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7 **Adaptive Capacity to Extreme Heat: Results from a Household Survey in Houston, Texas**
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27 **Abstract**

28 Extreme heat is the leading cause of weather-related mortality in the United States suggesting the

29   necessity for better understanding population vulnerability to extreme heat. The work presented

30   here is part of a larger study examining vulnerability to extreme heat in current and future

31   climates (SIMMER – System for Integrated Modeling of Metropolitan Extreme heat Risk) and

32   was undertaken to assess Houston, Texas residents' adaptive capacity to extreme heat. A

33   comprehensive, semi-structured survey was conducted by telephone at 901 households in

34   Houston in 2011. Frequency and logistic regression analyses were conducted. Results show that

35   that 20% of the survey respondents reported heat-related symptoms in the summer of 2011

36   despite widespread air conditioning availability throughout Houston. Of those reporting heat-

37   related symptoms experienced in the home (n=56), the majority could not afford to use air

38   conditioning because of the high cost of electricity. This research highlights the efficacy of

39   community-based surveys to better understand adaptive capacity at the household level; this

40   survey contextualizes population vulnerability and identifies more targeted intervention

41   strategies and adaptation actions.

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43   **Keywords:** extreme heat, vulnerability, adaptive capacity, household survey, Houston

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49   **1. Introduction**

50   Extreme heat is a leading cause of weather-related human mortality in the United States

51   (NOAA, 2016) and many countries worldwide (Hajat and Kosatsky 2010). Heat-related negative

52   health outcomes typically occur when daily temperatures exceed a normal range for a given

53   climate, local setting, and availability of adaptations (Patz et al. 2005, McMichael et al. 2006).

54   Societal vulnerability often determines the magnitude and the distribution of negative impacts of

55   extreme heat on human health (Harlan et al. 2006, Johnson et al. 2009, Wilhelmi and Hayden

56   2010, Uejio et al. 2011, Johnson et al. 2012, Harlan et al. 2014, Rosenthal et al. 2014). Climate

57   change, urbanization, and demographic trends (e.g., ageing population) suggest that extreme heat

58   will persist as a major hazard in the United States (Field et al. 2012, Oleson et al. 2015, Jones et

59   al. 2015), disproportionately affecting the most vulnerable populations. For both public health

60   and climate adaptation planning, it is essential to better understand which populations are most

61   vulnerable and how to best reduce the negative health impacts of extreme-heat exposure to these

62   populations (Balbus and Malina 2009).

63   Climate adaptation will require a range of behavioral and technological modifications to

64   reduce exposure to extreme heat. As cities develop climate adaptation and hazard risk

65   management plans (Harlan and Ruddell 2011, Boechmann and Rohn 2014), characterizing urban

66   vulnerability and especially, adaptive capacity among the most vulnerable residents, will help

67   identify strategies for heat-hazard mitigation and climate adaptation.

68   Research on adaptive capacity contributes to vulnerability research, which, in broad terms,

69   examines the nature and fabric of a society's ability to prepare for and recover from natural

70   hazards (Adger et al. 2004, Cutter and Finch 2008, Cutter et al. 2010, Wilhelmi and Hayden

71   2010; Hayden et al. 2011). Although the spectrum of vulnerability can be considered from a

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72 population level to an individual level, in this paper we focus on better understanding adaptive

73 capacity at a household level. Societal vulnerability in general, and lack of adaptive capacity in

74 particular, are both related to social inequalities, and earlier research indicates that there is

75 unequal distribution of heat-related health risks based on both physical and social parameters.

76 This suggests the need to go beyond examining demographic data to assess vulnerability to

77 extreme heat by incorporating social and behavioral factors into vulnerability research (Adger et

78 al. 2004; Wilhelmi et al. 2012).

79   After Wilhelmi and Hayden (2010), we characterize adaptive capacity to extreme heat as a

80 function of knowledge, attitudes, and practices (KAP) at the household level. This includes

81 household financial resources, access to public services and extreme heat risk reduction

82 programs, and availability of strong social networks. An important focus of researching adaptive

83 capacity is understanding existing access (or lack of access) to resources to cope with hazardous

84 events (Blaike et al. 1994, Wilhelmi and Hayden 2010). In this light, a range of factors including

85 household air conditioning as an adaptive response need to be studied, particularly as a

86 consideration of whether installation of air-conditioning presents a feasible, equitable, and

87 sustainable solution (Maller and Strengers, 2011) for urban households. Differential capacity to

88 cope with extreme heat exists even within similar demographic strata as shown in previous

89 research on vulnerability to extreme heat in Phoenix, Arizona. This may include information on

90 tree canopy and impervious surfaces, two factors that may reduce the impacts of extreme heat

91 but may be lacking in low-income neighborhoods (Harlan et al. 2006; Harlan et al. 2012, 2014)

92 or may focus strictly on adaptive capacity at a household level (Hayden et al.2011). The

93 framework developed by Wilhelmi and Hayden (2010) advocates for household-level research to

94   ensure that interventions are targeted so that sustainable, community-driven responses are

95   feasible. In the review of recent literature, Boechmann and Rohn (2014) identified several

96   studies that improve our understanding of adaptive capacity to extreme heat through surveys to

97   determine heat-risk awareness, effectiveness of heat warning systems, and protective behaviors

98   during heat waves. Our case study expands on this topic by investigating household-level

99   adaptive capacity to extreme heat in Houston, Texas. This research is part of a larger

100 interdisciplinary project that examined vulnerability to extreme heat in current and future

101 climates (SIMMER – System for Integrated Modeling of Metropolitan Extreme heat Risk)

102 (Heaton et al. 2014; Heaton et al. 2015; Wilhelmi and Hayden 2016). The objectives of the case

103 study presented here were 1) to characterize the adaptive capacity to extreme heat in diverse

104 urban households in Houston, Texas, and 2) to improve our understanding of how different

105 socio-economic disparities and behavioral factors interact to compound vulnerability to extreme

106 heat. We approached these objectives through examining knowledge, attitudes and practices,

107 access to resources, awareness and use of city heat-risk reduction programs, and existing social

108 capital. Section 2 of this article describes the methodology employed in this study, including

109 survey design, sampling strategy, and the data analysis. Section 3 presents the results of the

110 survey, and Section 4 offers a discussion of the main findings. We address study limitations in

111 Section 5 and summarize the key findings from this study and their implications in Section 6.

112 **2. Methods**

113 *a. Study site*

114 Houston, Texas, located in Harris County, is the largest city in Texas and the fourth largest in

115 the United States with a 2010 population of 2.1 million (U.S. Census 2016). Houston has a fast-

116　growing, multicultural population with over 145 languages spoken (Kriel, 2015). It is located on

117　the gulf coastal plain in southern Texas and has a humid subtropical (Koeppen *Cfa*) climate with

118　summer temperatures often above 32 °C (NWS 2014). In 2011, Houston experienced the hottest

119　summer on record with temperatures regularly topping 37 °C. August 2011 had 24 days with

120　ambient temperatures over 37 °C, making it the hottest month on record (Hoerling et al. 2012).

121　Furthermore, a study by Zhang et al. (2015) found a significant association between extreme heat

122　in the summer of 2011 and a higher than normal number of emergency department visits,

123　particularly among the elderly. Coupled with Houston's growth, diversity, and hot summer

124　climate, come challenges such as an aging population, educational and income disparities, and a

125　projected increase in high heat-stress days and nights (Oleson et al. 2015). Current and future

126　heat health risks in Houston (Heaton et al. 2014; Conlon et al. 2016; Marsha et al. 2016) call for

127　a better understanding of the population's capacity to cope with extreme heat and to adapt to

128　potentially more frequent and intense summer heat waves.

129　*b. Survey Development*

130　　　A semi-structured interview protocol, based on Hayden et al. (2011), was adapted for use in

131　Houston in collaboration with the Houston Department of Health and Human Services in the

132　aftermath of extreme heat in the summer of 2011. The survey sought to understand Houston

133　residents' adaptive capacity to extreme heat including knowledge, attitudes and practices,

134　participants' social capital, and their access to resources as well as knowledge of the availability

135　of heat-stress prevention programs. The survey consisted of both closed-ended and open-ended

136　questions. Closed-ended questions were used to generate quantitative data while open-ended

137　questions helped to contextualize closed-ended responses and allow respondents to describe their

138   experiences and views in greater depth. The survey was pretested in English and Spanish with

139   multiple residents of the Houston area in July of 2011 and revised prior to implementation.

140   *c.   Sampling Strategy*

141   The Random-Digit-Dial (RDD) survey was administered via telephone by Princeton Data

142   Source, LLC (PDS, 2016), a survey data collection company. Nine hundred and one adults

143   living in Houston were surveyed from October 31 to November 17, 2011. This time period was

144   chosen to ensure maximum recall of participants' experiences during the summer of 2011.

145   Telephone surveys were conducted in English and Spanish, based on the respondent's

146   preference. Calls were staggered over times of the day, and days of the week, to maximize the

147   chance of making contact with a wide variety of respondents.

148   Three samples were used for data collection. All three samples covered the entire Houston

149   area as defined by 71 ZIP codes (Fig. 1). The first sample was an equal probability sample of

150   RDD phone numbers drawn from landline telephone exchanges that serve the listed ZIP codes.

151   This sample was drawn using standard list-assisted random digit dialing methodology from

152   exchanges that serve the Houston area. The second sample was an equal probability landline

153   listed sample drawn from the same ZIP code list noted above but was designed to garner

154   information from unlisted numbers. The third sample was an equal probability RDD cellular

155   phone sample drawn from rate centers that serve the Houston area. Out of 901 survey

156   respondents, 767 participants provided the geolocation of their households or nearest cross-

157   streets. These households are shown in Fig. 1. Although not all 901 surveyed households are

158   represented on the map, Fig. 1 shows the general distribution of households across Houston and

159   the spatial pattern of this georeferenced subsample, which is representative of the overall sample.

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d. Statistical analysis

Analyses were performed using SPSS software (v. 21; IBM). Frequency analyses were conducted to provide descriptions of demographic characteristics and quantify participants' responses to survey questions. Logistic regression analyses were run to evaluate whether significant differences existed between different groups' responses to questions with binary responses. All analyses were unweighted. To maintain consistency in the analysis, each of these logistic regressions used the following explanatory variables: gender, income (less than $30,000, between $30,000 and $75,000, and greater than $75,000), education (did not graduate high school, high school graduate, and 4 or more years of college), age (30 years or less, 31-45, 46-65, greater than 65), employment status (employed, unemployed, and retired), race (Caucasian, African-American, Hispanic, or other), language (English spoken at home or no English spoken at home) , and home ownership.

3. Results

a. Demographics

Slightly more than half of the 901 respondents were female (56.9%). The majority of the participants reported their race as Caucasian (46.7%), while 26.6% of participants reported African American race/ethnicity, 20.9% Hispanic race/ethnicity, 4% identified as Asian, 0.8% as American Indian/Alaska Native, and 0.2% as Native Hawaiian/Pacific Islander. Most of the sample's respondents had lived in the Houston area for more than 20 years (63.9%) and over half of respondents were homeowners (58.9%). There was a bimodal distribution of yearly household income; nearly half (45.8%) of those respondents who reported their income indicated that it was

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182   less than $40,000 a year, while 19.2% reported that their income was greater than $100,000 a

183   year. The sample was relatively well educated; 41.9% reported completing at least four years of

184   college. Fully 47.4% of the sample was unemployed or retired. English was spoken by 88.3% of

185   participants, and 11.7% spoke no English at home. An overview of the survey participants'

186   demographics can be found in Table 1.

187   *b. Awareness of Heat Risks*

188   A crucial first step in mitigating heat-related illness is increasing a population's awareness of

189   the associated symptoms (CDC 2012). The most commonly reported symptoms among the study

190   participants (n=894) were dizziness (35.3%), fainting (22%), fatigue (18.9%), nausea/vomiting

191   (18.2%), headaches (14.9%), and finally, intense thirst (9.7%). A number of respondents

192   indicated heavy sweating (16.3%) as a symptom of too much heat exposure. Participants also

193   mentioned clammy skin (8.7%), dry mouth (8.6%), weak/rapid pulse (6.9%), and confusion

194   (6.2%) as potential symptoms. Fourteen percent of participants reported that they did not know

195   any symptoms of heat-related illness.

196   The results of the logistic regression analysis on the knowledge of common symptoms is

197   summarized in Table 2. Overall, the model is a good fit (p=0.0001), with income (p=0.009) and

198   age (p=0.008) being significant covariates. The odds of not knowing symptoms were almost

199   three times greater for those who make less than $30,000 per year than for those who make over

200     $75,000 (95%CI=1.41 to 5.55). Further, those over the age of 65 are significantly less likely to

201   know the most common symptoms of heat-related illness.

202   Respondents were asked where they felt most at risk for heat-related illness; most (92.1%)

203   felt at highest risk outdoors. Of those who felt most at risk outdoors, 19.1% reported working

204   outdoors.

205   *c. Sources of Information about Heat*

206   A majority of respondents (87.7%) recalled having heard excessive heat warnings or

207   advisories, likely due to the record-setting heat Houston experienced during the summer of 2011.

208   Of participants who recalled hearing the advisories, the primary source of heat-related

209   information was from local television (80.2%). Other sources cited by participants included radio

210   (34.7%) and newspapers (15.8%).

211   Results from the logistic regression analysis are displayed in Table 3. Overall, the model is a

212   good fit (p=0.002), with gender (p=0.048), education (p=0.051), and age (p<0.0001) being

213   significant covariates. Those who were significantly more likely to recall hearing the heat

214   advisories were between the ages of 31 and 65. Males were 1.7 times less likely to recall hearing

215   a heat advisory (p = 0.048; 95% CI=1.01-2.77) than females.

216   When asked where they received information about preventing heat-related illness, 66.6% of

217   all respondents mentioned Houston local television stations. The Internet (29.5%), radio (26.9%),

218   cable television (25.9%), newspapers (24.3%), and the Weather Channel (21.7%) were also

219   cited. More than a quarter of participants (27.5%) indicated that they received heat-related illness

220   information by word of mouth; evaluation of qualitative responses indicates that 'word of mouth'

221   includes respondents' friends, family, and co-workers.

222   *d. Experience with Extreme Heat in 2011*

223   The survey responses indicated that the presence of air conditioning did not always prevent

224   heat-related illness. Almost 87% of survey participants had central air conditioning in their

225   homes; however, 36.9% of all respondents said that they had felt too hot in their home during the

226   summer of 2011. Demographic factors associated with participants feeling too hot at home

227   included not being a homeowner and being female. Homeowners were 1.7 times more likely to

228   report feeling comfortable in their homes (p=0.016; 95%CI=1.11 to 2.61), and males were 1.5

229   times more likely to report feeling comfortable in their homes (p=0.028; 95%CI=1.04 to 2.09).

230   Participants were also asked, "This past summer, did you have symptoms such as fainting,

231   rapid heartbeat, hallucinations, confusion, dizziness, or muscle cramps that you believe were

232   heat-related?" Almost one-fifth of respondents (19.8%) experienced some symptoms; of those

233   experiencing symptoms, 74.7% experienced symptoms more than once, and 31.5% reported

234   experiencing symptoms inside their homes. Of the 56 respondents who experienced symptoms in

235   the home, 53 (94.6%) used air conditioning (central air and/or window units).

236   The logistic regression model for those who experienced heat-related symptoms was a good

237   fit (p<0.0001), with education (p=0.026) and home ownership (p=0.038) being significant. Those

238   reporting less than four years of college were significantly more likely to have experienced heat-

239   related illness and those who did not graduate from high school had an even greater risk. Those

240   who owned their homes were 1.7 times more likely to have had no symptoms of heat-related

241   illness (*p = 0.038;* 95%CI=1.03-2.84) than those who rented their homes.

242   Additionally, respondents were asked to self-report whether their health at the time of the

243   survey was good, fair or poor. A second logistic regression model was fit using health status,

244   knowing neighbors, and knowledge of symptoms as covariates. Those who reported their health

245 as either good or fair were almost 13 times more likely to report no heat-related symptoms

246 compared to those who reported poor health (p < 0.0001; 95%CI=6.25-28.79).

247 As a follow on to the previous question, we asked participants what might prevent them from

248 seeking medical care for heat-related symptoms; 122 (13.7%) reported that certain factors such

249 as lack of health insurance and cost of medical care might prevent them from seeking treatment

250 (Fig. 2).

251 *e. Coping with Extreme Heat*

252 Strategies most commonly employed by participants to protect themselves from heat were

253 staying indoors (55.4%), drinking plenty of water (53.9%), using an air conditioner (25%), and

254 avoiding outdoor activity (13.9%) (Fig. 3). A majority of the sample indicated that they alter

255 their daily activities (76.3%) when it gets too hot. The logistic regression model on changing

256 outdoor activities was a good fit (p<0.0001), with gender (p=0.001) and employment (p=0.006)

257 being significant and with education (p=0.059) and income (p=0.078) being marginally so.

258 Males were almost two times less likely than females to change their outdoor activity plans (p =

259 0.001; 95%CI=1.33 - 2.94). Those who did not graduate from high school were 2.3 times less

260 likely than college graduates to alter their daily activities in response to a heat warning. (p =

261 0.059; 95%CI=1.14 - 4.57). Participants who earn less than $30,000 per year were also 2.3 times

262 less likely than those who earn more than $75,000 per year to change their daily activities (p =

263 0.078; 95%CI=1.11- 4.64).

264 Participants noted that when they changed their routines, they typically limited outdoor

265 activities and/or engaged in outdoor activities early in the morning or late in the evening.

266 *f. Air Conditioning as a Coping Mechanism*

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267   Staying inside to avoid heat is only an effective strategy if the indoor environment is

268   cooled. In Houston, most of our survey respondents reported having central air conditioning

269   (86.9%) and/or a window-unit air conditioner (14.5%). Other methods mentioned for cooling a

270   house included fans (44.1%) and awnings, shades or shutters (22.2%). Even though the full

271   sample had high rates of air conditioning use, 14.4% of respondents reported that the cost of

272   electricity prevented them from using their air conditioner (Table 4).

273   Participants were asked, "This past summer, did you have trouble paying your electric

274   bill?" Almost one-fourth (24.5%) of respondents admitted having trouble paying their electric

275   bill, with the average monthly bill provided by participants at $241.52. The logistic regression

276   model was a good fit (p<0.0001) and income (p<0.001), education (p=0.003) age (p=0.017) and

277   race (p=0.019) were significant. More specifically, those whose income was less than $75,000

278   per year had more difficulty paying their electric bill (p<0.001). Additionally, those who had not

279   graduated from high school (p=0.003), those older than 30 years of age (p=0.017), and those who

280   reported race/ethnicity as African American (p<0.019) had more difficulty paying their electric

281   bill (Table 4).

282   *g. Awareness of Programs and Resources for Coping with Heat*

283   Paying the electric bill was problematic for some respondents; however, only 35.2% of all

284   participants knew of special assistance programs offered by the local utility company to help pay

285   electric bills. Based on the logistic regression model (overall p<0.0001), education (p=0.05), age

286   (p=0.005) and race (p=0.041) were significant. Those who had completed at least 4 years of

287   college were over twice as likely as those who had not graduated from high school to be aware of

288   assistance programs (p=0.05; 95%CI=1.13 to 4.26). Participants over 65 years of age were three

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289   times more likely to be aware of assistance programs than those under 30 years of age (p=0.005;

290   95%CI=0.96 to 9.67). Respondents who identified as Caucasian were twice as likely to be aware

291   of assistance programs than those who identified as Hispanic (p=0.04;95%CI=1.06 to 3.27) or

292   African American (p=0.04;95%CI=1.07 to 2.73).

293   During heat emergencies when the City of Houston Heat Emergency Plan (City of Houston,

294   2016) is activated, all public libraries and many Multi-Service Centers are open to the public as

295   cooling centers. These designated cooling centers and other City facilities provide an air-

296   conditioned environment for residents who need to escape the effects of the heat. To gauge the

297   population's knowledge of these cooling centers, participants were asked, "Do you know what a

298   cooling center is?" Less than half (44%) of respondents indicated that they knew what a cooling

299   center was. Of those respondents who knew what a cooling center was, 45.3% were familiar

300   with the location of a center, and 7% had used one. Of the 332 respondents who reported feeling

301   too hot inside their home, 120 (36.1%) knew what a cooling stations was. Most respondents

302   noted that they had never felt the need to use a cooling center because they had air conditioning

303   in their homes.

304   *h. Social Networks and Social Capital*

305   To better understand the potential role of social networks and social capital for reducing

306   vulnerability to extreme heat, participants were asked a series of questions about their neighbors

307   and neighborhoods. Participants were asked, "Thinking about your neighbors; would you say

308   you know all, some, or none of them?" A small percentage of respondents (17.4%) reported

309   knowing all of their neighbors while 71.3% reported knowing some of their neighbors. The

310   logistic model suggests that those who knew at least some of their neighbors were more likely to

311   be homeowners (p=0.004). The participants who knew all or some of their neighbors (88.7%),

312   would feel comfortable asking a neighbor for help and more than a third (34.3%) reported

313   checking on a neighbor when the weather is hot. Participants were also asked, "When the

314   weather is very hot, do any of your family members, friends, or neighbors who don't live in this

315   home check on you? Forty-six percent answered affirmatively. Almost 11% of the respondents

316   knew none of their neighbors; of these, 25.8% lived alone. Six percent of respondents knew none

317   of their neighbors and also were not members of either a religious or non-religious organization.

318   Participants were asked, "Do you consider people in your neighborhood vulnerable to heat?"

319   40.2% responded affirmatively. Of those who responded affirmatively, 89.4% knew at least

320   some of their neighbors, 85.5% talk to their neighbors at least occasionally, and 79.3% would

321   feel comfortable asking a neighbor for help.

322   Almost all of those surveyed (90.6%) reported feeling safe in their neighborhoods, although

323   the logistic regression model suggested that participants who lived in households with incomes

324   greater than $75,000 per year were five times more likely to feel safe in their neighborhoods than

325   those making less than $30,000 per year (p=0.03;95%CI=1.44 to 15.46). Additionally, those who

326   self-identified as being in good to fair health (p=0.009) and those who knew at least some of

327   their neighbors (p=0.014) reported feeling safe in their neighborhoods.

328   **4. Discussion**

329   Adaptive capacity at the household level is an understudied area in vulnerability research.

330   Yet, knowledge about adaptive capacity can shape short-term responses to extreme heat, public

331   health interventions, and long-term adaptation strategies. This study is one of the first systematic

332   attempts to characterize adaptive capacity to extreme heat at the household level across a major

333   metropolitan area. The population sample presented here represents a demographically broad

334   range of urban residents in Houston, TX.

335   Multiple demographic, socio-economic, and behavioral factors may interact to compound

336   vulnerability. In our study during the summer of 2011, non-homeowners, African Americans and

337   Hispanic/Latinos, those with household incomes less than $30,000 per year, those who reported

338   being in poor health, and those who were unemployed were significantly more likely to report

339   heat stress and symptoms of heat-related illness. Those who reported poor health were

340   significantly less likely to know their neighbors, be non-homeowners, or feel safe in their

341   neighborhoods, suggesting that they may be more vulnerable to heat-related illness.

342   Earlier studies have pointed to air conditioning as a present-day response to and a mechanism

343   for adaptation to extreme heat under future climate change (Davis et al. 2003, Donaldson et al.

344   2003, Curriero et al. 2002, Braga et al. 2001), with a study by Barnett (2007) suggesting that risk

345   of cardiovascular mortality from extreme heat had disappeared across 104 cities in the United

346   States, most likely due to increased air conditioning usage. While these finding may lead to the

347   assumption that air conditioning will alleviate negative health outcomes from extreme heat, other

348   studies begin to question whether household air conditioning is a short-sighted approach to

349   adaptation (Maller and Strengers, 2011). Recent research presents evidence that warmer

350   conditions due to a changing climate increase demand for air conditioning in cities. Increased use

351   of air conditioners contributes to greenhouse gas emissions at the global scale and generates

352   more heat at the local scale (Grimmond 2007, Lundgren and Kjellstrom 2013), thus increasing

353   extreme heat exposure. In addition to challenges associated with warmer urban conditions and

354   growing energy demand, research shows that household use of air conditioning may exacerbate

355   existing inequalities among urban residents. Farbotko and Waitt (2011) demonstrated that low-

356   income elderly residents in Australian households could not afford to use air conditioning

357   without energy subsidies. Therefore, while air conditioning may provide effective and immediate

358   relief from extreme heat, more sustainable approaches are needed to reduce extreme heat risk

359   (Lundgren and Kjellstrom 2013).

360

361   Our study provides quantitative empirical evidence that despite an overall high

362   percentage (almost 87%) of the population in Houston with either household central and/or

363   window-unit air conditioners, many study participants still experienced symptoms of heat stress

364   during the summer of 2011. More than a third (37%) of our study population expressed feeling

365   too hot inside their homes despite air conditioning, and almost 20% of our participants reported

366   experiencing heat related symptoms during the summer of 2011. Those who experienced heat-

367   related health problems also reported having access to air conditioning; however, those who

368   rented their homes and were unemployed were unable to employ air conditioning to the extent

369   needed to cool themselves adequately, either because the air conditioner was broken or they

370   could not afford the cost of electricity to run the air conditioner. Additionally, 44% of our study

371   population used fans in their homes; although only a small number (n=13) used fans exclusively

372   to cool their homes. Earlier studies have shown the risks of using fans as a sole cooling

373   mechanism, suggesting a need to continue to educate the public on this risk (Luber and

374   McGeehin 2008). Caution is needed in drawing conclusions from this question as we did not ask

375   respondents if the fans were in operation when they were not at home or if the windows were left

376   open when fans were used.

377   Moreover, large-scale power-grid failures are not uncommon in the United States,

378   leaving residents without air conditioning; one example occurred in Chicago during the heat

379   wave of 1995 when the city set new records for power usage resulting in selected grid failure,

380   and 49,000 people were left without power (Klinenberg 2002). In 2006, the U.S. experienced a

381   severe heat wave and in selected areas such as St. Louis, power was lost to over half a million

382   customers (CNN 2006). In the summer of 2012, four million people in the eastern U.S. were left

383   without power for a week in the aftermath of a derecho, an intense storm with winds in excess of

384   80 mph. The loss of power coupled with extreme heat resulted in 34 heat-related deaths (NOAA

385   2012). In Houston, power outages are common in the aftermath of hurricanes which often occur

386   during very hot summer conditions, even in the absence of a heat wave. For example, on

387   September 13, Hurricane Ike left 2.9 million residents of the Houston-Galveston area without

388   power; it took 16 days for power to be completely restored (Qiao and Vipulanandan 2009).

389   These examples, coupled with our findings on air conditioner access in Houston, suggest that

390   relying solely on residential air conditioning to combat heat exposure is not the ultimate answer

391   to reducing population vulnerability to extreme heat.

392   In many cities, offering cooling centers is becoming a common practice for reducing the

393   population's exposure to extreme heat (Berisha et al. 2016). During the European heat wave of

394   2003, even two-to-three-hour cooling sessions were shown to be beneficial to those who were

395   vulnerable to the negative impacts of extreme heat, in particular, the elderly (Salagnac 2011). In

396   Houston, only a small percentage of our study population was familiar with what a cooling

397   center was, and of those, an even smaller percentage knew where one was located. This suggests

398   that those populations identified as vulnerable might benefit from the provision of added

399   information on the value of cooling centers, their hours of operations, directions for getting there

400   using public or private transportation, and the importance of cooling oneself for at least a few

401   hours per day during extreme-heat events.

402   Most respondents surveyed in Houston reported hearing information about excessive heat

403   advisories from their broadcasters on local TV, a phenomenon that has been reported previously

404   with other extreme events such as hurricanes (Morss and Hayden 2009) as well as extreme heat

405   (Sheridan 2008). In this study, 14% of the population reported not knowing any symptoms of

406   heat stress, and these were potentially among the most vulnerable including those who were

407   unemployed and did not speak English as a first language. Additionally, 7% of our participants

408   reported using sunscreen as a means to protect themselves from heat stress, with Hispanic/Latino

409   populations significantly more likely to report this than other ethnic groups, suggesting a need to

410   ensure that straightforward messages about risk reduction reach those who are potentially more

411   vulnerable. In an earlier study undertaken in Phoenix, Arizona, Hayden et al. (2011) suggested

412   that public health collaboration with local broadcast meteorologists to inform television

413   audiences not only of an impending extreme heat event, but also to provide information on

414   symptoms of heat stress and risk reduction measures, may be a step in proactively reducing

415   vulnerability to heat.

416   **5. Study Limitations**

417   Houston is one of the fastest growing and most diverse cities in the United States; the

418   demographic shift in the past decades has been well-documented by Klineberg (2017) in research

419   conducted by the Kinder institute. Demographic groups with less access to resources are

420   somewhat under-represented in the survey sample presented in this manuscript (Table 1). While

421 weighting respondents is one way to address this issue, the results presented here are all un-

422 weighted. If a weighted response is considered, any results correlated with resource level (e.g.,

423 those related to income, thermostat setting, employment) will be of greater magnitude and higher

424 significance. The results presented here are not correlated to resource access and do not change

425 in significance when a weighted analysis is considered instead.

426 **6. Conclusions**

427 As a part of a larger study on urban vulnerability to extreme heat in Houston, Texas, we

428 conducted a household survey on population adaptive capacity to better understand a wide range

429 of socio-economic and health disparities. Our broad sample of urban households provided

430 important information about the roles of knowledge, attitudes and practices, access to resources,

431 use and awareness of city heat-risk reduction programs, and social capital. The survey identified

432 non-home owners, African American and Hispanic/Latinos, those with incomes less than

433 $30,000 per year, unemployed and those in poor health to be most vulnerable to heat stress.

434 Additionally, findings indicate that these populations have little or no knowledge of the

435 symptoms of heat stress, nor do they know where the closest cooling center is. Often, financial

436 barriers restricted the use of an air conditioner at home where the greatest number of participants

437 reported symptoms of heat stress. These findings suggest heat mitigation and climate adaptation

438 strategies have to include both technological and behavioral/community-based options.

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Table 1. Demographic characteristics of the survey participants.

Socio-Demographics			
Variable	**Frequency**	**Percent**	**5-year ACS (2006-2010)++**
SEX (n=901)			
Male	388	43.1%	50.1%
Female	513	56.9%	49.9%
RACE/ETHNICITY (n=872)			
Caucasian	407	46.7%	54.8%
Hispanic	182	20.9%	42.4% (any race)
African-American	232	26.6%	24.4%
Asian	35	4.0%	5.9%
Native Hawaiian/Pacific Islander	2	0.2%	0.1%
American Indian/Alaska Native	7	0.8%	0.4%
Other	7	0.8%	14.4%
LANGUAGE (n=901)			
English	796	88.3%	54.7%
Spanish	241	26.7%	37.2%
French	20	2.2%	*
Chinese	13	1.4%	*
Vietnamese	5	0.6%	*
Other	43	4.8%	1.1%
INCOME (n=690)			
Less than $10,000	103	13.4%	8.7%
$10,000-20,000	94	12.3%	13.3%
$20,000-30,000	98	12.8%	13.1%
$30,000-40,000	56	7.3%	11.7%
$40,000-50,000	44	5.7%	9.3%
$50,000-75,000	77	10.0%	16.6%
$75,000-100,000	71	9.3%	9.4%
More than $100,000	147	19.2%	17.9%
EDUCATION (n=890)			
No schooling	13	1.5%	2.5%
Grades 1-8	51	5.7%	11.9%
Grades 9-11	82	9.2%	9.5%
Grade 12/GED	166	18.6%	25.4%
College 1-3 years	204	22.9%	22.5%
College 4+ years	374	41.9%	28.2%

HOME OWNERSHIP (n=893)			
Own	527	58.9%	46.6%
Rent	333	37.2%	53.4%
Other arrangement	33	3.7%	-
LIVED IN HOUSTON AREA (n=901)			
Less than 1 year	14	1.6%	**
1 to 4 years	81	9.0%	**
5 to 9 years	82	9.1%	**
10 to 19 years	148	16.4%	**
20 years or more	576	63.9%	**
EMPLOYED (n=884)			
Yes	473	53.5%	62.5%
No (Unemployed or retired)	411	46.5%	@

++ All demographic data derived from 2010 American Community Survey (ACS) 5-year (2006-2010).

*French, Chinese, Vietnamese not reported individually in ACS data (see excel sheet)

** No data for how long people had been living in Houston

@ Unemployed: 5.4%, Not in Labor Force: 32%. Estimates of the retired population are not reported with employment information.

Table 2. Binary Logistic Regression on the Knowledge of Common Symptoms (Know Most Common = 0, Don't Know Most Common = 1)

Binary Logistic Regression on the Knowledge of Common Symptoms (Know Most Common = 0, Don't Know Most Common = 1)					
	Parameter	Estimate	Wald Chi-Square	Sig. Pr>ChiSq	Odds Ratio Estimates
Socio-Demographic Factors					
1.657	Male	-.196	.968	.325	.822
	Female				
INCOME $(X^2 = 9.527, p = 0.009)$	Less than 30,000	1.027	8.614	.003	2.793
	30,000-75,000	.359	1.368	.242	1.432
	Greater than 75,000 (REFERENCE)				
EDUCATION $(X^2 = 0.220, p = 0.896)$	Did not graduate high school	-.125	.134	.714	.882
	High school graduate	-.124	.231	.631	.884
	4 or more years of college (REFERENCE)				
AGE $(X^2 = 11.537, p = 0.009)$	30 years or less	-1.446	5.991	.014	.236
	31 – 45	-1.930	10.711	.001	.145
	46 – 65	-1.678	8.659	.003	.187
	Greater than 65 (REFERENCE)				
EMPLOYED $(X^2 = 2.636, p = 0.268)$	Employed	.907	2.355	.125	2.478
	Unemployed	1.020	2.696	.101	2.772
	Retired (REFERENCE)				
RACE $(X^2 = 2.535, p = 0.469)$	Other	.607	2.050	.152	1.835
	Hispanic	.168	.283	.595	1.183
	African-American	.283	1.102	.294	1.328
	Caucasian (REFERENCE)				
LANGUAGE	English spoken	-.333	1.128	.288	.717
	No English spoken				
HOME OWNERSHIP	Own home	-.251	1.073	.300	.778
	Do not own home				

Table 3. Binary Logistic Regression on the Recollection of Excessive Heat Warnings (Yes = 0, No)

Binary Logistic Regression on the Recollection of Excessive Heat Warnings (Yes = 0, No = 1)					
	Parameter	Estimate	Wald Chi-Square	Sig. Pr>ChiSq	Odds Ratio Estimates
Socio-Demographic Factors					
SEX	Male	.512	3.916	.048	1.669
	Female				
INCOME *(X^2 = 1.304, p = 0.521)*	Less than 30,000	-.503	1.212	.271	.605
	30,000-75,000	-.336	.794	.373	.715
	Greater than 75,000 (REFERENCE)				
EDUCATION *(X^2 = 5.950, p = 0.051)*	Did not graduate high school	.859	3.435	.064	2.360
	High school graduate	-.080	.053	.817	.923
	4 or more years of college (REFERENCE)				
AGE *(X^2 = 21.389, p < 0.0001)*	30 years or less	-.688	1.226	.268	.503
	31 - 45	-1.602	6.359	.012	.201
	46 - 65	-2.023	10.559	.001	.132
	Greater than 65 (REFERENCE)				
EMPLOYMENT *(X^2 = 4.346, p = 0.114)*	Employed	1.386	4.294	.038	3.998
	Unemployed	1.406	3.804	.051	4.081
	Retired (REFERENCE)				
RACE *(X^2 = 1.500, p = 0.682)*	Other	.306	.345	.557	1.358
	Hispanic	-.134	.104	.747	.874
	African-American	.254	.485	.486	1.289
	Caucasian (REFERENCE)				
LANGUAGE	English spoken	-.015	.001	.971	.985
	No English spoken				
HOME OWNERSHIP	Own home	-.303	.863	.353	.739
	Do not own home				

Table 4. Binary Logistic Regression on those that had Trouble Paying Their Electric Bill (Yes = 0, No = 1)

Binary Logistic Regression on Those that Had Trouble Paying Electric Bill (Yes = 0, No = 1)					
	Parameter	Estimate	Wald Chi-Square	Sig. Pr>ChiSq	Odds Ratio Estimates
Socio-Demographic Factors					
SEX	Male	.270	1.657	.198	1.310
	Female				
INCOME (X² = 20.639, p < 0.0001)	Less than 30,000	-1.855	20.608	.000	.156
	30,000-75,000	-1.213	10.851	.001	.297
	Greater than 75,000 (REFERENCE)				
EDUCATION (X² = 11.377, p = 0.003)	Did not graduate high school	-1.113	9.982	.002	.329
	High school graduate	-.298	1.145	.285	.742
	4 or more years of college (REFERENCE)				
AGE (X² = 10.249, p = 0.017)	30 years or less	.349	.166	.684	1.418
	31 – 45	-.589	.487	.485	.555
	46 – 65	-.391	.217	.642	.676
	Greater than 65 (REFERENCE)				
EMPLOYMENT (X² = 1.296, p = 0.523)	Employed	-.347	.158	.691	.707
	Unemployed	-.594	.443	.506	.552
	Retired (REFERENCE)				
RACE (X² = 9.947, p = 0.019)	Other	-.497	1.035	.309	.608
	Hispanic	-.332	1.036	.309	.717
	African-American	-.846	9.159	.002	.429
	Caucasian (REFERENCE)				
LANGUAGE	English spoken	-.074	.051	.821	.929
	No English spoken				
HOME OWNSHIP	Own home	.050	.040	.842	1.051
	Do not own home				

Fig. 1. Distribution of georeferenced households (n=767) surveyed in Houston, TX in 2011.
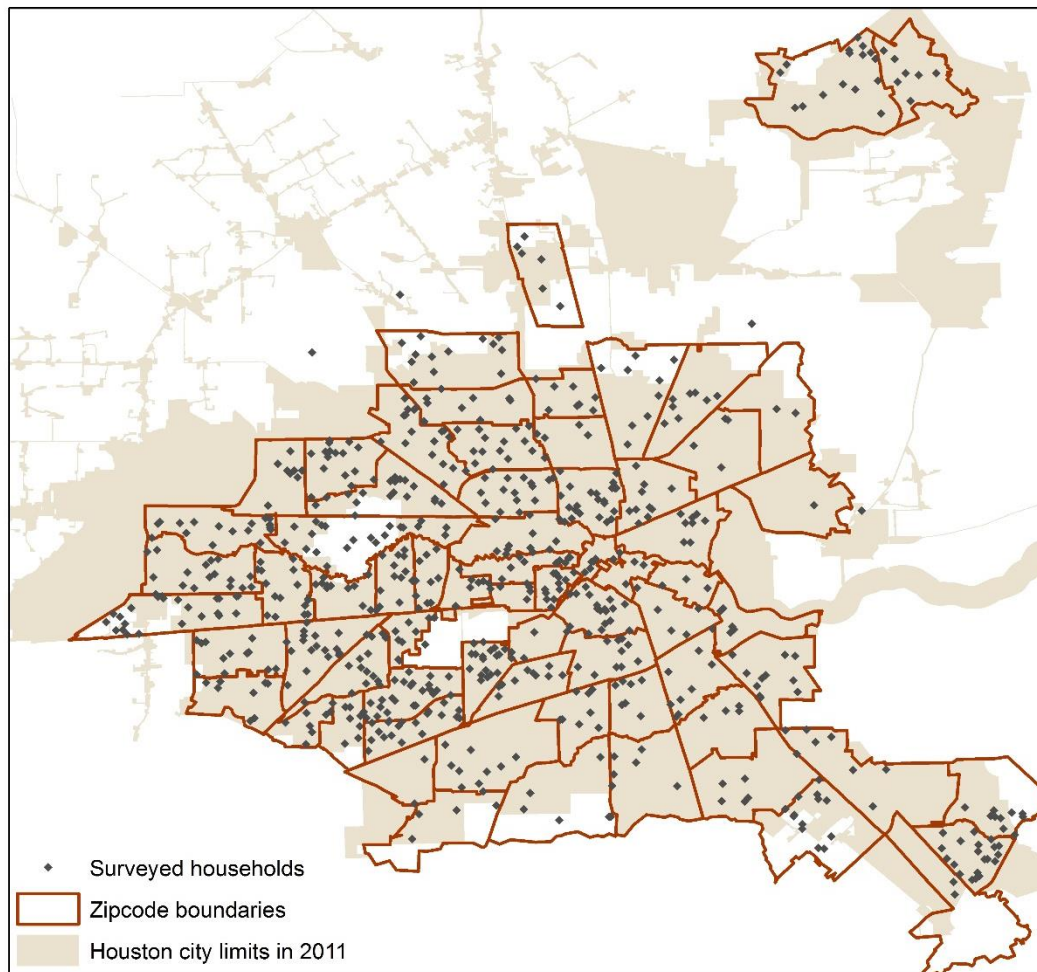
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Fig. 2. Participants were asked, "Would anything prevent you from seeking medical care for heat-related symptoms?" Those who responded "Yes", indicated the reasons for not seeking medical care for heat-related illness.
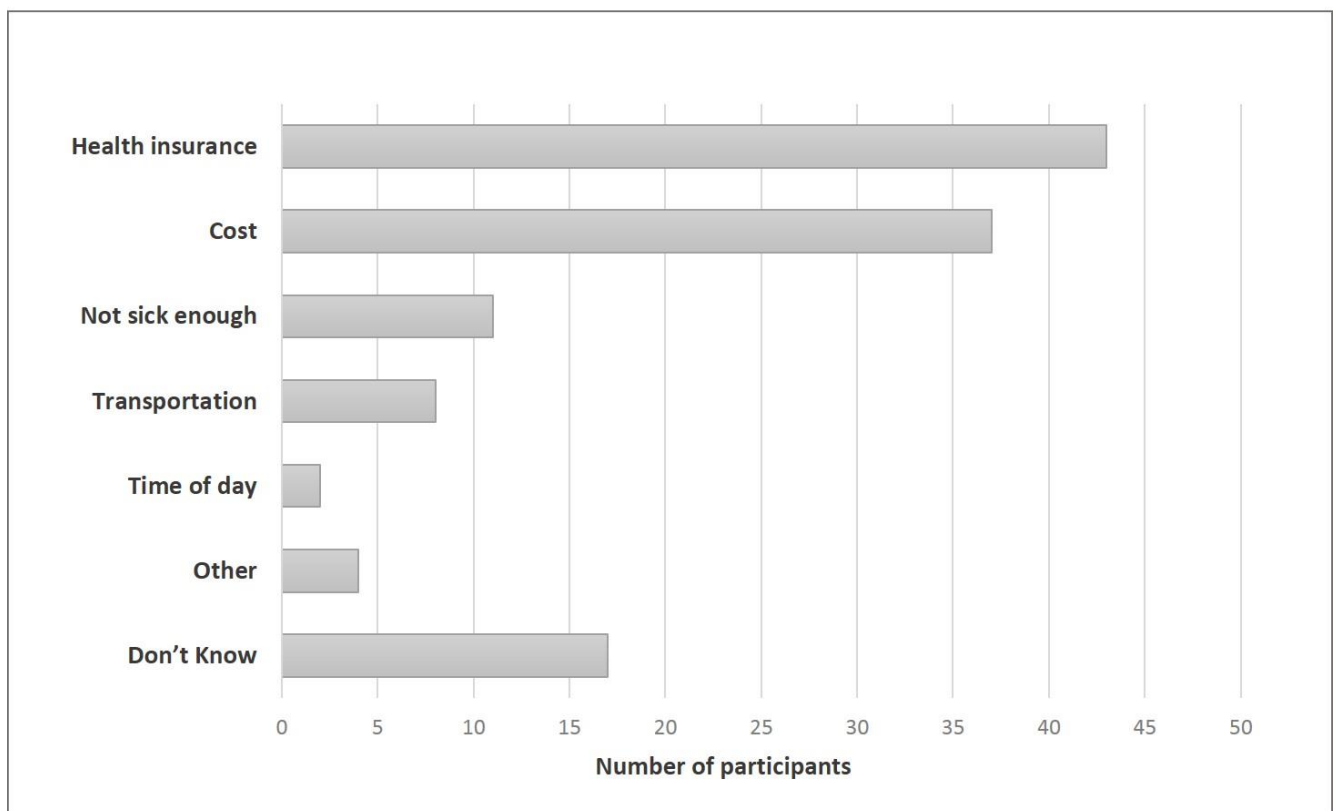
Fig. 3. Participants were asked, "During very hot weather, what steps do you take to protect yourself from the heat?"