

# A biometeorology study of climate and heat-related morbidity in Phoenix from 2001 to 2006

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**Abstract** Heat waves kill more people in the United States than hurricanes, tornadoes, earthquakes, and floods combined. Recently, international attention focused on the linkages and impacts of human health vulnerability to urban climate when Western Europe experienced over 30,000 excess deaths during the heat waves of the summer of 2003—surpassing the 1995 heat wave in Chicago, Illinois, that killed 739. While Europe dealt with heat waves, in the United States, Phoenix, Arizona, established a new all-time high minimum temperature for the region on July 15, 2003. The low temperature of 35.5°C (96°F) was recorded, breaking the previous all-time high minimum temperature record of 33.8°C (93°F). While an extensive literature on heat-related mortality exists, greater understanding of influences of heat-related morbidity is required due to climate change and rapid urbanization influences. We undertook an analysis of 6 years (2001–2006) of heat-related dispatches through the Phoenix Fire

Department regional dispatch center to examine temporal, climatic and other non-spatial influences contributing to high-heat-related medical dispatch events. The findings identified that there were no significant variations in day-of-week dispatch events. The greatest incidence of heat-related medical dispatches occurred between the times of peak solar irradiance and maximum diurnal temperature, and during times of elevated human comfort indices (combined temperature and relative humidity).

**Keywords** Health vulnerability · Heat Waves · Urban Climate · Morbidity · Emergency medical dispatch

## Introduction

Concerns regarding system interactions and complexities between global climate change and human health vulnerability are increasing significantly. Recently, the summer of 2003 brought international focus on the linkages and impacts of human health vulnerability to climate change not at the global scale but rather at the urban scale. Western Europe experienced over 30,000 excess deaths during the heat waves of the summer of 2003 (Kosatsky 2005)—surpassing the 1995 heat wave in Chicago, Illinois, that killed 739 (Shrader-Frechette 2002; Kalkstein and Greene 1997).

Concurrent with the European heat waves, in the United States, Phoenix, Arizona, established a new all-time high minimum temperature for the region on July 15, 2003. The low temperature of 35.5°C (96°F) was recorded, breaking the previous all-time high minimum temperature record of 33.8 (93°F) which was set on June 27 1990, July 20, 1989 and July 14, 2003. In the US, heat waves kill more people than hurricanes, tornadoes, earthquakes, and floods combined (Klineberg 1999; National Weather Service 2007a).

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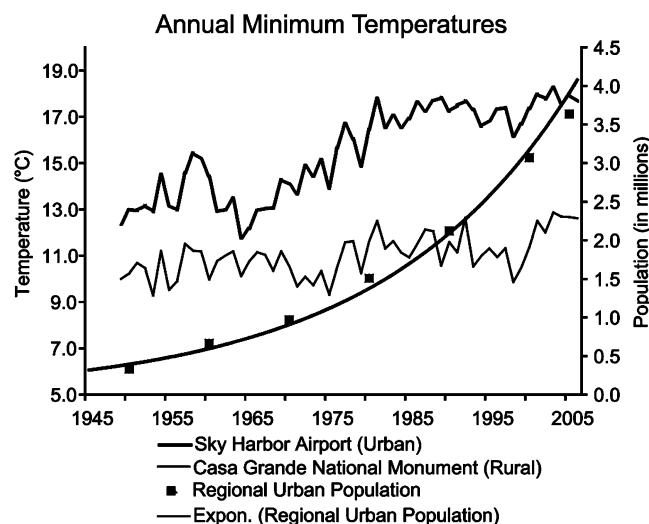
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A strong volume of literature exists concerning the system dynamics of heat waves and the urban heat islands in regards to sustainable development (Golden 2004; Golden et al. 2006) including heat-related mortality (Centers for Disease Control 1995; Semenza et al. 1996; Kalkstein et al. 1996). This paper is focused on heat-related morbidity and is the result of a joint research effort by the National Center of Excellence on SMART Innovations for Urban Climate and Energy at Arizona State University (NCE) and the National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC). The NCE in partnership with the CDC is undertaking studies of multiple urban regions to increase understanding of how climate change, including heat waves and electricity blackouts, influence human health vulnerability. This project examines findings from 6 years of emergency response dispatches for heat-related health incidents in the Phoenix metropolitan region. These fire/EMS dispatches were tracked and analyzed in comparison to meteorological conditions including heat waves and National Weather Service Heat Advisory Warnings.

#### Region of study

Phoenix, Arizona, was selected as the region of study. A Centers for Disease Control (Centers for Disease Control and Prevention 2005) study revealed that, from 1979 to 2002, a total of 4,780 heat-related deaths in the US resulted from weather conditions and that, from 1993 to 2002, the total incidence of such deaths was three to seven times greater in Arizona than in the US overall. Additionally, over the twentieth century, average annual temperatures in the arid subtropical Phoenix region increased 1.7°C (3.1°F) (Brazel et al. 2000). However, the urban portions of the region have realized mean annual temperature increases of 4.2°C (7.6°F), a rate of three times the total regional mean increase representing the pronounced influence of the built environment (Fig. 1).

The setting, Phoenix, (elevation 345.9 m, 33°25'40"N, 112°0'14"W) was incorporated in 1881 and is one of the nation's fastest growing cities and fifth largest in population (1,475,834 as of September 1, 2005 (U.S. Census 2007)). Geographically the city is over 1,295 km<sup>2</sup> (500 square miles) and larger than the City of Los Angeles. The Phoenix Fire Department 911 call center dispatches for the majority of the regional fire departments. Maricopa County, the regional jurisdiction containing the City of Phoenix, has a population of approximately 3.6 million (U.S. Census 2007) and has a land area of 23,836 km<sup>2</sup> (9,203 square miles). It is the fourth most populous county in the nation, and is home to more people than 21 states and the District of Columbia. The jurisdictions located within Maricopa County and dispatched by Phoenix Fire include



**Fig. 1** The role of urbanization and engineered materials to urban climate. A 50-year analysis of annual minimum temperatures for a urban vs rural site. Source: Golden (2004)

Tempe, Chandler, Scottsdale (added in 2005), Glendale, Surprise, Buckeye, Tolleson, Peoria, Paradise Valley, Guadalupe and Goodyear. Phoenix Fire does not dispatch for the City of Mesa, Arizona, which is located only 9.5 km (6 miles) from the Phoenix border. Mesa with a population of 452,000 is larger than (or similar in population to) Miami, FL; Atlanta, Cincinnati, Pittsburgh, PA; St. Louis, MO; Atlanta, GA; and Minneapolis, MN. Therefore, heat-related dispatches by the Mesa Fire Department are not included within this research, but should be considered in regards to the totality of heat-related impacts for the region.

#### Materials and methods

Climate data used in this study are from the National Weather Service Automated Surface Observing System located at Sky Harbor International Airport in Phoenix. Daily normal temperature data were obtained from the National Weather Service. Daily maximum and minimum temperature data were acquired from the National Climate Data Center. Hourly temperature, dew point and relative humidity, and cloud cover data were provided by the Arizona Office of Climatology. Solar radiation data were acquired from the Maricopa County Flood Control District's Durango weather station (central Phoenix). To correspond to the daily normal temperature data, the 30-year average daily dew point "normal" was calculated using the hourly dew point temperature data from January 1, 1971 through December 31, 2000 (which had <0.02% missing data points).

We examined the Heat Index (HI) (National Weather Service 2007b) as a possible explanation for annual variances. The heat index, also known as the "apparent temperature," is an index commonly used by the US National Weather Service and incorporates temperature with relative humidity to estimate the "feels like" temperature. Daily HI was calculated using hourly temperature and

relative humidity data from 1500 hours Local Standard Time (LST). For our *human comfort index* we use the model called OUTCOMES—OUTdoor COMfort Expert System (Heisler and Wang 2002)—that estimates the energy budget of a cylindrical person using weather data and a site's surrounding radiative and thermal environmental fluxes based upon inputs such as a site's vegetation, landscaping, shade, moisture, nearby buildings and ground cover, etc. In addition to producing an estimate of energy in watts per square meter, OUTCOMES also produces a level of comfort ranging from too cold or too hot which, in effect, is a function of a rational vote among a group of people based on past comfort research (e.g., Brown and Gillespie 1995). We used this model because it allows for incorporation of the many elements encountered at a given site.

The OUTCOMES model uses inputs for air temperature, wind speed, humidity, solar radiation, pre-specified shading objects, reflectivity of the ground and nearby objects, the sky view, tree and building cover of the site and clothing and human activity. For our daily human comfort estimates we used temperature and relative humidity records from 1500 hours LST. The diurnal human comfort estimations used a mean hourly temperature and humidity calculated from hourly temperature and relative humidity using all of the data from June and July, 2001–2006. Solar radiation measurements were measured on a typical clear day in June 2006 from a central Phoenix weather station. While we used actual measured climate variables we did not attempt to include variables for the multiplicity of sites likely encountered across the metropolitan area where Heat Related Dispatches (HRD) were encountered—this will be explored in-depth in future research. For our study, we chose input variables for OUTCOMES to produce a site more representative of a harsh site—conditions that would likely produce circumstances more taxing to a person and more likely to produce a heat-related emergency.

Inputs included Sky object: concrete uncolored building; Ground Cover: concrete uncolored; Sky View of 50%; Upwind Cover of 50%; Pollution: fairly polluted; Activity: standing or; walking slowly; Clothing: T-Shirt, short pants, running shoes.

In addition, we examined regional climatic and fire department HRD in comparison to the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) excessive heat products which are developed to provide advance notice of excessive heat events. These products are issued based on a single heat index value, derived from temperature and humidity, originated by Steadman (1979):

- Excessive Heat Outlook: used when the potential exists for an excessive heat event to develop in the next 3–7 days

- Excessive Heat Watch: used when conditions are favorable for an excessive heat event to develop in the next 12–48 h
- Excessive Heat Warning: used when an excessive heat event is occurring, imminent, or has a high probability of occurrence in the next 36 h and poses a threat to life and property
- Heat Advisory: used when a heat event is occurring, imminent, or has a high probability of occurrence in the next 36 h and causes significant inconvenience and, if caution is not exercised, could become life threatening

## Results

We found that similar to HRD calls declining in 2002 and 2004, there is a corresponding relative decline in the mean summer heat index for those years (Fig. 2a). And, as calls for service increase in 2003, 2005 and 2006, there is a corresponding increase in the mean summer Heat Index.

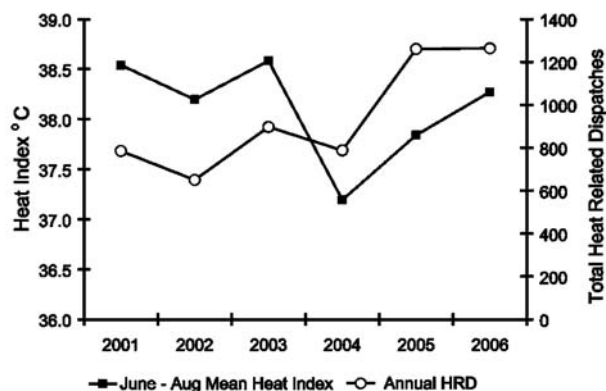
### Annual distribution

For the study period of 2001–2006, there was an overall increase in the number of HRD by the regional dispatch center (Fig. 2a). A small portion of the increase for emergency services is attributable to the population increase of the region. According to the U.S. Census (2007), the Phoenix metropolitan area had an increase of 787,306 persons from April 1, 2000 to July 1, 2006, placing it as one of the top 5 highest numerical population growth regions in the United States. The City of Scottsdale, which had a private subscription fire and medial service provider (Rural Metro), organized its own municipal fire department on July 1, 2005 with dispatch services being transferred to the Phoenix Fire Regional dispatch center at the same time. However, as noted in the results, the annual total of HRD calls for service varied between years. Calls for service dropped from 785 (2001) to 650 (2002) and then increased to 897 (2003) and declined again to 788 calls (2004). The number spiked to 1,261 calls (2005) and somewhat leveled to 1,264 calls in 2006.

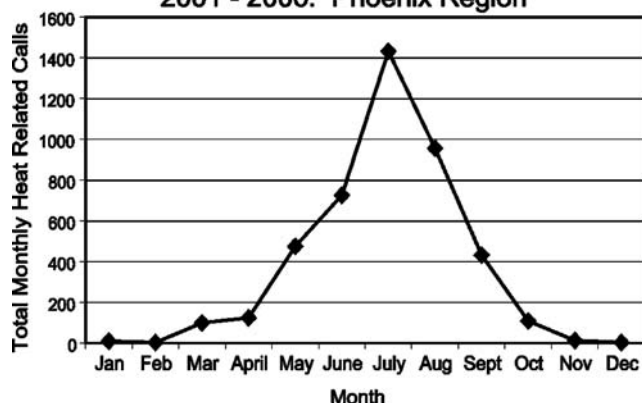
### Monthly distribution

The monthly distribution of HRD events peaks in July as presented in Fig. 2b. This is consistent throughout the 6-year study. Analysis of monthly dew point and maximum temperatures for the Phoenix region (Table 1) provides a platform to understand this monthly dynamic. For the study period, the month of July had both the highest maximum temperature of 41.8°C (107.2°F) and dew point of 12.8°C

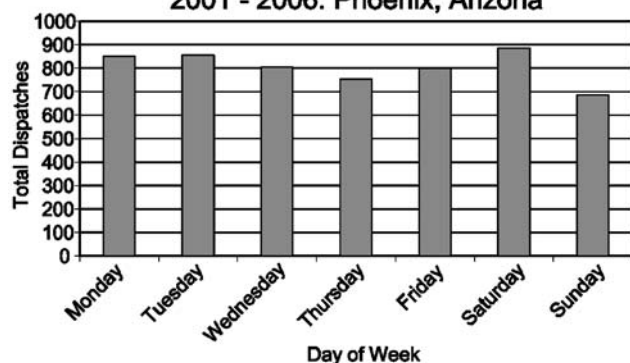
### a Total Heat Related Dispatches and Summer Mean Heat Index by Year



### b Monthly Distribution of Heat Related Dispatch Calls 2001 - 2006: Phoenix Region



### c Day of Week Distribution of Heat Related Dispatches 2001 - 2006: Phoenix, Arizona



**Fig. 2** Heat-related dispatches in Phoenix, Arizona for 2001–2006: **a** Annual summary, in comparison to annual heat Index; **b** monthly distribution; **c** day of week distribution

(55.1°F). Although June had the second highest average maximum temperature for the period of 40.8°C (105.4°F) as compared to August with the third-highest average maximum temperature of 40.2°C (104.3°F), it was August with the second-highest number of dispatch calls. This is potentially due to August having a higher average dew point

of 12.7°C (54.8°) than June with 9.9°C (49.9°). Further discussion of departures from normal temperatures and the human comfort index are presented later in this paper.

As would be expected, there was a strong seasonality to the data, with summer having the overwhelming number of calls, though a few HRD were made during winter months. We arbitrarily established a threshold of >5 HRD's / day as a high HRD day. There were 45 days with high HRD in 2001, 44 in 2002, 62 in 2003, 48 in 2004, 79 in 2005 and 95 in 2006. The majority of high HRD days had maximum temperatures considerably higher than normal. This is particularly the case during the months of May and June where the temperatures average about 7.2°C (13°F) higher than normal. On days with higher dew points, the ambient temperatures were higher than normal, but only about 3.3°C (6°F) higher. The 2006 summer season was particularly active in heat-related emergency calls in both overall numbers and single day counts—with July 22 and July 24 having 34 and 32 calls, respectively. For this reason, we have examined this summer in detail. The urban climate variability section provides further analysis in regards to variance in the dispatch events.

#### Day of week and diurnal trends

For 2006, the average daily number of heat-related medical dispatch calls was 3.47 calls per day. However, for the months of May–August 2006, the average HRD were 9.12 per day. Two days had 30+ related medical calls (22 and 24 July, 2006) with 7 days throughout the period with over 20 dispatch events. The distribution of fire department dispatches is fairly evenly distributed throughout the week for the years 2001–2006 (Fig. 2c). Saturdays have the highest cumulative total which might be attributed to greater outdoor activities of residents, in combination with outdoor job and work-related situations, while Sundays are the lowest day for dispatches, perhaps reflecting a reduction in both outdoor job-related activities or recreational activities, or both. While there was no day of week bias, the data do occasionally show an increase in calls associated with summer holidays. The Fourth of July holiday impacts HRD the most, with 4 of 6 years showing large spikes in calls (Table 2). A few Memorial Day and Labor Day holiday weekends also show spikes in HRD, but of a lesser magnitude.

Diurnal variability is an important factor for local and regional agencies developing daily resource allocation and capacity. When evaluating the average diurnal distribution of HRD, we examined the influence of ambient temperature as derived from the National Weather Service station at Phoenix Sky Harbor International Airport as well as solar incidence. Figure 3a shows the peak dispatch time falls in between peak solar radiance and maximum ambient temperature, and this was consistent for weekday and weekend dispatches.



**Table 1** Monthly dew point and maximum temperatures for Phoenix, Arizona, metropolitan region

	2001–2006 dew point		1971–2000 normal dew point		2001–2006 maximum temperature		1971–2000 average maximum temperature	
	°C	°F	°C	°F	°C	°F	°C	°F
Jan	−0.1	31.9	0.6	33.1	20.2	68.3	18.3	65
Feb	0.9	33.6	0.8	33.4	21.0	69.8	20.8	69.4
Mar	2.4	36.4	1.4	34.5	25.2	77.3	23.5	74.3
Apr	4.2	39.5	0.4	32.7	29.4	84.9	28.3	83
May	7.1	44.7	2.2	35.9	36.0	96.8	33.3	91.9
Jun	9.9	49.9	4.3	39.7	40.8	105.4	38.9	102
Jul	12.8	55.1	13.1	55.6	41.8	107.2	40.1	104.2
Aug	12.7	54.8	14.8	58.7	40.2	104.3	39.1	102.4
Sep	10.7	51.3	11.6	52.8	38.3	101	36.3	97.4
Oct	6.6	43.8	6.2	43.2	31.8	89.2	30.2	86.4
Nov	2.2	36	1.9	35.5	24.6	76.3	22.9	73.3
Dec	−0.1	31.9	0.6	33.1	19.1	66.3	18.3	65

Examining the solar radiation of a typical mid-June day with the hourly distribution of HRD shows a curve that is lowest at 0600 to 0700 hours LST and reaches the maximum at 1600 hours, about an hour prior to the maximum temperature. Solar radiation maximizes even earlier than HRD—at about 1200 hours—indicating a 2- to 3-h lag to solar maximum, but generally preceding the diurnal maximum temperature (Fig. 3a).

We examined the diurnal range of human comfort using the OUTCOMES model for an “average” day and compared our results to HRD. An average day was constructed using hourly temperature and humidity for June, July and August, 2001—2006, aggregated into hourly means.

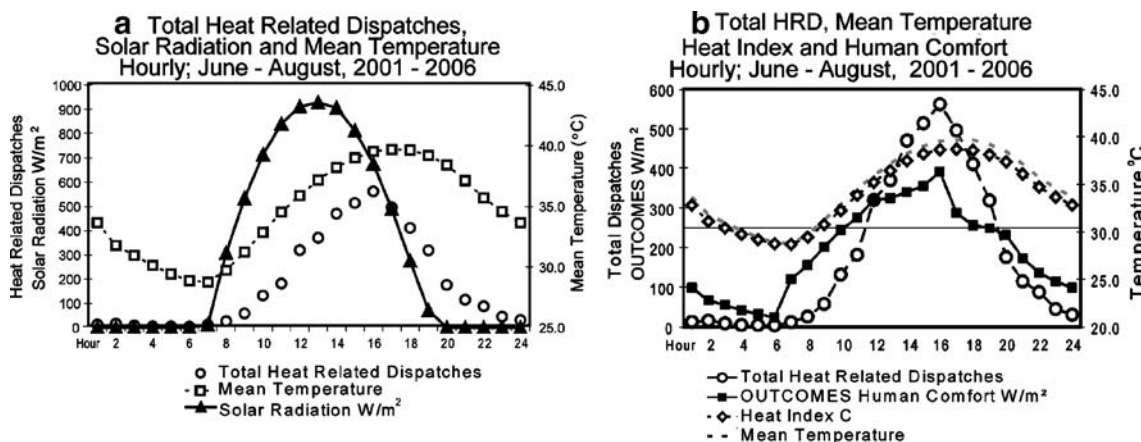
During the summer months, by 10000 hours the OUTCOMES comfort index reaches the level that produces a “heat stress warning” in its output. OUTCOMES, which is an index which incorporates temperature, humidity, solar radiation, shade (or lack thereof) and activity level, produced a similar pattern to the hourly totals for HRD. Both peak in mid-afternoon when human comfort is at its greatest discomfort level (Fig. 3b).

Urban climate role in heat dispatches

There were 361 high high HRD days in 2001—2006. All but 2 days had maximum temperatures higher than normal.

**Table 2** Fourth of July HRD. Four of 6 years (shown in bold italics) experienced an increase in calls

Year	Date	Calls	Day of Week	Temp °F	Temp °C	Heat Index °F	Heat Index °C
2001	July 3	34	Tuesday	114	45.6	109.3	42.9
	<b><i>July 4</i></b>	<b><i>20</i></b>	<b><i>Wednesday</i></b>	<b><i>108</i></b>	<b><i>42.2</i></b>	<b><i>109.9</i></b>	<b><i>43.3</i></b>
2002	July 5	4	Thursday	98	36.7	98.3	36.8
	<b><i>July 4</i></b>	<b><i>11</i></b>	<b><i>Thursday</i></b>	<b><i>107</i></b>	<b><i>41.7</i></b>	<b><i>99.8</i></b>	<b><i>37.7</i></b>
2003	July 3	10	Thursday	110	43.3	103.8	39.9
	<b><i>July 4</i></b>	<b><i>26</i></b>	<b><i>Friday</i></b>	<b><i>113</i></b>	<b><i>45.0</i></b>	<b><i>104.6</i></b>	<b><i>40.4</i></b>
2004	July 5	3	Saturday	111	43.9	104.9	40.5
	<b><i>July 4</i></b>	<b><i>5</i></b>	<b><i>Sunday</i></b>	<b><i>103</i></b>	<b><i>39.4</i></b>	<b><i>94.1</i></b>	<b><i>34.5</i></b>
2005	July 5	4	Monday	107	41.7	98.4	36.9
	<b><i>July 4</i></b>	<b><i>9</i></b>	<b><i>Monday</i></b>	<b><i>108</i></b>	<b><i>42.2</i></b>	<b><i>101.7</i></b>	<b><i>38.7</i></b>
2006	July 5	1	Wednesday	96	35.6	85.7	29.8
	<b><i>July 4</i></b>	<b><i>22</i></b>	<b><i>Tuesday</i></b>	<b><i>106</i></b>	<b><i>41.1</i></b>	<b><i>106.0</i></b>	<b><i>41.1</i></b>



**Fig. 3** a Diurnal variability of heat-related dispatches for 2001–2006 in Phoenix, Arizona, in relationship with solar radiance and ambient temperatures. b Heat-related dispatches in comparison to mean

temperature and human comfort (2001–2006). *W/m2* refers to the actual energy budget of the human body accounting for clothing and the energy flux terms

The mean *normal* maximum temperature for these 361 high HRD days would be expected to be 38.7°C (101.6°F), but the actual measured maximum temperature for high HRD days averaged 41.5°C (106.7°F). To increase understanding of how climate variability impacts HRD, we examined dew point, maximum temperature, the heat index and departure from normal maximum temperature in relation to dispatch events for the period of April 1 to September 30, 2006 (Table 3).

On average, May and June had considerably warmer monthly mean temperatures by 3.3°C (6.0°F) and 3.0°C (5.4°F) than normal. May had much drier than normal dew points averaging 3.1°C (5.5°F) lower than normal, while June was nearly normal. July experienced both warmer temperatures and higher dew points. August’s temperatures and dew points were close to normal. The results of the high HRD days in comparison to maximum temperatures, change from normal maximum temperatures and dew point for the period of May-August 2006 are presented in Fig. 4.

**Table 3** 2006 Monthly mean temperature and dew point - deviation from normal

	Mean number of HRD calls	Maximum temperature: deviation from normal	Dew point deviation from normal		
April	1.2	1.0°C 1.9°F	-2.0°C	-2.6°F	
May	4.2	3.4°C 6.0°F	-2.5°C	-5.5°F	
June	9.2	3.0°C 5.4°F	0.9°C	0.2°F	
July	14.5	1.4°C 2.5°F	0.5°C	2.7°F	
August	8.6	0.3°C 0.6°F	1.1°C	0.4°F	
September	2.7	-0.5°C -0.8°F	-5.0°C	-4.3°F	
Average (Apr–Sept)	2.6	1.5°C -1.7°F	0.8°C	6.8°F	

Increases in temperature and/or dew point alone do not initiate elevated HRD events as evidenced by days with high dew point and low dispatch events (late July 2006) and days with elevated dispatch events but lower than normal dew points (~July 20, 2006). Similarly, maximum temperature alone does not provide a direct relationship as evident on May 15. However, due to the relatively low dew points during Phoenix’s summer season, most days’ heat indices were lower than the measured ambient air temperature. Regression analyses of HRD to daily mean, maximum and minimum temperature, dew point and heat index show the strongest correlation to the heat index.

The numbers of HRD for summer of 2006 were then grouped into 5 categories: 1 to 4 calls; 5 to 9; 10 to 14; 15 to 20; and 21+ calls. Data for the 1500 LST heat index were categorized for mean heat index, minimum heat index, and maximum heat index for the days within the categories. There is a high, direct linear relationship between the categories with a high number of calls and the mean heat index for these categories (Fig. 5). Given forecasts of a mid-afternoon heat index for a day, it ought to be possible to anticipate the relative magnitude by category of expected calls based on the records thus far. Deviation within a category may be further explained by other non-climatic factors, such as holidays, etc.

Results in regards to human health heat warnings

During 2006, the National Weather Service issued for Phoenix a handful of warnings and advisories:

- 4 Heat Advisory days
- June 13, June 25, July 15 and July 23
- 3 Excessive Heat days
- July 14, July 21 and July 22

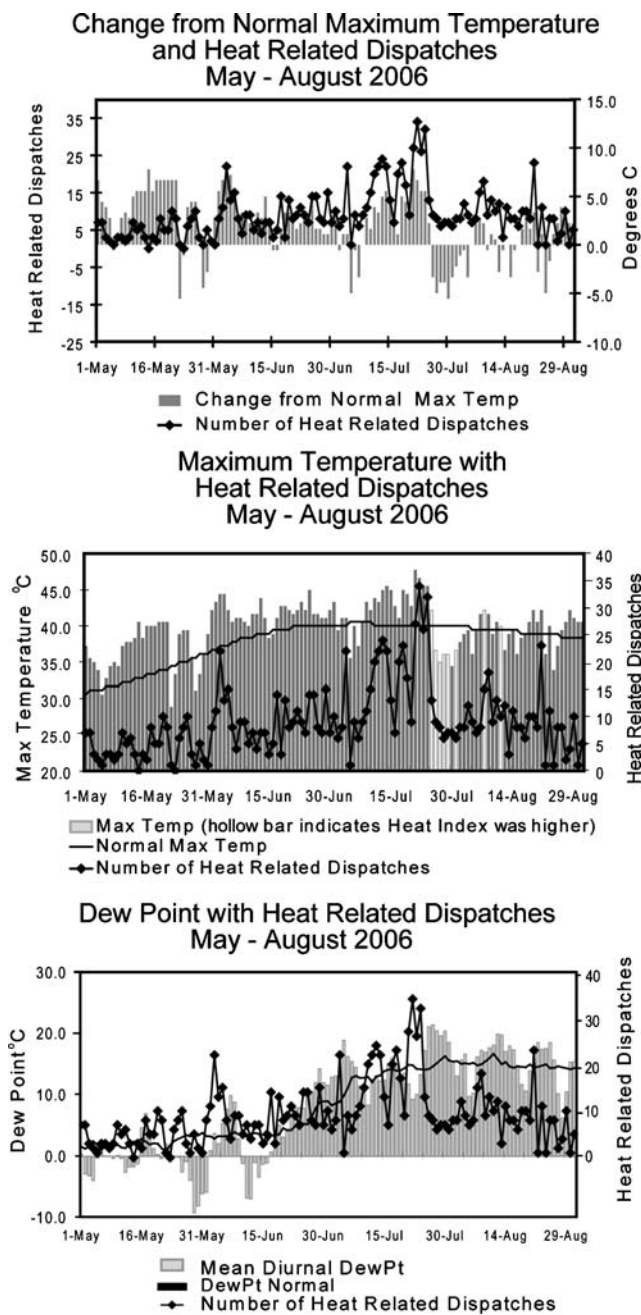


Fig. 4 Heat related dispatches in comparison to temperature and dew point deviation from normal, May–August 2006

The 2 days with the highest number of high heat related response days during 2001–2006 occurred during July 2006. July 22, 2006 had an excessive heat advisory and July 24, 2006 was a day following a heat advisory warning. As can be seen in Table 4, all of the warning advisory dates have “high” HRD—only June 13 is below the mean of 9 calls for summer. Notice the heat index for June 13 is considerably higher than the average for the previous 3 days. The July 15 heat index is lower than the previous 3-day means.

An additional evaluation criterion is the volume of HRD prior to and following a NWS heat event. Specifically, we evaluated the 3 days prior and 3 days post either a Heat Warning or Heat Advisory date for 2006. Table 4 shows all of the days when the National Weather Service-issued Heat Advisories or Warnings met our high HRD criteria. However, only June 15 and July 22 (the day with the highest HRD for the season) did not have at least one other day either prior to or subsequent of the advisory/warning with a higher number of HRD. Of the 7 Heat Warning/Advisory days issued by the NWS for 2006, 3 days had at least 1 day with a higher number of HRD occurring during the 3 days prior to the NWS event, and 3 days had at least 1 day with a higher number of HRD subsequent to the event.

**Discussion**

McGeehin and Mirabelli (2001) presented an overview of health impacts from extended heat events (heat waves). Their identification of research gaps and future research needs included a call for further research in quantifying which weather parameters are important in the relationship between heat events and health. This includes increased understanding of the relationship of heat and morbidity, which is the focus of this paper.

Our research effort attempts to build upon prior heat-related surveillance research, primarily of hospital data by Leonardi et al. (2006); Mastrangelo et al. (2006); Michelozzi et al. (2006) and Schwartz et al. (2004), by analyzing paramedic and emergency medical technician emergency dispatch data specific for heat related emergencies in Phoenix.

The findings of our research indicate that high Heat Index, a combination of humidity and temperature, had the highest statistical correlation to heat related dispatches. Exceedances

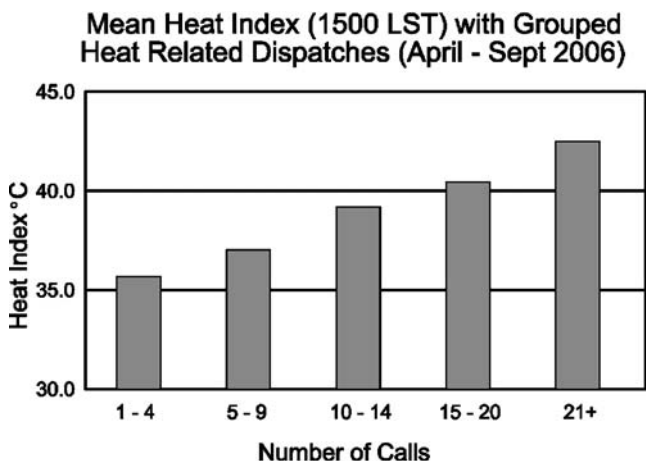


Fig. 5 Heat related dispatches in comparison to mean heat index for April–September 2006

**Table 4** Heat related dispatches 3 days prior and 3 days post a Heat Warning / Heat Advisory Event: Phoenix, Arizona, 2006

	Date	Heat response dispatches	Heat Index (HI)	Mean HI 3 days prior	Mean # calls 3 days prior	# calls for previous 3 days	# calls for 3 subsequent days
Heat Advisory Event	June 13	7	101.1	97.6	5	5, 7, 4	7, 7, 3
	June 25	14	105.6	101.5	9	11, 9, 7	14, 14, 8
	July 15	13 <sup>a,b</sup>	106.1	108.4	23	22, 24, 22	7, 20, 23
	July 23	26 <sup>a,b</sup>	107.1	108.7	23	9, 27, 34	32, 13, 9
Heat Warning Event	July 14	22 <sup>a</sup>	109.0	106.9	22	20, 22, 24	13, 7, 20
	July 21	27 <sup>b</sup>	111.2	106.9	16	23, 17, 9	34, 26, 32
	July 22	34	108.7	108.0	18	17, 9, 27	26, 32, 13

<sup>a</sup> At least 1 day with a higher number of HRD prior warning events

<sup>b</sup> At least 1 day with a higher HRD 3 days subsequent warning event

from the expected normal temperatures were a very strong influence as well for dispatch events. Diurnally, calls for service were highest post highest solar radiance (1300 hours) occurring greatest at 1400–1600 hours.

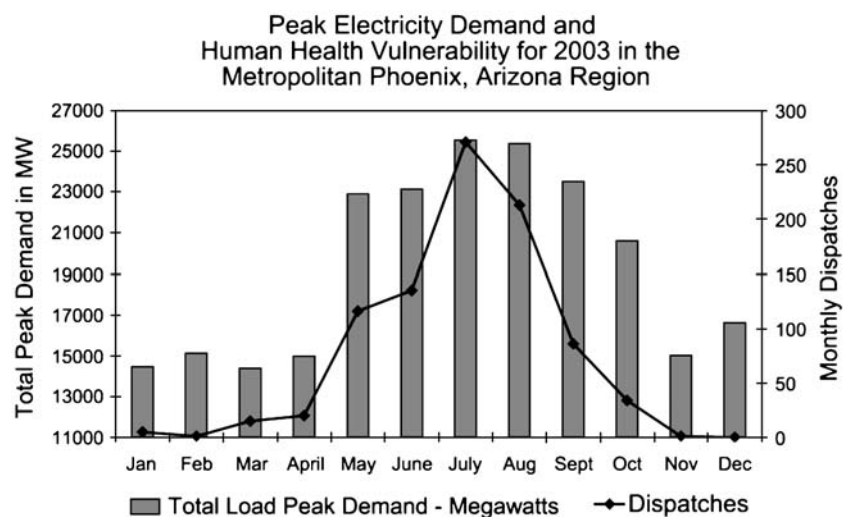
In addition, we find that our results add to work completed by Sheridan (2006) that analyzed municipal heat warning system efficacy in Phoenix and three other North American cities (Dayton, Philadelphia and Toronto). As presented in Sheridan's findings, the City of Phoenix has no official heat mitigation plan, yet this research indicates that the impacts of the large volume of heat related health emergency calls necessarily taps multiple financial and manpower resources of the local government as well as other local resources. However, in May 2006, The Arizona Department of Health Services Division of Public Health Preparedness, Division of Behavioral Health Services, Division of Licensing, Maricopa County Department of Emergency Management and City of Phoenix Emergency Management Office began working together to establish a statewide Heat Emergency Response Plan. This plan seeks to identify the roles and responsibilities of the state, county, city and other responsible agencies, and

to establish a response upon the issuing of heat warnings (ADHS 2006; City of Phoenix 2006).

Because the Phoenix region exhibits two distinct summer time climates (elevated temperatures and low humidity, and elevated temperatures with high humidity during the 'monsoon'), we were able to examine how urban climate variability influences human health vulnerability. The findings indicate that the heat index (heat and humidity) significantly drives the calls for service, and oppressive heat is the primary driver of calls for service. Additionally, there is a lag for heat-related emergency calls as compared to maximum solar radiation, with a maximum lag of 3 h. While there is little variation in day-of-week calls, Sunday is historically the lowest day for calls of service, but traditional outdoor holidays such as Independence Day (Fourth of July) and weekend days proceeding these holidays often show an above average number of calls for service.

Our use of the OUTCOMES model suggests that a more comprehensive index, rather than relying on simply temperature or even the temperature/humidity heat index,

**Fig 6** Peak electricity demand and human health vulnerability (Phoenix, 2003)





could be of considerable value for identifying probable days or times of day for increases in HRD. Our future plans to study the urban morphology in local pockets with high incidences of HRD, used in conjunction with a model such as OUTCOMES, could expand our ability to spatially predict vulnerability. Identification of temporal patterns, and eventually spatial patterns, will assist considerably in emergency response planning for capacity and geographical distribution of personnel and resources.

During the summer of 2006, the summer with the largest number of calls, only seven heat warnings or advisories were issued, yet many days in the Phoenix area have extreme climatic conditions. It is unclear whether or not heat warnings make a difference in the number of HRD. Our study shows that some of our highest days of HRD are on days with heat warnings, but many days without heat warnings also had very high HRD. In Sheridan's (2006) study of the four cities, nine out of ten respondents knew of the issuance of heat warnings. However, Phoenix respondents were the lowest in adjusting to the hot weather (35%), potentially due to the relatively high number of days of excessive heat in the region. The local National Weather Service personnel were continuously adjusting the parameters for issuing heat warnings and advisories during the study period. This suggests that one possible need is for local government to undertake further analysis of calls for service in relationship to urban morphology and climate to provide more specific and localized warnings.

Additionally, electricity blackouts and prolonged interruptions are highly relevant and can be even more problematic for policy makers in development of emergency response planning and resource allocations for manpower and equipment. As urban regions continue to grow, greater stress will be placed on existing infrastructure. As recently as August 14, 2003, the United States and Canada experienced the largest blackout ever, when more than 61,800 MW of electrical load was lost, causing power disruption to an estimated 50 million people. In Phoenix, a large transformer fire occurred on July 4, 2004 at the Arizona Public Service Westwing Substation causing a significant blackout (North American Electric Reliability Council 2006). However, the replacement transformer had to be trucked in from the State of Washington and did not arrive until July 31, 2004. Significant conservation measures had to be implemented as the maximum electric power that could be delivered within the Valley as a result of the fire was a range of 10,000–10,200 MW, while the forecasted summer peak was at 10,300 MW (Arizona Public Service 2004). The Westwing Substation, which services both Tucson and the Valley, operated at one-third capacity, creating the threat of rolling blackouts throughout Greater Phoenix. As presented in Fig. 6, the calls for heat-related medical calls is greatest at the same time as

maximum demand for electricity to support human adaptation through mechanical cooling (California Energy Commission 2007). Thus, any interruption of service, both during a short-term heat wave event, or during a longer-term event, increases exposure and vulnerability to heat-related morbidity.

Further research should be undertaken as comparative analyses for other major urban areas in varied geographies. Additionally, this research would provide a base layer to explore linkages with urban morphology through remote sensing as well as shape layers of socio-economic influences. Thus, we are currently developing follow-up analysis of the cities of Chicago, London and Phoenix as well as linkages of calls for service with any interruptions / outages of electricity.

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## References

- ADHS (2006) <http://www.azdhs.gov/phs/oeh/pdf/heatplan606.pdf>
- Arizona Public Service (2004). [https://www.aps.com/general\\_info/newsrelease/newsreleases/NewsRelease\\_265.html](https://www.aps.com/general_info/newsrelease/newsreleases/NewsRelease_265.html)
- Brazel A, Selover N, Vose R, Heiser G (2000) The tale of two climates-Baltimore and Phoenix urban LTER sites. *Clim Res* 15:123–135
- Brown RD, Gillespie TJ (1995) *Microclimatic Landscape Design*. J. Wiley & Sons, New York
- California Energy Commission (2007). Final staff forecast for 2008 peak demand. California Energy Commission, Sacramento, CA, CEC-200-2007-006SF
- Centers for Disease Control and Prevention (1995). Heat-related mortality-Chicago, July 1995. *Mor Mortal Wkly Rep* 44:577–579
- Centers for Disease Control and Prevention (2005) Heat-related mortality-Arizona, 1993–2002, and the United States 1979–2002. *Morb Mort Wkly Rep* 54(25):628–630, Department of Health and Human Services, July 1 2005
- City of Phoenix (2006) [http://www.mag.maricopa.gov/pdf/cms\\_resource/RESPONSE\\_PLAN\\_FOR\\_SUMMER\\_HEAT79908.pdf](http://www.mag.maricopa.gov/pdf/cms_resource/RESPONSE_PLAN_FOR_SUMMER_HEAT79908.pdf)
- Golden JS (2004) The built environment induced urban heat island effect in rapidly urbanizing arid regions - a sustainable urban engineering complexity. *Environ Sci* 1(4):321–349
- Golden J, Brazel A, Salmond J, Laws D (2006) Energy and water sustainability - the role of urban climate change from metropolitan infrastructure. *Engineering for Sustainable Development* 1(1):55–70
- Heisler GM, Wang Y (2002) Applications of a human thermal comfort model. Fourth Symposium on the Urban Environ-

- ment. May 2002. Norfolk, VA (American meteorological Society)
- Kalkstein LS, Greene JS (1997) An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environ Health Perspect* 105(1):84–93
- Kalkstein LS, Jamason P, Greene J, Libby J, Robinson L (1996) The Philadelphia hot weather–health watch/warning system: development and application, summer 1995. *Bull Am Meteorol Soc* 77:1519–1528
- Klineberg E (1999) Denaturalizing disaster: A social autopsy of the 1995 Chicago heat wave. *Theory Soc* 28(2):239–295
- Kosatsky T (2005) The 2003 European heat waves. *Eurosurveillance* 10:148–149, #7–9, Jul–Sept 2005
- Leonardi GS, Hajat S, Kovats RS, Smith GE, Cooper D, Gerard E (2006) Syndromic surveillance use to detect the early effects of heat-waves: an analysis of NHS direct data in England. *Soz-PraEventivmed* 51(4):194–201
- Mastrangelo G, Hajat S, Fadda E, Buja A, Fedeli U, Spolaore P (2006) Contrasting patterns of hospital admissions and mortality during heat waves: are deaths from circulatory excess or an artifact? *Med Hypotheses* 66(5):1025–1028
- McGeehin M, Mirabelli M (2001) The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environ Health Perspect* 109 (Suppl 2):185–189
- Michelozzi P, Accetta G, D'Ippoliti D, D'Ovidio M, Marino C, Perucci C, Ballester F, Bisanti L, Goodman P, Schindler C (2006) Short-term effects of apparent temperature on hospital admissions in European cities: Results from the PHEWE project. *Epidemiology* 17(6):S84
- National Weather Service (2007a) [http://www.nws.noaa.gov/om/heat/heat\\_wave.shtml](http://www.nws.noaa.gov/om/heat/heat_wave.shtml)
- National Weather Service (2007b). <http://www.crh.noaa.gov/pub/heat.php>
- North American Electric Reliability Council (2006). 2006 Long-Term Reliability Assessment. The Reliability of the Bulk Power Systems in North America.
- Schwartz J, Samet JM, Patz JA (2004) Hospital admissions for heart disease: The effects of temperature and humidity. *Epidemiology* 15(6):755–761
- Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, JL Wilhelm (1996) Heat-related deaths during the July 1995 heat wave in Chicago. *N Engl J Med* 335:84–90
- Sheridan SC (2006) A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. *Int J Biometeorol*
- Shrader-Frechette KS (2002) *Environmental justice: Creating equality, reclaiming democracy*. Environmental ethics and science policy series. Oxford University Press, Oxford, New York
- Steadman RG (1979) The assessment of sultriness, Part I: a temperature-humidity index based on human physiology and clothing science. *J Appl Meteorol* 18: 861–873
- US Census (2007) 50 fastest growing metro areas concentrated in the west and south. <http://www.census.gov/Press-Release/www/releases/archives/population/009865.html>