
Charles Darwin University

Perceived heat stress increases with population density in urban Philippines

Zander, Kerstin K.; Cadag, Jake Rom; Escarcha, Jacquelyn; Garnett, Stephen T.

Published in:
Environmental Research Letters

DOI:
[10.1088/1748-9326/aad2e5](https://doi.org/10.1088/1748-9326/aad2e5)

Published: 27/07/2018

Document Version
Publisher's PDF, also known as Version of record

[Link to publication](#)

Citation for published version (APA):

Zander, K. K., Cadag, J. R., Escarcha, J., & Garnett, S. T. (2018). Perceived heat stress increases with population density in urban Philippines. *Environmental Research Letters*, 13(8), 1-8. Article 084009. <https://doi.org/10.1088/1748-9326/aad2e5>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LETTER • OPEN ACCESS

Perceived heat stress increases with population density in urban Philippines

To cite this article: Kerstin K Zander *et al* 2018 *Environ. Res. Lett.* **13** 084009

View the [article online](#) for updates and enhancements.

Related content

- [Urban heat stress: novel survey suggests health and fitness as future avenue for research and adaptation strategies](#)
Christian Schuster, Jasmin Honold, Steffen Lauf et al.
- [Extreme heat waves under 1.5 °C and 2 °C global warming](#)
Alessandro Dosio, Lorenzo Mentaschi, Erich M Fischer et al.
- [Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century](#)
Ethan D Coffel, Radley M Horton and Alex de Sherbinin

Environmental Research Letters



LETTER

Perceived heat stress increases with population density in urban Philippines

OPEN ACCESS

RECEIVED

11 May 2018

REVISED

9 July 2018

ACCEPTED FOR PUBLICATION

12 July 2018

PUBLISHED

27 July 2018

Kerstin K Zander^{1,2,5} , Jake Rom Cadag³, Jacquelyn Escarcha¹ and Stephen T Garnett⁴

¹ Northern Institute, Charles Darwin University, Darwin, Australia

² German Development Institute, Bonn, Germany

³ Department of Geography, University of the Philippines Diliman, Quezon City, Philippines

⁴ Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Australia

⁵ Author to whom any correspondence should be addressed.

E-mail: kerstin.zander@cdu.edu.au

Keywords: adaptation, air-conditioning, climate change impact, increasing temperatures, South East Asia, survey, urbanization

Supplementary material for this article is available [online](#)

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



Abstract

The world's population is increasingly urban, with more than half the global population already living in cities. The urban population is particularly affected by increasing temperatures because of the urban heat island (UHI) effect. Increasing temperatures cause heat stress in people, even when not directly exposed to heat, since outdoor meteorological conditions also affect conditions inside, particularly in non-air-conditioned environments. Heat stress harms people's health, can impair their well-being and productivity, and may cause substantial economic losses. In this study, we investigate how people in urban areas across the Philippines are affected by heat, using data from 1161 responses obtained through an online survey. We found that almost all respondents (91%) are already experiencing heat stress quite severely and that the level of heat stress is correlated with population density. Controlling, in a multiple log it model, for variables commonly associated with heat stress, such as age, health, physical exertion and climate, we found that those least likely to be severely affected by heat live in areas with fewer than ~7000 people per km². Air-conditioning use at home relieved heat stress mostly for people in low-density areas but not where population density was high. The results provide evidence for the social impacts of increasing heat in urban areas, complementing understanding of well-known physical impacts such as the UHI effect.

1. Introduction

There is a 95% chance that global temperatures will increase by more than 2 degrees by 2100 [1] and extreme heat events such as heat waves and droughts are predicted to rise in frequency and severity as temperatures increase [2]. To date, around 30% of the world's population lives in areas in which the daily mean surface air temperature and relative humidity exceeds deadly thresholds for at least 20 days a year [3]. Under a Representative Concentration Pathways 8.5 (RCP 8.5) scenario, the pathway with the highest greenhouse gas emissions, this percentage is projected to increase to 74% by 2100. By that time, almost every day of the year is predicted to exceed deadly climate conditions in humid tropical areas such as the Philippines (under RCP8.5) [3].

Extreme temperatures and heat waves have some of the most severe impacts of climate change on people [3, 4]. The impacts include health issues, ranging from severe heat stroke to a general decline in well-being from milder symptoms such as headache and fatigue [5]. Exposure to extreme heat has been most commonly linked to increased risks of cardiovascular and respiratory diseases [6]. Heat also has economic impacts, including the costs from reduced labour productivity from people feeling heat stressed and being compromised in their capacity to work [7–9]. Labour productivity and economic losses can also occur from a higher heat-related work accident frequency [10]. Other socio-economic impacts of heat include increased energy demand, mostly for air-conditioning [11, 12], more crime and violence [13] and higher rates of migration [14, 15].

Urban areas are particularly at risk from climate change, as heat increases are amplified by the urban heat island (UHI) effect [16, 17]. It is predicted that people in urban areas will be twice as exposed to heat increases as people in non-urban areas [18]. The share of the global population living in urban areas is expected to grow from 54% to two-thirds by 2050 [19]. South Asian and African cities will be the most exposed to heat over the coming century due to a combination of rapid population growth and an increase in extreme temperatures [18]. Megacities (more than ten million inhabitants) in low- and middle-income countries are particularly threatened by climate change because vulnerable populations and infrastructure are concentrated in high-risk areas [20]. The UHI effect in cities, especially those developing rapidly in Asia, can be substantial [21, 22]. Under a RCP8.5 climate change scenario, some of the world's cities may be as much as 4 °C warmer by 2050 and 7 °C higher by 2100 [23], which could be higher if rainfall declines as predicted for cities like Manila in the Philippines [24].

Although the UHI is well known, little research has been conducted on how urban populations are being affected by climate change in cities [25, 26]. To plan effectively for the future and to improve the capacity of the urban population to cope with heat, there needs to be a greater understanding of how cities need to be redesigned [27] and how people can adapt to increased heat [28]. To date, most research on heat stress has focused on labour intensive and/or outside activities (e.g. agriculture, military, mining, sports). However, outdoor meteorological conditions also have a strong influence on people who work inside [29], such as most urban people, even if they have access to air-conditioning.

How thermal conditions affect people is most commonly assessed using measures based on temperature thresholds and the physiological ability of the human body to withstand heat. However, heat also affects emotions and mental function [30]. Thus, to understand how people adapt to heat also requires insight into their personal perceptions of heat, including acclimatization and coping mechanisms [31]. In this study, we assess heat stress among the urban population of the Philippines using a self-reported measure of heat impact ('heat stress') because this measure accounts for psychological aspects of heat stress such as acclimatization and belief systems that are known to affect responses to physiologically stressful heat [32]. The aim of our study was to assess the degree of heat stress among the urban population in the Philippines and to reveal factors that influence heat stress levels.

To date, studies of the impact of heat stress on the general public have been largely confined to OECD countries [e.g. 9, 32, 33]. This is the first study of its kind to investigate heat stress among the general public in a non-OECD country. The Philippines was selected as a case study because of its vulnerability to climate change impacts (see [34]) and its growing and highly urbanized

population: 45% of its population of 101 million people (2015 census) currently live in urban conditions, a proportion that is increasing more rapidly than almost any other country [35]. We focused on the urban population because this segment already generates more than 70% of the national GDP [35] so labour productivity losses and health issues arising from extreme heat will be particularly detrimental to the country's economy [36]. With a population of 22.4 million (in 2015), Metro Manila is the 10th most populated urban centre in the world, one of the fastest growing and, at 42 000 people per km², among the most densely inhabited [37]. The UHI effect in Metro Manila is particularly evident in the most densely populated areas where it can result in temperatures 3.0 °C above expected levels [38] (for regional variation see table S1 in supplementary materials) available at stacks.iop.org/ERL/13/084009/mmedia.

2. Data and methods

2.1. Survey data collection and sampling

We recruited respondents via MicroWorkers. MicroWorkers is an online crowdsourcing platform which offers access to a large number of internationally widespread users (see e.g. [39] for a discussion). Users can register for free and we only sampled adult users from the Philippines. We started a 'Hired Group' campaign and through the platform letters of invitation were sent to users from the Philippines. The invitation letter contained a brief description of the topic, the names and organisations of the researchers and a link to an external online survey (designed in Qualtrics). We offered USD1 for completion of the survey. This incentive was paid into users' MicroWorkers accounts when providing a code which showed upon completion of the survey. On average, respondents took 12 minutes to complete the survey. Ethics approval was obtained from the Charles Darwin University Human Research Ethics Committee (H17033).

The campaign was open for nine months, between 15 May 2017 and 14 February 2018. During this time we constantly updated the group to whom the invitation was sent, i.e. new users from the Philippines. We aimed for 1000 valid responses and received 1225. Of these, 64 could not be used because they were largely incomplete, so our final sample size was 1161. The two reasons why the campaign was open for nine months were that data collection was slow, averaging four responses per day, and also that we wanted to cover a wide range of temperatures during the survey and avoid a narrow time horizon in which extreme heat might have occurred and potentially biased the responses.

While self-reported estimates need caution in their interpretation [40], the bias to which they are subject was reduced by keeping the questionnaire simple, sampling a large number of people across a long-time horizon and by controlling for factors known to affect heat stress such as health, age, and gender.

Sampling bias related to differences in socio-economic background between our sample and national means, particularly regarding age, education and income, also needs to be considered in the interpretation of the results. For example, the nature of the survey mode (online surveys in general and crowdsourcing in particular) meant that the respondents were likely to be younger than the national average [41]. This could bias responses away from those most likely to feel heat stress since, in other countries, it has been shown that older people are particularly likely to suffer during extreme heat [42]. To confirm, this would need on the ground in-person interviews with older urban people in the Philippines. People in online surveys also tend to be well educated [41] and our sample is also unlikely to include the poorest people in the cities. More research and possible on-the-ground surveys with this group is warranted. Additionally, by targeting the urban population, we excluded the high percentage of people (25.4%) still occupied in the agricultural sector that mostly provides a very low income [43]. However, given that the Philippines is an emerging, rapidly urbanising country, we are confident that we sampled those likely to typify the future inhabitants of many Asian countries.

2.2. Questionnaire

The questionnaire (table S2 in supplementary materials) consisted of four parts, questions on: (1) heat stress perceptions, (2) daily activities and employment, (3) climate change beliefs and attitudes towards a range of environmental and social statements (the analysis of these was not the scope of this paper and these variables were not used here), and (4) socio-demographic background (age, gender, education, income, household situation, place of residence, health).

The question on perceived heat stress was posed as follows: ‘Do you ever feel stressed by heat in what you are doing?’ Respondents could tick one of the following responses:

- i. No, never
- ii. Yes, but rarely
- iii. Yes, sometimes
- iv. Yes, often
- v. Yes, very often

We grouped respondents answering (i) and (ii) into a ‘low’ heat stress category, those answering (iii) and (iv) into ‘medium’, and those answering (v) into a ‘high’ category.

2.3. Population, density and climate data

Both population and land area were obtained from the Philippines Statistics Authority [44]. Census data were from the latest census in 2015. Climate classifications (based on Köppen-Geiger; figure S4 in supplementary materials) were obtained from the NASA Data Access Tool (SDAT) [45].

2.4. Variables

The dependent variable was the level of heat stress, with three levels (low, medium, high). Variables indicating vulnerability to heat stress were used as independent control variables. These included individual or household socio-demographic characteristics relating to physical susceptibility to heat impacts, such as age, gender, health, physical exertion of daily activities and time spent outside [32, 42] and geographical variables such as the climate zone and the island group as proxies for the annual average temperatures of respondents’ places of residence. Income was included as a known social factor that can increase susceptibility to heat stress [46, 47] and the use of air-conditioning at home and at work as measures of heat relief. Physical exertion was measured on a scale from 1 (very low) to 10 (very high) assuming that those who are usually physically active during the day in their jobs and leisure times are more likely to have been heat stressed. The same assumption was made for people who spend a large proportion of their day outside. The variable ‘time spent outside’ was measured in three categories: little time (about a quarter), moderate time (about 50%) and a lot of time (about three quarters).

2.5. Analysis

We used R [48] for all data analysis, notably the packages *corrplot* [49] for visualizing correlations and *nnet* [50] for estimating the multinomial logit (MNL) models.

Bivariate relationships between heat stress levels and other variables were examined with the χ^2 test, ANOVA and Kruskal Wallice (KW) test. We used Pearson’s correlation and Spearman tests to assess the direction and strength of the relationships between the independent variables.

For multivariate analysis we estimated a series of MNL models. We started with an unrestricted model, including all relevant variables mentioned in the previous section (table S3 in supplementary materials). We then used the stepwise function in R, which, based on the Akaike information criterion (AIC), selected the best fitting model. The significance threshold of all statistical tests was set at the 5% level.

3. Results

About a third (34%) of respondents stated that they felt severely affected by heat (‘high levels of heat stress’), 57% moderately (‘medium levels’) and 9% were little affected (‘low levels’). Bivariate analyses showed that, as expected, healthy respondents reported lower levels of heat stress than unhealthy respondents ($\chi^2 = 8.03$, $df = 2$, $p = 0.0180$) and the more physically active people were in their daily activities, the higher their heat stress levels (KW = 7.58, $df = 2$, $p = 0.0226$). Significantly more women than men were in the highest heat stress category (37% vs. 30%). Other characteristics

which were expected to affect heat stress such as age, income, time spent outside during the day, climate, the location (island group) and the use of air-conditioning at work and at home had no significant direct impacts on the levels of heat stress (see table 1).

Population density per km² was positively associated with the level of heat stress (KW = 11.22, *df* = 2, *p* = 0.0037) with a median population density of 1467 for respondents in the lowest heat stress category, 2929 in the medium and 3044 in the highest categories (figure 1). This means that half of the respondents who felt little heat stress (9% of sample) lived in urban areas with a density of 1467 people per km² or less, and that half of the remaining 91% more severely impacted by heat (medium and high levels) lived in areas from about 3000 people per km² up to 41 500 km² (Manila City). The share of people little affected by heat was 11% in all areas with fewer than 3000 people per km² and dropped to 7% for all areas with a population density of 3000 or more. In areas of over 7500 people per km² (the approximate average density experienced by those in the medium and high heat stress categories), this share drops to 4.5% (see figure S1 in supplementary materials).

Air-conditioning at home and at work were highly correlated, so we only used air-conditioning at home for further analysis (figure S2 in supplementary materials) because cooling while sleeping may increase sleep quality and therefore the capacity to cope with heat the following day [51]. Also, respondents are likely to spend more time at home than at work. We had expected that the use of air-conditioning would have relieved heat stress, but there was no direct bivariate relationship (table 1). However, the use of air-conditioning and heat stress were both correlated with population density, with people in densely populated areas more likely to have air-conditioning at home (figure 1). Sixty-four percent of highly stressed respondents had air-conditioning at home (vs. 45% on average). It was therefore striking that people in the most densely populated areas were not less heat stressed if they had air-conditioning, but more. On further analysis we found that, while air-conditioning might help reduce heat stress in less densely populated areas, no relationship could be detected for the densest populations (figure S3 in supplementary materials).

The results of the best fitting MNL model, run with the three levels of heat stress (low, medium, high) as dependent variables (see Methods), also showed that people in less densely populated areas were more likely to have reported low (*p* < 0.01) and medium (*p* < 0.05) levels of heat stress than high levels (table 2). The odds of being in the lowest heat stress category, compared to the highest, decreased by 0.9985 per person increase in population density [$\exp(\log(0.46) * \log(1.01)) = 0.99853$] and of being in the medium heat stress category by 0.99957 [$\exp(\log(0.81) * \log(1.01)) = 0.99961$]. This means that for each person increase of the population density (per km²), the likelihood that people are in

the low heat stress category decreased by 0.147% [(1-0.99853)*100 = 0.147] and in the medium heat stress category by 0.039% [(1-0.99961)*100 = 0.039].

People living in a subtropical highland climate (Cwb) were 77% more likely (OR: 3.72) to be in the lowest heat stress category than those in the other climate zones, which is unsurprising because temperatures are generally cooler in highland areas. However, only a small proportion of the country has a subtropical highland climate (Cwb) with the dominant climates being equatorial/tropical rainforest (Af), monsoonal (Am) and tropical savanna climates (Aw; much of Metro Manila). People in Mindanao (mostly Af) were 70% less likely to be in the lowest (OR: 0.44), and 60% less likely to be in the medium heat category (OR: 0.68) than people from the other two island groups.

Healthy respondents were 70% more likely [$2.34/(2.34 + 1)$] than unhealthy respondents to report low levels of heat stress. The higher their physical exertion during the day, the less likely people were to be in the low heat stress group. These results were all as expected, including the non-linear relationship between heat stress and age, although our sample does not contain people older than 60 years. Older people were more likely to report low levels of heat stress, which is most likely to be related to social conditions, such as a capacity to afford air-conditioning or the extent to which they need to use public transport. The effect of age lessened as age increased (negative coefficient of 'age squared'), which may have been associated with poorer health.

People with air-conditioning at home were 88% more likely (OR: 7.56) to be in the lowest and 70% more likely (OR: 2.35) to be in the medium heat stress category than those without. The interaction effect between air-conditioning at home and population density (Air-conditioning use * Density) was highly significant and negative, confirming our earlier findings that having air-conditioning at home increases the odds of being in the low and medium heat stress categories (i.e. relieving heat stress), but more likely for respondents who live in less densely populated areas.

4. Discussion and conclusions

We conclude that the Philippines already faces substantial challenges because an increasing urban population is already severely heat stressed. The urban population appears to be coping poorly with heat, a problem that will be exacerbated by climate change. Public health interventions need to be directed at areas with the highest densities and where people of poor health live as well as those who cannot afford air-conditioning.

Our finding that air-conditioning might not deliver heat stress relief universally, with people living in the densest areas gaining the least benefit, was particularly notable. While there is little research directly linking poor sleep to coping with heat [51], heat affects sleep

Table 1. Sample description and statistics for testing impacts on the level of heat stress ($N = 1161$).

Characteristics	Sample description	Impact on heat stress
Level of perceived heat stress:		
Low	9%	
Medium	57%	
High	34%	
Female	55%	$\chi^2 = 5.65, df = 2, p = 0.0593$
Median age (mean; SD)	27 (28.2; 7.3)	KW = 3.91, $df = 2, p = 0.1417$
Being of good health	68%	$\chi^2 = 8.03, df = 2, p = 0.0180$
Median income level (mean; SD)	3 (3.5; 2.4)	KW = 1.42, $df = 2, p = 0.4911$
Median physical exertion (mean; SD)	6 (5.7; 2.5)	KW = 7.58, $df = 2, p = 0.0226$
Air-conditioning at home	45%	$\chi^2 = 1.43, df = 2, p = 0.4892$
Air-conditioning at workplace	56%	$\chi^2 = 0.34, df = 2, p = 0.8445$
Time spent outside during day:		
Little (about a quarter)	76%	
Moderate (about half)	13%	
A lot (about three quarters)	11%	
Median population density per km ² (mean; SD)	(7445; 10 059)	KW = 11.22, $df = 2, p = 0.0037$
Climate:		
Tropical rainforest climate (Af)	31%	
Tropical monsoon climate (Am)	47%	
Tropical savanna climate (Aw)	18%	
Subtropical highland climate (Cwb)	4%	
Island group:		
Luzon	60%	$\chi^2 = 1.01, df = 4, p = 0.8082$
Mindanao	19%	
Visayas	21%	

Note: N = Number of respondents; SD = Standard deviation; df = Degrees of freedom; KW = Kruskal Wallace.

Income had 11 categories, ranging from 1 (less than 10 000 PHP per month, before tax) to 11 (more than 250 000 PHP per month); 1 USD = 51 PHP (October 2017).

Physical exertion of daily activities was measured on a scale from 1 (very low) to 10 (very high).

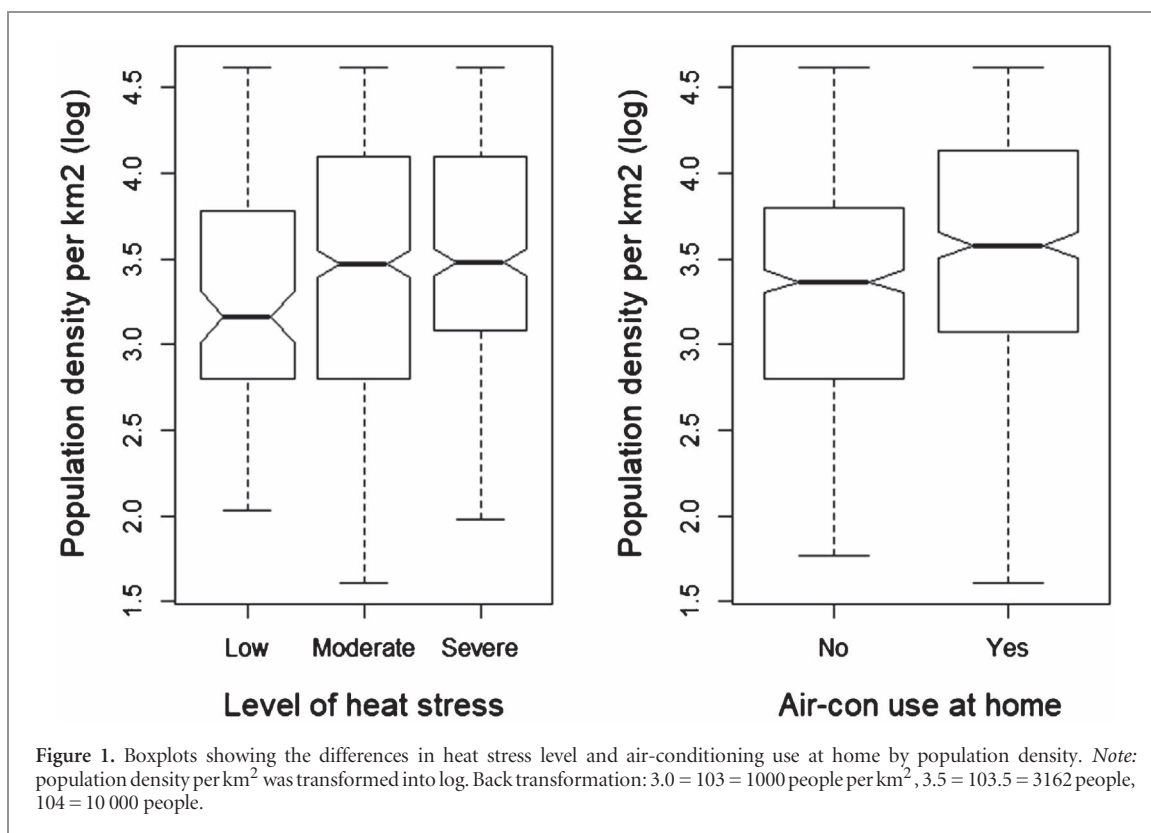


Figure 1. Boxplots showing the differences in heat stress level and air-conditioning use at home by population density. Note: population density per km² was transformed into log. Back transformation: 3.0 = 103 = 1000 people per km², 3.5 = 103.5 = 3162 people, 104 = 10 000 people.

quality [52] and sleep quality affects subsequent performance [53]. We had therefore expected that those who could afford air-conditioning at home would be less heat stressed as they can relieve it by cooling throughout the night, minimising the cumulative effects of high

temperatures. However, our results suggest that cooling relief at home is inadequate. We suspect that this is because people still have to spend a substantial amount of time in non-air-conditioned environments such as in offices or public transport. The contribution of trans-

Table 2. Results of final MNL model with the dependent variable being the category of heat stress (three levels: low, medium, high) ($N = 1161$).

	Heat stress category (reference level: high)			
	Coefficients (SE)		Odds ratios (95% CI)	
	Low	Medium	Low	Medium
Constant	-2.234*** (-0.012)	1.776*** (-0.017)		
Subtropical highland climate (Cwb)	1.184*** (-0.137)	0.091 (-0.244)	3.27 (2.50–4.27)	1.10 (0.68–1.77)
Mindanao	-0.829** (-0.322)	-0.381** (-0.183)	0.44 (0.23–0.82)	0.68 (0.48–0.98)
Age	0.220*** (-0.049)	-0.042 (-0.029)	1.25 (1.13–1.37)	0.96 (0.91–1.01)
Age squared	-0.003*** (-0.001)	0.001** (-0.0005)		
Being of good health	0.849*** (-0.270)	0.233 (-0.136)	2.34 (1.38–3.97)	1.26 (0.97–1.65)
Physical exertion of daily activities	-0.159*** (-0.047)	-0.043 (-0.026)	0.85 (0.78–0.94)	0.96 (0.91–1.01)
Air-conditioning use at home	2.023*** (-0.037)	0.855*** (-0.021)	7.56 (7.03–8.13)	2.35 (2.26–2.45)
Density per km ² (log)	-0.784*** (-0.190)	-0.206** (-0.108)	0.46 (0.31–0.66)	0.81 (0.66–1.01)
Air-conditioning use * Density	-0.470*** (-0.061)	-0.240*** (-0.034)		
AIC	2064.66			
Log likelihood	-1012.33			

Note: N = Number of respondents; SE = Standard errors; CI = Confidence interval.

Significance codes: *** = 1%, ** = 5%.

port to heat stress is likely to be particularly high in high density areas such as Manila. The traffic infrastructure of the city is unable to adequately service the growing urban population, growing demand for mobility and increasing numbers of private and public vehicles [54]. The resulting traffic congestion means that people spend extended periods commuting for work or other daily activities; Manila has the sixth highest average commute time of any city in the world [55]. This transport problem aggravates the effect of heat stress felt by the traveling public, especially public transport commuters. Public transportation is largely undertaken in non-air-conditioned vehicles with 'jeepneys', buses, motorized and non-motorized tricycles being the main transport modes used by commuters [56]. Many public vehicles are not air-conditioned and the comfort of those that are (buses and metro rail transits) is offset by overcrowding, especially during peak hours [56]. In addition to the actual commuting time, people often wait for lengthy periods, mostly outside, to get transport in the first place. Other urban agglomerations such as Davao and Cebu cities are also almost entirely road based, facing the same problems [56].

Another reason why air-conditioning might not have the desired effect is urban morphology. The lack of airflow associated with overcrowded housing reduces air quality and raises heat and moisture levels inside, making air-conditioning less efficient [57]. This is also most likely in the densest areas where many people share housing because rent is so expensive. An alternative explanation would be that the widespread use of air conditioning reduces physiological acclimatization

and can therefore make people more susceptible to heat see [58].

Increasing the number of air-conditioning units installed will contribute further to the UHI effect [11] and so may be counter-productive if adopted as the only solution. Instead, air-conditioning as an adaptation strategy to heat needs to be combined with other planning policies such as the protection and creation of green and blue spaces such as parks [59], passive cooling of buildings such as retrofitting of reflective coatings to buildings [60], and modifications of the existing built environment through, for example, green and cool roofs [61] and cool pavements [62]. Information on the geographical location of people in high heat stress categories can also help the planning of urban infrastructure to reduce heat stress.

However, if this strategy is adopted, care must be taken to avoid unintended consequences detrimental to the poorest members of society. In wealthier cities around the world, the gentrification of city centers has followed the creation of public green spaces [63, 64], increasing rents and property prices. The gentrification of cities in South East Asia, including Manila [65], has mostly been happening as a result of large-scale private-sector development, preserving large green areas or creating new ones (see, e.g. [66]) but this may also push poorer people into cheaper, less green areas, potentially requiring them to spend even more time commuting. So in certain areas of high density where gentrification might become an issue, alterations to houses themselves might be preferred as a more equitable adaptation strategy. As it is, high levels of heat stress in the Philippines

may aggravate climate injustice since the burden of climate change will be felt most by the poorest segment of the city [12, 67] especially if exacerbated by green inequality from poor policies and urban planning [68].

Most climate change impact research in tropical non-OECD countries has concentrated on the effects of extreme weather events such as floods and typhoons, particularly on rural communities, rather than increases in heat. Based on our results, more research on the urban impacts of heat and adaptation is warranted, particularly in developing countries [68]. This is particularly true for the Philippines, where the number of people in urban areas is predicted to double from 50 to 100 million by 2050, by which time about 65% of the national population is expected to live in cities [35]. Our research suggests that more detailed analysis of self-reported heat stress, including in rural areas, is warranted, as well as an examination of secondary data such as hospital admission or other data that can be linked to periods of extreme heat, as done elsewhere, mostly in developed countries e.g. [69].

Acknowledgments

The research was funded through a faculty grant at Charles Darwin University (Faculty of Law, Education, Business and Arts). The lead author holds a Humboldt Research Fellowship for experienced researchers that supports her research stay in Bonn, Germany.

ORCID iDs

Kerstin K Zander  <https://orcid.org/0000-0002-2237-1801>

References

- [1] Raftery A E, Zimmer A, Frierson D M W, Startz R and Liu P 2017 Less than 2 °C warming by 2100 unlikely *Nat. Clim. Change* **7** 637–41
- [2] Perkins S E, Alexander L V and Nairn J R 2012 Increasing frequency, intensity and duration of observed global heatwaves and warm spells *Geophys. Res. Lett.* **39** L20714
- [3] Mora C *et al* 2017 Global risk of deadly heat *Nat. Clim. Change* **7** 501–6
- [4] Coates L, Haynes K, O'Brien J, McAneney J and de Oliveira F D 2014 Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010 *Environ. Sci. Policy* **42** 33–44
- [5] Hajat S, O'Connor M and Kosatsky T 2010 Health effects of hot weather: from awareness of risk factors to effective health protection *Lancet* **375** 856–63
- [6] Ye X, Wolff R, Yu W, Vaneckova P and Tong S 2012 Ambient temperature and morbidity: a review of epidemiological evidence *Environ. Health Perspect.* **120** 19–28
- [7] Kjellstrom T, Kovats R S, Lloyd S J and Tol R S J 2009a The direct impact of climate change on regional labor productivity *Arch. Environ. Occup. H.* **64** 217–27
- [8] Dunne J P and John J G 2013 Reductions in labour capacity from heat stress under climate warming *Nat. Clim. Change* **3** 563–6
- [9] Zander K K, Botzen W J W, Oppermann E, Kjellstrom T and Garnett S T 2015 Heat stress causes substantial labour productivity loss in Australia *Nat. Clim. Change* **5** 647–51
- [10] Xiang J, Bi P, Pisaniello D and Sullivan T 2014a Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010 *Occup. Environ. Med.* **71** 246–52
- [11] Santamouris M, Cartalis C and Kolokotsa D 2015 On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—a review *Energy Build.* **98** 119–24
- [12] Byrne J, Ambrey C, Portanger C, Lo A, Matthews T and Davison A 2016 Could urban greening mitigate suburban thermal inequity?: the role of residents' dispositions and household practices *Environ. Res. Lett.* **11** 095014
- [13] Burke M and Miguel E 2015 Global non-linear effect of temperature on economic production *Nature* **527** 235–9
- [14] Kjellstrom T, Lemke B, Otto M, Briggs D, Zander K and Fiske L 2017 *Extreme Heat and Migration* (Geneva: IOM Migration, Environment and Climate Change Division)
- [15] Missirian A and Schlenker W 2017 Asylum applications respond to temperature fluctuations *Science* **358** 1610–4
- [16] Kalnay E and Cai M 2003 Impact of urbanization and land-use change on climate *Nature* **423** 528–31
- [17] Coffel E D and de Sherbinin A 2018 Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century *Environ. Res. Lett.* **13** 014001
- [18] Wouters H *et al* 2017 Heat-stress increase under climate change twice as large in cities as in rural areas: a study for a densely populated mid-latitude maritime region *Geophys. Res. Lett.* **44** 8997–9007
- [19] United Nations 2014 *World Urbanization Prospects: The 2014 Revision, Highlight* (New York: UN, Department of Economic and Social Affairs)
- [20] Matthews T K R and Murphy C 2017 Communicating the deadly consequences of global warming for human heat stress *Proc. Natl Acad. Sci. USA* **114** 3861–6
- [21] Araos M, Ford J, Berrang-Ford L and Moser S 2017 Climate change adaptation planning for Global South Megacities: the case of Dhaka *J. Environ. Polut. Plan.* **17** 682–96
- [22] Jin K, Wang F, Chen D, Jiao Q, Xia L and Mu X 2015 Assessment of urban effect on observed warming trends during 1955–2012 over China: a case of 45 cities *Clim. Change* **132** 631–43
- [23] Estrada F and Tol R S J 2017 A global economic assessment of city policies to reduce climate change impacts *Nat. Clim. Change* **7** 403–6
- [24] Philippine Atmospheric Geophysical Astronomical Services Administration PAGASA 2018 *Observed Climate Trends and Projected Climate Change for Metro Manila—Climate Information Risk Analysis Matrix (CLIRAM)* (Quezon City: DOST-PAGASA)
- [25] Hebbert M and Jankovic V 2013 Cities and climate change: the precedents and why they matter *Urban Stud.* **50** 1332–47
- [26] Dhar T K and Khirfan L 2017 Climate change adaptation in the urban planning and design research: missing links and research agenda *J. Environ. Plann. Man.* **60** 602–27
- [27] Georgeson L, Maslin M and Howard S 2016 Adaptation responses to climate change differ between global megacities *Nat. Clim. Change* **6** 584–8
- [28] Hatvani-Kovacs G, Belusko M, Skinner N and Boland J 2016 Heat stress risk and resilience in the urban environment *Sustain. Cities Soc.* **26** 278–88
- [29] Hooyberghs H, Verbeke S, Lauwaet D, Costa H and De Ridder K 2017 Influence of climate change on summer cooling costs and heat stress in urban office buildings *Clim. Change* **144** 721–35
- [30] López-Sánchez J I and Hancock P A 2017 Thermal effects on cognition: a new quantitative synthesis *Int. J. Hyperther.* **34** 423–31

- [31] Waters J and Adger W N 2017 Spatial, network and temporal dimensions of the determinants of adaptive capacity in poor urban areas *Glob. Environ. Change* **46** 42–9
- [32] Zander K K, Moss S A and Garnett S T 2017 Drivers of heat stress susceptibility in the Australian labour force *Environ. Res.* **152** 272–9
- [33] Schuster C, Honold J and Lakes T 2017 Urban heat stress: novel survey suggests health and fitness as future avenue for research and adaptation strategies *Environ. Res. Lett.* **12** 44021
- [34] Villarin J T *et al* 2016 *Philippine Climate Change Assessment (PhilCCA): The Physical Science Basis* (Pasig City: Oscar M Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation)
- [35] World Bank 2018 *Philippines Urbanization Review: Fostering Competitive, Sustainable and Inclusive Cities* Washington
- [36] Kjellstrom T, Kovats R S, Lloyd S J, Holt T and Tol R S 2015 *Climate Change and Increasing Heat Impacts on Labor Productivity* (Neslon: Ruby Coast Research Centre)
- [37] Pesaresi M, Melchiorri M and Kemper T 2016 Atlas of the human planet 2016 *Mapping Human Presence on Earth with the Global Human Settlement Layer* (Brussels: European Union)
- [38] Tiangco M and Argete J 2008 ASTER-based study of the night-time urban heat island effect in Metro Manila *Int. J. Remote Sens.* **29** 2799–818
- [39] Chandler J and Mueller P 2013 Risks and rewards of crowdsourcing marketplaces *Handbook of Human Computation* ed P Michelucci (Heidelberg: Springer) pp 377–92
- [40] Stone A A, Bachrach C A, Jobe J B and Cain V S 2000 *The Science of Self-Report: Implications for Research and Practice* (New Jersey: Lawrence Erlbaum Associates)
- [41] Nielsen J S 2011 Use of the internet for willingness-to-pay surveys: a comparison of face-to-face and web-based interviews *Resour. Energy Econ.* **33** 119–29
- [42] Basu R 2009 High ambient temperature and mortality: a review of epidemiologic studies from 2001–2008 *Environ. Health* **8** 40
- [43] Philippine Statistics Authority PSA 2017 *Annual Labor and Employment Status* (Manila: Preliminary Results of the 2017 Annual Estimates of Labor Force Survey)
- [44] Philippine Atmospheric Geophysical Astronomical Services Administration PAGASA 2018 *Observed Climate Trends and Projected Climate Change for Metro Manila - Climate Information Risk Analysis Matrix (CLIRAM)* (Quezon: DOST-PAGASA)
- [45] NASA 2018 *World Map of the Koppen-Geiger Climate Classification* (Washington, DC: Spatial Data Access Tool (SDAT))
- [46] Stafoggia M *et al* 2008 Factors affecting in-hospital heat-related mortality: a multi-city case-crossover analysis *J. Epidemiol. Comm. Health* **62** 209–15
- [47] Ng C F *et al* 2014 Sociogeographic variation in the effects of heat and cold on daily mortality in Japan *J. Epidemiol.* **24** 15–24
- [48] R Core Team 2014 *R: A Language and Environment for Statistical Computing* (Vienna: R Foundation for Statistical Computing)
- [49] Wei T, Simko V, Levy M, Xie Y, Jin Y and Zemla J 2017 *Package ‘Corrplot’: Visualization of a Correlation Matrix* (Vienna: CRAN)
- [50] Ripley V N and Venables B D 2016 *Package ‘NNET’: Feed-Forward Neural Networks and Multinomial Log-Linear Models* (Vienna: CRAN)
- [51] Tokizawa K, Sawada S, Tai T, Lu J, Oka T, Yasuda A and Takahashi M 2015 Effects of partial sleep restriction and subsequent daytime napping on prolonged exertional heat strain *Occup. Environ. Med.* **72** 521–8
- [52] Obradovich N, Migliorini R, Mednick S C and Fowler J H 2017 Nighttime temperature and human sleep loss in a changing climate *Sci. Adv.* **3** e1601555
- [53] Krause A J, Simon E B, Mander B A, Greer S M, Saletin J M, Goldstein-Piekarski A N and Walker M P 2017 The sleep-deprived human brain *Nat. Rev. Neurosci.* **18** 404–18
- [54] Mijares A C, Regmi M B and Yai T 2014 Enhancing the sustainability and inclusiveness of the Metro Manila’s urban transportation systems: proposed fare and policy reforms *Trans. Commun. Bull. Asia Pacific* **84** 28–40
- [55] Traffic Index Rate 2018 (www.numbeo.com/traffic/rankings_current.jsp)
- [56] Asian Development Bank 2012 *Philippines: Transport Sector Assessment, Strategy, and Road Map* Manila
- [57] Santamouris M, Pavlou K, Synnefa A, Niachou K and Kolokotsa D 2007 Recent progress on passive cooling techniques: advanced technological developments to improve survivability levels in low-income households *Energy Build.* **39** 859–66
- [58] O’Neill M 2003 Air conditioning and heat-related health effects *Appl. Environ. Sci. Publ. Health* **1** 9–12
- [59] Gunawardena K R, Wells M J and Kershaw T 2017 Utilising green and bluespace to mitigate urban heat island intensity *Sci. Total Environ.* **584–585** 1040–55
- [60] Rossi F *et al* 2015 Retroreflective façades for urban heat island mitigation: experimental investigation and energy evaluations *Appl. Energy* **145** 8–20
- [61] Sharma A, Conry P, Fernando H J S, Hamlet A F, Hellmann J J and Chen F 2016 Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model *Environ. Res. Lett.* **11** 064004
- [62] Qin Y 2015 A review on the development of cool pavements to mitigate urban heat island effect *Renew. Sust. Energy Rev.* **52** 445–59
- [63] Dooling S 2009 Ecological gentrification: a research agenda exploring justice in the city *Int. J. Urban. Reg. Res.* **33** 621–39
- [64] Richards D R, Passy P and Oh R R Y 2017 Impacts of population density and wealth on the quantity and structure of urban green space in tropical Southeast Asia *Landsc. Urban Plan.* **157** 553–60
- [65] Choi N 2016 Metro Manila through the gentrification lens: disparities in urban planning and displacement risks *Urban Stud.* **53** 577–92
- [66] Mabon L and Shih W-Y 2018 What might ‘just green enough’ urban development mean in the context of climate change adaptation? The case of urban greenspace planning in Taipei Metropolis, Taiwan *World Dev.* **107** 224–38
- [67] Adger W N 2001 Scales of governance and environmental justice for adaptation and mitigation of climate change *J. Int. Dev.* **13** 921–31
- [68] Sheridan S C and Allen M J 2018 Temporal trends in human vulnerability to excessive heat *Environ. Res. Lett.* **13** 043001
- [69] Pisaniello J, Bi P, Hansen D and Sullivan T 2014 Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010 *Occup. Environ. Med.* **71** 246–52