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Working Paper 1: Heat Stress in the Cambodian Brick Sector

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Executive Summary

Workers in the Cambodian brick sector face an exceptionally high risk of heat stress due to undertaking heavy work in high temperatures and humidities, as well as working around very hot environments during and after brick firing. Under climate change, this risk is increasing, as very hot days become more common. In Cambodia, the number of very hot days – meaning days over 35˚**C** or a Heat Index of 55+ assuming average humidity of 77% (UNICEF, 2022) – have increased by 46 days per year since 1990 (World Bank, 2021).

This report presents data from a survey of 30 brick workers in three kilns undertaken from 25th of March to May 5th 2023. Workers wore CORE body temperature monitoring devices for seven days whilst undertaking normal daily work. At the end of the day, working activities were collated via a daily activity report in order to assess the extent of their exposure to heat stress and the factors shaping that exposure. Qualitative data were generated to help interpret these data.

The results of the study show that 100% of surveyed workers recorded core temperatures over 38˚C – the generally agreed occupational safe working limit (Lamarche et al., 2017) – during the seven working days of their participation. Within this, brick workers spent on average 8.7% of working minutes with a core temperature over 38˚ C: equivalent to over 6 hours of an average 70 hour working week. However, this varied by brick kiln. In one brick kiln, workers spent 15.23% of working minutes with a core temperature over 38˚ C.

Even higher temperatures were also recorded during working hours. Across the sample as a whole, workers spent 0.79% of working minutes with a core temperature over 39˚ C: equivalent to an average 30 minutes per average 70 hour working week. Moreover, this figure also varied significantly by kiln. In one case, the average figure was 1.74% of working minutes with a core temperature over 39˚C. Across all 30 workers, two cases of heat stroke - clinically defined as a core temperature in excess of 40˚C – were identified. In one case, a worker spent 7.1% of working minutes with a core temperature over 40˚C, equivalent to almost 5 hours of an average 70 hour working week.

The type of work undertaken by brick workers played a major role in their exposure to heat stress. The three forms of work found to be associated with the highest levels of heat stress were: removing bricks from the kiln, which saw 14.06% of working minutes spent over 38˚C; carrying bricks, which saw 33.13% of working minutes spent over 38˚C; and removing ash from the brick kiln after firing, which saw 48.27% of working minutes spent over 38˚C.

Although working factors played the largest role in worker heat stress, ambient environmental factors were also significant. A heat index in the range of 25-30 was associated with an average core temperature of 37.05˚ C, whilst a heat index in the range of 55-60 was associated with an average core temperature of 37.33˚ C: a difference in average core temperature of 0.28˚ C. "Very hot" days – with a maximum heat index over 55 – were associated with a significantly higher proportion of workers experiencing acute heat stress. On days where the heat index reached 55+, 0.9% of working minutes were spent with a core temperature over 39˚ C, compared with 0.8% on days which did not reach a heat index of 55. At higher core temperatures the relationship was stronger still: 0.4% of working minutes were spent with a core temperature over 40˚ C, as opposed to 0.3% of working minutes on "normal" days.

Climate Change and Heat Stress in the Cambodian Brick Sector

The world is now 1.2 degrees warmer than the 1960s, making heatwaves twice as likely as the historical average. With global temperatures expected to reach 1.5 degrees above pre-industrial levels by the end of the decade (Diffenbaugh and Barnes, 2023), this is expected to double again, making once-a-decade heatwaves almost biannual events (IPCC, 2021). For billions of people around the world, excess heat is thus no longer a climate future, but an everyday part of life and work. Heat related deaths worldwide increased by 74% between 1990 and 2016 (Hill and Babin, 2021), with the most extreme single heatwaves claiming tens of thousands of lives and 'orders of magnitude more people requiring medical treatment and hospitalization' (Mitchell, 2021: 467).

Yet exceptional events like this belie a more mundane, but deadlier, reality. Without a major shift in course, more than three quarters of humanity will 'face the threat of dying' from extreme heat by 2100 (Leahy, 2100: 1). Heat under climate change is not, for most, a sudden shock, but an everyday emergency, a creeping 'crisis ordinary' (Berlant, 2011) of ill health, disease, fatigue and reduced productivity (Levi et al., 2018). The health impacts of prolonged heat exposure range from acute impacts such as heatstroke, to less visible, chronic disease vulnerability, especially when high temperatures meet high humidity and even more so when combined with heavy work (Levi et al., 2018). These impacts take a wide variety of forms: not only heat death, but impaired health, wellbeing and productivity.

What makes these impacts especially hard to assess, however, is the role of socio-economic factors in shaping exposure to heat extremes. In a meteorological sense, heat waves are measured geographically, yet their impact on human populations is much more varied. Heat stress, like cold exposure, is socially rather than geographically determined. The thermal experience of climate change is thus determined not by one's position in space, but one's position in society. The jobs we do, the roles we play in society, the conditions we work in, and our freedom within those roles, all shape our exposure to the changing climate.

This makes interpreting human vulnerability to heat stress highly complex and leaves considerable knowledge gaps as to nexus of health and heat. A particular impediment to bridging these gaps has been that the practical difficulties of measuring the everyday impacts of heat stress has impeded efforts to assess its harm to working populations. Yet recent technological advances in thermal measurement have begun to change this. Body worn thermal measurement is now accurate enough to provide vital data on hard-to-reach populations, without the need for a researcher to be present at all times, or for work to be interrupted to take readings.

This report presents data from one of the first detailed studies to employ this new technology, thus shining a new light on heat stress amongst brick workers, one of the most vulnerable populations to rising temperatures worldwide. Brick workers in Cambodia labour in extremely high temperatures, inside and around kilns that can reach up to 1500 degrees during firing and which are not adequately cooled by the time that workers must enter the kilns to stack and collect bricks. Evidence of the health impacts of working in such high temperatures has been outlined in qualitative reports by Licadho (2007; 2016) and Brickell et al. (2018). However, this report provides the first evidence of the extent of the heat exposure faced by brick workers.

This paper is thus the first to examine how climate-linked heat stress impacts brick workers producing materials for £1 billion+ of UK investment in Cambodia: both one of the world's hottest countries (NCEI, 2022) and amongst those most blighted by forced labour, ranked 9th globally in 2019 and 2nd in 2016 (GSI, 2019; 2016). Debt bondage, in particular, is a major issue, as shown in the *Blood Bricks* report (Brickell et al., 2018), which highlighted the extreme, often lethal, temperatures faced by bonded brick workers. However, whilst the *Blood Bricks* report was the first to evidence how climate change shapes entry to bonded labour, it stopped short of generating concrete evidence on health impacts. This working paper bridges that evidence gap, providing the first scientific data on heat stress in the Cambodian brick sector.

2. Climate Change and Brick Work in Cambodia

The brick sector is a vital component of Cambodia's growing economy, fuelling its recent boom in urbanisation. As per the most recent available figures, the sector comprises some 464 operational kilns, predominantly located along Cambodia's major waterways, the Mekong and the Tonle Sap. The brick sector is a feature of most Cambodian provinces, with 21 of Cambodia's 25 provinces possessing at least one kiln. However, the largest proportion of kilns – 109 kilns or 23.5% of the nation's total – are situated in Kandal province (BWTUC, 2020).

As of 2020, the population of the brick industry – i.e. those currently resident within brick kilns – stood at 10,217 people, of whom 4777 are female, 5440 are male, and 3937 people are aged under 18. With respect to this last figure, it should be noted that a significant proportion of those resident in brick kilns report are not currently employed in it. The total number of those confirming their employment in the brick industry is 6863 people of which 3098 are female, 3765 are male and 638 are aged under 18. Nevertheless, there is some uncertainty around these figures due to the informal nature of brick work (BWTUC, 2020).

Most brick workers do not possess a formal employment contract. Instead, they rely on family groups to organise work. In many cases, brick kiln owners thus tend not to view most of the people living on their worksites as their employees. Rather, workers are paid on a piece rate basis and family labour is used ad hoc at busy periods, which may mean that the above figures underestimate the true extent of underage labour. In place of employment contracts, most brick workers are debt bonded to the kiln in which they work. This means that they are unable to work elsewhere until they have repaid their outstanding debt to the brick kiln owner through piece rate work. The average loan owed to a brick kiln owner is 700 USD, but loans of several thousand are common (Brickell et al., 2018).

Like the majority of the industrial workforce in Cambodia, brick workers are predominantly migrant workers. Brick workers not only originate from every province in Cambodia but also from Vietnam in some cases. Nevertheless, the data demonstrate clear patterns in the province of origin of the brick kiln residents, with migrants from Kandal – at 2508 and 24.4% – and Prey Veng – at 2345 and 22.8% – making up almost half of the current brick kiln population. Moreover, viewed at a smaller scale, brick worker locations of origin are observed to be even more geographically concentrated. In total, 24 districts in Cambodia supply over 100 workers to the brick industry each, whilst three districts: Preah Sdach in Prey Veng, and Mukh Kampul and Ksach Kandal in Kandal province each supply over 500 workers to the brick industry. Mukh Kampul district alone supplies over 1200, over 1/8th of the brick kiln population of Cambodia.

2.2 The Health Impacts of Heat Stress in the Brick Sector

> *"Brick kiln work has harmed my health, I nearly died. I suffered from bleeding because the place was extremely hot …Most workers have health problems like me…and whilst some workers were allowed to go home, some died. The owner's only assistance was giving them a coffin to be buried in" (Tola, Brickell et al., 2018)*

Stories such as the above, by a female Cambodian brick worker, highlight a brutal truth about climate change: heat kills, but it kills the exploited first and fastest. Under climate change, heat stress becomes a viscous cycle that 'impedes progress towards decent work' (ILO, 2019: 18). Wherever they are found, forced labour and heat death go hand in hand.

As predominantly debt bonded workers, brick workers in Cambodia fully reflect this relationship. Many brick workers exist at the extremes of the human body's endurance. Bonded by debt into years of debilitating physical labour, those who produce the bricks feeding Cambodia's runaway construction boom must work at temperatures high enough to cause spontaneous nosebleeds and fainting, as well as a range of other health issues. After years of toil under such conditions, joints begin to degrade, eyes to fail and lungs to falter. All the while, punctuating this slow physical decline are sporadic events of sudden death from overwork, as parents, husbands, brothers and children expire without warning. Rather than being by-products or incidental occurrences, illness, injury and death are an integral part of work here.

The sweltering conditions of the kilns soon take their toll on formerly healthy bodies. Already heavy and physically demanding work is imbued with an additional dimension of difficulty by the extreme temperatures at which it must be carried out, often exceeding 50˚C or more in the vicinity of the kiln itself. At busy times, the drive to minimise the cycle of production sees workers encouraged into the kilns before they are properly cool, forcing workers to undertake strenuous activity in temperatures so high that fainting is a common risk, as one worker recounted:

> 'The fire made the kiln red hot inside. When we were working there for one or two hours the heat from the kiln strongly affected our bodies. As I recall, I fainted once during my work at a boat kiln [*lor touk*][1]. It was too hot as a result of burning bricks with more expensive firewood at the time (Sina, former brick worker, cited in Brickell et al., 2018)

Even beyond the immediate impact of this work, the long-term effect on the body is significant. Many workers report a higher incidence of illness after beginning work in the kiln, as well as idiosyncratic health problems associated with brick dust and other contaminants related to burning material in the kilns. Brick workers are affected by illnesses 'such as fever, [as] they are affected by the heat of the kiln, especially during removing hot burning charcoal and bricks from the kiln' (Sothi, brick worker, cited in Brickell et al., 2018). Moreover, as a former worker explained:

> 'It harmed my health almost to the point of death; I had blood falling [from me] because the place was extremely hot. Later, I went to check on my health at the state hospital…[where] most workers had health problems like me. They had problem with their lungs: most of them looked thinner and thinner, [but whilst] some workers were allowed to go home, other

[1] Boat kilns [*lor touk*] are the most common form of brick kiln in Cambodia. Each kiln is around 30m long and semi-cylindrical, in a manner similar to an upturned longboat.

> workers had died and the owner had helped the family only by providing a coffin' (Brick working family, cited in Brickell et al., 2018)

The result of working in these conditions is a higher rate of short- and long-term ill-health amongst brick workers. Known short-term health impacts include regular headaches, dizziness, limb weakness, difficulty concentrating, and fainting. Known long term impacts of work in the brick sector include heart and kidney problems, whilst in the most severe cases work under severe heat stress may result in sudden or premature death. The data below will extend understanding of both the extent of heat stress experienced by workers, and the link between heat stress and brick worker health.

3 Methodology

Reflecting the exploratory nature of the methodology, the data presented here were generated in two phases. During the first phase, undertaken from January to March 2023, preliminary qualitative interviews were conducted with brick workers, in order to understand heat impacts in the workplace. This phase centred on a participatory process of project design, facilitated and supported by project partners *Solidarity Centre*. The project team met with brick workers in order to discuss the heat-related issues they faced in the kilns, developing the qualitative and quantitative questionnaires to be deployed in Phase 2. This consultative scoping also informed the sampling methodology employed in Phase 2, ensuring that a spectrum of labour exploitation was captured through site selection and that brick workers' ethical concerns are incorporated into project design.

During Phase 2, a total of 30 brick workers were recruited across three worksites in the brick sector, each of whom wore CORE thermal monitoring devices for one week between March and April, during which point the Cambodian climate is approaching its hottest point. These devices collected core temperature, skin temperature and heart rate data throughout participants' working hours, which were automatically uploaded to an online database. These data were then methodologically integrated with 1) a preliminary quantitative livelihoods, assets and liabilities survey, 2) a daily quantitative surveys of participants' daily activity diaries, including experiences of heat stress, and 3) extended qualitative interviews at the beginning, middle and end of the study.

It should be noted that CORE thermal monitors do not match the level of accuracy of the most sensitive and reliable technologies available, orally ingested thermometric pills and rectal thermometer readings (see Casa et al., 2007 for a comparison of alternative technologies). Indeed, as outlined in a handful of recent papers that have explored the accuracy of these and similar devices (e.g. Ibrahim et al., 2023; Dolson et al., 2022), 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 (Ibrahim et al., 2023; Dolson et al., 2022) and others indicating unacceptable validity (Desroches, 2023; Verdel et al., 2021) compared to rectal and ingested thermal measurements. However, this is largely due to the nature 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), all current CORE studies indicate an acceptable level of accuracy.

In hot and humid environments, such as the context of this study, however, studies (e.g. Verdel et al., 2021) have shown that the measuring bias is downwards, meaning that the CORE sensors tend to underestimate the extent of high heat stress. Given that this study explores participants crossing predetermined thresholds, this is deemed an acceptable bias as it is unlikely that the data generated will overestimate the scale of the problem of heat stress in the contexts explored. This is especially so given that the data concern hard to reach populations with whom data could not be generated using oral or rectal thermometers.

In total, this approach generated an integrated dataset of 218,102 minutes of thermal data, for a total of 3635 working hours recorded, or 121 working hours per worker.

4 Brick Worker Livelihoods in their Own Words

As outlined in previous scholarship on the Cambodian brick sector (e.g. Brickell et al., 2018; Licadho, 2016; 2007), the majority of brick workers arrive in the sector as a result of unmanageable debts incurred due to agricultural failures, or family medical treatment. In the present sample, informants outlined a variety of reasons for entering the brick industry. Typically, some workers related accounts of agricultural issues. One stated that they did so 'because I failed in rice farming and lost money. I could earn enough money to pay for the chemical fertilizer and fuel and no money left for profit' (Worker 16, May 2023). In another, a second informant related that:

> 'I worked as a wage labourer but then I did not have money to pay for my children's wedding party. Then, I borrowed the brick owner and came to work here…I borrowed a lot of money because my wife was sick as well as my children. My children had dengue fever and I needed to send them to the hospital' (Worker 1, May 2023)

Brick workers across all three kilns expressed concern over the high temperatures in which they were required to work. Several workers highlighted the lack of ventilation that intensified the combined heat of the brick kiln and the weather itself. In the words of one worker, 'it is hot and no air because the roof is low... It burns our face and it turns red' (Worker 17, May 2023). However, although almost every worker complained of the high temperatures in which they worked, the most extreme temperatures were faced by those tasked with clearing bricks and other material from the kiln after firing. As one related, the work is 'so hot that when I take the brick out of the kiln, it burns my gloves' (Worker 13, May 2023). Similarly, as a second worker outlined, 'the fan cannot cool it down. When we hold the brick, it burns the glove and sometimes, it burns my hair' (Worker 13, May 2023).

Although the kiln itself is the primary source of heat stress faced by workers, the external environment was cited as a key factor in workers' ability to cope with this work. During the hot season, it is very difficult for workers to cool down, even after exiting the kiln. As one put it, at this time of year, it is 'very hot and it makes our hands and legs weaker. It is not like the cold months. At least then we feel colder [outside]. Moreover, the fluctuation of temperature throughout the day means the highest risk of heat stress occurs in the early afternoon. As one worker related, 'I feel very exhausted every day because it is so hot…I feel hot to the point of dying when it is around 12 or 1 or 2 pm. I cannot stand it' (Worker 2, May 2023).

Faced with working in very high temperatures, brick workers described a significant long-term impact on their health. One worker reported that '[my health] has changed a lot. It was ok in the past. Now I feel really exhausted and starved' (Worker 17, May 2023). As this worker continued, 'the main disease is lung [disease]. When [workers] go to hospital, the doctor always says it's a lung issue. It's because it is very hot (Worker 17, May 2023). A second worker noted, similarly, that 'before the time I worked for the brick kiln, my health was fine. After I worked in the brick kiln, I fall into the sickness, exhausted and when I cough, it makes me [more] exhausted' (Worker 2, May 2023). Not only does working in these conditions have a notable impact on workers' physical health, but in the longer term affects income as well. As one worker explained, 'a family member] called me to work here because I could make more money and yes it did [pay well] at first. Later on, [though] it became less and less. We are always sick and our body is getting weaker and weaker' (Worker 13, May 2023).

A repeated complaint outlined by workers was the lack of consideration given to the physical difficulties of kilns work by the kiln boss. Instead of providing workers with time to rest during periods of high temperature work, workers instead reported a high degree of pressure to work faster, at higher temperatures and with fewer breaks, increasing the risk of heat stress on the body. Workers reported that 'sometimes, we collect the ash alongside burning coal. And if [the boss] needs the bricks urgently, we have to take hot bricks out of the kiln for them' (Worker 17, May 2023). Brick workers report a direct and dangerous impact on their health as a result of high-pressure work in hot conditions. As one worker explained:

> 'When it is hot like this and I pick the bricks from the machine, I sometimes have a heart attack[2] and fall down, as I have a heart disease. The owner of the kiln does not care about us. He doesn't pay attention to us' (Worker 2, May 2023)

A very similar account was outlined by a second worker, who explained that:

> 'I have had [heart problems] when I am working at the brick kiln. It has been around 5 years since I had it. It was hard to breathe and then at some point I could not breathe and my heart stop beating. Then, somebody came to press my chest [perform CPR]' (Worker 17, May 2023)

Workers generally see a combination of factors as underpinning their vulnerability to severe health problems. In particular, three factors are identified as combining to engender the highest level of risk. First, the lack of food that workers are able to obtain from their pay. Second, the difficulty of taking breaks, and third, seasonal weather fluctuations. The combination of these factors is outlined in the following testimonies:

> '[My health is] is extremely exhausted. The owner does not care about the workers. He has not come here since Khmer New Year and paid us. Today, we don't have money to buy food, so we pawned a mobile phone to get some money to buy the food. I don't lie. I speak frankly' (Worker 4, May 2023)

In the words of a second worker:

> 'They don't let us to take a rest till break time. Then, I feel close to dying. If the time is not up, then we have to continue working although we are extremely exhausted…They don't allow us to take a break because they are afraid of slowing down the production. If [somebody] reports [an unauthorised break] to the boss, they will blame us badly…[It is normally hottest in] March and April. However, [this year] it is still hot till May. Now many workers and their children are sick. They are being injected [with glucose in order to work]' (Worker 17, May 2023)

Finally:

> 'If it is so hot like this, we cannot survive as the owner does not allow us to take a short break during the working time…It has been so hot since the Khmer New Year. The owner does not come and they don't lend money. We don't have money to buy food. It is very miserable.

[2] N.B. It is unclear whether self-reported heart attacks are being accurately described. They may refer to severe angina or heart palpitations. However, in either case, the symptoms are strongly related to heart disease, which is statistically linked to work in very hot conditions.

> Some workers look sad and have to find clams and snails at the back of the kiln for food. However, we get blamed by the kiln manager by not working at the brick but going to find the snail and clam' (Worker 17, May 2023)

Despite the harsh conditions endured in the kilns, brick workers have little choice but to persist in their labours due to the inescapability of the debt bonds that the vast majority of workers – and all of this sample – possess. As one worker put it, 'how [can I leave?]! Because we have debt with them. We can't stop working here unless we pay the debt off. I really want to do that but I don't have money to pay off the debt. If I had money, I would go back home' (Worker 1, May 2023). As an industry, therefore, debt bondage underpins a high-risk labour regime characterised by malnutrition, poor health and extremely high levels of heat stress resulting from a combination of heavy work in a hot environment, and acute heat stress linked to the presence of the firing kilns themselves. As outlined in the following sections, the result is an exceptionally high level of heat stress, even when compared to other high-risk occupations, such as construction and garment work.

5 Physiological Data on Heat Stress Experienced by Brick Workers

5.1 Inter-Kiln Variations in Heat Stress

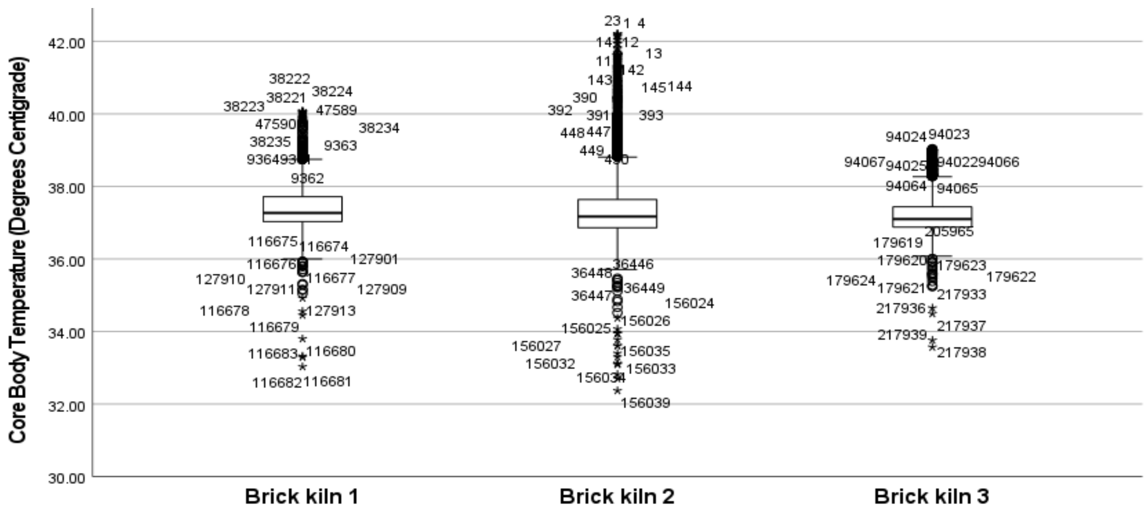
Measuring heat stress in the brick sector requires a degree of nuance in order to capture both the overall level of excess heat exposure, the range of heat stress amongst workers in the site and the most extreme cases of heat stress. Data across all three kilns are presented in Table 1. As would be expected across the duration of a working day, for example, average core temperature does not vary greatly across the worksite as a whole, remaining within the healthy boundaries of 37-37.5˚ C. Nevertheless, the highest temperatures recorded by workers within each kiln site far exceed healthy limits, even within the relatively small sample size of ten workers per kiln, across seven days of data collection.

Table 1. Descriptive statistics on core body temperature by kiln site

Worksite	Mean core temperature (˚ C)	Max core temperature (˚ C)	Min core temperature (˚ C)	Core temperature standard deviation
Brick kiln 1	37.4	40.1	33.0	0.54
Brick kiln 2	37.3	42.2	32.4	0.64
Brick kiln 3	37.2	39.04	33.6	0.41

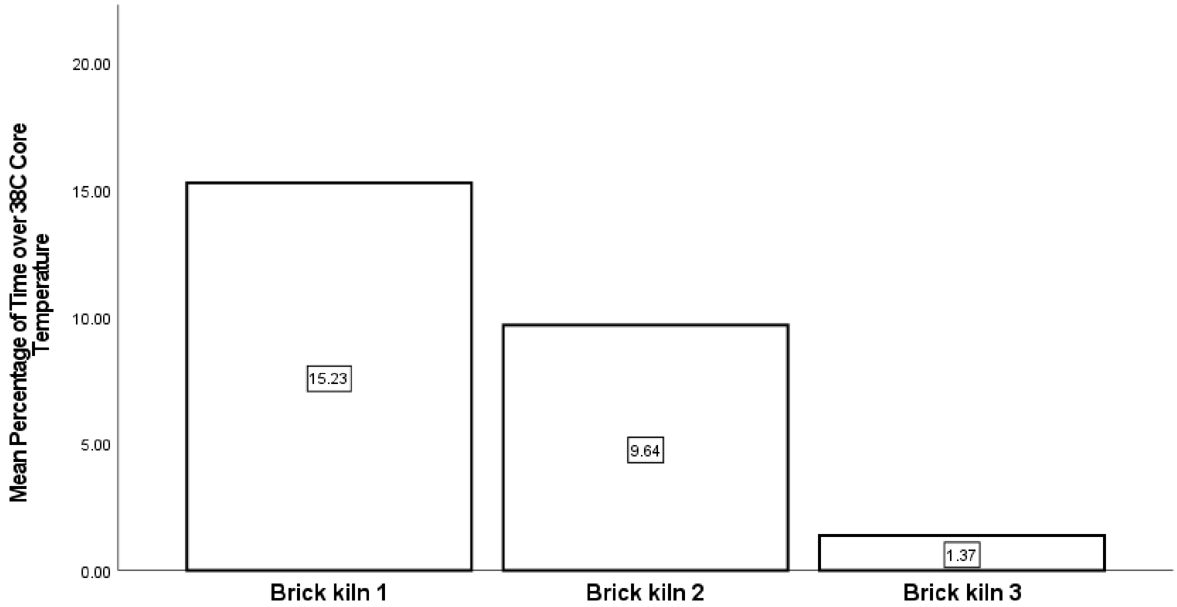
These data are presented visually in Figure 1, for a fuller picture of the range of core temperatures experienced by the participating brick worker population. As these data show, Brick Kiln 2 evidences the highest maximum core temperature recorded across the sample, as well as the greatest range of core temperatures and highest standard deviation. It should be noted that the low temperatures evidenced in the data were almost exclusively outliers, generated when sensing devices were first worn by participants. High temperatures, above the healthy working limit of 38˚C (Lamarche et al., 2017), on the other hand, were experienced by 100% of participants in the study across the study period as a whole, in many cases on a regular basis.

Figure 1. Core body temperature boxplot by kiln site



Indeed, as outlined in Figure 2, workers in Brick Kiln 1 spent over 15% of their working minutes with a core temperature exceeding 38˚C: equivalent to a mild fever and the generally accepted threshold for heat stress. Workers in Brick Kiln 2, evidenced a slightly lower figure, with 9.64% of minutes spent with a core temperature exceeding 38˚C. This figure was considerably lower in Brick Kiln 3, due in large part to a halt in brick production occurring during the study timeframe in this kiln. Nevertheless, the data overall indicate a high level of variation in the prevalence of heat stress across the industry.

Figure 2. Percentage of working minutes with a core temperature over 38˚C, by kiln site



These data are complemented also by those displayed in Figure 3, which show the percentage of time spent by workers in all three kilns above a core temperature of 39˚C: equivalent to a high fever. In Brick Kiln 1, 0.58% of working minutes were spent above 39˚C, whilst in Brick Kiln 2, a much higher figure of 1.74% was recorded, equivalent to 2.5 hours per worker per week, on average, based on an average 70 hour working week. The prevalence of heat stress over 39˚C was once again low in Brick Kiln 3, at 0.04% of working minutes.

Figure 3. Percentage of Working Minutes with a Core Temperature over 39˚C by Kiln Site

5.2 Intra-Kiln Variations in Heat Stress

Tables 2, 3 and 4 present data on the distribution of heat stress prevalence *within* each of the three studied brick kilns. These data show the percentage of time spent by each of the 30 surveyed workers within five core temperature boundaries between 36˚C and 41˚C.

Table 2. Distribution of working minutes within core temperature boundaries by worker, Kiln 1

		Kiln 1			
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚C+ (% mins)**
1	20.9	72.7	6.3	0	0
2	51.8	44.7	2.7	0.6	0.2
3	26.3	64.4	9.3	0	0
4	5.1	57.7	36.5	0.6	0
5	27.1	72.4	0.5	0	0
6	2.4	51.4	44.8	1.4	0
7	11	81.2	7.4	0.5	0
8	9.9	56.4	31.1	2.6	0
9	27.2	68.7	4.2	0	0
10	24.4	75.4	0.2	0	0

As outlined above in Table 2, which displays data obtained from Brick Kiln 1, the proportion of time spent above the safe working core temperature level of 38˚C varies substantially between workers. Whilst every worker in Brick Kiln 1 spent at least some time above 38˚C, the proportion of time varied from 0.2% of working minutes, in the case of Worker 10, to 44.8% of working minutes in the case of Worker 6. In addition, half of workers in Brick Kiln 1 spent at least some working minutes above a core temperature threshold of 39˚C, varying from 0.6% of working minutes in the case of Workers 2 and 4, to 2.6% of minutes in the case of Worker 8. Finally, one worker in Brick Kiln 1, Worker 2, recorded a core temperature of over 40˚C, the threshold for clinical heat stroke.

Table 3. Distribution of working minutes within core temperature boundaries by worker, Kiln 2

		Kiln 2			
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚C+ (% mins)**
1	10.3	62.9	25.5	1.2	0
2	14.6	78.9	6.5	0	0
3	11.4	71.4	17.2	0	0
4	69.3	27.9	2.8	0	0
5	38.9	54.3	6	0.7	0
6	30.2	46.8	9.9	6	7.1
7	44.1	50.4	5.5	0	0
8	57.6	42	0.4	0	0
9	66.3	31.2	2	0.6	0
10	21	77.9	1.2	0	0

The individual worker data for Brick Kiln 2 reflect the overall lower proportion of working minutes spent with dangerous core working temperatures, shown above in Figure 2. As in Brick Kiln 1, the proportion of time spent above the safe working core temperature level of 38˚C varies substantially between workers. Whilst every worker in Brick Kiln 2 spent at least some time above 38˚ C, the proportion of time varied from 0.4% of working minutes, in the case of Worker 8, to 25.5% of working minutes in the case of Worker 1. In addition, 3 workers in Brick Kiln 1 spent at least some working minutes above a core temperature threshold of 39˚ C, varying from 0.6% of working minutes in the case of Workers 9, to 1.2% of minutes in the case of Worker 1. Finally, one worker in Brick Kiln 1, Worker 6, recorded a core temperature of over 40˚ C, the threshold for clinical heat stroke. This 7.1% of working minutes spent in clinical heatstroke – over 10 hours based on an average 70 hour working week – is the highest of any surveyed worker.

Table 4. Distribution of working minutes within core temperature boundaries by worker, Kiln 3

Kiln 3					
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚˚ C+ (% mins)**
1	8	84.4	7.6	0	0
2	33.9	65.3	0.8	0	0
3	23.2	71.8	4.8	0.2	0
4	60.7	39.3	0	0	0
5	39.9	59.5	0.7	0	0
6	18.4	81.6	0	0	0
7	17.7	75.9	6.4	0	0
8	45	54.7	0.4	0	0
9	77.3	22.4	0.3	0	0
10	46.4	52.1	1.5	0	0

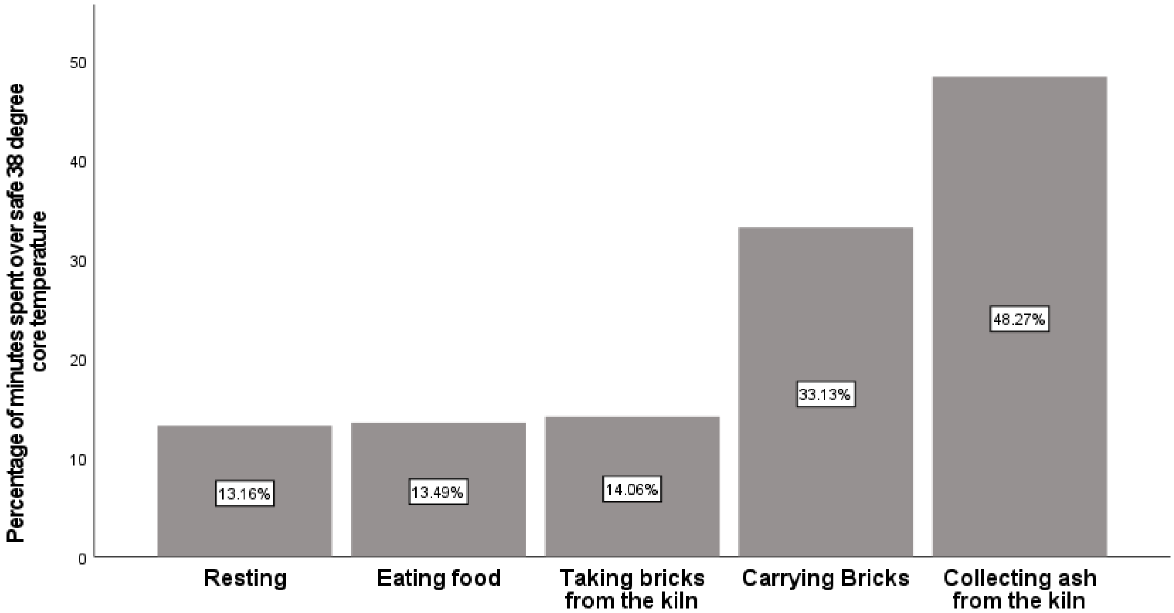
The individual worker data for Brick Kiln 3 reflect the relatively low proportion of working minutes spent with dangerous core working temperatures, shown above in Figure 2. As in Brick Kilns 1 and 2, the proportion of time spent above the safe working core temperature level of 38˚C varies substantially between workers. However, unlike Brick Kilns 1 and 2, some workers in Brick Kiln 3 recorded no core temperature readings above 38˚ C. Two workers spent 0 minutes above 38˚ C, with the highest proportion of time above this threshold being 7.6% of minutes, in the case of Worker 1. Only 1 worker in Brick Kiln 3, Worker 3, spent any working minutes above a core temperature threshold of 39˚ C, whilst no workers recorded a core temperature above 40˚ C.

5.3 Heat Stress by Activity

Figure 4, below, presents the proportion of time spent above the safe core temperature threshold of 38˚C, according to activity. This figure presents data on major activities undertaken by brick workers in the course of the study. Only activities with at least 1000 minutes of valid core temperature data across the three kilns are included. As it shows, brick workers either resting or eating spent on average 13% of their time above a safe core temperature. Although these figures are the lowest of any activity, they are much higher than would be expected in other occupations. This is likely due to, first, the high ambient temperature of brick kiln sites themselves, where firing kilns are located relatively close to worker accommodation, and second, to the overlap of high intensity activities with periods of rest, both of which are recorded by the research team in one-hour blocks.

Of the remaining activities, significantly different proportions of working minutes spent in heat stress were recorded. The lowest of these, "taking bricks from the kiln", saw just over 14% of working minutes spent with a core temperature over 38˚C, whilst brick workers "carrying and drying bricks" spent 33.13% of their working minutes undertaking this activity with a core temperature over 38˚C. The activity with the highest average core temperature was "collecting ash from the kiln", during which workers spent 48.27% of their time with a core temperature over 38˚ C.

Figure 4. Heat Stress by Activity across all three brick kilns



The below tables break down these data by kiln, in order to highlight commonalities and differences between key brick sector activities undertaken in each of the three kilns. As shown in Table 5, the lowest proportion of time spent with a core temperature over 38˚C was recorded when workers were taking bricks from the kiln. However, this activity was also the only one to see workers record a core temperature over 40˚C: the threshold for clinical heatstroke. As in the aggregated data, resting workers exhibited a higher core body temperature than might be expected, likely explained by the interspersing of rest with heavy or hot activities. The activities with the highest proportion of working minutes spent over 38˚C were carrying bricks and collecting ash from the kiln, at (a combined total) of 34.3% and 57.7% respectively.

Table 5. Distribution of working minutes within core temperature boundaries by activity, Kiln 1

		Kiln 1			
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚˚ C+ (% mins)**
Resting	19.5	61.6	18.9	0	0
Taking bricks from kiln	46.3	49.8	2.9	0.8	0.3
Carrying bricks	9.4	55.7	32.1	2.8	0
Collecting ash from the kiln	1.6	40.6	55.5	2.2	0

Stacking bricks inside the kiln	19	73.7	7.3	0	0

Table 6 shows core temperature data by activity in Brick Kiln 2. Unlike Kiln 1, resting was associated with the lowest percentage of time spent with a core temperature over 38˚C. However, in contrast to both kilns 1 and 3, collecting ash from the kiln was one of the activities associated with the lowest core temperatures. Taking bricks from the kiln was the activity associated with the highest proportion of time spent with a core temperature over 38˚C, at 19.4% of working minutes. This was closely followed by carrying bricks, at 16.16% of working minutes, and stacking bricks in the kiln, at 13.4% of working minutes.

Table 6. Distribution of working minutes within core temperature boundaries by activity, Kiln 2

Kiln 2					
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚˚ C+ (% mins)**
Resting	43.3	51.2	3.8	0.9	0
Taking bricks from kiln	21.8	58	19.4	0.8	0
Carrying bricks	25.7	57.7	16.6	0	0
Collecting ash from the kiln	47.2	48	4.3	0.5	0
Stacking bricks in the kiln	21.6	64	13.4	1	0

Reflecting the aggregated data presented in Figures 2 and 3, Table 7 shows workers in Brick Kiln 3 to be associated with the lowest overall proportion of time spent with a core body temperature over 38˚C. Reflecting this, and unlike the data from Kilns 1 and 2, one activity – stacking bricks in the kiln – evidenced no minutes spent by workers with a core temperature over 38˚C. The activity associated with the highest core temperature was taking bricks from the kiln, with collecting ash from the kiln – as in Brick Kiln 1 – producing one of the highest proportions of minutes over 38˚C, at 9.8%.

Table 7. Distribution of working minutes within core temperature boundaries by activity, kiln 3

Kiln 3					
Worker	**36˚ -37˚C (% mins)**	**37˚ -38˚C (% mins)**	**38˚ -39˚C (% mins)**	**39˚ -40˚C (% mins)**	**40˚˚ C+ (% mins)**
Resting	41.7	56.8	1.5	0	0
Taking bricks from kiln	34.8	53.6	11.6	0	0
Drying bricks	47.4	51.9	0.7	0	0
Collecting ash from the kiln	8.3	81.9	9.8	0	0
Stacking bricks in the kiln	69.2	30.8	0	0	0

These differences in the core temperature of brick workers, even whilst undertaking the same activities highlights the importance of specific labour regimes in place within each brick kiln. In some cases, brick kiln owners may allow longer for the brick kiln to cool after firing or permit a greater number of breaks than in other kilns, for example. These factors likely contribute substantially to increasing or decreasing the level of heat exposure faced by workers.

5.4 Environmental Conditions and Worker Heat Stress

In addition to the work undertaken, workers' core body temperature is primarily influenced by two additional variables – temperature and humidity – in combination. Nevertheless, if either of these variables is separately compared with worker core body temperature, a weak relationship at best is usually observed. In the case of brick workers, there was no significant corelation between (separately) either temperature or humidity and core body temperature. For comparative purposes, these data are shown in Figures 5 and 6, below.

Figure 5. Brick worker core body temperature compared with ambient temperature

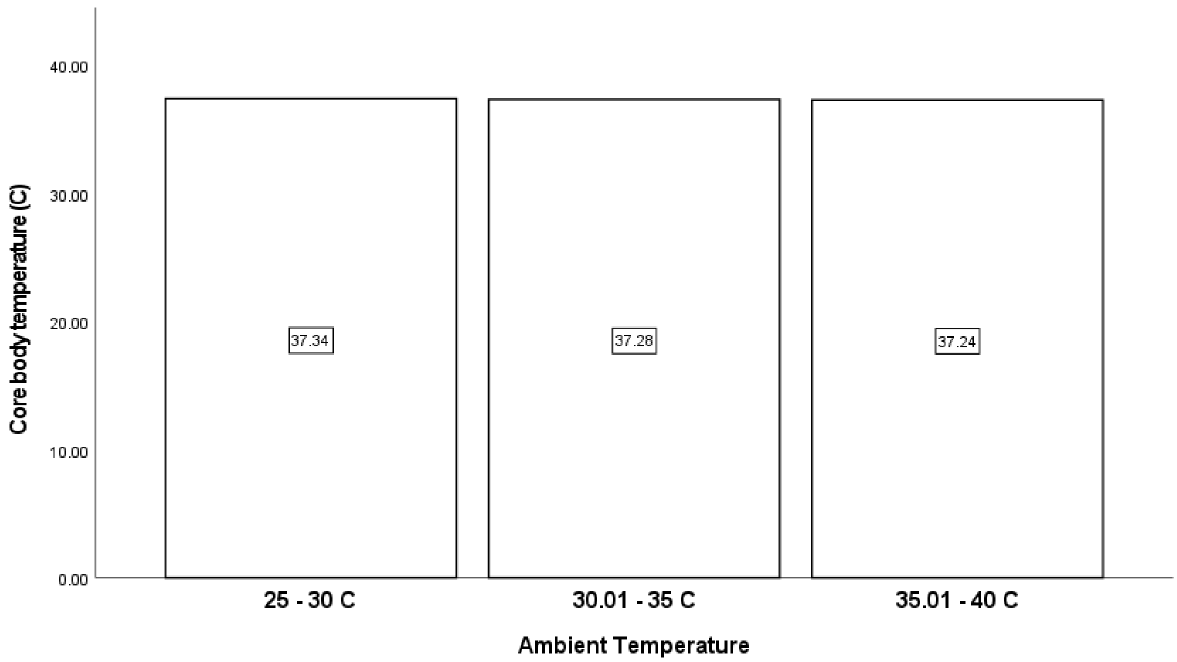
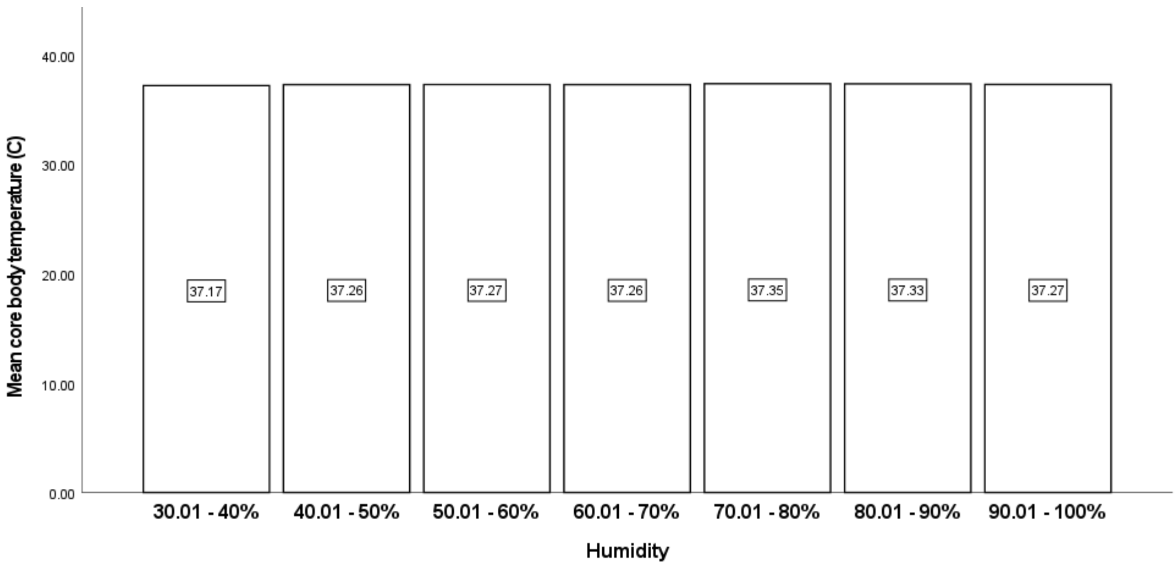
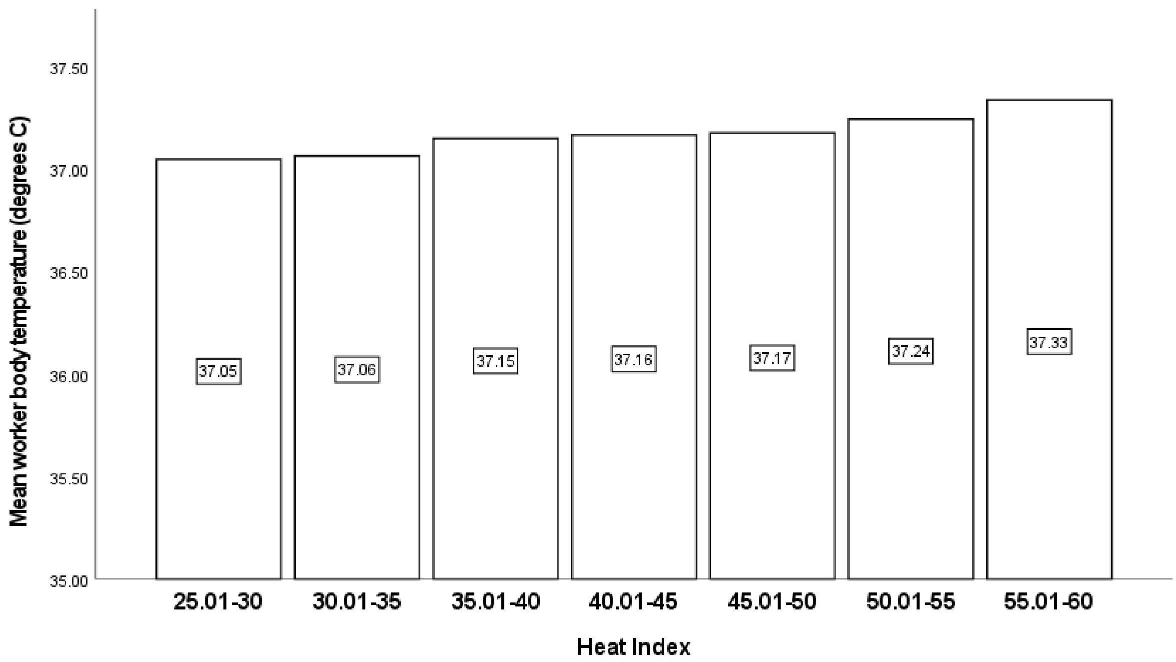


Figure 6. Brick worker core body temperature compared with ambient humidity



Nevertheless, although neither variable has a significant impact on worker core body temperature in isolation, their influence in combination is significant. The combined influence of these two variables is best expressed as the combined variable Heat Index, which broadly expresses what the temperature feels like to the human body when relative humidity is combined with the air temperature. All other factors being equal, the heat index thus correlates closely with to the risk of heat stress amongst human populations, as shown also by various authors on brick work (e.g., Lundgren-Kownacki, 2018; Hajizadeh et al., 2016). However, as evidenced in the above data, specific activities play a major role in shaping heat stress. Thus, the question of how environmental conditions and work industry interact is a key question for understanding brick worker vulnerability under climate change.

Figure 7. Brick worker core body temperature compared with ambient heat index

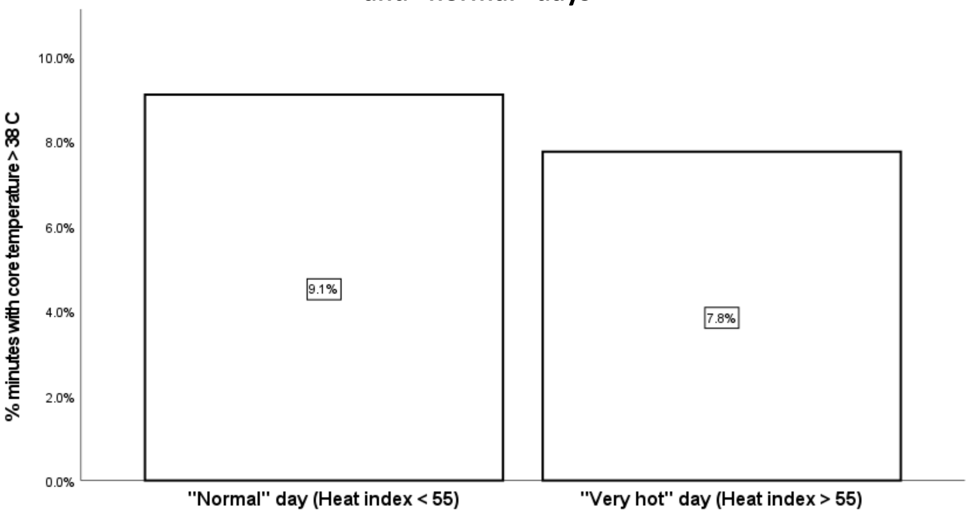


As shown in Table 7, ambient heat index has a clear and significant impact on brick workers' core body temperature, albeit a small one. To contextualise these data, the lowest recorded heat index, 25-30 is equivalent (at its middle point) to an air temperature of 24˚C at 100% humidity or 29˚C at 10% humidity. By contrast, highest heat index range recorded, 55-60 is equivalent to 41˚C at 50% humidity or 46˚C at 30% humidity[3]. Taking the annual mean Cambodian humidity of 77% (World Meteorological Association, 2014) as a reference point therefore, these data suggest that it would require an increase in ambient temperature of 10 degrees Celsius – from 25 C to 35˚C – in order to raise brick workers' average core temperature by 0.28˚C from 37.05˚C to 37.33˚ C.

Using these data as a baseline, it is possible also to calculate the implications of projected temperature changes due to climate change on brick worker exposure to heat stress. Humidity is not expected to change significantly as a result of climate change (WMO, 2014). However, with temperatures rising at a rate of 0.2-0.23˚C per decade, Cambodia's average heat index is expected to increase (World Bank, 2021). Of particular relevance here, under the most severe RCP 8.5 emission scenario, the number of "very hot days" – defined as days over 35˚C in the Cambodian context – is projected to increase by 49.2 days per year by 2050 from 64 days per year as of 2020 to 113.2 days by 2050.

Assuming average humidity of 77%, a 35˚C ambient temperature equates to a heat index of 55. Thus, from a total sample of 14 days undertaken during the course of the study, it is possible to identify 6 days that qualify as "very hot" because the heat index exceeded 55, and 8 days that do not qualify as "very hot" because the heat index remained below 55 throughout the day. Comparing the difference in brick workers' core temperature data on "very hot" days and "normal" days did not produce a clear relationship with the percentage of minutes spent with a core temperature over 38˚ C. Indeed, as shown in Figure 8, the percentage of working minutes spent over 38˚C is actually slightly lower on very hot days (9.1% versus 7.8%). This may reflect the capacity of some brick workers to avoid the heaviest work on the hottest days, or it may be a function of when the data were collected, with many workers in the sample coincidentally having less work on the hottest days.

Figure 8. Percentage of working minutes spent with a core temperature over 38˚C on "very hot" and "normal" days

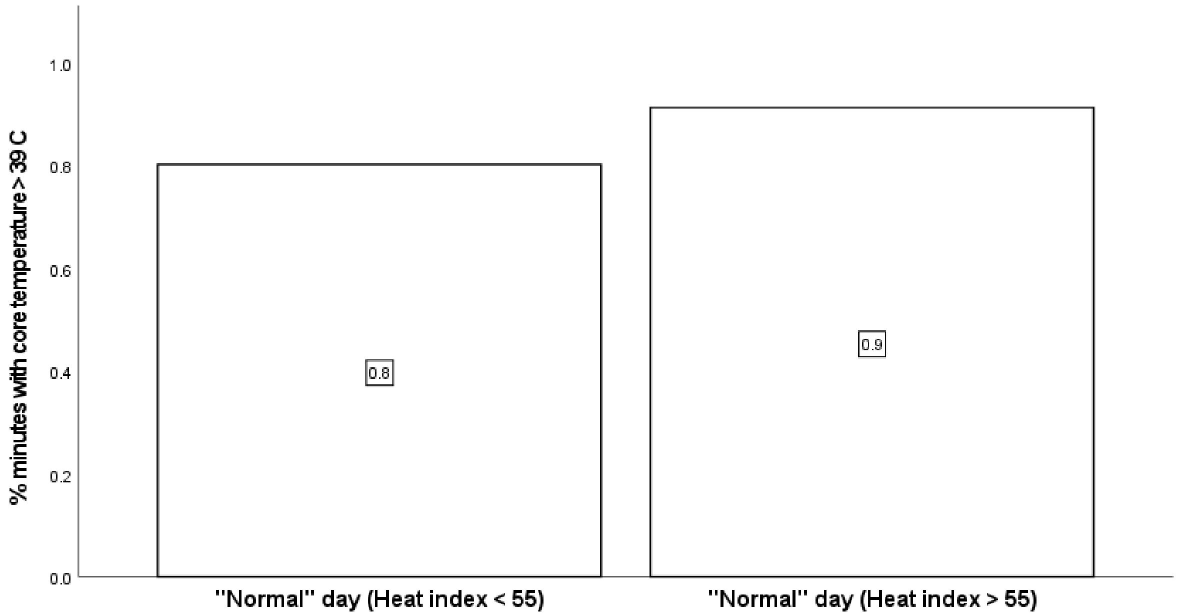


Nevertheless, the data on higher core temperatures presents a clear relationship between the hottest days and the highest core temperatures experienced by workers. As shown in Figures 9, brick workers

[3] See Appendix A for a chart of heat index calculation

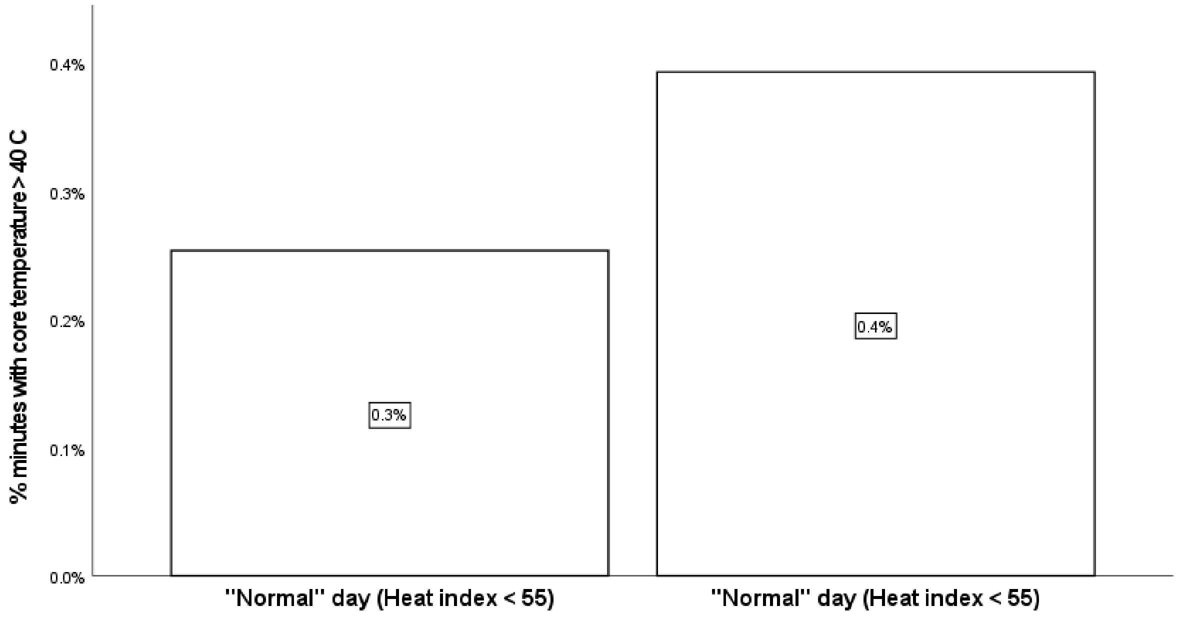
spend on average 12.5% more minutes with a core temperature over 39˚C (0.8% of minutes against 0.9% of minutes) on “very hot” days, compared with “normal” days.

Figure 9. Percentage of working minutes spent with a core temperature over 39˚C on “very hot” and “normal” days



The relationship becomes clearer still when considering higher core temperatures. As shown in Figure 10, the percentage of minutes spent by brick workers with a core temperature over 40˚C – clinically defined as heatstroke – is over 33% higher (0.4% of minutes against 0.3% of minutes) on “very hot” days as opposed to “normal” days.

Figure 10. Percentage of working minutes spent with a core temperature over 40˚C on “very hot” and “normal” days



With 40˚C being the threshold at which elevated core temperatures usually require active medical intervention, this implies an important relationship between the growing number of “very hot” days occurring under climate change and the health impacts of work in the brick sector. Indeed, if these small-scale data are extrapolated to the industry as a whole – working population 6864 (Parsons and Ly, 2020) – this suggests that 20 workers are currently experiencing heat stroke on any given “normal” day during the hot season. On “very hot” days, this rises to 27 brick workers on any given day. Based on the evidence of this sample, therefore, the additional 49.2 “very hot” days expected in Cambodia by 2050 would be expected to produce an additional 344 incidences of heat stroke in the brick industry each year.

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Appendix A. Calculation of the Heat Index

Relative Humidity %	Air temperature °C										
	21	24	27	29	32	35	38	41	43	46	49
0	18	21	23	26	28	31	33	35	37	39	42
10	18	21	24	27	29	32	35	38	41	44	47
20	19	22	25	28	31	34	37	41	44	49	54
30	19	23	26	29	32	36	40	45	51	57	64
40	20	23	26	30	34	38	43	51	58	66	
50	21	24	27	31	36	42	49	57	66		
60	21	24	28	32	38	46	56	65			
70	21	25	29	34	41	51	62				
80	22	26	30	36	45	58					
90	22	26	31	39	50						
100	22	27	33	42							

Serious risk to health - heatstroke imminent

Prolonged exposure and activity could lead to heatstroke

Prolonged exposure and activity may lead to fatigue