GeoHealth

RESEARCH ARTICLE
10.1029/2024GH001287

Key Points:
- Among heat-related emergency department visits, we analyzed Y codes that indicate locations at the time of injury or other conditions
- Higher temperature was associated with more emergency department visits with Y codes for several non-residential locations
- Our results support the need to develop targeted strategies and interventions that minimize heat exposure in non-residential areas

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Li, C., Hao, H., Lane, M., Scovronick, N., Zhang, R., Ebelt, S., & Chang, H. H. (2025). Associations between temperature and location of injury or condition among heat-related emergency department visits. *GeoHealth*, *9*, e2024GH001287. https://doi.org/10.1029/2024GH001287

Received 22 NOV 2024
Accepted 6 MAR 2025

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Associations Between Temperature and Location of Injury or Condition Among Heat-Related Emergency Department Visits

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Abstract High ambient temperature poses significant health risk globally. However, the relative importance of different exposure pathways leading to health risks remains unclear. For 9 US states during 2016–2018, ED visit records for heat exhaustion and heat stroke (HEAT), fluid and electrolyte imbalance (FEI), volume depletion (VD), and acute kidney injury (AKI) were identified via diagnosis codes. Co-diagnosed Y92 subcodes (Y codes) were used to categorize the patient's location at the time of injury or condition. Logistic regressions were used to estimate nonlinear associations between same-day temperature and Y codes for 11 non-residential versus residential locations among heat-related ED visits, including stratified analyses by patient age, race, and ethnicity. Odds ratios (OR) were calculated between the 95th versus 50th percentile of temperature. Overall, higher temperature was associated with increased risks of ED visits with Y codes for non-residential locations. HEAT ED visits were more likely to have Y codes for streets compared to residential locations (OR:1.68, 95% CI: 1.12–2.51). Similarly, VD visits were more likely to have Y codes for industrial area (OR: 2.68, 95% CI: 1.98–3.63), farms (OR:7.66, 95% CI: 4.05–14.50), recreation areas (OR:2.25, 95% CI: 1.78–2.84), and streets (OR:1.54, 95% CI: 1.39–1.70), but were less likely to have Y codes for public places (OR: 0.89, 95% CI: 0.84, 0.94). Similar associations were observed for FEI and AKI ED visits. Locations associated with higher heat risks may be due to exposure outdoor temperature and activities, supporting the need to develop strategies and interventions that minimize heat exposure in these areas.

Plain Language Summary Heat is an escalating public health challenge with profound implications for mortality and morbidity. Despite extensive epidemiological research linking heat exposure to a variety of health outcomes, significant knowledge gaps persist in understanding the pathways through which heat exposure occurs and leads to adverse health effects. A critical factor in heat exposure is the specific *location* in which the exposure occurs, as it relates to an individual's behavior, occupation, and activity patterns. Our study analyzed over half million discharge records from emergency department (ED) visits for several heat-related outcomes across 9 US states. We leveraged diagnosis Y code that indicates the patient's location at the time of injury or condition. On high temperature days, we found consistent higher rates of ED visits with Y code for industrial areas, farms, streets, and recreation areas compared to residential areas. In contrast, public places demonstrated protective associations. These findings provide valuable insights for public health authorities to enhance heat preparedness and response strategies by targeting high-risk locations. The protective role of public spaces highlights the potential benefits of expanding community-based cooling centers, increasing public awareness campaigns, and implementing targeted interventions to reduce heat-related morbidity and mortality.

1. Introduction

Heat is an escalating public health challenge in the United States (US), with profound implications for mortality and morbidity. In recent years, heat-related deaths have steadily increased in the US, with an estimated 1,602 deaths in 2021, 1,722 in 2022, and 2,325 in 2023 (Howard et al., 2024). As climate change progresses, future projections indicate that extreme heat events will become more frequent and severe in the coming decades. For instance, climate models project a four- to six-fold increase in the number of people exposed to high temperatures by 2070 in the US (Jones et al., 2015). Additionally, the intensity of heatwave episodes, as well as the number of heatwave days per year, are also expected to rise significantly throughout the 21st century (Lau & Nath, 2012).

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Rising temperatures associated with climate change amplify the risk of a wide range of health issues, many of which are preventable with timely intervention. Heat-related illnesses encompass a spectrum of conditions, from mild forms like heat exhaustion and heat cramps to life-threatening conditions such as heat stroke (Becker & Stewart, 2011). Fluid and electrolyte imbalance (FEI) and volume depletion (VD) are examples of dehydration-related health outcomes associated with high ambient temperature (Heidari et al., 2016), and both can lead to an increased risk of acute kidney injury (AKI) (Hajat et al., 2024). Other health outcomes associated with heat include other renal diseases (Borg et al., 2017), cardiovascular diseases (Yin & Wang, 2017), Alzheimer's disease and related dementias (Zhang et al., 2023), and septicemia (Bobb et al., 2014).

Despite extensive epidemiological research linking heat exposure to a variety of health outcomes, significant knowledge gaps persist in understanding the pathways through which heat exposure occurs and leads to adverse health effects. A critical factor in heat exposure is the specific *location* in which the exposure occurs, as it relates to an individual's behavior, occupation, and activity patterns. Insights into these contexts can help identify high-risk environments and inform adaptive strategies. For example, high occupational heat exposure has been well-documented in settings such as agriculture, construction, and food service (Ierardi & Pavilonis, 2020; Inaba & Mirbod, 2007; Jackson & Rosenberg, 2010). Similarly, case studies on extreme heat wave events have reported that higher proportions of heat-related deaths occur in outdoor settings (Iverson et al., 2020) and among unhoused individuals (Tetzlaff et al., 2024). However, few population-level epidemiologic studies have directly compared heat-related health risks among different exposure environments.

In 2015, health care institutions in the US adopted the 10th revision of the International Classification of Diseases (ICD-10) codebook for coding disease diagnoses, symptoms, and external causes of injury (Antoon et al., 2024; Langley & Chalmers, 1999). Notably, ICD-10 codes beginning with “Y92” were introduced to indicate the place of occurrence of the external cause (e.g., homes, paved roadway, vehicle, public places, and wilderness areas). These are secondary codes for identifying the location of the patient at the time of injury or other condition and offer a unique opportunity to study the role of different location-based risk environments in heat-related health outcomes. Y92 codes have recently been utilized in various research contexts, such as identifying injuries related to agricultural work (Walker et al., 2024) and examining injury locations in healthcare utilization studies (Saper et al., 2024).

ICD-10 Y92 codes have the potential to reflect risk factors associated with heat exposure pathways. The main objective of this study was to leverage these codes and quantify how temperature may impact the presence of Y codes for different location categories among heat-related morbidity outcomes. We analyzed emergency department (ED) visits for heat-related illness, including heat exhaustion, heat stroke, FEI, VD, and AKI across nine US states. Additionally, we applied stratification analysis by age, race, and ethnicity to identify potential vulnerable subpopulations. We chose ED visits because it is an important morbidity indicator for severe heat-related outcomes. ED visits are also an under-examined health indicator compared to hospitalization and mortality.

2. Methods

2.1. Emergency Department Visits

Patient-level ED visit records were obtained from hospital associations or state health departments in nine US states: Arizona (2016–2018), California (2016–2018), Georgia (2016–2018), North Carolina (2016–2017), Maryland (2016), Missouri (2016–2018), New York (2016–2018), New Jersey (2016), and Utah (2016–2018). These records included both patients who were admitted to the hospital following an emergency department visit and those who were discharged directly from the ED. Each visit record contained key patient information, including admission date, age in years or age group, race, ethnicity, ZIP code of residence, and ICD-10 diagnosis codes. We identified heat-related visits using primary ICD-10 diagnosis codes, including those for heat exhaustion and heat stroke visits (HEAT, ICD-10: T67), fluid and electrolytes imbalance visits (FEI, ICD-10: E86-87), volume depletion visits (VD, ICD-10: E86.9), and acute kidney injury visits (AKI, ICD-10: N17). To capture the potential location of heat exposure, we used secondary ICD codes beginning with Y92 (Y codes), which indicates the location of the patient at the time of the health event. Among the 9 states included in this study, the proportion of heat-related ED visits with Y codes ranged from 3.3% to 17.4%. We categorized these Y code locations into 12 relevant heat exposure settings, as shown in Table 1, and included only ED visits with a Y code in the analysis.

Table 1
ICD-10 Diagnosis Codes Beginning With Y92 (Y Codes), Which Indicates the Location of the Patient at the Time of the Health Event

Y code category	ICD-10-CM code	Examples
Farm	Y92.7	Barn, chicken coop, farm field, and orchard
Industrial	Y92.6	Building under construction, docks, factories, mines, and oil rigs
Nursing home	Y92.12	Any places in the nursing home
Prison	Y92.14	Any places in the prison
Residential place	Y92.0	Family houses, mobile homes, apartments, and boarding houses
Public place	Y92.2	Schools, hospitals, public administrative buildings, and cultural buildings
Recreation area	Y92.83	Public parks, amusement parks, beaches, campsites, and zoological gardens
Sports area	Y92.3	Athletic court, athletic field, and skating rink
Street	Y92.4	Street, highway, and other paved roadways
Trade	Y92.5	Private commercial establishments, like banks, restaurants, supermarkets, and shops. Service areas, like airports, bus and railway stations, and gas stations
Vehicle	Y92.81	Transport vehicles like cars, buses, airplanes, trucks, boats, trains, and subways
Wilderness area	Y92.82	Desert, forest, and other wilderness area

2.2. Meteorological Data

Daily maximum and minimum temperatures in degree Celsius and daily average absolute humidity were acquired from the High-resolution Urban Meteorology for Impacts Data sets (HUMID), a gridded data set that provides near-surface temperature data for the contiguous U.S. at a 1 km spatial resolution (Newman et al., 2024a, 2024b). This data set explicitly accounts for urban heat islands by employing an urban canopy model, which integrates land use information into hourly meteorological data from the North American Land Data Assimilation Phase 2 (NLDAS) (Xia et al., 2012) using the High-Resolution Land Data Assimilation System (HRLDAS) (Monaghan et al., 2014). Bias-correction was performed using observations from various networks to improve accuracy. We included daily minimum temperature as an exposure to better capture impacts of previous day's night-time temperature and daily average apparent temperature to account for the impacts of humidity.

We calculated ZIP code level temperature metrics by spatially averaging all 1 km grid cells within each ZIP code boundary, then linked these metrics to each emergency department visit based on the admission date. ED records that lacked corresponding temperature data due to out-of-state residential ZIP codes were excluded from the analyses.

2.3. Statistical Analyses

The analysis was restricted to the warm season (May–October) only. To estimate associations between temperature and the presence of different Y-code categories among heat-related ED visits, we conducted logistic regression models, using a case-only framework (Armstrong, 2003; Madrigano et al., 2015; Schwartz, 2005). Each health outcome and non-residential Y-code category was examined separately. Let Y_{ist} denote a binary variable for the ED visit of a particular outcome (e.g., FEI) observed in state s on day t. We define ED visits with Y-codes for residential places as controls ($Y_{\text{ist}} = 0$) and ED visits with Y-codes for a specific non-residential place as cases ($Y_{\text{ist}} = 1$). The general form of the model is given below:

$$\text{logit } P(Y_{\text{ist}} = 1) = \beta_0 + \beta_1 X_{\text{st}} + \boldsymbol{\gamma} \mathbf{Z}_{\text{st}}$$

where X_{st} represents the temperature exposure and $\mathbf{Z}_{\text{st}}$ represents the set of spatial and temporal confounders (described below). A positive log odds ratio β_1 can be interpreted as temperature increasing the rate of a non-residential Y code category (e.g., street) compared to residential locations among ED visits.. For continuous heat exposure analysis, we converted absolute maximum and minimum temperatures to their ZIP code-specific

Table 2
Total Count and Percent of Emergency Department Visits for Heat Exhaustion (HEAT), Fluid and Electrolyte Imbalance (FEI), Volume Depletion (VD), and Acute Kidney Injury (AKI) From 9 States During May to October (2016–2018), Stratified by Y Code Categories

Places	HEAT	FEI	VD	AKI
Farm	342 (2.3%)	401 (0.1%)	207 (0.2%)	143 (0.1%)
Industrial	1,320 (8.9%)	1,464 (0.5%)	830 (0.8%)	466 (0.3%)
Nursing home	80 (0.54%)	17,408 (5.8%)	6,843 (6.2%)	8,314 (5.9%)
Prison	67 (0.45%)	994 (0.3%)	353 (0.3%)	333 (0.2%)
Residential place	5,217 (35.2%)	176,499 (58.7%)	70,383 (64.2%)	80,089 (56.6%)
Public place	731 (4.9%)	68,941 (22.9%)	19,665 (17.9%)	41,702 (29.5%)
Recreation area	1,361 (9.2%)	2,146 (0.7%)	1,102 (1.0%)	542 (0.4%)
Sports area	1,373 (9.3%)	1,484 (0.5%)	896 (0.8%)	362 (0.3%)
Street	1,938 (13.1%)	21,672 (7.2%)	5,394 (4.9%)	6,368 (4.5%)
Trade	1,077 (7.3%)	7,558 (2.5%)	2,938 (2.7%)	2,466 (1.7%)
Vehicle	639 (4.3%)	1,032 (0.3%)	422 (0.4%)	316 (0.2%)
Wilderness area	636 (4. %3)	1,088 (0.4%)	680 (0.6%)	329 (0.2%)
Total	14,781	300,687	109,713	141,430

quantile levels (i.e., 0%–100%) based on historical data from 1996 to 2018. We modeled the associations between temperature and ED visits non-linearly using natural cubic splines with 4 degrees of freedom in our primary analysis. Odds ratios (OR) were reported as comparisons between the 95th and 50th temperature percentiles. In a secondary analysis, we also considered binary heat exposure, defined as temperatures exceeding the ZIP code-specific 98th percentile.

All models accounted for the following spatial and time-varying confounders: (a) indicators for weekdays, years, states, and federal holidays, and (b) state-specific temporal trends modeled using natural cubic splines of day-of-year with 3 degrees of freedom, and their interaction terms with year and with state indicators. From the exposure-response curves, we calculated odds ratios of a sequence of temperature levels, ranging from 40% quantile level to 100% quantile level in 0.5% increments, relative to the 50th quantile temperature level for four types of ED visits.

We further performed stratification analyses by age, race, and ethnicity to identify potential vulnerable populations. Age groups were categorized into children (<18 years), adults (18–65 years), and seniors (>65 years). Data were also stratified by race (White, Black or African American, and Asian/Pacific Islander) and ethnicity (non-Hispanic and Hispanic). Since FEI is frequently associated with other heat-sensitive outcomes, we also conducted sensitivity analyses with FEI ED visits that did not have a co-diagnosis of HEAT, VD, and AKI. We also conducted a sensitivity analysis that additional adjust for several patient-level covariates, including patient age (natural cubic splines with 4 degrees of freedom), patient race (White, Black, Asian, other), patient ethnicity (Hispanic, non-Hispanic) and ZIP code level percent population below poverty. All analyses were conducted in R version 4.4.1 (R Development Core Team, 2024). Example R code for model fitting and calculating odds ratios from the exposure-response functions are provided in Supporting Information S1.

3. Results

Table 2 gives the total counts and percentages of ED visits stratified by Y code categories. The study included a total of 503,749 ED visits, with FEI diagnosis being the most common. Residential areas were the most frequent reported Y codes for all types of ED visits, accounting for 35.2% of HEAT, 58.7% of FEI, 64.2% of VD, and 56.6% of AKI ED visits. Public places were the second most common Y codes: 22.9% for FEI, 17.9% for VD, and 29.5% for AKI ED visits. ED visits with Y codes indicating streets also accounted for a relatively large proportion of all HEAT visits (1938, 13.1%). For HEAT ED visits, nursing home and prison were the two least reported Y code categories. Table S1 in Supporting Information S1 gives counts and percentages that are further stratified by daily maximum temperature above or below the 95% quantile threshold. On high temperature days, HEAT ED

Table 3
Odds Ratios for Non-Residential Y Code Category Compared to Residential Places With an Increase in Same-Day Maximum Temperature (95th Percentile Versus 50th Percentile Exposure) Among Heat-Related Emergency Department Visits (95% Confidence Intervals in Parentheses)

	Emergency department visit outcome			
Y code category	Heat	FEI	VD	AKI
Farm	0.90 (0.41, 1.98)	3.33 (2.24, 4.95)	7.66 (4.05, 14.50)	2.27 (1.13, 4.56)
Industrial	1.07 (0.68, 1.69)	1.95 (1.59, 2.39)	2.68 (1.98, 3.63)	2.71 (1.82, 4.04)
Nursing home	0.80 (0.23, 2.73)	0.95 (0.90, 1.01)	0.94 (0.86, 1.02)	0.92 (0.85, 0.99)
Prison		0.97 (0.77, 1.21)	1.02 (0.70, 1.48)	1.08 (0.72, 1.61)
Public place	1.01 (0.65, 1.56)	0.90 (0.87, 0.93)	0.89 (0.84, 0.94)	0.89 (0.85, 0.93)
Recreation area	0.78 (0.54, 1.12)	1.71 (1.45, 2.01)	2.25 (1.78, 2.84)	1.53 (1.11, 2.11)
Sports area	1.26 (0.86, 1.85)	2.16 (1.78, 2.62)	2.80 (2.16, 3.62)	2.23 (1.49, 3.32)
Street	1.68 (1.12, 2.51)	1.18 (1.12, 1.24)	1.54 (1.39, 1.70)	1.22 (1.11, 1.34)
Trade	0.93 (0.60, 1.45)	1.15 (1.06, 1.25)	1.47 (1.28, 1.68)	1.13 (0.97, 1.31)
Vehicle	0.73 (0.45, 1.19)	1.42 (1.14, 1.78)	2.16 (1.49, 3.14)	1.41 (0.95, 2.10)
Wildness area	0.89 (0.53, 1.49)	2.40 (1.88, 3.06)	3.74 (2.68, 5.24)	3.57 (2.19, 5.83)

Note. The analysis included visits with Y codes from 9 states (May to October, 2016–2018).

visits were less frequently observed with Y codes for industrial areas, public places, and sports areas. FEI, VD, and AKI ED visits, were less frequently observed with Y codes for public places on hot days.

Table 3 gives the estimated odds ratios for each non-residential Y code category associated with changes in daily maximum temperature exposure from their 95th to the 50th percentiles. For HEAT ED visits, increased temperature was associated with higher rate of Y codes for streets compared to residential locations (OR:1.68, 95% CI: 1.12–2.51). For FEI ED visits, increasing temperature was associated with lower rate of Y codes for public places, but greater rates of Y codes for industrial areas, farms, recreation areas, streets, vehicles, and wilderness areas. The strongest association was for farm (OR 3.33, 95% CI: 2.24–4.95) and wilderness areas (OR: 2.40, 95% CI: 1.88–3.06). Results for VD and AKI ED visits were similar to those for FEI ED visits in terms of direction, but associations were more pronounced for VD. Finally, higher temperature was associated with lower rate of Y codes for nursing home and public places compared to residential places among ED visits for FEI, VD, and AKI.

Odds ratios for same-day daily minimum temperature are presented in Table S3 in Supporting Information S1. Overall, associations were weaker compared to those obtained by using maximum temperature. For example, with FED ED visits and minimum temperature, the association for Y codes for street versus residential locations (OR 2.20, 95% CI: 1.42–3.40) was lower than the same association (OR 3.33, 95% CI: 2.24–4.95) when using maximum temperature. However, there were a few exceptions. Most notably, we observed less ED visits with Y codes for prison for FEI and VD when minimum temperature was used. Tables S4 and S5 in Supporting Information S1 give the odds ratios for dichotomous heat exposure (maximum and minimum temperature above or below the 95th percentile). Findings for FEI, VD, and AKI ED visits were similar to those using continuous temperature exposure. However, for HEAT ED visits, we found stronger protective associations for most Y code categories.

Figure 1 shows the estimated exposure-response function from the FEI ED visit analysis. Overall, we observe monotonic positive and negative associations that are consistent across the range of temperature exposure. For some Y code categories (e.g., industrial, recreation, and vehicle), we see potential non-linear associations, where the increase in odds is more rapid at higher temperature. Exposure-response functions for minimum temperature and for the other ED visit diagnoses show similar patterns (Figures S1–S3 in Supporting Information S1).

Figure 2 shows results from stratified analyses by age, race, and ethnicity for FEI ED visits in four of the more common Y code categories: industrial areas, public places, streets, and trade areas. Black or African American individuals were more likely to experience FEI ED visits with Y codes for industrial areas compared to residential areas with increasing temperature. Adults, White, and Hispanic individuals were more likely to have Y codes

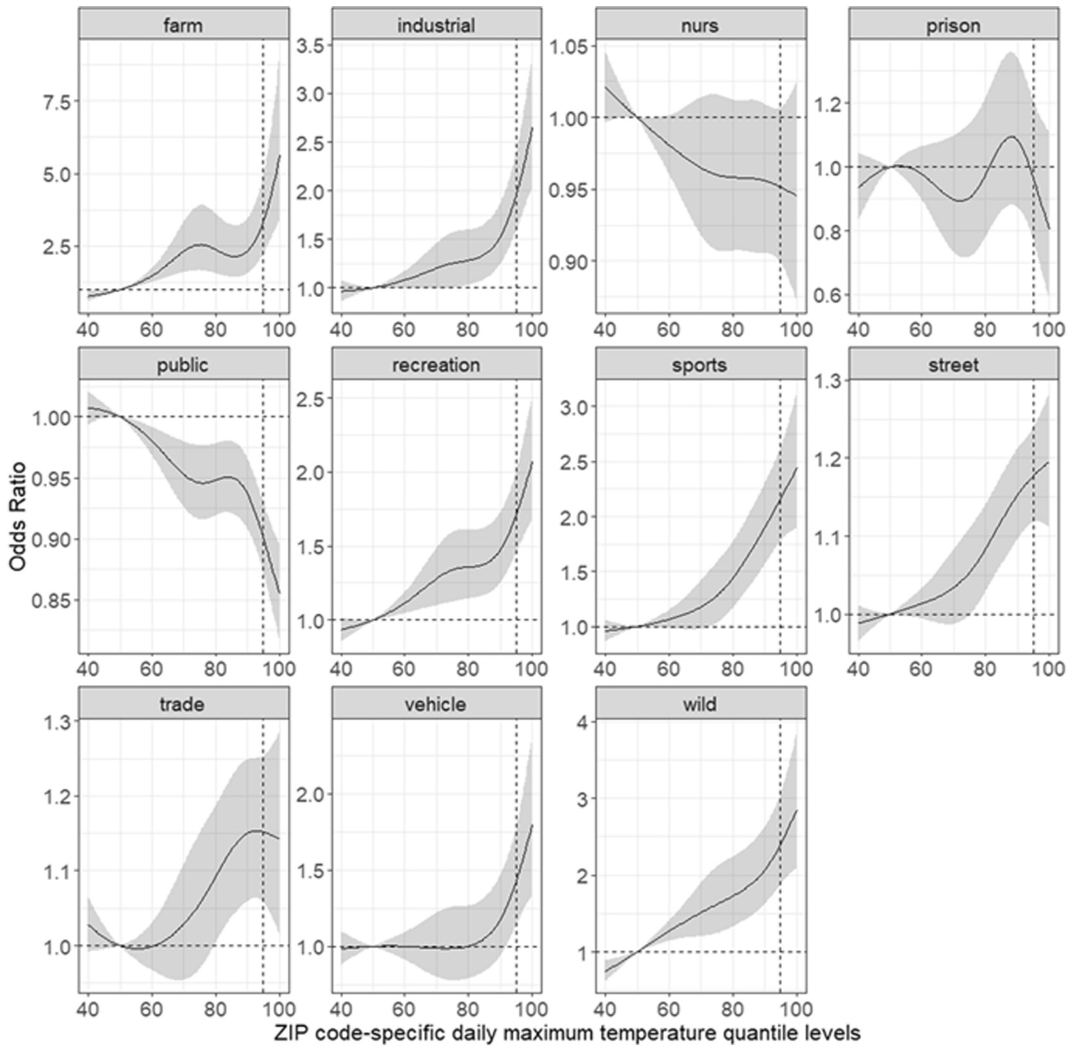

Figure 1. Exposure-response function among fluid and electrolyte emergency department visits with a specific Y code category compared to residential places and ZIP code-specific daily maximum temperature quantile levels. Nonlinear associations were specified via natural cubic splines with 4 degrees of freedom. Odds ratios are centered at the 50th quantile level and the 95th percentile is indicated by the vertical dotted line. Shaded regions represent pointwise 95% confidence intervals. The analysis included visits with Y codes from 9 states (May to October, 2016–2018).

indicate for streets compared to residential areas with increasing temperature. Numeric values for all results from stratified analysis are given in the Tables S7–S9 in Supporting Information S1. Here we highlight a few notable findings. Children were more likely to have HEAT ED visits with Y codes for recreation areas, sports areas, and public areas with increasing temperature. For VD ED visits, Black or African American individuals had stronger associations for recreation areas, sports areas, trade areas, and vehicles. For AKI, Hispanic individuals were more likely to have Y codes for street compared to residential places the with increasing temperature as well.

Table S6 in Supporting Information S1 gives the estimated odds ratios for FEI ED visits that did not have a co-diagnosed HEAT, VD, or AKI code. Compared with the results based on all FEI ED visits, fewer significant associations were identified, and the associations were generally weaker. However, a stronger protective association was observed when using daily minimum temperature as the exposure. Table S7 in Supporting Information S1 gives the estimated odds ratios for daily average apparent temperature was used. Generally, we found the associations were more similar to those obtained using daily minimum temperature, except for Y-code farm locations where positive associations were not found for average apparent temperature. Finally, additional

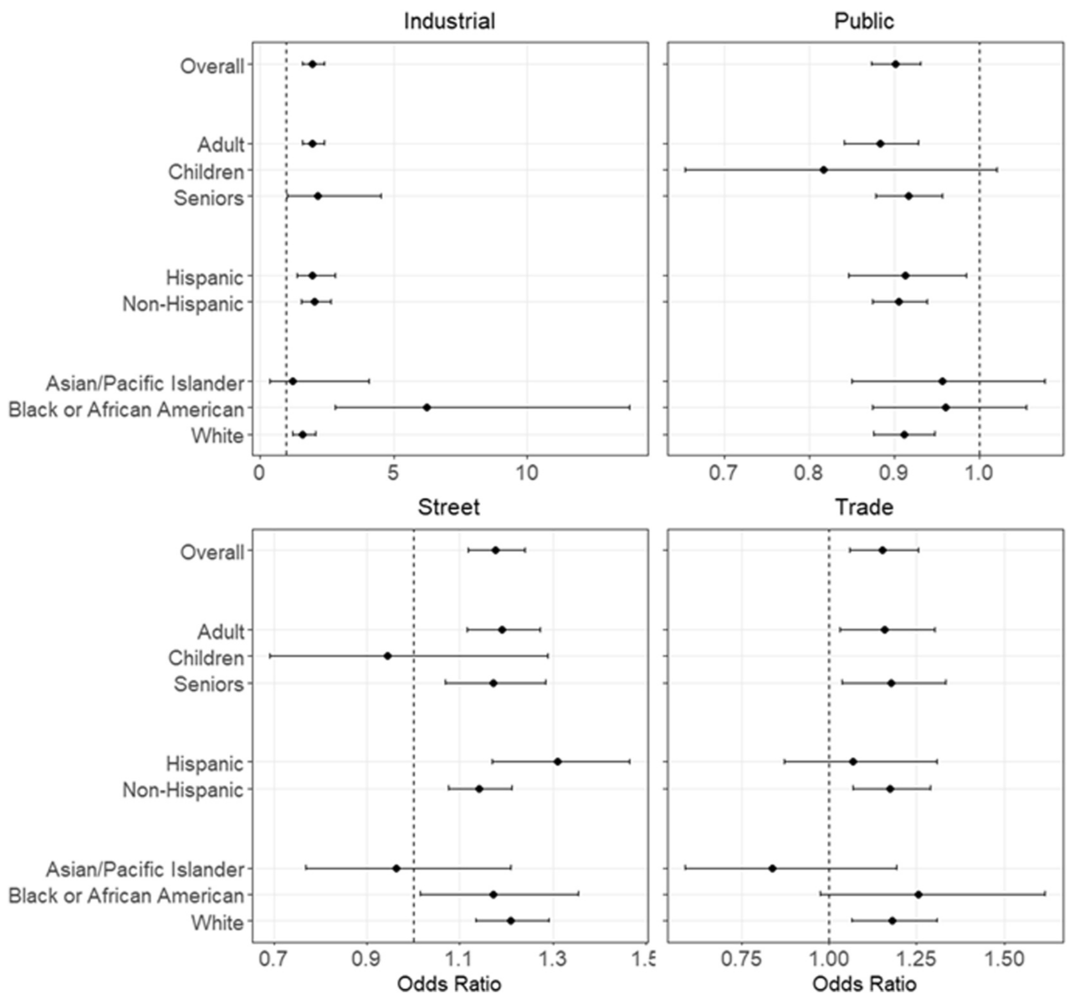

Figure 2. Odds ratios for Y code categories (industrial, public, street and trade) compared to residential places with an increase in same-day maximum temperature (95th percentile vs. 50th percentile exposure) stratified by age, race, and ethnicity among fluid and electronic imbalance emergency department visits. The analysis included visits with Y codes from 9 states (May to October, 2016–2018).

adjustment for patient age, race, ethnicity, and ZIP code poverty resulted in very similar estimated odds ratios (Tables S2–S5 in Supporting Information S1).

4. Discussion

Our study analyzed over half million ED visits for HEAT, FEI, VD, and AKI across 9 US states with varied climate regions. We explored the novel relationship between ambient temperature and Y code locations of injury or condition among heat-related ED visits. We found consistent higher heat-related risks in environments such as industrial areas, farms, streets, and recreation areas compared to residential areas. In contrast, public places demonstrated protective associations. There are well-established pathophysiological impacts of heat stress on thermoregulation, kidney function and the cardiovascular system (Chapman et al., 2021; Donaldson et al., 2003). Y-code locations with higher heat-risk may be due to exposure to higher outdoor temperature, as well as exertional activities that increase vulnerability (Garcia et al., 2022). These findings provide valuable insights for public health authorities to enhance heat preparedness and response strategies by targeting high-risk locations. The protective role of public spaces highlights the potential benefits of expanding community-based cooling centers, increasing public awareness campaigns, and implementing targeted interventions to reduce heat-related morbidity and mortality.

Our study suggested significant hazardous effects in trade areas (i.e., commercial and service areas) for FEI-related ED visits, which aligns with findings from a previous study in Boston that examined environmental factors linked to high heat-related mortality zones. That study found that areas in and around Roslindale and Mattapan in Boston, both characterized by a large percentage of developed land, experienced higher heat-related mortality rates, indicating that business areas tend to have higher heat-related mortality rates (Hondula et al., 2015). Other factors may be due to increased anthropogenic heat, higher impervious surface cover, and less air movement due to building morphology (Phelan et al., 2015).

Hondula et al. (2015) identified higher mortality rates in the lake district of the far west of Minneapolis, possibly driven by increased recreation activities on hot days. A similar trend was also reported in Toronto, where higher ambulance call-outs were reported near the lakeshore, where people sought relief from the heat (Bassil et al., 2009). This behavior, where individuals flock to recreational areas to escape the heat, may inadvertently increase their risk of heat-related mortality, consistent with our findings of elevated FEI, VD, and AKI ED visits with Y codes for recreation areas with increasing temperature.

We also observed hazardous associations in areas such as streets, industrial zones, and farms, which are closely related to specific types of occupations. Although few studies have focused specifically on these environments in relation to heat-related ED visits, our results aligned with one study on occupational heat-related mortality in the United States (Gubernot et al., 2015). That study found that agriculture and construction had the highest rates for heat-related deaths, supporting our findings of increased risk in farm, industrial areas, and streets. Workers in these settings often have limited access to adequate shelter for rest during shifts (Vallejos et al., 2011), and some may even avoid taking breaks on hot days due to concerns about lost income (Chicas et al., 2023; Gubernot et al., 2015), further increasing their heat exposure risk.

Compared with the extensive research on heat-related mortality, fewer studies have focused on the impact of heat on ED visits or morbidity by location. However, the findings of several studies are consistent with our results. For instance, a study in North Carolina found that labor-intensive agriculture was a major risk factor for heat-related ED visits in rural areas (Kovach et al., 2015), aligning with our observed hazardous associations in farm settings. Additionally, another study indicated that 40% of North Carolina farm workers experienced at least one heat-related symptom while working in extreme heat, further supporting our findings regarding the risks faced by agricultural workers (Mirabelli et al., 2010).

We also observed a protective association for public places compared to private places, which has been supported by findings from other studies. One study from California identified a higher risk of mortality at home compared to outdoors during heat waves (Joe et al., 2016; Kosatsky et al., 2012). Similarly, a study conducted in Canada found that the risk of mortality during a summer heatwave was higher for individuals at home compared to those residing in health care institutions (Kosatsky et al., 2012). One possible explanation is that people living alone may face an increased risk of heat-related mortality due to the absence of social contacts who could assist during extreme heat events (Price et al., 2013) while people in public places could get immediate aid from other people around or on-site professional rescue personnels. Additionally, risk factors at home, including chronic diseases, lack of mobility, sleeping on the top floor, and limited thermal insulation, (Kosatsky et al., 2012) may have been well addressed in public places due to adherence to certain safety and accessibility standards to accommodate larger groups of people.

Prisons have been noted as a potential high-risk environment for heat exposure due to overcrowding, building materials that retain heat, poor air circulation and the lack of air conditioning (Colucci et al., 2023; Skarha et al., 2020, 2022). Incarcerated adults are also more likely to have ED visits for assault and self-warm compared to nonincarcerated adults (Wulz, 2023). Previous studies have reported heat exposure and increased risks of and suicide watch incidents (Cloud et al., 2023), all-cause mortality (Skarha et al., 2022), and severe violent incidents (Mukherjee & Sanders, 2021). We did not observe increased risks of Y-code for prison, possibly due to the smaller sample size and choice of outcomes.

We found that specific subgroups, particularly children and seniors, were more likely to experience heat-related morbidity with Y codes for recreation area and sports area as temperature rises. Based on our results, interventions such as increasing shaded areas, providing water stations, issuing heat advisories, and implementing emergency response protocols could help mitigate the risk for these vulnerable populations. Additionally, we identified more intensive hazardous association for Hispanic people on streets compared with non-Hispanic people. A similar result has also been reported by the mortality study in the United States, reporting that Hispanics were 3.2 times more likely to die of work-related heat exposure than non-Hispanics (Gubernot et al., 2015). The influence of ethnicity may also be closely related to occupation of certain ethnicity groups because of their over-representation in construction work (Gubernot et al., 2015). Language and cultural barriers, migrant worker or day laborer status, economic status, access to health insurance and health care, and inadequate training, all of these could add risks for Hispanic people (Culp et al., 2011; Fleischer et al., 2013; Lowry et al., 2010; Mirabelli et al., 2010). To mitigate the heightened risk faced by Hispanic farmworkers, interventions should include culturally and linguistically appropriate training on heat safety, enhanced workplace regulations ensuring access to water, shade, and mandatory breaks, and improved access to healthcare services. Empowering workers through community advocacy and continuous monitoring of heat-related health outcomes can further protect this vulnerable population.

Our study has several strengths. First, unlike many previous studies that focus solely on heatwaves—typically defined as consecutive days of elevated temperatures—we analyzed daily minimum and maximum temperatures as continuous variables. This allowed us to capture the effects of isolated hot days, which are often overlooked but still contribute to heat-related health risks (Madrigano et al., 2015). Second, we analyzed differential heat risk due to patient-level interactions with their built environment, while previous studies have typically examined impacts of area-level topography, proximity to water bodies, urban form, and air conditioning prevalence (Nice et al., 2022; O'Neillet al., 2005). Third, we focused on heat-related morbidity rather than mortality, providing a more comprehensive understanding of the burden on healthcare systems. ED visits are a more immediate and widespread measure of heat's impact than mortality, reflecting the healthcare strain from emergency and inpatient care. Forth, while previous studies often categorized locations by social factors like age or income (Chakraborty et al., 2019; Green et al., 2001), we categorized places by function or usage, offering more practical insights into daily heat exposure. By providing quantitative estimates of heat-related morbidity across different locations, our study may offer a more precise, objective assessment of how environments impact health outcomes, aiding in trend identification, prediction, and policy development. Finally, the generalizability of our findings is strengthened by the use of state-wide hospital discharge records to capture ED visits for all ages, all insurance types, and both urban and rural regions. The nine states also represent diverse different climatic regions and diverse racial and socioeconomic subpopulations. Though how findings translate to other outcomes (e.g., mortality) and regions warrant further investigations.

Our study also has several limitations. First, like many ICD code-based analyses, there is potential for bias in the use of these codes (Baassiri et al., 2024; Bhatt et al., 2021). Imprecise outcome classification may occur when identifying HEAT, FEI, AKI, or VD-related ED visits, as these conditions often share similar symptoms, increasing the likelihood of misclassification. Moreover, one study in Canada found that identifying acute heat illness based on ICD-10 code had a relatively low and unstable sensitivity of 25.0 ± 42.4% (Baassiri et al., 2024). This motivated our inclusion of other heat-sensitive outcomes. Second, we found that the percentage of Y-code among ED visits to be variable across states. Our analyses excluded ED visits without a Y-code, even though occurrence location may be an important contributor. We also note that ICD codes were assigned upon discharge from hospital and some outcomes (e.g., FEI) may not necessarily align with the health event location. Additionally, residual confounding cannot be completely ruled out. While location provides valuable insights into patients' activities, behaviors may also play a significant role in the association between heat exposure and health outcomes. Other factors, such as diet, pre-existing comorbidities, and the timing of heat exposure throughout the day, may also influence the results, but were not examined in detail in this study because this information are not available from hospital discharge records.

5. Conclusion

We identified consistent hazardous associations in trade areas, streets, industrial zones, and farms for heat-related ED visits when temperature rises, while public places showed consistent protective associations. Hispanics may represent a vulnerable population in streets affected by short-term exposure to heat. These findings underscore the need for targeted, location-specific strategies to mitigate heat-related morbidity and mortality.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The High-resolution Urban Meteorology for Impacts Data set (HUMID) exposure data used in this analysis is publicly available (Newman et al., 2024a, 2024b). Patient-level ED data are not publicly available and cannot be shared by the authors because they contain protected health information, including hospital admission date and patient residential ZIP code. Data supporting this research are available from each state's data custodian described in the Acknowledgement section and can be requested by interested parties through a Data Use Agreement.

Acknowledgments

We acknowledge and greatly thank all sources of data and funding that made this study possible. In particular, data on ED visits were collected from patient-level hospital billing records acquired for Arizona (Arizona Hospital Discharge Data Set, Bureau of Public Health Statistics, Arizona Department of Health Services), California (California Health and Human Services Agency, Office of Statewide Planning and Development, now California Department of Health Care Access and Information), Georgia (individual hospitals and the Georgia Hospital Association), North Carolina (North Carolina Hospital (ambulatory surgery, emergency room) Discharge Database, Truven Health Analytics, Fiscal Year 2016), Maryland (Health Services Cost Review Commission), Missouri (Missouri Department of Health and Senior Services (DHSS)), New York (New York State Department of Health (NYSDOH)), New Jersey (New Jersey Department of Health (NJDOH)), and Utah (Utah Department of Health & Human Services: Utah Health Data Committee). Authorization to release these data does not imply endorsement of this study or its findings by these organizations.

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