EPiC Series in Built Environment
Volume XXX, 2026, Pages 1–10
Proceedings of Associated Schools of Construction 62nd Annual International Conference

COTVIS: A Novel Core Temperature Visualization Device for Enhanced Peer Awareness

Eric M. Wetzel[1]; Muhammad Umer[2]; Caleb M. Powell[1] and Kenneth S. Sands II[1]
[1]Auburn University, [2]University of West Florida

This study describes a newly developed Core Temperature Visualization System (COTVIS) and functionally tests the system, designed to improve safety among construction workers. COTVIS functions as a Peer Awareness Alert System (PAAS), enabling real-time visual alerts based on biometric data, specifically heart rate and core body temperature. Unlike existing wearable technologies that rely solely on individual awareness, COTVIS shifts the responsibility for intervention to the entire crew by displaying alerts visible to nearby workers and within Bluetooth low energy distance to the triggered COTVIS. This approach addresses a critical need where individual risk perception often limits the effectiveness of safety measures. Testing in controlled environments demonstrated that COTVIS can potentially be used as a deterrent to safety-related injuries and illnesses and be an advanced alert system for injured workers. The findings suggest that with further development and field testing, COTVIS could be an integral component of broader site safety strategies.

Keywords: Peer Awareness Alert System (PAAS), Automation, Microcontrollers, Construction

Introduction

The construction industry is widely recognized as one of the most labor-intensive industries, and protecting its workers from injuries resulting from exposure to occupational hazards is a primary concern (Almaskati et al., 2024). But the ground reality presents a worrying picture, according to the report of the Bureau of Labor Statistics, construction had the most fatalities (1,075) across all industry sectors in 2023, which was the most for the sector since 2011 (BLS, 2024). Aside from the suffering that is immediately related to these accidents, other negative consequences for the company are also associated with these like medical care, insurance premiums, penalties, damage to reputation, etc (Zou & Sunindijo, 2015; Waehrer et al., 2007). But the numbers clearly suggest that there is much that needs to be done to protect the construction manpower. Despite continuous enforcement of occupational safety on construction sites and companywide protocols, it nevertheless has a high rate of accidents and casualties (Rashidi et al., 2025; Mosly, 2015; Im et al., 2009; Allison et al., 2019). Physiological stress on construction sites cannot be eliminated, but with timely and collective monitoring of its impact on individual workers, its perilous impacts can be minimized.

Wearable technology research in construction safety has developed as a critical topic of investigation due to the industry's high frequency of occupational risks and fatalities, accounting for roughly 20% of workplace accidents globally (Rashidi et al., 2024). Advances in sensor integration, cloud computing, and IoT have gradually improved wearable device capabilities, allowing for real-time monitoring of physiological and environmental factors (Gao et al., 2022).

Preliminary findings from Sands II et al. (2025) show that, despite being aware of the risks of working in excessive heat, many respondents still suffer symptoms and continue working despite discomfort. Sands II et al. (2025) also identified decision-making elements that influence workers' unwillingness to stop working during heat stress and also to develop an instrument to better support workers experiencing such heat related stress and discomfort.

To support the notion of collective and timely monitoring of physiological factors of individual workers, this study describes a newly developed Core Temperature Visualization System (COTVIS) and functionally tests the system, designed to improve peer responsiveness in the event that any crew member is facing any trouble or discomfort. COTVIS functions as a Peer Awareness Alert System (PAAS), enabling real-time visual alerts based on biometric data, specifically heart rate and core body temperature. In the event of any incident, the expectation would be that those experiencing the symptoms would pause their activity until their physiological state returns to normal. The system takes advantage of available technology built into the sensor platform, COTVIS is built on top of the Slate Safety armband, allowing a user to send an alert packet to other COTVIS devices.

Unlike existing wearable technologies that rely solely on individual awareness, COTVIS shifts the responsibility for intervention to the entire crew by displaying alerts visible to nearby workers and within Bluetooth low energy distance to the triggered COTVIS.

System Development and Research Approach

The approach to this research study involved three major parts: understanding the need, developing a device to address it, and testing it in a controlled environment.

The Core Temperature Visualization System (COTVIS)

To improve the safety outcomes for construction workers, this research removes an individual worker's decision to ignore the acute health issues around their daily work or rely on a supervisor to pay strict attention to their phone or computer. By developing an on-person wearable that displays color, text, and lighting when a physiological marker has been exceeded or a worker is in distress, anyone in the proximity of the worker will be made aware of the warning. Placing the burden of individual safety at the crew level has shown promising results. Pandit et al. (2018) showed that crew-level cohesion and a positive safety climate improve safety communication levels.

COTVIS Functionality

COTVIS is a Peer Alert Awareness System (PAAS) that gathers physiological and alert data from an armband (by Slate Safety) through a microcontroller using Bluetooth Low Energy (BLE) Coded PHY. The COTVIS device is a 2.4 GHz Wi-Fi/BLE System-on-Chip (SoC) ESP-32 S3 microcontroller with a 1.14" IPS TFT 240x135 pixel display, a single LED, and a 3.7V lithium-ion polymer battery (see Figure 1). The data packets are emitted from the Slate Safety armband and captured by COTVIS. COTVIS then decrypts the packet, checks for the band's MAC address (it won't parse data from another band), and parses and displays the data. COTVIS is designed to respond to two types of data: trigger and alert.

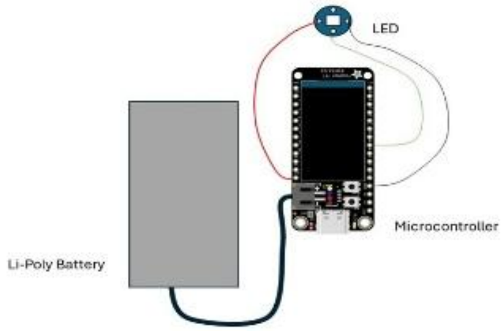

Figure 1. COTVIS hardware

Trigger data is a tracked biometric data value that exceeds a set threshold defined in the code. The two biometric data values COTVIS is tracking are heart rate and core body temperature. When either of these two values exceeds a set threshold, identified by NIOSH (2014) as a person under excessive heat strain (heart rate >= 180 beats per minute and core body temperature >= 101.3 degrees Fahrenheit), the system will illuminate an LED and change the state of the microcontroller's screen. These trigger packets will continue to influence the COTVIS device until the biometric data returns to below the trigger threshold. Figure 2 graphically presents this process.

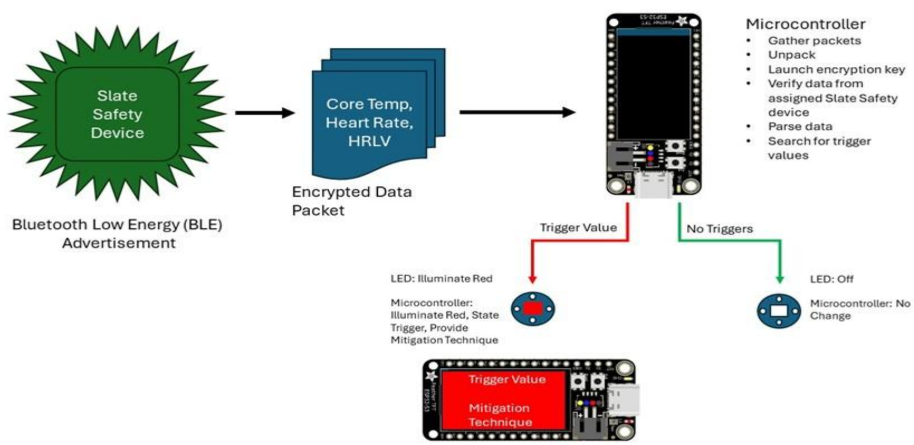

Figure 2. COTVIS while scanning for trigger data

Alert data packets have a higher priority than all biometric data packets and are transmitted to and accepted by all COTVIS devices within the BLE range. On construction sites, certain instances can occur that would hinder a worker's ability to be heard or to yell out for help. For example, an impact injury to the larynx, airway, or chest, disorientation due to heat, or simply colleagues wearing hearing protection during bouts of significant noise. In all these scenarios, a wearable device that could notify surrounding workers of distress would be very useful. The COTVIS device takes advantage of some native capabilities of the Slate Safety armband - namely the double tap alert function. To initiate an alert, the user double-taps the face of the armband using the palm of their hand and then holds their hand against it for 3 seconds. Doing so will transmit an "alert" packet that all COTVIS devices are coded to parse regardless of which MAC address the alert originates from. While trigger data only impacts the COTVIS of the person wearing that device, alert data is meant to reach as many COTVIS devices as possible. Alert data is transmitted by the armband for up to 30 minutes, meaning any

COTVIS not initially in the BLE range will acquire the alert packet upon entering the BLE range. Figure 3 illustrates the state changes for each device when an alert packet is sent/received.

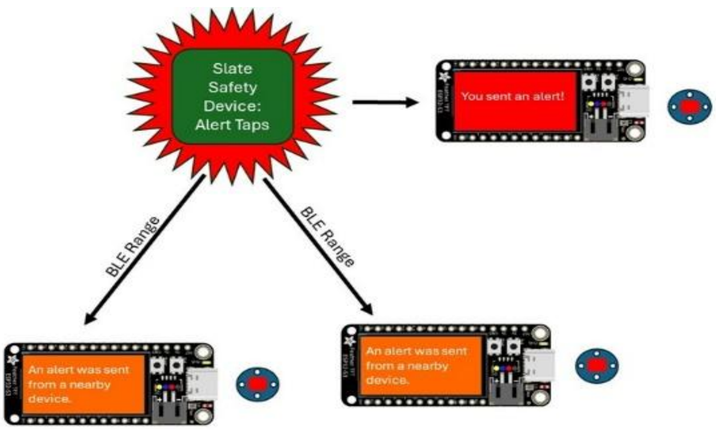

Figure 3. State change when an alert packet is sent

BLE Biometric Packet Scan/Rest Cycle

The Bluetooth controller within the armband will advertise the same packet multiple times for 2 seconds at an interval between 100ms and 150ms. The Bluetooth controller advertises several different types of packets: biometric, GPS, "return to work," alert, and status. COTVIS prioritizes biometric data, meaning the biometric data arrival interval is given precedence over other data packet arrival times. This holds in perpetuity until an alert packet is received. Alert packets are given the highest priority and become the only packet of concern for all devices within BLE proximity.

To conserve battery and limit heat, the COTVIS device is programmed to rest/scan cycle at a roughly 2 to 1 ratio. The research team identified a scan window of 10 seconds and a rest window of 20.48 seconds as optimal, a common scanning schedule approach where the scan period equals the "inter-packet arrival time" (IPAT) and a wait period that is twice the scan period. This cycle time predicts COTVIS will receive a biometric packet at least every 30 seconds, but often sooner. Figure 4 presents the Desmos Plot scan/rest cycle and the biometric packet advertisements.

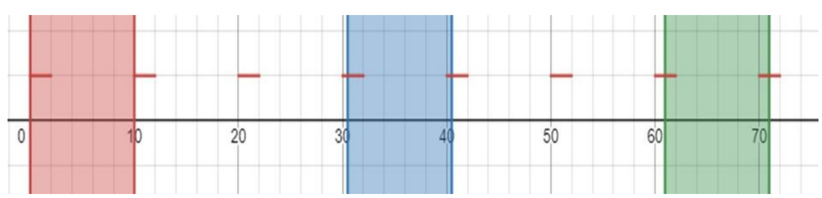

Figure 4. Desmos plot of scan/rest cycle for COTVIS

Prototype Housing

Figure 5 presents COTVIS in its housing. The housing is designed to be clipped to any exposed area on a construction worker – belt, hard hat, harness, vest, pocket, etc. The entire device is optimized to be as unintrusive as possible, measuring in at $3\frac{3}{16}$" x $2\frac{3}{8}$" x $1\frac{1}{8}$" (WxHxD). The research team built three COTVIS device prototypes for testing.

Figure 5. Images of the COTVIS hardware

Example COTVIS Placement on Wearer

Figure 6 shows a worker wearing the COTVIS system. The device is securely attached to a safety harness, demonstrating its compatibility with standard personal protective equipment commonly used in construction. Its position on the harness allows for core temperature monitoring and recognition of visual alerts by peers without impeding movement or comfort. The device can be attached to a belt loop, shirt, harness, or hard hat.

Figure 6. Example of COTVIS system on a worker

Testing

With the aim of this research being to evaluate the functionality and effectiveness of the Core Temperature Visualization System (COTVIS), a series of controlled tests allowed for an investigation of the device's visibility at distance and the ability to transmit user alert data promptly at specific distances and locations. This evaluation seeks to determine whether the real-time visual alerts provided by COTVIS can prompt timely interventions from peers, thereby mitigating the risks associated with acute health events and significant injuries occurring away from peers. All testing used the three prototypes built by the research team. The following approaches were taken to obtain range data. Brightness testing of the COTVIS measured the distance at which the TFT screen and

LED could be seen in direct sunlight conditions. While not all applications of COTVIS will be in direct sunlight, other scenarios, such as cloudy days, under cover, or indoors, would improve the line of sight. The research wanted to evaluate the worst-case scenario. This system functionality is meant to notify, at the crew level, that a peer has triggered any health-related threshold and is in danger. If a peer is within visual proximity to the microcontroller screen and/or LED, there will be a visual notification of an at-risk colleague.

Open-field “alert” testing of COTVIS involved evaluating the BLE alert system, meant to supplement the double tap feature on the Slate Safety devices in an open environment without intermittent hindrances between the device sending an alert and receivers. Device users affixed the biometric sensor to their arms (armband). They observed COTVIS devices while using a stopwatch to record the time between initial alert transmission and receipt of the alert by the COTVIS devices. The sender communicated the initial alert to the receivers using two-way radio devices. The devices remained stationary during signal transmission. Iterations of the test were done in 50ft increments from 20 feet to 170 feet. After each test, all COTVIS devices were reset. There were 3 observations for each intermittent point between the sender and the receiver(s). Both sender and the receivers were in straight line of site without any obstacles or hinderances. The first point was at 20 feet from the sender, and the intervals increased by 50 feet in the same straight line, with the last observation point being at 170 feet from the sender.

Indoor “alert” testing involved the system indoors on a single floor with partition walls, windows, and door obstructions. Both static (like open-field tests) and dynamic tests were done. The dynamic tests involved a stationary sender simulating an individual in distress and dynamic receivers simulating an active construction worker. In the dynamic tests, receivers initiated a consistent walking path once they were notified of signal transmission. In order to reduce the error associated with any hardware inconsistencies, each COTVIS did half of the runs in the Grad Lab area and half of the runs in the Conference Room area.

Results

Brightness Test

A brightness test was conducted to evaluate the performance of the custom-built PAAS in communicating the distress signal to the peer group. As mentioned earlier, receiving the distress signal illuminates the red LED on the device. A test was conducted to establish the distance a peer will be able to recognize that the red LED is illuminated on a person’s PAAS. Observations were taken with the help of individuals of different age groups in various conditions, i.e., LED in direct sunlight, LED in indirect sunlight, and LED in indoor environments. From the observations, it can be concluded that the red LED distress signal was recognizable within 16 feet of the device being in direct sunlight, 100 feet when the device is indirectly facing the sun, and about 165 feet in an indoor environment such as a building hallway. It can be concluded that proximity to the PAAS is crucial in bright conditions. In contrast, the LED-based distress signal can be observed from far away in conditions with comparatively low ambient light. While exact quantitative measurements were not taken during the brightness testing, the evaluation was purposely qualitative in character, with the goal of determining the overall practicality and visibility of the LED signal under varied settings. Though this method lacked the precision of rigorous analysis, it was adequate for presenting proof-of-concept and proving that the LED-based communication system can perform effectively in ordinary outdoor conditions. Future research could use more rigorous quantitative measurements with light meters or photodetectors to provide numerical data on signal strength and distance connections.

Open-field "Alert" Test

The open-field range field test was done to evaluate any distance constraint and time intervals an alert trigger from a sender to reach two additional COTVIS without any obstruction. At each distance (20 feet to 170 feet), the experiment was conducted three times. The distance variable represents the Euclidean distance (in feet) between the receiver and the sender. The time variable represents the duration (in minutes) for the sender's distress packet to reach the two receiver COTVIS devices. Two individuals were wearing one arm band each and they are referred to as B3 and G2. The naming nomenclature is internal to the team, for the reader this should only mean there were two mutually exclusive but exactly same receivers.

Mean Time vs Distance from the Sender by Armband Group

Figure 6 illustrates the average duration (in minutes) on the y-axis relative to the distance (in feet) on the x-axis. A blue line represents receiver device G2, while a red line depicts receiver device B3. The blue labels indicate the difference in average durations between the two groups at each distance interval. At 20 feet, the mean time for G2 is approximately 1.97 minutes longer than that of B3. The variation in this time difference is 0.45 minutes at 70 feet, 0.71 minutes at 120 feet, and 0.38 minutes at 170 feet. The black dashed lines connect the time points for each distance, emphasizing the differences in duration between the two groups at each distance interval.

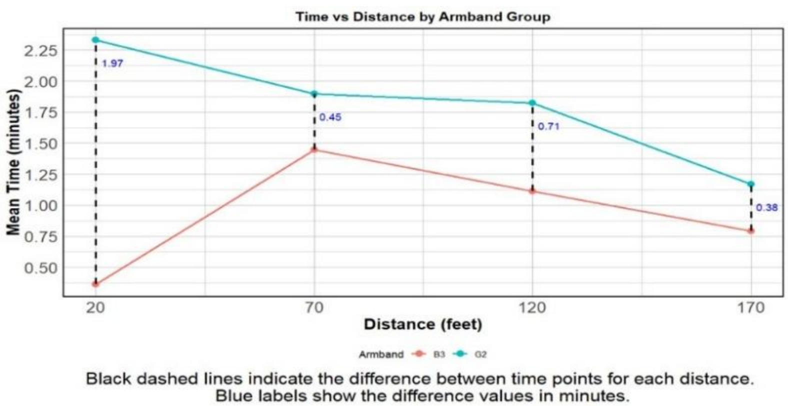

Figure 7. Average time vs distance from the sender by device

According to the data collected for the open-field range test conducted in an outdoor environment, the minimum time required by the distress signal to reach the receivers was around 0.018 minutes (1.08 seconds) with a mean receive time of 1.4 minutes (SD of 1.3 minutes). In other words, if a distressed worker, who is working in an area alone, sends out an alert, on average, a COTVIS without any obstruction would capture the BLE alert within 1 minute and 24 seconds, but possibly as early as 1 second. While it isn't known why G2 appeared worse at capturing packets when compared to B3, a few factors could cause the issue such as power supply variations, antenna issues, and manufacturing variations. While the exact issue is unknown and likely a hardware issue (both COTVIS are running the same code), the deviations between microcontrollers are likely to persist. However, as the number of COTVIS devices increases, there is a greater likelihood of BLE capture and notification. Functionally, an alert only needs to reach one person to be effective.

Indoor "Alert" Test

For this experimental testing, a total of 12 runs were performed. The receiver in the graduate lab had an average of 1.9 minutes, a median value of 1.7 minutes, and a standard deviation of 1.8 minutes. The receiver in the lobby (nearest to the sender) had an average of 1.0 minutes, a median value of 0.6 minutes, and a standard deviation of 1.1 minutes. The receiver of the conference room had higher values, with a mean of 3.2 minutes, a median of 2.9 minutes, and a standard deviation of 1.5 minutes.

Discussion

The results of this study highlight the potential of the Core Temperature Visualization System (COTVIS) as a peer-based alert mechanism for improving safety among construction workers. The integration of visual indicators directly addresses a gap in the literature: the lack of immediate recognition and response to physiological distress among workers (Fang et al., 2021). By providing real-time feedback visible to peers, COTVIS enables collective safety responses, aligning with findings by Pandit et al. (2019), who suggest that crew-level cohesion and communication significantly improve safety outcomes. This approach shifts the onus from individual workers, who may underestimate their risk of heat strain (Rameezdeen & Elmualim, 2017; Jia et al., 2016), to a more communal awareness that leverages the team dynamic to ensure swift intervention.
Moreover, COTVIS offers a practical solution to the challenges identified in prior studies involving wearable technology for heat safety. Previous research, such as that by Guo et al. (2019) on hybrid cooling vests and Chan et al. (2016) on anti-heat stress clothing, has demonstrated the effectiveness of wearable devices in reducing physiological strain. However, these solutions often require active compliance from the wearer, which can be inconsistent. In contrast, COTVIS's passive visual alert system ensures that those nearby can act even if a worker fails to recognize or report symptoms. The study's findings suggest that this passive yet collective approach could complement existing wearable technologies and address the issue of underreporting that limits their effectiveness.

The study also raises questions regarding the adaptability of COTVIS in diverse field conditions, echoing limitations noted by Hassandokht Mashhadi et al. (2022) in the deployment of drone-based cooling systems. Just as environmental factors like wind and weather impact the effectiveness of UAVs in cooling, factors such as signal interference and the physical layout of construction sites could influence the performance of COTVIS's Bluetooth Low Energy (BLE) transmission. This research confirmed an expected amount of packet loss with obstructions between the sender and the receivers. These considerations emphasize the need for further testing in varied environments to optimize COTVIS's functionality. Additionally, while the emphasis on peer intervention aligns well with literature stressing the importance of social dynamics in safety (Li et al., 2021), the effectiveness of this approach may vary depending on team cohesion and workplace culture, suggesting a need for tailored implementation strategies.

Implications and Limitations

The development and testing of the COTVIS device contribute to the growing body of research on wearable technology for occupational safety. This study highlights the potential of integrating visual alert systems into wearable safety devices, offering a new avenue for research into behavioral safety interventions. The research team hopes this work encourages further academic exploration into peer-based safety systems and their role in improving on-site safety culture. COTVIS can offer practical implications for improving stress management. By enabling real-time monitoring and peer intervention, COTVIS can potentially mitigate the risks associated with work site-related illnesses, reducing downtime and improving productivity. The device's future development will focus on being a low-maintenance, easily implementable tool, making it a viable option for construction firms looking to enhance safety protocols without significantly disrupting workflow. This study has several limitations that should be considered when interpreting the results. First, the testing environment for COTVIS was controlled, which may not fully replicate the diverse and dynamic conditions found on actual construction sites. The effects of additional factors, such as floor levels, actual movements and positions of construction workers, and other obstructions on the Bluetooth Low-Energy (BLE) signal transmission were not fully explored. The testing relied on the wearer's physiological data at rest or in a low activity state, not actual physiological fluctuations as may be experienced by construction workers.

Conclusions and Future Research

The COTVIS device demonstrates a promising approach to enhancing safety in construction by enabling peer-level awareness and intervention through visual alerts. This research underscores the importance of developing technology that shifts safety responsibilities to the crew level, potentially increasing safety compliance and reducing the risks associated with heat-related illnesses. While the experimental results of these studies were based on three COTVIS devices (the number of prototypes built by the research team), results from an actual jobsite would likely show significantly different results. A hypothesis developed as a result of this study states that the more COTVIS devices present, the shorter the time interval for a receiving device to capture an alert packet. While mean capture time is a useful academic metric, in practice, only one device needs to capture the alert for it to be effective. If a single device captures a packet 15 seconds into the alert, then that minimum value becomes the actual notification metric. It is not relevant how long it takes all other devices. To that end, further validation in diverse real-world settings with additional devices is necessary to confirm the device's efficacy and adaptability, including a test where a tight cluster of COTVIS devices may slow packet reception due to interference. The findings suggest that with refinement and broader testing, COTVIS could become an integral part of the broader safety strategies in the construction industry.

Future research should focus on testing COTVIS across varied environmental conditions to assess its performance under different conditions with various physical obstructions. The device needs to be tested among a diverse range of construction crews to obtain practical feedback on the device’s usability. Moreover, integrating additional biometric data for alerts could enhance the device's functionality. There is also potential for exploring how COTVIS can be combined with other safety technologies, such as IoT-based monitoring systems, to create a more comprehensive safety network on construction sites. Although the current tested range of approximately 170 ft (~50 m) aligns with standard BLE performance, this distance could theoretically be extended by increasing the ESP32’s transmission power. However, such adjustments would likely reduce battery life and increase heat generation. Addressing these limitations would require a larger battery and an expanded housing design with improved heat dissipation. Finally, longitudinal studies assessing the long-term impact of COTVIS on safety behavior and incident rates in the field would provide valuable insights into the device's effectiveness and sustainability as a worker safety intervention.

References

Allison, R.W., Hon, C.K.H. and Xia, B. (2019), “Construction accidents in Australia: evaluating the true costs”, Safety Science, Vol. 120, pp. 886-896, doi: https://doi.org/10.1016/j.ssci.2019.07.037.

Almaskati, D., Kermanshachi, S., Pamidimukkala, A., Loganathan, K., & Yin, Z. (2024). A review on construction safety: hazards, mitigation strategies, and impacted sectors. *Buildings*, *14*(2), 526.

Bureau of Labor Statistics. (2024, December 19). *2023 Census of Fatal Occupational Injuries (CFOI) news release* [PDF]. U.S. Department of Labor. https://www.bls.gov/news.release/pdf/cfoi.pdf

Chan, A. P., Guo, Y. P., Wong, F. K., Li, Y., Sun, S., & Han, X. (2016). The development of anti-heat stress clothing for construction workers in hot and humid weather. *Ergonomics*, *59*(4), 479-495. https://doi.org/10.1080/00140139.2015.1098733

Fang, Z., Tang, T., Zheng, Z., Zhou, X., Liu, W., & Zhang, Y. (2021). Thermal responses of workers during summer: An outdoor investigation of construction sites in South China. *Sustainable Cities and Society*, *66*, 102705.doi:10.1016/j.scs.2020.102705

Gao, R., Mu, B. J., Lyu, S., Wang, H. J., & Yi, C. (2022). Review of the Application of Wearable Devices in Construction Safety: A Bibliometric Analysis from 2005 to 2021. *Buildings*, *12*(3), 344. https://doi.org/10.3390/buildings12030344

Guo, Y., Chan, A. P., Wong, F. K., Li, Y., Sun, S., & Han, X. (2019). Developing a hybrid cooling vest for combating heat stress in the construction industry. *Textile Research Journal*, *89*(3), 254-269. https://doi.org/10.1177/0040517517743685

Hassandokht Mashhadi, A., Handy, R., Farhadmanesh, M., Rashidi, A., Honda, T., Sleeth, D. K., & Henry, T. (2022). Feasibility study of using nebulizer-retrofitted UAVs at construction projects: The case study of residential jobsites in Utah. *Journal of Construction Engineering and Management*, *148*(10), 05022009. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002368

Im, H.-J., Kwon, Y.J., Kim, S.G., Kim, Y.K., Ju, Y.S. and Lee, H.P. (2009), "The characteristics of fatal occupational injuries in Korea's construction industry, 1997-2004", Safety Science, Vol. 47 No. 8, pp. 1159-1162, doi: https://doi.org/10.1016/j.ssci.2008.11.008.

Li, Z., Bao, X., Sheng, Y., & Xia, Y. (2021). Research on unsafe behavior of construction workers under the bidirectional effect of formal rule awareness and conformity mentality. *Frontiers in Psychology*, *12*, 794394.

Mosly, I. (2015), "Safety performance in the construction industry of Saudi Arabia", International Journal of Construction Engineering and Management, Vol. 4 No. 6, pp. 238-247, doi: https://doi.org/10.5923/j.ijcem.20150406.03.

National Institute for Occupational Safety and Health (NIOSH). (2014). *Health hazard evaluation report: Evaluation of heat stress and heat-related illness* (Report No. 2013-0109-3214). Centers for Disease Control and Prevention. https://www.cdc.gov/niosh/hhe/reports/pdfs/2013-0109-3214.pdf

Pandit, B., Albert, A., Patil, Y., & Al-Bayati, A. J. (2018). Fostering Safety Communication among Construction Workers: Role of Safety Climate and Crew-Level Cohesion. *International journal of environmental research and public health*, *16*(1), 71. https://doi.org/10.3390/ijerph16010071

Rameezdeen, R., & Elmualim, A. (2017). The impact of heat waves on occurrence and severity of construction accidents. *International journal of environmental research and public health*, *14*(1), 70. https://doi.org/10.3390/ijerph14010070

Rashidi, A., Woon, G. L., Dasandara, M., Bazghaleh, M., & Pasbakhsh, P. (2025). Smart personal protective equipment for intelligent construction safety monitoring. *Smart and Sustainable Built Environment*, *14*(3), 835-858.

Sands II, K. S., Wetzel, E. M., & Tatum, M. (2025). Toward an Understanding of Construction Workers' Decision to Stop Work When Experiencing Symptoms of Heat Strain: A Pilot Investigation. *Proceedings of Associated Schools of Con*, *6*, 893-902.

Waehrer, G. M., Dong, X. S., Miller, T., Haile, E., & Men, Y. (2007). Costs of occupational injuries in construction in the United States. *Accident Analysis & Prevention*, *39*(6), 1258-1266.

Zou, P. X., & Sunindijo, R. Y. (2015). *Strategic safety management in construction and engineering*. John Wiley & Sons.