EPiC Series in Built Environment
Volume 5, 2024, Pages 921–929
Proceedings of 60th Annual Associated Schools of Construction International Conference

Toward an Understanding of Heat Stress & Strain on Roofing Technicians

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There is an escalating threat of heat stress exposure by all and those at a disproportionate risk are construction workers. Beyond this, roofers as a subset of those workers are second when it comes to the risk of heat-related deaths, but there are not many studies that specifically focus on the need to protect roofers. That is why it is imperative to further investigate the impact environmental heat has on roofers and this study begins to forward this work by understanding the physiological response of roofers to heat stress to advocate for more research in this area of work. To determine the conditions and physiological response to working in hot environments by roofers, the research team used two wearable devices to obtain environmental heat and core body temperature measures. What is found is that participants experienced significantly high heat index values while working. This is reflected in the measure of workers' core body temperature readings that in some cases have shown core body temperatures significantly exceeding normal core body temperatures.

Key Words: Construction, Roofers, Wearables, Safety, Heat Stress, Heat Strain

Introduction

Amidst a changing global climate, there is an escalating threat of heat stress exposure by all who engage in activities without climatic controls. The year 2022 was the world's sixth warmest year on record since global records began in 1880 (NOAA, 2023). To underscore this hazardous trend, the ten warmest years on record have all been since 2010 (NOAA, 2023). The human impact of this trend cannot be understated. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states with very high confidence that heat-related mortality and morbidity rates are projected to rise globally (Cissé, 2022). Temperatures will continue to rise, and it is important to note that outdoor workers have died of heat stroke when the maximum heat index was only 86ºF and less severe heat-related illnesses (HRIs) can happen at even lower heat index values.

Conditions for heat stress, as an occupational hazard, are set to worsen for outdoor workers. Due to the nature of their work, construction workers face an escalating threat from the conditions of heat exposure as they continue performing a significant amount of heavy tasks in an outdoor environment (Acharya, Boggess, & Zhang, 2018). It is such a pressing issue that the U.S. Government has recognized that construction workers specifically are disproportionately impacted by extreme heat (The White House 2023).

Moreover, roofers as a subset of the construction workforce are at a greater risk than other construction subgroups. According to a study by Dong et al. (2019), roofers have the second highest risk of heat-related deaths in the U.S. So, we must know the environmental heat they are experiencing, their physiological response to those conditions (heat strain), and the ways we can reduce the impact of working in hot conditions.

Problem & Purpose

It has been recognized that the roofing trade has a high risk of deaths due to heat, but research does not focus on this specific subgroup. Therefore, the purpose of this study is to move toward an understanding of the experiences that roofers have when working in hazardous hot conditions and highlight why more investigation must take place in this domain of work.

Literature Review

In recent years, the escalating impacts of heat stress on construction workers have garnered attention in academic research and public discourse. There has been a fair amount of research that has utilized various means to understand the environmental impacts construction workers face and what their physiological responses are. It was found that utilizing heat stress monitors and biosensors of various forms was the main way of understanding the environmental conditions and heat strain of workers who were primarily working in hot environments.

Environmental Heat Monitoring in General

Environmental heat plays a key role in causing heat stress in construction workers (Song & Zhang, 2022). Environmental heat focuses on four contributing factors of heat stress in workers which include air temperature, relative humidity, radiant heat, and air movement. Environmental heat and various factors can be assessed on a project site primarily by the use of a Wet Bulb Globe Temperature (WGBT) device to measure heat stress, but a device measuring heat stress index is also a common way to measure heat stress (OSHA, 2023).

Recent studies have observed heat stress in a variety of ways. Primarily, heat stress was observed using non-wearable devices and wearable devices. Researchers have used non-wearable devices to measure heat stress for a variety of purposes and these non-wearable devices are good indicators of environmental heat of workers (Hassandokht et al., 2022; Fang et al., 2021; Tang et al., 2021; Wan, Jia and Goh, 2021; Rasdan et al., 2020; Al-Bouwarthan et al. 2019).

Wearable Heat Stress Monitoring

There are a few factors that help to determine indicators for heat strain, this includes heart rate, sweating rate, core body temperature, and skin temperature (Song & Zhang, 2022). Researchers have investigated heart rate increases as an early sign of heat-related illness by using wearable sensors to measure skin temperature, energy consumption, and heart rate (Kakamu et al., 2022). Others have measured the core temperature of an individual's external auditory canal to verify an individual's response to heat stress (Moreno, Zea and Monroy 2020).

Other Contributing Factors

It should be noted that there are other contributing factors to understanding the heat strain experienced by construction workers. As Kakamu et al. (2021) state, "the constant use of machinery and powered tools, working on elevated surfaces, heavy workload, simple accommodation conditions near the worksite, being temporarily employed by a subcontractor on a daily payment basis, and constant direct exposure to sunlight" and clothing are all contributing to the risk of heat-related illness. These are all important factors; however, this research paper focuses on observing the environmental heat and the heat strain of roofers.

Methodology

Roofing activities are unique as there are different working elevations, roof slopes, and installation/repair approaches. The research team wanted to approach this study by observing environmental heat and heat strain experienced by roofers to use economical, practically based, non-invasive wearables that can immediately be deployed and are available for commercial use. Additionally, the team got preliminary data from questionnaire responses and a team member observed roofer activity throughout the workday. An IRB expedited approval was obtained for this study.

Wearable Devices for Heat Stress and Heat Strain

The research team found two economical, commercially available wearable devices for observing heat stress and strain. The first device used for observing environmental heat stress was the Kestrel Drop D2 wireless data logger (see Figure 1.) with the device being able to be worn on a worker's belt loop. This device provides pertinent measures for heat stress such as the ambient temperature, relative humidity, and pressure, and calculates density altitude, dew point, heat index, temperature-humidity index (which uses the dry bulb temperature), and the wet bulb temperature (psychometric). The accuracy ranges for key measurements are +/- 0.9ºF for ambient temperatures, +/- 2%RH for relative humidity, +/- 7.1ºF for heat index, and +/- 3.2ºF for wet bulb temperature (psychometric). This device has been used in a variety of research contexts such as horticulture and farming and laboratory monitoring (Kestrel, 2023). This device was set to collect heat stress index values at 10-minute intervals. Data was extracted at the end of each workday into .csv files for analysis.

Figure 1. Kestrel Drop D2

The second device found was the CORE® body temperature sensor (see Figure 2.), a device that can be worn on the arm or across the chest of a worker. Traditionally, core body temperature monitoring can be found to be inaccurate, expensive, non-continuous, or highly invasive such as an electronic ingestible pill (e-pill) or rectal thermometer. CORE® uses a thermal energy transfer sensor (that is not skin temperature) and the CORE® team has compared their device against accurate, yet more invasive approaches to validate the CORE device (CORE, 2023) internally. Additionally, Ajčević et al. (2022) validated the CORE device through an independent clinical study. The CORE sensor has a measurement accuracy of +/- 0.378ºF. This device was set to collect participants' core body temperature at 5-minute intervals. Data was extracted at the end of each workday into a .csv for further analysis.

Figure 2. CORE® Body Temperature Sensor Device

Participants

Working alongside the Roofing Alliance Task Force, an invitation was sent out to roofing companies requesting permission to conduct the study in the central and southwest Florida regions and the southeast Texas regions. From this, five companies allowed for 11 participants to be monitored throughout an entire workday or multiple workdays during the summer months of May through August. Table 1. provides key demographic data of participants. Participant IDs were set up with the number being the group of observation and the letter being the participant designation that correlated with the device name. Asterisks next to participant IDs denote that multiple observations were made of the same participants, i.e., multiple days in different months throughout the summer. Participants were asked to provide demographic data and to provide information on their experiences at the end of the workday. All workers identified that they were acclimatized with participant 2A being the only participant who had worked for the company for less than a month (2 weeks). Worker activity was monitored throughout the day and recorded by observers. Key observations are noted for workers' heat strain more than the normal core body temperatures of 97ºF – 99ºF (NIH, 2023).

Table 1

Participant Response Data Received on Data of Observation by Participant ID

ID	Gender	Age (Years)	Weight (lbs)	Project Type	Chronic Illnesses?	Experience (Years)	Healthy?
1A*	Male	28	135	Res. Repair[1]	None	1.5	Mod.[1]
1B*	Male	27	180	Res. Repair[1]	None	8	Mod.[1]
2A*	Male	40	270	Edu. Strip and Reroof	None	20	Mod.[1]
2B*	Male	50	206	Edu. Strip and Reroof[2]	None	10	Very
3A	Male	43	217	Edu. Strip and Reroof[2]	None	.8	Very
3B	Male	37	160	Edu. Strip and Reroof[2]	None	3	Very
4A*	Male	45	140	New Roof	None	25	Healthy
4B*	Male	20	132	New Roof	None	2.5	Healthy
5A*	Male	46	198	Res. Repair[1]	None	15	Healthy
6A*	Male	21	176	Res. Repair[1]	None	5	Healthy
6B*	Male	23	180	Res. Repair[1]	None	3	Healthy

[1]Residential Repair [2]Educational Strip and Reroof [3]Workers self-identifying as moderately healthy.

Results & Analysis

Average Heat Stress Index Values Recorded

Based on the collected data, the average and maximum heat stress index values reported by the Kestrel Drop D2 devices throughout the workdays of all participants were plotted in the chart below (see Figure 3.). It is evident that in general, participants experienced high heat index values throughout the workday.

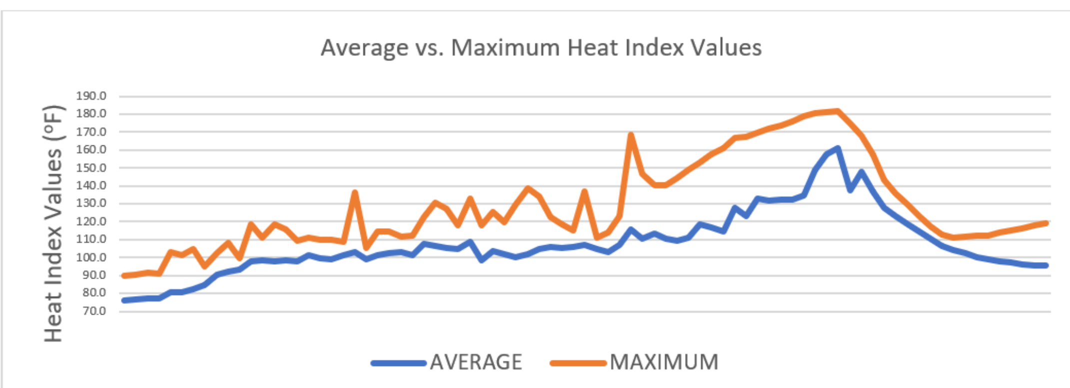

Figure 3. Average and Maximum Heat Index Values Experienced by Roofing Technicians

Average Core Body Temperatures – Heat Strain

The following core body temperatures were observed by each participant and resultant core body temperatures were plotted via the charts below (see Figure 4.) The *y-axis* represents core temperatures while the *x-axis* represents time throughout the workday. Red bubbles on each chart indicate a slippage or disconnection of the device. Troughs in the data indicate periods of rest or minimal work (lunch and water breaks) which coincide with observers' observation. In general, the CORE® body temperature sensor provides data indicating participants' starting core body temperatures expected at the start of the workday (between 98ºF and 99ºF) with core temperature increases experienced by all participants during heavy work activity. All participants experienced significant core temperature increases except for participant 4a who experienced moderate core temperature increases which is interesting as they have the most roofing experience.

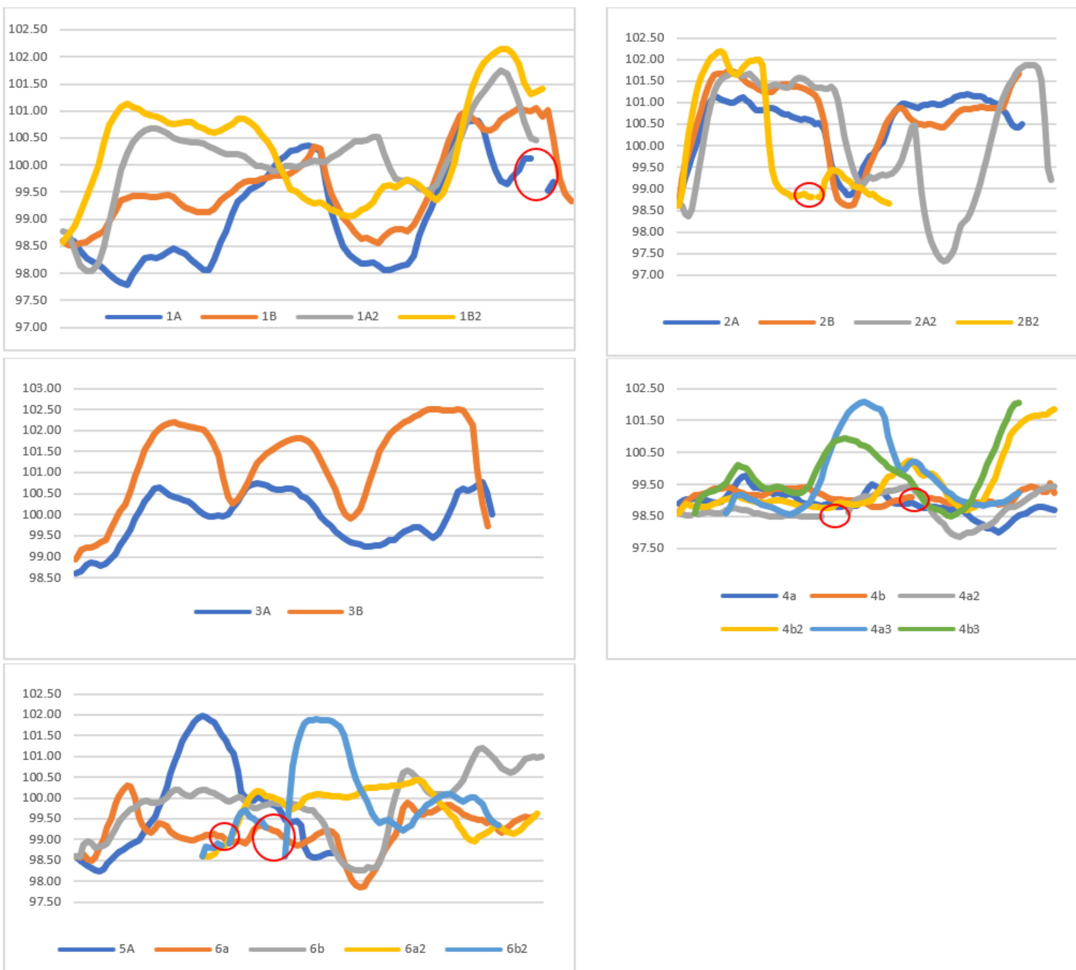

Figure 4. Summary of Core Body Temperature Values Experienced by Roofers

Key Observations and Reported Data

From on-site observations and notes, it was noticed that workers tend to take multiple breaks throughout the day, but it was done on the roof. Rest and hydration stations were set up on the roof even when in some cases, workers had shaded dedicated rest areas on the ground floor. The problem with shaded rest areas on the ground floor versus on the roof with workers is that it was too cumbersome to travel across a roof and go up and down whenever a break was needed as reported by some roofers. Additionally, for residential roofing workers, it was observed that there was difficulty determining finding a shaded rest area around the home that would not be intrusive to the client. Also, there wasn't a consistent break schedule for work-rest periods other than lunch breaks.

Workers were asked what their perceived level of effort was when performing roofing activities. Two workers said very high, five said high, two said moderate, and two said low. When asked how they handle working in hot environments under this perceived level of effort, workers stated that they take breaks, hydrate, try to get in the shade often and work in the early morning periods. Some of the workers also mentioned that their companies have provided them with electrolyte supplements when working in hot environments. Even while doing this, workers reported there can be losses in productivity and some indicated productivity losses upwards of 30%.

When asked what the overall impact of working in hot environments was, in addition to the loss in productivity, workers mentioned a decline in well-being, bodily exhaustion, loss in concentration, increased safety risks, and overall deterioration of health. Workers also were observed experiencing excessive sweating, severe thirst, and exhaustion. It was also reported by workers that sunburn was a common issue which is why long-sleeved shirts, long pants, hats, and gaiters were worn. What was observed is that the clothing worn was relatively light and did not warrant consideration for a clothing adjustment.

When asked about heat advisement, educational materials, and satisfaction with training, worker responses were varied. Three of the workers did not answer whether the employer provides advisement on working in hot environments and two of those declined to answer whether they were satisfied with measures to reduce heat stress by their employers. Others have stated that they tend to be advised orally by their employer, or that there is some other educational material provided. When asked about the satisfaction of measures to reduce heat stress on the job site by their employer, an additional three workers declined to answer that question. Only one worker stated that they received formal safety training.

An important comment made by one of the safety managers on the site is that workers tend to be driven by "machismo" when working alongside colleagues doing the same work. He mentions that no one wants to be viewed as weak or lazy, so they continue to work through the symptoms that lead to heat-related illness.

Discussion & Conclusion

Understanding that heat index values of 86ºF can pose a severe risk to workers, the average heat index values participants experienced should be alarming. On average, most heat index values were sustained above 90ºF for most of the workday as reported by the Kestrel Drop D2. There were some anomalies with heat index value readings being maxed out at roughly 180ºF causing the average heat index values to be skewed; however, we believe this is an extraneous device reading and it may be related to the location of the worker at that period.

Although there were no resulting heat-related illnesses due to heat strain during times of observation, worker core body temperatures consistently exceeded the normal core body temperature of 99ºF as reported by the CORE® body temperature sensor, putting them at a significant risk of experiencing severe heat-related illnesses such as heat stroke. Moderate core temperature increases were experienced by the roofer with the most experience; however, the authors cannot determine any correlation at this point in the research. It was also identified through worker reporting and observation that there are significant impacts on worker productivity and general well-being when working in these extreme conditions.

With this new knowledge coupled with what we know of the high-risk nature of the roofing trade related to working in hot environments, it is important to continue the efforts to not only ensure accurate measurement of worker heat strain but to enact means of external intervention to prevent HRIs, especially in a pride-driven work environment.

Future Work

The research team anticipates that with this benchmark study, there should be more investigation into the modern technologies available that can not only identify, but that can also intervene when a worker experiences heat hazard conditions. Also, additional efforts should be placed on awareness campaigns and training programs and the research team intends to delve into the various ways that can not only educate roofers about the hazards of working in hot environments but also how change can be made in a machismo-driven work environment so that workers are inevitably safe.

Acknowledgments

The research team is grateful for the contributions of the Roofing Alliance for the commitment made to this work and roofing safety.

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