Title: Heat exposure, heat strain, and off-work recovery of Guatemalan sugarcane workers

Running head: Sugarcane workers' heat exposure, heat strain, and recovery

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NEW & NOTEWORTHY:
This study examined the trajectory of heat exposure and core body temperature (Tc) across the workday into off-work hours among agricultural workers at risk of heat related illness. Workday heat strain was common, and a significant proportion of workers experienced higher off-work Tc compared to their workday Tc. Survey and environmental data collected from workers provide insights into the off-work practices and conditions of the home environment that could influence recovery of workers.

Keywords: Heat stress; Agricultural workers; Recovery; Home environment

Abstract

Background: Agricultural workers are at high risk for heat related illnesses when performing heavy labor in hot conditions. Occupational heat strain, the physiological response to heat stress, is hypothesized to be common in this worker population but has rarely been measured objectively through core body temperature (Tc). The objective of this study was two-fold 1) evaluate workday heat strain and 2) examine the trajectory of heat exposure and Tc from the workday through the off-work hours to advance understanding of the recovery process and conditions of heat-exposed agricultural workers.

Methods: Among 55 male Guatemalan agricultural workers, individual heat exposure (using ambient temperature loggers) and Tc (via an ingestible pill) were measured across a 24-hour period including workday and off-work hours. Urine samples were collected to assess hydration status on and off-work. Workers reported off-work activities, hydration practices, sleep, and nutrition through a survey. Data were summarized using descriptive statistics and visualizations.

Results: Workers experienced excessive heat strain (44% with Tc > 38.0 °C, 16% with Tc > 38.3 °C, and 6% with Tc > 38.5 °C) during the workday. Approximately 29% achieved a higher maximal Tc during off-work hours than during the workday. Nearly 15% of workers reported sleeping < 7 hours.

Discussion: There is a need to understand off-work conditions, practices, and resources available to workers to mitigate heat strain and related illnesses. Heat stress and Tc monitoring should extend to post-work shift for assessment of workers'

physiological recovery and to inform more comprehensive interventions to protect worker health.

Introduction

Heat stress, dehydration, intense physical labor and exposure to toxins and toxicants are some of the occupational hazards experienced by agricultural workers in Latin America (1–9). Since agricultural workers frequently labor outdoors, they are at high risk of morbidity and mortality due to heat exposure. The projected rise in global temperatures due to climate change will further increase workers' susceptibility to excessive heat exposure (10). Often, workers have limited access to potable water and adequate nutrition at the worksite, are unable or disincentivized to take rest breaks, and have limited training and awareness of heat-related adverse health outcomes (11). Such working conditions put workers at a higher risk for heat related illnesses (HRI) and have prompted researchers and policy makers to consider how to modify work practices to mitigate HRI. However, less is known about how heat exposure and social determinants of health faced by workers in their off-hours — outside the workplace — may contribute to the overall risk of HRI. Among the many socioeconomic disparities they experience, agricultural workers worldwide frequently live in housing without air conditioning or adequate ventilation needed for recovery from the heat and exertion during their workday (12–17).

Environmental as well as occupational risk factors contribute to the heat stress, or net heat load, experienced by workers. Environmental factors include heat, humidity, and solar radiation, while exertional heat stress results from metabolic heat that is generated internally through physical activity, such as that performed in agricultural work settings (7,18). During such physical activity in hot environments, the body dissipates heat by increasing skin blood flow and sweat rate; however, the metabolic heat production can sometimes exceed these heat loss mechanisms. In such situations, heat stress is considered uncompensable, where core body temperature (Tc) will continue to rise (19,20) increasing the risk of heat-related illnesses and injuries, mortality, as well as lost productivity (18). Repeated bouts of heat strain, the physiological response to heat stress, and elevated Tc further increase the risk for HRI (21) and are associated with long term adverse physical and mental health effects (22).

Current guidelines that address heat exposure in occupational settings include the National Institute for Occupational Safety and Health's (NIOSH) *Criteria for a Recommended Standard – Occupational Exposure to Heat and Hot Environments* (18). Meanwhile, off-work heat exposure, including temperature related to living conditions in the home environment, has been evaluated only minimally among agricultural workers, primarily in the United States (23) and more recently in a sample of sugarcane workers in Nicaragua (24). Agricultural workers may be exposed to high temperature and humidity levels during their off-work hours that inhibits the normal decrease in Tc that occurs naturally during sleep (25), thus limiting their ability to fully recover from the heat and exertion of their workday.

Despite the recognition of the short and long-term health and economic impacts of heat stress, occupational heat exposure continues to cause morbidity and mortality among agricultural and other workers (26,27). While agricultural workers have frequently reported symptoms of HRI (3,28–30), few studies have examined heat strain objectively in this population, through measurement of Tc during work. Furthermore, the trajectory of agricultural workers' Tc off-work will be useful for evaluating workers' response to heat stress, for example, by examining the pattern and recovery of Tc at the end of the workday and overnight. Our central hypothesis is that some workers are unable to cool off, and therefore recover, after their workday, creating a cumulative effect of heat stress and exertion that increases the risk for adverse health outcomes and HRI. The information presented in this paper is helpful for informing next steps for understanding the cumulative burden of heat stress in this high-risk population that can ultimately lead to the development of more effective interventions that are needed to better address the effects of heat on workers.

The primary objective of this paper is to characterize heat exposure and physiological response (Tc), both on and off-work, among a group of male Guatemalan sugarcane workers considered to be at particularly high risk of work- and off-work related heat stress. We will describe the continuous trajectory of core body temperature from the workday through the off-work recovery period, i.e., until the start of the following workday (24 hours). To characterize workers' temperature exposure over a full 24-hour period, we examined the variability of ambient environmental temperature using heat index measurements as well as individual ambient temperature loggers worn at work and home. Finally, we describe workers' off-work recovery practices reported in a survey and through urinary hydration measurement.

Methods

Study population: This study was conducted with male sugarcane cutters who were employed for either the 2021-2022 or 2022-2023 six-month harvest season by the agribusiness Pantaleon, in southwest Guatemala. These workers represent a subset of study participants whom we recruited as part of the "CKDu Heat and Air Pollution" (CHAP I) Study (grant R01 ES31585) focused on occupational exposures and practices during the work shift. All participants were at least 18 years old at the time of recruitment and were residing in local communities in the coastal lowland region surrounding the sugarcane fields. The sugarcane harvest lasts from November – May. During their work shift, sugarcane cutters manually cut and stack cane in the fields for approximately eight hours per day with two hours of interspersed rest, roughly from 7:00 to 17:00, and each man cuts on average six tons of cane daily (31). Rest breaks include two 30-minute breaks, taken in the shade, including one in the morning around 10:00 and one in the afternoon around 14:30, as well as a one-hour break for lunch at noon. Workers are provided with free access to purified water directly in the field and, in addition, receive at least five liters of electrolyte solution daily. Other details of the work setting and practices have been published previously (5). When these workers have completed their work shift, they return home to their communities each evening on non-air conditioned buses. This commute can take from 30 minutes up to two hours, each way, to their worksite and back depending on the daily field location. Workers return to homes in the communities that lack air conditioning or other cooling mechanisms such as fans, with limited ventilation. As a pilot (n=9), we assessed the conditions of the home environment that may contribute to heat exposure among a subset of workers involved in this study. Additional details will be described further below.

Study Design: This cross-sectional descriptive study characterized individual heat exposures for this group of agricultural workers, following them individually for 24 hours to include both their workday (CHAP I study) and off-work exposures (sub-study). For the sub-study, the period of observation and data collection was extended to include time off work (~ 17:00 to 06:00 the next morning). Across the two years of fieldwork, the study design was integrated within CHAP I at one of the three time points during the six-month harvest. Over a 6-day period in February 2022 (Days 1-6) and a 4-day period in April 2023 (Days 7-10) measures of heat exposure and Tc response were collected during the workday and the off-work period. February represents the approximate mid-point of the harvest season, while April is closer to the end of the season, allowing us to sample workers who are acclimatized to the climate and work (18). A total of 55 workers were evaluated from 10 work groups. Data were collected from one work group (2-9 workers) each study day.

Briefly, to begin the 24-hour monitoring period, workers and the research team arrived at the surgarcane field at approximately 06:00 where workers provided a urine sample, had body mass measured, were given a Tc monitoring pill to ingest, and were equipped with an ambient temperature logger; a wet bulb globe temperature meter was set up in the field. At the end of work around 17:00, researchers returned to the field to meet the workers and collect another urine sample and provide a second pill. To end the 24-hour monitoring period another urine sample and survey data were collected the following morning in the sugarcane field before the start of the next workday. Details about each measurement are provided below.

Ethics: The participants for this study were recruited and consented in November 2021 and November 2022. Workers who could not sign their name provided a thumb print with a witness present. This research was approved by the Colorado Multiple Institutional Review Board (COMIRB #20-0509) of the University of Colorado and the Comité de Ética Independiente ZUGUEME in Guatemala.

Heat index: Environmental data were collected on heat exposure by two methods. During the workday, wet bulb globe temperature (WBGT) data were measured continuously in the sugarcane fields within approximately 1 km of all workers using the Kestrel 5400 (Kestrel Instruments, Boothwyn, PA). These data were used to calculate the heat index (HI) which was derived from dry temperature and humidity using the National Weather Service formula through the *weathermetrics* package in R (32,33).

Personal temperature monitoring: Personal ambient temperature (Tpa) was collected for each individual worker in the fields during the workday and in those same individuals during off-work hours at home using a small, wireless temperature logger (Hygrochron™ iButtons, model DS1923, Maxim Integrated, California, USA) set to record temperature once every 10 minutes. The temperature loggers were mounted to plastic key fobs and worn by workers on a running vest during the workday.At the end of the work shift, the temperature logger placement was moved from the vest to a bracelet around the wrist. The data were downloaded each day using the 1-Wire® viewer software (Maxim Integrated™, California, USA).

Core body temperature: Core body temperature (Tc) was measured from the start of the workday through the next morning using a pill-sized ingestible telemetric sensor (Bodycap e-Celsius Performance®, Caen, France) that measures and saves data. Ingestible, telemetric temperature capsules are used to measure gastrointestinal temperature, particularly in field and occupational settings, and are considered both a valid and reliable surrogate indicator of Tc (34–36).

Study workers ingested the telemetric pill the morning of their monitored workday, shortly before starting their shift. The external wireless receiver (e-Viewer, BodyCap, Caen, France) for the telemetric pill was worn in a fanny pack around the waist by the workers to receive the data from the pill in real time (at work and off-work) before it was excreted (36). Pilot testing with the telemetric pills in this population revealed two main takeaways. One, if workers were provided with the pill the night before their workshift, many workers excreted the pill before work began the next morning, as other researchers have observed (37); therefore the pill was given to workers shortly before the workshift. Second, although the pill records data, it was often excreted prior to meeting the research team at the end of the work day. Therefore, to limit missing data, workers were equipped with the wireless receiver to collect the data before excretion.

Because of the rapid excretion of the pill observed in pilot testing, workers were asked to take a second pill at the end of their work shift prior to returning home, a practice which had been cleared as safe by the pill manufacturer. The number of workers who could have their Tc monitored overnight on each of the 10 study days varied based on how many receivers were available (Table 2).

Recovery survey, hydration and anthropometric measures

Workers were weighed in work clothing only (pants and long-sleeved shirt) with boots, shin guards and other equipment removed. The morning weight was measured with a digital scale that was calibrated prior to each data collection session (Seca 874 DR, Seca Corporation, Chino, CA) and was used to calculate body mass index (BMI) with height which had been collected at baseline in November (beginning of the harvest) of each study year. Hydration was assessed by urine specific gravity (USG) immediately in the field using a digital refractometer (5) (ATAGO PAL-10S, Tokyo, Japan). Urine samples were collected at the end of the workday to evaluate workday hydration and the next morning pre-shift to estimate off-work hydration. A recovery survey was administered verbally in Spanish at the end of the 24-hour monitoring period to ask workers about their recovery practices after work, i.e., the evening and overnight prior. The survey included questions related to hydration, sleep and rest quantity and quality (38–40), and nutrition, behaviors including off-work medication, tobacco, and alcohol use, how and when they arrived home the previous evening, activities they did after arriving home, the time they went to bed, and the time they woke up that morning.

Statistical Analysis

Data cleaning: Our goal was to collect and analyze continuous environmental and core body temperature over a 24-hour period. Since workers ingested the first pill for the workday and the second pill for the off-work period, the Tc data were initially comprised of two separate datasets; potential “overlap” between the two pills was not a concern since each pill was linked to a separate receiver. To address the missing data in the Tc measurements, which occurred at random, we removed individuals from analysis with more than 30% missing data or through visual inspection to determine whether there were sufficient data across the monitoring period. A total of 55 participants had both Tpa and workday Tc and were included in the final dataset for analysis, with 64 participants (54%) having been removed for missing either Tc or Tpa data. Of the final 55, 17 workers had off-work Tc available for analysis. Other than calculation of heat index as described above and Tc data cleaning described below, all analyses were conducted using SAS version 9.4 (Cary, NC, USA).

Several measures were taken to clean and smooth the Tc data based on methods applied in similar work (37,41). First, to allow time for the pill to reach the lower gastrointestinal tract and for the readings to stabilize, we excluded observations within the first 60 minutes from the time the pill was ingested at the beginning of the monitoring period to begin analysis. Next, there were abrupt decreases in Tc that were outside of physiological plausibility given the body cooling measures that are available in the fields to the sugarcane cutters. These abrupt changes (termed the "bouncing ball" effect) were likely due to beverage consumption (36,37). To clean the Tc data, a script in R Statistical Software (v4.4.1; R Core Team 2021) developed by Petropoulos and colleagues (41) was employed, which flagged physiologically implausible drops in the Tc data resulting from the "bouncing ball" effect—but otherwise deemed usable—and removed Tc data outliers based on a) the magnitude of the slope between neighboring points 1, 2, and 3 points away, or b) the data point was deemed physiologically implausible based on the change in Tc. These methods are described in detail by Petropoulos et al. All Tc data were then smoothed using local regression (LOESS).

Data analysis: Descriptive statistics were generated to characterize heat exposure (Tpa and heat index) and Tc on and off work. Descriptive statistics are reported as mean ± standard deviation (SD) and maximum unless otherwise stated. The average and maximum for Tc and ambient temperature for each individual during the workday and off-work period were used separately, and also produced descriptive statistics for each Study Day (1-10) and each hour of the monitoring periods. For figures of heat exposure and Tc data, a smoothed line was fit with 95% confidence interval (CI) using LOESS regression estimation procedures and splines, in SAS (9,42). Heat strain is presented as Tc exceeding 38.0 °C, 38.3 °C or 38.5 °C for at least two consecutive measures, in accordance with the the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV®) for safe repeated exposure to heat stress and to be consistent with other occupational studies using the telemetric pill. (41,43–45). Briefly, the ACGIH TLV incorporates both internal metabolic and environmental heat factors, and states that for acclimatized, euhydrated, and unmedicated workers to be exposed to heat stress conditions safely, Tc should not exceed 38.0 °C (100.4 °F) “for extended periods”, the level which indicates heat strain, although it is not clear what the limit of time should be, and agricultural workers often labor long hours daily under heat stress conditions (18,46). The 2017 TLV (47) further states that while most individuals should maintain Tc below 38.3°C, in some cases, i.e., acclimatized individuals who are under close medical supervision and physiological monitoring, Tc may safely exceed 38.3, but should go no higher than 38.5 °C (101.3 °F) (18), the level which indicates excessive heat strain. The TLV references personal risk factors that should also be considered, such as chronic health conditions as well as repeated heat exhaustion, since there is evidence of a “carry-over effect” from heat exposure on the previous day (47). While at rest, human body Tc is generally maintained close to 37 ± 0.5 °C, with the lowest Tc level occurring around 04:00 and the highest typically around 18:00 (48,49).

Results

Table 1 displays cohort demographics and anthropometric data. The median age of the cohort was 29 years (interquartile range (IQR): 24, 36). The average weight was

57 ± 6 kg and the average body mass index was 21 ± 2 kg/m^2 . Most workers (96%) were "normal weight" based on BMI. The average hours worked per day during the study period was 9.5 ± 0.5 hours.

Workday data

Table 2 shows the average workday heat index and Tpa across the 10 study days, with the frequency (%) of heat strain (exceeding Tc of 38.0 °C, 38.3 °C, and 38.5 °C) on each day. Based on the Tpa data, Study Days 7 and 10 had the highest mean temperatures. The highest average HI was on Day 9 (39.4 °C). Study Days 8 and 10 saw the highest frequency of individuals exceeding a Tc of 38.0 °C (80%) followed by Day 4 and then Day 3. Day 4 was the coolest day based on HI, and yet 75% of workers exceeded a Tc of 38.0 °C, while 3 workers also exceeded 38.3 °C and 2 workers exceeded 38.5 °C. At least 50% of study participants exceeded a Tc of 38.0 °C on four of the 10 days.

Overall, 44% of workers experienced workday heat strain (exceeded 38.0 °C), 16% exceeded 38.3 °C and 6% exceeded 38.5 °C (Table 2). Figure 1 shows a time series with LOESS estimate of the central tendency of Tc of the workers across the workday period and on average, Tc increased across the workday. A total of five individuals (9%) were dehydrated (USG > 1.020) post-shift. Two of the five workers (one on Study Day 4 and the other on Study Day 8) also exceeded Tc 38.0 °C on the day they were dehydrated.

During the workday, Tpa temperature increased until ≈ 13:00 then decreased slightly until the end of the workday (Figure 2). Shown in Table 2, the average Tc across all workers during the workday was 37.3 °C ± 0.5 °C) and reached an average maximum of 37.9 ± 0.4 °C in the early afternoon. The average and maximum Tc tended to increase across the day (Figure 1). Workers who exceeded Tc of 38.0 °C did so starting from the 10:00 am hour until the end of the workday.

Off-work data

The Tpa temperatures were lower during the early evening hours and started to increase around 21:00-22:00 (Figure 2) until about 03:00 when they started to decrease again, on average. Tc measures were highest from 19:00 to 22:00. The hourly off-work Tpa and Tc data can be viewed in the Appendix.

Figure 3 displays the off-work trajectory of Tc following the workday. The average off-work max was 37.6 °C and was recorded early in the off-work period, between 18:00-20:00 before starting to decrease after 20:00. As described above, after 20:00 when Tc started to decrease, Tc gradually increased sometime after 04:00, which is also when many workers are beginning to wake up and get ready for the commute to work the next day, described further below. On average, Tc decreased by one degree during the off-work/overnight period. Seven workers (41%) exceeded 37.5°C while off-work. No one exceeded Tc of 38.0 °C during the off-work period. Five individuals (29%) experienced a higher or equal off-work max Tc compared to their max workday Tc. These data are shown in the Appendix (Table S2 and Figure S1) which contains Tc and Tpa data for each of the workers individually across both the workday and off-work period, as well as the workers' reported time returning home from work and time they reported going to bed, as a preliminary assessment of off-work practices. Of note, in the same survey, which is detailed further below, most workers, including those individuals with higher (> 37.5°C) off-work Tc, reported not doing any physical activity like sports playing after work and most arrived home after dark (Table S3).

Among at least four individuals (24%), their Tc off-work increased again after having already reported going to bed, before they woke up the next morning. Indeed, in Figure 3, average Tc increased just before 02:00, and decreased again just before 04:00. As shown in the Appendix (Table S1) and Figure 2, the average Tpa was also elevated at this time, during the 01:00-1:59 hour.

Recovery practices

Workers' reported practices from the Recovery Survey and off-work hydration are displayed in Table 3. The survey was administered just before workers began their next workday, at the end of the 24-hour monitoring period; the average amount of time elapsed since waking up and the AM survey time was 2.8 hours (range: 1.5 - 4.4 hours). Few workers were dehydrated in the morning (5.5%), although approximately three quarters reported drinking fewer than 5 cups of water after leaving work the previous day, before bed, and 35% had only had one cup of water since waking up that morning. Workers consumed a range of other beverages during the off-work period, shown in the Appendix, including atol, which is a warm, traditionally corn-based beverage, coffee, juice or soda, and electrolyte solution.

In terms of sleep and rest, 15% slept fewer than seven hours overnight; approximately the same proportion reported this to be their usual amount of sleep (18%). The average amount of time spent at home between shifts was 10 hours (range: 8-13 hours). Several questions were asked related to sleep issues, shown in Table 3. Six workers (11%) reported feeling exhausted when they woke up that morning. One of the 6 workers who felt exhausted were among those who reported sleeping fewer than seven hours overnight. Shown in the Appendix, 5 workers (9%) reported feeling neither alert nor sleepy at the time of the survey, and one worker felt sleepy. Most workers were sharing a bed with at least one other person (partner or child), with 15% sharing with 2 other people, and 4% with 3 others. Just 2 workers reported doing any physical activity after work – either playing sports or doing work around their home/land.

No one reported drinking alcohol during off-work hours, and one individual reported taking an unnamed medication, to help with sleeping. Four workers (7%) reported feeling a little to moderately hungry before going to bed. Of those four, one of them was among the six who reported feeling exhausted. Four percent (two workers) reported that their family did not have enough food to eat during the previous month. The most common foods that workers reported eating for dinner were beans (44%), chicken or meat (33%), rice or pasta (27%) and eggs (18%). Other examples of foods consumed by a minority of workers (< 10%) included soup, cheese, and potatoes. Corn tortillas are commonly consumed at most meals by the workers in this population, based on anecdotal evidence and our prior experience with and knowledge of workers' diets (50), however workers did not specifically report tortillas in this survey.

Discussion

In this study we characterized the trajectories of ambient and core body temperature, across both the workday and off-work hours, among male Guatemalan sugarcane workers at daily risk for HRI. We found that a high proportion (44%) of workers experienced heat strain, a known risk factor for developing HRI (Tc > 38.0 °C) during the workday, including 16% who exceeded 38.3 °C and 6% who exceeded Tc

38.5 °C, despite workplace hydration and rest break programs. In this study, Tc increased on average across the workday, and continued to rise after ambient temperature began to fall in the late afternoon. Over 40% of workers sustained a Tc > 37.5°C while off-work, thus exceeding what is considered the human body's normal range of resting Tc (49). We found preliminary evidence that some workers' Tc may not sufficiently decrease, and may even increase, after going to bed. We do not yet know whether the off-work findings are primarily driven by the inability to cool down following heat strain during the workday, to the conditions of the home environment, normal diurnal variation, or perhaps multiple factors. Workers' Tc decreased by 1.0°C on average during off-work/overnight hours. As has been noted by other researchers, it is not yet understood what 'normal' Tc recovery looks like in this or other agricultural worker populations, both during rest breaks and after the completion of the work shift (51). Approximately 29% of workers experienced a higher off-work max Tc compared to their workday max Tc, which tended to occur several hours after having already left work for the day. Future research is needed to further assess how much heat strain is extending into the off-work period, and whether conditions of the home environment are conducive to nighttime cooling and recovery. Finally, our evaluation of the off-work recovery practices of workers provides preliminary information of workers' available time and resources for recovery in their off-work period, which will guide future intervention research to improve health in this population.

A strength of the study was that it was conducted during the second half of sugarcane harvest season at a time that workers were already acclimatized to the heat. Acclimatization, which improves thermoregulation, has been shown to be one of the most important prevention measures against heat related illness (HRI), both in workers and in athletes (18). And yet, we saw that acclimatized workers still experience heat strain. Our results are similar to findings from a three-day study in Florida among fernery workers which also used the ingestible pill to measure Tc, finding that Tc exceeded 38.0 °C at some point on 61% of the workdays, and that 83% of workers had Tc ≥ 38.0 °C on at least one of the days (37). In that study, among those who had three full days of data (N = 37), 32% had 1 day, 16% had 2 days, and 41% had all 3 days on which Tc ≥ 38.0 °C (37), indicating that workers are experiencing heat strain on consecutive days. Another study among agricultural workers in the central valley of California found 8.5% of workers had a Tc ≥ 38.5 °C during a work shift (51). A study by Petropoulos and colleagues (2023) conducted among sugarcane workers in El Salvador and Nicaragua found between 41% and 81% of workers exceeded 38.0 °C for at least 5 minutes (41). Finally, a recent study among sugarcane workers in Brazil observed all nine participants exceeded 38.0 °C and roughly half met or exceeded 38.5 °C. Other studies of heat stress in agricultural workers have often depended on reporting of symptoms of HRI by workers using questionnaires. Our previous studies have shown that reliance on self-reported symptoms may underestimate the true burden of HRI in this population. For example, in a study at the same sugar mill, only three (3%) participants reported common signs and symptoms of HRI (5). This discrepancy in reported and measured HRI highlights the importance of additional studies with objective field measurement of heat strain to better understand the current extent of HRI among agricultural workers, as well as the future burden due to rising temperatures from climate change (52). These data are also valuable for developing practical heat exposure thresholds in workplace settings, and for measuring the impact of interventions to prevent HRI and other negative health outcomes, such as kidney injury (5).

Workers in this study were provided with purified water, electrolytes and mandatory rest breaks by their employer (5). Few (9% overall) were dehydrated at the end of the work shift based on USG. Nonetheless, we found that many workers' Tc reached 38.0 °C before 12:00, similar to what was observed among sugarcane workers in Brazil (45) and was often sustained or continued to rise across the work shift, despite ambient temperature decreasing in the afternoon. These findings combined with those of other researchers (37,51) suggest that current work-to-rest schedules such as those recommended by NIOSH (18) and a new occupational heat rule proposed by the Occupational Safety and Health Administration (OSHA) (https://www.federalregister.gov/documents/2024/08/30/2024-14824/heat-injury-and-illness-prevention-in-outdoor-and-indoor-work-settings) should be further evaluated for safe strenuous work under these environmental conditions, especially at the level of work intensity of sugarcane harvesting, which is likely to be even higher than that of some other types of farm work, pointing to the need for more context-specific guidance (51,53). In the new proposed OSHA rule, which would be the first federal heat safety standard for workers in the United States, the threshold for providing drinking water and break areas begins at a heat index of 26.7 °C. Employers must monitor for signs of HRI and provide mandatory 15-minute rest breaks every 2 hours beginning at 32.2 °C. In the present study, the average heat index across the study period was 36.8 ± 4.7 °C. Finally, regarding Tc, most agricultural workers are not under close medical supervision or physiological monitoring, which the ACGIH states should be the case for workers exceeding Tc thresholds of of 38 °C or 38.3 °C (47). Since these workers are exposed to heat stress conditions daily, it is important to also consider the potential health impact of such "carry-over" heat exposure that accumulates from one day to the next, across the harvest season (47).

We found that Tc continued to rise even after the work shift ended, and a significant proportion (41%) exceeded the normal range of Tc while at rest after work (> 37.5 °C). Almost one third experienced a higher or equal off-work max Tc compared to their max workday Tc. The pattern of off-work Tc varied among the workers in this sub cohort. Survey data indicated the workers rarely participated in physical activity during the off-work time (only 2 workers reported any additional activity). Based on the limited amount of time (10 ± 1 hours) at home, we believe that most would only have had enough time to eat and rest prior to the next workday. Additional research is needed to understand the variability of Tc recovery both during and after work in this population.

Based on the Tpa data, environmental temperature increased after workers reported going to bed. We speculate that workers may spend the first part of their evening outside where it is cooler, returning inside to sleep. Therefore, it will be helpful to better understand the drivers of off-work heat exposure, since it is known that a hot sleep environment can inhibit normal declines in Tc during the night, and also may increase risk for HRI and other health effects (54). The average off-work environmental temperatures collected with the iButtons were comparable to those observed in a recent study in Nicaragua (24). Through the pilot home visits, we observed that most homes consisted of 1-2 rooms, with one or zero windows. No one had air conditioning available, and few had access to a fan. Nearly all homes used an open wood-burning stove for cooking, sometimes located inside the home, with little ventilation. The majority of homes had little to no shade cover available from trees or other vegetation, and roofs and siding are constructed of corrugated metal sheeting. Future work will further assess these home environment factors.

It is important to understand off-work recovery practices that may be beneficial in helping workers recover and prepare themselves for work the following day, as are frequently recommended for athletes competing in hot environments. The preliminary information presented here from the surveys provide insights into workers' available time and resources, especially those related to hydration, rest, and nutrition, that are necessary for their physical and cognitive recovery. Future studies should include examination of the relationship of Tc with measures of physical exertion (9,55). In this study, workers' Tc continued to rise during the workday even after ambient temperature began to fall in the late afternoon; it may be that workers exert additional effort during this period to increase their production.Overexertion may also explain why levels of heat strain were so high on Day 4, which was the coolest day of the study based on the heat index. We acknowledge that there are other ways to explore changes in Tc, and thus examine recovery, such as by comparing workers' Tc during different periods of the workday and off-work and comparing it to their baseline for that period, or for that day, as well as looking at whether they return to their baseline, and when (56).

Finally, with this study we demonstrated that off-work, community-based data collection of heat exposure and core body temperature is both feasible and acceptable to agricultural workers in this setting. Additional research is needed to confirm these findings and to help inform interventions to address the current and future risk for HRI in agricultural worker populations.

Limitations and Future Directions

This study carries several limitations. We were limited by a small sample size during the off-work period, restricting our ability to draw comparisons. Nonetheless, this was the first study to examine off-work Tc, and one of the very few to date to have measured Tc in the field during the workday in a relatively large agricultural worker population. We did not analyze the potential lag between environmental heat exposure and Tc. This may be an important consideration in understanding the relationship between Tc and the ambient environment that may have implications for proposed mitigation strategies. In this analysis we were not accounting for the potential variability in workload during the workday, which will influence workday Tc. We speculate from the recovery survey data that off-work activity levels are more similar across the cohort, though this will require further study. In addition, we conducted this study across six days in February 2022 and four days in April 2023, and therefore the results may not be indicative of other times in the harvest season, or generalizable to agricultural workers in other regions. Nonetheless, we observed variability in the HI and Tpa data even across those 10 days. Ultimately, future studies will be needed to understand the generalizability of our findings to other conditions of work and to other home environments of agricultural workers.

Perspectives and Significance

The data presented in this study lay the groundwork for further investigation into the physiological recovery process of workers exposed to daily heat and physical exertion. In this study male agricultural workers in Guatemala experienced high rates of heat strain during their workday, as measured internally through Tc. Tc continued to increase across the workday, including into the off-work hours after completing the work shift. Questions remain around how to define ‘recovery’ of Tc in this population, including following workday rest breaks, right after work, and during overnight sleep. Longitudinal studies are needed to understand whether workers are experiencing heat strain daily, and whether such cumulative stress, without adequate recovery, leads to adverse health outcomes over the longer term. Future research in this cohort will further explore the relationship between Tc and ambient temperature and humidity, as well as other factors that can impact heat related illness, including physical exertion. Our results point to the need to better understand the conditions and practices relevant to the home environment and off-work hours that may influence recovery and the subsequent response to heat and exertion at work. By also capturing round-the-clock environmental heat exposure, this work will help inform future intervention research to identify strategies that better protect workers from heat related illness and related effects.

Grants

Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Grant number: 1U19OH011227;
National Institutes of Health, National Institute for Environmental Health Sciences, Grant number R01 ES31585-01A1.
Resources were also provided by Pantaleon, under a memorandum of understanding with the University of Colorado.

Disclosures

The authors declare they have no actual or potential competing financial interests.

Disclaimers

The contents of this manuscript are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

Funders had no role in data analysis, interpretation of data, writing the manuscript, or the decision to submit the findings for publication.

Author Contributions

Conceived and designed research: LK, JBD, LN; Performed experiments: LK, KVH, DJ; Analyzed data: LK, YL, KM; Interpreted results of experiments: LK, KVH, YL, JBD, EJ, MD; Prepared figures: LK, YL; Drafted manuscript: LK; Edited and revised manuscript: LK, KVH, YL, JBD, DJ, HY, KM, EJ, KJ, MD, EC, DP, AC, JS, JA, LN; Approved final version of manuscript: LK, KVH, YL, JBD, DJ, HY, KM, EJ, KJ, MD, EC, DP, AC, JS, JA, LN.

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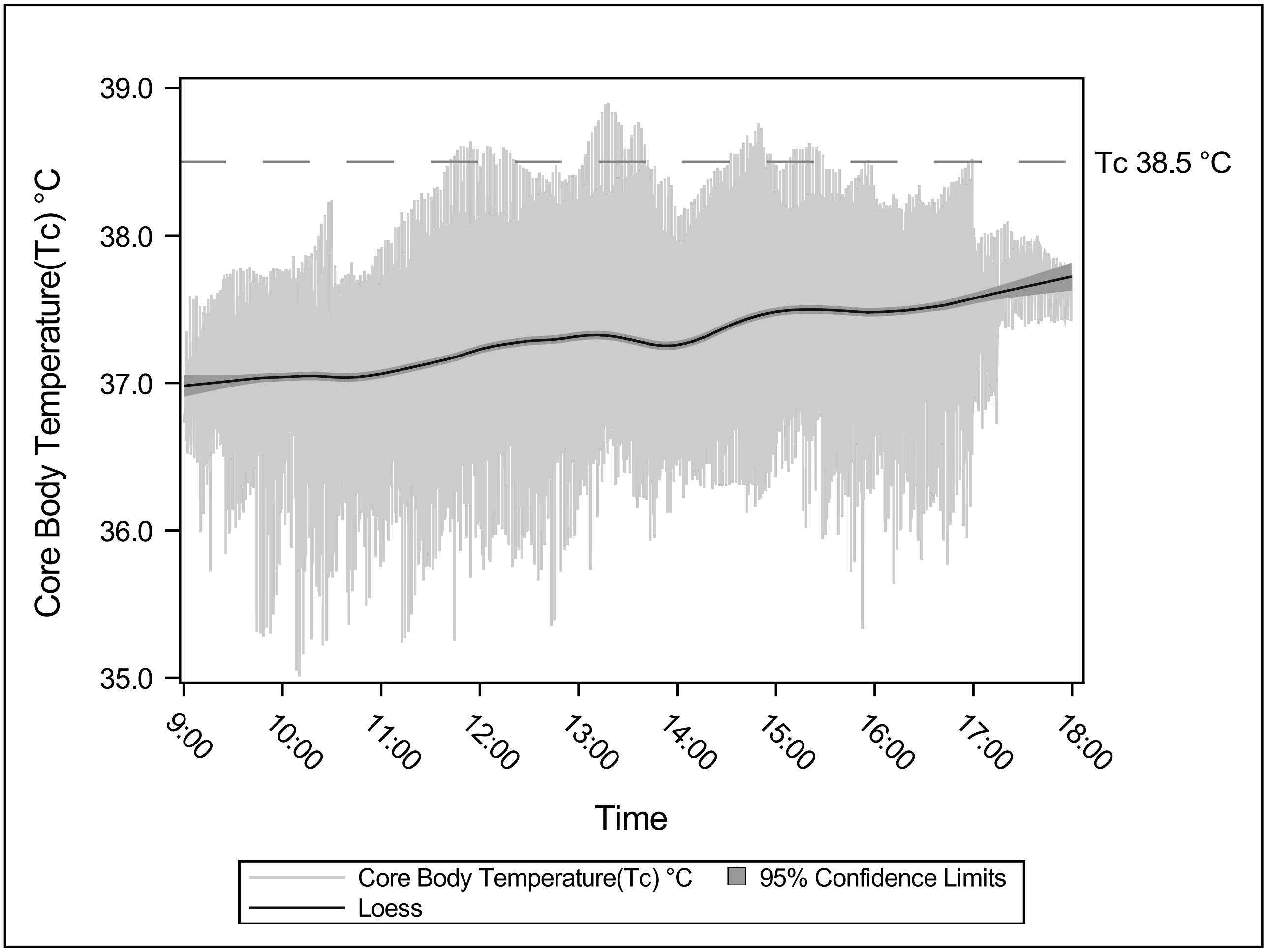
Figure 1. Time series of core body temperature (Tc) across the workday for 55 workers. The horizontal line is at 38.5 °C. The central trend line was estimated using a local regression (LOESS) smoother with 95% confidence limits indicated in dark gray. Vertical light gray lines represent the range of observations.

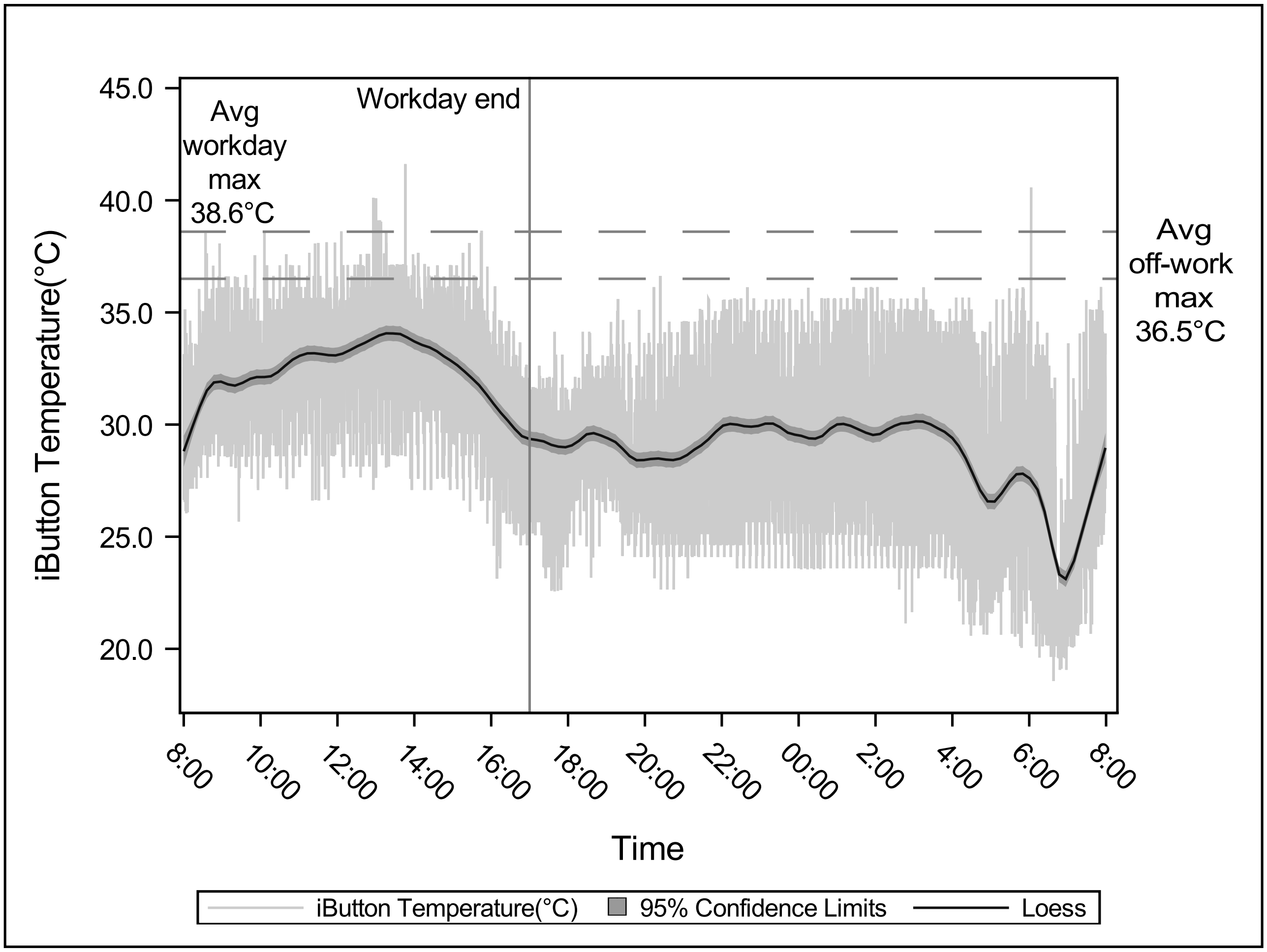
Figure 2. Workday + Off-work personal ambient temperature from iButtons (Tpa) (°C) (n=55 workers) with local regression (LOESS) estimated curve of central tendency, and 95% confidence limits, in dark gray. Vertical light gray lines represent the range of observations.

Figure 3. Time series of workday + off-work Tc (n=17) with LOESS estimated curve of central tendency, and 95% confidence limits. Vertical lines show the range of observations. LOESS = local regression; Tc= core body temperature.

Appendix Figure S1. Timeline of workday and off-work core body temperature (Tc) by individual Study ID, among those workers with both Tc workday and overnight data available (n=17). Dashed horizontal reference lines indicate max workday Tc and max off-work Tc. Solid vertical reference lines indicate time of workday end, time worker returned home, time he went to bed and time he woke up. Tc = core body temperature.



39.0
38.0
37.0
36.0
35.0
Core Body Temperature(Tc) °C
Tc 38.5 °C
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
Time
Core Body Temperature(Tc) °C
95% Confidence Limits
Loess


45.0
40.0
35.0
30.0
25.0
20.0
iButton Temperature(°C)
Avg workday max 38.6°C
Workday end
Avg off-work max 36.5°C
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time
iButton Temperature(°C)
95% Confidence Limits
Loess

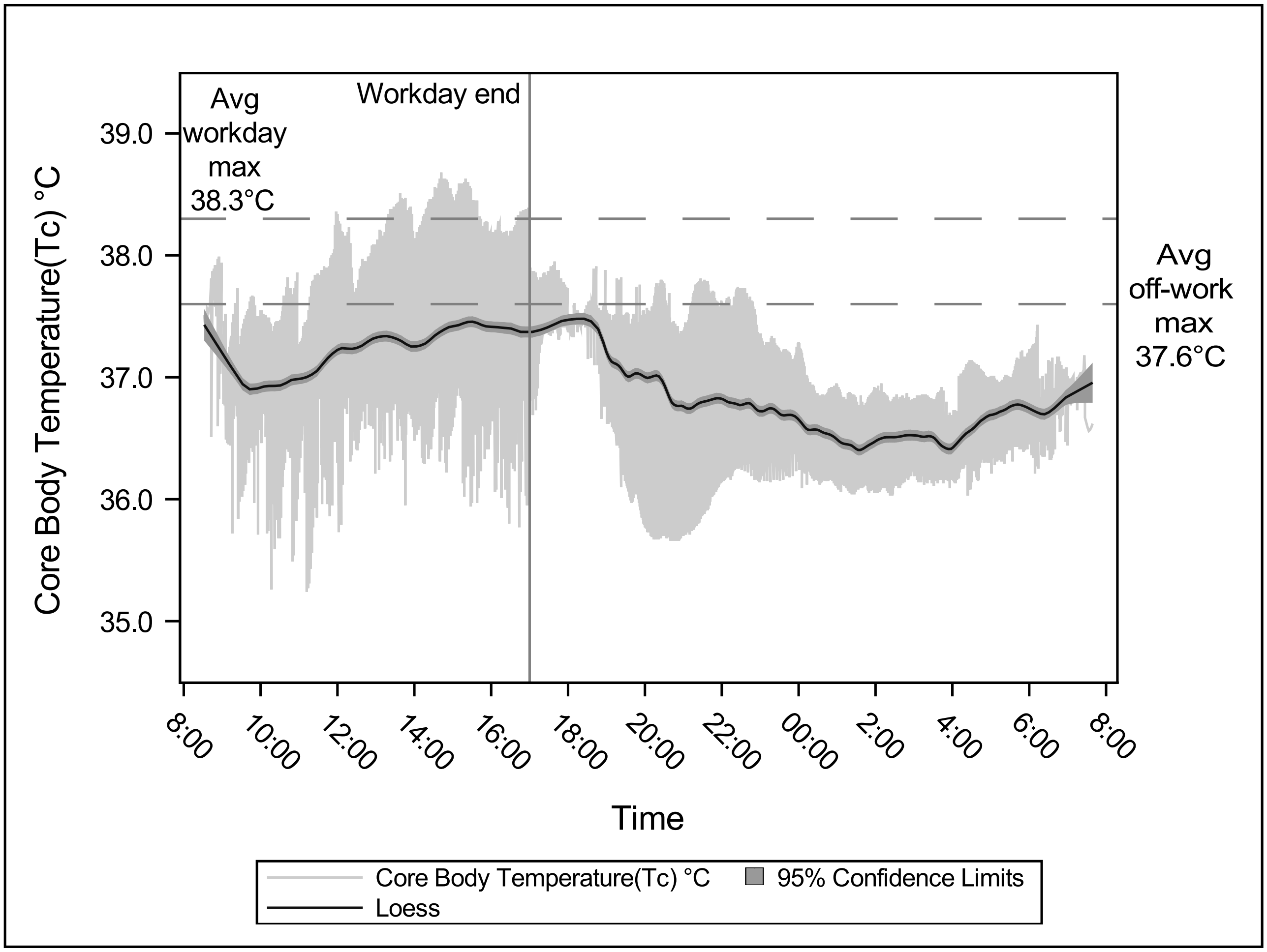

Avg
workday
max
38.3°C
Workday end
Avg
off-work
max
37.6°C
39.0
38.0
37.0
36.0
35.0
Core Body Temperature(Tc) °C
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time
Core Body Temperature(Tc) °C
95% Confidence Limits
Loess

Table 1. Demographics and anthropometric data of sugarcane workers in Guatemala (n=55)

Characteristic	**Mean (SD)**	**Reference values**
Age (median and IQR, years)	29 (24, 36)	
Weight pre-shift (kg)	57 (6)	
Height (cm)	163 (6)	
Body mass index (BMI) kg/m^2	21 (2)	
-- Underweight n (%)	0	≤ 18.5 kg/m^2
-- Overweight n (%)	2 (4%)	≥ 25 kg/m^2
Gender (male) n (%)	55 (100%)	

Table 2. Summary of workday exposure data and frequency of exceeding Tc 38.0 °C, 38.3 °C and 38.5 °C by Study Day. Data in the first 4 rows are reported as Mean ± SD and data in the last 4 rows are reported as N (%).

	Study Day										
Variable	**1 (N = 5)**	**2 (N = 6)**	**3 (N = 7)**	**4 (N = 8)**	**5 (N = 6)**	**6 (N = 9)**	**7 (N = 2)**	**8 (N = 5)**	**9 (N = 2)**	**10 (N = 5)**	**Overall (N = 55)**
Heat Index (HI)*	36.7 ± 3.0	37.1 ± 3.2	34.6 ± 7.8	30.1 ± 6.9	35.1 ± 5.2	38.8 ± 5.4	38.9 ± 3.3	39.0 ± 2.0	39.4 ± 4.0	37.8 ± 2.7	36.8 ± 4.7
iButton Temp (°C)	32.2 ± 2.1	31.6 ± 2.5	31.8 ± 2.7	32.3 ± 3.7	32.2 ± 2.7	31.8 ± 3.9	32.5 ± 2.3	31.7 ± 2.4	32.1 ± 3.1	32.5 ± 2.4	32.0 ± 3.0
Average Tc (°C)	37.1 ± 0.4	37.1 ± 0.5	37.5 ± 0.5	37.5 ± 0.6	37.1 ± 0.4	37.1 ± 0.5	37.0 ± 0.3	37.7 ± 0.5	37.2 ± 0.3	37.4 ± 0.5	37.3 ± 0.5
Average Tc max (°C)	37.9 ± 0.4	37.6 ± 0.4	38.1 ± 0.2	38.3 ± 0.4	37.7 ± 0.4	37.8 ± 0.3	37.5 ± 0.2	38.2 ± 0.4	37.6 ± 0.0	38.2 ± 0.3	37.9 ± 0.4
Tc > 38.0 °C	2 (40)	1 (17)	4 (57)	6 (75)	1 (17)	2 (22)	0 (0)	4 (80)	0 (0)	4 (80)	24 (44)
Tc > 38.3 °C	0 (0)	0 (0)	1 (14)	3 (38)	0 (0)	1 (11)	0 (0)	2 (40)	0 (0)	2 (40)	9 (16)
Tc > 38.5 °C	0 (0)	0 (0)	0 (0)	2 (25)	0 (0)	0 (0)	0 (0)	1 (20)	0 (0)	0 (0)	3 (6)
USG > 1.020 post shift	0 (0)	0 (0)	0 (0)	1 (12.5) ‡	2 (33)	0 (0)	0 (0)	1 (20) ‡	1 (50)	0 (0)	5 (9)

Tc = core body temperature; Tc max = maximal Tc achieved ‡ Dehydrated and exceeded Tc > 38.0 °C
ACGIH TLV for heat strain = Tc > 38.0 °C, Tc > 38.3 °C and Tc > 38.5 °C (indicating excessive heat strain, exceeded on ≥ 2 consecutive measurements)

Table 3. Descriptive statistics of off-work hydration and recovery factors among sugarcane workers in Guatemala (N = 55)

Hydration	
Off-work hydration (AM USG)	1.011 ± 0.006
-- Dehydrated (USG > 1.020)	3 (5.5%)
Post-shift cups (0.25 L) of water (between end of shift and going to bed)	
-- < 5 cups	39 (72%)
-- 5-15 cups	11 (20%)
-- > 15 cups	4 (7%)
Pre-shift cups of water since waking up (8 oz)	
-- 1 cup	13 (35%)
-- 2-4 cups	18 (49%)
-- > 4 cups	6 (16%)
Sleep & rest	
Total time at home (hours)	10 ± 1
Sleep hours last night < 7	8 (15%)
Usual sleep hours < 7	10 (18%)
(Sleep complaints) Felt too hot	7 (13%)
(Sleep complaints) Partner or child kept me awake	3 (6%)
(Sleep complaints) Woke up feeling exhausted	6 (11%)
How many people, including children, do you share a bed with? (not counting yourself)	
--None	22 (41%)
--1 other person	22 (41%)
--2 others	8 (15%)
--3 or more	2 (4%)
Behaviors & nutrition	
Smoked at least 1 cigarette yesterday	3 (5%)
Felt hungry before going to bed	
-- Not hungry at all	51 (93%)
-- A little to moderately hungry	4 (7%)
Ate snack(s) in addition to dinner	
-- No	32 (58%)
Had eaten something since waking up this morning	
-- No	8 (15%)

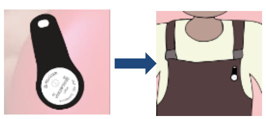
Data are reported as mean ± SD or as N(%). USG = urine specific gravity.

Sugarcane workers' cumulative heat stress, heat strain, and recovery

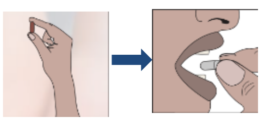
METHODS

N=55 male sugarcane workers

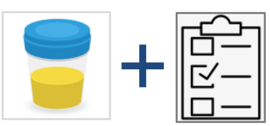
Monitored across 24 hours in southwestern Guatemala.



Heat stress: Personal ambient temperature (Tpa) measured with a wireless temperature logger



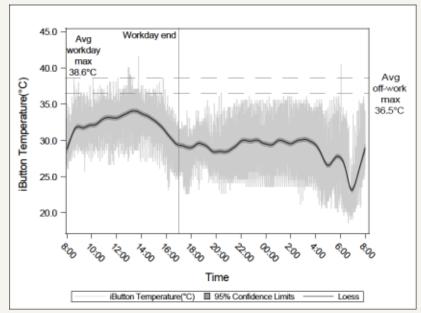
Heat strain: Core body temperature (Tc) measured using a pill-sized ingestible telemetric sensor

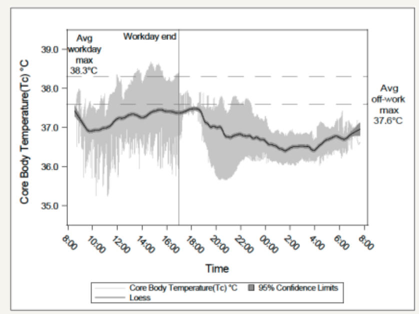


Urine samples collected to evaluate on and off-work hydration. A **Recovery survey** captured off-work practices

This study characterizes the daily recovery process of heat-exposed workers, both during and off-work, with the goal of informing future intervention research to protect workers from heat related illnesses and related effects.

OUTCOME





Workers are exposed to heat stress conditions at work and at home

Workday heat strain

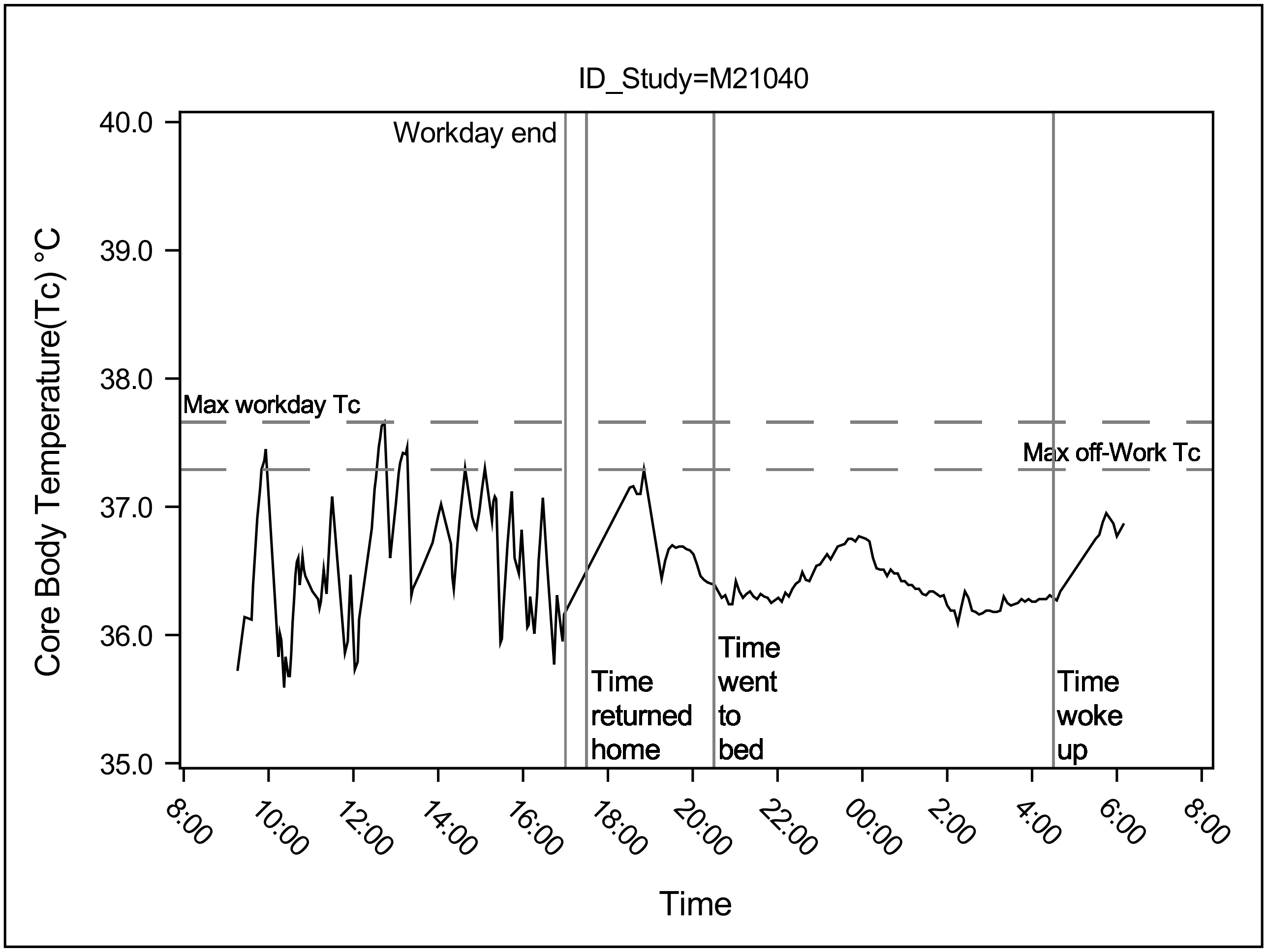
- *44% of workers with excessive heat strain (Tc > 38.0°C); 6% with Tc > 38.5°C*

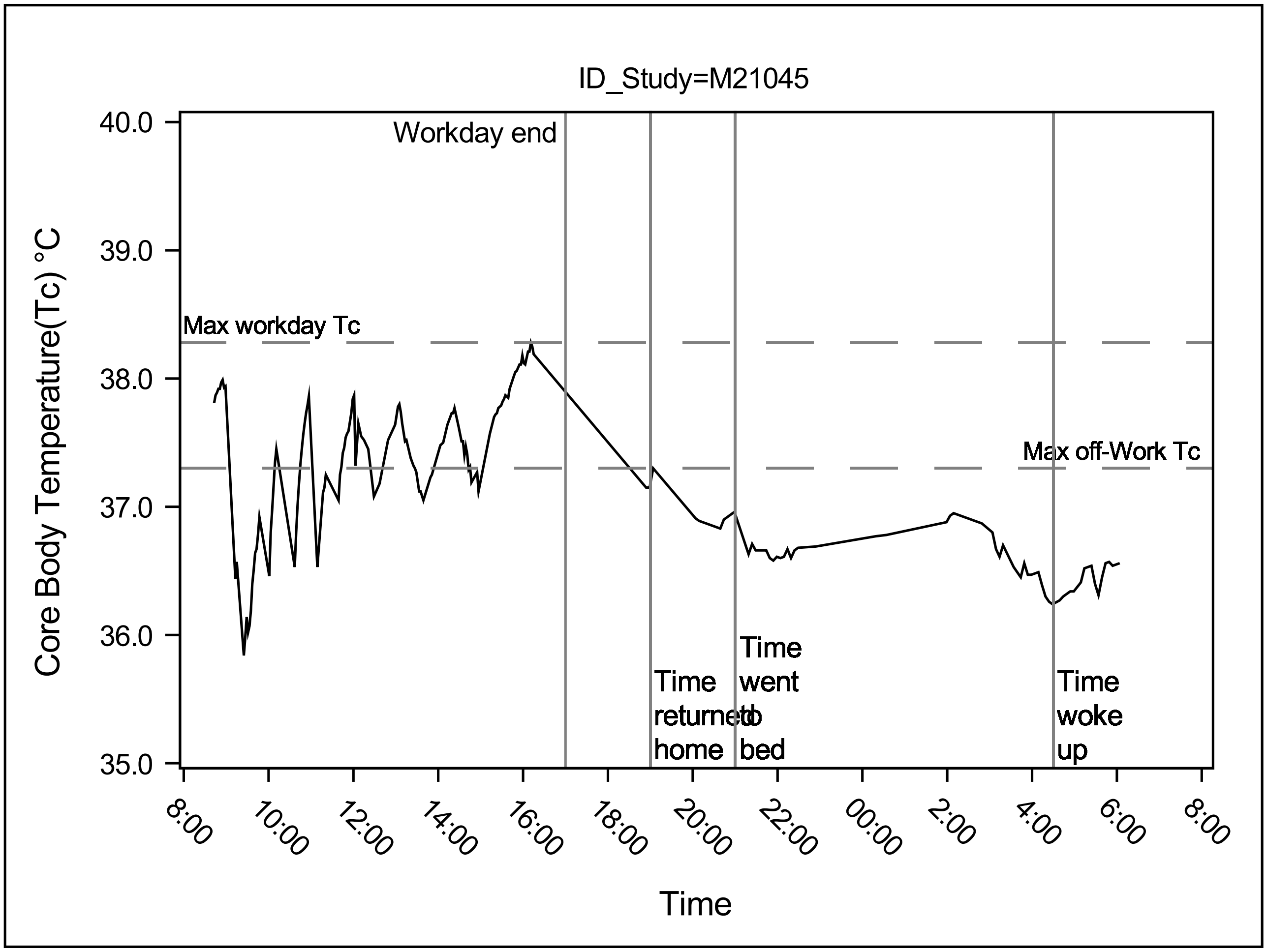
Off-work heat strain and recovery

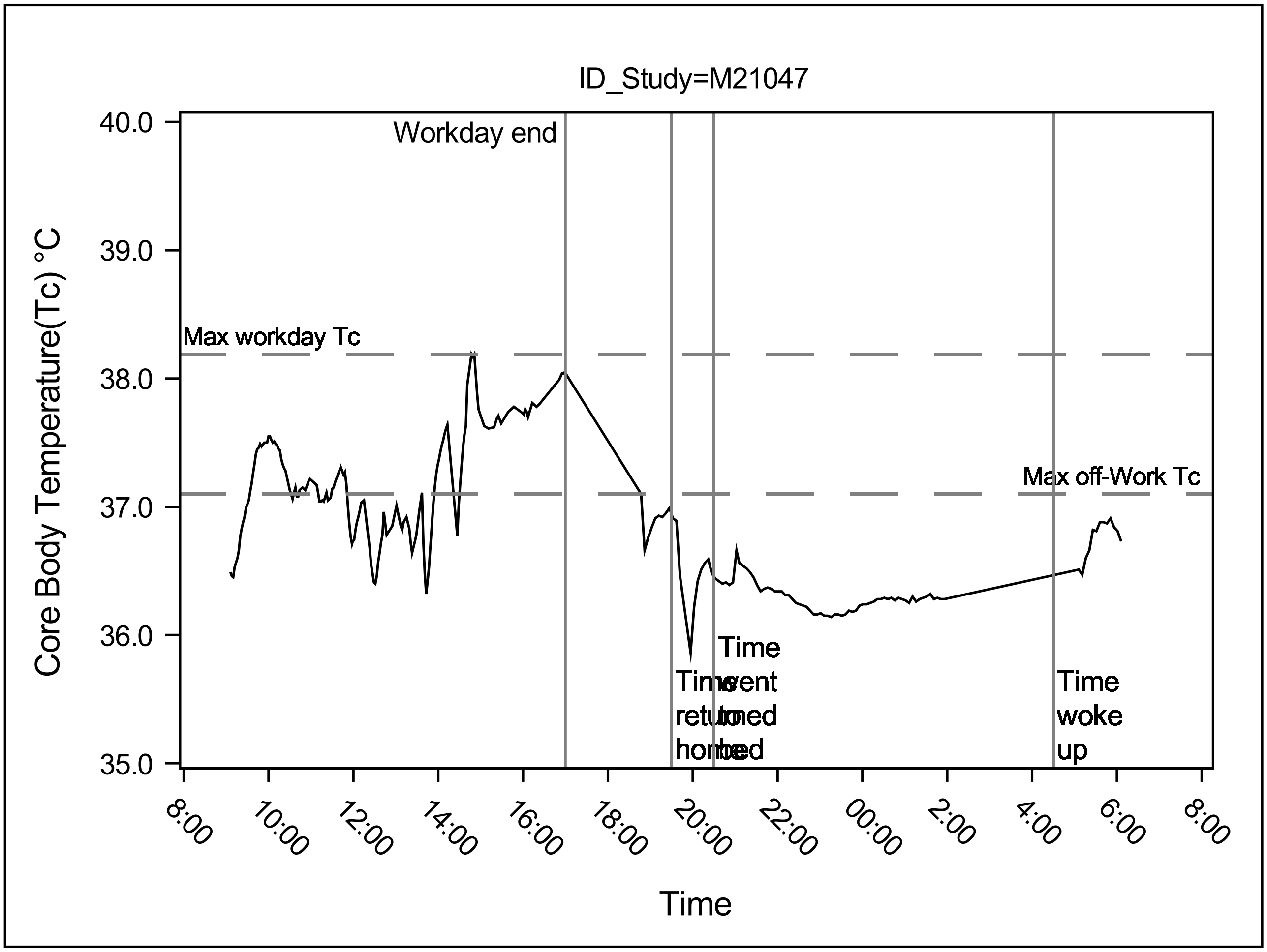
- *29% of workers had higher maximal Tc off-work compared to the workday*
- *15% of workers slept < 7 hours before their next shift*

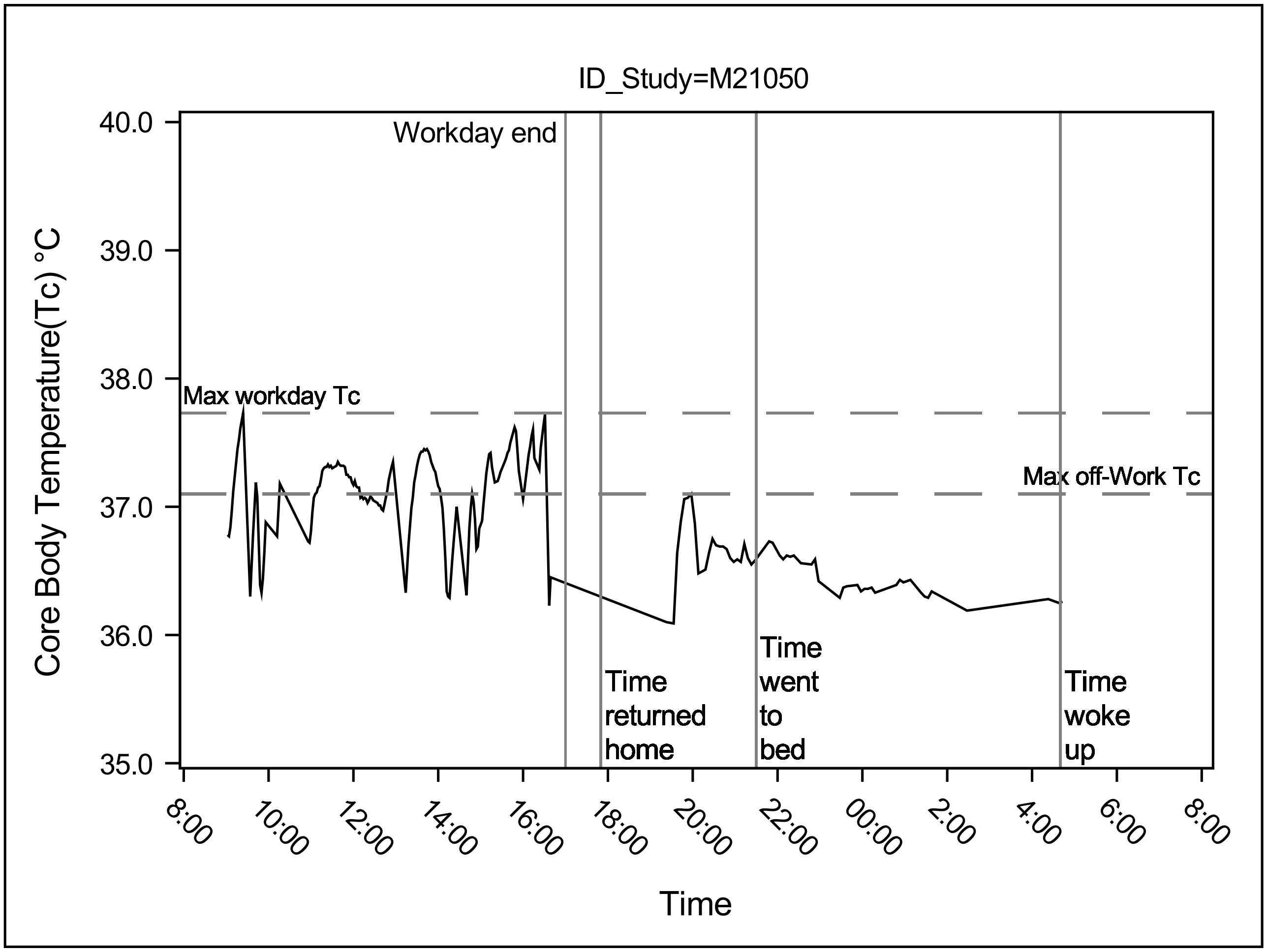
CONCLUSION

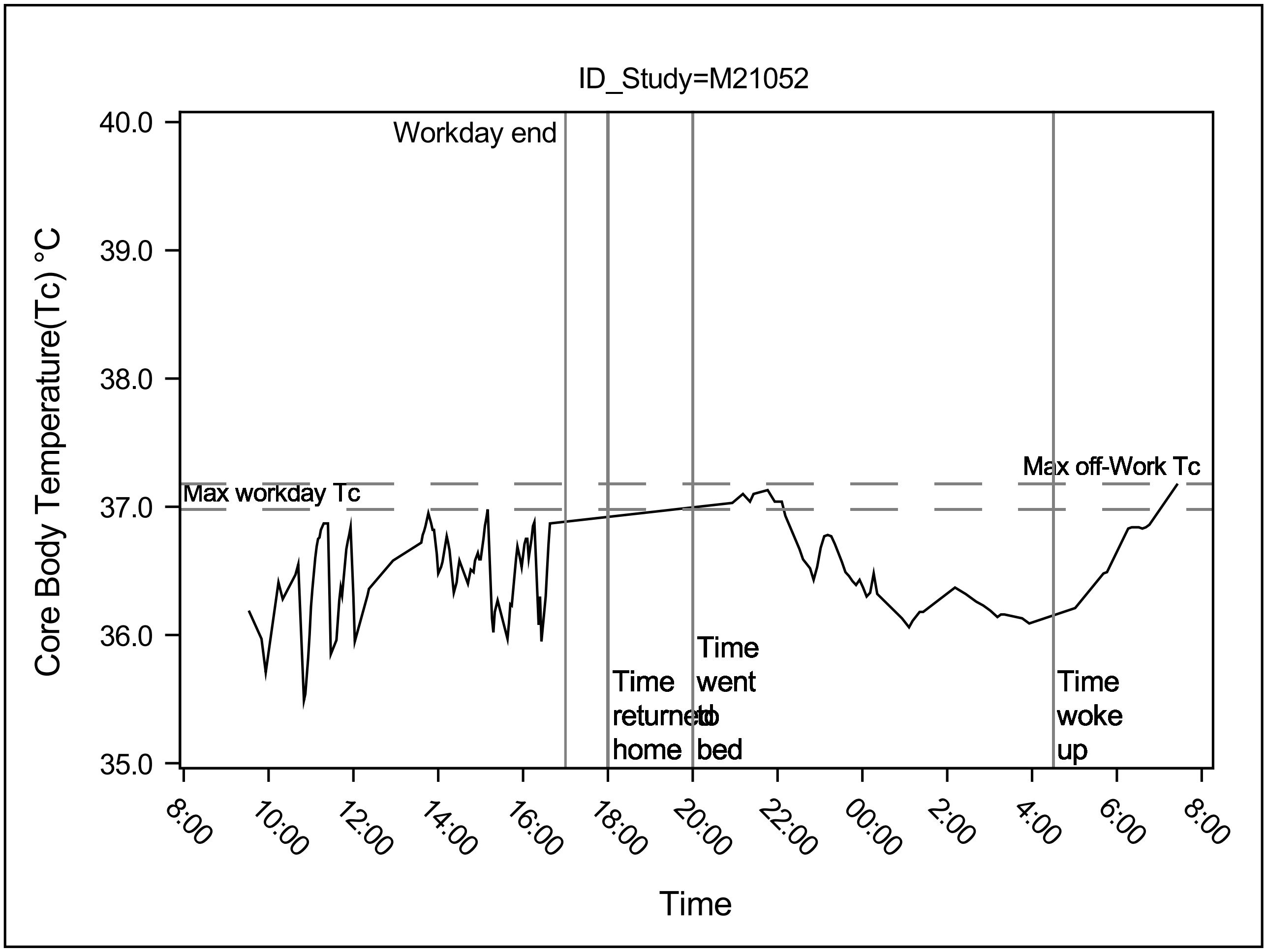
Heat stress persists beyond the work shift, potentially limiting worker recovery. Further research is needed on off-work conditions and interventions to mitigate excessive heat strain and protect worker health.

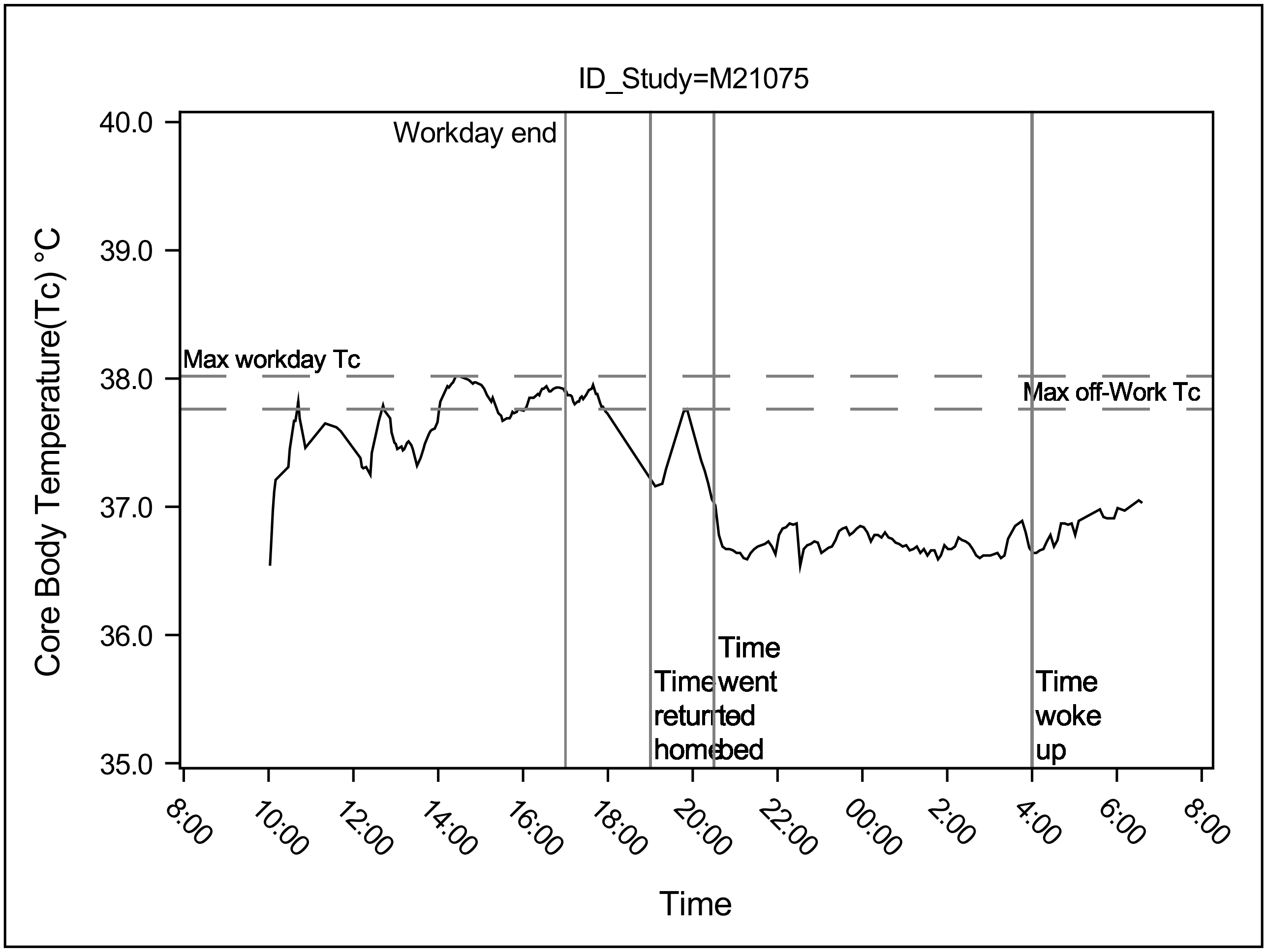

ID_Study=M21040
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

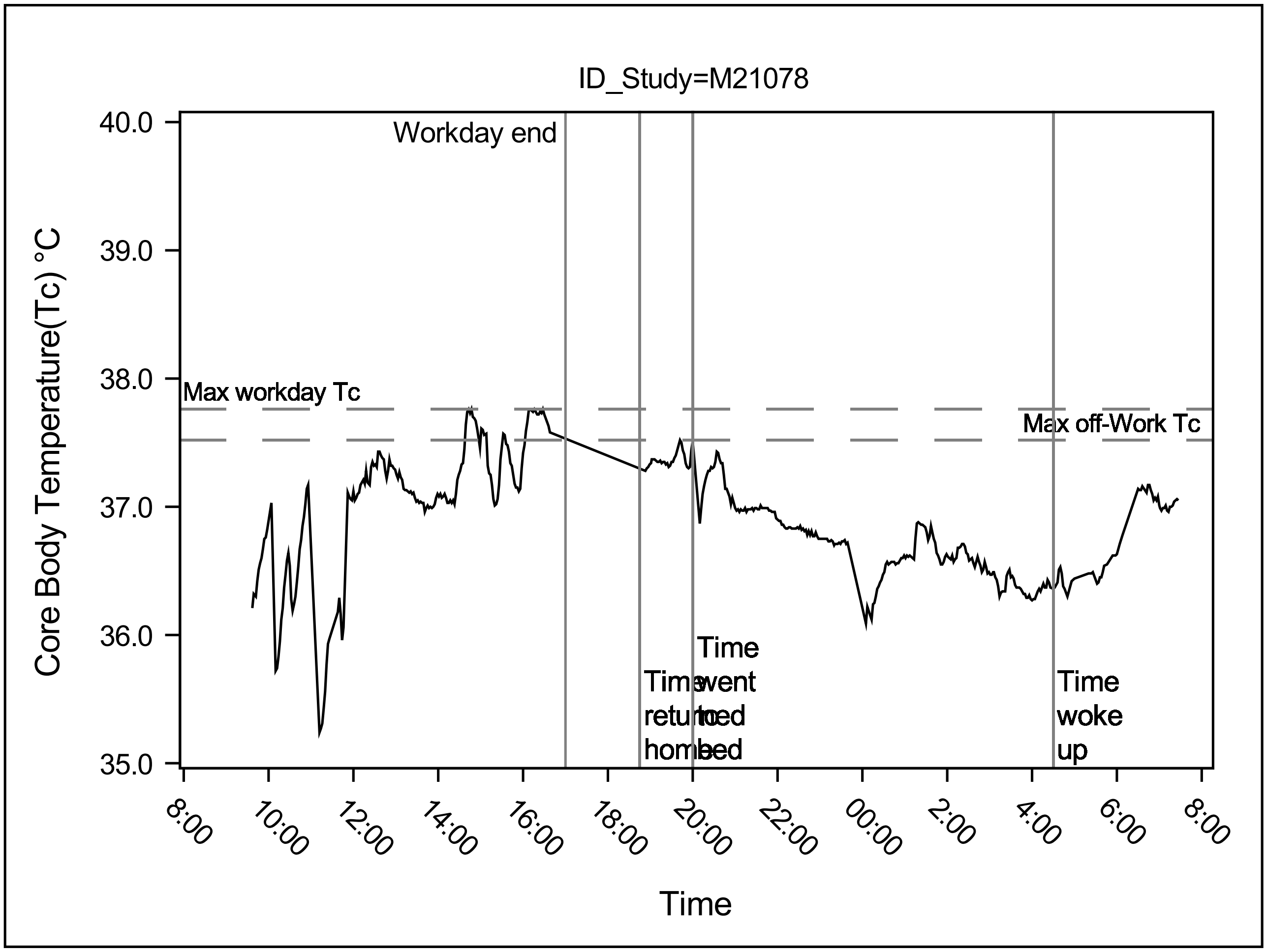

ID_Study=M21045
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

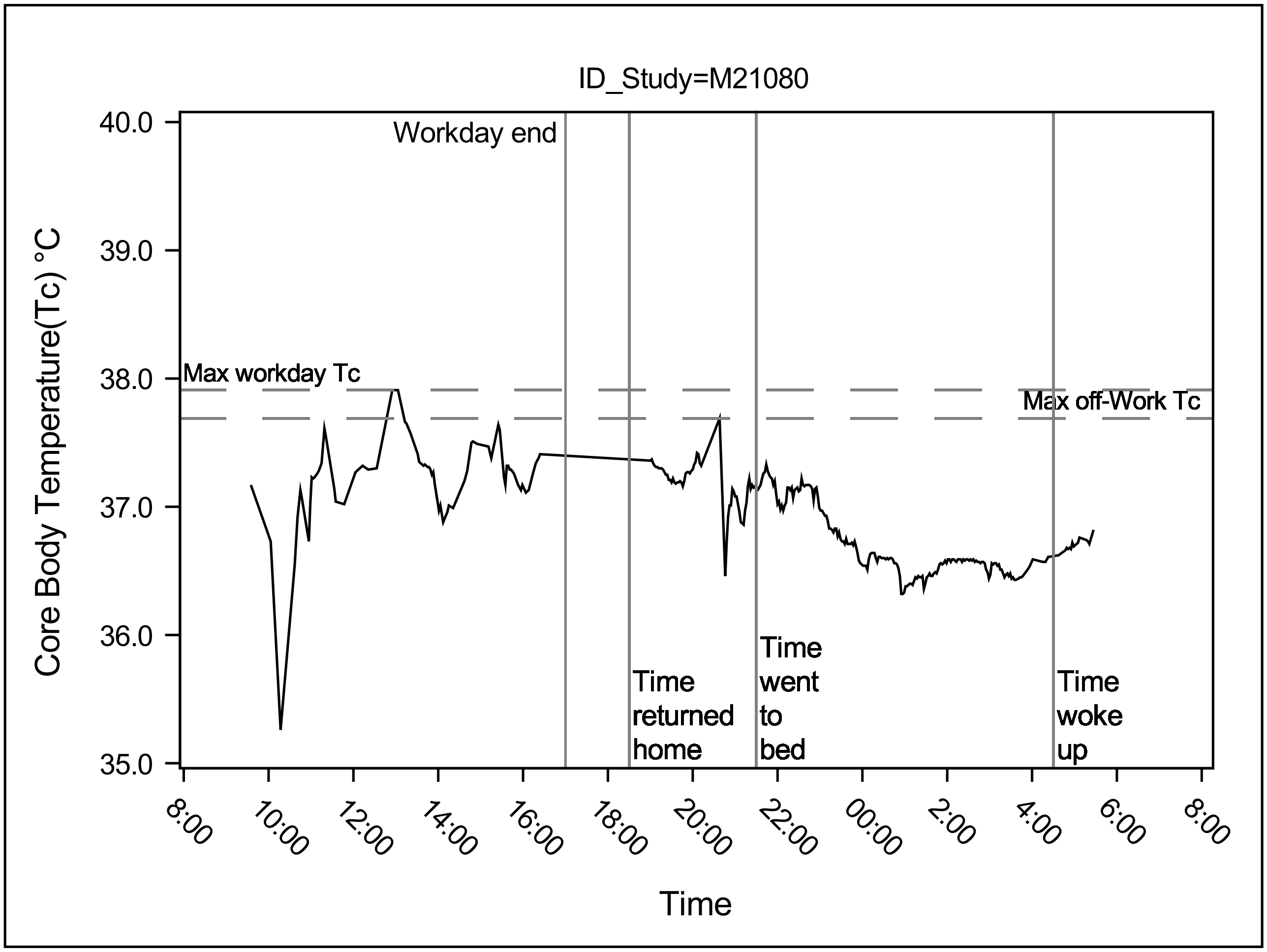

ID_Study=M21047
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

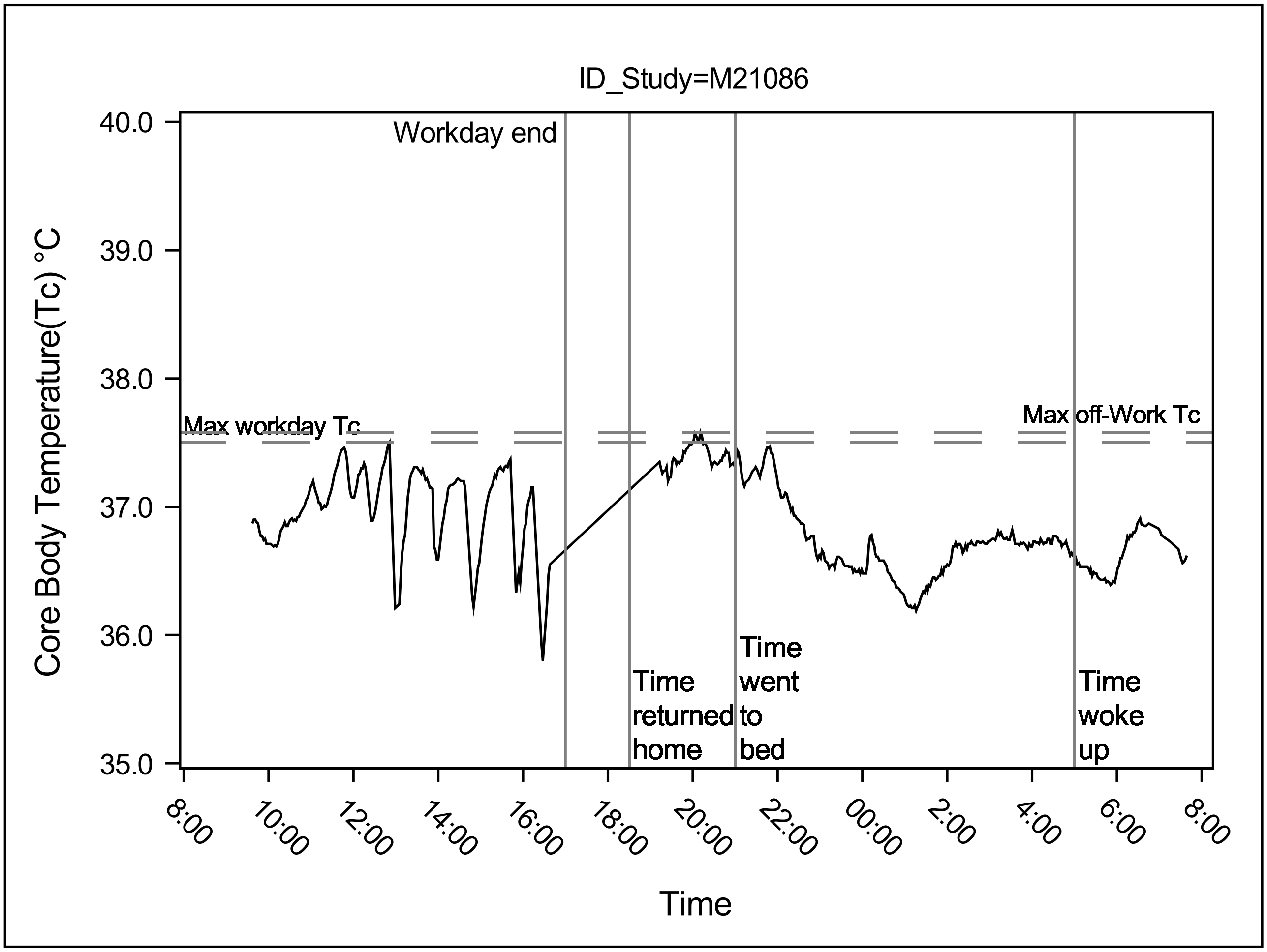

ID_Study=M21050
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

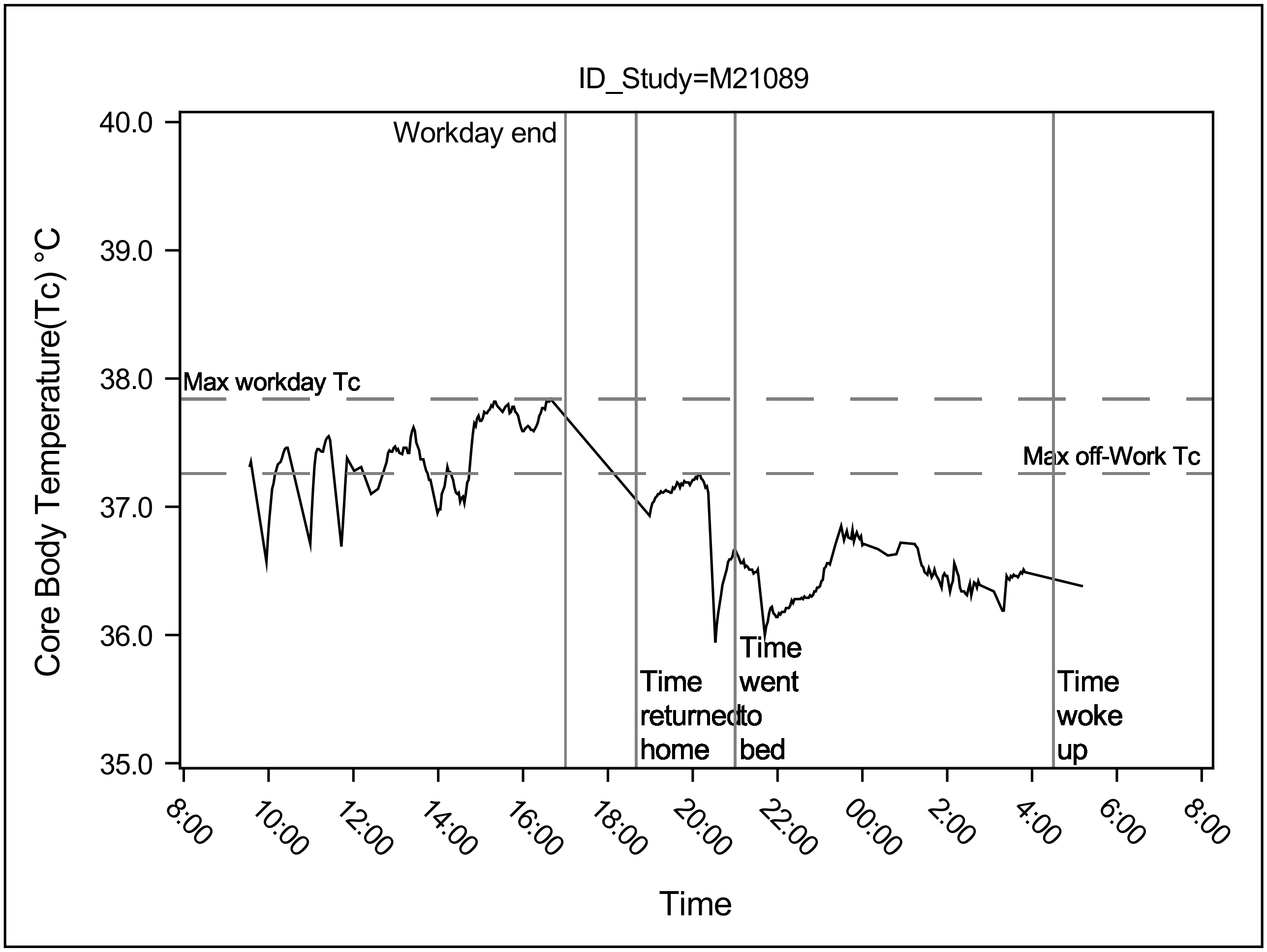

ID_Study=M21052
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

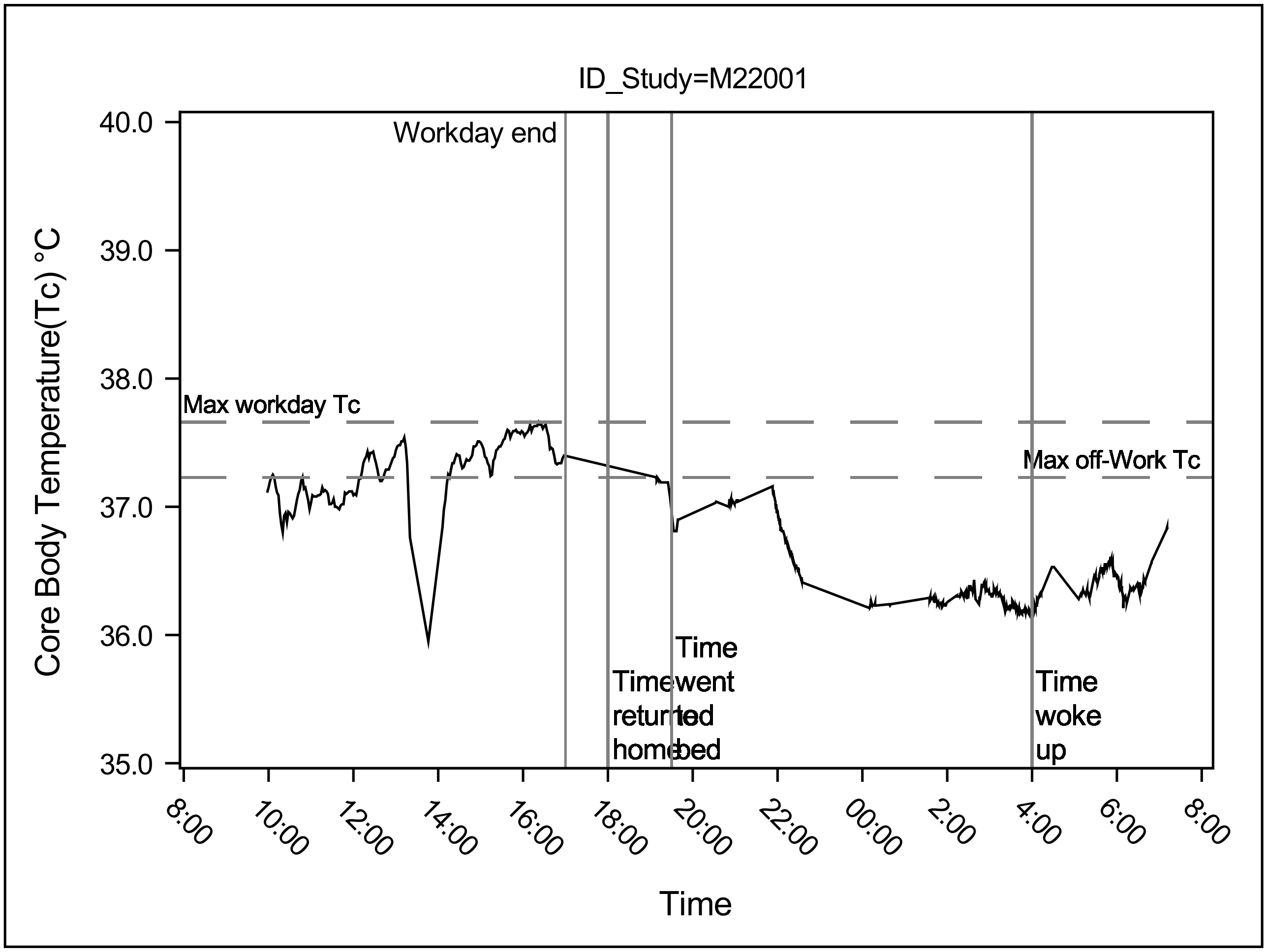

ID_Study=M21075
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

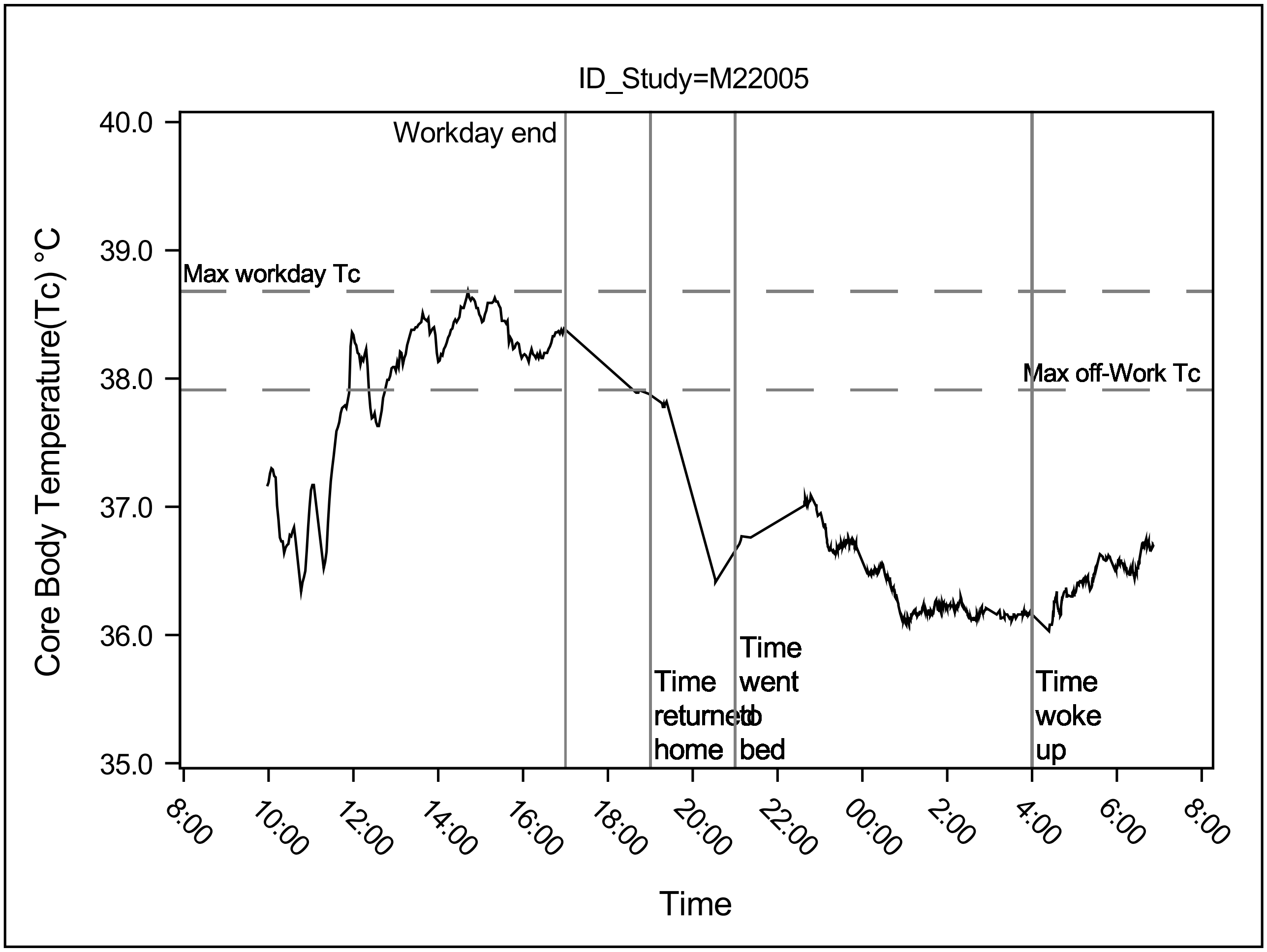

ID_Study=M21078
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

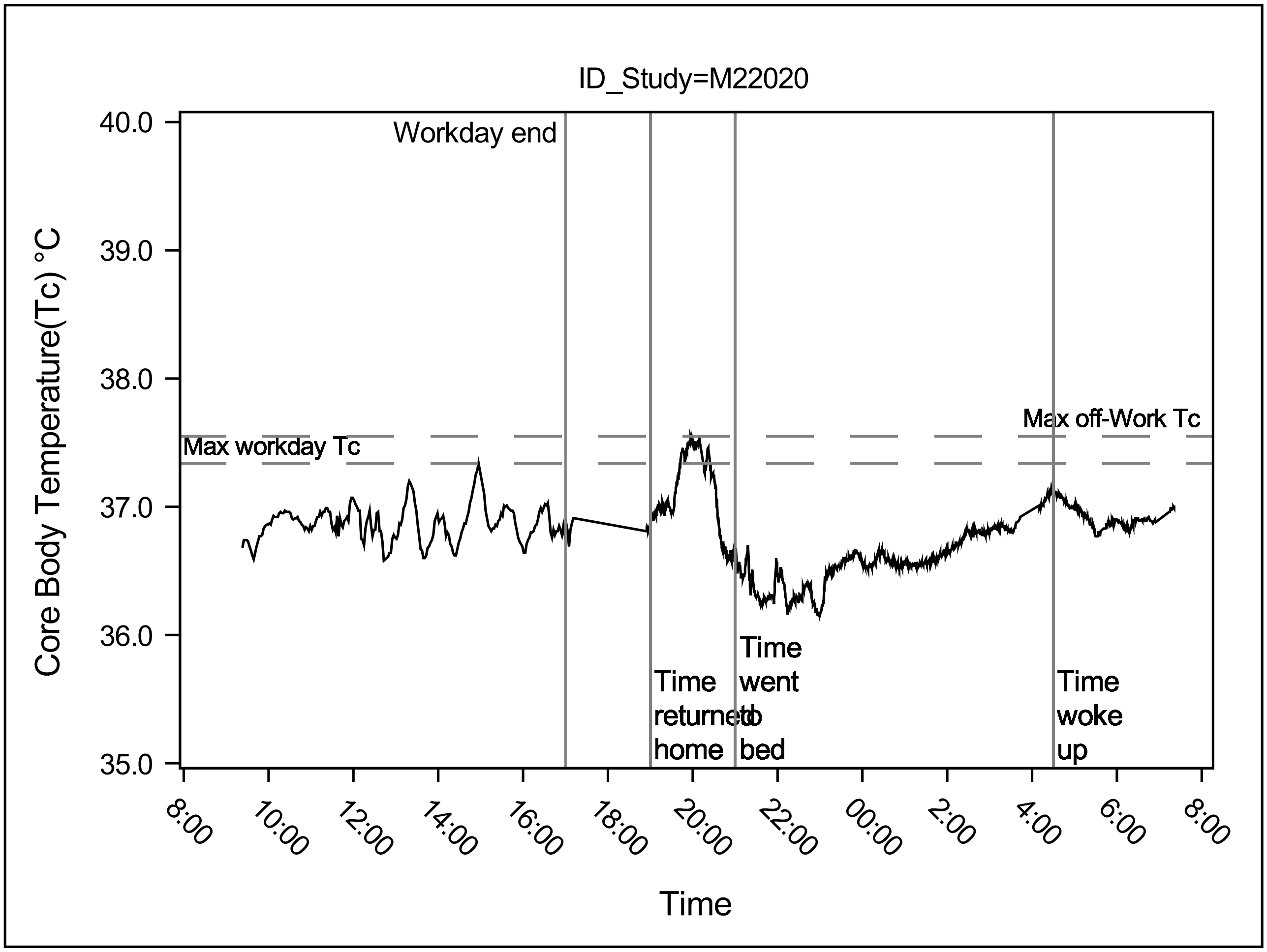

ID_Study=M21080
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Max workday Tc
Max off-Work Tc
Workday end
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

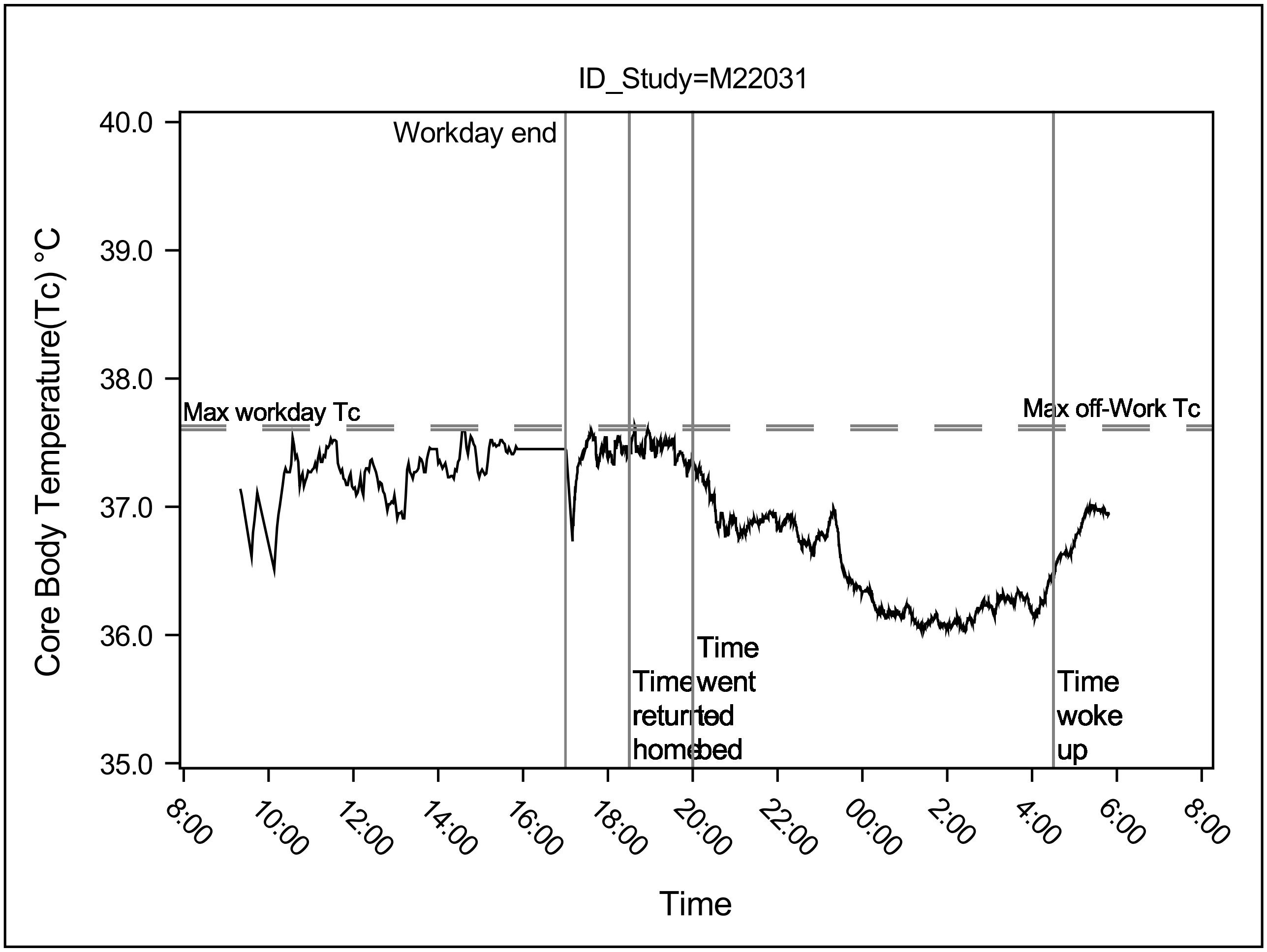

ID_Study=M21086
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time


ID_Study=M21089
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

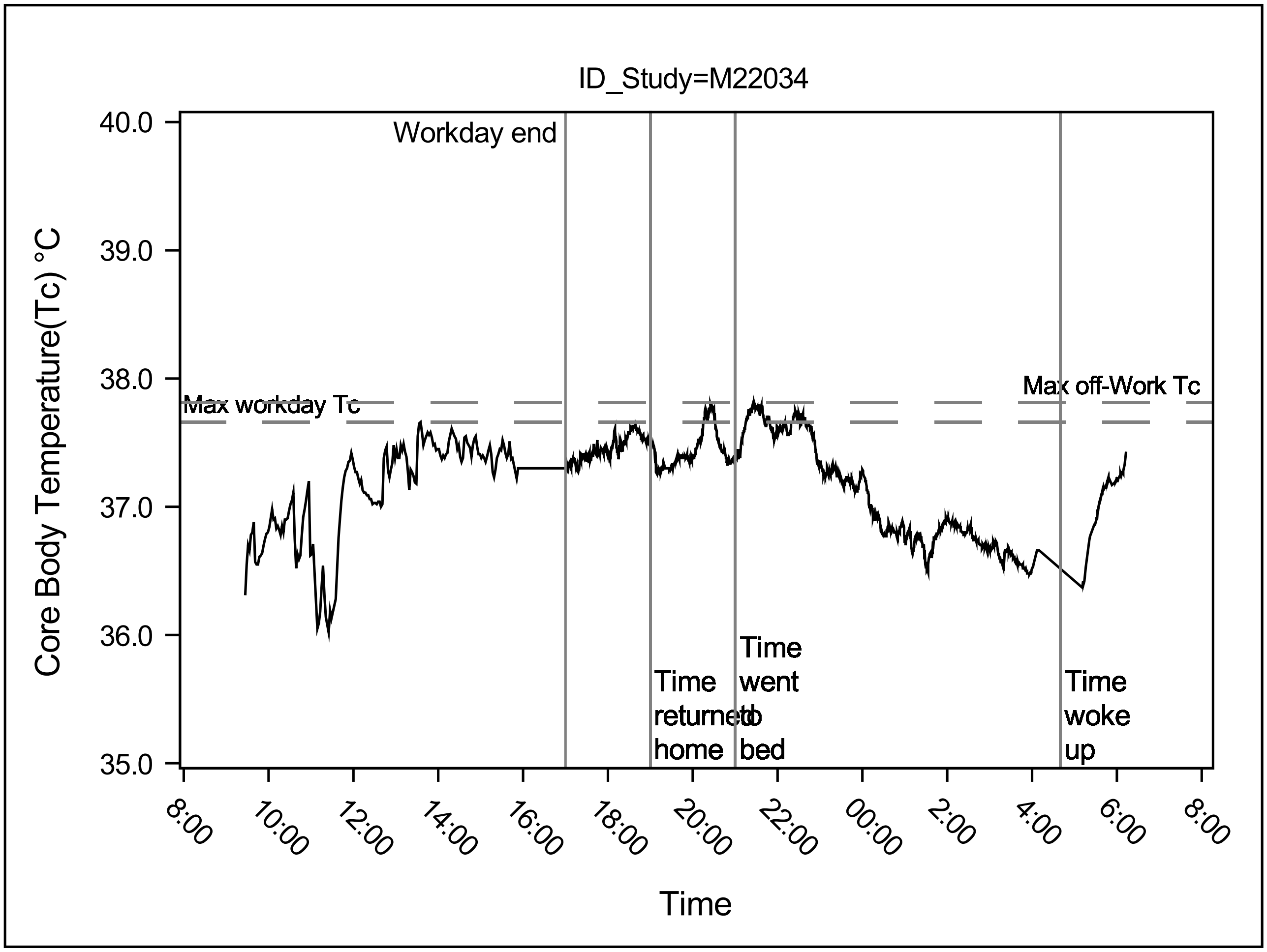

ID_Study=M22001
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

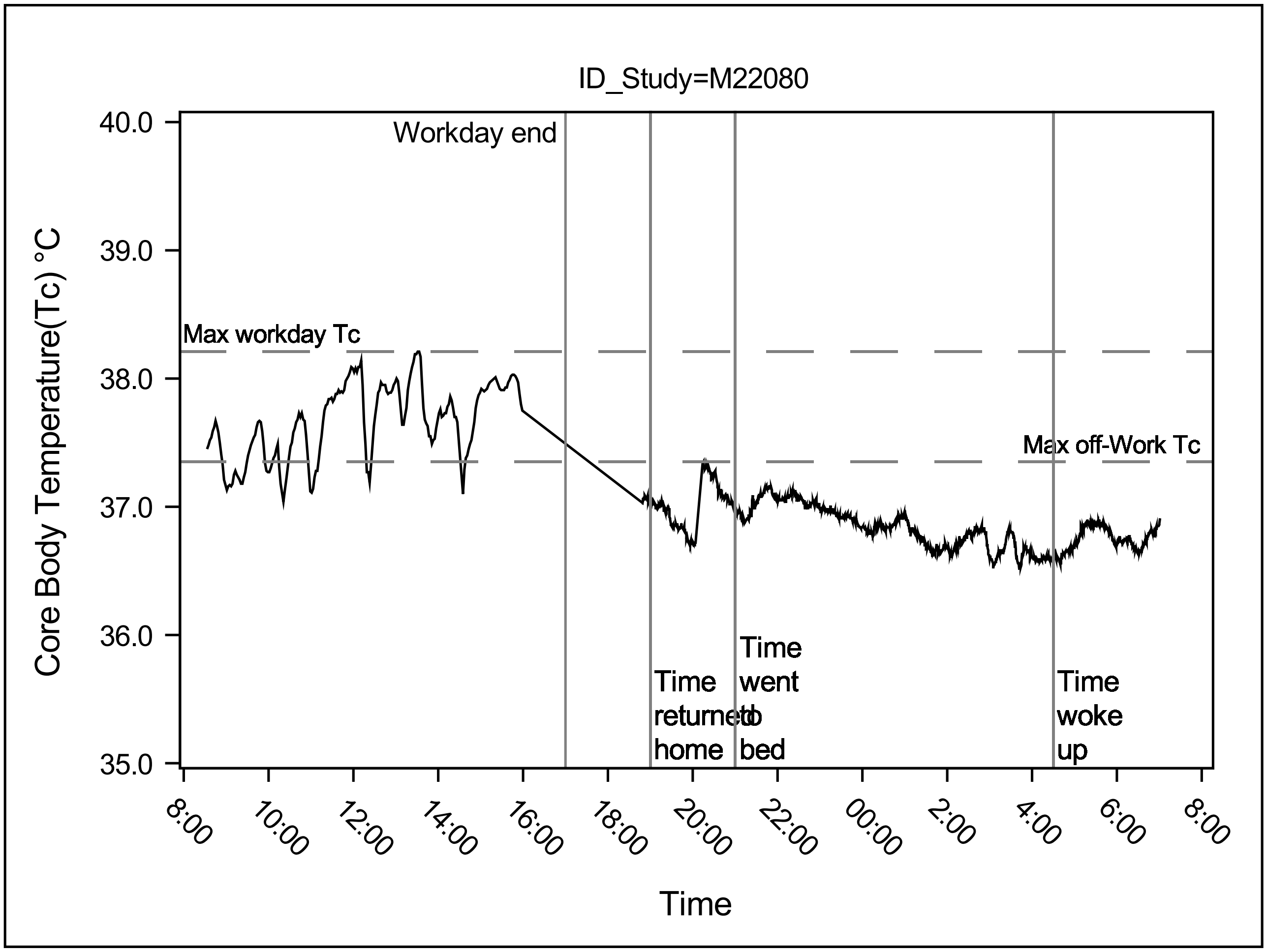

ID_Study=M22005
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

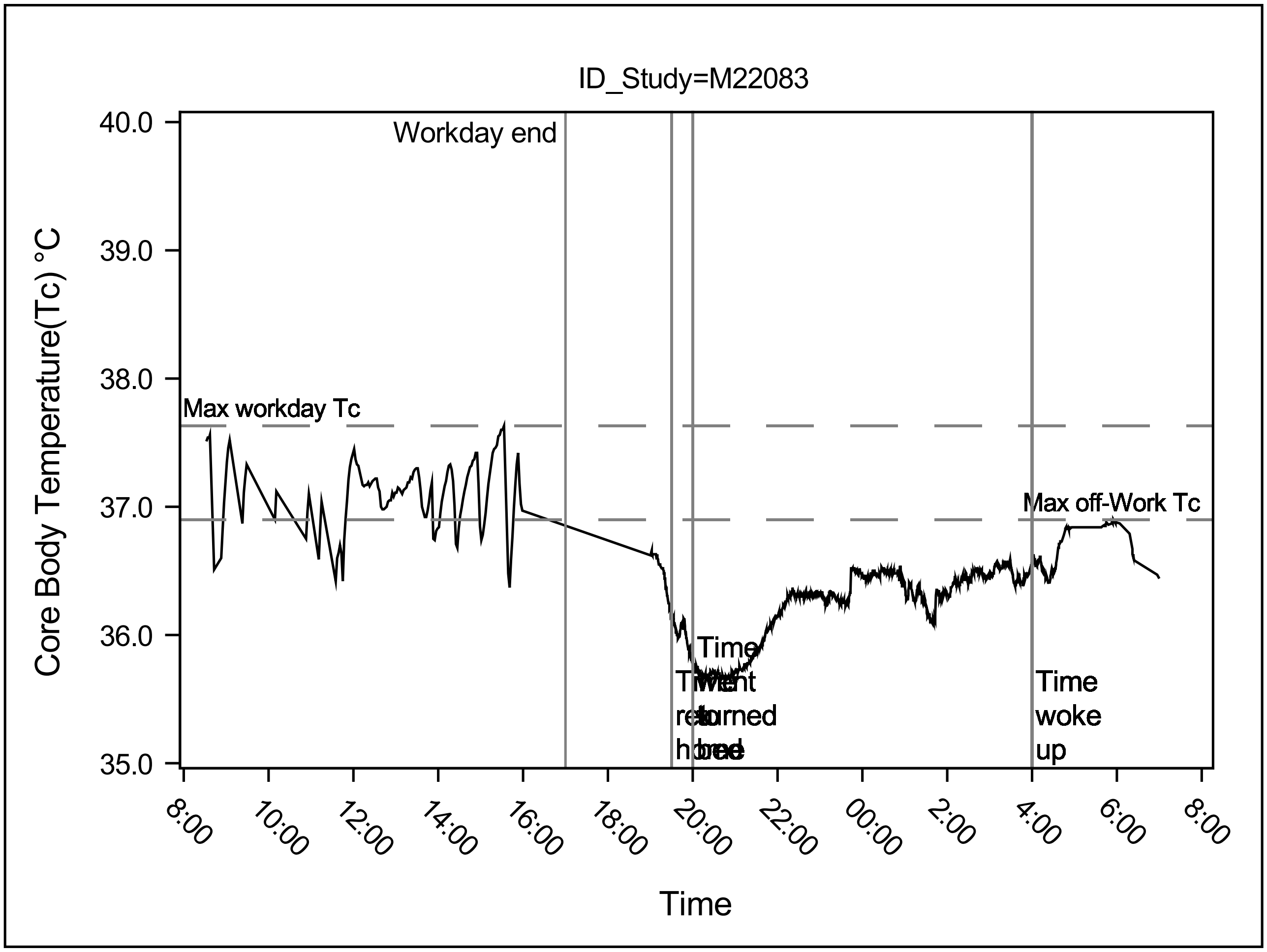

ID_Study=M22020
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time



ID_Study=M22031
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time


ID_Study=M22034
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time


ID_Study=M22080
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time


ID_Study=M22083
Workday end
Max workday Tc
Max off-Work Tc
Time returned home
Time went to bed
Time woke up
Core Body Temperature(Tc) °C
40.0
39.0
38.0
37.0
36.0
35.0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
2:00
4:00
6:00
8:00
Time

Appendix

Table S1. Summary of heat exposure data by hour during off-work hours, among those workers with off-work Tc data available (n=17)

Time	**Hourly Off-work Tc (°C)**	**Hourly Off-work Tpa Temp (°C)**
	Mean (SD) max	**Mean (SD) max**
18:00-18:59 PM	**37.4 (0.2) 37.9**	29 (2) 32.6
19:00-19:59 PM	37.1 (0.4) 37.8	28.4 (1.7) 33.2
20:00-20:59 PM	**36.9 (0.6) 37.8**	**28.5 (2.3) 36.6**
21:00-21:59 PM	36.8 (0.6) 37.8	29.7 (2.7) 35.6
22:00-22:59 PM	36.8 (0.4) 37.7	31 (2.1) 35.5
23:00-23:59 PM	36.7 (0.3) 37.4	30.9 (1.9) 35.6
0:00-0:59 AM	36.6 (0.3) 37.3	31 (2.5) 36.1
1:00-1:59 AM	36.4 (0.3) 36.9	**31.2 (2.5) 36.1**
2:00-2:59 AM	36.5 (0.3) 37	31 (2.7) 35.6
3:00-3:59 AM	36.5 (0.2) 36.9	30.3 (3.1) 35.2
4:00-4:59 AM	36.6 (0.3) 37.1	29.1 (3.8) 35.7
5:00-5:59 AM	36.7 (0.2) 37.2	26.7 (3.2) 36.1
6:00-6:59 AM	36.7 (0.2) 37.4	24.3 (3.7) 32.6

Bold indicates the overall column maximums (mean and max) for each variable
°C = Celsius; Tpa = personal ambient temperature; Tc = core body temperature

Appendix Figure S1 displays the core body temperature (Tc) data for each of the workers individually (n=17), across both the workday and off-work period linked together. Those workers who did not have workday Tc data due to missingness are not included in the figure (n=7). Horizontal reference lines indicate workers' Tc max off-work and Tc max during the workday, and vertical lines show the approximate time that the workday ended, time when worker reported returning home, time he went to bed and time he woke up. Of all the 24 workers observed off-work, most experienced their off-work Tc max between the start of the evening and about 20:00. One worker (M22083) reached their maximum early the following morning, just before beginning their next work shift. Several workers' Tc continued to rise even after the workday ended and they had returned home, and some experienced a higher off-work max Tc compared to their workday max Tc, shown in Table S2. Among at least four workers (M21040, M21089, 22020, 22083), their Tc increased again after having already reported going to bed, before they woke up the next morning.

Table S2 shows the same individual timeline data as in Figure S1, with the individual personal ambient temperature (Tpa) data alongside, for all those with off-work Tc data (n=24). As had been shown in Figure 3, the overnight Tpa data shows variability among these 24 individuals. M2205 was exposed to the highest off-work environment temperature with an average of 30.9 °C (2.5 °C) while also having exceeded Tc of 38.5 °C during the workday; during off-work hours, he reached a maximum Tc of 37.9 °C at 18:44 pm. Of the 17 workers with both workday and off-work Tc data available, five (29%) experienced a greater or equal max Tc during their off-work hours as they did during the workday. Eleven workers total (46%) reached or exceeded 37.5°C during off-work.

Table S2. Timeline of workday and off-work Tc and iButton data by individual Study ID (n=24).

Study ID	**Max Workday Tc (°C)**	**Time of Tc max-work**	**Time home**	**Tc off-work (°C)**	**Time of Tc max-off-work**	**Time went to bed**	**Time woke up**	**Tpa off-work (°C)**
				mean (SD) max				**mean (SD) max**
M21040	37.7	12:44:09	17:30:00	36.5 (0.2) 37.3	18:51:19	20:30:00	4:30:00	29.5 (3.6) 34.6
M21045	38.3	16:11:17	19:00:00	36.6 (0.2) 37.3	19:04:38	21:00:00	4:30:00	29.1 (3.9) 35.7
M21047	38.2	14:51:33	19:30:00	36.4 (0.3) 37.1	18:47:06	20:30:00	4:30:00	27.2 (3) 33.6
M21050	37.7	14:47:33	17:50:00	36.5 (0.2) 37.1	19:58:51	21:30:00	4:40:00	27.9 (3.3) 35.6
M21052	37.0	9:24:33	18:00:00	**36.6 (0.3) 37.2**	19:26:22	20:00:00	4:30:00	29.2 (3.2) 34.1
M21071	No data	15:10:20	19:30:00	36.3 (0.3) 37.1	19:37:18	21:00:00	4:30:00	29 (3.2) 35.1
M21075	38.0	14:25:57	19:00:00	36.8 (0.2) 37.8	19:52:47	20:30:00	4:00:00	29 (3.3) 35.5
M21078	37.8	14:43:51	18:45:00	36.8 (0.3) 37.5	19:42:55	20:00:00	4:30:00	30.6 (2.6) 36.6
M21080	37.9	12:55:52	18:30:00	36.8 (0.3)	20:38:12	21:30:00	4:30:00	30.8 (3.4) 36.1

				37.7				
M21086	37.5	12:51:03	18:30:00	**36.8 (0.4) 37.6**	20:11:33	21:00:00	5:00:00	28.8 (3.6) 35.6
M21089	37.8	16:39:54	18:40:00	36.6 (0.3) 37.3	20:08:58	21:00:00	4:30:00	28.6 (3.2) 34.6
M22001	37.7	16:22:23	18:00:00	36.4 (0.3) 37.2	19:08:30	19:30:00	4:00:00	29.2 (1.8) 33.1
M22005	38.7	14:42:32	19:00:00	36.4 (0.3) 37.9	18:44:26	21:00:00	4:00:00	30.9 (2.5) 35.6
M22007	No data	-	20:00:00	36.6 (0.2) 37.2	19:01:04	22:00:00	4:30:00	28.1 (2.8) 35.1
M22016	No data	-	19:00:00	36.4 (0.2) 36.9	19:05:32	21:00:00	4:25:00	29.2 (2.7) 34.6
M22017	No data	-	16:40:00	36.6 (0.3) 37.5	19:34:22	20:30:00	4:40:00	24.8 (2.7) 30.6
M22020	37.3	14:57:25	19:00:00	**36.7 (0.3) 37.6**	19:58:36	21:00:00	4:30:00	28.6 (3.7) 35.1
M22022	No data	-	19:00:00	36.9 (0.3) 37.7	19:38:13	20:30:00	5:00:00	29.2 (2.4) 35.6
M22025	No data	-	18:35:00	36.9 (0.2) 37.4	19:09:41	21:30:00	4:30:00	29.6 (3.2) 35.5
M22031	37.6	14:34:48	18:30:00	**36.7 (0.5) 37.6**	18:38:53	20:00:00	4:30:00	30.1 (2.9) 35.5
M22032	No data	-	19:30:00	37.1 (0.4) 38.1	18:14:10	21:00:00	4:30:00	30.2 (2.9) 36.7
M22034	37.7	13:35:17	19:00:00	**37.2 (0.4) 37.8**	21:27:08	21:00:00	4:40:00	29.8 (2.8) 34.7
M22080	38.2	13:31:32	19:00:00	36.8 (0.2) 37.4	20:15:20	21:00:00	4:30:00	29.1 (3.1) 36.1
M22083	37.6	15:33:24	19:30:00	36.3 (0.3) 36.9	5:55:50	20:00:00	4:00:00	28.8 (3.2) 35.6
Overall	-	-	-	36.7 (0.4) 38.1	-	-	-	29.1 (3.3) 36.7

Bold indicates having experienced a higher off-work Tc max compared to workday Tc max.
°C = Celsius; Tc = core body temperature

Table S3: Additional Recovery survey variables	
Hydration	
What other types of beverages did you drink between ending work yesterday until going to bed? Select all that apply	N (%)
-- atol	21 (40)
-- alcohol	0
-- coffee	7 (13)
-- energy drink	0
-- juice	11 (20)
-- soda	2 (4)
-- electrolyte solution	15 (28)
-- other	3 (6)
What did you drink since waking up this morning?	
-- water	37 (67)
-- atol	23 (43)
-- coffee	9 (17)
-- energy drink	0
-- juice	5 (9)
-- soda	3 (6)
-- electrolyte solution	16 (30)
-- other	3 (6)
Cups of water since waking up (8 oz)	
-- 1 cup	13 (35)
-- 2-4 cups	18 (49)
-- > 4 cups	6 (16)
Cups of electrolyte solution since waking up (8 oz)	
-- ½-1 cup	4 (25)
-- 2-4 cups	6 (37.5)
-- > 4 cups	6 (37.5)
Sleep & rest	
(Sleep complaints) Did not feel refreshed on waking up	2 (4)
How would you rate your sleepiness now? (past 5 mins)	
--Extremely alert	25 (46)
--Alert	24 (44)
--Neither alert nor sleepy	5 (9)
--Sleepy	1 (2)
Apart from your sleep, did you get enough rest yesterday after work?	
--Yes, definitely enough	47 (86)
--Yes, almost enough	7 (13)
--No, slightly too little	1 (2)
Behaviors & nutrition	
During the last month, do you feel that your family had enough food to eat?	
-- Yes	53 (96)

-- No	2 (4)