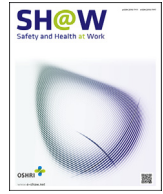




Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Review Article

Exploring Intervention Strategies to Prevent Occupational Heat Stress. A Scoping Review

Sepehr Khorshid¹, Siyuan Song^{2,*}¹ Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL 35487, USA² Safety Automation and Visualization Environment (SAVE) Laboratory, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287, USA

ARTICLE INFO

Article history:

Received 31 July 2024

Received in revised form

7 March 2025

Accepted 31 March 2025

Available online 5 April 2025

Keywords:

Cooling strategies

Heat stress interventions

Occupational heat stress

Prevention strategies

ABSTRACT

Rising global temperatures threaten workers worldwide, especially in outdoor and indoor industries like construction, manufacturing, agriculture, and mining. The current guidelines for reducing heat-related risks in these sectors lag behind those in sports and military settings. The objective of this study is to map applicable strategies across various sectors and summarize preventive strategies and methodologies. A scoping review was conducted using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) extension for scoping reviews. PubMed and ScienceDirect were searched for articles on internal, external, and administrative interventions. In total, 5,280 articles published between January 2020 and March 2024 were initially identified. Following a meticulous screening process, 49 articles were selected for in-depth review in this study. Notably, a considerable proportion (56%) of these studies focused on external interventions. This review revealed that a multifaceted approach is necessary to enhance the decision-making process for effectively addressing heat stress, regardless of occupational settings. This approach encompasses considerations of environmental factors, individual physiological aspects, and cooling methods. The review also highlighted limitations in effective and practical heat stress prevention strategies across various industry sectors, including the absence of dietary guidelines.

© 2025 Occupational Safety and Health Research Institute. Published by Elsevier B.V. on behalf of Institute, Occupational Safety and Health Research Institute, Korea Occupational Safety and Health Agency. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Workers in high-risk industries like construction engage in physically demanding tasks while wearing personal protective equipment (PPE) under intense sun radiation, which can increase metabolic rates and generate body heat. Crucial strategies for combating heat stress include access to cool drinking water, rescheduling work to cooler times with shade for outdoor workers, and ensuring adequate ventilation for indoor environments [1].

In hot conditions, sweating leads the body to lose water, serving as a key mechanism for thermoregulation. Dietary intake also plays a crucial role in regulating the core body temperature, and hydration states [2,3]. Mental health conditions, including stress [4] and sleep deprivation can influence core body temperature and diminish heat tolerance. Additionally, certain prescribed medications can adversely

affect the body's thermoregulation system, the sensation of thirst, and urine output [5].

Sun exposure intensifies physiological heat strain. Sunshades mitigate ambient temperatures, solar radiation, and terrestrial heat absorption [6]. Personal cooling is more practical and cost-effective than cooling entire spaces [7]. The researchers integrate cooling systems into workers' vests and hard hats to enhance heat tolerance and productivity [8]. However, identifying optimal cooling strategies in industrial settings remains challenging.

This study aims to provide an overview of strategies to mitigate occupational heat stress, deliberately incorporating insights from other heat-vulnerable sectors like sports and general population studies. This inclusive approach is justified because heat stress poses a common physiological threat across diverse populations, characterized by shared risks like dehydration and impaired thermoregulation,

Sepehr Khorshid: <https://orcid.org/0009-0005-0266-7284>; Siyuan Song: <https://orcid.org/0000-0002-6444-3914>

* Corresponding author. Safety Automation and Visualization Environment (SAVE) Laboratory, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287, USA.

E-mail addresses: skhorshid1@crimson.ua.edu (S. Khorshid), Siyuan.Song.1@asu.edu (S. Song).

making cross-sectoral findings broadly relevant. That said, individual responses to heat stress can differ significantly, particularly in vulnerable groups like the elderly, where age-related changes or medications may heighten susceptibility or alter physiological outcomes. A scoping literature review was conducted to overview intervention methodologies and tools, identify sector-specific research gaps, and propose future research to refine existing guidelines for better management of occupational heat stress.

2. Research methodology

Scoping reviews outline broad topics, identify patterns in scientific fields, and assess literature extent on specific subjects [9,10]. Arksey and O'Malley [11] propose five stages for the scoping review: (1) formulating research questions; (2) identifying relevant literature; (3) selecting studies; (4) structuring data; and (5) compiling and summarizing results. This review follows Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) extension for scoping reviews guidelines.

2.1. Formulating the research questions

Heat stress emerges from the interplay of endogenous heat production via metabolic and thermoregulatory processes and exogenous stressors such as elevated humidity, reduced air velocity, and solar radiation, which collectively amplify physiological strain in occupational settings. To address this multifaceted challenge, this study delineated heat stress interventions into three evidence-informed categories, systematically derived to frame the scoping review's research questions: (1) internal interventions, bolstering physiological resilience through targeted measures like hydration optimization and dietary supplementation to mitigate heat-related morbidity; (2) external interventions, counteracting environmental heat loads with physical tools such as fans, cooling vests, or shaded structures; and (3) administrative interventions, instituting organizational controls, including real-time monitoring of physiological responses (e.g., core temperature) and environmental conditions (e.g., wet-bulb globe temperature), to preempt and manage heat stress risks. Based on these classifications, the research questions are as follows: 1) What are the existing prevention strategies for mitigating heat stress? 2) What methodologies and tools are employed for each intervention? 3) What are the research gaps concerning industry sectors and challenges, and what future research could enhance existing guidelines for improved management?

2.2. Identifying the pertinent literature

To examine the current trends in heat stress management, we reviewed English language research published between January 2020 and March 4, 2024. The review targeted prevention and cooling strategies across different sectors. The selection criteria required articles to do the following: (1) focus on heat stress or heat-related illness, (2) study human subjects, and (3) be peer-reviewed primary research. Exclusions included the following: (1) review papers, (2) consensus reports, (3) conference papers, and (4) studies on non-human subjects (e.g., animals, cells) or unrelated fields (e.g., food industry). Studies from general population and athletic contexts were included to inform occupational heat practices.

The search strategy was developed through a structured process. An initial literature scan identified three intervention categories mentioned earlier: internal (e.g., hydration), external (e.g., cooling vests), and administrative (e.g., monitoring) shaping keyword selection. Keywords (e.g., "heat stress," "worker," "cooling garment") were organized into category-specific strings as shown in Table 1. Searches in PubMed and ScienceDirect utilized each database's advanced search feature to refine results. Boolean operators were applied: AND linked core terms for specificity (e.g., "heat stress AND worker" targeted occupational studies), while OR combined related concepts within categories (e.g., "electrolytes OR fluid intake" for internal interventions; "cooling garment OR fan" for external interventions). Table 1 details these strings.

The advanced search feature in PubMed yielded 446 records by combining these sets. ScienceDirect's advanced search returned 4834 records within the timeframe, totaling 5280 records as per Table 1 and Fig. 1. These Boolean combinations ensured relevance, for instance "AND worker" focused on occupational contexts and "OR fan" captured diverse cooling methods. Publication date filters (2020–2024) standardized the timeframe across both databases. All 5,280 records were exported to Rayyan for screening (see 2.3), establishing a comprehensive pool of pertinent literature.

2.3. Study selection

The 5,280 records identified in PubMed and ScienceDirect were downloaded and imported into the Rayyan Web App, a free tool for systematic screening [12]. Two authors independently screened titles and abstracts using Rayyan's filter feature to apply inclusion and exclusion criteria from subsection 2.2. We configured the filters in Rayyan by entering "keywords to include"—such as "heat stress," "heat-related illnesses," "construction workers," "drug"

Table 1
Study search strings

	Search strings	Number of search results (January 1st, 2020–March 4th, 2024)	
		PubMed	Science Direct
Internal interventions	((heat stress) AND (worker)) OR (heat-related illness) AND (electrolytes OR food intake OR fluid intake)	53	950
	((heat stress) AND (worker)) OR (heat-related illness) AND (sleep deprivation OR mental disorders OR Drug OR Medication)	255	1891
External interventions	((heat stress) AND (worker)) OR (heat-related illness) AND (cooling garment OR fan OR menthol OR water immersion OR pre-cooling OR per-cooling OR post-cooling)	54	1794
Administrative interventions	((heat stress) AND (worker)) OR (heat-related illness) AND (heat stress monitoring OR early warning system)	84	199
Total		446 5280	4834

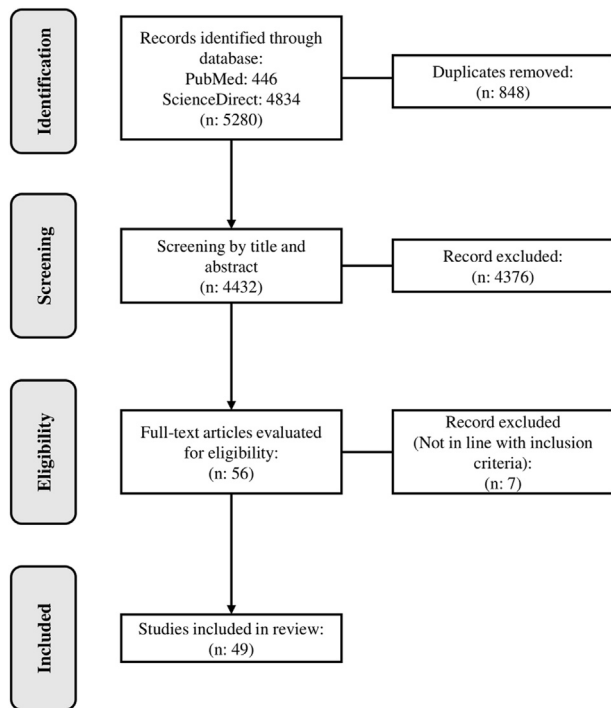


Fig. 1. Flow diagram of study selection process.

“medication”—which the tool highlighted in green within titles and abstracts. This visual aid accelerated identification of relevant studies. We also entered “keywords to exclude”—such as “plant,” “cells,” “urban,” “dairy,” “review,” “animals,” “drought,” “cows”—highlighted in red, simplifying exclusion of off-topic studies. This screening excluded 4,376 records not meeting criteria (e.g., plant physiology, systematic reviews) as shown in Fig. 1.

As scoping reviews typically do not address highly specific research questions or assess study quality [11], this study did not evaluate the quality of included studies. This two-stage process systematically refined the initial pool to studies supporting the review’s objectives.

2.4. Structuring included studies

Following title and abstract screening in Rayyan, the remaining 56 records were exported from Rayyan to an Excel spreadsheet for full-text analysis and article characteristics analysis. Two authors independently reviewed these full texts to confirm eligibility against subsection 2.2 criteria: focus on heat stress, human subjects, and peer-reviewed primary research. This step excluded seven records that did not meet the inclusion standards (e.g., irrelevant focus) as detailed in the PRISMA flow diagram (Fig. 1). Discrepancies during full-text review were resolved through discussion, ensuring alignment with the review’s focus on heat stress

interventions in occupational sectors. The final 49 studies were selected for inclusion.

The 49 included studies were categorized in the Excel spreadsheet. The categories included title, publication year, first author, country, prevention strategy context, methodology, tool, and aim(s). Prevention strategy context captured intervention type (e.g., internal, external, administrative), while methodology, and tool detailed study design (e.g., trials, observational studies) and intervention tools or approaches (e.g., cooling vests, hydration protocols). The aims reflected study objectives (e.g., evaluating efficacy, assessing responses). This structured approach enabled analysis of intervention trends and sector-specific gaps (see 2.5), supporting the scoping review’s goal of mapping heat stress prevention strategies without quality appraisal [11].

The entire study selection process, from initial identification to final inclusion, is illustrated in the PRISMA flow diagram (Fig. 1), ensuring a transparent and reproducible approach consistent with the PRISMA guidelines [13].

2.5. Compiling and summarizing the results

The 49 studies selected from full-text review (see 2.4) were compiled and summarized to map heat stress intervention strategies across occupational and related settings. Studies were initially grouped into the three intervention categories established in subsection 2.1: internal, external, and administrative, with some studies addressing multiple categories concurrently, identified as combined interventions. This grouping was conducted within the Excel spreadsheet from subsection 2.4, leveraging the “prevention strategy context” category to systematically assign each study to its respective intervention type(s). Combined intervention studies, by design, explored the integration of two or more approaches, broadening the scope beyond a single predefined category.

Data from each study were extracted and synthesized across key characteristics: publication years spanning 2020 to 2024, application contexts reflecting the study populations or settings, methodologies employed in the research, tools or approaches used for intervention, and the studies’ stated objectives. Application contexts were determined based on the focus populations or environments investigated, such as industrial workers (e.g., firefighting, construction, agriculture), military personnel, sports participants, or the general population, capturing the diversity of heat stress exposure scenarios. Methodologies varied widely, including randomized controlled trials (e.g., comparing intervention effects under controlled conditions), observational field studies (e.g., assessing real-world worker responses), and simulated experiments (e.g., using heat chambers) as detailed in Tables 3, 5, 7, and 9. Tools and approaches encompassed physical devices like physiological monitoring systems and environmental modifications (e.g., cooling vests), alongside physiological strategies such as dietary or hydration interventions, reflecting the range of practical applications studied.

This information was organized into Tables 2–9 to present intervention-specific findings, with Tables 10 and 11 synthesizing

Table 2
Studies characteristics for internal interventions

Intervention	First author, year [reference]	Context of application	Objective (s)
Internal interventions (n = 8)	Tabuchi et al., 2021 [14]	Industry sector (Firefighting)	Assess ice slurry and carb–electrolyte effects on firefighter.
	Mao et al., 2021 [15]	Military sector	Identify Exertional Rhabdomyolysis (ER) risk factors in military exercise.
	Deming et al., 2021 [16]	General population	Compare electrolyte/carb supplements vs. water on hydration and cognition.
	Benjamin et al., 2021 [17]	Sports	Evaluate hydration and ice-water dousing effects on performance.
	Nakamura et al., 2021 [18]	Sports	Evaluate ice slurry effects on blood pressure and cooling post-heat exercise.
	Asano et al., 2022 [19]	General population	Assess hot environment walking effects on cognitive performance.
	Deming et al., 2023 [20]	General population	Compare carbs vs. electrolytes on cognition during prolonged exercise.
	Kakamu et al., 2024 [21]	Industry sector (Firefighting)	Identify optimal salt intake timing to reduce HRI in firefighters.

Table 3
Methodologies and prevention tools for internal heat stress interventions

Methodology	Solution/tool(s)	First author, year [reference]
Simulated firefighting: physiological, perceptual, and biochemical responses.	Pre-exercise ice slurry ingestion; post-exercise carbohydrate-electrolyte solution.	Tabuchi et al., 2021 [14]
Cadet ER case analysis: medical data and risk factor assessment.	Fruit intake, and hydration practices.	Mao et al., 2021 [15]
Heat chamber trial: loaded walking with varied interventions.	Carbohydrate supplementation.	Deming et al., 2021 [16]
Crossover trial: cognitive and physical performance with physiological monitoring	Optimal hydration pre-activity and during breaks.	Benjamin et al., 2021 [17]
Heat exercise trial: physiological responses during and post-treadmill.	Post-exercise ice slurry ingestion.	Nakamura et al., 2021 [18]
Outdoor trial: Heat effects on math test performance.	Adequate sleep.	Asano et al., 2022 [19]
Randomized trial: physiological and cognitive assessments.	Carbohydrate supplementation.	Deming et al., 2023 [20]
Firefighter study: pre/post-exercise surveys with environmental data.	Timely salt consumption.	Kakamu et al., 2024 [21]

Table 4
Studies characteristics for external interventions

Intervention	Reference (first author, year)	Context of application	Objective(s)
External interventions (n = 23)	Herron and Alleway, 2020 [22]	Military sector	Evaluate handheld water spray fan.
	Chicas et al., 2020 [23]	Industry sector (Agriculture)	Evaluate cooling devices in farm workers.
	Wang et al., 2020 [24]	General population	Hybrid cooling vests: PCMs with electric fans.
	Del Ferraro et al., 2021 [25]	Industry sectors (General)	Evaluate ventilation jacket cooling on heat insulation/loss.
	G. Wu et al., 2021 [26]	Industry sectors (General)	Evaluate air-pressurized cooling vest effects on heat loss.
	Aljaroudi et al., 2021 [27]	Industry sector (Firefighting)	Evaluate chilled-water cooling gear impact on firefighters.
	Al-Rjoub et al., 2021 [28]	Industry sectors (General)	Assess PCM head cooling system duration under heat loads.
	Mori et al., 2022 [29]	Industry sectors (General), Sports	Assess fan-attached cooling vest effectiveness
	Li et al., 2022 [30]	General population	Assess mist, shade, and combined effects on outdoor thermal comfort.
	Del Ferraro et al., 2022 [31]	Industry sectors	Evaluate fan-attached cooling vest.
	Zheng et al., 2022 [32]	General population	Evaluate cooling performance of liquid cooling garments (LCGs).
	Inoue et al., 2023 [33]	General population	Assess targeted water-cooled clothing.
	Ciuha et al., 2023 [34]	Industry sectors (General)	Evaluate cooling vest efficacy in reducing heat strain during simulated work.
	Wang et al., 2023 [35]	Industry sector (Manufacturing)	Evaluate phase change cooling garment (PCCG) efficacy.
	Z. Li et al., 2023 [36]	Industry sectors (General)	Evaluate portable thermoelectric LCG cooling across temperatures and exercise levels.
	Z. Li, Zhang, et al., 2023 [37]	General population	Develop and evaluate new wearable thermoelectric LCG performance.
	Liu et al., 2023 [38]	Industry sector (Manufacturing)	Evaluate PCM cooling vest impact on comfort, cognition, and productivity in factories.
	Zhang et al., 2023 [39]	General population	Compare fanned vs. ordinary shade for outdoor heat mitigation.
	Z. Li, Pan, et al., 2023 [40]	Industry sector (Healthcare)	Assess ice-bag cooling vest effects on comfort across different coverage areas.
	Wei et al., 2023 [41]	General population	Assess multimodal cooling garment (MECG) combining passive and active cooling.
	Ding et al., 2023 [42]	General population	Evaluate ventilation temperature and speed impact on cooling garment efficacy.
	Choudhary and Udayraj, 2023 [43]	General population	Assess fan cooling vest impact on comfort during diverse intermittent tasks.
	Del Ferraro et al., 2024 [44]	Industry sectors (General)	Evaluate ventilation jacket performance in warm, dry conditions.

PCMs, phase-change materials.

sector-specific strategies and evidence levels, respectively. For Table 11, presented in the conclusion section, we tallied studies from Tables 2–9 per sector intervention pair, with standalone studies (Tables 2–7) and combined studies (Table 8) contributing one count to each relevant category, such as firefighting internal, which includes two standalone studies and one combined study. Evidence levels reflect the documentation extent: ● (≥3 studies), ● (1–2 studies), ○ (0 studies within 2020–March 2024). Table 11 focuses on key occupational sectors, excluding broader (e.g., general industry) or minor (e.g., sanitation) categories for clarity, with full data in Tables 2–9. Publication trends over the review period were visualized in Fig. 4, while Fig. 3 illustrated the distribution of studies across intervention categories. This structured compilation and synthesis provided a comprehensive overview of current heat stress intervention strategies and highlighted research gaps, directly supporting the scoping review's objectives.

3. Results

3.1. Characteristics of the included studies

Table 2 details characteristics and summaries of included studies. Of 49 studies, most were from China (n: 16; 32.65%), followed by the United States (n: 13; 26.53%) and Japan (n: 8; 16.32%) (Fig. 2). Publication origin was determined by corresponding authors' institutional addresses or affiliations.

Among the 49 articles, 23 (46.93%) were classified as "External Interventions," 10 (20.40%) as "Administrative Interventions," and 8 (16.32%) as "Internal Interventions." Additionally, three (6.12%) addressed both internal and administrative interventions, four (8.16%) covered internal and external interventions, and one (2.04%) discussed external and administrative interventions (Fig. 3).

Table 5
Methodologies and prevention tools for external heat stress interventions

Methodology	Solution(s)/tool(s)	Reference (first author, year)
Experimental trials on effectiveness of water spray fan.	Spray mist fan.	Herron and Alleway, 2020 [22]
Randomized trial of cooling devices' effects on workers.	Cooling bandana.	Chicas et al., 2020 [23]
Trials comparing cooling strategies during walking/rest, measuring temperature, energy, and perceptions.	PCM-fan cooling vest.	Wang et al., 2020 [24]
Dry tests with thermal manikin: varying fan speeds and clothing.	Dual-fan cooling vest.	Del Ferraro et al., 2021 [25]
Trials in hot, humid chamber: treadmill walking with labor suit or cooling vest.	Pressurized air cooling vest.	G. Wu et al., 2021 [26]
Trials in hot environment: protective clothing with and without cooling garment.	18°C water-infused vest.	Aljaroudi et al., 2021 [27]
Testing closed-loop cooling system with ice under varying heat loads and flows.	PCM active head cooler.	Al-Rjoub et al., 2021 [28]
Trials in hot-dry and warm-humid conditions for 60 minutes.	Dual-fan cooling vest.	Mori et al., 2022 [29]
Trials assessing responses to shade, and mist spraying.	Mist spray shade.	Li et al., 2022 [30]
Wet tests: sweating manikin evaluating cooling at varied fan speeds and clothing.	Dual-fan cooling vest.	Del Ferraro et al., 2022 [31]
Modeling LCG performance: effects of water temp, insulation, pipe length, and cooling mode.	Liquid cooling garment (LCG).	Zheng et al., 2022 [32]
Exercise trials in heat: comparing full, partial, and no cooling vest.	10°C targeted water cooling vest.	Inoue et al., 2023 [33]
Trials comparing cooling vests in hot environment: physiological and cognitive measures.	Cooling vests.	Ciuha et al., 2023 [34]
Indoor heat trials: comparing normal vs. PCCG, measuring physiology and comfort.	Phase change cooling garment (PCCG).	Wang et al., 2023 [35]
LCG cooling trials: effects of temperature and exercise intensity.	Liquid cooling garment (LCG)	Z. Li et al., 2023 [36]
Heat trials: cooling efficiency at varied water temps and activity levels.	Thermoelectric LCG.	Z. Li, Zhang, et al., 2023 [37]
Cooling vest trials at 27–31°C: physiological and cognitive measures.	PCCG.	Liu et al., 2023 [38]
Comparing no shade, ordinary shade, and fanned shade: measuring environmental factors.	Fan-cooled shade.	Zhang et al., 2023 [39]
Outdoor medical tasks in PPE: comparing cooling vests with varied ice placement.	Ice-pack vest.	Z. Li, Pan, et al., 2023 [40]
Multimodal cooling garment trials: indoor/outdoor tests of thermal effects and comfort.	Multimodal cooling garment (MECG).	Wei et al., 2023 [41]
Cycling trials at varied intensities: ventilation preferences and responses across body segments.	Vented cooling gear.	Ding et al., 2023 [42]
Hot climate trials: AVC with/without fan during varied activities, measuring responses.	Dual-fan cooling vest.	Choudhary and Udayraj, 2023 [43]
Sweating manikin tests: varied metabolic rates and fan speeds.	Dual-fan cooling vest.	Del Ferraro et al., 2024 [44]

PCMs, phase-change materials.

Table 6
Studies characteristics for administrative interventions

Intervention	Reference (first author, year)	Context of application	Objective(s)
Administrative interventions (n = 10)	Lazaro and Momayez, 2020 [45]	Industry sector (Mining)	Enhance predicted heat strain (PHS) model for improved heat strain prediction in hot environments
	Al-Bouwarthan et al., 2020 [46]	Industry sector (Construction)	Assess extreme heat effects on construction workers' physiology and workload.
	Ioannou et al., 2021 [47]	Industry sectors (General)	Assess heat stress effects on workers' physiology and productivity.
	Han et al., 2021 [48]	Industry sector (Construction)	Analyze workers' heat perceptions and adaptations to inform targeted strategies.
	G. Zheng et al., 2021 [49]	Industry sector (Sanitation)	Develop heat stress warning index for sanitation workers.
	G. Zheng, Li, et al., 2021 [50]	Industry sector (Sanitation)	Determine heat safety thresholds for sanitation workers using mathematical models.
	Pryor et al., 2021 [51]	Sports	Evaluate 5-day heat acclimation effects on day 6 exercise-heat strain.
	Santos et al., 2022 [52]	Industry sector (Agriculture)	Evaluate farmworker heat training and supervisor app effects.
Goodman et al., 2023 [53]	General population	Assess employment status impact on heat stress management in outdoor workers.	
Abbasi et al., 2023 [54]	Industry sector (Steel and petrochemical)	Validate heat stress indices for worker physiology.	

Publication numbers fluctuated between January 1st, 2020, and March 4th, 2024, as shown in Fig. 4. The years 2021 (n = 16; 32.65%) and 2023 (n = 15; 30.61%) had the highest number of relevant publications. These fluctuations should be considered in the context of the potential long-term impact of the COVID-19 pandemic and related disruptions on research activities and workplace practices.

3.2. Internal interventions

Internal interventions focus on physiological adjustments to mitigate heat stress. This category includes eight studies (Table 2):

firefighting (n = 2; 25%), military (n = 1; 12%), general population (n = 3; 38%), and sports (n = 2; 25%).

Several studies have demonstrated the effectiveness of ice slurry ingestion (Table 3). Tabuchi et al. (2021) [14] found that pre-exercise ice slurry (-1.7°C) and post-exercise carbohydrate–electrolyte solution intake helped manage core and intestinal temperatures, heart rate, and perceived exertion during simulated firefighting. Two studies showed post-exercise ice slurry (0.5°C) accelerated core and skin temperature recovery [18,56]. These studies indicate ice slurry ingestion can reduce core temperatures by 1–2°C and improve recovery rates [14,18,56].

Carbohydrate supplementation reduces heat stress-induced cognitive impairments during prolonged exertion more

Table 7
Methodologies and prevention tools for administrative heat stress interventions

Methodology	Solution/tool(s)	Reference (first author, year)
Mining task trials: validating modified PHS model with core/skin temperature data.	Modified predicted heat strain (PHS) model.	Lazaro and Momayez, 2020 [45]
Multi-day construction worker study: workload, heart rate, hydration measures.	Hydration, self-pacing, wearable devices, work-rest cycles.	Al-Bouwarthan et al., 2020 [46]
Observational and interventional field studies.	Hydration, work-rest cycles, cooling vests, mechanization.	Ioannou et al., 2021 [47]
Online survey: construction workers' heat perceptions, adaptations, and safety attitudes.	Hydration, self-pacing, heat-related training, shaded rest areas, rescheduled working hours.	Han et al., 2021 [48]
Industrial worker field study: developing heat stress index from physiological data.	Warning index using heart rate, core body temperature, and skin temperature to monitor and manage physiological stress.	G. Zheng et al., 2021 [49]
Sanitation worker heat study: environmental and physiological measures, comfort surveys, safety limit modeling.	Determination of safety and danger limits for various environmental parameters.	G. Zheng, Li, et al., 2021 [50]
Pre/post-heat acclimation exercise trials: hot and temperate conditions, physiological monitoring.	A short-term heat acclimation.	Pryor et al., 2021 [51]
Comparison study: PSI _{max} and HRI symptoms via physiological measures and surveys.	Heat safety application and training.	Santos et al., 2022 [52]
Surveys and interviews with 18 participants.	Self-pacing, work scheduling, hydration, and using shade.	Goodman et al., 2023 [53]
Steel and petrochemical worker study: physiological and environmental measures during rest/work.	Prediction of physiological heat strain.	Abbasi et al., 2023 [54]

Table 8
Studies' characteristics for combined interventions

Intervention	Reference (first author, year)	Context of application	Objective(s)
Internal and external interventions (n = 4)	Kim et al., 2020 [55]	Industry sector (Firefighting)	Evaluate skin cooling and cold drink effects on heat strain reduction.
	Nakamura et al., 2020 [56]	Sports	Assess combined forearm cooling and ice slurry ingestion effects.
	Maley et al., 2020 [57]	Industry sectors (General)	Assess cooling methods' impact on heat tolerance in protective gear.
	Wang et al., 2024 [58]	Industry sectors (General)	Compare ice slurry ingestion vs. desk fan for indoor thermal comfort.
Internal and administrative interventions (n = 3)	Kakamu et al., 2021 [59]	Industry sector (Construction)	Analyze factors influencing construction workers' heat illness risk using wearable sensors.
	Mizelle et al., 2022 [60]	Industry sector (Agriculture)	Assess factors affecting Latino farmworkers' hydration in hot conditions.
	Lin et al., 2023 [61]	Industry sector (Oil and gas)	Identify heat risk factors and prevention for oil/gas extraction workers.
External and administrative interventions (n = 1)	Yoshimura et al., 2023 [62]	Sports	Evaluate CO ₂ -rich cool water immersion effects on heat stress indicators.

Table 9
Methodologies and prevention tools for combined heat stress interventions

Methodology	Solution/tool(s)	Reference (first author, year)
Heat chamber study: comparing hydration and cooling during exercise and recovery.	Hybrid cooling vest.	Kim et al., 2020 [55]
Hot cycling study: comparing cooling methods' effects on physiology and performance.	Combined forearm cooling and ice slurry ingestion.	Nakamura et al., 2020 [56]
CBRN ensemble heat study: comparing various cooling methods during prolonged walking.	Combination of an ice slushy consumed before work with an ice vest.	Maley et al., 2020 [57]
Climate chamber study: comparing ICE vs FAN cooling at varying temperatures.	Ice slurry ingestion and desk fan cooling.	Wang et al., 2024 [58]
Construction worker study: wearable sensors for physiological and environmental monitoring.	Multi-sensor HRI risk monitoring.	Kakamu et al., 2021 [59]
Migrant farmworker heat study: focus groups, surveys, urine tests, and WBGT measurements.	Hydration + timed rest protocol.	Mizelle et al., 2022 [60]
NIOSH/OSHA database review: heat-related incidents among OGE workers (2014-2021).	Heat stress training, acclimatization regimens, medical screening, and workplace-supportive recovery programs.	Lin et al., 2023 [61]
Cold water immersion study: physiological and perceptual responses during recovery.	CO ₂ -rich cool water immersion at 20°C for 20 minutes and monitoring physiological parameters.	Yoshimura et al., 2023 [62]

WBGT, wet-bulb globe temperature.

Table 10
Heat stress prevention strategies and tools by sector

Sector	Internal interventions	External interventions	Administrative interventions
Firefighting	<ul style="list-style-type: none"> Pre-exercise ice slurry (−1.7°C). Post-exercise carbohydrate-electrolyte solution. Optimized salt intake protocols. 	<ul style="list-style-type: none"> Water-cooled vest (18°C). Liquid cooling garments. Hybrid cooling systems. 	<ul style="list-style-type: none"> Physiological monitoring systems. Work-rest schedules.
Military	<ul style="list-style-type: none"> Regular fruit intake. Hydration protocols. 	<ul style="list-style-type: none"> Water spray systems. Personal cooling devices. 	<ul style="list-style-type: none"> Activity monitoring protocols. Heat exposure guidelines.
Construction	<ul style="list-style-type: none"> Hydration monitoring. Body mass tracking. 	<ul style="list-style-type: none"> PCM cooling garments. Ventilation systems. Shaded rest areas. 	<ul style="list-style-type: none"> Self-pacing protocols. WBGT-based work-rest cycles. Heat stress training.
Agriculture	<ul style="list-style-type: none"> Hydration monitoring. 	<ul style="list-style-type: none"> Personal cooling garments. Mist spraying systems. Shade structures. 	<ul style="list-style-type: none"> Early scheduling (6 AM start). Heat safety protocols. Supervisor training programs.
Manufacturing	-	<ul style="list-style-type: none"> PCM cooling garments. Fan-integrated cooling systems. 	<ul style="list-style-type: none"> Work scheduling optimization. Environmental monitoring.

PCM, phase-change material.

Table 11
Heat stress intervention types and evidence levels by industry sector

Sector	Internal interventions	External interventions	Administrative interventions
Firefighting	●	○	○
Military	●	○	○
Construction	●	○	●
Agriculture	●	●	●
Manufacturing	○	●	○
Mining	○	○	●
Healthcare	○	●	○
Oil & Gas	●	○	●
Sports	●	●	●

● Well-documented intervention (≥3 studies) ● Limited evidence (1–2 studies) ○ Not documented in Review (0 studies)

effectively than water or electrolyte-enhanced water [16,20]. Optimal hydration, achieved by consuming fluids at activity onset and during breaks based on body mass loss, helps maintain performance and prevent heat stress [17]. Regular fruit intake and consistent hydration help prevent exertional rhabdomyolysis in cadets [15]. Adequate sleep is crucial to prevent cognitive decline after high heat stress exposure [19]. Timely and appropriate salt consumption is recommended to prevent heat-related illnesses among firefighters [21].

3.3. External interventions

External interventions apply cooling mechanisms to the body or environment. Table 4 shows that this category covers firefighting, military, agriculture, manufacturing, and general population sectors. General population (n = 9; 39%) and industry (n = 13; 57%) are most represented, with various cooling devices evaluated. Military (n = 1; 4%) is also included. Research focuses on innovative technologies like phase-change materials (PCMs), liquid cooling garments, and fan-attached vests.

Table 5 shows cooling vests' extensive study and effectiveness against heat. A water spray fan was proved viable for heat relief [22]. A cooling bandana significantly reduced core body temperature for agricultural workers [23]. Cooling vests with PCMs and electric fans reduced mean skin temperatures and improved thermal comfort. Several studies consistently demonstrated that cooling vests significantly reduce physiological heat strain indicators and enhance user comfort [24–27]. These vests can lower core temperatures by 1–2°C and improve thermal comfort ratings by 20–30% compared with control conditions.

Combining shade and mist spraying has proven effective in multiple studies. Li et al. (2022) found this combination significantly reduced skin temperatures and improved thermal comfort [30]. Another study showed that shade with fan cooling improved thermal comfort by up to 30% and reduced physiological strain indicators like heart rate and skin temperature [39].

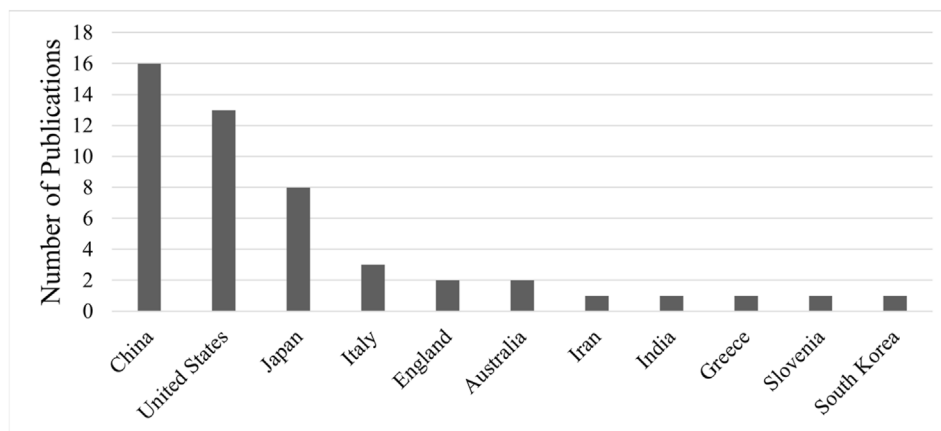


Fig. 2. Distribution of publications per country of origin.

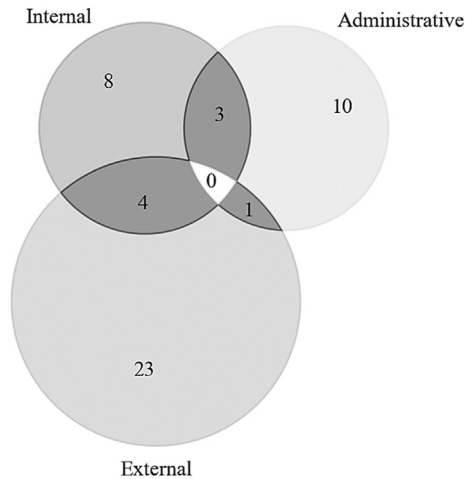


Fig. 3. Distribution of studies by intervention categories.

3.4. Administrative interventions

Administrative interventions use organizational and procedural strategies to mitigate heat stress. Table 6 shows 10 articles on this topic. Contexts include mining, construction, sanitation, agriculture, sports, and general population. Construction and sanitation sectors are most represented ($n = 2$; 20% each), focusing on predictive models, physiological strain monitoring, and heat-related training effects. Mining, agriculture, and sports contribute one article each (10%), addressing heat stress management strategies.

Administrative strategies include physiological monitoring, work–rest cycles, acclimatization, and self-pacing (Table 7). Lazaro and Momayez proposed a modified predicted heat strain model for underground mining, predicting core body temperature based on skin temperature and stored heat [45]. A study emphasized two key strategies for managing heat stress in construction workers: self-pacing and implementing work–rest cycles based on wet-bulb globe temperature measurements [46]. Ioannou et al. (2021) recommended work–rest cycles and mechanization to mitigate heat stress [47]. Comprehensive measures include heat-related training, adjusted working hours, shaded rest areas, and suspending non-essential tasks when temperatures exceed 40°C [48]. These measures reduced heat-related incidents by 40–50%, improving hydration compliance and workforce health. A warning index using heart rate, core and skin temperatures was developed to monitor heat stress in industrial settings [49], enhancing timely mitigation and reducing heat-related illnesses.

Table 8 shows combined effects of various intervention strategies across multiple contexts. This group includes eight articles covering firefighting, sports, general industry, construction, agriculture, and oil/gas industries. Internal and external interventions subgroup has four articles (50% of combined interventions), with firefighting, sports, and general industry each represented by one article (25%). Studies in this group examine combined effects of internal and external cooling methods (skin cooling, cold fluid ingestion, various cooling devices) on reducing heat strain. Internal and administrative interventions subgroup has three articles (37.5% of combined interventions), covering construction, agriculture, and oil/gas industries, each with one article (33.3%). These studies explore personal and environmental factors, sociocultural influences on fluid intake, and common risk factors for heat-related illnesses. The aim was to provide insights into mitigating heat stress through a combination of internal and administrative strategies.

The external and administrative interventions subgroup has one article (12.5% of combined interventions), focusing on sports. It examines CO_2 -enriched cool water immersion's impact on physiological metrics, including heart rate, in hot environments. This study highlights the potential of combining external cooling with administrative strategies for heat stress management.

Combining internal and external strategies improved heat stress management effectiveness. A dual-function cooling vest (skin cooling and hydration) proved effective during treadmill exercise [55]. Forearm water immersion (10°C) with ice slurry ingestion enhanced heat stress management during cycling [56]. Maley et al. (2020) found cooling vests with ice slushy consumption significantly improved heat tolerance and comfort [57]. A study showed combining ice slurry ingestion with desk fan cooling effectively provided comprehensive internal and external cooling [58] (Table 9).

4. Discussion

Occupational heat exposure presents multifaceted challenges that extend beyond direct heat-related illnesses to encompass secondary risks, including falls from heights [63] and dizziness-related accidents [64]. Effective prevention necessitates comprehensive monitoring of environmental conditions and workers' physiological status through advanced monitoring technologies [65]. Our systematic analysis of heat stress prevention strategies across different industrial sectors reveals distinct patterns in intervention implementation and documentation (Table 10).

As illustrated in Table 10, sectors such as firefighting and military demonstrate comprehensive implementation across all intervention types, while manufacturing, construction, and agriculture

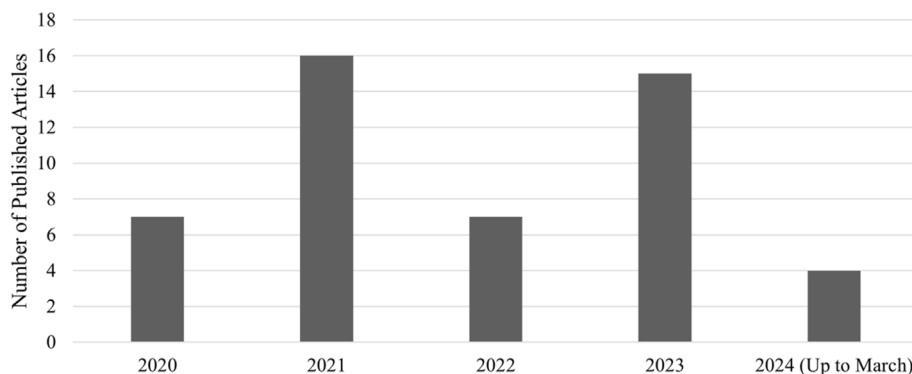


Fig. 4. Published articles per year.

show gaps particularly in internal interventions. This sectoral variation reflects industry-specific challenges and operational constraints. Heat stress response varies significantly across demographic groups, particularly age cohorts. While older workers traditionally face higher heat-related health risks due to medications and physical vulnerabilities, recent data show younger workers (18–34) report more Heat-Related Illness (HRI) claims [68], highlighting the need for age-specific intervention strategies.

The analysis of included studies reveals distinct patterns in intervention effectiveness across three primary categories: internal, external, and administrative approaches. Internal interventions, particularly ice slurry ingestion, demonstrate significant benefits in reducing core temperatures by 1–2°C and improving recovery rates [14,18,56]. Carbohydrate supplementation has proven superior to water or electrolyte-enhanced water in mitigating heat stress–induced cognitive impairments during prolonged exertion [16,20]. The timing and composition of nutritional interventions are crucial as evidenced by studies highlighting the importance of timely salt intake among firefighters [21].

External interventions show consistent effectiveness across various occupational settings. Cooling vests utilizing PCMs and electric fans demonstrate significant reductions in physiological heat strain indicators, improving thermal comfort by 20–30% compared with control conditions [24–27]. In manufacturing environments, PCCGs prove particularly effective while maintaining workflow compatibility [35,38], while ventilation-based cooling solutions show promise in settings requiring continuous PPE use [31,44]. Agricultural settings benefit from integrated approaches combining portable cooling devices with environmental modifications, such as shade and mist spraying systems, which significantly reduce skin temperatures [23,30]. The evolution of cooling technologies demonstrates increasing sophistication, with newer designs incorporating multiple cooling mechanisms [41,42], including fan-integrated shade systems that improve thermal comfort while reducing physiological strain indicators [39].

Environmental monitoring through wet-bulb globe temperature meters, while widely used, requires integration with individual risk factor assessment for comprehensive heat stress management. Critical factors include hydration status, acclimatization, medication use, lifestyle factors (alcohol consumption, smoking), physical characteristics (body mass index), and demographic variables [67]. The effectiveness of administrative interventions depends heavily on organizational implementation and worker engagement. Construction sectors benefit from combining self-pacing with structured work–rest cycles [46,47], while comprehensive measures including heat-related training and adjusted working hours have reduced heat-related incidents by 40–50% [48]. Mining operations have enhanced heat strain prediction through models incorporating environmental and physiological parameters [45], while warning indices using multiple physiological indicators have improved monitoring precision [49,50]. Technological advances have significantly enhanced heat stress management capabilities. The HEAT-SHIELD platform provides tailored risk alerts based on individual traits and work environments [69], while the ClimApp system offers real-time personalized monitoring integrating individual characteristics with environmental data [70]. The WORK-LIMATE system further advances this approach by predicting location-specific heat stress levels up to 72 hours ahead [71], influencing regional policies on agricultural work during peak heat hours [71,72].

Combined intervention strategies demonstrate superior effectiveness compared with single-approach methods. The integration of cooling vests with hydration protocols [55] and ice slurry ingestion with external cooling [56,57] shows enhanced heat stress management capabilities. In construction and agricultural settings,

coordinating personal cooling methods with administrative controls proves particularly effective [59,60], especially when considering specific occupational constraints. A recent study involving 115 stakeholders identified facilitated hydration, protective equipment optimization, and work task rescheduling as preferred heat stress management solutions [73], aligning with the intervention categories examined in this review. Field studies demonstrate significant productivity implications, with shaded work areas reducing productivity losses by 80% and early work scheduling (6 AM start) reducing losses by 33% in agricultural settings [74]. However, the effectiveness varies across sectors and climates.

This review revealed critical sector-specific research gaps and methodological limitations. The manufacturing sector lacks robust empirical evidence on internal intervention effectiveness and cost-benefit analyses of cooling implementations, particularly in automated versus manual production areas. Construction sector demonstrates insufficient research on combined effects of mandatory PPE and environmental heat exposure, while lacking standardized protocols for mobile worker monitoring systems. Agriculture shows marked disparities in heat stress research between greenhouse and open-field settings, with limited documentation of seasonal worker adaptation strategies and inadequate assessment of small-farm versus industrial-scale prevention measures. Although firefighting and military sectors demonstrate more comprehensive documentation, they lack sufficient longitudinal studies on chronic heat exposure effects and female-specific physiological responses. Cross-sector challenges include limited standardization of heat stress measurement protocols, insufficient integration of wearable technology data, and gaps in understanding the interaction among multiple occupational hazards. Additionally, the short review period (January 2020–March 2024) may limit the scope of captured evidence, with publication fluctuations potentially influenced by the COVID-19 pandemic and its disruptions to research activities and workplace practices. These limitations are particularly significant given the increasing frequency of extreme heat events and the evolving nature of workplace environments, highlighting the urgent need for more rigorous, sector-specific research approaches that incorporate real-world operational conditions. Future research priorities should address several key areas. First, methodologies to isolate heatstress–induced productivity decline from other workplace variables are needed for more targeted intervention strategies. Second, comprehensive dietary guidelines for industrial settings are lacking, despite established protocols in military sectors [66]. While hydration and electrolyte replacement are well-documented, specific recommendations for high water content fruits and electrolyte-rich foods require further investigation. Finally, most studies occur in controlled environments, necessitating more on-site, real-work experiments to assess intervention effectiveness under actual working conditions, considering factors like physical exertion, environmental variability, and PPE usage. Such field-based research is essential to validate the practical applicability and cost-effectiveness of interventions across diverse occupational contexts.

5. Conclusion

This scoping review overviews current heat stress prevention strategies across sectors. Heat-related policy development and application are still nascent and need further enhancement. The findings stress the need for multifaceted approaches integrating internal, external, and administrative interventions. As illustrated in our cross-sector analysis (Table 11), the documentation of heat stress interventions varies significantly across industries, with sports showing the strongest research focus, including well-documented internal and external interventions. Firefighting is

notable for internal strategies, while sectors like manufacturing, construction, and healthcare exhibit gaps across different intervention types. Table 11, derived from the synthesis in section 2.5, clearly identifies sectors like sports with well-documented internal and external interventions—marked by three or more studies—and gaps such as firefighting's lack of administrative studies, underscoring key areas for future research. Notably, sports has received significant attention for heat stress interventions, with robust documentation across internal and external categories. This suggests an opportunity to test these well-documented approaches in sports to determine if they could benefit other industries, such as construction or manufacturing, where similar heat stress challenges persist.

Despite the promising findings of existing studies, significant gaps persist in dietary guidelines and real-world experimental data across various sectors. These gaps include considerations of job types, the practicality of solutions, cost-effectiveness, and other factors. Furthermore, while combining interventions has the potential to optimize outcomes, a clear deficiency in the integration of these approaches is evident as highlighted in Fig. 3. Future research should focus on field-based studies replicating actual working conditions in high-hazard industries, assessing specific dietary impacts, and testing cooling technologies in real settings. The study emphasizes personalized heat prevention strategies based on individual factors. Effective guidelines for high-hazard industries should consider medical histories and diverse hot environments' impacts. Future studies should expand their search terminology across all intervention categories, including but not limited to "thermoregulation response" for internal interventions, and "cooling efficiency" for external interventions to capture more comprehensive research outcomes. Future reviews should also incorporate productivity-focused search terms such as "work efficiency" and "productivity loss" to better understand the relationship between heat stress interventions and workplace productivity outcomes. Refining these guidelines will enhance worker safety, productivity, and reduce economic burdens from heat-related illnesses.

CRedit authorship contribution statement

Sepehr Khorshid: Writing – original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. **Siyan Song:** Writing – original draft, Visualization, Resources, Methodology, Investigation, Conceptualization.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Varghese BM, Hansen AL, Williams S, Bi P, Hanson-Easey S, Barnett AG, Heyworth JS, Sim MR, Rowett S, Nitschke M, Di Corleto R, Pisaniello DL. Heat-related injuries in Australian workplaces: perspectives from health and safety representatives. *Saf Sci* 2020;126:104651.
- [2] Gandy J. Water intake: validity of population assessment and recommendations. *Eur J Nutr* 2015;54(2):11–6.
- [3] Xie A, Huang H, Kong F. Relationship between food composition and its cold/hot properties: a statistical study. *J Agric Food Res* 2020;2:100043.
- [4] Oka T. Stress-induced hyperthermia and hypothermia. *Handb Clin Neurol* 2018;157:599–621.
- [5] Puga AM, Lopez-Oliva S, Trives C, Partearroyo T, Varela-Moreiras G. Effects of drugs and excipients on hydration status. *Nutrients* 2019;11(3):669.
- [6] Otani H, Lee JK. The use of sun-shade on safe heat exposure limit on a sunny summer day: a modelling study in Japan. *Int J Biometeorol* 2022;1–10.
- [7] Yang Y, Stapleton J, Diagne BT, Kenny GP, Lan CQ. Man-portable personal cooling garment based on vacuum desiccant cooling. *Appl Therm Eng* 2012;47:18–24.
- [8] Hu W, Liu Z, Yuan M, Peng Y, Meng X, Hou C. Composite design and thermal comfort evaluation of safety helmet with phase change materials cooling. *Therm Sci* 2021;25(2 Part A):891–900.
- [9] Boudra L, Lémonie Y, Grosstephan V, Nascimento A. The cultural-historical development of occupational accidents and diseases prevention in France: a scoping review. *Saf Sci* 2023;159:106016.
- [10] Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med Res Methodol* 2018;18(1):143.
- [11] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol* 2005;8:19–32.
- [12] Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. *Syst Rev* 2016;5(1).
- [13] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71.
- [14] Tabuchi S, Horie S, Kawanami S, Inoue D, Morizane S, Inoue J, Nagano C, Sakurai M, Serizawa R, Hamada K. Efficacy of ice slurry and carbohydrate–electrolyte solutions for firefighters. *J Occup Health* 2021;63(1).
- [15] Mao H, Li X, Liu S, Xing L, Zhao J, Zhang Y, Tan Z, Sun H. Exertional rhabdomyolysis in newly enrolled cadets of a military academy. *Muscle Nerve* 2021;64(3):336–41.
- [16] Deming NJ, Anna JL, Colon-Bonet BM, Dinunno FA, Richards JC. Carbohydrate ingestion attenuates cognitive dysfunction following long-duration exercise in the heat in humans. *J Therm Biol* 2021;100:103026.
- [17] Benjamin CL, Sekiguchi Y, Morrissey MC, Butler CR, Filep EM, Stearns RL, Casa DJ. The effects of hydration status and ice-water dousing on physiological and performance indices during a simulated soccer match in the heat. *J Sci Med Sport* 2021;24(8):723–8.
- [18] Nakamura M, Nakamura D, Yasumatsu M, Takahashi H. Effect of ice slurry ingestion on core temperature and blood pressure response after exercise in a hot environment. *J Therm Biol* 2021;98:102922.
- [19] Asano Y, Nakamura Y, Suzuki-Parker A, Aiba S, Kusaka H. Effect of walking in heat-stressful outdoor environments in an urban setting on cognitive performance indoors. *Build Environ* 2022;213:108893.
- [20] Deming NJ, Steer S, Hernandez J, Dinunno FA, Richards JP. Carbohydrate ingestion attenuates the reduction in complex cognitive function and cerebral blood flow during prolonged passive heat stress in humans. *J Therm Biol* 2023;117:103698.
- [21] Kakamu T, Ito T, Endo S, Hidaka T, Masuishi Y, Kasuga H, Fukushima T. Inappropriate timing of salt intake increases the risk of heat-related illness: An observational study. *PLoS One* 2024;19(1):e0296388.
- [22] Herron JBT, Alleyway P. Use of water spray fan for heat injury management in military personnel exercising in Belize. *BMJ Mil Health* 2020;166(5):365.
- [23] Chicas R, Xiuhtecutli N, Elon L, Scammell MK, Steenland K, Hertzberg V, McCauley L. Cooling interventions among agricultural workers: a pilot study. *Workplace Health Saf* 2020;69(7):315–22.
- [24] Wang F, Kong Y, Udayraj Yang B, Xu P, Noor N. Effect of cooling strategies on overall performance of a hybrid personal cooling system incorporated with phase change materials (PCMs) and electric fans. *J Therm Biol* 2020;92:102655.
- [25] Del Ferraro S, Falcone T, Morabito M, Messeri A, Bonafede M, Marinaccio A, Gao C, Molinaro V. Cooling garments against environmental heat conditions in occupational fields: measurements of the effect of a ventilation jacket on the total thermal insulation. *Int J Ind Ergon* 2021;86:103230.
- [26] Wu G, Liu H, Wu S, Liu Z, Mi L, Gao L. A study on the capacity of a ventilation cooling vest with pressurized air in hot and humid environments. *Int J Ind Ergon* 2021;83:103106.
- [27] Aljaroudi A, Bhattacharya A, Yorio PL, Strauch A, Quinn TD, Williams WJ. Probability of hyperthermia in a hot environment while wearing a liquid cooling garment underneath firefighters' protective clothing. *J Occup Environ Hyg* 2021;18(4–5):203–11.
- [28] Al-Rjoub MF, Kazmierczak MJ, Bhattacharya A, Rakkimuthu S, Ramadurai S, Stuckey JP, Banerjee RK. Better thermoregulation of brain temperature using phase change material-mediated head cooling system. *Int J Heat Mass Transf* 2021;173:121204.
- [29] Mori K, Nagano C, Fukuzawa K, Hoshuyama N, Tanaka R, Nishi K, Hashimoto K, Horie S. Mitigation of heat strain by wearing a long-sleeve fan-attached jacket in a hot or humid environment. *J Occup Health* 2022;64(1).
- [30] Li Y, Hong B, Li H, Bai H, Chen H. Assessing heat stress relief measures to enhance outdoor thermal comfort: a field study in China's cold region. *Sustain Cities Soc* 2022;80:103813.
- [31] Del Ferraro S, Falcone T, Morabito M, Messeri A, Bonafede M, Marinaccio A, Gao C, Molinaro V. A potential wearable solution for preventing heat strain in workplaces: the cooling effect and the total evaporative resistance of a ventilation jacket. *Environ Res* 2022;212:113475.
- [32] Zheng Q, Ke Y, Wang H. Numerical simulation of the human thermophysiological responses with a liquid circulating garment: experimental validation and parametric study. *Energy Build.* 2022;271:112332.

- [33] Inoue D, Nagano C, Tabuchi S, Endo Y, Hashimoto K, Tanaka H, Nakayama M, Hibino H, Morizane S, Inoue J, Horie S. Partial cooling of the upper body with a water-cooled vest in an environment exceeding body temperature. *J Occup Health* 2023;65(1).
- [34] Ciuha U, Valenčić T, Ioannou LG, Mekjavić IB. Efficacy of cooling vests based on different heat-extraction concepts: the HEAT-SHIELD project. *J Therm Biol* 2023;112:103442.
- [35] Wang H, Xu Z, Ge B, Li J. Experimental study on a phase change cooling garment to improve thermal comfort of factory workers. *Build Environ* 2023;227:109819.
- [36] Li Z, Yuan T, Hu P, Jia Q, Wang Q, Xu Y. Performance research of portable thermoelectric cooling garment under different working conditions. *Int J Refrig* 2023;150:327–37.
- [37] Li Z, Zhang M, Yuan T, Wang Q, Hu P, Xu Y. New wearable thermoelectric cooling garment for relieving the thermal stress of body in high temperature environments. *Energy Build.* 2023;278:112600.
- [38] Liu B, Wu H, Zhang G, Li J. Experimental study on improvement effect of a cooling vest on thermal comfort of manufactory workers. *J Build Eng* 2023;68:106067.
- [39] Zhang S, Niu D, Song D, Sun Y, Huan C, Lin Z. Cooling effect of fanned parasol for mitigating outdoor heat stress. *Sol Energy* 2023;259:338–47.
- [40] Li Z, Pan B, Yang B, Zhou B, Wang F. Heat stress mitigation with ice cooling vests in PPE-clad medical workers: effects of cooling area and gender differences. *Build Environ* 2023;245:110943.
- [41] Wei W, Wu B, Guo Y, Hu Y, Liao Y, Wu C, Zhang Q, Li Y, Chen J, Hou C, Wang H. A multimodal cooling garment for personal thermal comfort management. *Appl Energy* 2023;352:121973.
- [42] Ding Y, Zhang Z, Chen Z. Effect of local ventilation temperature and speed under garments on the thermal response of humans at different metabolic rates. *Appl Ergon* 2023;113:104102.
- [43] Choudhary B. Udayraj. Effectiveness of air ventilation clothing in hot and humid environment for decreasing and intermittent activity scenarios. *Build Environ* 2023;239:110436.
- [44] Del Ferraro S, Falcone T, Morabito M, Bonafede M, Marinaccio A, Gao C, Molinaro V. Mitigating heat effects in the workplace with a ventilation jacket: simulations of the whole-body and local human thermophysiological response with a sweating thermal manikin in a warm-dry environment. *J Therm Biol* 2024;119:103772.
- [45] Lazaro P, Momayez M. Development of a modified predicted heat strain model for hot work environments. *Int J Min Sci Technol* 2020;30(4):477–81.
- [46] Al-Bouwarthan M, Quinn M, Kriebel D, Wegman DH. A field evaluation of construction workers' activity, hydration status, and heat strain in the extreme summer heat of Saudi Arabia. *Ann Work Expo Health* 2020;64(5):522–35.
- [47] Ioannou LG, Mantzios K, Tsoutsoubi L, Nintou E, Vliora M, Gkiata P, Dallas CN, Gkikas G, Agaliotis G, Sfakianakis K, Kapnia AK, Testa DJ, Amorim T, Dinas PC, Mayor TS, Gao C, Nybo L, Flouris AD. Occupational heat stress: multi-country observations and interventions. *Int J Environ Res Public Health* 2021;18(12):6303.
- [48] Han SR, Wei M, Wu Z, Duan S, Chen X, Yang J, Borg MA, Lin J, Wu C, Xiang J. Perceptions of workplace heat exposure and adaptation behaviors among Chinese construction workers in the context of climate change. *BMC Public Health* 2021;21(1):2160.
- [49] Zheng G, Fan Z, Meng G, Li C. Establishing a warning index for evaluating the physiological stress of sanitation workers in high temperature weather. *J Therm Biol* 2021;100:103074.
- [50] Zheng G, Li C, Feng Y, Gao Y. Determining the thresholds of environmental parameters for health protection of sanitation workers in summer based on mathematical programming. *Build Environ* 2021;188:107442.
- [51] Pryor RR, Pryor JL, Vandermark LW, Adams EL, Brodeur RM, Armstrong LE, Lee EC, Maresh CM, Casa DJ. Short term heat acclimation reduces heat strain during a first, but not second, consecutive exercise-heat exposure. *J Sci Med Sport* 2021;24(8):768–73.
- [52] Santos ÉC, Spector JT, Egbert J, Krenz J, Sampson PD, Palmández P, Torres E, Blancas M, Carmona J, Jung J, Flunker JC. The effect of the participatory heat education and awareness tools (HEAT) intervention on agricultural worker physiological heat strain: results from a parallel, comparison, group randomized study. *BMC Public Health* 2022;22(1).
- [53] Goodman J, Humphrys E, Newman F. Working in heat: contrasting heat management approaches among outdoor employees and contractors. *Saf Sci* 2023;165:106185.
- [54] Abbasi M, Golbabaee F, Yazdanirad S, Dehghan H, Ahmadi A. Validity of eighteen empirical heat stress indices in predicting the physiological parameters of workers under various occupational and climatic conditions. *Urban Clim* 2023;52:101708.
- [55] Kim D, Bae G, Lee J. A novel vest with dual functions for firefighters: combined effects of body cooling and cold fluid ingestion on the alleviation of heat strain. *Ind Health* 2020;58(2):91–106.
- [56] Nakamura D, Muraishi K, Hasegawa H, Yasumatsu M, Takahashi H. Effect of a cooling strategy combining forearm water immersion and a low dose of ice slurry ingestion on physiological response and subsequent exercise performance in the heat. *J Therm Biol* 2020;89:102530.
- [57] Maley MJ, Minett GM, Bach AJE, Stewart KK, Stewart I. Extending work tolerance time in the heat in protective ensembles with pre- and per-cooling methods. *Appl Ergon* 2020;85:103064.
- [58] Wang F, Tang Y, Kong Y, Zheng Q, Lei T. Ice slurry ingestion for enhanced occupant thermal comfort in warm/hot indoor environments: a comparative study with an energy-efficient desk fan. *Build Environ* 2024;253:111350.
- [59] Kakamu T, Endo S, Hidaka T, Masuishi Y, Kasuga H, Fukushima T. Heat-related illness risk and associated personal and environmental factors of construction workers during work in summer. *Sci Rep* 2021;11(1).
- [60] Mizelle E, Larson KL, Bolin LP, Kearney GD. Fluid intake and hydration status among North Carolina farmworkers: a mixed methods study. *Workplace Health Saf* 2022;70(12):532–41.
- [61] Lin NW, Ramirez-Cardenas A, Wingate KC, King BS, Scott K, Hagan-Haynes K. Risk factors for heat-related illness resulting in death or hospitalization in the oil and gas extraction industry. *J Occup Environ Hyg* 2023;21(1):58–67.
- [62] Yoshimura M, Nakamura M, Hojo T, Arai A, Fukuoka Y. The field study about the effects of artificial CO₂-rich cool-water immersion after outdoor sports activity in a hot environment. *J Exerc Sci Fit* 2023;21(3):268–74.
- [63] Lyu P, Song S, Khorshid S. Exploring the influence of extreme weather on construction worker safety. In: *Construction research congress 2024* 2024. p. 508–17.
- [64] Song S, Zhang F. A study on assessing the awareness of heat-related illnesses in the construction industry. In: *Construction research congress 2022* 2022. p. 431–40.
- [65] Khorshid S, Song S, Chen K, Lyu P. A review of non-invasive heat stress monitoring systems for construction workers using wearable device and computer vision technology. In: *Construction research congress 2023* 2023. p. 606–13.
- [66] Marriott BM, editor. *Nutritional needs in hot environments: applications for military personnel in field operations* 1993.
- [67] Lyu P, Song S. Severity analysis for occupational heat-related injury using the multinomial Logit model. *Saf Health Work* 2024;2024:508–17.
- [68] Bonauto D, Anderson R, Rauser E, Burke B. Occupational heat illness in Washington State, 1995–2005. *Am J Ind Med* 2007;50(12):940–50.
- [69] Morabito M, Messeri A, Noti P, Casanueva A, Crisci A, Kotlarski S, Orlandini S, Schwierz C, Spirig C, Kingma BRM, Flouris AD, Nybo L. An occupational heat-health warning system for Europe: the HEAT-SHIELD platform. *Int J Environ Res Public Health* 2019;16(16):2890.
- [70] Kingma BRM, Steenhoff H, Toftum J, Daanen HAM, Folkerts MA, Gerrett N, Gao C, Kuklane K, Petersson J, Halder A, Zuurbier M, Garland SW, Nybo L. ClimApp—integrating personal factors with weather forecasts for individualized warning and guidance on thermal stress. *Int J Environ Res Public Health* 2021;18(21):11317.
- [71] Grifoni D, Messeri A, Crisci A, Bonafede M, Pasi F, Gozzini B, Orlandini S, Marinaccio A, Mari R, Morabito M. on behalf of the WORKLIMATE Collaborative Group. Performances of limited area models for the WORKLIMATE Heat-Health Warning System to protect worker's health and productivity in Italy. *Int J Environ Res Public Health* 2021;18(18):9940.
- [72] Marinaccio A, Bonafede M, Morabito M. Research and public health prevention policies of occupational heat exposure in Italy. *Occup Environ Med* 2022 Jan 12;79(3):215–6.
- [73] Morris NB, Levi M, Morabito M, Messeri A, Ioannou LG, Flouris AD, Samoutis G, Pogacar T, Bogataj LK, Piil JF, Nybo L. Health vs. wealth: employer, employee and policy-maker perspectives on occupational heat stress across multiple European industries. *Temperature* 2020 Dec 14;8(3):284–301.
- [74] Morabito M, Messeri A, Crisci A, Bao J, Ma R, Orlandini S, Huang C, Kjellstrom T. *Int J Productivity Perform Manage* 2020 Apr;70(3):507–25.