HHS Public Access
Author manuscript
Indoor Air. Author manuscript; available in PMC 2017 August 01.

Published in final edited form as:
Indoor Air. 2016 August ; 26(4): 594–604. doi:10.1111/ina.12227.

Summer indoor heat exposure and respiratory and cardiovascular distress calls in New York City, NY, U.S

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Abstract

Most extreme heat studies relate outdoor weather conditions to human morbidity and mortality. In developed nations, individuals spend ~90% of their time indoors. This pilot study investigated the indoor environments of people receiving emergency medical care in New York City, NY, U.S., from July to August 2013. The first objective was to determine the relative influence of outdoor conditions as well as patient characteristics and neighborhood sociodemographics on indoor temperature and specific humidity ($N = 764$). The second objective was to determine whether cardiovascular or respiratory cases experience hotter and more humid indoor conditions as compared to controls. Paramedics carried portable sensors into buildings where patients received care to passively monitor indoor temperature and humidity. The case–control study compared 338 respiratory cases, 291 cardiovascular cases, and 471 controls. Intuitively, warmer and sunnier outdoor conditions increased indoor temperatures. Older patients who received emergency care tended to occupy warmer buildings. Indoor-specific humidity levels quickly adjusted to outdoor conditions. Indoor heat and humidity exposure above a 26 °C threshold increased (OR: 1.63, 95% CI: 0.98–2.68, $P = 0.056$), but not significantly, the proportion of respiratory cases. Indoor heat exposures were similar between cardiovascular cases and controls.

Keywords

Extreme heat; Emergency medical service; Temperature; Humidity; Indoor; Case; control study

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Introduction

There are multiple definitions of extreme heat such as temperatures or dew points above an absolute (e.g. 32 °C) or relative (e.g. 95th percentile) threshold or physiologically comfortable level. Extreme heat contributes to an estimated 600–1800 U.S. deaths and over 8000 emergency department visits per year (Centers for Disease Control and Prevention 2006; Wu et al., 2014). This disease burden disproportionately impacts individuals with preexisting physical or mental health conditions, people with high occupational or recreational heat exposure, young children, and older adults (age >65).

The human body's skin temperature influences thermal comfort and thermoregulation (Gagge and Gonzalez, 1996). Air temperature and humidity are both important to the thermoregulatory process, as sweating (evaporative cooling) is the most important cooling mechanism when ambient temperatures are greater than the body's skin temperature. Humidity levels modulate the skin-air vapor gradient and the efficacy of evaporative cooling. The cardiovascular system's ability to thermoregulate diminishes in older adults who are less physically active, overweight, or exposed to long periods of heat (Kinney et al., 2008). A higher proportion of older adults have comorbidities, take drugs that increase heat sensitivity, have limited mobility, and have behaviors that also contribute to higher mortality and morbidity rates compared to the general public (e.g., Semenza et al., 1999; Stafoggia et al., 2008; White-Newsome et al., 2011).

Most extreme heat studies relate outdoor weather conditions to human morbidity and mortality. However, many at-risk populations are exposed to warm temperatures that may affect health inside of buildings. In developed countries, people spend approximately 90% of their time indoors (Klepeis et al., 2001; Schweizer et al., 2007). Of the time spent indoors, older adults tend to spend most of their time at home (Basu and Samet, 2002; Loughnan et al., 2013). In France, during the 2003 European extreme heat event, ~50% of excess mortalities occurred inside of households (Fouillet et al., 2006). In New York City, NY, U.S., almost all (85%) classified hyperthermia cases succumbed to heat in their own home (Centers for Disease Control and Prevention 2013).

Outdoor temperatures may only be loosely associated with indoor temperatures, and these relationships may be place and season specific. Indoor/outdoor-specific humidity associations tend to be stronger than indoor/outdoor temperature relationships (Nguyen et al., 2014; Tamerius et al., 2013). In Detroit, MI, U.S., maximum temperatures inside the households of older adults were an average of 13.8 °C warmer than outdoor maximum temperatures (White-Newsome et al., 2012).

Air conditioning access and usage are important determinants of summer indoor environments and extreme heat mortality. Even in households with air conditioning, electricity prices may limit indoor climate control in at-risk households (Hayden et al., 2011; Sheridan, 2007; Snyder and Baker, 2010). Households receiving federal energy assistance spend 16% of their income on electricity (National Energy Assistance Directors' Association, 2009). Constrained air conditioning usage may be reflected in neighborhoods with a high proportion of minorities with greater heat-related disease burdens (Medina-Ramon et al., 2006).

The composition and configuration of the built environment, air exchange rates, and sociodemographic characteristics further alter indoor/outdoor linkages (Franck et al., 2013; Smargiassi et al., 2007; Tamerius et al., 2013). Important built environment determinants of indoor summer temperatures include building materials, the type of housing structure (e.g., apartment, detached home), level (floor) in a building, and surrounding tree cover (Loughnan et al., 2013; Smargiassi et al., 2007; White-Newsome et al., 2012). Analogous studies of air leakage suggest similar built environment characteristics influence indoor/outdoor linkages (e.g., Chan et al., 2013; Pan, 2010). The same factors such as lacking centralized air conditioning or inhabiting the upper stories of buildings consistently increase extreme heat mortality risk (e.g., Heaton et al., 2014; Ostro et al., 2010).

A previously published review of 96 papers found only a couple of studies that explicitly linked indoor heat exposure to human health (Anderson et al., 2013). The notable exceptions were an observational personal heat exposure study and a mechanistic modeling study. In Baltimore, MD, U.S., personal body temperatures of older adults were slightly lower indoors than outdoors (Basu and Samet, 2002). A mechanistic built environment and human physiology model suggests people in unventilated buildings are 2–3.8 times more likely to experience heat-related symptoms compared to people outdoors (Chan et al., 2001). Another relevant case report in Philadelphia, PA, U.S., documented indoor temperatures of people who died during an extreme heat event. Indoor household temperatures were up to 18.8 °C greater than the outdoor temperature of 35.6 °C (Hawkins-Bell and Rankin, 1994). Personal heat exposure studies also suggest that individuals experience a wide range of temperatures during the summer (Bernhard et al., 2015; Kuras et al., 2015).

The present study evaluated indoor heat exposures of people receiving emergency care for a 1-month period in the summer. The study's first objective was to quantitate how outdoor conditions, patient characteristics, and neighborhood sociodemographics relate to the indoor conditions of people receiving emergency care and the second objective was to compare the indoor heat exposure of cases and controls. We subsequently compared the indoor heat exposure of respiratory or cardiovascular cases relative to all other distress calls.

Methods

Study area

The study area included all five boroughs (Manhattan, Bronx, Brooklyn, Queens, and Staten Island) of New York City, NY, U.S., served by the Fire Department of New York (FDNY). The FDNY receives nearly 1.3 million medical emergency distress calls per year. Prior data from this paramedic system have demonstrated a significant increase in overall emergency medical service responses during times of increased outdoor temperatures (Freese et al., 2007). In the study area, neighborhoods with higher household incomes tend to have cooler indoor temperatures (Tamerius et al., 2013). These households likely have higher rates of air conditioning adoption and usage compared to low-income households.

In New York City, an extreme heat event is defined as either two or more days when the outdoor heat index >35 °C or one or more days with a heat index above 37.8 °C (Centers for Disease Control and Prevention, 2013). New York City uses the National Weather Service heat index. This study was conducted from July 31 to August 27, 2013. Average August 2013 New York City temperatures (mean: 23.7 °C, minimum: 19.8 °C, maximum: 27.5 °C) were cooler than the long-term average (1980–2010) August temperatures (mean: 24.0 °C, minimum: 19.9 °C, maximum: 28.1 °C) (NOAA National Climatic Data Center 2014). An extreme heat event did not occur during the study, and the maximum average daily outdoor heat index was 28 °C.

Study design and ethical approvals

The study design measured indoor conditions of people receiving emergency care from 10 paramedic teams operating throughout all five boroughs. The study design provided a systematic sample of distress calls across the entire city. The FDNY classifies distress calls into 66 categories of health outcomes that are prioritized by need for medical attention. Previous studies validated certain FDNY categories (respiratory, hyperthermia, and cardiac arrest) against medical diagnosis (Jacobs et al., 2004; Sarkar and Amelung, 2006). The FDNY shared Health Insurance Portability and Accountability Act compliant Patient Care Reports (PCR) corresponding to patients visited by paramedics carrying data loggers, having removed all patient-specific identifiers. The Florida State University Human Subjects Committee approved the project (# 2013.10234).

Data sources

The primary data sources were as follows: (i) temperature and humidity inside buildings where patients received emergency care and (ii) patient demographics from the PCR. The secondary data sources included outdoor weather conditions, aggregated sociodemographics, and land cover. Table 1 summarizes the data sources and resolution or level of analysis for each variable.

Patient care reports

The PCR document the type of distress call, patient age, gender, preexisting medical conditions, and zip code where the patient received care (full analysis data set). The study occurred during a transition between PCR systems. Six of 10 paramedic PCRs also recorded patient race, insurance status, and the approximate geographic location where the patient received care (subanalysis dataset). The FDNY anonymized the geographic location by deprecating the latitude/longitude coordinates precision to the thousands place (error of ~110 m).

Indoor conditions

Paramedics passively monitored indoor temperature and relative humidity of people receiving emergency care. HOBO U23 Pro v2 U23-002 portable data loggers (Onset, Bourne, MA, USA) recorded temperature and humidity at 2-min intervals. This sampling frequency balanced the number of indoor measurements vs. data storage capacity. The study investigators downloaded the HOBO data to a computer at the end of the study period.

Quality control procedures flagged an observation if the difference between indoor/outdoor conditions was >3 standard deviations.

Indoor conditions where the patient received care were defined as the period 4 min after paramedic arrival on scene and 4 min prior to departure. The rationale for using indoor measurements 4 min after paramedic arrival is based on the sensor's response time. When carried by a paramedic (airflow ~1 m/s), the sensor reliably measures indoor conditions 5 min after moving indoors. Indoor temperature and humidity were defined as the average of the remaining observations for each visit. Indoor-specific humidity was calculated from indoor relative humidity and temperature using Clausius–Clapeyron relationships (Shaman and Kohn, 2009).

Outdoor conditions

The North American Land Data Assimilation System (NLDAS) provided hourly outdoor temperature, specific humidity, solar radiation, and wind speed at a ~14 km^2 spatial resolution (Mitchell et al., 2004). NLDAS uses a weather model to interpolate conditions between weather stations. There is good agreement between the NLDAS variables used in this study and independent observations (Luo et al., 2003). We chose not to use the three *in situ* weather stations for outdoor conditions as they were missing data (4.7% of hourly observations) and not distributed across the city (Quinn et al., 2014). NLDAS averages over microclimates and may introduce outdoor observation measurement error. The outdoor conditions for each distress call were selected using the nearest NLDAS grid cell (Euclidean distance) and closest study hour.

The New York State Department of Environmental Conservation provided air quality information. Particulate matter <2.5 μm in diameter was recorded by seven monitors and ozone by four. Distress calls were assigned the average air quality information of the surrounding borough. As Brooklyn did not have an ozone monitor, Brooklyn's ozone values were imputed as the average of the other four boroughs. We considered the effects of air pollution at temporal lags of 0–6 h, 24 h, and 48 h preceding the distress call.

Demographic and land cover data

The U.S. American Community Survey 5-year estimates (2008–2012) provided sociodemographic information about the area surrounding each paramedic visit. However, the study could not determine whether patients received care at their residence, workplace, or another building. Each distress call was assigned the aggregated U.S. American Community Survey sociodemographics of the surrounding census tract (sub-analysis) or zip code (full analysis). The proportion of an area covered by vegetation may provide complementary microclimate information on outdoor air temperature, moisture, and momentum to the NLDAS observations. The shade generated by vegetation may also influence indoor conditions. The North American Land Cover Database 2011 provided summer tree canopy cover in the 100 m area surrounding each distress call (subanalysis) or zip code (full analysis) (Jin et al., 2013).

Analysis

Descriptive statistics—The demographics of the patients receiving emergency care were compared against the City of New York. If city-specific demographics were unavailable, patients were compared with the demographics of the state. Summary statistics compared indoor/outdoor temperature and specific humidity. Where appropriate, the statistics were stratified by 'daytime' hours (07:00–19:59) and 'nighttime/early morning' (20:00–06:59) hours.

Indoor/outdoor relationships—The first objective examining indoor/outdoor relationships used the subset of latitude/longitude records. Records were excluded if the paramedic visitation time was missing or <10 min. Separate statistical models were constructed for indoor temperature and specific humidity. Outdoor weather up to 4 h preceding the distress call could plausibly impact indoor conditions (Quinn et al., 2014). We could not further restrict the temporal lags under investigation due to the diversity of buildings and human behaviors that alter heat transfer and air exchange (Asan, 2006). A sensitivity analysis first screened interrelated outdoor conditions. Physical variables were associated with indoor conditions using generalized linear models (Gaussian) that controlled for the daily weather cycle. The daily cycle was represented by indicator variables that controlled for each 4-h period in a day. A forward stepwise Akaike's information criterion selection procedure determined the best fitting combination of outdoor condition(s) and lags. Once an outdoor variable entered the model, the selection procedure did not consider other lags of the same variable.

The multiple variable analyses include the significant outdoor condition(s) and indicator variables to control for the daily temperature/humidity cycle. A stepwise Akaike's information criterion variable selection procedure (forward and backwards) also considered patient characteristics, neighborhood level sociodemographics, and land cover. The selection procedure used a penalty term with two degrees of freedom to balance model fit vs. the number of independent variables. The analysis was conducted in R version 2.15.3 (R Core Team, Vienna, Austria) using the MASS package.

Case–control study—For the second objective, separate case–control studies analyzed (i) the full record of eligible PCR and (ii) the subanalysis of PCR with latitude/longitude information. This full PCR record excluded records missing the distress call's time, location, air pollution levels, or encounters shorter than 10 min in duration. The subanalysis excluded records missing air pollution levels, the paramedic visitation time or encounters shorter than 10 min in duration.

The selection of cases and controls was guided by distress calls recorded during the 2003 northeastern U.S. blackout, which occurred during a period with elevated heat exposure (Freese et al., 2006). Cases were selected from distress call categories that were elevated during this event and plausibly related to extreme heat. The investigators created separate case definitions for respiratory (difficulty breathing, respiratory, and asthmatic) or cardiovascular cases (cardiac condition, cardiac arrest, and cardiovascular). Respiratory distress calls translate into the clinical diagnoses of asthma, pneumonia, insufficient cardiac blood flow, lung diseases, and emphysema (Sarkar and Amelung, 2006). We excluded distress calls that were likely caused by outdoor conditions (pedestrian strikes, motor vehicle injuries, trauma, and major amputations) or where patients received care in a public park. We also excluded gunshot and stabbing calls as the literature suggests a sizeable proportion of cases either occur outside (17.9–23.6%) or the location is unreported (28.3–51.9%) (Gotsch et al., 2001; Vyrostek et al., 2004). The control group included all other non-case distress calls.

As there is no universal extreme heat definition, the case–control study considered both absolute and threshold heat exposure metrics (Basu, 2009). Absolute metrics (indoor temperature, indoor heat index) may linearly overwhelm a personal heat coping range. Threshold metrics presume that only heat exposures above a certain threshold are potentially harmful to human health. The analysis considered indoor heat indices ≥25, 26, or 27 °C which correspond to the ~73rd, 83rd, and 88th heat index percentiles. Thresholds were operationalized as binary indicator variables for indoor heat indices above or below each threshold. The U.S. National Weather Service heat index, which combines temperature and humidity, was created using the weathermetrics R package.

The case–control study considered the influence of air pollution on respiratory or cardiovascular cases compared to control distress calls. Respiratory and cardiovascular distress calls are sensitive to extreme heat, but not specific to extreme heat health outcomes. Elevated ozone and $PM_{2.5}$ levels also increase respiratory and cardiovascular morbidity. Furthermore, rates of ozone formation increase during periods of hot weather (e.g., Anderson and Bell, 2011; Basu, 2009).

Generalized linear models (Binomial) tested whether cases were more likely to be exposed to elevated heat compared to controls after controlling for time of day and air pollution. The results are reported as odds ratios. For threshold exposures, the odds ratio compares the odds of a case with exposures above and below the threshold. For continuous exposures, the odds ratio is the change in the odds of a case for a one unit risk factor increment. Thus, an odds ratio of 1 suggests no systematic exposure and outcome association. Correspondingly, odds ratios significantly >1 suggest an exposure increases the odds of a heat-sensitive distress call.

First, a screening procedure determined the best fitting ozone and particulate matter 2.5 μm temporal lag (0–6, 24, and 48 h preceding the call). Generalized linear models associated each air pollution lag against cases and controls while controlling for the daily cycle. The best fitting ozone and particulate matter 2.5 μm lag, determined by the lowest Akaike's information criterion, were considered in the subsequent multiple variable analyses. Next, separate multiple variable models were created for each heat exposure metric. Each model controlled for the daily cycle with indicator variables for each 4-h period. A stepwise Akaike's information criterion variable selection procedure (forward and backwards) with two degrees of freedom penalty term selected each final model. The variable selection procedure considered individual patient characteristics (age, gender, and preexisting medical condition), zip-code level sociodemographics, air pollution (best fitting lag), and canopy cover to increase comparability between groups (Kovats and Hajat, 2008; Romero-Lankao et al., 2012). We report the best fitting multiple variable absolute or threshold heat exposure model. The analysis was repeated using the entire PCR record and the subset of records with latitude/longitude (Table S1).

Results

Descriptive statistics

Table 2 summarizes the demographics of individuals served by the paramedics and compares them to the entire city or state. The median patient age was older than the median New York City resident. A larger proportion of males received emergency care than females even though the city has a higher proportion of females than males.

The type of insurance provides some information on access to care and socioeconomic status. Compared to the entire state, the uninsured were overrepresented, privately insured correspondingly underrepresented, with a similar proportion served by Medicare or Medicaid (New York City Department of Health and Mental Hygiene 2014). A majority of individuals receiving emergency care self-reported a preexisting medical condition (59%). Hypertension (32%), diabetes (19%), and cardiac conditions (16%) were the most common comorbidities. The most common categories of distress calls were respiratory (29%), cardiovascular (25%), unconscious (20%), status epilepticus (6%), and altered mental status (6%).

We report stratified indoor/outdoor temperature summary statistics by ‘daytime’ or ‘nighttime/early morning’ hours. During the daytime, average indoor temperatures (mean: 23.9 °C, standard deviation: 2.5 °C, range: 13.5–33.5 °C) were slightly cooler than synchronous outdoor temperatures (mean: 25.6 °C, standard deviation: 2.5 °C, range: 16.4–32.0 °C), although 31.9% of buildings were warmer than outdoor conditions. Conversely, during the nighttime, average indoor temperatures (mean: 22.9 °C, standard deviation: 2.5 °C, range: 12.8–29.3 °C) were slightly warmer than comparable outdoor temperatures (mean: 20.1 °C, standard deviation: 2.4 °C, range: 13.4–25.2 °C) and 80.8% of buildings were warmer than corresponding outdoor conditions. Indoor temperatures were notably elevated (≥2 °C) above synchronous nighttime conditions in a proportion (6.2%) of buildings. The contrast between indoor/outdoor-specific humidity was not modified by the time of day. Indoor-specific humidity (mean: 10.1 g/kg, standard deviation: 2.3 g/kg, range: 4.7–17.9 g/kg) tended to be drier than outdoor humidity (mean: 11.9 g/kg, standard deviation: 2.5 g/kg, range: 6.7–17.9 g/kg).

Outdoor conditions, patient characteristics, and neighborhood sociodemographics influence on indoor temperature and humidity

The subanalysis included 764 records after excluding those missing time information (n = 20) and contact time <10 min (n = 63). Table 3 summarizes the generalized linear model results for indoor temperature and specific humidity. Indoor temperatures were modulated by the outdoor conditions preceding the distress call. Intuitively, the outdoor temperatures (preceding hour) and solar radiation (4 h before the call) increased the indoor heat load.

Conversely, windier conditions slightly lowered indoor temperatures, likely due to increased heat transfer.

Older individuals receiving emergency care tended to have slightly warmer indoor environments than younger patients. With each 10-year increase in the patient's age, indoor temperatures modestly increased by 0.09 °C (95% CI: 0.01–0.17 °C, $P = 0.014$). Similarly, indoor temperatures directly increased with the proportion of Black/African American residents in the surrounding neighborhood and in neighborhoods with a lower proportion of people living alone or with lower vacancy rates.

Indoor air moisture levels were very strongly linked to outdoor ambient moisture levels. Outdoor temperatures, solar radiation, or wind speeds did not directly impact indoor moisture. Older patients tended to receive care in more humid indoor environments. Similarly, specific humidity inside of buildings increased with the proportion of Black/African American or Hispanic residents in the surrounding neighborhood and buildings in areas with a low proportion of people living alone.

Case–control study

The case–control study compared indoor heat exposure of respiratory or cardiovascular cases compared to controls. The analysis was repeated using (i) the full record of eligible PCR (ii) the subanalysis of PCR with latitude/longitude information. The full PCR record ($N = 1100$) excluded visits <10 min in duration ($n = 126$) and records missing time information ($n = 47$), incident zip code ($n = 52$), or air pollution ($n = 34$). The subanalysis ($N = 739$) excluded records missing air pollution ($n = 25$), time information ($n = 20$), or contact time <10 min ($n = 63$).

Indoor heat indices above a threshold more consistently distinguished cases from controls than absolute exposure metrics. In both the full PCR and subanalysis, buildings with indoor heat indices ≥26 °C increased, but not significantly, the proportion of respiratory distress calls (Table 4, Table S1). Heat indices above the threshold increased the odds of making a respiratory distress call in the full analysis by 43% (OR: 1.43, 95% CI: 0.97–2.10, $P = 0.071$) and by 63% in the subanalysis (OR: 1.63, 95% CI: 0.98–2.68, $P = 0.056$). Of the patients exposed to indoor heat indices ≥26 °C, 45.0% were classified as respiratory distress cases in the full analysis. By comparison, only 40.2% of the respiratory distress calls were reported by patients with lower indoor heat indices (<26 °C). Respiratory cases were more likely to be older and to suffer from preexisting medical conditions than controls in both analyses. The variable selection procedure included $PM_{2.5}$ in the full analyses model, suggesting that it is important to account for levels of $PM_{2.5}$ in analyses of the association between heat index and case–control status.

Cardiovascular cases were not more likely to be exposed to higher indoor heat exposures. The absolute and threshold heat exposure metrics produced similar results. For illustration, we report the indoor heat index threshold results. Cases were not more likely than controls to surpass a higher indoor heat index threshold (≥26 °C) in the full record (OR: 0.85, 95% CI: 0.55–1.31, $P = 0.472$) or the subanalysis (OR: 1.04, 95% CI: 0.58–1.85, $P = 0.887$). In both analyses, individual cardiovascular cases were more likely to be older and suffer from preexisting conditions. Neighborhood level racial composition was also a significant risk factor. Neighborhoods and zip codes with a higher proportion of Hispanics recorded more cardiovascular cases. In the full analysis, the proportion of Black residents in a neighborhood was inversely related to cardiovascular calls. Higher ozone levels (24 h preceding the distress calls, units parts per 10 billion) were not significantly associated (OR: 1.22, 95% CI: 0.98–1.51, $P = 0.070$) with cardiovascular cases. In the subanalysis, neighborhoods located in Staten Island, with a higher proportion of people living alone and/or vacant households recorded a higher proportion of cardiovascular distress calls.

Discussion

The first objective determined the relative influence of outdoor conditions, patient characteristics, and neighborhood sociodemographics on indoor temperature and specific humidity. Consistent with previous New York City studies, hotter outdoor temperatures increased indoor temperatures (Quinn et al., 2014; Tamerius et al., 2013). Contemporaneous outdoor-specific humidity was very strongly linked to indoor moisture levels. Older adults and patients in neighborhoods with more Black/African Americans experienced slightly warmer and more humid indoor environments. While the magnitude of these effects may not be clinically important, the risk factors provide some support for the mechanistic link between demographic factors and extreme heat health outcomes. Buildings in neighborhoods with a higher proportion of people living alone tended to be slightly cooler and drier than neighborhoods with more multiperson households. Living alone may be a proxy for greater air conditioning usage in workplaces and/or affluent urban professional residences in Manhattan and Brooklyn Heights.

We summarize the limitations of the collection of indoor conditions and the analysis of indoor/outdoor relationships. Indoor sampling measured conditions of the room where a patient received care. In other words, the indoor conditions were measured at a standardized height above the floor but not from a standardized room in a building. However, a small New York State study suggests temperatures in the living room were slightly cooler (−0.56 °C, standard deviation 1.23 °C) than the master bedroom (Roberts and Lay, 2013). Our study likely captured representative indoor conditions. Nonetheless, the sampling of different rooms in a building and within building variation may introduce additional uncertainty to indoor measurements. This analysis was unable to control for the type of dwelling, building materials, floor of the building, and air conditioning. Future research will address this limitation by incorporating building-specific information from tax parcels and collecting air conditioning adoption and usage information.

The second objective determined whether cardiovascular or respiratory cases experience higher indoor heat exposures compared to controls. Buildings with indoor heat indices above 26 °C increased the proportion of respiratory distress calls, although not significantly ($P = 0.056$). Previous New York City studies suggest respiratory morbidity is sensitive to extreme heat. Respiratory distress calls exhibited the largest increase during the 2003 citywide blackout during a hot period (Freese et al., 2006). Similarly, Lin et al. (2009) investigated threshold relationships between temperature and heat-related hospital admissions and found that outdoor apparent temperatures above a 31.7 °C threshold (95% CI: 27.6–30.2 °C) increased respiratory hospital admissions.

Our study implies a lower indoor heat index threshold (26 °C) is associated with respiratory distress calls. A lower heat threshold is consistent with the broader range of morbidity captured by distress calls. A person receiving emergency care may be transported to the hospital or emergency room, refuses further care, or not require additional attention. Collectively, the New York City studies suggest that there is a range of deleterious heat thresholds for different severities and types of heat-related illness. Heat adaptation programs such as checking in on elderly neighbors, energy subsidies, or cooling shelters could be proactively targeted to at-risk groups. Furthermore, facility managers could develop indoor heat stress policies (Maine Indoor Air Quality Council 2014).

It was important for the case–control study to adjust for the time of day as there was a daily cycle in the number and composition of distress calls. Control distress calls notably decrease during the hours of 0:00–03:00, while the number of respiratory distress calls remains relatively constant throughout the 24-hour period. Different daily cycles in respiratory and control distress calls have also been reported in London, UK (Horn et al., 1987). Few studies have examined the relationship between outdoor temperature, time of day, and the number of distress calls. A Phoenix, AZ, U.S study found that peak outdoor temperatures coincided with heat-specific distress calls (Golden et al., 2008).

Indoor heat exposures were similar between cardiovascular cases and controls, even though cardiovascular morbidity and mortality are sometimes exacerbated by extreme heat (e.g., Knowlton et al., 2009; Li et al., 2012). Some previous studies suggest respiratory health outcomes may be more sensitive to high temperatures than cardiovascular outcomes (e.g., D'Ippoliti et al., 2010; Monteiro et al., 2013). Hotter summer temperatures than those observed in this study may modify the relationship between indoor heat exposure and cardiovascular cases. In New York City, only apparent temperatures above a 35.6 °C (32.5–38.6 °C) threshold increased cardiovascular hospitalizations (Lin et al., 2009).

Outdoor ozone levels (24 h preceding distress call) suggested a positive but statistically insignificant relationship with the proportion of cardiovascular distress calls. Previous studies suggest New York City mortality rates are sensitive to ambient ozone levels (Bell et al., 2004). Households without air conditioning may receive higher air pollution exposures during hot weather due to the opening of windows to cool the building (Bell and Dominici, 2008). Future personal exposure studies can jointly examine indoor/outdoor heat exposure, air pollution, and distress call relationships.

We briefly discuss the case–control study limitations and caveats. First, there may be some exposure misclassification error. For example, individuals suffering from outdoor heat exposure could have sought care inside of buildings. However, this effect would likely minimize indoor exposures differences between cases and controls. Similarly, other exposure metrics (e.g., wet bulb globe temperature, mean radiant temperature) may exhibit stronger relationships with heat health outcomes (Thorsson et al., 2014). Second, the analysis of the full record controlled for individual and zip-code level risk factors. More precisely controlling for individual level confounders may further increase comparability between groups. Third, we classified unconscious distress calls into the control comparison group. Respiratory or cardiovascular conditions may plausibly cause unconsciousness which would artificially minimize exposure differences between cases and controls. Future work linking the paramedic visits to subsequent emergency department or hospitalization records will provide more information on how distress call types translate into clinical diagnosis. Finally, the relatively cool study period likely minimized the differences between indoor and outdoor heat exposures. This is a common limitation of prospective studies. Expanding the length of the study to the entire summer may increase the chances of observing more extreme temperatures.

This manuscripts study design is compared and contrasted with the broader thermal comfort literature (e.g., Djongyang et al., 2010). In general, thermal comfort studies focus on relatively healthier populations and indirectly relate thermal discomfort to health outcomes. In contrast, our study directly observes vulnerable populations receiving care for environmentally sensitive health outcomes. On the other hand, our study does not measure thermal discomfort which is related to personal exposure, physiology, and psychology. Recent thermal comfort surveys related indoor conditions to self-reported health status. Indoor evening temperatures were associated with perceived heat stress in Leipzig, Germany (Franck et al., 2013). Similarly, the proportion of older adults reporting thermal discomfort increased with outdoor temperatures in Victoria, Australia (Loughnan et al., 2013). Paramedic distress call types may provide more standardized morbidity information than self-reported health status.

To the best of our knowledge, we present the first indoor heat exposure case–control study. Previous studies of indoor conditions, the built environment, and human health focused on air pollutants and air exchange rates (e.g., $PM_{2.5}$, O_3) (e.g., Ebelt et al., 2005; Sarnat et al., 2013). Our study design efficiently captures a large sample of indoor exposures and potentially related emergency distress. This study could be adapted to other indoor environmental exposures (e.g., indoor air pollution) and health outcomes. The sampling scheme explicitly focuses on vulnerable populations that disproportionately suffer from indoor environmental exposures (Gurley et al., 1996; Uejio et al., 2011).

Conclusion

Patient and neighborhood level sociodemographics modified indoor heat exposures despite similar outdoor conditions. Indoor temperatures were related to outdoor temperature, solar radiation, wind speed, age of the patient, and neighborhood level sociodemographic characteristics. In 6.2% of the buildings where patients received care, indoor temperatures were at least 2 °C warmer than the outdoor conditions. Higher indoor heat exposures increased, but not significantly, the odds of respiratory emergency distress calls compared to controls. This effect was quantified during a summer period with below-average heat exposures. This innovative study design directly observes indoor environments of individuals requiring emergency medical assistance. The study design could be adapted to efficiently study other indoor environmental exposures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank the Fire Department of New York Lieutenants and Rescue Medics who participated in this study. This publication was developed under Assistance Agreement No. (RD #83574901) awarded by the U.S. Environmental Protection Agency to Christopher K. Uejio. It has not been formally reviewed by the EPA. The views expressed in this document are solely those of the authors and do not necessarily reflect those of the Agency. EPA does not endorse any products or commercial services mentioned in this publication.

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Practical Implications

There is limited evidence directly linking indoor heat exposure to health outcomes. By partnering with emergency medical services, the study design observes indoor conditions of people receiving emergency care. The study design efficiently targets vulnerable populations. The results suggest people may suffer from hot indoor environments even during ‘moderate’ summer periods.

Table 1

Study data sources. Data sources are used in both analyses unless otherwise annotated

Data source	Variable	Level of analysis/resolution
Patient care reports (PCR)	Type of distress call[a]	Individual
	Age (years)	Individual
	Preexisting medical condition	Individual
	Gender	Individual
US American Community Survey	Population age >65 (%)	Census tract or zip code
	Living alone (%)	Census tract or zip Code
	All cause disability (%)	Census tract or zip code
	Vacant households (%)	Census tract or zip code
	Median household income (USD)	Census tract or zip code
	Households without plumbing (%)	Census tract or zip code
	Uninsured (%)	Census tract or zip code
	Black, Asian American, Hispanic (%)	Census tract or zip code
National land cover database	Canopy cover (%)	100 m or zip code
North American Land Data	Outdoor surface temperature (°C)	14 km^2
Assimilation system (NLDAS)	Outdoor-specific humidity[b] (g/kg)	14 km^2
	Outdoor wind speed[b] (m/s)	14 km^2
	Outdoor solar radiation[b] (W/m^2)	14 km^2
HOBO (Onset) Data Loggers	Indoor temperature (°C)	Building
	Indoor-specific humidity (g/kg)	Building
The New York State Department of Environmental Conservation	Outdoor ozone[a] (parts per 10 billion)	7 stations
	Outdoor particulate matter 2.5 μm[a]	4 stations

[a]Data sources only used in the case–control study.

[b]Data sources only used in the analysis of outdoor influences on indoor temperature or humidity.

Table 2

Summary statistics comparing the demographics of study patients with the 2010 census for the City of New York. The comparison health insurance information was provided by the New York City Department of Health and Mental Hygiene (2014)

Demographic	Patient care reports	Comparison
Age	52 years (range: 0–98 years old)	35.5 years
Gender	56% Male, 44% Female	48% Male, 53% Female
Race	Black/African Americans (42%), Hispanic (25%), White (21%), Other (12%)	Black/African Americans (22.8%), Hispanic (28.6%), White (33.3%), Other (15.3%)
Health insurance	Out of pocket (42%), Medicare/Medicaid (36%)	Out of pocket (20%), Medicare/Medicaid (35%)
	Private insurance (22%)	Private insurance (43%)

Table 3

Generalized linear model results relating outdoor conditions and sociodemographics to indoor temperature or specific humidity

Indoor condition	Independent variable	Estimate (95% CI)	s.e.	*P*-value
Temperature °C *N* = 764	Intercept	19.44 (17.64, 21.24)	0.90	<0.001
	Outdoor temperature °C (Lag 1)	0.16 (0.08, 0.25)	0.04	<0.001
	Outdoor solar radiation W/m^2 (Lag 4)	0.19 (0.08, 0.30)	0.05	<0.001
	Outdoor wind speed m/s^2 (Lag 3)	−0.14 (−0.24, −0.04)	0.05	0.007
	Time of day (04:00–07:59)	0.40 (−0.25, 1.04)	0.32	0.218
	Time of day (08:00–11:59)	0.35 (−0.33, 1.03)	0.34	0.297
	Time of Day (12:00–15:59)	−0.12 (−1.10, 0.86)	0.49	0.801
	Time of day (16:00–19:59)	0.14 (−0.79, 1.07)	0.46	0.757
	Time of day (20:00–23:59)	0.95 (0.31, 1.58)	0.32	0.003
	Patient age	0.01 (0.001, 0.017)	0.004	0.014
	Living alone (% Neighborhood)	−0.02 (−0.03, 0.00)	0.007	0.017
	Vacant (% neighborhood)	−0.04 (−0.07, −0.01)	0.01	0.003
	Black (% neighborhood)	0.008 (0.002: 0.013)	0.003	0.006
Humidity (g/kg) *N* = 764	Intercept	2.79 (1.91, 3.67)	0.44	<0.001
	Outdoor-specific humidity g/kg (no lag)	0.56 (0.50, 0.61)	0.03	<0.001
	Time of day (04:00–07:59)	0.41 (−0.06, 0.88)	0.24	0.082
	Time of day (08:00–11:59)	0.20 (−0.23, 0.63)	0.22	0.364
	Time of day (12:00–15:59)	0.04 (−0.40, 0.48)	0.22	0.865
	Time of day (16:00–19:59)	0.05 (−0.36, 0.47)	0.21	0.798
	Time of day (20:00–23:59)	−0.05 (−0.49, 0.39)	0.22	0.831
	Patient age	0.01 (0.005, 0.017)	0.003	<0.001
	Living alone (% neighborhood)	−0.02 (−0.03, 0.00)	0.005	<0.001
	Black (% neighborhood)	0.02 (0.01, 0.02)	0.002	<0.001
	Hispanic (% neighborhood)	0.009 (0.003, 0.014)	0.003	0.003

Table 4

Case–control study results associating indoor heat exposure and respiratory or cardiovascular cases vs. controls. The analysis was conducted on the full patient care report record

Cases	Independent variable	Odds ratio (95% CI)	s.e.	*P*-value
Respiratory (*N* = 809, 338 cases, 471 controls)	Intercept	0.64 (0.24, 1.74)	0.51	0.387
	Indoor heat index >26 °C	1.43 (0.97, 2.10)	0.20	0.071
	Time of day (04:00–07:59)	0.84 (0.48, 1.45)	0.28	0.523
	Time of day (08:00–11:59)	0.58 (0.34, 0.97)	0.26	0.039
	Time of day (12:00–15:59)	0.65 (0.39, 1.08)	0.26	0.099
	Time of day (16:00–19:59)	0.62 (0.38, 1.01)	0.25	0.054
	Time of day (20:00–23:59)	0.76 (0.45, 1.27)	0.26	0.296
	Patient age (years)	1.01 (1.00, 1.01)	0.004	0.041
	Income $10 000 (neighborhood)	0.99 (0.98, 1.00)	0.004	0.132
	Hispanic (% neighborhood)	1.01 (0.99, 1.02)	0.006	0.136
	Preexisting condition	1.88 (1.36, 2.59)	0.16	<0.001
	$PM_{2.5}$, average 0–48 h prior	0.96 (0.92, 1.01)	0.02	0.102
Cardiovascular (*N* = 762, 291 cases, 471 controls)	Intercept	0.15 (0.06, 0.35)	0.45	<0.001
	Indoor heat index >26 °C	0.85 (0.55, 1.31)	0.22	0.472
	Time of day (04:00–07:59)	0.97 (0.53, 1.79)	0.31	0.928
	Time of day (08:00–11:59)	1.29 (0.75, 2.21)	0.28	0.359
	Time of day (12:00–15:59)	1.05 (0.60, 1.81)	0.28	0.874
	Time of Day (16:00–19:59)	0.79 (0.46, 1.37)	0.28	0.401
	Time of day (20:00–23:59)	0.99 (0.56, 1.73)	0.29	0.958
	Patient age (years)	1.01 (1.00, 1.02)	0.004	0.006
	Black (% neighborhood)	0.99 (0.99, 1.00)	0.003	0.037
	Hispanic (% neighborhood)	1.01 (1.00, 1.02)	0.004	0.037
	Preexisting condition	1.89 (1.36, 2.63)	0.17	<0.001
	Renters (% neighborhood)	0.99 (0.99, 1.00)	0.002	0.073
	Ozone (average previous 24 h) per 10 ppb	1.22 (0.98, 1.51)	0.11	0.070