Climate and Development

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tcld20

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To cite this article: Laurie Parsons, Pratik Mishra, Jennifer Cole, Sabina Lawreniuk & Ly Vouch Long (11 Mar 2025): Climate-linked heat inequality in the global southern workforce: Cambodian workers' economic and health vulnerability to high core temperatures in five occupational sectors, Climate and Development, DOI: 10.1080/17565529.2025.2474026

To link to this article: https://doi.org/10.1080/17565529.2025.2474026

Published online: 11 Mar 2025.

CLIMATE AND DEVELOPMENT
https://doi.org/10.1080/17565529.2025.2474026

RESEARCH ARTICLE

Climate-linked heat inequality in the global southern workforce: Cambodian workers' economic and health vulnerability to high core temperatures in five occupational sectors

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ABSTRACT
Under climate change, the risk of heatwaves is increasing worldwide. However, the health risks resulting from heatwaves are uneven. Relatively socially disadvantaged people are disproportionately affected by temperature extremes. This paper explores this point in Cambodia: one of the world's hottest and most humid countries, and a Least Developed Country (LDC) as designated by the UN. The paper evidences the extent of the heat exposure faced by workers in Cambodia and the way occupational, environmental and geographical dynamics combine to shape it. It explores heat stress in five occupational sectors – construction, garment work, informal selling, agriculture and tourism work – across four climatic zones of Cambodia. The results of the study show that 64% of the 100 surveyed workers recorded core temperatures over 38°C – considered an unhealthy body temperature – at least once within 7 days of work. However, substantial variances were observed within and between occupations. Even within the same study region, the number of working minutes over 38°C ranged from 0.8% on average for tourism workers to 8.4% of working minutes for construction workers. These variations translate to significant differences in occupational sensitivity to high temperatures, especially when combined with humidity.

ARTICLE HISTORY
Received 2 July 2024
Accepted 27 January 2025

KEYWORDS
Climate change; heat stress; labour; global supply chains; environmental inequality

Heat stress inequality in the global southern workforce

Extreme temperatures are rapidly becoming an everyday part of working life around the world. With global temperatures now 1.5°C above pre-industrial levels (Diffenbaugh & Barnes, 2023), once-a-decade heatwaves will become biannual events by 2030 (IPCC, 2021). The ILO (2019) estimates that extreme heat will cost global GDP some 2.4 trillion USD annually by 2030 (ILO, 2019). Furthermore, this heightened risk has situated heat stress as a concern within the Global Burden of Disease Study (Burkart et al., 2021) and pushed climate change up the agenda for the World Health Organization, which estimates heat stress will cost the healthcare sector between 2 and 4 billion USD annually by 2030 (WHO, 2024), causing an estimated 7.1 trillion USD in productivity losses by 2050 (WEF, 2024) and resulting in an additional 250,000 deaths per year between 2030 and 2050 and (WHO, 2024).

Extreme heat has major implications for decent work globally but disproportionately affects workers and countries in the global South. In the global North, there are often occupational guidelines specifying upper limits of heat exposure for workers. However, such guidelines are often generic over a broad range of settings (see Jackson and Rosenberg, 2010) and their implementation is sketchy, even in organized workplaces (Humphrys et al., 2022). In the global South however, there is even more biogeographical vulnerability to extreme heat (see Zhang et al. 2023), and a large proportion of the workforce is engaged in outdoor work such as in agriculture and construction where workers are more affected by extreme heat. Additionally, high levels of informality in these countries combine with lack of access to social protection and accident and injury insurance for which workers face the brunt of heat impacts upon their health (O'Brien et al., 2015) and on their livelihoods (Odonkor and Adams, 2022). The resulting intersection of health detriments with small- and large-scale economic impacts has major implications for the development trajectories of many low- and middle-income countries (LMIC) and their efforts to achieve the UN Sustainable Development Goals (Birkmann et al., 2022).

In mapping out the geography of impact from extreme heat, it is important to highlight that the risk of heat stress is highly variegated, and unequal heat exposure exacerbates health and socio-economic inequities along multiple axes and scales. Vulnerable populations, women, young people, older, low-income and precarious communities are all at greater risk, making distributive justice a key ethic of heat action (see Mitchell and Chakraborty, 2015; Grineski et al., 2015). Current analysis lacks the nuance needed to disentangle complex and variegated health and economic impacts under climate change. Seeking to bridge this gap, this paper demonstrates the

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variation in heat exposure faced by workers in different sectors in Cambodia, providing a key evidence base to link these heat exposures to associated health impacts.

The Southeast Asian nation of Cambodia exemplifies the multiple intersecting vulnerabilities that present a complex landscape of risk. In Cambodia, the number of very hot days – days over 35°C or a Wet Bulb Global Temperature [WBGT] of 32°C (UNICEF, 2022) – have increased by 46 days per year since 1990 (World Bank and ADB, 2021), making the country one of the world's most vulnerable to the impacts of rising temperatures. In climates like Cambodia's, WBGT is a major threat to health (Lo et al., 2023) and between 386 and 500 DALYs per 100,000[1] are attributable to high temperature (Burkart et al., 2021). With a large proportion of the working population of Cambodia (and Southeast Asia in general) centred in high-risk sectors such as construction and agriculture, these factors place Cambodian workers at exceptionally high risk of climate-linked heat waves.

The data in this paper was generated from 100 Cambodian workers, divided equally amongst four sites in each of the four major agro-climatic zones in Cambodia; and Cambodia's five largest occupational sectors: tourism, construction, food sellers, garment workers, and agricultural workers. These workers undertake a combination of indoor and outdoor work. Garment workers work almost exclusively indoors, whilst food sellers and agricultural workers work predominantly outdoors. Tourism and construction workers undertake a combination of the two. Participants wore CORE thermal monitors during working hours for 7 days, which automatically uploaded core temperature, skin temperature and heartrate data to an online database. Concurrently, these data were methodologically integrated with daily activity surveys secondary weather station data in order to connect core temperature readings to work and environmental conditions.

The data evidences greater variations in excess core temperature than predicted by conventional modelling and structured to an equal or greater extent by economic and occupationally specific factors such as geography and weather. Specifically, these factors include (1) differences in the built environment linked to each occupation, with an additional factor being whether the working day was spent indoors or outdoors, (2) differences in working practices and capacity for self-regulation of core temperatures, and (3) differences in economic capacity to adapt.[2] This paper therefore highlights the need for a broader sampling base of heat stress data generation and health impacts, in order to interpret the socioeconomic determinants of heat stress variation in vulnerable populations.

Unlike previous studies, our work compares heat stress both *within* occupations and *across* geographical locations with different climatic and occupational environment conditions. By comparing occupations and climatic conditions across four climatological regions of Cambodia – which vary in terms of heat and humidity – the aim is to generate a clearer picture of how climatic, social determinants and occupational dynamics combine to shape heat stress risk amongst vulnerable populations.

Cambodia: climate vulnerability in a dynamic low-income economy

Cambodia is both one of the world's hottest and most humid countries (NCEI, 2022), and one of its least developed (UNCTAD, 2022). Despite spending 6% of GDP on healthcare, above the regional average, health outcomes are amongst the poorest in Southeast Asia (Asante et al., 2019). Cambodia lacks universal healthcare provision, with 53% of the population lacking any social health protection (Kolesar et al., 2020). As a result, much of the population lacks economic capacity to manage high temperatures and their health impacts, a problem compounded by, 'a lack of the empirical data needed to estimate the exposure-response functions', meaning that little concrete is known on the specific impacts of heat stress in Cambodia (Vicedo-Cabrera et al., 2021, p. 498), or its direct impact on health.

Although Cambodia is a relatively small country in terms of area, it includes at least four major climatic regions, as shown in Figure 1: The Tonle Sap, Lower Mekong, Highland, and Coastal regions (Sar et al., 2012; Weng et al., 2023). These four zones cover the range of climatic variability in Cambodia, from a mean annual high of 29.9°C (85.82°F) in Svay Rieng to a low of 24.5°C (76.1°F) in Rattanakiri. Under climate change, these variations have significant implications for heat stress vulnerability. Heavy labour can only be undertaken safely for sustained periods at temperatures below 26°C (Basu & Ostro, 2008), and even light labour requires a rest every half hour at temperatures above 32°C to prevent organ damage. When high temperatures meet high humidity and even more so when combined with heavy work (Levi et al., 2018) impacts can range from acute impacts such as heatstroke to less visible, chronic disease vulnerability. Moreover, the more-than-health impacts are significant. Between 2000 and 2015, global labour productivity declined by 5% due to climate change (Watts et al., 2015) and labour capacity loss, which is more acute in LMICs, threatens to reduce the Gross Domestic Product (GDP) of countries already low on the Human Development Index (HDI – Cambodia is ranked 148 out of 193 countries) by 3.8–6.1%, with heat-related labour loss predicted to rise by 50% by 2050 without mitigation (Romanello et al., 2023).

Nevertheless, assessing the dynamics of climate change on human populations is a major research challenge due to the complexity and granularity of their manifestation. The risk resulting from heatwaves is highly uneven in its distribution: those who are relatively socially disadvantaged are likely to find themselves 'disproportionately affected by temperature extremes' (Hansen et al., 2013, p. 2) and simultaneously less able to mitigate those impacts. As a result, major data limitations exist on how heat stress impacts workers in low-wage, informal sectors, both in Cambodia and internationally, leaving such impacts 'challenging and underexplored' (Li et al., 2018, p. 171).

Recent research has highlighted the risks faced by garment workers globally (e.g. Anderson Hoffner et al., 2021) and in Cambodia specifically, where multiple reports (Judd et al., 2023; Kjellstrom & Phan, 2016; Kor et al., 2023; Parsons et al., 2022) have shown that climate change is a major concern for Cambodian garment workers. However, outside the garment sector, data are sparse. A handful of studies have highlighted the heat stress risk faced by construction workers

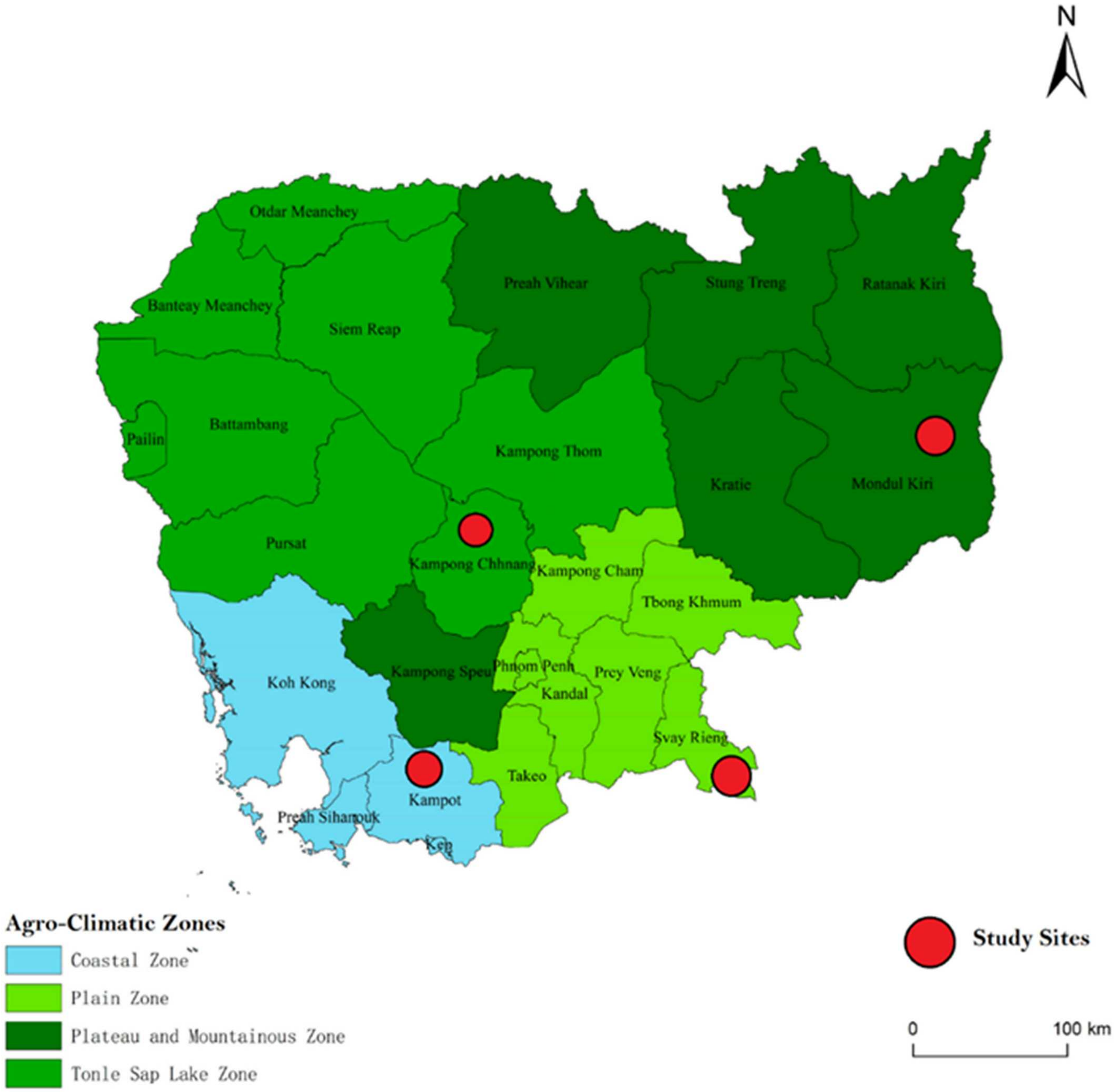

Figure 1. Location of Study Sites within Cambodia's Agro-climatic zones (map adapted from Weng et al., 2023).

under climate change (see Acharya et al., 2018; Parsons, 2021). Yet informal and agricultural workers are even more poorly served by data, despite the International Labour Organization (ILO) having flagged these sectors as areas of risk in its global *Working on a Warmer Planet* report (2019, p. 14), which notes that 'on the whole, the countries that are most affected by heat stress have higher rates of working poverty, informal employment and subsistence agriculture'.

For example, despite 33% of Cambodians working in the agricultural sector (NIS, ILO and ADB, 2019), data on the health impacts of agricultural heat stress is – excepting two notable papers on cassava (Hashim et al., 2018) and sugar (Radir et al., 2017) farmers – extremely limited, whilst the final two occupations explored in this paper, street vendors and tourism workers, lack any data at all. How the thermal vulnerability arising from climate change impacts occupational groups in differing regions and different environmental conditions – including, but not limited to, indoor and outdoor work – is thus a key question, both for scholarship and the development of effective healthcare policy for this large and underserved population.

Methods

The data presented here were generated between January and July 2023 in three phases. During Phase 1, from January to

April 2023, preliminary qualitative interviews were conducted with workers to understand heat impacts in the workplace. These discussions on heat-related health issues faced by workers, then fed into the qualitative and quantitative questionnaires, and sample frame, deployed in Phase 2.

During Phase 2, from June to August 2023, 100 workers were recruited, 25 in each of the four study sites: Kampong Chhnang, Svay Rieng, Kampot and Mondulkiri, selected to represent the four major agro-climatic zones in Cambodia (Sar et al., 2012; Weng et al., 2023). In total, five occupations were incorporated into the study: garment workers (indoors) construction workers tourism workers, informal food sellers (all outdoors in urban settings) and agricultural workers (outdoors in rural settings), representing the 5 largest occupational sectors in the Cambodian economy. In each of these study sites, 5 workers from each occupation were recruited to participate for 7 days, whilst working as normal in their occupation.

Each participant wore a CORE thermal monitor during their working hours for 7 days, which automatically uploaded core temperature, skin temperature and heartrate data to an online database. Research logistics operated in three cycles, each lasting 9–10 days in June, July and August. During each of these cycles, the research team moved between the four study sites, to ensure data were generated on the same days in different locations. Across this period, comparable data were generated on 29 calendar day, across which the methodology generated an integrated dataset of 576,292 min of thermal data, or 96 working hours per participating worker.

Whilst these data do not match the accuracy of the most sensitive thermometric tools, i.e. orally ingested thermometric pills and rectal thermometer readings (see Casa et al., 2007 for a comparison of alternative technologies), the deviation from this standard is within acceptable limits. As outlined in a handful of recent papers that have explored the accuracy of these and similar devices (e.g. Dolson et al., 2022; Ibrahim et al., 2023), CORE readings deviate from gold standard thermometric pills and rectal measurements by more than the manufacturers' claimed 0.2°C in some cases. Studies are split over the validity of the core temperature measurement, with some studies indicating acceptable validity (Dolson et al., 2022; Ibrahim et al., 2023) and others indicating unacceptable validity (Desroches et al., 2023; Verdel et al., 2021) compared to rectal and ingested thermal measurements. However, this discrepancy is largely due to the threshold employed. Overall, a systematic review of CORE and similar technologies (Dolson et al., 2022), this deviation averages from 0.1 to 0.4 degrees, averaging under 0.3 degrees of deviation. When compared to the 0.27°C threshold applied by Casa et al. (2007) in a meta-review of existing technologies, all current CORE studies indicate an acceptable level of accuracy, especially given that the data concern hard to reach populations with whom data could not be generated using oral or rectal thermometers.

Moreover, the methods we have developed – whilst applied to a small sample size in this study, which we recognise as a limitation – can be employed by the workers themselves in participatory action approaches. In this case, these thermal data were methodologically integrated with (1) a preliminary quantitative livelihoods, assets and liabilities survey, (2) a survey of participants' daily activity diaries, including experiences of heat stress, and (3) extended qualitative interviews at the beginning, middle and end of the study. Thus, by empowering hard-to-reach workers to participate in the assessment of their own conditions, this study helps to counter the challenges of post-colonial health research methods (Khan et al., 2024) in the academy and wider policy.

Results

The duration of time spent working at or above 38°C – the generally agreed safe limit (Lamarche et al., 2017) – varies substantially between sectors. Whilst informal food sellers spent 0.8% of working minutes ≥38°C core temperature, and tourism workers spent 1.4% of working minutes above this threshold. Considerably higher were garment workers, spending 5.4% of working minutes ≥38°C, followed by 7.1% of working minutes for agricultural workers, and 8.4% for construction workers. In total, 64% of the 100 surveyed workers recorded core temperatures ≥38°C at least once during the study: 45% of food sellers, 50% of garment workers, 55% of tourism workers, 75% of agricultural workers and 100% of construction workers.

As shown in Figure 2, these data were also used to calculate prolonged heat stress (each instance of core temperature equating to or exceeding 38°C for 5 consecutive minutes) in each occupational group. The results show that construction (1.2%) and agricultural (1.07%) workers spent more than 1% of working minutes in prolonged heat stress, with garment workers (0.84%) slightly lower, and tourism workers (0.21%) and food sellers (0.12%) considerably lower.

Geographic-environmental differences were a significant factor in this variation, as shown in Figure 3. Across the four study sites, temperature and humidity (expressed here by combined Wet Bulb Global Temperature [WBGT]) varied geographically. Mean WBGT in Mondulkiri was 25.98°C. In Svay Rieng it was 28.49°C. In Kampot it was 28.56°C, whilst in Kampong Chhnang it was 27.85°C. Consequently, whereas surveyed workers in Mondulkiri spent only 4.8% of working minutes ≥38°C core temperature, this figure was 7.3% in Svay Rieng, 9.5% in Kampong Chhnang, and 11.7% in Kampot. This emphasizes the relevance of WBGT, as humid conditions, which make it more difficult for the body to regulate temperature through sweating, are more challenging to human health than high temperature alone (Kong & Huber, 2022), but WBGT is currently under-used as an indicator of healthy climatic conditions by public health observatories (Spangler et al., 2022).

Nevertheless, geographic averages conceal substantial occupational variations, which persist across climatic regions. For example, the data in Figure 4 show that certain occupations experienced larger variation within and across locations than others. Agricultural workers, varied between a low of 5.3% in Svay Rieng and 9% in Kampot. Garment workers, on the other hand, varied from a low of 0.1% of working minutes in Mondulkiri to a high of 10.9% in Kampong Chhnang. This may indicate differences in the balance of socioeconomic and demographic influences underpinning heat stress amongst the different occupational groups. For example, food sellers,

Figure 2. Percentage of working minutes in prolonged heat stress (5 + minutes ≥ 38°C), by occupational group.

who display consistently low proportions of unsafe core temperatures across all four locations, tend to do low intensity work outside in the shade, whilst garment workers, working inside, may be more sensitive to differences in the built environment, such as urban heat islands (Wong et al., 2017) or unventilated spaces (Judd et al., 2023). Construction and agricultural workers, both working outside at high intensity, are likely to be more prone to hot days than their peers working indoors, but also less sensitive to geographic variations, due to the significant role of exertion on core body temperature.

These data indicate that, although certain high intensity, predominantly outdoor occupations – such as agricultural and construction work – produce consistently high proportions of working minutes at unsafe core temperatures, other occupations generally deemed at lower risk of heat stress – such as food sellers, garment workers and tourism workers – may be more sensitive to climatic variations across both time and space. With this in mind, Figure 5, displays the daily percentage of working minutes over the 38°C safe threshold against the maximum WGBT on that day. From this arrangement of the data, a clearer relationship emerges, with rises in daily maximum WBGT associated with rises in the percentage of working minutes spent over a core temperature of 38°C.

However, this variation is masked by aggregate figures. As shown in Figure 6, whereas workers spent only 5.3% of working minutes with core temperatures over 38°C at low ambient WBGT, this figure rises to 9.1% at moderate WBGT and 12.4% at high WBGT. Where external WBGT reached severe levels, the percentage of working minutes spent with core temperatures over 38°C rose to 26.8% across the whole sample. Overall, the data evidenced a moderate correlation between average daily WBGT and worker core temperature (Spearman's = 0.259; $p = 0.000$) underpinned by a J-shaped curve when ambient temperature reaches 'severe' levels.

However, environmental factors are only one dimension of this nexus. To demonstrate this, Figure 7 consolidates WBGT into a binary variable – severe and non-severe WGBT (i.e. above or below 31.1°C as per Figure 6) – and disaggregates the data by occupation. Viewed thus, significant differences are observable in occupational sensitivity to severe WBGT. Whilst all occupational groups saw rises in the proportion of working minutes spent above 38°C, the biggest proportional rise – a more than twelvefold increase – was experienced by food sellers, albeit from a low base, of 0.7% to 8.7%, whereas the smallest proportional rise of 50%, from 1.4% to 2.1%, was experienced by tourism workers. Garment workers saw a rise of 77% on severe WBGT days, from 5.4% to 9.6%.

Based on current climatic projections for 2050, this relationship will have substantial implications for workers in multiple sectors. Under the IPCC's RCP 8.5 emission scenario – the most severe scenario, which climatic trends are currently tracking (Schwalm et al., 2020) – Cambodia will see a rise in days where the temperature reaches the severe WBGT threshold of 31.1°C from 87 days annually to 135.7 days annually (World Bank and ADB, 2021). Amongst the five occupations included in the study here, representing just over half of the workforce, therefore, Cambodia can expect an additional 227,818,146 working hours above safe temperatures by 2050. This is likely to bring with it a corresponding increase in days lost due to heat-stress related illness, heat-stress related healthcare costs and chronic conditions in which heat exposure is a key risk factor, such as kidney disease (Foster et al., 2020), cardiorespiratory conditions and mental health (Ebi et al., 2021) (Table 1).

When applied to existing data on the Cambodian labour force, currently estimated at 7.9 million people (NIS, ILO and ADB, 2021),[3] these data indicate Cambodia will see an increase in working hours lost to high temperatures of 18.2% by 2050. However, this proportion will vary from a 5.1% increase in the case of the tourism sector, to 7.8% in the case of the garment sector, 17.7% amongst agricultural workers, and 20% amongst construction workers. From a very low base, informal food sellers can expect to see an increase of 58% due to a high sensitivity to high temperatures.

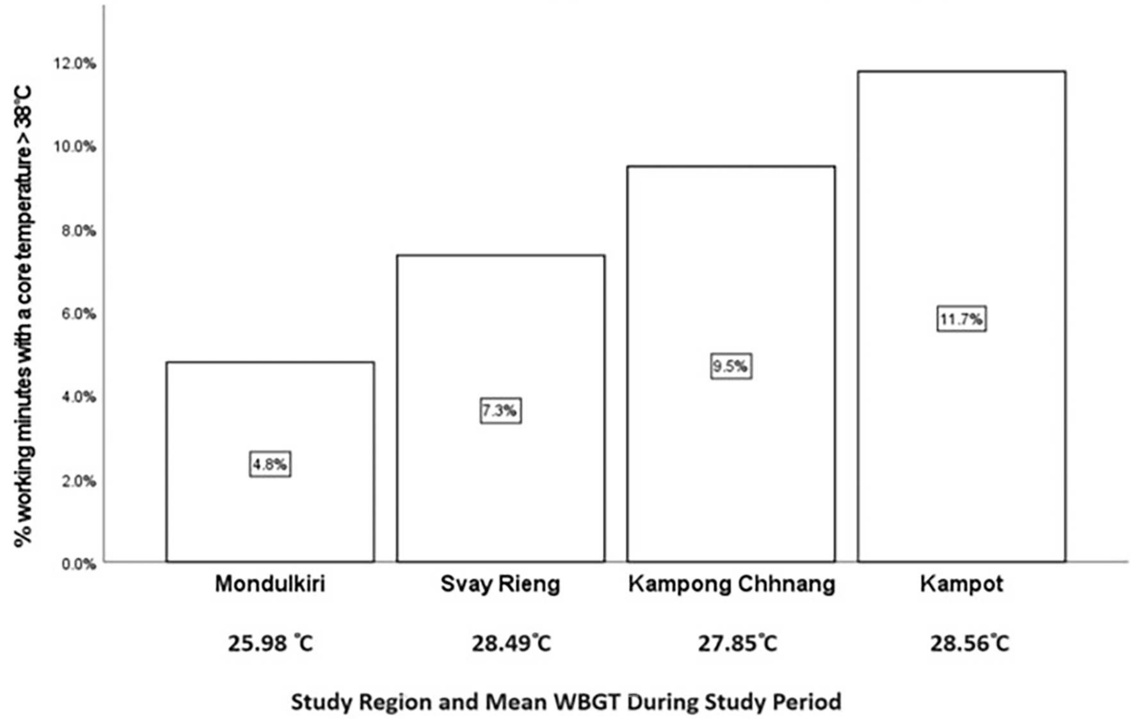

Figure 3. Percentage of working minutes ≥38°C core body temperature disaggregated by Study Site.

Overall, therefore, these data indicate the need for a more occupationally-specific, and occupational-environment specific interpretation of heat stress impacts on health. We argue, for example, that not all working hours lost are lost either to ill-health or efforts to avoid ill-health, but that work productivity and healthcare provision are closely linked, particularly in a country such as Cambodia where high out-of-pocket health expenses mean the number of households facing 'catastrophic' health expenditure is 4–6 x higher than the Southeast Asian average, and the core capacity index for the International Health Regulations is amongst the region's lowest (Ministry of Health and JICA, 2018).

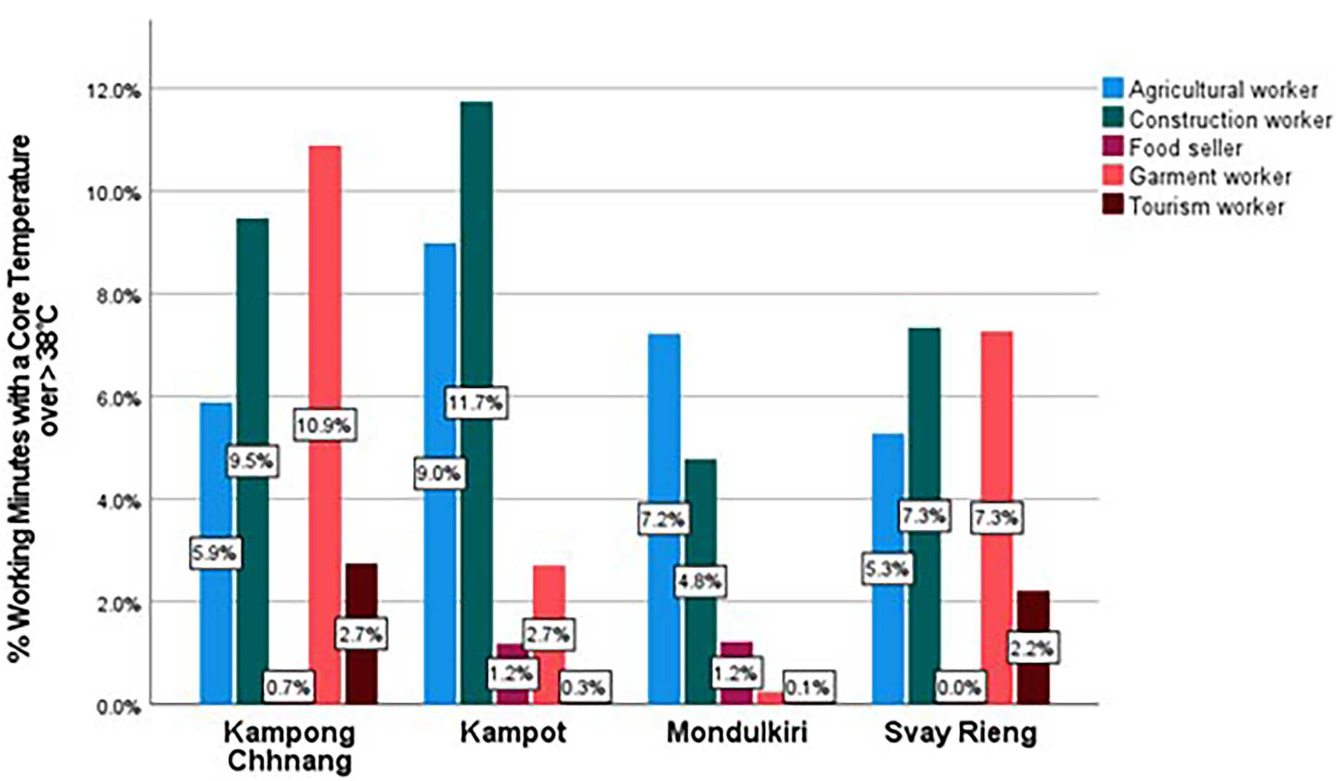

Figure 4. Percentage of working minutes at ≥ 38°C Core Temperature, Disaggregated by Occupation and Location.

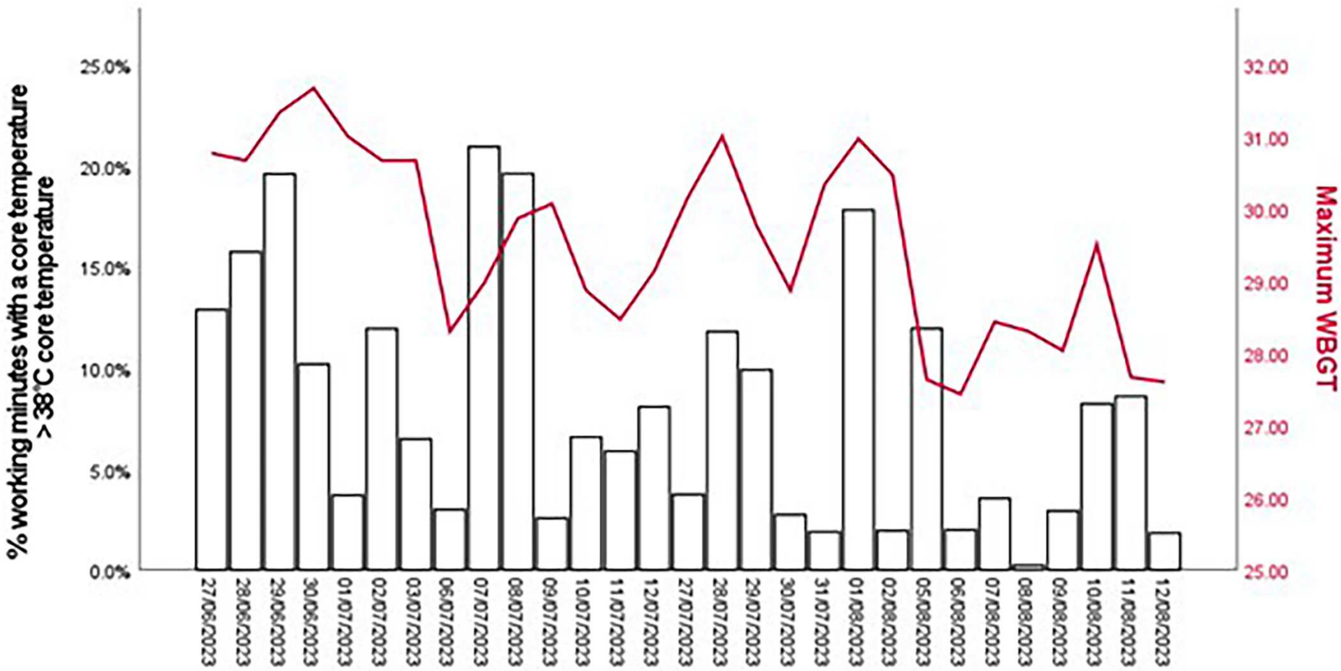

Figure 5. Percentage of daily working minutes spent above 38°C core body temperature against maximum daily WBGT.

Integrating these data with productivity loss figures facilitates a disaggregation of heat stress-induced productivity loss far more detailed than existing estimates (e.g. ILO, 2019; Kjellstrom et al., 2009). This analysis shows that by 2050, Cambodia will each year see an additional 151,527,958 hours of unsafe temperatures amongst agricultural workers; 58,090,000 additional hours of high temperatures amongst construction workers, 8,486,400 additional hours amongst garment workers; 7,547,878 additional hours amongst tourism sector workers, and 2,165,910 additional hours amongst informal food sellers. Amongst the five occupations included in the study here, representing just over half of the workforce, Cambodia can expect an additional 227,818,146 hours of working hours above safe temperatures by 2050 (Table 2).

These data broadly align with the ILO's (2019) projection of working hours lost to heat stress. Whilst the ILO report forecast 60% of these lost hours will come from agriculture and 19% from construction work, data generated for this report place these figures at 67% and 25% respectively.[4] Based on

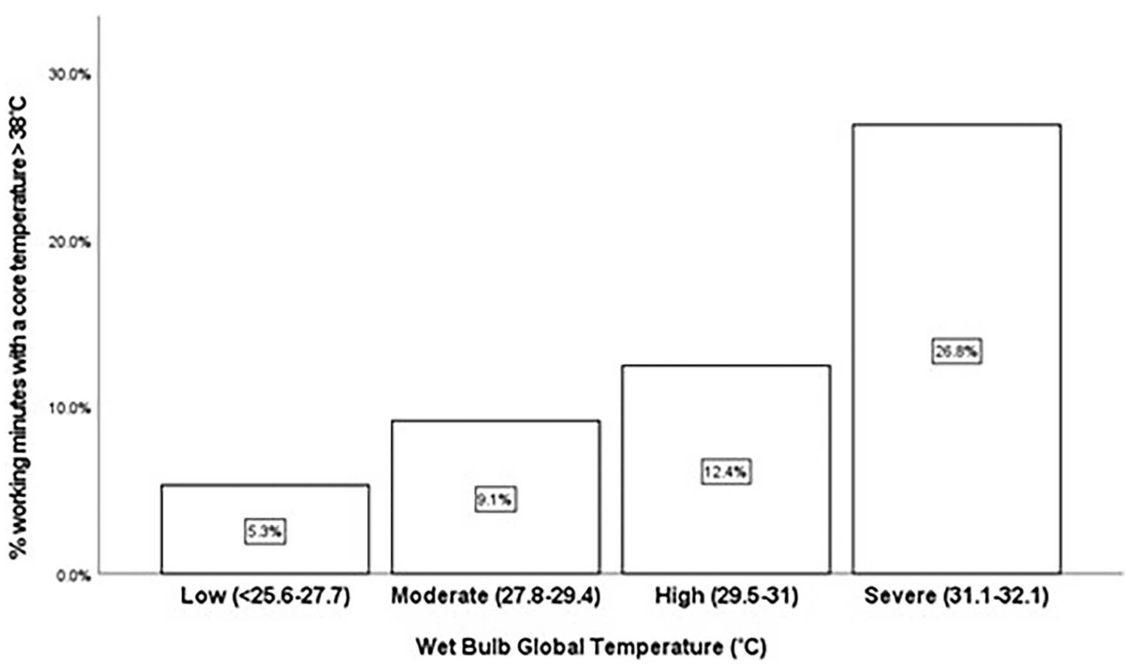

Figure 6. Percentage of working minutes ≥ 38°C core temperature disaggregated by ambient WBGT.

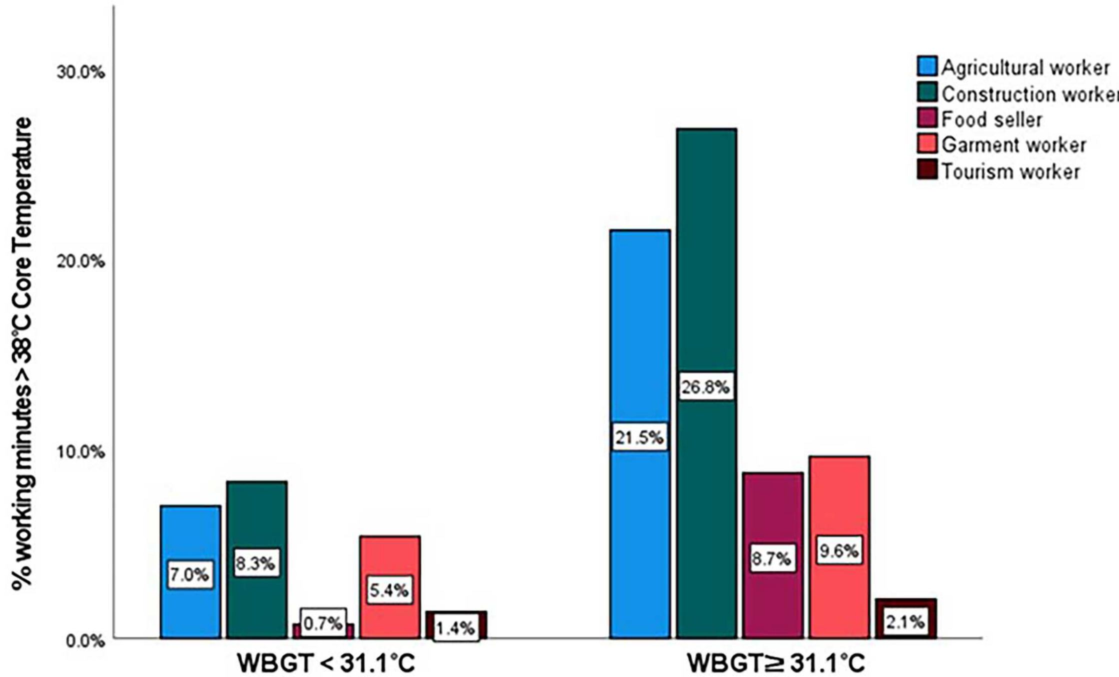

Figure 7. Percentage of working minutes ≥ 38°C core temperature disaggregated by occupation and severe/ non-severe WBGT.

Table 1. Projected sectoral changes in workers' core temperatures ≥38°C by 2050, per IPCC RCP 8.5.

	Core Temperatures ≥38°C		
Occupation	Present average (87 annual days 'severe' WBGT >31.1°C)	2050 projection (135.7 annual days 'severe' WBGT >31.1°C)	Additional working hours ≥38°C core temperature by 2050
Agricultural worker	313.7	371.7	58.0
Construction worker	381.3	455.3	74.0
Food seller	63.8	98.4	34.5
Garment worker	184.9	197.7	12.8
Tourism worker	47.0	49.8	2.8

Table 2. Estimated productivity loss by 2050 by sector.

Occupation	Additional working hours per year per worker with core temperatures > 38°C by 2050	Mean productivity loss at severe WBGT (%)	Annual equivalent hours lost per worker	Annual equivalent hours lost by population
Agricultural worker	58	75.00	43.5	113,645,968.5
Construction worker	74	75.00	55.5	43,567,500
Food seller	34.5	25.00	8.625	541,477.5
Garment worker	12.8	25.00	3.2	2,121,600
Tourism worker	2.8	25.00	0.7	188,696.9
Total				160,065,242.9

Table 3. Percentage productivity loss.

Occupation	% productivity loss due to high temperatures now	% total productivity loss due to high temperatures by 2050	% additional productivity loss due to high temperatures by 2050
Agricultural worker	7.9	9.3	1.4 (17.7% increase)
Construction worker	9.5	11.4	1.9 (20% increase)
Food seller	0.5	0.8	0.29 (58% increase)
Garment worker	1.5	1.6	0.11 (7.3% increase)
Tourism worker	0.39	0.41	0.02 (5.1% increase)
Total	6.6	7.8	1.2 (18.2% increase)

the ILO's (2019) estimation that working in high temperatures reduces productivity by an average of 75% for those undertaking heavy work (defined as 400W working output) and 25% for those undertaking light work (200W working output), the estimated output loss is 6.6% of total working hours across all five sectors at present, rising to 7.8% of all working hours by 2050.[5] However, as shown in Table 3, the impact of rising temperatures is expected to vary substantially by sector.

The greatest percentage increase in lost productivity between now and 2050 is expected to be seen in the construction sector, which will see the proportion of working hours lost rise from 9.5% of potential productivity to 11.4% of potential productivity, a difference of 1.9% of working hours. This is closely followed by the agricultural sector, which will see the proportion of working hours lost rise from 7.9% of potential productivity to 9.3% of potential productivity, a difference of 1.4% of working hours. The smallest difference is expected to be seen in the tourism sector, where only a 0.02% decrease in productivity is expected by 2050. The next least sensitive is the garment sector, which is expected to see a decrease in productivity of only 0.11% by 2050. Food sellers, starting from a low base of 0.5% of working hours lost, is expected to increase by a further 0.29% over the same period. Proportionally, these figures indicate a significant increase in the proportion of working hours lost as a result of heat by 2050, compared with the present time.

Overall, Cambodia will – based on the five surveyed sectors – see an increase in working hours lost to high temperatures of 18.2% by 2050. However, this proportion will vary from an only 5.1% increase in the case of the tourism sector, to 7.8% in the case of the garment sector, 17.7% amongst agricultural workers, and 20% amongst construction workers. From a very low base, informal food sellers can expect to see an increase of some 58% due to an unexpectedly high sensitivity to high temperatures.

Conclusions

Employing a novel, integrated methodology combining body-worn temperature sensors with qualitative and quantitative data collection, the data presented here show variations in excess core temperature that were (1) higher than predicted by conventional modelling and (2) structured as much by economic and occupationally specific factors as geography and weather.

Heat stress in the Cambodian workplace is already a serious issue in many sectors. Moreover, it is one that is growing in severity as rising global temperatures are increasing the number of very hot days in the Kingdom. This report has aimed to build on existing understanding of this growing risk by using new technology to emphasize the variegation of heat stress impacts across the Cambodian economy and to specific economic sectors. In particular, it has aimed to highlight that propensity to heat stress depends upon the combination of climate, geography, work and work environment. Depending on the particular circumstances, any one of these factors may be the dominant factor in shaping worker heat stress.

For example, the proportion of working minutes spent at unsafe core temperatures was strongly influenced by occupation and working environment. Informal food sellers, working outdoors in urban settings, spent only 0.8% of working minutes with a core temperature exceeding 38°C, the lowest of the five occupations surveyed. Tourism workers, working in similar conditions, were only slightly higher at 1.4% of working minutes above 38°C. Considerably higher, though, were indoor garment workers, who spent on average 5.4% of working minutes above 38°C, followed by 7.1% of working minutes for agricultural workers outdoors in rural settings, and 8.4% of working minutes above 38°C for urban construction workers.

Moreover, occupational sectors play a role in shaping the impacts of very hot days. On days when WBGT reached severe levels (over WBGT 31.1°C), food sellers saw an increase in the percentage of working minutes with core temperatures over 38°C increase from 0.7% to 8.7%, whereas the smallest proportional rise of 50%, from 1.4% to 2.1%, was experienced by food sellers. Garment workers saw a rise of 77% on severe WBGT days, from 5.4% to 9.6%. On severe WGBT days, agricultural workers saw their proportion of working minutes increase more than 300%, from 7% to 21.5%. Construction workers, similarly, saw an increase of 315% from 8.5% to 26.8%.

At the same time, differences within occupations are as important as differences between occupational sectors. In each of the five sectors included in this study, certain forms of work were associated with little or no risk of heat stress, whilst a smaller number are associated with high levels of heat stress. This finding supports the conclusion that the landscape of heat stress is highly uneven. Rather than impacting working populations in broadly the same way, the physiological and productivity impacts of heat stress are predominantly focused on certain occupational sub-sectors, who experience acute impacts whilst others are less affected. On a sectoral basis, these acute impacts aggregate to significant productivity losses in economic output. The estimated national productivity loss is 6.6% of total working hours across all five sectors at present, rising to 7.8% of all working hours by 2050. However, the impact of rising temperatures is expected to vary substantially by sector and sub-sector.

The implications of this variegation for decent work are substantial because of the ways in which productivity impacts livelihoods. In certain sectors, such as the garment sector, reduced productivity is likely to lead not only to lost income, but loss of bonuses, potential job loss and longer hours for those remaining in work (Judd et al., 2023; Parsons et al., 2022). In construction or agriculture, by contrast, productivity loss may be offset by working longer or more intensively in dangerous temperatures. Food sellers, who possess a greater degree of informal autonomy, may be able to balance their exposure to heat stress and income loss more effectively than other sectors, whilst tourism workers, from a low base may be facing substantial proportional impacts from heat stress, the extent and response to which are uncertain. In all cases, though, the economic and health impacts manifest at the nexus of time, sector, *and* small-scale geographic variation.

This approach presents significant potential for further research. Whilst core body temperature monitoring of this kind has been used to monitor health of military and emergency services personnel operating in high temperatures (Buller et al., 2021; Hintz et al., 2024; Richmond et al., 2015) and are routinely used in the livestock sector to monitor animal health (Chung et al., 2020; Levit et al., 2021), this represents the only study to use this methodology to evidence heat stress impact on the health of workers across multiple industries simultaneously.

Moreover, this approach has also raised key questions for policy, which must respond to differences in occupational sensitivity to temperature extremes. Drawing on the above data, we hypothesise that these differences arise from the combination of (1) differences in the built environment linked to each occupation, (2) differences in working practices, work environment and capacity for self-regulation of core temperatures, and (3) differences in economic capacity to adapt. However, further research is needed to establish the specific mechanisms through which adaptive capacities in each occupational group differentiate, and the relationship of these mechanisms to working practices and health.

Working populations currently deemed less vulnerable to heat stress on health and productivity bases may be far more sensitive to high WBGT than previously observed. The implications of this for workers, as noted by Kjellstrom (forthcoming), and for populations as a whole are both more-than-somatic and more-than-economic. Towards a lens better attuned to integrated geographic, occupational and climatic trends, this paper therefore highlights the need for a broader sampling base of heat stress data, and better recording of health and economic outcomes to link heat stress exposure to the diverse socio-economic circumstances that it meets.

Notes

1. Disability-adjusted life years are the sum of the years of life lost to due to premature mortality and the years lived with a disability.
2. We also considered different heat stress according to gender within our study by disaggregating our findings. However, the gendered nature of different roles mean that sub-occupational differences are often the key metric shaping these differences. Overall, for example, men spend 20% more minutes working minutes $\geq 38°$ because they are over-represented in the hottest occupations, agriculture and construction, though men are also over-represented as tourism workers with low levels of heat stress. In agriculture and construction, the sampled women workers experience almost equal rates of heat stress. By contrast, women are over-represented in garment work, reflecting the overall industry, where 85-90% of the workforce is female, and informal food selling, in which only one male respondent against 22 female respondents was sampled. In the garment sector, women (N = 15) spend 12 times more working minutes $\geq 38°$ than men (N = 5), likely reflecting the more senior (e.g. management) positions occupied by men. These differences warrant further research into the gendered dynamics of the occupation. However, for the reasons outlined, this would require a specifically designed sample, in order to reflect how gendered differences in the nature of work supersede the influence of specific roles.
3. Some 33% of the Cambodian labour force (2,612,551 people) is employed in agriculture, whilst 10% (or 785,000 people) are employed in construction. The latest available data indicate 663,000 workers employed in the formal garment sector, or 8.4% of the total labour force (Responsible Business Hub, 2022). The tourism sector, best represented by the 3.4% of workers employed in "accommodation and food service activities" accounts for 269,567 people, whilst 62,780 people were employed as street vendors, or 0.79% of the total labour force in 2019 (Oxfam, 2020). As such, the sample here represents data relating to some 55.59% of the Cambodian workforce as a whole.
4. These calculations should be treated as indicative estimations, rather than modelled outcomes, for three reasons. First, the data collected have been selected to represent the full variety of climatic, geographic and labour variations in Cambodia. However, they are not sampled to a statistically significant level: a criterion that would require a much larger sample. Second, the assumptions around productivity loss are based, following ILO (2019), on the Universal Thermal Index, which considers the risk of clinical health effects when the heat limits are reached and the exposed person keeps working, but also the loss in productivity when someone reduces his or her metabolic rate by slowing the pace of work to avoid such effects (Kjellstrom et al., 2009). As such, they do not reflect empirically measured changes in output in each sector. Third, the data generated here pertain to a 7-week period of the year and are not sampled across the entire year. Most notably, they do not include the hottest part of the year, from March to May. This final factor is likely to mean that the data here represent a low estimate of heat stress and its impacts on workers.
5. While Productivity loss is a predicted outcome, another outcome is also deteriorating health especially where livelihood concerns or the pressure to maintain production rates push workers to continue functioning. Oppermann et al. (2020) observes this of open pit mine workers in northern Australia among whom chronic heat stress was widespread as it was internalized and normalized. Indeed, she observes how individualized chronic heat stress enabled the assemblage of mine production to remain functional rather than being disruptive of production. Working despite heat stress is also related to increased risk of making mistakes leading to work-related accidents (see Kjellstrom et al., 2018; Mathee et al., 2010).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Wellcome Trust [grant number 227968/Z/23/Z] and UKRI Future Leaders Fellowship [grant number MR/W013797/1].

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References

Acharya, P., Boggess, B., & Zhang, K. (2018). Assessing heat stress and health among construction workers in a changing climate: A review. *International Journal of Environmental Research And Public Health*, *15*(2), 247. https://doi.org/10.3390/ijerph15020247

Anderson Hoffner, L., Simpson, J., Martinez-Fernandez, M. C., & Patumtaewapibal, A. (2021). *Turning up the heat: Exploring potential links between climate change and gender-based violence and harassment in the garment sector*. ILO Working Paper 31.

Asante, A. D., Ir, P., Jacobs, B., Supon, L., Liverani, M., Hayen, A., … Wiseman, V. (2019). Who benefits from healthcare spending in Cambodia? Evidence for a universal health coverage policy. *Health Policy and Planning*, *34*(Supplement_1), i4–i13. https://doi.org/10.1093/heapol/czz011

Basu, R., & Ostro, B. D. (2008). A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *American Journal of Epidemiology*, *168*(6), 632–637. https://doi.org/10.1093/aje/kwn170

Birkmann, J., Liwenga, E., Pandey, R., Boyd, E., Djalante, R., Gemenne, F., Leal, W., Filho, W., Pinho, P. F., Stringer, L., & Wrathall, D. (2022). Poverty, livelihoods and sustainable development. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the sixth assessment report of the intergovernmental panel on climate change* (pp. 1171–1274). Cambridge University Press. https://doi.org/10.1017/9781009325844.010

Buller, M. J., Delves, S. K., Fogarty, A. L., & Veenstra, B. J. (2021). On the real-time prevention and monitoring of exertional heat illness in military personnel. *Journal of Science and Medicine in Sport*, *24*(10), 975–981. https://doi.org/10.1016/j.jsams.2021.04.008

Burkart, K. G., Brauer, M., Aravkin, A. Y., Godwin, W. W., Hay, S. I., He, J., Iannucci, V. C., Larson, S. L., Lim, S. S., Liu, J., & Murray, C. J. (2021). Estimating the cause-specific relative risks of non-optimal temperature on daily mortality: A two-part modelling approach applied to the Global Burden of Disease Study. *The Lancet*, *398*(10301), 685–697. https://doi.org/10.1016/S0140-6736(21)01700-1

Casa, D. J., Becker, S. M., Ganio, M. S., Brown, C. M., Yeargin, S. W., Roti, M. W., Siegler, J., Blowers, J. A., Glaviano, N. R., Huggins, R. A., Armstrong, L. E., & Maresh, C. M. (2007). Validity of devices that assess body temperature during outdoor exercise in the heat. *Journal of Athletic Training*, *42*(3), 333–342.

Chung, H., Li, J., Kim, Y., Van Os, J. M., Brounts, S. H., & Choi, C. Y. (2020). Using implantable biosensors and wearable scanners to monitor dairy cattle's core body temperature in real-time. *Computers and Electronics in Agriculture*, *174*, 105453. https://doi.org/10.1016/j.compag.2020.105453

Desroches, A. J., Naulleau, C., Deshayes, T. A., Pancrate, T., & Goulet, E. D. (2023). CORE™ wearable sensor: Comparison against gastrointestinal temperature during cold water ingestion and a 5 km running time-trial. *Journal of Thermal Biology*, *115*, 103622. https://doi.org/10.1016/j.jtherbio.2023.103622

Diffenbaugh, N. S., et Barnes, E. (2023). Data-driven predictions of the time remaining until critical global warming thresholds are reached. *Proceedings of the National Academy of Sciences*, *120*(6), e2207183120. https://doi.org/10.1073/pnas.2207183120

Dolson, C. M., Harlow, E. R., Phelan, D. M., Gabbett, T. J., Gaal, B., McMellen, C., Geletka, B. J., Calcei, J. G., Voos, J. E., & Seshadri, D. R. (2022). Wearable sensor technology to predict core body temperature: A systematic review. *Sensors*, *22*(19), 7639. https://doi.org/10.3390/s22197639

Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., & Morris, N. B. (2021). Hot weather and heat extremes: Health risks. *The Lancet*, *398*(10301), 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3

Foster, A., Cole, J., Petrikova, I., Farlow, A., & Frumkin, H. (2020). Planetary health ethics. In S. Myers & H. Frumkin (Eds.), *Planetary health: Protecting nature to protect ourselves* (pp. 453–473). Island Press.

Grineski, S. E., Collins, T. W., McDonald, Y. J., Aldouri, R., Aboargob, F., Eldeb, A., Aguilar M. L., & Velázquez-Angulo, G. (2015). Double exposure and the climate gap: Changing demographics and extreme heat in Ciudad Juárez, Mexico. *Local Environment*, *20*(2), 180–201. https://doi.org/10.1080/13549839.2013.839644

Hansen, A., Bi, L., Saniotis, A., & Nitschke, M. (2013). Vulnerability to extreme heat and climate change: Is ethnicity a factor? *Global Health Action*, *6*(1), 21364. https://doi.org/10.3402/gha.v6i0.21364

Hashim, Z., Shafii, S., Phan, K., Rao, V., & Hashim, J. H. (2018). The impact of heat on the health and productivity of cassava farmers in kratie, Cambodia. *Proceedings of the Summer Crash Course Programme*, 139.

Hintz, C., Presley, D. M., & Butler, C. R. (2024). Heat stroke burden and validity of wearable-derived core temperature estimation during elite military training. *The Physician and Sports Medicine*, *52*(2), 154–159. https://doi.org/10.1080/00913847.2023.2190729

Humphrys, E., Goodman, J., & Newman, F. (2022). Zonked the hell out': Climate change and heat stress at work. *The Economic and Labour Relations Review*, *33*(2), 256–271. https://doi.org/10.1177/10353046221092414

Ibrahim, A. A., Khan, M., Nnaji, C., & Koh, A. S. (2023). Assessing Non-intrusive wearable devices for tracking core body temperature in hot working conditions. *Applied Sciences*, *13*(11), 6803. https://doi.org/10.3390/app13116803

Intergovernmental Panel on Climate Change [IPCC]. (2021). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change* (pp. 3–32). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://doi.org/10.1017/9781009157896.001

Jackson, L. L., & Rosenberg, H. R. (2010). Preventing heat-related illness among agricultural workers. *Journal of Agromedicine*, *15*(3), 200–215. https://doi.org/10.1080/1059924X.2010.487021

Judd, J., Bauer, A., Kuruvilla, S., & Williams, S. (2023). *Higher ground? Report 1: Fashion's climate breakdown and its effect for workers*. Cornell ILR Global Labour Institute.

Khan, M. S., Naidu, T., Torres, I., Noor, M. N., Bump, J. B., & Abimbola, S. (2024). The lancet and colonialism: Past, present, and future. *The Lancet*, *403*(10433), 1304–1308. https://doi.org/10.1016/S0140-6736(24)00102-8

Kjellstrom, T., Freyberg, C., Lemke, B., Otto, M., & Briggs, D. (2018). Estimating population heat exposure and impacts on working people in conjunction with climate change. *International Journal of Biometeorology*, *62*(3), 291–306. https://doi.org/10.1007/s00484-017-1407-0

Kjellstrom, T. (forthcoming). *The emergence of the 'non-health' health effects. Draft manuscript*, forthcoming 2024.

Kjellstrom, T., Holmer, I., & Lemke, B. (2009). Workplace heat stress, health and productivity–an increasing challenge for low and middle-income countries during climate change. *Global Health Action*, *2*(1), 2047, 1–6. https://doi.org/10.3402/gha.v2i0.2047

Kjellstrom, T., & Phan, K. (2016). *Heat exposure and effects on productivity at a garment factory in Phnom Penh, Cambodia – a pilot study*. ClimateCHIP.org, Technical report 2017:1.

Kolesar, R. J., Pheakdey, S., Jacobs, B., Chan, N., Yok, S., & Audibert, M. (2020). Expanding social health protection in Cambodia: An assessment of the current coverage potential and gaps, and social equity considerations. *International Social Security Review*, *73*(1), 35–63. https://doi.org/10.1111/issr.12227

Kong, Q., & Huber, M. (2022). Explicit calculations of wet-bulb globe temperature compared with approximations and why it matters for labor productivity. *Earth's Future*, *10*(3), e2021EF002334. https://doi.org/10.1029/2021EF002334

Kor, P., Vongchanh, K., Heang, L., Chan, S., & Yang, J. (2023). Measurement survey on construction labour productivity under heat stress during the cool season in Cambodia. *Journal of Emerging Technologies and Innovative Research*, 1–8.

Lamarche, D. T., Meade, R. D., D'Souza, A. W., Flouris, A. D., Hardcastle, S. G., Sigal, R. J., & Kenny, G. P. (2017). The recommended Threshold Limit Values for heat exposure fail to maintain body core temperature within safe limits in older working adults. *Journal of Occupational and Environmental Hygiene*, *14*(9), 703–711. https://doi.org/10.1080/15459624.2017.1321844

Levi, M., Kjellstrom, T., & Baldasseroni, A. (2018). Impact of climate change on occupational health and productivity: A systematic literature review focusing on workplace heat. *La Medicina del Lavoro*, *109*(3), 163.

Levit, H., Pinto, S., Amon, T., Gershon, E., Kleinjan-Elazary, A., Bloch, V., Meir, Y. B., Portnik, Y., Jacoby, S., Arnin, A., & Miron, J. (2021). Dynamic cooling strategy based on individual animal response mitigated heat stress in dairy cows. *Animal*, *15*(2), 100093. https://doi.org/10.1016/j.animal.2020.100093

Li, Y., Ren, T., Kinney, P. L., Joyner, A., & Zhang, W. (2018). Projecting future climate change impacts on heat-related mortality in large urban areas in China. *Environmental Research*, *163*, 171–185. https://doi.org/10.1016/j.envres.2018.01.047

Lo, Y. E., Mitchell, D. M., Buzan, J. R., Zscheischler, J., Schneider, R., Mistry, M. N., Kyselý, J., Lavigne, É, da Silva, S. P., Royé, D., & Urban, A. (2023). Optimal heat stress metric for modelling heat-related mortality varies from country to country. *International Journal of Climatology*, *43*(12), 5553–5568. https://doi.org/10.1002/joc.8160

Mathee, A., Oba, J., & Rose, A. (2010). Climate change impacts on working people (the HOTHAPS initiative): Findings of the South African pilot study. *Global Health Action*, *3*(1), 1–9. https://doi.org/10.3402/gha.v3i0.5612

Ministry of Health and Japan International Cooperation Agency [JICA]. (2018). *The project for development of social health insurance for the informal sector in The Kingdom of Cambodia: Final report*. Ministry of Health.

Mitchell, B. C., & Chakraborty, J. (2015). Landscapes of thermal inequity: Disproportionate exposure to urban heat in the three largest US cities. *Environmental Research Letters*, *10*(*11*), 115005. https://doi.org/10.1088/1748-9326/10/11/115005

National Environmental Information Centre [NEIC]. *National Oceanic and Atmospheric Administration Climate Data Record.* Accessed on 05/01/2022 at [https://data.noaa.gov/]

National Institute of Statistics, International Labour Organisation, and Asia Development Bank [NIS, ILO and ADB]. (2019). *Report on the Cambodia Labour Force Survey 2019.* Phnom Penh: NIS, ILO and ADB.

O'Brien, K., Eriksen, S., Inderberg, T. H., & Sygna, L. (2015). Climate change and development: Adaptation through transformation. In T. H. Inderberg, S. Erikson, K. O'Brien, & L. Sygna (Eds.), *Climate change adaptation and development* (pp. 273–289). Routledge.

Odonkor, S. T., & Adams, S. (2022). Climate change-mediated heat stress vulnerability and adaptation strategies among outdoor workers. *Climate and Development*, *14*(*7*), 591–599. https://doi.org/10.1080/17565529.2021.1954867

Oppermann, E., Walker, G., & Brearley, M. (2020). Assembling a thermal rhythmanalysis: Energetic flows, heat stress and polyrhythmic interactions in the context of climate change. *Geoforum; Journal of Physical, Human, and Regional Geosciences*, *108*, 275–285. https://doi.org/10.1016/j.geoforum.2019.09.012

Oxfam. (2020). *Street Vendor Groups: Social Protection for the Most Marginalised Informal Workers*. Retrieved on 23/10/2023 at [https://cambodia.oxfam.org/]

Parsons, L. (2021). Thermal inequality in a changing climate: Heat, mobility, and precarity in the Cambodian brick sector. In N. Natarajan & L. Parsons (Eds.), *Climate change in the global workplace* (pp. 15–31). Routledge.

Parsons, L., Lawreniuk, S., Sok, S., & Buckley, J. (2022). *Hot trends: How the global garment industry shapes climate vulnerability in Cambodia*. Royal Holloway.

Radir, A. F., Hashim, Z., Phan, K., Sao, V., & Hashim, J. H. (2017). The impact of heat on health and productivity among sugarcane workers in Kampong Cham, Cambodia. *Asia Pacific Environmental and Occupational Health Journal*, *3*(1).

Responsible Business Hub. (2022). *Cambodia garment, footwear and travel goods sector brief.* EuroCham.

Richmond, V. L., Davey, S., Griggs, K., & Havenith, G. (2015). Prediction of core body temperature from multiple variables. *Annals of Occupational Hygiene*, *59*(9), 1168–1178. https://doi.org/10.1093/annhyg/mev054

Romanello, M., Di Napoli, C., Green, C., Kennard, H., Lampard, P., Scamman, D., Walawender, M., Ali, Z., Ameli, N., Ayeb-Karlsson, S., & Beggs, P. J. (2023). The 2023 report of the Lancet Countdown on health and climate change: The imperative for a health-centred response in a world facing irreversible harms. *The Lancet*, *402*(10419), 2346–2394. https://doi.org/10.1016/S0140-6736(23)01859-7

Sar, S., Gilbert, R., & Marks, G. (2012). Household rice choice and consumption behaviour across agro-climatic zones of Cambodia. *Journal of Hunger & Environmental Nutrition*, *7*(2–3), 333–346. https://doi.org/10.1080/19320248.2012.707107

Schwalm, C. R., Spencer, G., & Duffy, P. B. (2020). RCP8. 5 tracks cumulative CO_2 emissions. *Proceedings of the National Academy of Sciences*, *117*(33), 19656–19657. https://doi.org/10.1073/pnas.2007117117

Spangler, K. R., Liang, S., & Wellenius, G. A. (2022). Wet-bulb globe temperature, universal thermal climate index, and other heat metrics for US counties, 2000–2020. *Scientific Data*, *9*(1), 326. https://doi.org/10.1038/s41597-022-01405-3

UNCTAD Secretariat. (2022). *The least developed countries report. Prepared by the UNCTAD Secretariat*. UNCTAD.

UNICEF. (2022). *The coldest year of the rest of their lives: Protecting children from the escalating impacts of heatwaves*. UNICEF.

Verdel, N., Podlogar, T., Ciuha, U., Holmberg, H.-C., Debevec, T., & Supej, M. (2021). Reliability and validity of the CORE sensor to assess core body temperature during cycling exercise. *Sensors*, *21*(17), 5932. https://doi.org/10.3390/s21175932

Vicedo-Cabrera, A. M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., … Gasparrini, A. (2021). The burden of heat-related mortality attributable to recent human-induced climate change. *Nature Climate Change*, *11*(6), 492–500. https://doi.org/10.1038/s41558-021-01058-x

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., & Cox, P. M. (2015). Health and climate change: Policy responses to protect public health. *The Lancet*, *386*(10006), 1861–1914. https://doi.org/10.1016/S0140-6736(15)60854-6

Weng, L., Dou, W., & Chen, Y. (2023). Study on the coupling effect of agricultural production, road construction, and ecology: The case for Cambodia. *Agriculture*, *13*(4), 780. https://doi.org/10.3390/agriculture13040780

Wong, L. P., Alias, H., Aghamohammadi, N., Aghazadeh, S., & Sulaiman, N. M. N. (2017). Urban heat island experience, control measures and health impact: A survey among working community in the city of Kuala Lumpur. *Sustainable Cities and Society*, *35*, 660–668. https://doi.org/10.1016/j.scs.2017.09.026

World Bank and Asia Development Bank [ADB]. (2021). *Climate risk profile: Cambodia*. World Bank.

World Economic Forum [WEF]. (2024). *Quantifying the impact of climate change on human health*. World Economic Forum.

World Health Organisation [WHO]. (2024). *Climate change*. Retrieved on 18/04/2024 at [https://who.int]

Zhang, K., Cao, C., Chu, H., Zhao, L., Zhao, J., & Lee, X. (2023). Increased heat risk in wet climate induced by urban humid heat. *Nature*, *617*(*7962*), 738–742. https://doi.org/10.1038/s41586-023-05911-1