Estimating economic losses from perceived heat stress in urban Malaysia

Zander, Kerstin K.; Mathew, Supriya

Published in:
Ecological Economics

DOI:
10.1016/j.ecolecon.2019.01.023

Published: 01/05/2019

Document Version
Peer reviewed version

Estimating economic losses from perceived heat stress in urban Malaysia

Kerstin K. Zander[a),b)*], Supriya Mathew[a),c)]

Authors' affiliations:

a) Northern Institute, Charles Darwin University, Darwin, Australia.
b) German Development Institute, Bonn, Germany
c) Flinders University, Alice Springs, Australia

*Corresponding author: Kerstin Zander, Northern Institute, Charles Darwin University, Ellengowan Drive, Darwin, NT 0909, Australia, Phone: +61 8 8946 7368, E-mail: kerstin.zander@cdu.edu.au

Abstract

Increases in temperatures and heat waves linked to climate change lead to people feeling increasingly heat stressed compromising their health and reducing economic activity. In this paper we assess the potential economic impact of increasing temperatures and heat waves on working people in urban Malaysia by analysing the loss in productivity that they associate with heat stress. We found that nearly every respondent (99%) from a sample of 514 drawn from an online survey sometimes feels heat stressed and less productive as a result (98%). The median number of days in a year on which people felt their productivity had been compromised because of heat stress was 29. On those days half of the respondents felt their work capacity had been at least halved. The estimated median annual economic loss from reduced productivity was 257 €, or nearly 10% of respondents' median annual income. Respondents who work in mentally challenging jobs are more affected by heat than those in physically intense jobs. They also receive the highest incomes, so suffer the highest losses. Our research suggests that the real economic costs of heat has probably been under-estimated because most research has so far focused only on people working in physically intense outdoor jobs or those performed in very hot environments.

Key words: climate change; heat waves, labor productivity loss, South-east Asia, urbanization

Highlights:

- We conducted an online survey with 514 people across urban Malaysia
- Almost every respondent reported to feel heat stress where they live
- When feeling hot many respondents only work at half of their capacity
- The median annual productivity loss from heat stress is 257 € per person

Introduction

Climate change has profound effects on the economy although few studies have estimated the economic costs (Stern et al. 2013; Burke et al. 2015a). There is a 95% chance that global temperatures will increase by more than 2 degrees by 2100 (Raftery et al. 2017). To date, around 30% of the world' population already live in areas in which the daily mean surface air temperature and relative humidity exceeds deadly thresholds for at least 20 days a year (Mora et al. 2017). Extreme heat events such as heat waves and droughts are also predicted to rise in frequency and severity (Perkins et al. 2012).

Of all extreme weather events, extreme temperatures and heat waves have some of the most severe impacts on people (Coates et al. 2014; Mora et al. 2017). Heat effects on health range from severe heat stroke to general decline in well-being with light symptoms such as headache and fatigue (Hajat et al. 2010). Exposure to extreme heat has been linked to increased risks of respiratory diseases, cardiovascular diseases, renal problems, mental and behavioural disorders and poor perinatal outcomes (Tawatsupa et al. 2012; Borg et al. 2017; Padhy et al. 2015; Mathew et al. 2017).

One of the economic impacts of heat includes the costs from reduced labour productivity. It is suggested that productivity loss from heat stress may increase by 11 to 27% by 2080 in hot regions such as Asia and the Caribbean (Kjellstrom et al. 2009a), and globally by up to 20% by 2050 (Dunne et al. 2013). Zander et al. (2015) estimated the costs of heat related productivity loss at USD 6.2 billion over one year for the Australian economy. In South-east Asia, 15-20% of annual work hours are lost in heat-exposed jobs, and the loss is projected to double by 2050 as climate changes (Kjellstrom 2016). These costs have to be borne by the whole economy, employees and employers alike. Employees, and also those working not for profit or doing other activities that contribute to the economy, have to self-pace their actions and also take breaks (for resting, cooling and drinking) when heat stressed which in turn reduces their effective work time. This constitutes a cost to the employer if there is no compensation for time lost and work not done. Employees bear the costs if they have to work longer hours to redress productivity losses. Labour productivity and economic losses can also occur from higher work accident frequency because of concentration lapses, higher levels of fatigue and poor decision-making because time perceptions change from being heat stressed (Tawatsupa et al. 2013; Tamm et al. 2014). Other socio-economic impacts of heat include increase in crime and violence (Burke et al. 2015b) and increased migration (Kjellstrom et al. 2017).

Workplace heat stress and labour productivity loss was first discussed in the context of increasing heat exposure from climate change by Kjellstrom and colleagues (Kjellstrom et al. 2009b&c). To date it is still mainly limited to the application of physical models of heat exposure. These studies calculate thresholds for wet bulb global temperature (WBGT) for different activity levels beyond which people are assumed to be unable to cope. Only a few studies have used perceived impacts of heat to explore productivity loss (Zander et al. 2015, 2018; Schuster et al. 2017).

Furthermore, while most research on heat stress focuses on labour intense and/or outside activities (e.g. agriculture, military, mining, sports), a large proportion of the population engages in activities and employment which are usually concentrated indoors. Indoor climate conditions are strongly influenced by outdoor meteorological conditions and therefore also by climate change (Hooyberghs et al. 2017). In addition, heat stress not only influences the physiological body functions, but can also have negative impacts on mental/emotional state (Tawatsupa et al. 2012; López-Sánchez et al. 2017). To understand how society adapts to heat also requires an understanding about how individuals personally perceive heat, including underlying facets of acclimatisation and personal coping capacity (Waters and Adger 2017). These subtle factors are not well understood because commonly used measures of heat are based on temperature thresholds and the physical ability of the human body to withstand heat.

Research to date on the impacts of climate change in developing and emerging countries has largely focused on farming communities, where both humans and production systems are affected (e.g. crop yield; Knox et al. 2012; Teixeira et al. 2013), and those heavily dependent on natural resources (Hebbert and Jankovic 2013; Dhar and Khirfan 2017). Globally, however, people in urban areas are predicted to be twice as affected by heat than people in non-urban areas (Wouters et al. 2017), partly because of the urban heat island (UHI) effect, with those in the rapidly growing cities of South Asia and Africa being particularly vulnerable (Matthews et al. 2017).

Against this background, the aims of this study were to 1) assess the perception of heat stress and 2) the associated perceived labour productivity losses among the urban population of Malaysia where average temperatures are projected to increase by between 1.7 and 4.2 °C by 2100 (Loh et al 2016). Malaysia is already one of the most urbanized countries in East Asia (World Bank 2015), with more than half its population (53%) already living in urban areas, and the proportion is increasing rapidly. Based solely on physiological thresholds to heat exposure (using WBGT), Malaysia could face a loss of 5.9% of its GDP by 2030 from heat related productivity loss (Kjellstrom 2016).

Our results, obtained from a nation-wide online survey targeting adults in urban areas, can be used to reduce this impact by improving understanding of the capacity of the urban population to cope with heat in Malaysia and identifying opportunities for effective adaptation.

Data and methods

Data collection

We used Microworkers to collect the data. MicroWorkers is an online crowdsourcing platform which offers access to a large number of internationally widespread users (see, e.g. Chandler et al. 2013 for a discussion). Users can register for free and we only sampled adult users from Malaysia. We started a “Hired Group” campaign and send out letters of invitations to users from Malaysia. The invitation letter contained a brief description of the topic, the names and organisation of the researchers and a link to an external online survey (designed in Qualtrics). We offered USD 1 for the completion of the survey which respondents received from MicroWorkers when providing a code which was revealed upon completion of the survey. On average, respondents took 19 minutes to complete the survey. Ethics approval was obtained from the Charles Darwin University Human Research Ethics Committee (H17033).

The campaign was open for eight months, between 22 May 2017 and 21 January 2018. During this period, we constantly updated the group to which the invitation was sent to, i.e. new users from Malaysia. We aimed for 500 valid responses. Of the 552 received during the survey period, 38 could not be used because they were largely incomplete, so our final sample size was 514. The reason the campaign was open for eight months was two-fold: first, we wanted to cover a wider range of temperatures during the survey and avoid a narrow time horizon during which extreme heat might have occurred and potentially biased the responses; second data collection was slow with an average of 64 responses per month.

Questionnaire

The questionnaire 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 those was not the scope of this paper), and 4) socio-demographic background (age, gender, education, income, household situation, place of residence, health). The core questions to elicit respondents' perceptions about their heat stress and productivity loss are summarized in Table 1.

Following the approach of Zander et al. (2015), 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

The question measuring the perceived degree of labour productivity loss was asked on a percentage scale, from 1 to 100%, as follows: "*On average, how much less productive are you on a hot day, in percentage of your usual productivity from 1% (not much less productive) to 100% (a lot less productive)?"*. This question was only presented to respondents who said that they had at least been rarely stressed and was not presented to those who had never perceived themselves as having been stressed by heat.

The question to reveal the frequencies of feeling less productivity was asked as follows: "*On how many days in the last 12 months did you feel less productive because of heat stress?"*.

Both, physical and mental exertion were asked as follows: "*On a scale from 1 to 10, how physically / mentally demanding is your job?*" which, for further analysis, was transformed into three categories: "Light" (1-3), "Medium" (4-7) and "High" (8-10). This question also contained a note saying: "If not in a job, please state the physical and mental exertion of your usual day-to-day activities." to accommodate the few respondents without income-generating jobs (e.g. students or carers).

[Table 1 here]

Analysis

Individual economic losses from heat stress related productivity losses were calculated as follows:

$$Economic\ loss = affected\ days * \frac{income}{day} * degree\ of\ productivity\ loss \qquad \text{(Eq. 1)}$$

Where economic loss is the loss in Malaysian Rupees per year (for the readers transformed into €), the income is the annual income stated by respondents, calculated per working day, the affected days are the number of days per year respondents feel less productive because of heat and the degree of productivity loss is measured by the extent to which respondents perceive their productivity to have been reduced by heat (from 0% if not at all less productive to 100% if no work can be done at all because of heat stress).

We used non-parametric Kruskal-Wallis (KW) rank sum tests or χ^2 tests to gauge differences in heat stress levels and in economic loss across different factors. If necessary, we applied post-hoc tests. To test the strength of relationship between two continuous variables, we used Pearson's correlation tests. All analysis was carried out using R (R Core Team 2013).

Results and Discussion

Sample characteristics

Of the 514 respondents, exactly 50% (257) were female and the average age was 28 (SD: 8) with a range from 18 to 65 and a median of 25. The age of the sample corresponds well with the national median age of 28.5 years (2017 estimate; Index Mundi 2018). About half (53%) of the respondents reported good health, 21% excellent health and 26% fair health. Almost half of the respondents were employed full-time (48%), the others either part-time or casual (Table 2). The mean annual income was 42,957 Malaysian Rupees (~ 3,875 €) with a median of 30,000 Malaysian Rupees (~ 2,706 €). Kernel density estimations are provided for respondents' key demographics as well as productivity measures in the Supplementary Materials (Figure S1).

Heat stress

Of all 514 respondents, only seven (1.4%) reported that they never felt heat stressed in the previous 12 months and only 12 (2.3%) mentioned that they never felt less productive because of heat. This indicates that heat stress and its impact on productivity among the respondents was relatively high: comparable studies from Thailand (Tawatsupa et al. 2013) and Australia (Zander et al. 2015) found lower percentages of people feeling heat stressed (50% and 75%, respectively).

For further analysis we created three levels of heat stress. We grouped those respondents who said that they had 'never' or 'rarely' been heat stressed into a "low" level (13%), those

’sometimes’ or ‘often’ heat stressed into a “medium” (65%) and those who were ‘very often’ heat stressed into a “high” level (22%) of heat stress category (see Methods). Older respondents were more likely to have a low level of heat stress (KW=20.97, p=0.00003) than younger ones. This could be because of their lower level of activity, although the degree of physical exertion itself had no significant impact on heat stress (χ^2=5.12, p=0.2749). We also did not detect a significant relationship between age and physical exertion, so the reason for older people being less heat stressed must be because of other reasons such as lower exposure to the outdoor environment, better access to cooling facilities, better acclimatisation, more awareness of the potential effects of heat that we could not detect in our survey. Often factors such as age, living at residential care and having a higher number of co-morbidities can help protect people from heat stress (Zhang et al 2013). The degree of mental exertion also did not have a significant impact on heat stress (χ^2=5.54, p= 0.236).

Income (KW=2.23, p=0.3267), education (χ^2=2.57, p=0.6318), and gender (χ^2=2.60, p=0.2728) had no significant impact on the level of perceived heat stress. In contrast to existing literature that assumes outdoor workers are more exposed to high heat related risks (Xiang et al. 2014), we found that the time spent outside had no significant impact on the level of perceived heat stress (χ^2= 7.35, p=0.1184). Health, in contrast, had a strong impact on the level of heat stress (χ^2=24.34, p=0.00007) with those with excellent health being more likely to have reported high levels of heat stress (39% versus 18% for those with low and medium levels of heat stress). On one hand, this finding was surprising since we expected that people with excellent and good health would have reported lower levels of heat stress since some pre-existing illness can compromise an individual’s ability to cope with heat (Basu 2009; Kim et al. 2014). One explanation could be that those with excellent health showed higher levels of physical exertion, but there was no significant relationship (χ^2=7.28, p=0.1218). It could also be that people with excellent health were less aware of the consequences and were more exposed to outdoor conditions for various physical activities. People with fair health may have been more aware of heat effects and took precautionary measures, i.e. the presence of minor illnesses or reduced fitness may have been a protective factor to heat stress (Zhang et al. 2013). However, this finding could also be related to our sample which was drawn from on online survey with few elderly people and none who rated their health as being very poor.

Estimation of economic loss from heat stress

The mean number of days in the last 12 months on which people felt their productivity to have been compromised because of heat stress was 48 (SD: 65) with a median of 29 (see Figure S1 in Supplementary Materials for Kernel density). The mean perceived percentage productivity loss was 48% (SD: 22%) with a median of 50% which means that half of the respondents would only be able to work at half their usual capacity or less on those days when they had felt heat stressed.

We estimated that, on average, respondents faced an annual economic loss of 818 €, which was distorted by a high standard deviation of 1,809 €. The median was 257 € and might be a better measure. This is 9.5% of the median annual income. People with a university degree (completed Undergraduate or Postgraduate or pursuing degree) had a higher annual loss (Table 2), which is probably related to their employment with higher degree of responsibility and income. In fact, people with university degrees had significantly higher incomes than those with medium or low levels of education (KW=11.31, p=0.0035).

Gender and health had no significant impact on the annual economic loss, nor had age (r=-0.04; t=-0.88, p=0.3812). Those spending a lot of time outside during the day for employment and daily activities had the highest economic loss while those spending some time (about half) had the lowest loss. While it may seem surprising that those spending about half of their time outside had lower losses than those spending hardly any time there, but this could be related to the types of jobs that people working inside do and the higher income they receive. People who spent at least some time outside more acclimatised than those spending most of the daytime indoors, who could be more affected when moving in and out of air-conditioned environments (Cao et al. 2012).

[Table 2 here]

Workload, exertion and sectors

Full-time employment (as compared to part-time or casual) had no impact on the level of heat stress or economic loss (KW=2.51, p=0.1132). However, while the degree of physical and mental exertions had no impact on the level of heat stress, they did have on economic losses (Table 2; Figure 1). The median economic loss of those with medium and high levels of physical exertion were not significantly different from each other (as per post-hoc test) at 281 € and 289 €, respectively, but people with low levels of physical exertion had much lower economic losses at 132 € (KW=6.20, p=0.0450). The effect of mental exertion was greater with significant differences in economic losses across all three levels (KW=11.82, p=0.0027). Respondents with low levels of mental exertion had a median economic loss of 104 €, those with medium levels of mental exertion 195 € and those with high levels 369 €, 80 € more than for those who reported high levels of physical exertion.

The reason for this finding could be because people in jobs requiring high levels of mental exertion had higher incomes. However, we could not detect a significant relationship between income and the level of mental exertion (KW=2.28, p=0.3198). The degree of mental exertion, however, was positively related to education (χ^2=20.67, p=0.0004). It could also be that those in the most labour-intensive jobs, who may also be less well educated and have less wealth (not just income, which we had asked about in the survey), cannot afford to be less productive. They may depend on wages derived from insecure and poorly paid employment to feed their families and, although they would have liked to rest and slow down because of heat stress, they could not afford to, and hence reach their physical or mental limit. They might also have adjusted their working hours to early mornings and evenings in order to avoid the hottest times of day. If these people perceived that their productivity had declined, they would also be likely to compensate for it by working longer hours or harder in cooler times, particularly if they are self-employed, as compared to people in less physically challenging (office) jobs for whom reductions in productivity might jeopardize neither their jobs nor their livelihoods.

Respondents with high and medium degrees of mental exertion perceived their percentage productivity loss as being significantly higher than those with low levels of mental exertion (see Eq. 1), with 51% and 50% losses in productivity, respectively compared to 40% (KW=9.59, p=0.0083). Although the number of days respondents felt they had been less productive during the previous year did not differ significantly across the levels of mental exertion (20, 25, 30 for low, medium or high; Figure 2; KW=4.00, p=0.1352), these differences would have made a difference in calculating the economic loss (see Eq. 1). The number of affected days differed even less among different levels of physical exertion (24, 30 and 30 for low, medium and high levels) (KW=2.40, p=0.3005). This lack of difference in the number of days between the medium and high levels of physical exertions explains the similarity in economic losses in these two categories. Surprisingly, given other studies (e.g. Venugopal et al. 2015), there was no significant relationship between work intensity and perceived heat stress (see Table S1 in Supplementary Materials).

Overall our findings suggest that occupational health guidelines in Malaysia (Department of Occupational Safety and Health 2016) may need revising to consider more sectors than the high intensity outdoor sectors usually targeted by such policies. While previous studies have shown the link between mental health risks and heat stress (Tawatsupa et al. 2012; López-Sánchez et al. 2017), few guidelines cater for the impact of heat on employees working inside and requiring mostly mental exertion for their work.

Acclimatisation and air-conditioning use

The reason why mental exertion has a stronger impact on the number of days being heat stressed, the percentage reduction in productivity and therefore the economic loss than physical exertion could also be associated with a lack of acclimatisation. People in mentally challenging jobs often work in offices (inside with low labour intensity) and they might therefore not be as acclimatised to heat as those people who work in physically demanding jobs.

The lack of acclimatisation could even be exaggerated by the increasing use of air-conditioning. Exposure to increased temperatures over several weeks can assist in developing acclimatisation (Anderson and Bell 2011; Bain and Jay 2011), while people in air-conditioned environments may have low exposure to heat and hence exhibit reduced thermal adaptation, increasing heat health risks (Cao et al. 2012). While the use of air-conditioning at work was not significantly different among mental exertion levels, it was among physical. Those working in highly physically challenging jobs, had significant lower availability of air-conditioning at work (68%) than those with medium and low levels of physical exertion (~81%) (KW=9.80, p=0.0074). This can mean that those respondents who physically work in non-air-conditioned environments developed heat acclimatisation which would be in line with our finding that those who spend about half of their daytime outside had the lowest economic loss from productivity reductions.

People who said they had air-conditioning at home had higher incomes (KW=26.44, p<0.0001) which was not surprising when relating to affordability of air-conditioning units and the increased energy costs. Because of their higher incomes (see Eq. 1), the estimated economic loss was double for those with air-conditioning at home than for those without (median of 330 € vs. 165 €; Table 2). Additionally, those with air-conditioning at home considered that their percentage productivity loss had, on average, been 6% higher than those without air-conditioning at home. This was surprising since heat stress induced sleep deprivation affects work productivity and daily activities of both indoor and outdoor workers (Tawatsupa et al. 2012) and we would have expected that respondents with air-conditioning at home to sleep better and report lower degrees of productivity loss. One explanation for our finding could again be reduced acclimatisation. Those who sleep in air-conditioning might feel more heat stressed and less productive during the day because of the temperature differences between indoors and outdoors.

[Figure 1 here]

[Figure 2 here]

Study limitations and future research

We used perceived or self-assessed measures of heat stress and productivity loss because self-assessed health is regarded as the most informative health measure in population studies (Jylhä

2009; Maheswaran et al. 2015), and has also been used and validated in other studies (Schuster et al. 2017; Zander et al. 2015,2018). While self-reported estimates need caution in their interpretation (Stone et al. 2000), the biases 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 and age (see Methods).

Likewise, we used a subjective measure of labour productivity loss, respondents perceptions of the percentage loss of productivity that they attributed to heat on days when they had felt heat stressed. Subjective measures of performance are commonly employed as accurate and reliable indicators of actual productivity (e.g. Wall et al. 2004; Forth and McNabb 2008, Bryson et al. 2017) because data on actual productivity or performance which can be linked to specific situations, like in our case to individual heat stress, are either not available or commercially sensitive (Forth and McNabb 2008). Even if they were available, actual productivity measures are rarely linked to individuals and their personal levels of heat stress. The performance of those not heat stressed might also be affected if they resent the impaired performance of those who are, and because of the impact this has on co-operation and group processes (see Felps et al. 2006). Subjective productivity measures are criticized because the small number of response categories prevents direct quantification of the impact of any particular practice or stress situation on workplace performance (Forth and McNabb 2008). However, while subjective and objective measures might produce different results, the two measures are nevertheless correlated and at least weakly equivalent (Wall et al. 2004; Forth and McNabb 2008).

Because of the nature of the data source (crowdsourcing), people without access to the Internet have been excluded. However, Internet coverage in Malaysia is high, estimated at 76.9% in 2016 (MCMC 2017). In 2017 it was probably even higher, and in the urban population still higher, so that we are confident that we reached a representative sample of the Malaysian urban population. Our sample did include few elderly people (>60), and, partly related to this, also no sick people. Elderly and unhealthy people have been found to be particularly vulnerable to the health impacts of extreme heat (Basu 2009) and in order to investigate how older people are affected by and cope with heat in urban Malaysia, on the ground in-person interviews will be needed. In-person interviews with people working in different sectors in Malaysia, ranging from outdoor to indoor work of different intensity, would also help to understand better where heat relief plans are most needed and what other policies can help reduce heat stress outside workplaces.

Conclusions

Increasing average temperatures and more frequent and longer heat waves will have profound social, health and economic impacts on global society. Urban locations are more prone to the impacts of heat due to the aggravated effects of the urban heat island. Economic impact can be measured through reductions in productivity of both outdoor and indoor workers in times when they felt heat stressed. In this study from Malaysia, a rapidly urbanizing society, we estimated that people lose nearly 10% of their annual median income because of heat related productivity loss. People working in mentally challenging jobs perceived that their productivity losses had been even higher than did those performing physically intense jobs. Economic costs from productivity loss could be reduced by updating and encouraging compliance with workplace guidelines for climate adaptation and acclimatisation. In particular, more research needs to be done on workplace guidelines for indoor workers and workers involved in mentally challenging jobs, in addition to the well-recognised impact of heat on workers in outdoor and labour intense jobs.

Acknowledgments

The data collection for this project was funded by a Small Faculty Grant provided by Charles Darwin University, Faculty of Law, Economics, Business and Arts (LEBA). The lead author received funding through a Humboldt Foundation Fellowship while writing up this paper. We would like to thank Stephen Garnett for reviewing and editing the final draft of this paper.

References

Anderson G and Bell M. Heat Waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environ Health Perspect.* 2011;19:210–219.

Bain A, Jay O. Does summer in a humid continental climate elicit an acclimatization of human thermoregulatory responses? *Eur J Appl Physiol.* 2011;111:1197–1205.

Basu R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environ Health.* 2009;8:4.

Borg M, Bi P, Nitschke M, Williams S, McDonald S. The impact of daily temperature on renal disease incidence: an ecological study. *Environ Health.* 2017;16(1):114.

Bryson A, Forth J, Stokes L. Does employees' subjective well-being affect workplace performance? *Hum Relat.* 2017;70:1017–1037.

Burke M, Hsiang SM, Miguel E. Climate and conflict. *Annu Rev Econ.* 2015a;7:577–617.

Burke M, Hsiang SM, Miguel E. Global non-linear effect of temperature on economic production. *Nature*. 2015b;527:235–239.

Chandler J, Paolacci G, Mueller P. Risks and rewards of crowdsourcing marketplaces. In: Michelucci, P. (Ed.) pages 377-392. *Handbook of human computation* 377-392 (Heidelberg: Springer; 2013).

Chapman S, Watson JEM, Salazar A, Thatcher M, McAlpine CA. The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecol.* 2017;32:1921–1935.

Coates L, Haynes K, O'Brien J, McAneney J, de Oliveira, FD. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. *Environ Sci Policy*. 2014;42:33–44.

Department of Occupational Safety and Health. *Guidelines on Heat Stress Management at Workplace.* Kuala Lumpur: Ministry of Human Resources Malaysia; 2016.

Dhar TK, Khirfan L. Climate change adaptation in the urban planning and design research: missing links and research agenda. *J Environ Plann Man.* 2017;60:602–627.

Dunne JP, Stouffer RJ, John JG. Reductions in labour capacity from heat stress under climate warming. *Nature Clim Change.* 2013;3:563–566.

Felps W, Mitchell TR, Byington E. How, when, and why bad apples spoil the barrel: negative group members and dysfunctional groups. *Res Organ Behav.* 2006;27:175–222.

Forth J, McNabb R. Workplace performance: a comparison of subjective and objective measures in the 2004 Workplace Employment Relations Survey. *Ind Relat J.* 2008;39:104–123.

Hajat S, O'Connor M, Kosatsky T. Health effects of hot weather: from awareness of risk factors to effective health protection. *The Lancet.* 2010;375:856–863.

Hebbert M, Jankovic V. Cities and climate change: the precedents and why they matter. *Urban Stud.* 2013;50:1332–1347.

Hooyberghs H, Verbeke S, Lauwaet D, Costa H, Floater G, De Ridder K. Influence of climate change on summer cooling costs and heat stress in urban office buildings. *Clim Change.* 2017;144:721–735.

Index Mundi. Malaysia Demographics Profile 2018. https://www.indexmundi.com/malaysia/demographics_profile.html (Accessed 13 April 2018).

Jylhä M. What is self-rated health and why does it predict mortality? Towards a unified conceptual model *Soc Sci Med.* 2009;69:307–316.

Kim SH, Jo SN, Myung HN, Jang JY. The effect of pre-existing medical conditions on heat stroke during hot weather in South Korea. *Environ Res.* 2014;133:246–252.

Kjellstrom T, Kovats RS, Lloyd SJ, Holt T, Tol RSJ. The direct impact of climate change on regional labor productivity. *Arch Environ Occup H.* 2009a;64:217–227.

Kjellstrom T. Climate change, direct heat exposure, health and well-being in low and middle income countries. *Glob Health Action.* 2009b;2.

Kjellstrom T, Gabrysch S, Lemke B, Dear K. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. *Glob Health Action.* 2009c;2.

Kjellstrom, T. Impact of Climate Conditions on Occupational Health and Related Economic Losses: A New Feature of Global and Urban Health in the Context of Climate Change. *Asia Pac J Public Health.* 2016;28:28S–37S.

Kjellstrom T, Lemke B, Otto M, Briggs D, Zander K, Goodman J, Fiske L. *Extreme heat and migration*. Geneva: IOM Migration, Environment and Climate Change Division; 2017.

Knox J, Hess T, Daccache A, Wheeler T. Climate change impacts on crop productivity in Africa and South Asia. *Environ Res Lett.* 2012;7:034032.

Loh JL, Tangang F, Juneng L, Hein D, Lee D-I. Projected rainfall and temperature changes over Malaysia at the end of the 21st century based on PRECIS modelling system. *Asia-Pacific J Atmos Sci.* 2016;52:191–208.

López-Sánchez JI, Hancock PA. Thermal effects on cognition: a new quantitative synthesis. *Int J Hyperther*. 2017;Published Online, doi:10.1080/02656736.2017.1345013.

Maheswaran H, Kupek E, Petrou S. Self-reported health and socio-economic inequalities in England, 1996–2009: repeated national cross-sectional study. *Soc Sci Med.* 2015;136:135–146.

Mathew S, Mathur D, Chang AB, McDonald E, Singh GR, Nur D, Gerritsen R. Examining the effects of ambient temperature on pre-term birth in central Australia. *Int J Environ Res Public Health.* 2017;14(2):147.

Matthews TKR, Wilby RL, Murphy C. Communicating the deadly consequences of global warming for human heat stress. *P Natl Acad Sci USA.* 2017;114:3861–3866.

MCMC. Internet users survey 2017. Statistical Brief No 21. Cyberjaya: Malaysian Communications and Multimedia Commission; 2017.

Mora, C, Dousset B, Caldwell IR, Powell FE, Geronimo RC, Bielecki CR, *et al.* Global risk of deadly heat. *Nature Clim Change.* 2017;7:501–506.

Padhy SK, Sarkar S, Panigrahi M, Paul S. Mental health effects of climate change. *Indian J Occup Environ Med.* 2015;19:3–7.

Perkins SE, Alexander LV, Nairn JR. Increasing frequency, intensity and duration of observed global heatwaves and warm spells. *Geophys Res Lett.* 2012;39:L20714.

Raftery AE, Zimmer A, Frierson DMW, Startz R, Liu P. Less than 2 °C warming by 2100 unlikely. *Nature Clim Change.* 2017;7:637–641.

R Core Team. *R: A language and environment for statistical computing.* R Foundation for Statistical Computing; 2013.

Schuster C, Honold J, Lauf S, Lakes T. Urban heat stress: novel survey suggests health and fitness as future avenue for research and adaptation strategies. *Environ Res Lett.* 2017; 12:044021.

Stern N. The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *J Econ Lit.* 2013;51:838–859.

Stone AA, Bachrach CA, Jobe JB, Kurtzman HS, Cain VS. *The science of self-report: implications for research and practice.* Mahwah: Lawrence Erlbaum Associates; 2000.

Tamm M, Jakobson A, Havik M, et al. The compression of perceived time in a hot environment depends on physiological and psychological factors. *Q J Exp Psychol.* 2014;67:197–208.

Tawatsupa B, Yiengprugsawan V, Kjellstrom T, Berecki-Gisolf J, Seubsman S-A, Sleigh A. Association between heat stress and occupational injury among Thai workers: findings of the Thai cohort study. *Ind Health* 2013;51:34–46.

Tawatsupa B, Yiengprugsawan V, Kjellstrom T, et al. Heat stress, health and well-being: findings from a large national cohort of Thai adults. *BMJ Open*. 2012;2:e001396.

Teixeira EI, Fischer G, van Velthuizen H, Walter C, Ewert F. Global hot-spots of heat stress on agricultural crops due to climate change. *Agric For Meteorol.* 2013;170:206–215.

Venugopal V, Chinnadurai JS, Lucas RAI, Kjellstrom T. Occupational heat stress profiles in selected workplaces in India*.* *Int J Environ Res Public Health.* 2016;13:89.

Wall T, Michie J, Patterson M, Wood S, Sheehan M, Clegg CW, West M. On the validity of subjective measures of company performance. *Pers Psychol.* 2004;57:95–118.

Waters J, Adger WN. Spatial, network and temporal dimensions of the determinants of adaptive capacity in poor urban areas. *Global Environ Chang.* 2017;46:42–49.

World Bank. East Asia's changing urban landscape: measuring a decade of spatial growth. Urban Development Series. Washington, DC: World Bank; 2015.

Wouters H, De Ridder K, Poelmans L, Willems P, Brouwers J, Hosseinzadehtalaei P, *et al.* 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.* 2017;44:8997–9007.

Xiang J, Bi P, Pisaniello D, Hansen A. Health Impacts of Workplace Heat Exposure: An Epidemiological Review. *Ind Health*. 2014;52:91–101.

Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST. Heat stress causes substantial labour productivity loss in Australia. *Nature Clim Change.* 2015;5:647–651.

Zander KK, Matthew S, Garnett ST. Exploring heat stress relief measures among Australian labour force. *Int J Environ Res Public Health.* 2018;15(3):E401.

Zhang Y, Nitschke M, Bi P. Risk factors for direct heat-related hospitalization during the 2009 Adelaide heatwave: A case crossover study. *Sci Total Environ.* 2013;442:1–5.

Tables

Table 1. Questions used in the online survey to elicit respondents' subjective heat stress and associated loss in productivity

Question	Explanation	Responses
Do you ever feel stressed by heat in what you are doing?	To address **aim 1**: assessing perceived (subjective) heat stress	No never Yes, but rarely Yes, sometimes Yes, often Yes, very often
On average, how much less productive are you on a hot day, in percentage of your usual productivity from 1% (not much less productive) to 100% (a lot less productive)?	The response measures the degree of subjective productivity loss, as a percentage of the usual productivity which respondents would expect on a normal day when not feeling heat stressed. To address **aim 2**: assessing perceived (subjective) productivity loss (see Eq. 1)	Percentage from 1 to 100 on a slider
On how many days in the last 12 months did you feel less productive because of heat stress?	The response measures the frequency of being less productive because of heat stress, as perceived and recalled over the last 12 months by respondents. To address **aim 2**: assessing perceived (subjective) productivity loss (see Eq. 1)	Open question (days per last 12 months)

Table 2. Factors affecting annual economic loss from the productivity impact of heat stress

Variable	Levels (% of respondents)	Annual loss (Median in €)	Test of significance
Gender	Female (50%)	302	KW=1.34, p=0.2472
	Male (50%)	215	
Health	Fair (26%)	278	KW=0.43, p=0.8061
	Good (53%)	273	
	Excellent (21%)	215	
Education	Low (14%)	210 [a]	KW=4.84, p=0.0889
	Medium (35%)	206 [b]	
	High (University; 51%)	309 [b]	
Time spent outside	Little (30%)	289 [a]	KW=9.88, p=0.0071
	About half (57%)	197 [b]	
	A lot (13%)	408 [b]	
Degree of physical exertion	Light (20%)	132 [a]	KW=6.20, p=0.0450
	Medium (60%)	281 [b]	
	Heavy (20%)	289 [b]	
Degree of mental exertion	Light (8%)	104 [a]	KW=11.82, p=0.0027
	Medium (46%)	195 [b]	
	Heavy (46%)	369 [c]	
Air-conditioning at home	Yes (58%)	330 [a]	KW=8.73, p=0.0031
	No (42%)	165 [b]	
Air-conditioning at work	Yes (78%)	278	KW=0.55, p=0.4563
	No (22%)	196	
Workload	Full-time (48%)	289	KW=2.64, p=0.2676
	Part-time (37%)	193	
	Casual (15%)	289	
Work intensity of sector	Light (39%)	198	KW=1.38, p=0.5014
	Medium (41%)	289	
	Heavy (20%)	340	

Note: different subscripts imply significant differences across levels; KW = Kruskal-Wallis

Figures

Figure 1. Relationship between physical (left) and mental (right) exertions of activities and economic loss from heat stress related reductions in labour productivity

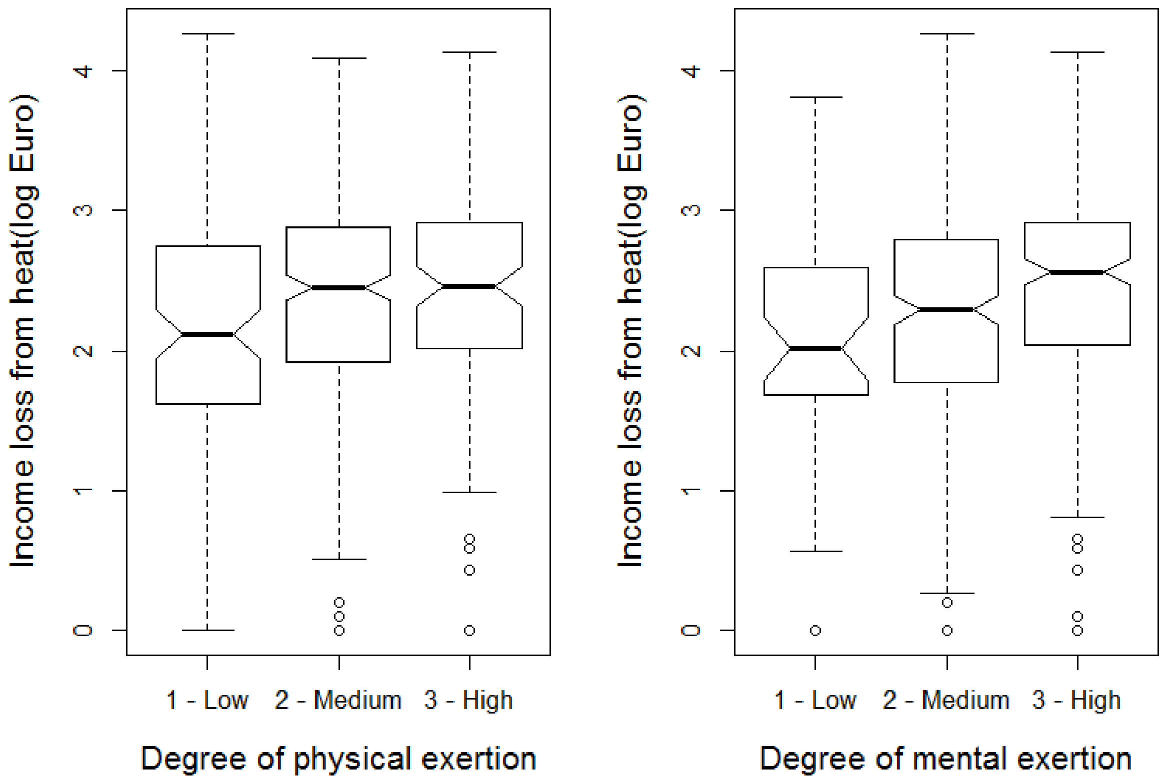

Figure 2. Relationship between days affected by heat stress and physical and mental exertion