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Physiological Strain in Construction Workers: A Systematic Review of Heat-Workload Synergy and the Impact of Personal Protective Equipment

Sujan Acharya¹, Krishna Kisi¹ and Rujan Kayastha¹
¹Texas State University

Construction workers face a severe physiological burden from the synergistic interaction between ergonomic workload and environmental heat stress. However, current risk assessments fail to account for a critical amplifying factor: the additional thermal load imposed by mandatory Personal Protective Equipment (PPE), a research gap this study addresses by synthesizing the available evidence on dual stressors. This study uses a systematic literature review, following Preferred Reporting Items for Systemic Reviews guidelines, to analyze secondary data from peer-reviewed studies that concurrently investigated both heat and ergonomic stressors using objective physiological or performance-based outcomes. The results show that the combined exposure produces a multiplicative strain, causing quantifiable decrements in physical work capacity, including endurance time reductions of up to 35%, and significant productivity losses. Critically, none of the synthesized studies measured the thermal burden of PPE, indicating that current risk models systematically underestimate the total physiological strain on workers. This study benefits the construction industry by establishing that even dual-stressor safety models are insufficient. It provides a directive for professionals and policymakers to shift future research and development from simply documenting the problem to engineering solutions, such as thermally managed PPE, which is essential for creating genuinely safer and more resilient work environments.

Keywords: Heat stress, ergonomic workload, construction workers, PPE, productivity

Introduction

The construction industry is characterized by its reliance on strenuous manual labor, with tasks like lifting, carrying, and operating heavy machinery in difficult outdoor environments remaining central to its operations (Melagoda & Rowlinson, 2021). Despite representing only 7–9% of the global workforce, the industry accounts for 20–25% of work-related mortality and morbidity including roughly one in six fatal workplace accidents that highlights a stark imbalance between its employment share and safety outcomes (Chinnadurai et al., 2017; Kayastha et al., 2025). At the individual level, this intense physical strain is an intrinsic part of daily work, not an occasional event; physiological measurements confirm that workers routinely exceed established safety limits for energy expenditure, oxygen consumption, and heart rate (Abdelhamid & Everett, 2000). This constant state of physical overexertion is exacerbated by an embedded workplace culture where economic incentives and productivity targets consistently override health considerations. As a result, physical strain and pain

are often normalized and accepted by the workforce as an inescapable condition of their employment (Ajslev et al., 2013).

This pervasive physical strain directly results in muscle fatigue, a condition defined as an exercise-induced reduction in a muscle's capacity to generate force or power (Acharya et al., 2025). In an occupational context, this state directly compromises worker safety and operational integrity. A fatigued individual exhibits slower reaction times, impaired decision-making, and reduced situational awareness, factors that heighten accident risk in dynamic construction environments (Azzamullah et al., 2025; Namian et al., 2021). Fatigue also leads to a measurable decay in postural stability, which increases the likelihood of slips, trips, and falls which is a primary cause of serious injury in the industry (Nussbaum, 2003). The economic consequences of these performance decrements are equally direct, manifesting as productivity losses from decreased work speed, as well as increased costs tied to errors, rework, and workplace accidents (Macfarlane et al., 2024).

The physical demands of construction are rooted in several core ergonomic stressors. Manual material handling is universal where mechanization is limited. Frequent awkward postures like bending and reaching place targeted stress on the musculoskeletal system (Anagha & Xavier, 2020). In addition, static exertion from holding tools or materials in a fixed position contributes directly to fatigue in the back and neck. Even without thermal stress, these factors alone elevate metabolic demand and cardiovascular strain, which in turn accelerates localized muscle fatigue by depleting energy stores and allowing metabolic byproducts to accumulate in the muscle tissue (Nybo et al., 2014).

The ergonomic burden on construction workers is compounded by significant environmental thermal stressors. Outdoor work creates direct exposure to high ambient temperatures, solar radiation, and radiant heat from equipment and surfaces such as asphalt and concrete (Baizhan & Andrew, 2018; He et al., 2024). High humidity critically impairs the body's primary cooling mechanism, evaporative cooling, thereby trapping heat and increasing the risk of heat-related illness (Esfahani et al., 2024). The composite measure for this environmental challenge is the Wet Bulb Globe Temperature (WBGT) index which is used to estimate the effect of temperature, humidity, wind speed, and solar radiation on humans. The body must manage this external heat load in addition to the metabolic heat generated by physical labor. This dual demand from heat load and physical labor triggers widespread cutaneous vasodilation, which can raise skin blood flow to seven liters per minute, and sweating, which leads to a substantial risk of dehydration if fluids are not replenished (Trangmar & González-Alonso, 2019).

This dual exposure forces the cardiovascular system to meet two competing demands: supplying oxygenated blood to working muscles and simultaneously diverting blood flow to the skin for heat dissipation (González-Alonso et al., 2008). This competition for limited cardiovascular resources results in a synergistic interaction where the total physiological strain is multiplicative, not simply additive (Adams et al., 2017). Consequently, the observed increase in heart rate and core temperature are greater than the sum of their responses to each stressor in isolation. Yet, the majority of research has historically investigated these stressors independently. This single-stressor approach, while methodologically convenient, fails to capture the non-linear dynamics of the occupational environment and therefore underestimates the physiological risk to workers (Griffen et al., 2016).

While the dual stressors of heat and ergonomic workload have received increasing attention, a critical amplifying factor remains systematically understudied: the additional thermal burden imposed by mandatory PPE. Construction workers are legally required to wear equipment—including high-visibility safety vests, hard hats, and heavy safety boots—to mitigate mechanical hazards (OSHA, 2020), yet this gear creates a paradoxical safety challenge by exacerbating heat-related physiological strain. This burden operates through two primary mechanisms. First, protective garments such as

high-visibility vests and overalls act as an insulative barrier that restricts evaporative cooling (Havenith et al., 2013), significantly increasing skin humidity and thermal discomfort (Mao et al., 2022). Second, the additional weight of gear, particularly heavy safety boots (weighing approximately 1.5–1.6 kg), increases metabolic heat production by elevating the energy cost of movement by as much as 20% (Dorman & Havenith, 2009). These combined effects can elevate core body temperature by an additional 0.3–0.8°C (Wibowo et al., 2024), pushing workers beyond safe occupational thresholds of 38.0–38.5°C and increasing the risk of exertional heat stroke and cardiovascular events (Casa et al., 2015; NIOSH, 2016). Despite this, current risk models like the WBGT often rely on static correction factors that fail to capture the complex metabolic and insulative interactions of modern, multi-component construction gear (Parsons, 2006). Integrating PPE into the heat-workload framework is therefore essential for achieving a high-fidelity representation of physiological risk in construction.

The importance of this knowledge gap is magnified by global climate change. Projections from the Intergovernmental Panel on Climate Change (IPCC) indicate with very high confidence that extreme heat events will continue to become more frequent, more intense, and longer-lasting as global temperatures rise, with global surface temperature already 1.1°C above 1850–1900 levels in 2011–2020 and hot extremes assessed as virtually certain to increase with further warming (IPCC, 2023). In a sector where work is performed primarily outdoors, this development elevates a known occupational hazard to a critical public health concern. Developing evidence-based strategies to mitigate amplified, heat-related fatigue seems like an economic and ethical imperative for the health and sustainability of the construction workforce.

This study systematically synthesizes scientific evidence from literature that quantifies the combined effects of ergonomic and thermal factors on muscle fatigue among construction workers. This study uses Preferred Reporting Items for Systemic Reviews (PRISMA) 2020 guidelines to evaluate the effectiveness of documented interventions and identify key research gaps that need to be addressed in the context of a changing climate.

This study addresses the following research objectives:

1. To explore the extent of combined ergonomic load and environmental heat factor on producing synergistic physiological strain on cardiovascular and thermoregulatory systems.
2. To understand how this combined physiological strain translates into measurable effects on worker performance, physical work capacity, and productivity.
3. To investigate which intervention strategies, including cooling technologies, work-rest schedules, and administrative controls—are effective in mitigating this combined stress.
4. To investigate whether there are any emerging technologies and personal protective equipment that affect worker fatigue and heat strain and understand what conditions there in literature are that might exacerbate these factors.

Methodology

This systematic review was conducted and reported in accordance with the PRISMA 2020 guidelines (Page et al. 2021). The following sections go into the detail about the process followed.

Information Sources and Search Strategy

A systematic literature search was performed across multiple electronic databases, including Google Scholar, PubMed, Web of Science, Scopus and Scispace to identify all relevant peer-reviewed studies published since the year 2000. To ensure comprehensive coverage, the reference lists of all included

articles and relevant review papers were manually screened to identify additional studies not captured by the initial search (a process known as citation tracking). The search strategy employed a structured Boolean approach that combined keywords and MeSH terms across four conceptual domains: (1) the construction worker population (e.g., "construction worker", "manual labor"); (2) ergonomic and workload factors (e.g., "workload", "lifting", "manual handling"); (3) thermal and environmental heat stress (e.g., "heat stress", "WBGT", "hot climate"); and (4) muscle fatigue and physiological strain outcomes (e.g., "muscle fatigue", "physiological strain", "work capacity").

Eligibility Criteria

Studies were selected for inclusion based on a predefined protocol with the following criteria:

1. Inclusion Criteria: (1) The study had to be original, peer-reviewed research; (2) the study population consisted of human construction workers (in field settings) or participants performing simulated construction tasks (in a laboratory); (3) the study must have investigated and quantified both an ergonomic/workload factor and an environmental thermal stressor; and (4) the study reported at least one objective physiological (e.g., heart rate, core temperature) or performance-based (e.g., work capacity, productivity) outcome.
2. Exclusion Criteria: Studies were excluded if they were (1) review articles, meta-analyses, or commentaries; (2) did not involve a construction-specific population or task; (3) examined only thermal or only ergonomic stressors in isolation; (4) relied exclusively on subjective measures of fatigue; or (5) were non-peer-reviewed literature, such as conference abstracts or dissertations.

Study Selection

All records identified through the search were collated, and duplicates were removed. Subsequently, two researchers independently screened the titles and abstracts of all unique records against the eligibility criteria. The full texts of all potentially relevant articles were then retrieved and assessed independently by two researchers. Any disagreements at either the title/abstract or full-text screening stage were resolved through discussion and consensus.

Data Extraction and Synthesis

A standardized data extraction form was used to capture relevant information from each included study, including study design, population characteristics, details of the thermal and ergonomic exposure, outcome measures and principal findings. Data was extracted by one researcher and subsequently verified by a second researcher. Given the heterogeneity in study designs, population and outcome measures across the included articles, a narrative synthesis approach was employed to thematically analyze and integrate the findings. AI tools assisted the review under strict human oversight. SciSpace identified initial leads, which were manually cross validated in Scopus and Google Scholar. Gemini 2.5 Pro generated abstract summaries for screening; these were independently verified by authors against original texts to ensure accuracy. Google AI Studio optimized linguistic consistency without altering scientific findings.

Results

The initial search across all databases yielded 221 records. After 111 duplicates were removed, 110 unique records were screened by title and abstract, of which 78 were excluded for not meeting the inclusion criteria. This led to the retrieval of 32 full-text reports for eligibility assessment. After a thorough full-text review, a further 17 studies were excluded, primarily for providing insufficient data

on one of the required stressors or for using only subjective outcome measures. 15 studies met all inclusion criteria and were included in this systematic review. The complete study selection process is detailed in the study flow diagram based on the PRISMA guideline as shown in Figure 1.

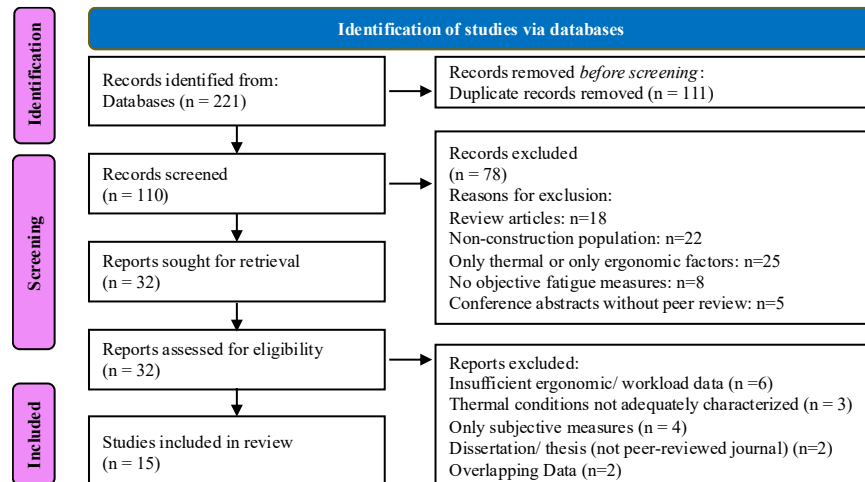


Figure 1. Study flow diagram based on PRISMA guideline

The 15 included studies had a range of designs, including field observational studies (n=6), laboratory experiments (n=4), and field intervention trials (n=3). The collective sample included approximately 450 construction workers who were predominantly male (>95 %). The ergonomic tasks investigated most frequently involved manual material handling (n=11) and repetitive work (n=7) while thermal conditions ranged from a WBGT of 24.5 °C to 38.0 °C. Heart rate (n=14) and core/tympanic temperature (n=10) were the most reported physiological outcomes.

Magnitude of Synergetic Physiological Strain

The synthesized evidence indicates that combining ergonomic workload with environmental heat produces a quantifiable, synergistic physiological strain. Under field conditions, performing physically demanding tasks in hot environments (WBGT greater than 30°C) elevated heart rates by an additional 15 to 30 beats per minute (bpm) compared to cooler settings, which sustained a near-maximal cardiovascular load for prolonged periods. This was accompanied by significant thermoregulatory strain, with core body temperatures increasing by 0.5°C to 1.5°C over a single work shift and frequently approaching dangerous hyperthermic thresholds of greater than 38.5°C. Dehydration was also a critical factor, as several studies documented sweat-induced body mass losses of 2-3%, a level known to impair both cardiovascular function and thermoregulatory capacity. Table 1 summarizes key physiological findings.

Effect of Synergetic Physiological Strain on Performance and Productivity

This physiological strain directly translated into measurable reductions in worker performance, physical capacity, and productivity. In controlled laboratory simulations, endurance time for construction-related tasks decreased by 25-35% when the work was performed in hot versus thermoneutral environments. This finding was consistent with field data, where one study documented a 3-7% decline in productivity, measured as bars installed per hour, for every 1°C increase in WBGT above 28°C. The cumulative effect of heat stress also significantly prolonged physiological recovery;

workers who performed tasks to exhaustion in the heat required 50-80% more rest time to functionally recover compared to after equivalent work in cooler conditions. Table 2 summarizes these critical performance and productivity impacts.

Table 1: Summary of Physiological Strain Outcomes from Combined Stressors

Study	Thermal Stress (WBGT)	Ergonomic Workload	Key Physiological Finding
Yi & Chan (2017)	24.5 - 34.2°C	Rebar bending and fixing	Heart rate increased by 15-25 bpm when WBGT exceeded 32°C.
Yoopat et al. (2002)	High heat-humidity	Physical workload analysis	Body temperature increased by 0.8-1.2°C; cardiovascular load exceeded 50% of maximum.
Al-Bouwarthan et al. (2020)	27 - 38°C	Activity monitoring (mixed trades)	65% of shifts exceeded safe WBGT thresholds; 70% of workers were dehydrated (USG >1.020).
Zhao et al. (2017)	(Lab) 37°C, 60% RH	Simulated work-rest cycles	Core temperature reached 38.2-38.8°C; heat stress accounted for a 20-30 bpm increase in HR.

Effective Intervention Strategies

Evaluations of specific intervention strategies demonstrated their effectiveness in mitigating combined thermal and ergonomic stress. Personal cooling vests, validated in both laboratory and field settings, proved to be practical control; their use reduced worker core temperature by 0.4°C to 0.7°C, lowered heart rate by 8 to 12 bpm (Zhao et al. 2018), and extended work duration by 18-35%. Administrative controls, particularly scientifically designed work-rest schedules, were also identified as a critical mitigation tool. For heavy work in hot conditions, these schedules must incorporate frequent rest periods of 30-40 minutes in a cooled or shaded environment to allow for adequate physiological recovery and prevent the accumulation of heat strain over a work shift. Table 3 provides a summary of the evidence for these effective interventions.

Table 2: Summary of Performance and Productivity Outcomes from Combined Stressors

Study	Conditions	Performance Outcome	Key Performance Finding
Zhao et al. (2017)	(Lab) 37°C, 60% RH	Work Duration (Endurance)	Endurance time to exhaustion was reduced by 25-35% in the heat compared to neutral conditions.
Yi & Chan (2017)	Field WBGT 24.5-34.2°C	Productivity (bars/hour)	3-7% productivity loss for every 1°C WBGT increase above 28°C.
Chan et al. (2012)	Field WBGT 28-35°C	Physiological Recovery Time	Optimal recovery time was 30-40 minutes; 50-80% longer than required in cooler conditions.
Sett & Sahu (2014)	Hot vs. Cooler Days	Productivity (bricks/hour)	Productivity decreased by 12-18% and walking speed slowed by 15-20% on hot days.

Role of Technology in Managing Fatigue

A few of the included studies examined the role of emerging technology in managing fatigue. Acharya et al. (2025) developed and validated a machine learning model for muscle fatigue detection

using surface electromyography data collected in a controlled laboratory setting. Their model achieved over 82% accuracy across all posture (standing, stooping, and kneeling) with consistently strong F1-scores (a statistical measure that evaluates a model's accuracy by balancing precision and recall) ranging from 0.77 to 0.78, validated using a subject-independent Leave-One-Subject-Out cross-validation protocol. Anwer et al. (2021) validated a textile-based wearable sensor system for real-time physical fatigue assessment that achieved 88–95% accuracy in detecting fatigue states using EMG measurements, establishing the feasibility of proactive, data-driven fatigue management on-site. Other research successfully used validated wearable sensors to continuously monitor heart rate and core temperature to accurately quantify physiological strain in the field (Guo, Chen, & Zhang, 2025).

Table 3: Summary of Effectiveness of Intervention Strategies

Study	Intervention	Physiological Benefit	Performance
Zhao et al. (2017)	Cooling vests	Core temp ↓ 0.4-0.7°C, HR ↓ 8-12 bpm	Work time ↑ 18-35%
Constable et al. (1994)	Microclimate cooling	Core temp ↓ 0.5-0.8°C, HR ↓ 10-15 bpm	Work time ↑ 30-35%
Chan et al. (2012)	Optimized work-rest	Maintains HR <85% max, core temp <38.5°C	Sustains productivity
Al-Bouwarthan et al. (2020)	Hydration protocols	Prevent dehydration, maintains cardiovascular function	Preserves work capacity
Yasmeen et al. (2020)	Acclimatization	HR ↓ 10-15 bpm, improved thermal comfort	Modest performance benefit

Discussion

The synthesized results confirm that the combined exposure to heat and ergonomic workload produces a multiplicative physiological strain. However, the most critical finding regarding the current state of research is the consistent omission of PPE as a measured variable across the 15 included studies. While these investigations accurately quantified environmental heat and ergonomic workload, the failure to account for mandatory gear such as safety boots, high-visibility vests, and hard hats reveals a systemic disconnect between current research conditions and real-world construction environments.

As established in the introduction, the metabolic cost and insulative properties of PPE are primary amplifiers of thermal strain. Therefore, the physiological values reported in the reviewed studies likely represent an idealized scenario that underestimates the actual burden experienced by fully equipped workers in the field. This oversight suggests that current safety models are built on incomplete data. Until research incorporates PPE as a standard variable, occupational risk assessments will remain inadequately calibrated to the actual working conditions of the construction industry.

Future research must move toward engineering solutions by prioritizing two key areas: (1) integrating realistic PPE as a primary independent variable in field and laboratory investigations to develop adjusted risk indices that reflect the true cumulative burden of insulation and weight; and (2) validating active cooling technologies, such as phase-change material vests and active-cooling footwear, to transform protective gear from a source of strain into a tool for heat management.

This review is limited by a small evidence base of 15 studies with a predominantly male sample (>95%), restricting generalizability and leaving the physiological responses of female workers underrepresented. Furthermore, the focus on acute exposures provides limited insight into chronic

health consequences, such as renal or cardiovascular dysfunction. Finally, as the reviewed studies did not directly quantify PPE, the specific magnitude of its interaction with construction stressors remains a theoretical projection requiring urgent empirical validation.

Conclusion

Current occupational safety models for the construction industry systematically underestimate the true physiological risk to workers. This systematic review establishes that while the synergistic interaction between high ergonomic workload and environmental heat stress is severe, the existing body of literature provides an idealized and insufficient representation of occupational strain by omitting the thermal burden of mandatory personal protective equipment such as safety boots and high-visibility vests. This systemic omission is increasingly critical as global climate change intensifies the frequency and intensity of extreme heat events, rendering existing safety protocols and work-rest schedules inadequately calibrated for real-world conditions. Consequently, the most vital contribution of future research lies in transitioning from documenting the dual-stressor problem toward engineering solutions. The development of integrated cooling technologies, including phase-change material vests and active-cooling footwear, must be established as a primary research priority. Transforming protective gear into an tool for heat management is essential for creating the data-driven policies and engineering practices required to build a safer and more resilient construction sector.

References

- Abdelhamid, T. S., & Everett, J. G. (2000). Ironworkers: Physiological Demands during Construction Work. *Journal of Construction Engineering and Management-Asce*.
- Acharya, S., Kisi, K., Gautam, S. R., Mahmud, T., & Kayastha, R. (2025). A high-performance hybrid Transformer–LSTM–XGBoost model for sEMG-based fatigue detection in simulated roofing postures. *Buildings*, 15(17), 3005.
- Adams, E. L., Casa, D. J., Huggins, R. A., DeMartini-Nolan, J. K., Stearns, R. L., Kennedy, R. M., Bosworth, M. M., DiStefano, L. J., Armstrong, L. E., & Maresh, C. M. (2017). Heat Exposure and Hypohydration Exacerbate Physiological Strain During Load Carrying. *Journal of Strength and Conditioning Research*, 31(7), 1831–1841.
- Ajslev, J. Z. N., Lund, H. L., Møller, J. L., Persson, R., & Andersen, L. L. (2013). Habituating Pain: Questioning Pain and Physical Strain as Inextricable Conditions in the Construction Industry. *Nordic Journal of Working Life Studies*, 3(3), 17-30.
- Al-Bouwarthan, M., Quinn, M. M., Kriebel, D., & Wegman, D. H. (2020). A field evaluation of construction workers' activity, hydration status, and heat strain in the extreme summer heat of Saudi Arabia. *Annals of Work Exposures and Health*, 64(5), 522-535.
- Anagha, R., & Xavier, A. S. (2020). A Review on Ergonomic Risk Factors Causing Musculoskeletal Disorders among Construction Workers. *International Journal of Engineering Research And*, 19(1S06).
- Anwer, S., Li, H., Antwi-Afari, M. F., Umer, W., Mehmood, I., Al-Hussein, M., & Wong, A. Y. L. (2021). Test-retest reliability, validity, and responsiveness of a textile-based wearable sensor for real-time assessment of physical fatigue in construction bar-benders. *Journal of Building Engineering*, 44, 103348.
- Azzamullah, A., Izzoelhq, A., Supeno, S. R. A., Purwoko, W. A., & Trisnawaty, D. (2025). The relationship between fatigue and workplace accidents in the construction sector: A statistical study on contributing factors and risk implications. *Calamity*, 3(1).
- Baizhan, L., & Andrew, B. (2018). Meeting the challenge of climatic heat stress in construction. *Industrial Health*, 56(4), 275–277.

- Casa, D. J., DeMartini, J. K., Bergeron, M. F., Csillan, D., Eichner, E. R., Lopez, R. M., Ferrara, M. S., Miller, K. C., O'Connor, F., Sawka, M. N., & Yeargin, S. W. (2015). National Athletic Trainers' Association position statement: Exertional heat illnesses. *Journal of Athletic Training*, 50(9), 986–1000.
- Chan, A. P., Yi, W., Wong, D. P., Yam, M. C., & Chan, D. W. (2012). Determining an optimal recovery time for construction rebar workers after working to exhaustion in a hot and humid environment. *Building and Environment*, 58, 163-171.
- Chinnadurai, J., Venugopal, V., Kumaravel, P., & Paramesh, R. (2016). Influence of occupational heat stress on labour productivity – a case study from Chennai, India. *International Journal of Productivity and Performance Management*, 65(2), 245-255.
- Constable, S. H., Bishop, P. A., Nunneley, S. A., & Chen, T. (1994). Intermittent microclimate cooling during rest increases work capacity and reduces heat stress. *Ergonomics*, 37(2), 277-285.
- Dorman, L. E., & Havenith, G. (2009). The effects of protective clothing on energy consumption during different activities. *European Journal of Applied Physiology*, 105(3), 463–470.
- Esfahani, M. T., Awolusi, I., & Hatipkarasulu, Y. (2024). Heat Stress Prevention in Construction: A Systematic Review and Meta-Analysis of Risk Factors and Control Strategies. *International Journal of Environmental Research and Public Health*, 21(12), 1681.
- Fang, Z., Mao, Y., Zhu, Y., Lu, J., Zheng, Z., & Chen, X. (2023). Human thermal physiological response of wearing personal protective equipment: An educational building semi-open space experimental investigation. *Science of The Total Environment*, 877, 162779.
- González-Alonso, J., Crandall, C. G., & Johnson, J. M. (2008). The cardiovascular challenge of exercising in the heat. *The Journal of Physiology*, 586(1), 45-53.
- Griffen, B. D., Belgrad, B. A., Cannizzo, Z. J., Knotts, E. R., & Hancock, E. R. (2016). Rethinking our approach to multiple stressor studies in marine environments. *Marine Ecology Progress Series*, 543, 1-13.
- Guo, X., Chen, Y., & Zhang, J. (2025). Automated detection of physical fatigue in transportation maintenance workers through physiological and motion data. *Theoretical Issues in Ergonomics Science*, 26(2), 158–177.
- Havenith, G., Bröde, P., den Hartog, E., Kuklane, K., Holmer, I., Rossi, R. M., Richards, M., Farnworth, B., & Wang, X. (2013). Evaporative cooling: Effective latent heat of evaporation in relation to evaporation distance from the skin. *Journal of Applied Physiology*, 114(6), 778–785.
- IPCC. (2023). Climate Change 2023: Synthesis Report. AR6 Synthesis Report. Geneva, Switzerland.
- Irzmańska, E. (2015). The microclimate in protective firefighter footwear: Foot temperature and air temperature and relative humidity. *Autex Research Journal*, 16(2), 75–84.
- Kayastha, R., Acharya, S., Gautam, S. R., Mahmud, T., & Kisi, K. (2025). Plantar pressure distribution and posture stability analysis in a construction roofing task. *EPiC Series in Built Environment*, 6, 674–683.
- Lavoie, E. M., Holden, L. D., Vangala, S. V., Santee, W. R., Pryor, R. R., Friedl, K. E., & others. (2023). Effects of modern military footwear on the oxygen costs of walking in US Army personnel. *Footwear Science*, 15(1), 1–8.
- He, M., Liu, H., Fang, Z., He, B., & Li, B. (2024). High-temperature and thermal radiation affecting human thermal comfort and physiological responses: An experimental study. *Journal of Building Engineering*, 86, 108815.
- Macfarlane, G. J., D'Angelo, S., Ntani, G., & Walker-Bone, K. (2024). Impact of fatigue on work productivity and health-related job loss. *Occupational Medicine*, 74(3), 119-125.
- Mao, Y., Zhu, Y., Guo, Z., Zheng, Z., Fang, Z., & Chen, X. (2022). Experimental investigation of the effects of personal protective equipment on thermal comfort in hot environments. *Building and Environment*, 222, 109352.

- McLellan, T. M., & Havenith, G. (2016). Protective clothing ensembles and physical employment standards. *Applied Physiology, Nutrition, and Metabolism*, 41(6), S121–S130.
- Melagoda, D. G., & Rowlinson, S. (2022). Heat stress management in the construction industry: A socio-technical systems perspective. In N. L. Black, W. P. Neumann, & I. Noy (Eds.), *Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)* (pp. 804–810). Springer.
- NIOSH. (2016). *NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments* (DHHS Publication No. 2016-106). National Institute for Occupational Safety and Health.
- Nussbaum, M. A. (2003). Postural stability is compromised by fatiguing overhead work. *Aiha Journal*, 64(1), 56-62.
- Nybo, L., Rasmussen, P. V., & Sawka, M. N. (2014). Performance in the Heat—Physiological Factors of Importance for Hyperthermia-Induced Fatigue. *Comprehensive Physiology*, 4(2), 657-689.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71.
- Parsons, K. (2006). Heat stress standard ISO 7243 and its global application. *Industrial Health*, 44(3), 368–379. <https://doi.org/10.2486/indhealth.44.368>
- Sett, M., & Sahu, S. (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India. *Global Health Action*, 7(1), 21923.
- Smallwood, J. (2000). Ergonomics in Construction: Management and Worker Perceptions. In *Proceedings of the IEA 2000/HFES 2000 Congress* (pp. 3-305).
- Trangmar, S. J., & González-Alonso, J. (2019). Heat, Hydration and the Human Brain, Heart and Skeletal Muscles. *Sports Medicine*, 49(S1), 69-85.
- Turner, N. L., Chiou, S., Zwiener, J., Weaver, D., & Spahr, J. (2010). Physiological effects of boot weight and design on men and women firefighters. *Journal of Occupational and Environmental Hygiene*, 7(8), 477–482. <https://doi.org/10.1080/15459624.2010.486285>
- Wibowo, R., Do, V., Quartucci, C., Koller, D., Daanen, H. A. M., Nowak, D., Bose-O'Reilly, S., & Rakete, S. (2024). Effects of heat and personal protective equipment on thermal strain in healthcare workers: Part B—Application of wearable sensors to observe heat strain among healthcare workers under controlled conditions. *International Archives of Occupational and Environmental Health*, 97(1), 35–43.
- Yasmeen, S., Liu, H., Wu, Y., Li, B., & Zhao, Y. (2020). Physiological responses of acclimatized construction workers during different work patterns in a hot and humid subtropical area of China. *Journal of Building Engineering*, 30, 101281.
- Yi, W., & Chan, A. P. (2017). Effects of heat stress on construction labor productivity in Hong Kong: A case study of rebar workers. *International Journal of Environmental Research and Public Health*, 14(9), 1055.
- Yoopat, P., Toicharoen, P., Glinsukon, T., Vanwonderghem, K., & Louhevaara, V. (2002). Ergonomics in practice: Physical workload and heat stress in Thailand. *International Journal of Occupational Safety and Ergonomics*, 8(1), 83-93.
- Zhao, Y., Yi, W., Chan, A. P., Wong, F. K., & Yam, M. C. (2017). Evaluating the physiological and perceptual responses of wearing a newly designed cooling vest for construction workers. *Annals of Work Exposures and Health*, 61(7), 883-901.
- Zhao, Y., Yi, W., Chan, A. P., & Wong, F. K. (2018). Impacts of cooling intervention on the heat strain attenuation of construction workers. *International Journal of Biometeorology*, 62(10), 1825-1837.