

In our empirical model we assessed the change in the incidence of injuries with two outcome measures: (1) the daily injury count in a county, and (2) the daily injury rate in a county—measured as the daily number of injuries per 100,000 employees. We weighted the injury rate measure by county employment to give more importance to the locations with more employees.

EMPIRICAL APPROACH

The empirical approaches in Dillender (2021) and Park et al. (2021) allow for an effective estimation of the impact of excessive heat on the frequency of injuries. This approach relies on the isolation of confounding factors, such as the injury risk that can vary by month or year, and specific local area characteristics, including economic and work-specific trends. The estimation of an effect that is attributable to excessive heat is obtained by exploiting the variation in temperature (or, ostensibly any other measure of excessive heat) within different locations, such as zip code, county, or metropolitan statistical area. The main underlying assumption is that any other unobservable determinants of injury risk in a given location are not correlated with the excessive heat reported in that location. As long as this assumption holds, the model yields causal estimates of a residual injury risk due to excessive heat.

Following a similar approach to Dillender (2021) and Park et al. (2021), we estimated models in which the outcomes of interest are the two measures discussed above: the daily injury count in a county, and the daily injury rate in a county—measured as the daily number of injuries per 100,000 employees. We modeled these outcomes at the county-day level as a function of maximum daily temperature and accounted for the trends in the risk of injuries by including indicators for year in the model. We controlled for local area characteristics that can be correlated with the risk of injuries by including county indicators in the model. We included indicators that allowed for the control of state-specific factors, such as state policies and the workers' compensation system features. We accounted for local area economic changes and national trends in workplace injuries by including interaction terms between month-year and county indicators. The estimates on maximum temperature measure, in essence, the difference in the probability of work-related accidents between days with and without excessive heat, all else constant. We limited the sample to include all working days from May to October in the 2016–2021 time frame. More details on our statistical specification are available in the technical appendix.

This empirical approach also considers the potential impact of safety and prevention measures since it looks at injuries that are ultimately caused by excessive heat. This means that as long as heat-related safety

[5] We excluded from our sample four Western states (Arizona, California, Nevada, and New Mexico) for two reasons. First, we identified discrepancies in maximum daily temperatures between the weather data obtained from Commenda, LLC and other weather data sources, such as the PRISM Climate Group, that are likely caused by the Commenda temperature data having temperatures based on the nearest zip code. This is likely to lead to inaccuracies, especially given the significant temperature variations across zip codes within a county in the Western states. The second reason why we dropped the Western states from the analysis was that the substantial variation across zip codes within these states makes a zip code-day level analysis more appropriate than the county-day level approach we adopted in our study.

measures do not change from one day to another, all variation in the frequency of injuries, all else constant, can be attributable to excessive heat in a given location.[6]

[6] It is important to note that even if there are safety changes adopted in response to daily temperatures, our analysis still yields unbiased estimates of excessive heat as long as there are no immediate behavioral responses to temperature.

4

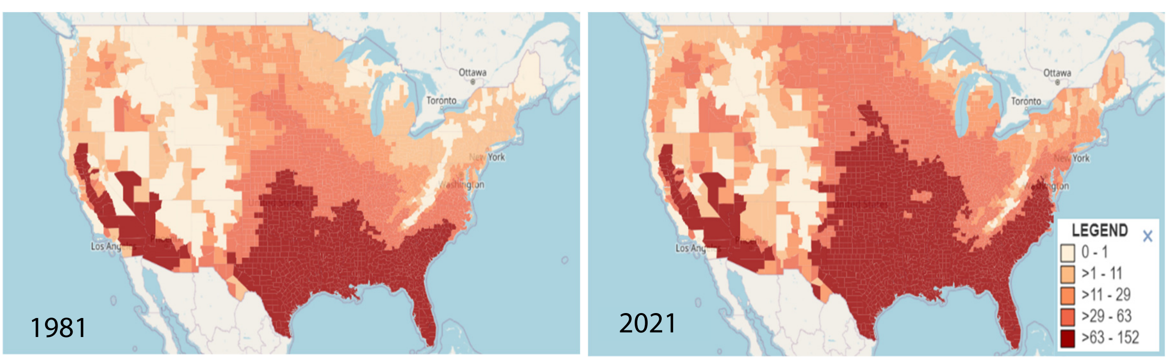
EXPOSURE TO EXCESSIVE HEAT AND THE FREQUENCY OF INJURIES

Next, we provide an overview of the extent of excessive heat in recent years. Then we discuss features of our data and the outcome measures considered in the empirical analysis.

HOW FREQUENT HAS EXCESSIVE HEAT BECOME?

In Figure 4.1, we provide a comparison between the number of days with excessive heat (i.e., with a heat index above 90°F) by county in 1981 and 2021. The number of days above the 90°F heat index threshold increased notably in many counties in the South, the Midwest, and even the Northeast over this 40-year span. The number of counties with more than 63 days of excessive heat (the darkest shade) increased, mainly in the South and parts of the Midwest, but even the number of counties with 29 to 63 days of excessive heat (the second darkest shade) increased substantially in the Midwest and the Northeast from 1981 to 2021.

Figure 4.1 Annual Number of Extreme Heat Days from May to September (daily maximum heat index >90°F)



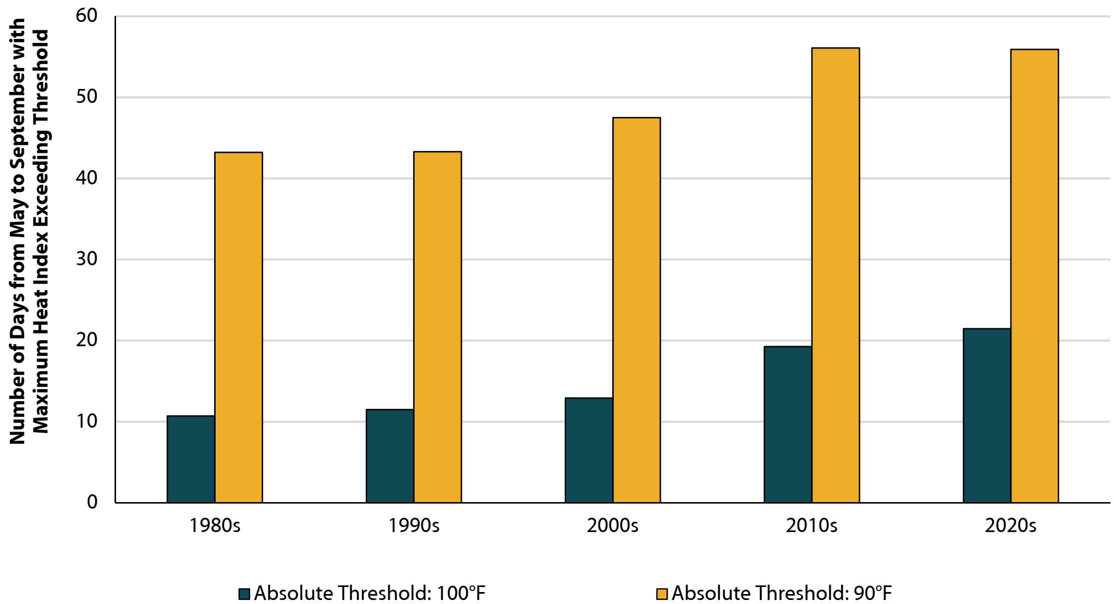
Notes: Census tract and county-level estimates of heat index were obtained by the data source by processing modeled data, which are available by 1/8th-degree grid. The process of converting grid-level data to other geographies using a population-weighted centroid approach may lead to potential misclassification of heat index for some areas. Modeled temperature data obtained from North American Land Data Assimilation System (NLDAS) were used to create measures. More about NLDAS is available here: https://www.emc.ncep.noaa.gov/mmb/nldas/.

Source: These figures were generated from the Centers for Disease Control and Prevention, National Environmental Public Health Tracking Network (NEPHTN).

Assessing the trend in excessive heat days over the last decades, there has been a clear increase in the number of days with temperatures above 90°F and 100°F annually, from 43 and 11 days above the thresholds in the 1980s, to 56 and 21 days above the thresholds in the 2020s, respectively. It is apparent from Figures 4.1

and 4.2 that excessive heat has become more frequent, and if these trends continue, the result will be more heat exposure for the workforce.

Figure 4.2 Trend in Number of Excessive Heat Days from May to September



Notes: The underlying data were obtained by converting county-level estimates of the annual days from May to September with a maximum heat index exceeding the threshold to annual national-level estimates using employed population weights. The annual estimates were averaged over the decade. County-level estimates of the number of days with maximum heat exceeding 90°F and 100°F are from the Centers for Disease Control and Prevention, National Environmental Public Health Tracking Network (NEPHTN).

EXCESSIVE HEAT AND THE FREQUENCY OF WORK-RELATED INJURIES

The next two tables provide several insights into the data we used for this study. Table 4.1 shows the distribution of temperature as reflected by our data. It reflects the level of heat exposure workers experienced over this period, overall, by region, by month, and by year. About 53 percent of observations (at the county-day level) are concentrated in the 75–90°F temperature range, while 19 percent of observations are concentrated in the temperature ranges above 90°F. As expected, the proportion of county-days peaks in the warmer months of our sample (July and August). Overall, we have a balanced distribution of temperatures in our data, with a higher concentration of colder days (below 65°F) in the Midwest and the Northeast relative to the South, and a higher concentration of hotter days (above 90°F) in the South than in the Northeast and Midwest.

Table 4.1 Distribution of Daily Maximum Temperatures by Month, Year, and Region

	Below 65°F	65 to 70°F	70 to 75°F	75 to 80°F	80 to 85°F	85 to 90°F	90 to 95°F	95 to 100°F	Above 100°F
Overall	12.3%	6.8%	8.9%	12.8%	19.1%	21.1%	15.4%	3.0%	0.5%
Region									
Midwest	21.9%	9.1%	11.8%	16.7%	21.0%	14.0%	5.0%	0.5%	0.1%
Northeast	19.0%	10.7%	13.2%	16.8%	18.5%	14.2%	6.9%	0.7%	0.0%
South	3.9%	3.4%	5.1%	8.6%	18.6%	28.5%	25.4%	5.6%	0.9%
Month									
May	20.3%	10.2%	10.0%	14.2%	22.7%	16.4%	5.1%	0.9%	0.2%
June	3.4%	3.7%	7.1%	14.2%	24.9%	25.8%	17.2%	3.0%	0.7%
July	1.9%	0.7%	2.0%	7.1%	21.7%	29.9%	27.8%	7.1%	1.8%
August	1.6%	1.3%	4.2%	11.7%	25.5%	26.2%	22.0%	5.8%	1.7%
September	6.8%	6.9%	9.8%	15.5%	20.6%	21.9%	15.2%	2.9%	0.3%
October	33.1%	12.8%	11.8%	13.0%	15.3%	10.3%	3.2%	0.6%	0.1%
Year									
2016	8.9%	5.6%	6.6%	11.9%	21.8%	22.7%	17.5%	4.1%	0.9%
2017	11.8%	6.9%	9.0%	14.4%	23.4%	20.5%	11.7%	2.0%	0.5%
2018	11.7%	5.2%	6.8%	11.7%	21.7%	22.2%	16.1%	3.6%	1.1%
2019	13.3%	6.4%	7.9%	11.9%	18.8%	20.0%	15.8%	4.8%	1.1%
2020	14.9%	6.9%	7.7%	12.4%	20.8%	19.8%	13.7%	2.9%	0.8%
2021	8.2%	5.1%	7.3%	13.5%	24.0%	24.5%	14.6%	2.3%	0.4%

Notes: This table provides a distribution of the maximum daily temperatures at the county-day level from May to October 2016–2021 covering the 24 states included in this study. Daily maximum temperature data at the zip code level was provided by Commenda, LLC, which obtained the data collected by the National Oceanic and Atmospheric Administration (NOAA) from local weather stations. The daily maximum temperature for the zip code is set to the value from the weather station that is closest to a given zip code. Zip code-day level estimates of the maximum daily temperature were aggregated to the county-day level using employed population weights.

In Table 4.2 we show the distribution of work-related injuries at the county and day level—by the temperature categories considered in Table 4.1—in the aggregate, for each industry, by region, and by injury type.

As shown in Tables 4.1 and 4.2, the work-related injuries were more frequent on the warmer days of our time frame overall and for each industry. While this may indicate a correlation with excessive heat, we cannot draw any clear conclusions in this direction since there may be other factors at play that could influence the higher probability of injuries when the daily maximum temperature is above a certain threshold, such as seasonality, state-specific features, local area characteristics, economic trends, workforce changes, and so on. We account for these differences in the empirical analysis presented in the next chapter.

Table 4.2 Distribution of Injury Counts by Month, Year, and Region

	Below 65°F	65 to 70°F	70 to 75°F	75 to 80°F	80 to 85°F	85 to 90°F	90 to 95°F	95 to 100°F	Above 100°F
Overall	3.8%	6.2%	7.2%	12.8%	23.0%	24.2%	18.2%	3.8%	1.0%
Region									
Midwest	9.0%	9.5%	11.0%	18.9%	27.3%	17.0%	6.5%	0.7%	0.1%
Northeast	6.0%	10.9%	12.0%	19.1%	26.0%	17.5%	7.6%	0.9%	0.0%
South	0.6%	2.8%	3.6%	7.5%	19.9%	30.1%	27.6%	6.3%	1.7%
Month									
May	7.8%	11.0%	10.7%	14.8%	26.4%	20.9%	7.1%	1.0%	0.1%
June	0.1%	4.3%	6.8%	14.0%	24.4%	26.7%	19.7%	3.2%	0.8%
July	0.0%	0.8%	1.9%	7.0%	21.2%	29.6%	29.9%	7.7%	2.0%
August	0.0%	1.1%	3.6%	11.4%	24.4%	26.8%	24.6%	6.0%	2.0%
September	0.4%	7.6%	10.1%	16.2%	22.0%	23.0%	17.6%	2.8%	0.3%
October	18.6%	15.7%	12.5%	14.1%	18.7%	15.2%	4.6%	0.5%	0.0%
Industry									
Agriculture, forestry, and fishing	3.1%	5.7%	6.7%	11.9%	21.7%	25.9%	19.7%	4.5%	0.8%
Clerical & professional	4.0%	6.4%	7.5%	12.3%	22.1%	24.4%	18.4%	3.9%	0.9%
Construction	3.0%	4.9%	6.0%	10.8%	20.8%	25.1%	22.2%	5.5%	1.8%
Health care and social assistance	3.9%	6.6%	7.4%	13.2%	22.9%	24.4%	17.5%	3.3%	0.7%
Manufacturing	4.5%	6.7%	7.8%	13.9%	24.5%	22.5%	15.8%	3.4%	0.8%
Mining (including oil and gas)	3.2%	5.4%	6.1%	12.0%	21.3%	23.5%	19.3%	6.4%	2.9%
Public safety	2.8%	5.3%	6.3%	11.6%	22.1%	26.0%	20.1%	4.5%	1.3%
Restaurants and entertainment	2.8%	4.9%	6.0%	10.8%	21.5%	26.4%	21.7%	4.7%	1.2%
Services	3.5%	5.9%	7.0%	12.2%	22.4%	25.1%	19.1%	3.9%	1.0%
Transportation, warehousing, and utilities	3.5%	6.0%	6.9%	12.6%	23.0%	24.2%	19.1%	3.8%	1.0%
Wholesale and retail trade	4.0%	6.6%	7.7%	13.5%	23.8%	23.7%	16.8%	3.2%	0.7%
Injury type									
Traumatic (fractures, contusions, lacerations)	3.9%	6.3%	7.3%	12.8%	23.0%	24.1%	18.1%	3.7%	0.9%
Sprains and strains	3.8%	6.2%	7.3%	12.8%	23.0%	24.1%	18.0%	3.7%	0.9%
Other injuries	3.6%	6.0%	7.1%	12.6%	22.9%	24.4%	18.4%	4.0%	1.0%
Year									
2016	3.1%	5.9%	6.5%	11.2%	23.6%	25.1%	19.2%	4.4%	1.0%
2017	3.3%	7.2%	8.8%	14.8%	24.7%	23.0%	14.8%	2.8%	0.6%
2018	5.1%	5.5%	6.3%	11.7%	22.5%	24.4%	19.2%	3.9%	1.4%
2019	4.3%	6.9%	7.8%	12.7%	20.3%	22.4%	19.4%	5.1%	1.1%
2020	4.9%	6.9%	7.2%	12.7%	22.7%	23.4%	17.8%	3.5%	0.9%
2021	1.4%	4.2%	6.7%	13.7%	24.8%	27.6%	18.5%	2.7%	0.3%

Note: This table provides a distribution of the injury counts from May to October 2016–2021 covering the 24 states included in this study. Injury counts were obtained from the WCRI Detailed Benchmark/Evaluation (DBE) database.

5

IMPACT OF EXCESSIVE HEAT ON INJURIES

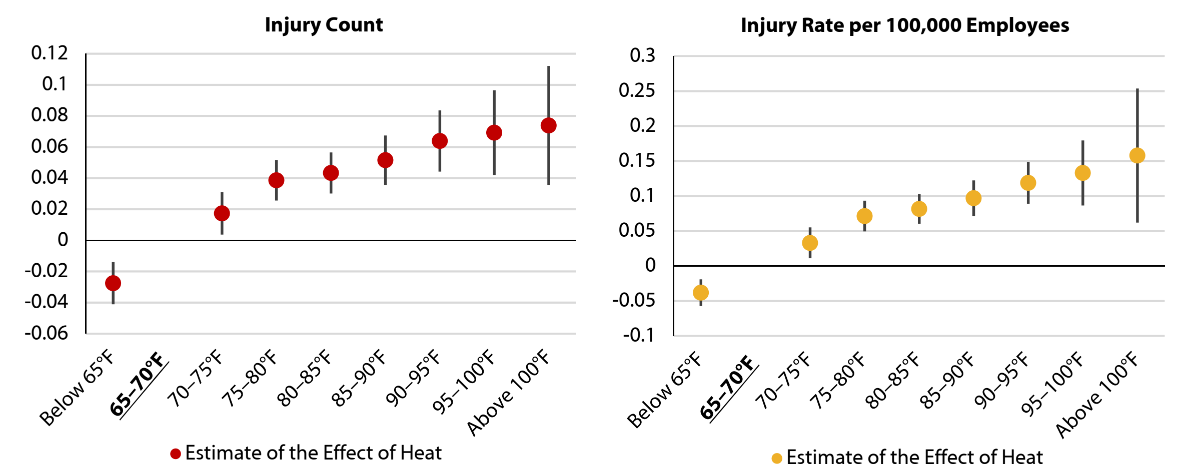
In this chapter, we discuss the findings from our empirical analysis described above. We start with the overall effect of maximum daily temperature on injury frequency, followed by sub-analyses by region, industry group, and injury type.

IMPACT OF MAXIMUM DAILY TEMPERATURE

In Figure 5.1 below, we show our estimates (the colored dots) from regression models including all states available in our sample. The two panels of Figure 5.1 correspond to the two outcomes we considered: daily injury count per county and daily injury rate per 100,000 employees per county. The vertical lines around the estimates are 95 percent confidence intervals, indicating that our estimates are statistically significant.

The injury counts gradually (and non-linearly) increase as the daily maximum temperatures grow. Higher temperatures are associated with an increase in the incidence of work-related injuries, relative to the reference category of temperatures between 65 and 70°F.[1]

Figure 5.1 Regression Estimates of Injury Incidence Changes Due to Excessive Heat for Injury Counts and Injury Rates per 100,000 Employees

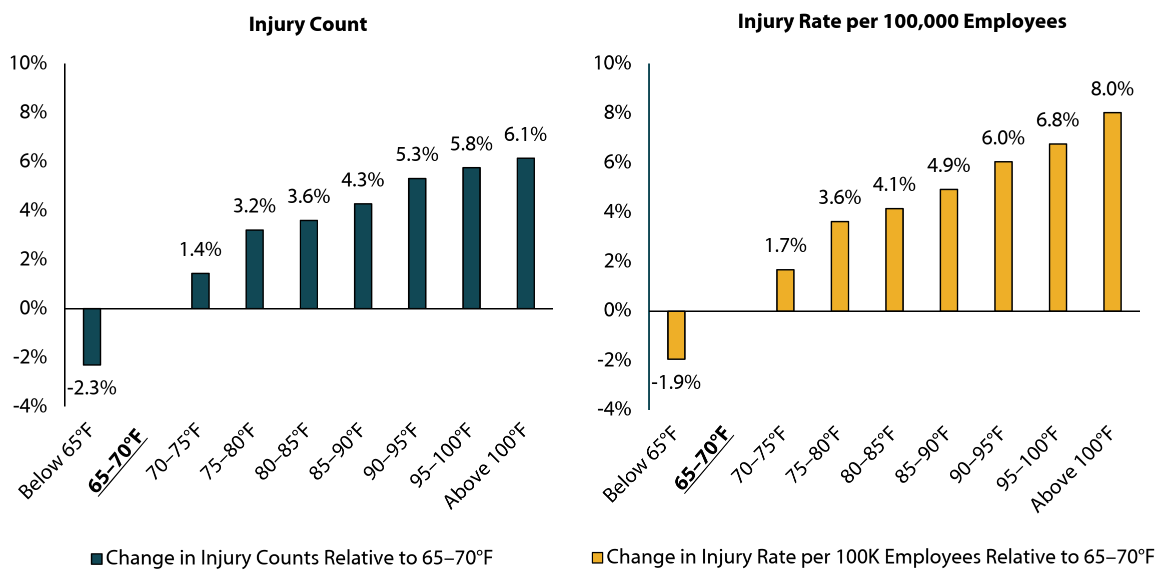


Notes: These charts show the full set of estimated coefficients of maximum daily temperatures on injury counts (left panel) and injury rates per 100,000 employees (right panel) obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level. Lines around the estimates indicate 95 percent confidence intervals.

[1] We chose this reference category in accordance with OSHA's recommendations, according to which temperatures below 70°F (in terms of effective WBGT) pose a low risk of heat-related illnesses: https://www.osha.gov/heat-exposure/hazards.

Figure 5.2 provides the magnitude of the effects displayed in Figure 5.1 in percentage terms. The bars in Figure 5.2 indicate the proportion by which the number of injuries and number of injuries per 100,000 employees, respectively, increase when temperatures reach higher values, relative to the reference category (65–70°F). For instance, the incidence of injuries increases by 5–6 percent when the daily maximum temperature goes over 90°F relative to the reference category, when measured as the number of injuries, and by 6–8 percent when measured as the number of injuries per 100,000 employees. These are non-trivial estimates of the effect of excessive heat and are to a large extent comparable in terms of magnitude with the estimates from the recent literature. Dillender (2021) found increases in the frequency of injuries of 7.6–8.2 percent on a day with a high temperature over 100°F relative to a day with a high temperature in the 58–61°F range. Park et al. (2021) found that a day with temperatures between 85 and 90°F leads to a 5–7 percent increase in same-day injury risk, relative to a day in the 60s, and a day above 100°F leads to a 10–15 percent increase.

Figure 5.2 Estimated Percentage Change in Injury Incidence Due to Excessive Heat



Notes: These charts show the full set of estimated effects of maximum daily temperatures on injury counts (left panel) and injury rates per 100,000 employees (right panel) obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

For moderate levels of heat (between 70 and 90°F), the frequency of injuries increases by 1–4 percent according to the injury count metric, and by 2–5 percent according to the injury rate per 100,000 employees metric. This is also in line with one of Dillender's (2021) findings, that injury rates began to increase once temperatures reach the mid-70s or mid-80s, and with previous studies showing increases in the risk of injuries for high energy activities even in moderate temperatures (e.g., Armstrong et al., 2007).

To test the robustness of the estimates in Figure 5.1, we estimated several alternative model specifications and concluded that our main estimates are not sensitive to various specifications. Regression estimates from the main and alternative models are shown in Table TA.2 in the technical appendix.

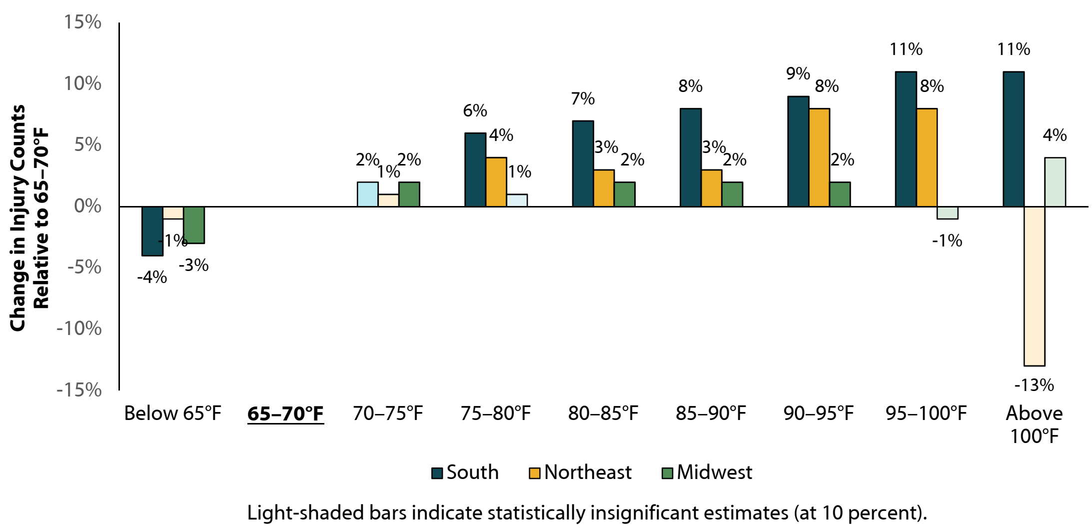
Next, we conducted several sub-analyses to better understand whether this main effect varies by region, industry, and injury types.

IMPACT OF MAXIMUM DAILY TEMPERATURE BY REGION

We now explore how the main effect of excessive heat varies by region. We have data on 12 Southern states (Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia), 7 Midwest states (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, and Wisconsin), and 5 Northeast states (Connecticut, Massachusetts, New Jersey, New York, and Pennsylvania). While these states are not a full representation of these three U.S. Census regions, they nonetheless include the most populous and largest states in these regions.

As shown in Figure 5.3, we detected the largest effects of excessive heat in the South. When the daily maximum temperature increases above 90°F, the injury frequency increases by 9–11 percent. This is consistent with one of the major findings from Dillender (2021) that hot days appear to be more harmful in warmer climates, suggesting a limited scope for adaptation to heat risks. The finding of a larger impact of excessive heat in the South is particularly noteworthy, as the number of days with excessive heat increased substantially over the last decades (as shown in Figure 4.1) and are expected to continue to increase. Current estimates indicate that the Southeast is expected to experience at least 40 more days with temperatures above 90°F per year by 2040–2050 (Reidmiller et al., 2018). It may also be important to point out that even for temperatures between 75°F and 90°F, our estimated effects of excessive heat are in the 6–8 percent range.

Figure 5.3 Estimated Percentage Change in Injury Incidence Due to Excessive Heat, by Region



Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level. The estimate for "above 100F" in the Northeast is based on a very small subsample and is therefore unreliable; it is also statistically insignificant. We nonetheless report it for completeness.

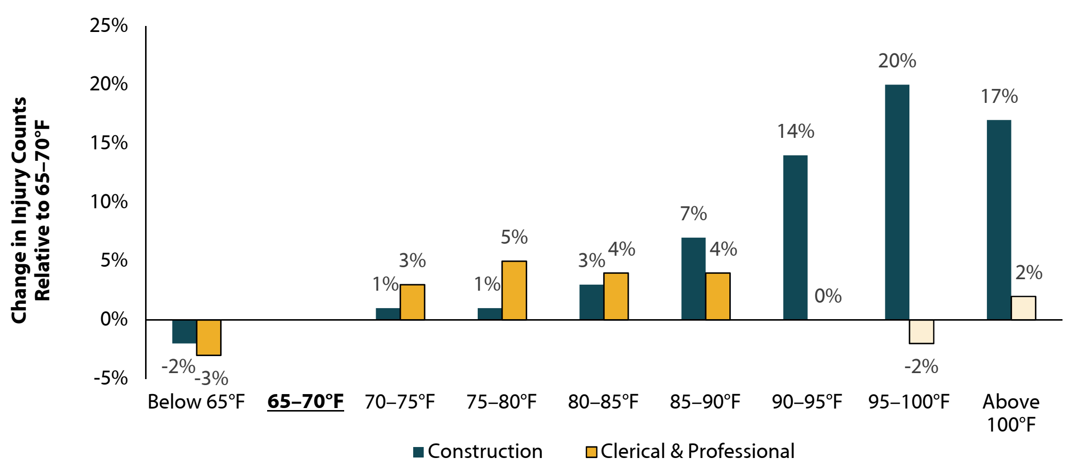
While the South drives the overall effect, we nonetheless found effects of excessive heat in the Northeast and Midwest as well. The number of injuries increases by 8 percent in the Northeast when the maximum temperature reaches 90–100°F. This relatively large effect is potentially driven by many of the locations in the Northeast experiencing excessive heat on a more frequent basis than before. As such, adaptation and protection measures against heat may be lagging behind. We also found that when temperatures increase to values between 80 and 95°F, the incidence of injuries increases in the Midwest by about 2 percent. While this effect is on the smaller side, it may be important to monitor in the future, as the number of excessive heat days is likely to continue to increase in the Midwest too. Regression coefficients from models by region are available in Table TA.3 in the technical appendix.

Impact of Maximum Daily Temperature by Industry

As discussed above, heat exposure and the mechanisms through which heat exposure leads to work-related injuries are diverse. Heat exposure for work that is largely performed outdoors, like construction, is one of the most direct ways in which excessive heat can lead to occupational injuries. However, heat exposure can be from indoor sources, like working near a hot furnace, or from a combination of indoor and outdoor sources, like working near a hot furnace on a hot day. Turning to an analysis of the effect of excessive heat by industry, we provide a higher-level exploration of these hypotheses.[2]

Figure 5.4 below shows that for workers in construction the effect of excessive heat is substantially larger than the overall effect shown in Figure 5.2. Specifically, we found effects in the 14–20 percent range for construction for temperatures above 90°F, relative to days when the temperature is in the 65–70°F range. This is consistent with the hypothesis of direct exposure to outdoor heat. However, we also found effects of excessive heat in the case of workers in the clerical and professional industry. While in the case of construction workers, exposure to excessive heat is intuitive, it may not be intuitive how clerical and professional workers are exposed to excessive heat. The conventional wisdom is that these workers perform their duties indoors and typically in air-conditioned environments. It is possible nonetheless that, especially in areas where excessive heat is not an issue on a regular basis, air-conditioned environments are not that frequent, or they may not be able to keep pace with the outside heat. Additional support for this hypothesis may come from the finding that the effects for clerical and professional workers are for temperatures between 70°F and 90°F rather than above 90°F.

Figure 5.4 Estimated Percentage Change in Injury Incidence Due to Excessive Heat for Construction and Clerical & Professional Workers



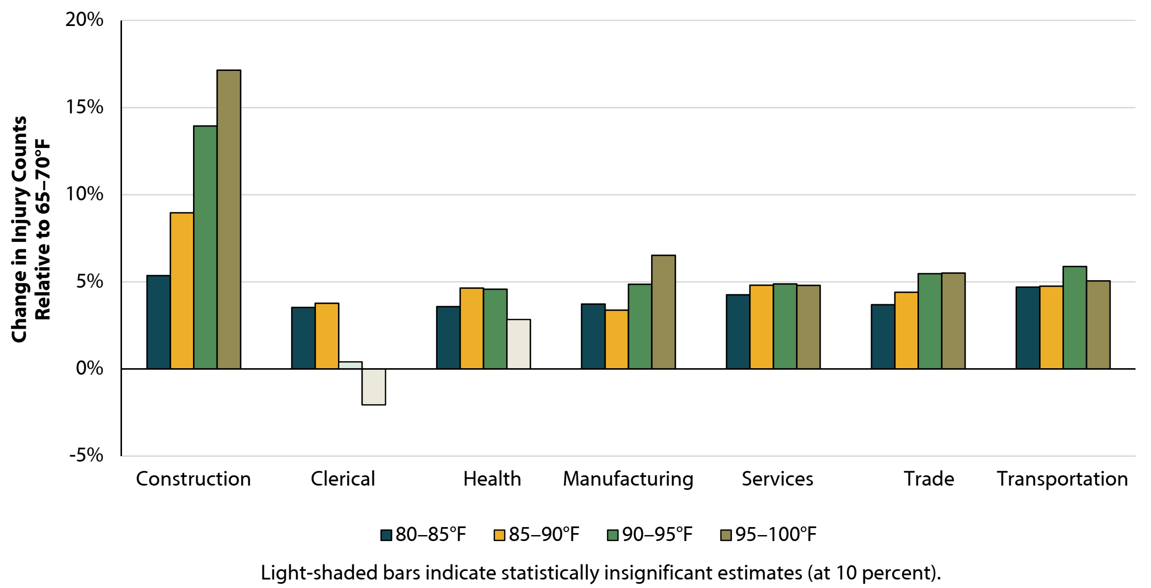
Light-shaded bars indicate statistically insignificant estimates (at 10 percent).

Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

[2] The industry groups used here and throughout the study are not the same as the industry groups used in other WCRI reports. We constructed this industry grouping to ensure a good correspondence with BLS's industry forecasts used in this study. We provide some details on how we constructed this new industry grouping in Table TA.10.

Expanding our view, other industries are affected by excessive heat as well, in varying degrees (Figure 5.5). Specifically, we found effects in the 4–7 percent range for manufacturing, services, trade, and transportation. These effects are for temperatures between 80 and 100°F, relative to the reference category of temperatures between 65 and 70°F. Our data do not allow us to drill down to the occupation level to clearly determine which workers are exposed to which source of heat, that is, indoor versus outdoor heat. Previous studies found that indoor heat exposure is also dangerous for workers. Since jobs in industries like manufacturing, services, trade, or transportation are a combination of jobs with indoor and outdoor heat exposure, the effects we estimate for these industries are likely to reflect a combination of these heat exposures.

Figure 5.5 Estimated Percentage Change in Injury Incidence Due to Excessive Heat, by Industry



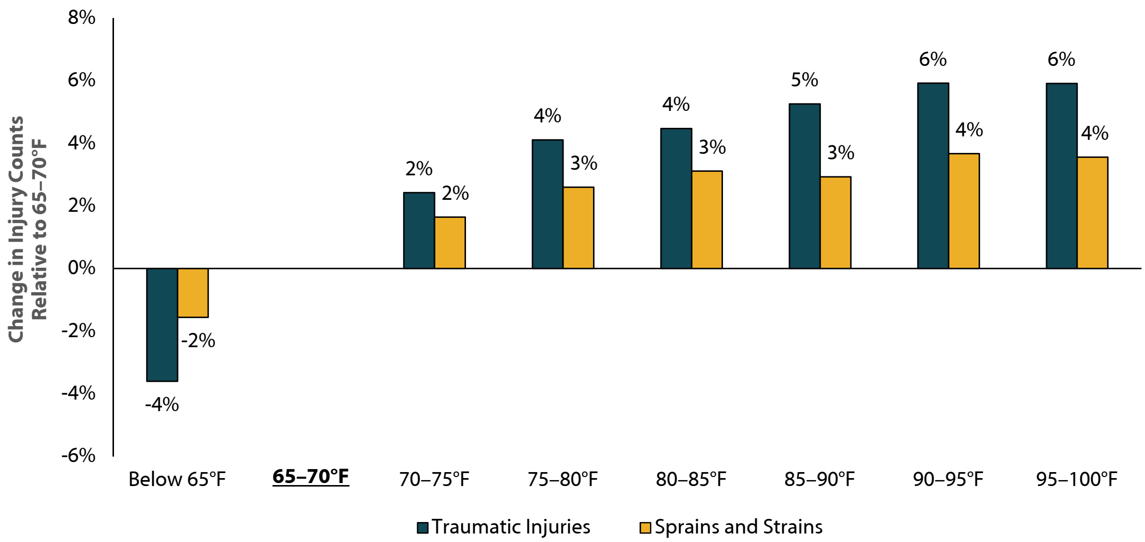
Notes: This chart shows the estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

We also conducted an analysis of the impact of excessive heat by industry and by region. We found that the estimates by industry are larger across the board in the South. In the Northeast and Midwest, the effects tend to be smaller, and in many cases, statistically insignificant, potentially due to the increasingly smaller subsamples when drilling down to industries with smaller representation in our data. Estimates from this analysis are available in the technical appendix (Tables TA.6 and TA.7).

IMPACT OF MAXIMUM DAILY TEMPERATURE BY INJURY TYPE

We now turn to the effect of excessive heat by type of injury. We created two categories of injuries: (i) traumatic injuries, including fractures, dislocations, and contusions and lacerations; and (ii) soft tissue injuries, like sprains and strains. We found that the frequency of traumatic injuries increases more for traumatic injuries than for sprains and strains (Figure 5.6). This finding is in line with past literature, indicating increases in the incidence of traumatic injuries due to excessive heat (e.g., Spector et al., 2016; Calkins et al., 2019). Regression estimates by injury type are available in Table TA.5.

Figure 5.6 Estimated Percentage Change in Injury Incidence Due to Excessive Heat, by Injury Type



Notes: This chart shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

As shown in Tables TA.8 and TA.9 in the technical appendix, the effect of excessive heat is larger (and increases with temperature) on traumatic injuries in the South, in the range of 6 to 10 percent for temperatures above 80°F. Similarly, we estimate increases in the incidence of sprains and strains in the South of the same order of magnitude as for traumatic injuries. In the Midwest, some effects on traumatic injuries are statistically significant, around 3 percent, for the 75–95°F temperature range; effects are insignificant for sprains and strains. Finally, in the Northeast we found increases in the incidence of both traumatic injuries and sprains and strains, with larger increases for traumatic injuries.

DISCUSSION

As shown in this chapter, we found strong and robust evidence that excessive heat increases the frequency of injuries. Our estimates point to increases in the frequency of injuries by 5–8 percent per county on a day when the outside temperature surpasses 90°F, relative to a day with maximum temperatures in the 65–70°F range. The identification of our estimates is ensured by a methodological approach that controls for state-specific factors (including state policies and other relevant features of the workers' compensation system), county-level characteristics, local area economic and workforce trends, and annual trends. The validity of our estimates relies on the assumption that there are no other systematic determinants of work-related injuries in addition to the factors accounted for in our empirical models.

Our study could contribute to the current policy debates around state-level heat standards as well as the design of a federal heat standard that is currently being pursued by OSHA. We provide additional evidence to the broad extent of the effect of excessive heat on occupational injuries by accounting for injuries that are coded in administrative data as heat-related injuries as well as injuries that are indirectly caused by heat. Dillender (2021) found that the effect of high temperatures on heat-related claims (recorded with ICD-9 code 992) are notable once temperatures reach the mid-80s and appear to rise non-linearly as temperatures increase. However, the share of these direct heat-related injuries was only about 14 percent of the estimated overall effect of excessive heat on all injuries on days with temperatures above 100°F. Park et al. (2021) also found an increase in work-related accidents, such as injuries caused by falling from heights, being struck by a moving vehicle, or mishandling dangerous machinery. In addition, we found evidence consistent with the notion that excessive heat increases the injury probability not only for occupations with outdoor activities, such as construction, but also for many workers who perform activities indoors. Park et al. (2021), too, found that hotter temperatures increase workplace accidents in both indoor and outdoor settings.

One question that remains is whether our findings point to the "pure" effect of excessive heat or a combination of the "pure" effect of excessive heat and the effect of adaptation, acclimatization, or mitigation efforts against excessive heat. As mentioned above, states such as California, Colorado, Minnesota, Oregon, and Washington have heat standards in place that are specifically aimed at curbing the risk of heat-related illnesses. Park et al. (2021) found evidence that is consistent with the possibility that the heat standards adopted by California for outside workers reduced the incidence of work-related injuries. However, except for Minnesota (which has a heat standard for inside workers), no state with a heat standard was included in our data. Park et al. (2021) also found limited evidence of changes in the way employers and employees adapt and change the flow of economic activities in the presence of excessive heat. While this finding was limited to California, it could potentially be informative for other parts of the country, especially regions that have not experienced prolonged exposure to excessive heat in recent decades.

LIMITATIONS

Our analysis has several limitations. As discussed in Chapter 3, although our claim-level data sample is large, it remains a convenience, rather than a representative, sample of all work-related injuries. As a result, the outcome variables we constructed for our analysis—injury count and injury rate per 100,000 employees at the county-day level—may not always be representative for the risk of injury in local areas. However, if the proportion of injuries in a county in a given day in the total work-related injuries remains about the same over time, then our analysis provides a valid approximation of the impact of heat on the overall number of work-related injuries. This issue is likely to be more pronounced in rural areas with lower levels of employment. Using weights based on employment in the empirical analyses ensures a level of mitigation for this limitation. Also, the injury rate per 100,000 employees uses employment counts that are recorded annually, rather than monthly, in the U.S. Census-County Business Patterns data source. As local employment tends to fluctuate over the year, the injury rate per 100,000 employees may potentially misrepresent the actual injury rates at certain points throughout the year. Nonetheless, this issue is unlikely to drive the overall results, though it may be more problematic in rural areas, where fewer injuries occur to begin with. The empirical models using the injury rate per 100,000 employees also include month-county interacted terms that likely control for this issue, and, as shown in Figure 5.2, yield effects that are very consistent with the estimates from the injury count models. Moreover, most of the analysis in the study was not based on the injury rate per 100,000 employees models.

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CONCLUDING REMARKS

Our study points to important effects of excessive heat on the incidence of occupational injuries. Using claims data from 2016 to 2021, we found that the incidence of work-related accidents increases by 5–8 percent when the maximum daily temperature rises above 90°F, relative to a day with temperatures in the 65–70°F range. The effect is stronger in the South, where the injury frequency increases by 9–11 percent when the daily maximum temperature increases above 90°F. Additionally, the effect of excessive heat is substantially larger for workers in construction than the overall effect. Specifically, we found effects in the 14–20 percent range for construction for temperatures above 90°F, relative to days when the temperature is in the 65–70°F range. We also found that the impact of excessive heat is larger on traumatic injuries, including fractures, dislocations, and contusions and lacerations.

This study contributes to the literature documenting the overall effect of excessive heat, going beyond direct heat-related injuries, by using more recent data and data from areas of the country that were not studied before. It also informs the public policy debate on the importance of work safety, protection, and prevention against excessive heat under the scenario of increasingly frequent occurrences of excessive heat in the future.

There are multiple venues for future research. Excessive heat is only one of the broader weather events, such as wildfires, excessive cold, more frequent floods or hurricanes, and so on. These adverse events are likely to have impacts on occupational health similar to those of excessive heat. Other venues for future research include studies of the impact of excessive heat, and other weather events in general, on other outcomes, such as medical payments, indemnity benefits, or disability duration. Also, while a thorough investigation of direct heat-related injuries, such as heat stroke, was beyond the scope of the current study, examinations of these specific injuries in relation to changes in temperature would not only be informative from a public policy perspective but could also provide assessments of more specific hypotheses on how workers are affected by, or adapt to, excessive heat. Other valuable future analyses could include the assessment of the effectiveness of heat standards already in place across the country, or event studies of specific adverse events, like a prolonged heat wave in a given area. For instance, Dillender (2021) found that the time frame over which the effect of a day's temperature is realized extends to several days beyond the day when the temperature rises. Prolonged heat waves, or longer times during the day with excessive temperatures, could be one of the reasons behind our larger estimates of excessive heat in the South relative to other regions.

Furthermore, although we expanded the regions and areas of the country that were included in the analysis relative to the recent literature, we nonetheless were unable to include the larger, more populous states from the West in our sample for the reasons discussed above. Additional analyses could be conducted at the zip code level, with more accurate temperature data from the Western states. A zip code-level analysis would provide additional variation at the state level to further assess the impact of excessive heat. Finally, while our current study only focused on the estimation of temperature effects, relative humidity in conjunction with high temperatures could further increase the risk of work-related accidents. An analysis considering both temperature and relative humidity, especially in places that experience high levels of humidity, would provide additional insights into how excessive heat affects occupational health and other outcomes.

TECHNICAL APPENDIX

The empirical framework used in this report relies on estimating the following econometric models in which the outcomes of interest are the daily injury count in a county, and the daily injury rate in a county—measured as the daily number of injuries per 100,000 employees, in county *c*, state *s*, day *d*, month *m*, and year *y*:

$$y_{csdmy} = \alpha + T'_{cdsmy} \cdot \boldsymbol{\beta} + c_{cs} + \delta_{csmy} + \varepsilon_{csdmy} \quad (1)$$

We model these outcomes at the county-day level as a function of maximum daily temperature (T) and account for the trends in the incidence of injuries by including in the model indicator for year (y_y). We group the maximum daily temperature in the following categories: below 65°F, 65–70°F, 70–75°F, 75–80°F, 80–85°F, 85–90°F , 95–100°F, and above 100°F degrees (with 65–70°F being the reference category). We also control for local area characteristics, including state workers' compensation features, by including county-state indicators (c_{cs}) that can be correlated with the probability of injuries. In addition, we account for local area economic changes and national trends in workplace injuries by including interaction terms between month-year and county indicators (δ_{csmy}). The estimates on maximum daily temperature, grouped in the vector of coefficients $\boldsymbol{\beta}$, measure the difference in work-related accidents between days with and without excessive heat, all else constant. We also cluster standard errors at the county-state level, to account for the possibility of serial correlation in injury risk within counties.

Table TA.1 Summary of State-Specific Occupational Heat Stress Standards

Standard Requirements	CA[a]	MN[b]	OR[c]	WA[d]
Worksite coverage	Outdoor, year-round	Indoor, year-round	Indoor and outdoor, emergency rule	Outdoor, year round
Thresholds triggering protection requirements	80°F (ambient temp.)	Between 77°F and 86°F (WBGT) based on workload	80°F (NOAA NWS Heat Index)	80°F (ambient temp.); lower if wearing non-breathable clothing
Additional high heat protections	At 95°F (certain industries only)	No	At 90°F	At 90°F, 100°F
Water/hydration	1 quart/hour/worker	No	1 quart/hour/worker, cool or cold	1 quart/hour/worker, suitably cool
Shade	Yes	n/a	Yes	Yes
Training	Yes (new hire)	Yes (new hire and annual)	Yes	Yes (new hire and annual)
Breaks	Yes (encouraged generally, mandatory if symptoms)	Yes (after two hours exposure at threshold)	Yes (mandatory if symptoms at any temp., every 2 hours for all at 90°F)	Yes (encouraged preventative and must be paid); >90°F – 10 minutes every 2 hours; >100°F – 15 minutes every hour
Acclimatization plan	Yes	No	Yes (in practice at 90°F)	Training; close observation for non-acclimatized workers
Heat illness prevention plan	Yes	No	No	Yes (as part of accident prevention plan)
Emergency medical response plan	Yes	No	Yes	Yes
Medical monitoring	Reactive, proactive when above 95°F	Reactive	Reactive	Reactive
Record-keeping requirements	Yes	Yes	No	Yes

[a] Cal/OSHA, Title 8, section 3395. Heat Illness Prevention: https://www.dir.ca.gov/Title8/3395.html.

[b] Minnesota Administrative Rules. Section 5205.0110 Indoor ventilation and temperature in places of employment: https://www.revisor.mn.gov/rules/5205.0110/.

[c] Oregon Administrative Rules. 437-002-0155 Temporary Rule Heat Illness Prevention: https://osha.oregon.gov/OSHARules/adopted/2021/ao6-2021-letter-heatillnessprevention.pdf.

[d] Washington Administrative Code (WAC) Title 296, General Occupational Health Standards. Sections 296-62-095 through 296-62-09560. Outdoor Heat Exposure: https://apps.leg.wa.gov/wac/default.aspx?cite=296-62-095.

Key: NOAA NWS: National Oceanic and Atmospheric Administration's National Weather Service; PPE: personal protective equipment; WBGT: wet bulb globe temperature index.

Table TA.2 Sensitivity Analysis of the Regression Estimates of Injury Incidence Changes Due to Excessive Heat to Alternative Specifications

	Injury Count		Injury Rate per 100,000 Employees	
	(1)	(2)	(3)	(4)
Below 65°F	-0.0276***	-0.0116	-0.0383***	-0.0188*
	(0.007)	(0.007)	(0.010)	(0.010)
70–75°F	0.0173**	0.0069	0.0329***	0.0005
	(0.007)	(0.006)	(0.011)	(0.010)
75–80°F	0.0386***	0.0229***	0.0711***	0.0296***
	(0.007)	(0.006)	(0.011)	(0.011)
80–85°F	0.0433***	0.0249***	0.0815***	0.0406***
	(0.007)	(0.006)	(0.011)	(0.010)
85–90°F	0.0515***	0.0390***	0.0967***	0.0769***
	(0.008)	(0.007)	(0.013)	(0.012)
90–95°F	0.0639***	0.0592***	0.1188***	0.1190***
	(0.010)	(0.008)	(0.015)	(0.013)
95–100°F	0.0692***	0.0766***	0.1328***	0.1740***
	(0.014)	(0.014)	(0.024)	(0.021)
Above 100°F	0.0739***	0.0768***	0.1578***	0.1933***
	(0.020)	(0.021)	(0.049)	(0.052)
Constant	1.3091***	1.3174***	2.3624***	2.3789***
	(0.006)	(0.005)	(0.010)	(0.009)
County x Month x Year	Yes		Yes	
County x Month		Yes		Yes
County	Yes	Yes	Yes	Yes
Year		Yes		Yes
Observations	1,129,584	1,129,739	1,129,563	1,129,718

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts and injury rates per 100,000 employees per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. Alternative specifications use alternative sets of fixed effects. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level. Preferred specification shown in model (1) for injury counts and (5) for injury rate dependent variables.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.3 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Region

	Injury Count			Injury Rate per 100,000 Employees		
	(1)	(2)	(3)	(4)	(5)	(6)
	South	Midwest	Northeast	South	Midwest	Northeast
Below 65°F	-0.0290*** (0.011)	-0.0336*** (0.011)	-0.0168 (0.015)	-0.0584*** (0.022)	-0.0670*** (0.017)	-0.0127 (0.012)
70–75°F	0.0168 (0.011)	0.0191** (0.009)	0.0167 (0.020)	0.0463* (0.024)	0.0424* (0.022)	0.0149 (0.016)
75–80°F	0.0487*** (0.010)	0.0098 (0.008)	0.0785*** (0.021)	0.1178*** (0.021)	0.0273 (0.018)	0.0673*** (0.015)
80–85°F	0.0544*** (0.011)	0.0180** (0.007)	0.0701*** (0.020)	0.1313*** (0.021)	0.0480*** (0.017)	0.0605*** (0.015)
85–90°F	0.0650*** (0.013)	0.0209*** (0.008)	0.0725*** (0.027)	0.1547*** (0.024)	0.0549*** (0.020)	0.0613*** (0.019)
90–95°F	0.0739*** (0.016)	0.0232** (0.011)	0.1696*** (0.034)	0.1721*** (0.027)	0.0630** (0.028)	0.1130*** (0.018)
95–100°F	0.0838*** (0.019)	-0.0071 (0.021)	0.1834* (0.109)	0.1946*** (0.033)	-0.0603 (0.086)	0.1078** (0.048)
Above 100°F	0.0857*** (0.025)	0.0428 (0.039)	-0.2840 (0.503)	0.2099*** (0.054)	0.2447 (0.253)	-0.5942 (0.631)
Constant	1.1805*** (0.012)	1.0667*** (0.006)	2.5091*** (0.015)	2.4639*** (0.021)	2.5426*** (0.014)	1.9813*** (0.011)
Observations	639,282	352,688	137,614	639,282	352,667	137,614

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts and injury rates per 100,000 employees per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.4 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Industry

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Agriculture	**Clerical**	**Construction**	**Health**	**Manufacturing**	**Mining**	**Public**	**Leisure**	**Services**	**Transportation**	**Trade**
	-0.0004	-0.0033**	-0.0036***	-0.0032	-0.0089***	-0.0004	-0.0001	-0.0024*	-0.0046**	-0.0022	-0.0087***
Below 65°F	(0.001)	(0.002)	(0.001)	(0.002)	(0.003)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)
	0.0006	0.0032*	0.0026*	0.0022	0.0061**	-0.0003	0.0009	0.0022	0.0028	-0.0009	0.0046**
70–75°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
	0.0008	0.0055***	0.0028*	0.0068***	0.0062**	-0.0001	0.0020***	0.0021	0.0061***	0.0037**	0.0103***
75–80°F	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
	0.0002	0.0039***	0.0042***	0.0054***	0.0097***	-0.0001	0.0016**	0.0031**	0.0076***	0.0058***	0.0098***
80–85°F	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
	0.0006	0.0042***	0.0071***	0.0070***	0.0088***	-0.0001	0.0018**	0.0030**	0.0086***	0.0058***	0.0117***
85–90°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
	0.0008	0.0004	0.0111***	0.0069***	0.0126***	0.0001	0.0014*	0.0040**	0.0087***	0.0072***	0.0146***
90–95°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.000)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
	0.0022**	-0.0023	0.0136***	0.0043	0.0170***	0.0011*	0.0021*	0.0051**	0.0086**	0.0062**	0.0147***
95–100°F	(0.001)	(0.003)	(0.004)	(0.003)	(0.004)	(0.001)	(0.001)	(0.002)	(0.004)	(0.003)	(0.004)
	-0.0035*	0.0023	0.0169**	0.0017	0.0084	-0.0011	0.0040*	0.0026	0.0163**	0.0046	0.0227***
Above 100°F	(0.002)	(0.004)	(0.007)	(0.004)	(0.006)	(0.001)	(0.002)	(0.005)	(0.007)	(0.005)	(0.007)
	0.0248***	0.1125***	0.0981***	0.1463***	0.2449***	0.0037***	0.0228***	0.0833***	0.1931***	0.1305***	0.2607***
Constant	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
Observations	1,010,643	1,065,848	1,062,109	1,088,993	1,170,061	991,531	1,007,004	1,052,745	1,109,000	1,071,311	1,166,760

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.5 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Injury Type

	Injury Count		Injury Rate per 100,000 Employees	
	(1)	(2)	(3)	(4)
	Traumatic Injuries	Sprains and Strains	Traumatic Injuries	Sprains and Strains
	-0.0141***	-0.0074**	-0.0188***	-0.0095*
Below 65°F	(0.003)	(0.004)	(0.005)	(0.005)
	0.0095***	0.0078**	0.0166***	0.0133**
70–75°F	(0.004)	(0.003)	(0.006)	(0.005)
	0.0161***	0.0123***	0.0286***	0.0214***
75–80°F	(0.003)	(0.003)	(0.006)	(0.006)
	0.0175***	0.0148***	0.0320***	0.0265***
80–85°F	(0.004)	(0.003)	(0.006)	(0.006)
	0.0206***	0.0139***	0.0373***	0.0245***
85–90°F	(0.004)	(0.004)	(0.006)	(0.006)
	0.0232***	0.0174***	0.0416***	0.0306***
90–95°F	(0.005)	(0.004)	(0.007)	(0.007)
	0.0232***	0.0169***	0.0420***	0.0306***
95–100°F	(0.007)	(0.006)	(0.011)	(0.010)
	0.0153	0.0316***	0.0213	0.0733***
Above 100°F	(0.009)	(0.011)	(0.026)	(0.026)
	0.4281***	0.5089***	0.7438***	0.8769***
Constant	(0.003)	(0.003)	(0.005)	(0.005)
Observations	1,040,895	1,064,162	1,040,874	1,064,141

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts and injury rates per 100,000 employees per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.6 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Industry and Region

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Agriculture	**Clerical**	**Construction**	**Health**	**Manufacturing**	**Mining**	**Public**	**Leisure**	**Services**	**Transportation**	**Trade**
South											
	0.0007	-0.0023	-0.0095***	-0.0042	-0.0116**	-0.0004	-0.0013	-0.0005	-0.0016	-0.0008	-0.0082*
Below 65°F	(0.001)	(0.002)	(0.003)	(0.003)	(0.005)	(0.001)	(0.001)	(0.002)	(0.004)	(0.002)	(0.004)
	0.0006	0.0022	0.0002	0.0006	0.0056	0.0001	0.0002	0.0040	0.0031	-0.0006	0.0058
70–75°F	(0.001)	(0.003)	(0.003)	(0.003)	(0.004)	(0.000)	(0.001)	(0.002)	(0.003)	(0.002)	(0.004)
	0.0005	0.0039*	0.0001	0.0067**	0.0072**	-0.0001	0.0031**	0.0060***	0.0107***	0.0050**	0.0120***
75–80°F	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.000)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)
	0.0004	0.0053**	0.0040	0.0050*	0.0118***	0.0002	0.0021*	0.0063***	0.0107***	0.0037*	0.0153***
80–85°F	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.000)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
	0.0008	0.0066***	0.0068**	0.0061**	0.0119***	0.0002	0.0023*	0.0069***	0.0109***	0.0051**	0.0166***
85–90°F	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.000)	(0.001)	(0.002)	(0.004)	(0.002)	(0.004)
	0.0012	0.0013	0.0112***	0.0058*	0.0166***	0.0005	0.0017	0.0072***	0.0093**	0.0066**	0.0204***
90–95°F	(0.001)	(0.003)	(0.003)	(0.003)	(0.004)	(0.000)	(0.001)	(0.002)	(0.004)	(0.003)	(0.004)
	0.0027*	-0.0007	0.0137***	0.0045	0.0209***	0.0015**	0.0019	0.0080***	0.0108**	0.0058*	0.0208***
95–100°F	(0.001)	(0.003)	(0.005)	(0.004)	(0.006)	(0.001)	(0.002)	(0.002)	(0.005)	(0.003)	(0.005)
	-0.0029	0.0032	0.0172**	0.0016	0.0112*	-0.0005	0.0046*	0.0049	0.0188**	0.0039	0.0265***
Above 100°F	(0.002)	(0.005)	(0.009)	(0.005)	(0.006)	(0.001)	(0.003)	(0.005)	(0.008)	(0.005)	(0.008)
	0.0261***	0.1037***	0.1034***	0.1275***	0.1946***	0.0034***	0.0263***	0.0888***	0.1890***	0.1165***	0.2180***
Constant	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.000)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
Observations	578,416	603,311	606,244	617,135	649,927	566,762	577,202	604,055	629,557	605,813	652,021
MidWest											
	-0.0009	-0.0051***	-0.0018	-0.0038	-0.0100**	-0.0007*	-0.0010	-0.0058***	-0.0048*	-0.0048*	-0.0111***
Below 65°F	(0.001)	(0.002)	(0.002)	(0.003)	(0.004)	(0.000)	(0.001)	(0.002)	(0.003)	(0.003)	(0.004)
	-0.0000	0.0023	0.0041*	0.0028	0.0077*	-0.0009*	-0.0001	0.0004	0.0047	-0.0044	0.0031
70–75°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.005)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)
	0.0008	0.0023	0.0018	0.0033	0.0043	-0.0004	0.0001	-0.0025	0.0018	-0.0011	0.0050*
75–80°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.004)	(0.000)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)
	0.0009	-0.0006	0.0023	0.0013	0.0090***	-0.0004	-0.0001	-0.0013	0.0041	0.0052**	0.0006
80–85°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.000)	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)
	0.0021**	0.0025	0.0051***	0.0035	0.0048	-0.0003	0.0004	-0.0022	0.0047	0.0027	0.0029
85–90°F	(0.001)	(0.002)	(0.002)	(0.002)	(0.004)	(0.000)	(0.001)	(0.002)	(0.003)	(0.003)	(0.004)
	0.0005	0.0016	0.0057**	0.0047*	0.0024	-0.0003	0.0001	-0.0017	0.0070**	0.0045	0.0037
90–95°F	(0.001)	(0.002)	(0.002)	(0.003)	(0.005)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)	(0.004)
	0.0028	-0.0085*	0.0090**	0.0008	0.0065	-0.0005	-0.0002	0.0018	-0.0034	-0.0016	-0.0004
95–100°F	(0.002)	(0.004)	(0.004)	(0.005)	(0.010)	(0.001)	(0.002)	(0.004)	(0.006)	(0.004)	(0.008)
	-0.0050*	0.0057	0.0100	-0.0040	0.0065	-0.0033	-0.0022	0.0053	0.0046	0.0035	0.0339*
Above 100°F	(0.003)	(0.010)	(0.011)	(0.006)	(0.020)	(0.002)	(0.004)	(0.006)	(0.009)	(0.007)	(0.019)
	0.0149***	0.0823***	0.0624***	0.1042***	0.2949***	0.0035***	0.0135***	0.0476***	0.1364***	0.1014***	0.2379***
Constant	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.000)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	306,542	320,831	318,311	321,927	366,794	303,160	305,653	313,201	329,742	321,549	352,531

continued

Table TA.6 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Industry and Region (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Agriculture	**Clerical**	**Construction**	**Health**	**Manufacturing**	**Mining**	**Public**	**Leisure**	**Services**	**Transportation**	**Trade**
Northeast											
	-0.0005	-0.0009	-0.0004	-0.0009	-0.0041	0.0004	0.0027	0.0009	-0.0083	0.0016	-0.0057
Below 65°F	(0.002)	(0.004)	(0.003)	(0.006)	(0.006)	(0.001)	(0.002)	(0.003)	(0.005)	(0.006)	(0.006)
	0.0017	0.0066	0.0036	0.0040	0.0035	0.0001	0.0041	0.0031	-0.0007	0.0054	0.0056
70–75°F	(0.002)	(0.005)	(0.004)	(0.006)	(0.006)	(0.001)	(0.003)	(0.004)	(0.006)	(0.005)	(0.006)
	0.0016	0.0150***	0.0090**	0.0130**	0.0076	0.0006	0.0035**	0.0041	0.0060	0.0104**	0.0172***
75–80°F	(0.002)	(0.005)	(0.004)	(0.006)	(0.006)	(0.001)	(0.002)	(0.004)	(0.006)	(0.005)	(0.006)
	-0.0014	0.0097**	0.0060	0.0134**	0.0053	-0.0005	0.0039*	0.0064*	0.0084	0.0132**	0.0152***
80–85°F	(0.002)	(0.004)	(0.004)	(0.006)	(0.005)	(0.001)	(0.002)	(0.004)	(0.005)	(0.005)	(0.005)
	-0.0029	-0.0053	0.0092*	0.0159***	0.0085	0.0002	0.0026	0.0025	0.0122*	0.0143**	0.0194***
85–90°F	(0.002)	(0.005)	(0.005)	(0.006)	(0.007)	(0.001)	(0.002)	(0.004)	(0.007)	(0.006)	(0.006)
	-0.0015	0.0013	0.0165**	0.0167**	0.0184*	-0.0010	0.0049	0.0139**	0.0295***	0.0125*	0.0165
90–95°F	(0.004)	(0.006)	(0.008)	(0.007)	(0.010)	(0.001)	(0.003)	(0.006)	(0.009)	(0.007)	(0.011)
	-0.0106	0.0009	0.0171	-0.0242	0.0176	0.0002	0.0311*	0.0169	0.0220	0.0205	0.0094
95–100°F	(0.013)	(0.019)	(0.020)	(0.026)	(0.023)	(0.004)	(0.018)	(0.019)	(0.035)	(0.029)	(0.027)
	-0.0333	-0.0775*	-0.0186	-0.0444	0.1646*	-0.0002	0.0069**	0.0408	-0.1015*	-0.0825*	-0.0935
Above 100°F	(0.023)	(0.039)	(0.031)	(0.139)	(0.085)	(0.001)	(0.003)	(0.040)	(0.058)	(0.043)	(0.155)
	0.0420***	0.2162***	0.1591***	0.3166***	0.3330***	0.0046***	0.0291***	0.1334***	0.3302***	0.2566***	0.4728***
Constant	(0.001)	(0.003)	(0.003)	(0.005)	(0.005)	(0.001)	(0.001)	(0.003)	(0.004)	(0.004)	(0.004)
Observations	125,685	141,706	137,554	149,931	153,340	121,609	124,149	135,489	149,701	143,949	162,208

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects, year month-county fixed effects, and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.7 Magnitude of the Estimated Effects of Injury Incidence Changes Due to Excessive Heat, by Region and Industry

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Agriculture	**Clerical**	**Construction**	**Health**	**Manufacturing**	**Mining**	**Public**	**Leisure**	**Services**	**Transportation**	**Trade**
South											
Below 65°F	4%	-3%	-16%	-4%	-7%	-17%	-6%	-1%	-1%	-1%	-4%
70–75°F	3%	3%	0%	1%	3%	2%	1%	8%	2%	-1%	3%
75–80°F	3%	6%	0%	7%	4%	-4%	15%	12%	8%	6%	7%
80–85°F	2%	8%	7%	5%	7%	8%	10%	12%	8%	5%	8%
85–90°F	4%	10%	11%	6%	7%	7%	11%	13%	8%	6%	9%
90–95°F	6%	2%	19%	6%	10%	21%	8%	14%	7%	8%	11%
95–100°F	14%	-1%	23%	5%	12%	64%	9%	16%	8%	7%	11%
Above 100°F	-15%	5%	29%	2%	7%	-21%	22%	10%	14%	5%	15%
Midwest											
Below 65°F	-6%	-6%	-3%	-4%	-3%	-22%	-7%	-13%	-3%	-5%	-5%
70–75°F	0%	3%	7%	3%	3%	-26%	-1%	1%	3%	-4%	1%
75–80°F	5%	3%	3%	3%	1%	-11%	1%	-6%	1%	-1%	2%
80–85°F	6%	-1%	4%	1%	3%	-12%	-1%	-3%	3%	5%	0%
85–90°F	14%	3%	9%	3%	2%	-10%	3%	-5%	3%	3%	1%
90–95°F	4%	2%	9%	4%	1%	-8%	1%	-4%	5%	4%	2%
95–100°F	19%	-10%	15%	1%	2%	-15%	-2%	4%	-2%	-2%	0%
Above 100°F	-34%	6%	17%	-4%	2%	-99%	-17%	12%	3%	4%	15%
Northeast											
Below 65°F	-1%	0%	0%	0%	-1%	11%	9%	1%	-3%	1%	-1%
70–75°F	4%	3%	2%	1%	1%	2%	14%	2%	0%	2%	1%
75–80°F	4%	7%	6%	4%	2%	15%	12%	3%	2%	4%	4%
80–85°F	-4%	4%	4%	4%	2%	-12%	13%	5%	3%	6%	3%
85–90°F	-7%	-2%	6%	5%	3%	5%	9%	2%	4%	6%	4%
90–95°F	-4%	1%	11%	5%	6%	-27%	17%	11%	9%	5%	4%
95–100°F	-27%	0%	12%	-8%	6%	6%	105%	14%	7%	9%	2%
Above 100°F	-85%	-35%	-13%	-15%	52%	-6%	23%	33%	-31%	-35%	-21%

Notes: This table shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors are clustered at the county level.

Please refer to Table TA.6 for the underlying set of estimated coefficients showing statistical significance.

Table TA.8 Regression Estimates of Injury Incidence Changes Due to Excessive Heat, by Injury Type and Region

	South		Midwest		Northeast	
	(1)	(2)	(1)	(2)	(1)	(2)
	Traumatic Injuries	Sprains and Strains	Traumatic Injuries	Sprains and Strains	Traumatic Injuries	Sprains and Strains
Below 65°F	-0.0188***	-0.0077	-0.0108**	-0.0151***	-0.0151	0.0067
	(0.005)	(0.005)	(0.004)	(0.005)	(0.010)	(0.009)
70–75°F	0.0032	0.0060	0.0174***	0.0094**	0.0058	0.0087
	(0.005)	(0.006)	(0.005)	(0.004)	(0.011)	(0.009)
75–80°F	0.0166***	0.0187***	0.0103**	-0.0028	0.0264**	0.0301***
	(0.005)	(0.005)	(0.004)	(0.005)	(0.011)	(0.009)
80–85°F	0.0197***	0.0220***	0.0097**	0.0031	0.0277**	0.0212**
	(0.005)	(0.005)	(0.005)	(0.004)	(0.013)	(0.009)
85–90°F	0.0242***	0.0236***	0.0116**	-0.0023	0.0220*	0.0154
	(0.006)	(0.006)	(0.005)	(0.004)	(0.013)	(0.013)
90–95°F	0.0254***	0.0253***	0.0107*	0.0028	0.0546***	0.0377**
	(0.007)	(0.007)	(0.006)	(0.007)	(0.021)	(0.017)
95–100°F	0.0266***	0.0278***	-0.0000	-0.0253**	0.0577	0.0297
	(0.008)	(0.007)	(0.011)	(0.012)	(0.067)	(0.066)
Above 100°F	0.0171	0.0393***	0.0117	0.0282	0.0797	0.0266
	(0.011)	(0.013)	(0.021)	(0.024)	(0.095)	(0.206)
Constant	0.3973***	0.4573***	0.3521***	0.4154***	0.7609***	0.9582***
	(0.005)	(0.005)	(0.004)	(0.003)	(0.009)	(0.007)
Observations	593,689	605,115	320,227	326,383	126,979	132,664

Notes: This table shows the full set of temperature coefficients obtained from the regression analysis of injury counts per county and day as dependent variables. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, reported in parentheses, are clustered at the county level.

* Statistically significant at 10 percent; ** statistically significant at 5 percent; *** statistically significant at 1 percent.

Table TA.9 Magnitude of the Estimated Effects of Injury Incidence Changes Due to Excessive Heat, by Injury Type and Region

	South		Midwest		Northeast	
	(1)	(2)	(1)	(2)	(1)	(2)
	Traumatic Injuries	Sprains and Strains	Traumatic Injuries	Sprains and Strains	Traumatic Injuries	Sprains and Strains
Below 65°F	-7%	-2%	-3%	-4%	-2%	1%
70–75°F	1%	2%	5%	2%	1%	1%
75–80°F	6%	6%	3%	-1%	4%	4%
80–85°F	7%	7%	3%	1%	4%	2%
85–90°F	9%	7%	3%	-1%	3%	2%
90–95°F	9%	8%	3%	1%	8%	4%
95–100°F	10%	9%	0%	-6%	9%	3%
Above 100°F	6%	12%	3%	7%	12%	3%

Notes: This table shows the full set of estimated effects of maximum daily temperatures on injury counts obtained from the regression analysis at the county and day level. The underlying claim data are from May to October 2016–2021, covering 24 states. All regressions control for county, state, and year fixed effects; year month-county fixed effects; and a set of maximum high temperature indicators. Daily maximum temperatures are assigned to a vector of 9 temperature bins, ranging from below 65°F to temperatures greater than 100°F in 5°F increments. The omitted category is the temperature bin with daily maximum temperatures between 65°F and 70°F. Standard errors, are clustered at the county level.

Please refer to Table TA.8 for the underlying set of estimated coefficients showing statistical significance.

Table TA.10 Industry and Occupation Categories (with examples of included classifications)

Clerical and professional
Clerical
Instructional professions
Construction
Erection
Shipbuilding
Miscellaneous construction
Manufacturing
Food and tobacco
Textiles
Cloth products
Leather
Rubber/bone products
Paper/pulp products, printing
Wood
Metallurgy
Metal forming
Machine shops/fine machines
Vehicles
Stone products
Clay products
Glass products
Chemicals
Miscellaneous manufacturing
Wholesale and retail trade
Retail trade
Wholesale trade
Services
Laundering, cleaning, and dyeing
Automobile hauling; automobile sales and services
Building maintenance; janitorial services; elevator services; sign installation; window cleaning
Hotels
Computer data processing; motion picture productions
Automobile parking and garage
Insurance; real estate; travel agencies; addressing; mailing; mail packaging; advertising
Schools; museums
Commercial service and repair; architect or engineer consulting
Property management; leasing services
Personal service, such as beauty salons and hair styling
Transportation, warehousing, and utilities
Stevedoring/freight handling; explosives or ammunition shipping; refrigerator car loading or unloading
Railroad operations
Package delivery; hauling (long-distance or local)
Electric light or power; steam light or power; waterworks operation; sewage disposal plant operation; recycling and garbage collection
Warehousing and storage
Telephone, telegraph, internet access providers; radio/TV broadcasting; cable TV
Health care and social assistance
Health care facility-related services: nursing home, home care (excluding physician and dentist services)
Physicians/dentists
Day care centers
Leisure and hospitality
Restaurants, clubs
Dinner theater/theater operations
Amusement park or exhibition operations

continued

Table TA.10 Industry and Occupation Categories (with examples of included classifications) (continued)

Agriculture, forestry, and fishing
Agriculture
Mining
Mining and oil/gas production
Quarrying, stone/sand/clay
Public
Policeman, ambulance services, firefighters, correctional institutions

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