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THESIS

SAFEGUARDING OUTDOOR WORKERS' HEALTH DURING HEATWAVES: A SCOPING REVIEW OF INTERVENTION STUDIES AND THE DEVELOPMENT OF RECOMMENDATIONS TO ADVANCE OCCUPATIONAL HEALTH PROTECTION IN HEAT-RELATED EMERGENCIES

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Abstract

Background: Climate change is increasing the frequency, intensity, and duration of extreme heat events, placing outdoor workers at growing occupational and public health risk. However, evidence on interventions specifically designed to protect this population during heatwaves and extreme heat remains fragmented.

Objective: This scoping review aimed to map the existing literature on health protection strategies for outdoor workers exposed to heatwaves and extreme heat, with a particular focus on the types of interventions implemented, their effectiveness, and feasibility across various contexts.

Methods: A scoping review was conducted following the Joanna Briggs Institute guidance and the PRISMA-ScR framework. PubMed and Web of Science were searched for peer-reviewed original studies addressing outdoor workers exposed to heatwaves or extreme heat and describing or evaluating a specific intervention, tool, protocol, or protective strategy. Data were extracted on study characteristics, intervention type, outcomes, effectiveness, and feasibility.

Results: Thirty-two studies were included. Interventions were grouped into six domains: education and awareness raising, cooling garments, policies/guidelines/protocols, wearable and technological devices, behavioural strategies, and hydration practices. Many studies reported beneficial effects, including reduced heat strain, improved hydration, increased heat-related knowledge, and reduced injury or mortality rates. However, feasibility and scalability were less consistently assessed. Key barriers included economic disincentives, productivity concerns, technical limitations, mismatch with work routines, and limited autonomy.

Conclusions: Occupational heat protection requires integrated, context-sensitive strategies rather than isolated interventions. Future research and policy should strengthen feasibility assessment, worker participation, intersectoral accountability, and heatwave-specific preparedness within broader occupational health and climate adaptation frameworks.

Introduction

Climate change represents one of the main global health threats, with mean surface temperatures having risen already by nearly 1.1° C above pre-industrial levels. This warming trend reached a new critical high in 2023, described as the "*hottest year in human history*", with the global average surface temperature that was 1.45°C higher compared to pre-industrial values (Romanello et al., 2024; Stott, 2016).

This manifests through the increased frequency, intensity and duration of extreme heat events (Bouchama et al., 2022; WHO & WMO, 2016). Without significant effort to mitigate climate change, these events, once considered statistically rare, are projected to become a climatological norm, potentially exposing almost 78% of the world population to a lethal amount of environmental heat within just a few decades (Bouchama et al., 2022).

Heatwaves are meteorological hazards characterized by prolonged periods of abnormally high temperatures relative to local climatic baselines (Perkins & Alexander, 2013). A broadly accepted definition conceptualises these events as at least 3 consecutive days exceeding the 90th percentile of the historical temperature baseline, aligned with the World Health Organization (WHO) guidance framework (Perkins & Alexander, 2013; Romanello et al., 2024; WHO & WMO, 2016). Heatwaves lack the immediate visible destruction of other natural-hazard-induced disasters, but they can cause more fatalities than hurricanes and floods combined (Gubernot et al., 2015). In addition, the public health risk is critically augmented by high nighttime temperatures, which prevent the physiological recovery from daytime heat strain (Bouchama et al., 2022; Perkins & Alexander, 2013; Romanello et al., 2024; WHO & WMO, 2016). The 2003 European heatwave, which resulted in over 70.000 excess deaths, remains a great example of their catastrophic consequences (Robine et al., 2007; Russo et al., 2015).

Outdoor workers, defined by their vocational duties performed without the protection of a building envelope or mechanical climate control, are a uniquely vulnerable population (WHO & WMO, 2016; XIANG et al., 2014). The combination of high physical workload and sustained environmental exposure put sectors such as agriculture and construction at high risk; in particular, agricultural workers are 35 times more likely to die from heat-related causes than the general workforce (Gubernot et al., 2015).

Health impacts range from acute, direct effects, such as heat strain and heatstroke, to the onset and deterioration of chronic conditions, including Chronic Kidneys Disease (CKD), cardiovascular diseases, and diabetes (EU-OSHA, 2023; International Labour Organization, 2024; WHO & WMO, 2016).

Despite well documented risks affecting outdoor workers, there exists a significant knowledge gap concerning interventions that are implemented to protect this population while at work during heat emergencies. The majority of public health strategies are designed for the general population, and they often suggest measures that are incompatible with labour duties (Flouris et al., 2018; International Labour Organization, 2024). The fragmented and scarce literature on the effectiveness and scalability of public health interventions targeting outdoor workers during heatwaves constitute the primary rationale for this scoping review.

The health impacts of heatwaves on outdoor workers do not occur in isolation; rather, they operate within a broader risk framework that can be effectively managed through Disaster Risk Management (DRM) strategies. This cycle is composed by four phases: prevention, preparedness, response, and recovery, and it offers a useful conceptual model for acknowledging how extreme heat can be managed across all four different phases, from disaster risk reduction, to post-event response and adaptation (Coppola, 2015).

It follows that protective interventions for outdoor workers could be positioned at different stages of the cycle: prevention and preparedness measures may include heat risk planning, access to water, rest and shade, training, acclimatization protocols, and early warning systems at the worksite level, whereas response and recovery measures may involve first-aid, medical referral, occupational health check-ups, and the revision of safety procedures after heat-related incidents. Although interventions can span the entire cycle, effective occupational heat protection requires a fundamental shift in focus toward the preparedness phase. While organisational practices often tend to prioritise response measures, the Sendai Framework for Disaster Risk Reduction explicitly emphasises prioritising the prevention and reduction of disaster risks (UNDRR, 2015).

Therefore, aligning with these international standards, proactive interventions addressing the root causes of heat vulnerability are paramount for safeguarding outdoor workers' health.

This idea is also consistent with the WHO's Heat Health Action Plans (HHAPs) framework, which advocates for the integration of heat-risk management into routine public health governance rather than describing heatwaves as acute and isolated events (WHO, 2008). HHAPs are particularly relevant for outdoor workers because the health impacts of heatwaves are mediated by regional policies, as well as workplace regulations. Thus, integrating occupational heat protection into policy frameworks may be a strategic entry point to disrupt the causal chain of heatwave impacts on outdoor workers. This could strengthen public health preparedness and foster interventions that are not only evidence-based, but also scalable, sustainable, and replicable across diverse settings.

To date, the most relevant evidence on interventions protecting outdoor workers from heatwaves stems from the review by Friedrich et al. (2025), which examined wearable device-based interventions for heat-exposed outdoor workers across 19 different studies. The authors made an important contribution to understanding how and under what conditions wearable device technologies can prevent heat stress exposure in occupational settings. That said, their review was relying on a single specific class of interventions, namely wearable device technologies, neglecting interventions addressing broader public health domains.

Protecting outdoor workers from heatwave risks transcends individual physiological monitoring and technological devices. Consequently, examining a comprehensive spectrum of interventions, including macro-level policies, behavioural change interventions, and community-building initiatives, is essential to assess scalability, feasibility, and contextual relevance across diverse socio-economic and workplace settings.

Aim of this Scoping Review

The aim of this scoping review is to map the existing literature on health protection strategies for outdoor workers exposed to heatwaves and extreme heat. Specifically, this review is guided by two main research questions: "*What type of interventions have been proposed, implemented, and evaluated to reduce or mitigate heat-related health risks for outdoor workers?"*; and *"Are these interventions effective, feasible and scalable across various occupational settings and contexts?"*

By answering these questions, this review aims to organize all available evidence across different domains, such as technological, behavioural and educational, physiological, policy, and structural strategies. In doing so, the review moves beyond isolated approaches to consider how different protective strategies can combine to support occupational health preparedness during extreme heat events.

Materials and methods

Study Design

A scoping review was conducted, following the Joanna Briggs institute Reviewers' Manual (Aromataris et al., 2024) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Review (PRISMA-ScR) (Tricco et al., 2018).

Search Strategy

The literature search was conducted on PubMed and Web of Science databases to identify all relevant peer reviewed articles using a specific search string. Additionally, a backward citation search of included articles was undertaken to identify relevant articles that eluded the search string. These two databases were chosen because of their relevance to the research topic; PubMed represents the primary reference for biomedical and health research, whereas Web of Science broadens the spectrum of the research question encompassing interdisciplinary fields potentially relevant to the research question. Both databases apply rigorous indexing criteria, ensuring the inclusion of high-quality, peer-reviewed literature.

Operational Definitions

In this study, a heatwave is defined as a period of at least three consecutive days during which the daily maximum temperature exceeds the 90th percentile of the historical baseline. This definition aligns with the multi-dimensional framework for heatwave measurement defined by Perkins & Alexander (2013) and with the institutional guidance for heat-health risk assessment provided by the World Meteorological Organization and World Health Organization (WHO & WMO, 2016). During the data collection process, however, it became evident that relatively few studies provide a clear and standardized definition of heatwaves supported by institutional scientific sources. Therefore, for the purpose of this review, this definition was applied with a degree of flexibility, allowing the inclusion of studies referring to related phenomena such as extreme heat, prolonged periods of hot weather, or unusually intense summer temperatures, even in the absence of an explicit definition of heatwave. This broader interpretation reflects not only the heterogeneity of terminology in the occupational heat-health literature, but also the increasing difficulty of establishing a single precise and globally valid definition of heatwaves in the context of climate change.

In this review, an outdoor worker is identified as any individual, regardless of contractual status or employment arrangement, whose vocational duties demands exposure to environmental conditions without the mitigation of a building envelope or mechanical climate control. This definition aligns with the physiological risk assessments provided by the National Institute for Occupational Safety and Health (NIOSH) and the structural exposure criteria formulated by the European Agency for Safety and Health at Work regarding heat-stress susceptibility (EU-OSHA, 2023; Jacklitsch, B. et al., 2026). This classification adheres with the International Labour Organization (ILO) framework for universal worker protection (International Labour Organization, 2024b). In this review, studies involving outdoor workers, such as agricultural and construction workers, were included. In addition, experimental studies simulating outdoor working conditions either through human participants or manikins were also considered eligible.

Eligibility Criteria

For the purpose of this review, only original studies were eligible for inclusion, while reviews of the literature, book chapters, perspective papers, letters and editorials were excluded. Eligible studies were assessed against the following inclusion criteria: a) Full text availability; b) Publication in the English language; c) Study population consisting of outdoor workers (as defined in the previous section); d) Occupational exposure to heatwaves or extreme heat (according to the heatwave definition previously reported); e) Presentation and/or implementation and/or evaluation of a specific intervention or tool (example: technical/engineering, physiological, behavioural, organizational); f) Consideration of outcomes related to occupational health and/or public health; g) Study setting located in high-income countries (HIC) and upper middle-income countries (UMIC) as per The World Bank definition for the year 2026 (World Bank, 2026).
Studies were excluded when they did not satisfy the inclusion criteria.

No time restriction was applied in the search process, in order to capture the full breadth of the available literature on intervention strategies aimed at protecting outdoor workers from heatwaves.

Screening Process and Study Selection

The screening and study selection process was conducted in subsequent stages and is illustrated by the PRISMA flow diagram (Page et al., 2021). After all articles were identified, they were exported to an Excel spreadsheet for an initial screening and removal of duplicates. Once this process was completed, the author proceeded with the title and abstract screening, during which articles that did not meet the inclusion criteria were excluded. The full texts of the remaining articles were then screened to determine the final eligibility for inclusion. Any discrepancies or uncertainties in the selection process were discussed and solved with the thesis supervisor.

Data Appraisal and Extraction

Data from the included studies were extracted and organised in an Excel spreadsheet specifically developed for this review. The data extraction form was designed to ensure a systematic and consistent collection of relevant information across all included studies (Appendix 1). Some of the extracted variables included bibliographic details, study setting, study design, characteristics of the study population, sample size, main exposure of the study, intervention or tool assessed, occupational and public health outcomes investigated, and the main findings of the study. Before data extraction, the methodological quality of the included studies was assessed using the Assessment of Real-World Observational Studies (ArRoWS) critical appraisal tool (Coles et al., 2021).

Each included article was appraised by responding to a set of predefined questions derived from the selected assessment tool (Appendix 2). For each item, studies were rated using the following categories: good++, moderate+, poor−, or not applicable (n/a). These qualitative ratings were subsequently converted into numerical scores (2, 1, 0, and n/a, respectively) to enable the calculation of an overall quality score. The score was then normalized to a percentage scale (×100) and used to classify studies into three quality categories: 0–33 (poor), 34–66 (moderate), and 67–100 (good).

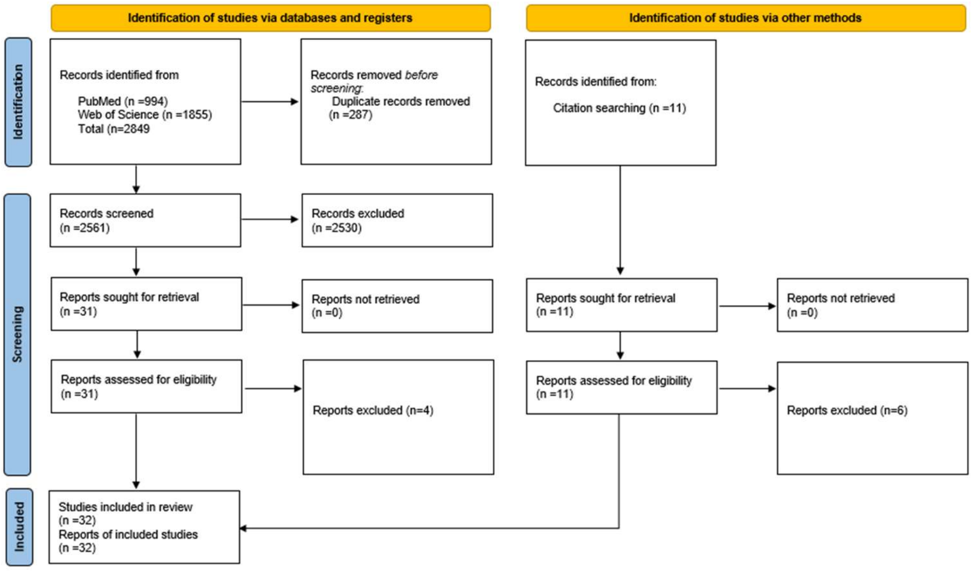
Ethical Consideration

Given that this study consisted of a review of previously published literature, ethical approval was not required. The review did not involve the collection of primary data, direct contact with human participants, or access to identifiable personal information.

Results

A total of 2849 records were retrieved (994 from PubMed and 1855 from Web of Science). After the removal of 287 duplicates, 2561 entries remained for title and abstract screening; of these, 31 were eligible for full-text assessment according to the previously defined eligibility criteria. Overall, 4 studies that did not satisfy the inclusion criteria at the full-text stage were excluded. After the inclusion of 5 additional articles identified through a backward citation search from the included articles, 32 studies were included in the review. The selection process is summarised in the PRISMA flow diagram (Page et al., 2021). (Figure 1).

Figure 1: PRISMA flowchart detailing the screening process and selection of final records.



<u>Characteristics of the Included Studies</u>

The studies' publication year varies, ranging from 2010 to 2026, even though their distribution lean towards the most recent years (a total of 21 records in 2020-2026), reaching the peak in 2024 and 2025, with 5 records published per year. A pattern appears showing a steadily growing interest in the topic over the years.

The included studies are conducted across a limited yet heterogeneous set of countries, with the greater contributors being the United States of America (USA) (Chavez Santos et al., 2022; Chicas et al., 2021a; Dean & McCallum, 2025; Dillane & Balanay, 2020; Idris, Markham, Mena, Perkison, et al., 2024; Marquez et al., 2023;

McCarthy et al., 2019; Perkison et al., 2024; Siegler et al., 2025; Thompson et al., 2018; Tigchelaar et al., 2020), followed by China (Ding et al., 2025; Li et al., 2025; Wang et al., 2024; Zhao et al., 2018; Zhao, Yi, Chan, & Chan, 2017; Zhao, Yi, Chan, Wong, et al., 2017), South Korea (Choi et al., 2024; Kim & Yoo, 2023; J. Lee et al., 2026; S.-W. Lee et al., 2020) and Japan (Ishikawa et al., 2010; Kawakami et al., 2024; Miura et al., 2017). The other studies took place in Australia (Sinclair & Brownsberger, 2013), Canada (Fazel et al., 2023; Haynes et al., 2018), El Salvador (Bodin et al., 2016; Wegman et al., 2018), Italy (Del Ferraro et al., 2021; Morabito et al., 2025) and The Netherlands (Roossien et al., 2021).

In terms of methodology, the majority of the evidence is quantitative; with the experimental design being the most predominant approach, followed by the observational design. Mixed-methods and qualitative studies are the least represented in this scoping review.

The target population of outdoor workers is heterogeneous, though some categories are more predominant than others: agricultural and construction workers are the most frequently studied population (Bodin et al., 2016; Chavez Santos et al., 2022; Chicas et al., 2021b; Choi et al., 2024; Del Ferraro et al., 2021; Dillane & Balanay, 2020; Kawakami et al., 2024; J. Lee et al., 2026; Marquez et al., 2023; Miura et al., 2017; Morabito et al., 2025; Siegler et al., 2025; Tigchelaar et al., 2020; Wegman et al., 2018; Zhao et al., 2018; Zhao, Yi, Chan, & Chan, 2017; Zhao, Yi, Chan, Wong, et al., 2017), followed by municipal and council workers (Fazel et al., 2023; Haynes et al., 2018; McCarthy et al., 2019; Perkison et al., 2024; Sinclair & Brownsberger, 2013), airport ground-handling personnel (Ishikawa et al., 2010), maintenance workers (Thompson et al., 2018), sanitation workers (Wang et al., 2024) and a much broader category of outdoor workers who are engaged in physically demanding activities (Dean & McCallum, 2025; Ding et al., 2025; Idris, Markham, Mena, & Perkison, 2024; Kim & Yoo, 2023; S.-W. Lee et al., 2020; Li et al., 2025; Roossien et al., 2021). It is worth noticing that some of the studies were carried out in a simulated environment and in a laboratory setting (Choi et al., 2024; Del Ferraro et al., 2021; Li et al., 2025; Miura et al., 2017; Siegler et al., 2025; Zhao, Yi, Chan, & Chan, 2017; Zhao, Yi, Chan, Wong, et al., 2017), usually with the involvement of healthy young adults or thermal manikins acting as outdoor workers.

Outcome-wise, the selected studies predominantly focus on morbidity, examining heat stress and heat strain through perceptual, physiological, and occupational health measures, and using indicators such as core body temperature, hydration status, heart rate, kidney related biomarkers, and heat related illness. Mortality outcomes are marginally represented. Few other articles address basic heat knowledge, and intervention feasibility and acceptance.

The methodological quality of in the included studies was generally moderate to good. Based on the ArRoWS critical appraisal tool (Coles et al., 2021), 16 studies were classified as Good++ (50%), 15 as Moderate+ (46.9%), and only one study as Poor (3.1%) (Appendix 1). No study was excluded on the basis of quality appraisal, as the purpose of this scoping review was to map the available evidence rather than giving a restriction based on quality thresholds.

Exposure

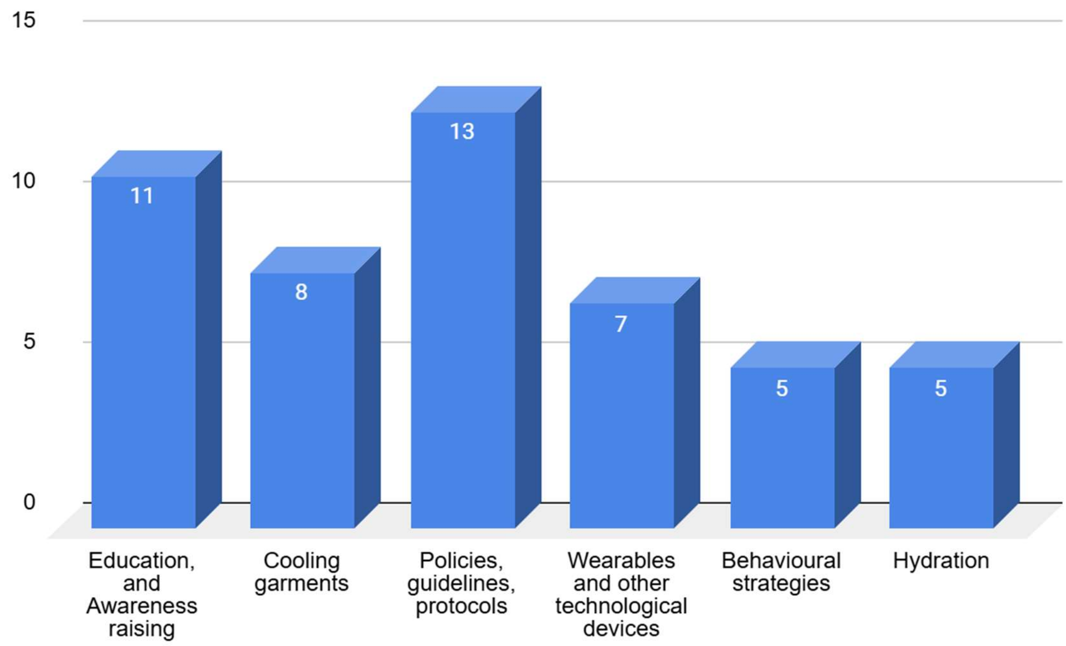
Although the study focused on heatwaves, few studies provide an explicit definition of the exposure construct itself; the vast majority (~97%) broadly refers to elevated ambient temperatures or extreme summer heat, thereby conceptualizing heat as a recurrent occupational stressor rather than a discrete extreme weather event (Bodin et al., 2016; Idris, Markham, Mena, & Perkison, 2024; Siegler et al., 2025; Wegman et al., 2018; Zhao et al., 2018; Zhao, Yi, Chan, Wong, et al., 2017).

Only one study explicitly addressed heatwaves as a distinct exposure condition. Kim & Yoo (2023) examined heatwave exposure among road construction workers, defining a heatwave as: “periods of at least two consecutive days with daily maximum temperatures at or above 33°C” (or 35°C, depending on the threshold applied) as per the operational definition of the Korea Meteorological Administration (KMA).

Intervention

The evidence was synthesized by focusing on intervention typology. Interventions were clustered according to their underlying mechanisms and modes of implementation. Specifically, these were inductively grouped into six overarching domains: (I) education and awareness raising; (II) cooling garments; (III) policies, guidelines, and protocols; (IV) wearable and other technological devices; (V) behavioural strategies; and (VI) hydration. These domains are not mutually exclusive, and several studies incorporated multicomponent approaches spanning more than one category (See Table 1).

Table 1 Distribution of Intervention Frequencies by Intervention Type



Education and awareness raising

Overall, 11 studies fall in this category, most of them conducted in the USA (n=8), followed by China (n=1) and Canada (n=2) (Chavez Santos et al., 2022; Dean & McCallum, 2025; Ding et al., 2025; Fazel et al., 2023; Haynes et al., 2018; Idris, Markham, Mena, & Perkison, 2024; Marquez et al., 2023; McCarthy et al., 2019; Perkison et al., 2024; Thompson et al., 2018; Tigchelaar et al., 2020). These interventions have shifted from generic and traditional safety communications to participatory and contextualized programs. For instance, the HEAT intervention, implemented in the USA, provided agricultural workers with participatory, culturally tailored heat education in Spanish and English that addressed the identification, prevention, and treatment of heat-related illnesses. This educational intervention demonstrated that using participatory educational tools greatly improves agricultural workers' general knowledge about the symptoms, the treatment and the consequences of heat-related illness (Chavez Santos et al., 2022; Marquez et al., 2023). Programs of this type often include specific training components for both employees and supervisors, aimed at addressing critical elements such as emergency first aid and heat-related procedures (McCarthy et al., 2019; Perkison et al., 2024). Another intervention is the use of tailored messaging. In particular, Fazel et al. (2023) proposed a set of evidence-based, practical sun safety messages specifically adapted to the occupational language and needs of outdoor workers, ensuring their feasibility in numerous different settings; and Haynes et al. (2018) proposed a knowledge transfer and exchange (KTE) intervention, in which a new figure called “knowledge broker” collaborated directly with workplaces to deliver training and resources specifically adapted to each organization’s specific context and needs. The authors point out that warning messages and safety communications are far more effective when practicality and feasibility are taken into account (Fazel et al., 2023; Haynes et al., 2018).

<u>Cooling garments</u>

Overall, 8 studies fall in this category, most of them conducted in China (n=4), followed by USA (n=1), Japan (n=1), Italy (n=1) and Australia (n=1) (Chicas et al., 2021; Del Ferraro et al., 2021; Li et al., 2025; Miura et al., 2017; Sinclair & Brownsberger, 2013; Zhao et al., 2018; Zhao, Yi, Chan, & Chan, 2017; Zhao, Yi, Chan, Wong, et al., 2017). Advanced cooling and ventilation garments are presented by the studies as primary interventions for counteracting occupational heat stress in outdoor environments during extreme heat. Ventilation jackets that are equipped with battery fuelled fans have shown a significant reduction of about 35% in the total thermal insulation particularly in the trunk area of the body facilitating the heat dissipation by convection for agricultural and construction workers in a study conducted in Italy (Del Ferraro et al., 2021). Researchers have also developed hybrid cooling vests combining the use of fans with Phase-Change Material (PCM) packs, which absorb heat through a solid-to-liquid transition at a set temperature (28°C), providing a cooler microclimate next to the user’s skin. The use of these devices drastically reduced skin temperature and cardiac strain with a potential increase of subsequent work duration by almost 200%, as demonstrated by a study conducted in China (Zhao, Yi, Chan, & Chan, 2017). The work of Chicas et al. highlighted, however, that despite the physiological effectiveness of these vests, most of the workers find them either heavy or uncomfortable, preferring simpler solutions, like bandanas (Chicas et al., 2021)

Policies, guidelines, and protocols

Overall, 13 studies fall in this category, most of them conducted in USA (n=6), followed by Canada (n=2), South Korea (n=1), Italy (n=1), Japan (n=1) and El Salvador (n=2) (Bodin et al., 2016; Chavez Santos et al., 2022; Dean & McCallum, 2025; Fazel et al., 2023; Haynes et al., 2018; Idris, Markham, Mena, & Perkison, 2024; Kawakami et al., 2024; S.-W. Lee et al., 2020; McCarthy et al., 2019; Morabito et al., 2025; Perkison et al., 2024; Tigchelaar et al., 2020; Wegman et al., 2018). Public policies and corporate protocols provide the administrative pillars necessary to protect workers' health; in Italy some urgent regional ordinances redacted in 2024 banned any activities related to outdoor work during the day's hottest hours (from 12.30 to 16:00) on high-risk days. As shown by Morabito and colleagues, this policy led to a decrease of about 21.9% in injuries in 15 different Italian regions in the construction sectors (Morabito et al., 2025). Similarly, the California Heat Standard, an occupational safety standard for outdoor workers requires employers to provide to their employees' water, shade zones and mandatory rest periods when a specific temperature threshold is surpassed (Dean & McCallum, 2025). Standardized protocols like the OSHA's WRS program ("Water.Rest.Shade") have proven effective even in demanding environments such as El Salvador's sugarcane fields. These protocols require workers to take scheduled 10-to-15-minutes rest breaks in mobile shaded tents and to maintain a continuous hydration using the provided 3-liter water backpacks (Camelbacks) and led to a measurable reduction in both physiological heat stress and biomarkers associated with renal injury (Bodin et al., 2016; Wegman et al., 2018). Regular medical surveillance stands as a fundamental cornerstone for identifying vulnerable workers and preventing fatal outcomes (McCarthy et al., 2019; Perkison et al., 2024).

Wearable and other technological devices

Overall, 7 studies fall in this category, most of them conducted in South Korea (n=3), followed by China (n=2), USA (n=1) and in The Netherlands (n=1) (Choi et al., 2024;

Dillane & Balanay, 2020; Ding et al., 2025; Kim & Yoo, 2023; J. Lee et al., 2026; Roossien et al., 2021; Wang et al., 2024). One significant advantage of integrating wearable technologies is the capacity for continuous physiological monitoring, which overcomes the limitations of generic environmental estimates. Specialized sensors, such as those measuring ear canal temperature, enable the precise prediction of individual thermal strain (Roossien et al., 2021). However, concerns regarding data privacy, device ergonomics, and physical discomfort have shifted research interest toward 'wearable-free' machine learning models. These systems leverage easily accessible proxy variables, including ambient environmental data and general anthropometric parameters, to estimate heat strain without requiring devices in direct contact with the worker's body (Choi et al., 2024; J. Lee et al., 2026). A study conducted by Wang et al. (2004) in China used Artificial Intelligence (AI) to flag prolonged work periods during critical heat conditions. Specifically, the authors developed an alert system based on a Convolutional Long Short-Term Memory (C-LSTM) network, designed to automatically identify excessive occupational exposure. Upon detection, the system triggers auditory or visual notifications, prompting workers to suspend activity and seek rest (Wang et al., 2024).

Behavioural strategies

Overall, 5 studies fall in this category, most of them conducted in El Salvador (n=2) and USA (n=2), followed by China (n=1) (Bodin et al., 2016; Ding et al., 2025; Idris, Markham, Mena, & Perkison, 2024; Thompson et al., 2018; Wegman et al., 2018). In the included studies, behavioural change is often tied up with attempts to increase risk awareness of workers and the culture of safety in the workplace. Practices like the "report-back", whereby workers are provided with their own heat stress monitoring data, have shown a significant increase in environmental health literacy. Furthermore, this approach enhances participants' motivation to modify usual habits to mitigate the risk of heat-related illness and stress (Thompson et al., 2018). Other effective practices for behavioural change are presented by Idris et al. and concern enhancing individual preparation, such as an adequate rest cycle and a good hydration, and establishing the "brother's keeper system", where colleagues are prompted to monitor each other (Idris, Markham, Mena, & Perkison, 2024).

Hydration

Overall, 5 studies fall in this category, most of them conducted in El Salvador (n=2) and USA (n=2), followed by Japan (n=1) (Bodin et al., 2016; Idris, Markham, Mena, & Perkison, 2024; Ishikawa et al., 2010; Siegler et al., 2025; Wegman et al., 2018). Interventions focused on two aspects of hydration: increasing the volume of fluid intake and improving the quality of electrolyte replacement to mitigate the physiological impact of heat. For example, the implementation of 3-liter hydration backpacks (Camelbacks) for sugarcane workers in El Salvador has proved effective in providing continuous access to water, resulting in a 1.2-liter increase in self-report daily consumption (Bodin et al., 2016; Wegman et al., 2018). Oral Rehydration Solutions (ORS) that contain electrolytes have been deemed superior to free choice beverages in reducing the perception of fatigue at the end of the work shift for airport personnel in Japan (Ishikawa et al., 2010). However, Siegler et al. questioned the use of sodium bicarbonate supplementation, noting its capacity to attenuate the Rating of Perceived Exertion (RPE) despite heart rate and core temperature remaining elevated. To ensure safety, this intervention followed a strict hydration regimen requiring 500 mL of water intake the evening prior and again the morning of the work shift (Siegler et al., 2025). Some monitoring tools like hydration logs and urine colour charts were also frequently employed to ensure that workers could autonomously track their hydration status (Idris, Markham, Mena, & Perkison, 2024).

Effectiveness

Of the 32 studies analysed, 78.1% assessed effectiveness (n=25) while 21.9% did not report any effectiveness measures (n=7). Among the studies that did assess effectiveness of interventions, outcomes spanned a wide spectrum of measures, from mortality and morbidity indicators to physiological and behavioural outcomes. As for morbidity, Morabito et al. (2025) reported a statistically noticeable reduction by 21,9% of injury rates among construction workers following the implementation of regional ordinances in Italy that prohibited work during peak heat hours. In terms of mortality reductions, Dean & McCallum (2025) found that California's heat standard implementation was

associated with an estimated 51,4% reduction in heat-related deaths among outdoor workers, the strongest effect size reported across all the selected studies.
Other outcomes were considered in the included studies. The WRS protocol used in El Salvador was associated with an increase in self-reported daily water consumption of 1,2 litres/day, with stabilization of kidney functions, measured by estimated glomerular filtration rate (eGFR) among sugarcane workers (Bodin et al., 2016; Wegman et al., 2018). Cooling garments were found to be effective in reducing core body temperature during rest or recovery periods; for instance, the work from Zhao et al. found that wearing a hybrid cooling vest during rest periods accelerated core temperature recovery (Zhao, Yi, Chan, Wong, et al., 2017). Similarly, Li et al. (2025) reported that the use of an active-ventilation suit increased safe operational time by an 8,3% (~130 minutes) compared to passive desiccant systems, which manage microclimate humidity using moisture-absorbing materials such as silica gel packs, requiring neither electrical power nor mechanical fans. Simulations in controlled climate chambers showed that the use of a ventilation jacket could reduce the total thermal insulation up to 35% (Del Ferraro et al., 2021).

Effectiveness was also assessed through behavioural and educational indicators. Marquez et al. (2023) demonstrated increase up to almost 1,6 points in the heat-related knowledge compared to the control groups after implementing the Heat Education and Awareness Tools (HEAT) intervention, a bilingual, culturally tailored, and participatory educational program addressing the identification, prevention, and treatment of heat-related illnesses. Ishikawa et al. (2010) found that 57,5% of workers who used ORS (oral rehydration solution) recorded a lower self-reported fatigue score than those choosing self-selected beverages.

Feasibility, barriers and facilitators

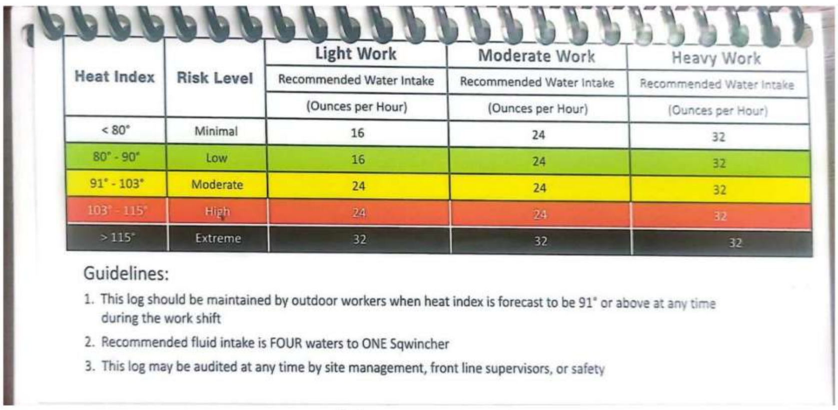
Feasibility was not always addressed by the included studies. Only a minority of them addressed it in a structured way, whereas the majority touched upon it very briefly in the discussion (Bodin et al., 2016; Chicas et al., 2021; Fazel et al., 2023; Sinclair & Brownsberger, 2013). Such limitations preclude the formulation of definitive conclusions on feasibility and underscore a critical gap in how the field conceptualizes the scope of heat-related interventions.

Feasibility of implementation appeared to depend heavily on compatibility with the working schedules of outdoor workers, practical usability of solutions, and the perceived economic value. A primary example is the WRS program implemented in El Salvador, where a clear understanding of local leadership structures and a shared sense of ownership among all actors involved proved to be key components for both scalability and feasibility (Bodin et al., 2016). Chicas et al. (2021) stated that low-cost tools like a 5-dollar bandana were widely accepted due to their ease of use and affordability, while more complex cooling garments were seen as less feasible to implement. Clothing adaptation, such as choosing between long or short pants, are considered highly feasible (Sinclair & Brownsberger, 2013). Safety messaging effectiveness increases significantly when the content is tailored to specific working contexts and groups (Fazel et al., 2023). Several barriers emerged that could hinder implementation procedures. One of them is the so-called *"piece-rate payment system"*, a practice that would incentivize workers to skip rest breaks to protect their daily earnings (Chavez Santos et al., 2022; Chicas et al., 2021; Tigchelaar et al., 2020). Organizational barriers also include concerns and doubts over productivity loss (S.-W. Lee et al., 2020). An additional challenge concerns technical and logistical barriers, doubts on the reliability of wearable sensors because of sweat and movements, and mobile apps that are often unreliable for heavy workloads (Dillane & Balanay, 2020; Roossien et al., 2021). The physical distance between worksites and cooler rest areas may lead workers to end their breaks earlier to avoid delays (Kawakami et al., 2024).

Several facilitators emerged that could ease the implementation of protective measures. In particular, *"knowledge brokers"* are considered helpful in sustaining workplace safety programs, encouraging behaviour change, and helping worksites adapt to withstand heat (Haynes et al., 2018). Participatory approaches facilitate implementation; for instance, ensuring that the educational tools are culturally adapted and grounded in the workers lived experiences (Chavez Santos et al., 2022; Marquez et al., 2023). The practice of *"report-back"* is shown to be a powerful psychological motivator, as it strengthens environmental health literacy and encourages behavioural change, such as seeking shade (Thompson et al., 2018).

Figure 2 Example of worksite-level heat stress communication tools used in a natural gas construction site. Figure (b) shows visual on-site heat index flags used to communicate heat risk levels to workers during the shift. Figure (c) shows an individual heat index chart included in the hydration log, indicating recommended water intake according to heat index, risk level, and workload intensity. (Idris et al., 2024)

(b)



Heat Index	Risk Level	Light Work Recommended Water Intake (Ounces per Hour)	Moderate Work Recommended Water Intake (Ounces per Hour)	Heavy Work Recommended Water Intake (Ounces per Hour)
< 80°	Minimal	16	24	32
80° - 90°	Low	16	24	32
91° - 103°	Moderate	24	24	32
103° - 115°	High	24	24	32
> 115°	Extreme	32	32	32

Guidelines:

1. This log should be maintained by outdoor workers when heat index is forecast to be 91° or above at any time during the work shift
2. Recommended fluid intake is FOUR waters to ONE Sqwincher
3. This log may be audited at any time by site management, front line supervisors, or safety

(c)

Discussion

This scoping review aimed to map the existing literature on health protection strategies for outdoor workers exposed to heatwaves and extreme heat, with a particular focus on the types of intervention implemented, their effectiveness, and feasibility across various contexts.

Overall, the findings show that occupational heat protection is not ruled by a single intervention model, but by a heterogeneous set of strategies implemented at different levels (e.g., education and awareness raising, cooling garments, policies, guidelines, and protocols, wearable and other technological devices, behavioural strategies, and hydration practices). This suggests that heat-related occupational risk can be seen as a multidimensional public health threat, rather than an isolated problem that can only be addressed by a single approach. This interpretation is consistent with recent international guidance, which frames extreme heat as a major climate-related occupational hazard requiring preventive, organizational and policy-based responses (International Labour Organization, 2024; World Health Organization, & World Meteorological Organization., 2025). Feasibility, scalability, and long-term implementation challenges were addressed far less than effectiveness, representing an important gap in the current evidence.

Geographic patterns

The type of interventions studied appears to vary across countries. However, this does not imply that a specific country adopts a favourite model of intervention, since the number of studies per country is limited and the included literature may not fully reflect national practices. Nevertheless, the distribution of intervention types suggests that research priorities are shaped by a combination of occupational sectors, technological expertise, climatic conditions, and the worker population studied.

In the USA, for example, the included literature is oriented towards education and awareness raising through participatory, culturally-tailored approaches, behavioural change practices, and policy making (Chavez Santos et al., 2022; Dean & McCallum, 2025; Idris, Markham, Mena, & Perkison, 2024; Marquez et al., 2023; McCarthy et al., 2019; Perkison et al., 2024; Thompson et al., 2018). This is consistent with the US occupational heat prevention context, where the Occupational Safety and Health Administration (OSHA) considers training and education central pillars of the California's Heat Illness Prevention Standard (California Department of Industrial Relations, 2020; United States Department of Labor, 2016). At the same time, the implementation of participatory and culturally tailored interventions may also reflect the profile of the population studied, meaning mainly Latino migrants and seasonal agricultural workers, for whom language accessibility and cultural relevance are key factors for effective health interventions (Castillo et al., 2021).

Conversely, studies conducted in China show a stronger focus on cooling garments, hybrid cooling vests, ventilation systems and AI-based solutions (Ding et al., 2025; Li et al., 2025; Wang et al., 2024; Zhao et al., 2018; Zhao, Yi, Chan, & Chan, 2017; Zhao, Yi, Chan, Wong, et al., 2017). This strategic orientation can be interpreted within the context of China's regulatory framework, where occupational heat protection is already institutionalised through formal heatstroke prevention mandates and standardised cooling protocols. For instance, directives from the Chinese Center for Disease Control and Prevention notify that when ambient temperatures reach 35–37°C, employers must cut continuous working hours, prohibit overtime, and provide adequate hydration (Chinese Center for Disease Control and Prevention., 2022). Su et al. (2020) demonstrated that the implementation of these CDC policies in Guangzhou province significantly correlated with a reduction in occupational heat-related injuries (Su et al., 2020). Therefore, the observed Chinese emphasis on technological interventions likely reflects an effort to complement established regulatory frameworks with advanced engineering-based solutions.

South Korean and Japanese studies focus more on technological monitoring, structured rest protocols, and workplace-level procedures such as hydration supplements and defined rest schedules. In Japan, heat stress prevention has historically emphasized WBGT-based assessment (Wet Bulb Globe Temperature) and the application of measures guided by threshold values and recommendations issued within the occupational safety and health system, including frequent breaks, breathable clothing, sodium-containing fluids, and emergency-care education (Seichi Horie, 2013). Similarly, in South Korea employers are required to provide at least 20 minutes of rest within every two-hours when the perceived temperature reaches 33°C or higher (Ministry of Employment and Labor, 2025). Together, these monitoring-oriented approaches suggest that occupational heat protection in such contexts tends to be shaped around measurable thresholds and standardized workplace procedures.

European countries were less represented in this scoping review, and their contribution does not suggest a single intervention type. Italy, in particular, is represented in the work by Morabito et al. (2025) and Del Ferraro et al. (2021). The second study examined ventilation garments as an engineering solution to improve heat dissipation during outdoor work, while the first evaluated the effectiveness of a regional ordinance banning work during the hottest hours of the day reporting a reduction in injuries among construction workers (Del Ferraro et al., 2021; Morabito et al., 2025).

Overall, three key insights emerge when it comes to geographic patterns. First, despite substantial heterogeneity among the identified interventions, some patterns appear to reflect the occupational, institutional, and technological contexts in which they were developed. Second, the implemented strategies span the entire spectrum of occupational heat protection, ranging from macro-level national or regional policies to micro-level devices for individual monitoring. Finally, their broader implications mainly concern sustainability, scalability, and transferability across different communities and work settings. For this reason, interventions should be understood as adaptable strategies rather than universally applicable solutions.

Feasibility and context dependency of interventions

While most of the included studies reported positive outcomes, only a few examined whether or not these interventions could be realistically implemented across different countries, workplaces, and climatic conditions. This is relevant because an intervention may perform well under the study conditions but be difficult to scale up if it collides with broader economic, organizational, and social structures.

Across all the included studies, feasibility and scalability barriers can be grouped in three core categories: economic disincentives intertwined with local labour policies, technical limitations of device-based and technology-driven solutions under real life conditions, and the mismatch between intervention design and actual working routines.

These barriers suggest that feasibility challenges are not incidental but mainly structural and that they are unlikely to be solved through intervention refinement alone without addressing the broader organizational and economic frames in which outdoor workers operate.

Lower-complexity measures, such as potable water access, shaded rest areas, scheduled breaks, acclimatization, and work organization, are widely recognized as core components of occupational heat prevention (EU-OSHA, 2023; Jacklitsch, B. et al., 2026). Their strength lies not in technological innovation, but in their potential to be seamlessly integrated into everyday working routines. Therefore, simplicity should not be interpreted as a limitation; rather, these interventions may carry great public health value precisely because they are easier to communicate, enforce, and implement across different settings. Technological interventions, by contrast, offer clear advantages in terms of personalization and early risk detection, yet their public health utility ultimately depends on their real-world feasibility and compliance within outdoor work scenarios.
Notably, however, feasibility and scalability can encounter barriers even in the context of lower-complexity interventions; even the simplest protective measure can fail if the workplace does not support it or does not allow workers to use it without economic, social or organizational penalties.

Overall, feasibility is not an intrinsic property of the interventions themselves; rather, it emerges from the relationship between the intervention and its specific setting. Safeguarding outdoor workers' health could therefore be best achieved through the combination of multiple, complementary intervention types. This multifaceted approach directly aligns with guidelines from the WHO and the WMO (WHO &WMO, 2025).

Considering heatwaves as disasters

A noticeable finding from this scoping review is that almost all of the included studies addressed extreme heat as a prolonged environmental condition rather than considering heatwaves as discrete, time-sensitive events. Many interventions were designed to mitigate or manage occupational heat exposure during hot season or in persistently hot climates, without having a clear distinction between the background heat condition and the acute, time-sensitive nature of heatwaves. This distinction is relevant, because heatwaves can potentially generate acute and severe health emergencies in a limited time frame, overburdening the health system and generating cascading consequences. Failing to recognize heatwaves as potential disaster-inducing hazards impedes the development of disaster preparedness strategies and response interventions, including those within the workplace (Coppola, 2015; Perkins et al., 2012; Perkins & Alexander, 2013; Rakesh et al., 2025; UNDRR, 2015).

A further issue concerns the temporal definition of heatwaves. Heatwaves are not only defined by temperature intensity, but also by duration. If response systems rely mainly on daily temperature peaks, they may overlook the cumulative burden of repeated exposure over consecutive hot days, particularly when high nighttime temperatures limit physiological recovery between shifts. Evidence from occupational heat research suggests that consecutive workdays in hot conditions can impair thermoregulatory function and increase the risk of heat-related illness, especially among older workers and those performing physically demanding tasks (Ioannou et al., 2017). Therefore, the way heatwaves are operationally defined can directly influence when protective measures are activated, how long they remain in place, and whether recovery needs are considered. Yet, with the exception of Kim and Yoo (2023), the included studies rarely addressed heatwaves as multi-day events or incorporated their cumulative burden into intervention design.

Clarifying these aspects is important, because heatwaves are increasingly getting recognized as occupational safety and health hazards requiring urgent and preventive action. The International Labour Organization (ILO) identifies heatwaves' increase in severity and frequency as a major threat to (outdoor) workers' safety and health. Meanwhile the UN Secretary-General's Call to Action on Extreme Heat talks about a growing crisis requiring coordinated, multi-sectoral response (International Labour Organization, 2024; Rakesh et al., 2025). Future research should explore the benefits of considering heatwaves as public health emergencies, alongside investigating the integration of a disaster preparedness approach in mitigating their impacts.

Quality of included records

The included studies concern a small set of interventions and are mostly published in recent years. This suggests that research on interventions targeting outdoor workers exposed to heatwaves is still developing. This is important considering that approximately 2.41 billion workers are exposed to excessive heat globally each year, resulting in more than 22 million heat-related injuries annually (International Labour Organization, 2024). and that a large number of occupational heat-related injuries may be overlooked.

The evidence base presented in this scoping review appears informative but not yet sufficient to address the scale of the problem. Studies are still concentrated on a limited number of countries. Furthermore, evidence appears to have methodological weaknesses: small sample size, short follow-up periods, or lack of real-world implementation. Long-term evaluations and occupational heat-health surveillance are rare, reducing the ability to assess population-level impact. This gap calls for a much stronger integration between climate projections, policy responses and occupational epidemiology (AREO et al., 2025; Dean & McCallum, 2025; Morabito et al., 2025).

Overall, the evidence provided suggests that some interventions can work, but there is far less clarity on where they work best, for which population they are more suitable, under what conditions, and how scalable they are (Levi et al., 2018).

Accountability considerations

The scoping review highlights a lack of clarity regarding who is responsible for action, raising critical questions about which sectors or agencies design, implement, monitor, and maintain occupational heat mitigation strategies. In the included studies, implementation is often carried out by employers, occupational safety officers, workplace supervisors (Chavez Santos et al., 2022; Fazel et al., 2023; Haynes et al., 2018; Kim & Yoo, 2023; Marquez et al., 2023) or, in fewer cases, state and regional regulatory institutions (Dean & McCallum, 2025; Morabito et al., 2025). By contrast, the health sector, including occupational health physicians and public health officers, was rarely mentioned. The fact that the interventions considered are not exclusively health-related highlights the significant role of the social determinants of health, such as work schedule organisation and workplace characteristics, in mitigating health impacts. However, there remains a scarcity of interventions designed and implemented by public health actors, specifically targeting outdoor workers, and accompanied by a systematic evaluation of their effectiveness (EU-OSHA, 2023; International Labour Organization, 2024; Tustin et al., 2021).

Several barriers and facilitators may influence the willingness of actors in implementing interventions. Employers have immediate control over work organization, task shifting, rest cycles, hydration and access and usage of equipment, but they may face economic disincentives to invest in prevention, especially in sectors heavily dependent on seasonal work, or when there are precarious work conditions and subcontracting (Chicas et al., 2021). Evidence from the US agricultural sector suggests that occupational heat protection measures could affect productivity, earnings, and labour costs, indicating that effective protection requires systemic change beyond the worker and workplace level (Tigchelaar et al., 2020). State and regional authorities can enact policies, issue heat-warnings, and enforce structural regulations, but they lack the resources or the reach to ensure the correct implementation at each worksite.

The health sector may have the ability to bridge prevention measures and public health preparedness, by contributing to the identification of vulnerable workers and the evaluation of interventions through occupational heat-health surveillance (McCarthy et al., 2019; Tustin et al., 2021). The American College of Occupational and Environmental Medicine (ACOEM) guidance highlights that occupational and environmental medicine professionals can protect workers through primary prevention, secondary prevention, and treatment, and can support both workers and employers in sectors where heat exposure occurs (Tustin et al., 2021). Similarly, recent climate related occupational health literature argues that workers protection should intertwine with climate adaptation strategies (Godderis et al., 2026). Overall, these suggestions encourage intersectoral agency and coordination across different bodies to protect workers' health amid climate change, advancing the principle of health-in-all-policies.

This is consistent with recent evidence on heat-related illness prevention in outdoor workers, which stresses that heat-related illness prevention should not be reduced to individual worker behavioural strategies alone (Edgerly et al., 2025).

Recommendations and Future Developments

The findings of this scoping review support a set of recommendations targeting future research, intervention design, and governance of occupational heat protection.

Promote workplace heat protection tools through cross-sectoral collaboration

Worksites should be equipped with evidence-based tools in order to protect outdoor workers during heatwaves. These tools should not be limited to generic recommendations, but they should consist of sector- and context-specific protocols co-created by occupational health agencies, public health institutions, employers, workers, and disaster risk reduction bodies all together. The included studies suggest that interventions of this type are more likely to be effective when they include clear operational thresholds, preventive procedures, and mechanisms for monitoring and evaluation. For instance, McCarthy et al. (2019) described a Heat Stress Awareness Program integrating worker and supervisor training, worksite monitoring, emergency response procedures and medical monitoring (McCarthy et al., 2019). Standardized tools should include adaptable components allowing the workplace to choose the most appropriate set of measures according to their needs.

Expand participatory approaches with peer-to-peer support systems

Participatory processes should be heavily promoted as one of the key pillars of occupational heat protection, rather than being seen as optional in favour of technically oriented interventions. In the reviewed literature, two mechanisms appeared to be particularly effective. First, knowledge brokers can help in bridging the gap between the research evidence and routine workplace practices, by adapting resources to local constraints and needs, and by building the trust necessary for behavioural and organizational change (Haynes et al., 2018). Second, peer-to-peer support systems, such as the “buddy system”, help workers to monitor each other; in his work Idris et al. (2024) presented this type of system as a practical and low-cost mechanism to strengthen heat stress prevention among construction workers (Idris, Markham, Mena, & Perkison, 2024).

These two approaches are complementary and can strengthen the reach and the feasibility of interventions in sectors characterized by language barriers and precarious work practices (Chavez Santos et al., 2022; Chicas et al., 2021b; Marquez et al., 2023). Workers' participation needs to be considered a key pillar of this process, because even the most appropriate set of interventions may fail if they are not accepted by the people who will use them.

Investments in education and training as a condition for all interventions

Education and training should not be treated as a standalone category but rather a mandatory condition that enables all the other protective measures; training is necessary for all the actors involved in order to recognize early symptoms and use appropriately all the tools available. Culturally tailored means of communication and education are particularly useful; in their works Marquez et al (2023) found out that tailored communication significantly improved the heat knowledge and education among the Hispanic working population in the USA over the course of a summer season. Future training sessions should become participatory, culturally and linguistically tailored and intertwined within a much broader heat management system. This is especially meaningful in sectors employing migrant or seasonal workers, where language barriers and fear of income loss may reduce the effectiveness of safety communication. Training should also target and involve supervisor and crew leaders, because their role is usually to translate the formal protocols into the daily working routines.

Heatwaves as discrete events

Heatwaves should be seen as time-limited, usually predictable, discrete events; occupational heat protection should include escalation protocols that can be activated during high-risk periods. Measures should include seasonal temperature measuring, defining clear triggers for exceptional rest breaks, temporary reorganization of work schedule and structure, and the dissemination of post-event recovery assessments. If feasible, thresholds should rely more on worksite-level data, rather than municipality temperatures, because these may be underestimating the microclimatic conditions experienced by outdoor workers (Kim & Yoo, 2023; Perkins et al., 2012; Perkins & Alexander, 2013; Romanello et al., 2024; World Health Organization, & World Meteorological Organization., 2025).

Economic support measures

A final recommendation concerns the economic dimensions that determine if a protective measure can actually be implemented or not. Heat protection measures usually require the worker to slow down, take additional breaks or stop working during peak hours; however, these actions can create productivity loss for both employers and workers. This creates a structural disruption in complying with heat protection measures, even if their effectiveness is clear. Evidence from the agricultural sector in the US shows that the piece-rate system actually discourage workers from taking a break or just slowing down their pace, because doing that would directly reduce daily earnings (Chicas et al., 2021b; Tigchelaar et al., 2020).

Notably, however, occupational heat stress generates substantial economic costs through productivity losses, medical costs, income loss, and injury compensation (Borg et al., 2021; International Labour Organization, 2019, 2024, 2024). Therefore, future policies should explore state-level economic support mechanisms that could protect both workers and employers during extreme heat. This suggestion is similar to current agricultural disaster relief funds and compensation schemes for emergency work restrictions. Introducing these types of mechanisms would reduce the need for employees to work in unsafe conditions. Additionally, it would make it easier for both workers and employers to adopt heat protection measures without fearing financial losses.

Conclusion

This scoping review aimed to map the existing literature on health protection strategies for outdoor workers exposed to heatwaves and extreme heat, with a particular focus on the types of intervention implemented, their effectiveness, and feasibility across various contexts. The findings show that occupational heat protection is addressed through a heterogeneous set of strategies, ranging from education and awareness raising to cooling garments, hydration practises, behavioural strategies, and policy or protocol-based solutions. This kind of diversity confirms that heat-related occupational risks cannot be reduced to a single technical or behavioural problem. Rather, they should be understood as a multidimensional occupational and public health challenge, that requires coordinated action across workplace, health, regulatory and community levels. Overall, the included studies suggest that several interventions can contribute to reducing heat-related risk among outdoor workers, but effectiveness alone is not sufficient to determine their value. Feasibility, sustainability, scalability, and contextual implementation remain the central unresolved issues.

References

AREO, I. O., Ashikodi, M. O., Mupenzi, C., & Ediagbonya, T. F. (2025). Climate induced thermal stress in the workplace and its implications for health risks adaptation and policy responses. *Discover Public Health*, *22*(1), 819. https://doi.org/10.1186/s12982-025-01227-9

Aromataris E, Lockwood C, Porritt K, Pilla B, & Jordan Z. (2024). *JBI Manual for Evidence Synthesis*. https://jbi-global-wiki.refined.site/space/jbi-global-wiki.refined.site

Bodin, T., García-Trabanino, R., Weiss, I., Jarquín, E., Glaser, J., Jakobsson, K., Lucas, R. A. I., Wesseling, C., Hogstedt, C., & Wegman, D. H. (2016). Intervention to reduce heat stress and improve efficiency among sugarcane workers in El Salvador: Phase 1. *Occupational and Environmental Medicine*, *73*(6), 409–416. https://doi.org/10.1136/oemed-2016-103555

Borg, M. A., Xiang, J., Anikeeva, O., Pisaniello, D., Hansen, A., Zander, K., Dear, K., Sim, M. R., & Bi, P. (2021). Occupational heat stress and economic burden: A review of global evidence. *Environmental Research*, *195*, 110781. https://doi.org/10.1016/j.envres.2021.110781

Bouchama, A., Abuyassin, B., Lehe, C., Laitano, O., Jay, O., O’Connor, F. G., & Leon, L. R. (2022). Classic and exertional heatstroke. *Nature Reviews Disease Primers*, *8*(1), 8. https://doi.org/10.1038/s41572-021-00334-6

California Department of Industrial Relations. (2020). *California Code of Regulations, Title 8, Section 3395. Heat Illness Prevention in Outdoor Places of Employment.* https://www.dir.ca.gov/Title8/3395.html

Castillo, F., Mora, A. M., Kayser, G. L., Vanos, J., Hyland, C., Yang, A. R., & Eskenazi, B. (2021). Environmental Health Threats to Latino Migrant Farmworkers. *Annual Review of Public Health*, *42*(Volume 42, 2021), 257–276. https://doi.org/10.1146/annurev-publhealth-012420-105014

Chavez Santos, E., Spector, J. T., Egbert, J., Krenz, J., Sampson, P. D., Palmández, P., Torres, E., Blancas, M., Carmona, J., Jung, J., & Flunker, J. C. (2022). 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*, *22*, 1746. https://doi.org/10.1186/s12889-022-14144-2

Chicas, R., Xiuhtecutli, N., Dickman, N. E., Flocks, J., Scammell, M. K., Steenland, K., Hertzberg, V., & McCauley, L. (2021a). Cooling Interventions Among Agricultural Workers: Qualitative Field-Based Study. *Hispanic Health Care International: The Official Journal of the National Association of Hispanic Nurses*, *19*(3), 174–181. https://doi.org/10.1177/1540415321993429

Chinese Center for Disease Control and Prevention. (2022). *Work in high temperatures and protective measures*. https://en.chinacdc.cn/health_topics/occupational_health_poisons/202207/t20220722_260518.html

Choi, Y., Seo, S., Lee, J., Kim, T. W., & Koo, C. (2024). A machine learning-based forecasting model for personal maximum allowable exposure time under extremely hot environments. *Sustainable Cities and Society*, *101*, 105140. https://doi.org/10.1016/j.scs.2023.105140

Coles, B., Tyrer, F., Hussein, H., Dhalwani, N., & Khunti, K. (2021). Development, content validation, and reliability of the Assessment of Real-World Observational Studies (ArRoWS) critical appraisal tool. *Annals of Epidemiology*, *55*, 57-63.e15. https://doi.org/10.1016/j.annepidem.2020.09.014

Coppola, D. P. (2015). *Introduction to International Disaster Management*. ScienceDirect. http://www.sciencedirect.com:5070/book/monograph/9780128014776/introduction-to-international-disaster-management?utm_source=chatgpt.com

Dean, A., & McCallum, J. (2025). California's Heat Standard And Heat-Related Deaths Among Outdoor Workers. *Health Affairs*, *44*(12), 1490–1496. https://doi.org/10.1377/hlthaff.2025.00096

Del Ferraro, S., Falcone, T., Morabito, M., Messeri, A., Bonafede, M., Marinaccio, A., Gao, C., & Molinaro, V. (2021). Cooling garments against environmental heat conditions in occupational fields: Measurements of the effect of a ventilation jacket on the total thermal insulation. *International Journal of Industrial Ergonomics*, *86*, 103230. https://doi.org/10.1016/j.ergon.2021.103230

Dillane, D., & Balanay, J. A. G. (2020). Comparison between OSHA-NIOSH Heat Safety Tool app and WBGT monitor to assess heat stress risk in agriculture. *Journal of Occupational and Environmental Hygiene*, *17*(4), 181–192. https://doi.org/10.1080/15459624.2020.1721512

Ding, R., Wang, Y., Yu, Y., Meng, X., Gong, Q., Tang, Y., Wang, J., Mu, X., Li, H., Zhou, H., Wang, S., & Liu, P. (2025). Effectiveness of a Multifaceted Intervention (TEMP) for Prevention of Occupational Heat-Related Illness among Outdoor Workers in the Power Grid Industry: A Cluster Randomized Controlled Trial. *Environmental Health Perspectives*, *133*(1), 017001. https://doi.org/10.1289/EHP14172

Edgerly, A., Gillespie, G. L., Bhattacharya, A., & Hittle, B. M. (2025). Summarizing Recommendations for the Prevention of Occupational Heat-Related Illness in Outdoor Workers: A Scoping Review. *Workplace Health & Safety*, *73*(2), 63–84. https://doi.org/10.1177/21650799241281998

EU-OSHA. (2023). *Heat at work – Guidance for workplaces | Safety and health at work*. https://osha.europa.eu/en/publications/heat-work-guidance-workplaces

Fazel, S. S., Fenton, S., Braun, N., Forsman-Phillips, L., Linn Holness, D., Kalia, S., Arrandale, V. H., Tenkate, T., & Peters, C. E. (2023). Tailored Sun Safety Messages for Outdoor Workers. *Safety and Health at Work*, *14*(1), 43–49. https://doi.org/10.1016/j.shaw.2023.01.001

Flouris, A. D., Dinas, P. C., Ioannou, L. G., Nybo, L., Havenith, G., Kenny, G. P., & Kjellstrom, T. (2018). Workers' health and productivity under occupational heat strain: A systematic review and meta-analysis. *The Lancet Planetary Health*, *2*(12), e521–e531. https://doi.org/10.1016/S2542-5196(18)30237-7

Friedrich, J., Schick, T. S., Mess, F., & Blaschke, S. (2025). Wearable device-based interventions in heat-exposed outdoor workers—A scoping review and an explanatory intervention model. *BMC Public Health*, *25*(1), 2893. https://doi.org/10.1186/s12889-025-24262-2

Godderis, L., Pronk, A., Straif, K., Viegas, S., Canu, I. G., Burdorf, A., Broberg, K., Albin, M., Scholten, B., Julvez, J., Rivera, M. R., Turner, M. C., & Ghosh, M. (2026). Embedding worker protection in climate action for climate-responsive occupational health. *Journal of Exposure Science & Environmental Epidemiology*, 1–4. https://doi.org/10.1038/s41370-026-00854-x

Gubernot, D. M., Anderson, G. B., & Hunting, K. L. (2015). Characterizing Occupational Heat-Related Mortality in the United States, 2000–2010: An Analysis Using the Census of Fatal Occupational Injuries Database. *American Journal of Industrial Medicine*, *58*(2), 203–211. https://doi.org/10.1002/ajim.22381

Haynes, E., Kramer, D. M., Strahlendorf, P., Holness, D. L., Kushner, R., & Tenkate, T. (2018). A cross-Canada knowledge transfer and exchange workplace intervention targeting the adoption of sun safety programs and practices: Sun Safety at Work Canada. *Safety Science*, *102*, 238–250. https://doi.org/10.1016/j.ssci.2017.10.013

Idris, M. A., Markham, C., Mena, K. D., & Perkison, W. B. (2024). Examining Management and Employees' Perceptions of Occupational Heat Exposure and the Effectiveness of a Heat Stress Prevention Intervention on Safety and Well-Being among Natural Gas Construction Workers: A Qualitative

Field-Based Study. *International Journal of Environmental Research and Public Health*, *21*(9), 1255. https://doi.org/10.3390/ijerph21091255

International Labour Organization. (2019). *Working on a WARMER planet The impact of heat stress on labour productivity and decent work* [Dataset]. https://doi.org/10.1163/9789004322714_cclc_2019-0196-546

International Labour Organization. (2024a). *Ensuring safety and health at work in a changing climate*. https://www.ilo.org/publications/ensuring-safety-and-health-work-changing-climate

International Labour Organization. (2024b). *Heat at work: Implications for safety and health*. https://www.ilo.org/publications/heat-work-implications-safety-and-health

Ioannou, L. G., Tsoutsoubi, L., Samoutis, G., Bogataj, L. K., Kenny, G. P., Nybo, L., Kjellstrom, T., & Flouris, A. D. (2017). Time-motion analysis as a novel approach for evaluating the impact of environmental heat exposure on labor loss in agriculture workers. *Temperature*, *4*(3), 330–340. https://doi.org/10.1080/23328940.2017.1338210

Ishikawa, T., Tamura, H., Ishiguro, H., Yamaguchi, K., & Minami, K. (2010). Effect of Oral Rehydration Solution on Fatigue during Outdoor Work in a Hot Environment: A Randomized Crossover Study. *Journal of Occupational Health*, *52*(4), 209–215. https://doi.org/10.1539/joh.L9156

Jacklitsch, B., Williams, W. J., Musolin, K., Coca, A., Kim, J.-H., & Turner N. (2026). *Criteria for a recommended standard: Occupational exposure to heat and* *hot environments - revised criteria 2016*. https://doi.org/10.26616/NIOSHPUB2016106

Kawakami, R., Hasebe, H., Yamamoto, Y., Yoda, S., Takeuchi, G., Abe, R., Tosaka, Y., & Nomura, Y. (2024). Cooler break areas: Reducing heat stress among construction workers in Japan. *Building and Environment*, *262*, 111821. https://doi.org/10.1016/j.buildenv.2024.111821

Kim, A., & Yoo, G. (2023). Field-based Heatwave Risk Assessment of Outdoor Workers Measured by Wearable Sensors. *Asia-Pacific Journal of Atmospheric Sciences*, *59*(4), 447–458. https://doi.org/10.1007/s13143-023-00326-4

Lee, J., Seo, S., Choi, D., Choi, Y., & Koo, C. (2026). Climate-change adaptation to extreme heat on construction sites: A wearable-free, simplified machine-learning model for predicting workers' heat strain. *Building and Environment*, *289*, 114041. https://doi.org/10.1016/j.buildenv.2025.114041

Lee, S.-W., Kim, I.-G., Kim, H.-M., Lee, D.-G., Lee, H.-C., & Choi, G. (2020). Spatio-temporal patterns of the minimum rest time for outdoor workers exposed to summer heat stress in South Korea. *International Journal of Biometeorology*, *64*(10), 1755–1765. https://doi.org/10.1007/s00484-020-01956-3

Levi, M., Kjellstrom, T., & Baldasseroni, A. (2018). Impact of climate change on occupational health and productivity: A systematic literature review focusing on workplace heat. *La Medicina Del Lavoro*, *109*(3), 163–179. https://doi.org/10.23749/mdl.v109i3.6851

Li, J., Wu, J., & Li, J. (2025). A physio-perceptual thermal strain index for assessing cooling garments and occupational heat exposure limits. *The Journal of The Textile Institute*, *0*(0), 1–14. https://doi.org/10.1080/00405000.2025.2534596

Marquez, D., Krenz, J. E., Chavez Santos, É., Torres, E., Palmández, P., Sampson, P. D., Blancas, M., Carmona, J., & Spector, J. T. (2023). The Effect of Participatory Heat Education on Agricultural Worker Knowledge. *Journal of Agromedicine*, *28*(2), 187–198. https://doi.org/10.1080/1059924X.2022.2058667

McCarthy, R., Shofer, F., & Green Mckenzie, J. (2019). Outcomes of a Heat Stress Awareness Program on Heat-Related Illness in Municipal Outdoor Workers. *Journal of Occupational and Environmental Medicine*, *61*. https://doi.org/10.1097/JOM.0000000000001639

Ministry of Employment and Labor. (2025). *Mandatory 20-Minute Break Every Two Hours During Extreme Heat*. https://www.moel.go.kr/english/news/moelNewsDetail.do?idx=3173

Miura, K., Takagi, K., & Ikematsu, K. (2017). Evaluation of two cooling devices for construction workers by a thermal manikin. *Fashion and Textiles*, *4*(1), 23. https://doi.org/10.1186/s40691-017-0108-y

Morabito, M., Crisci, A., Guerri, G., Bonafede, M., & Marinaccio, A. (2025). Exploring the effectiveness of a heat-related occupational prevention policy: A case study from Italy. *Journal of Exposure Science &*

Environmental Epidemiology, 1–6. https://doi.org/10.1038/s41370-025-00831-w

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Perkins, S. E., & Alexander, L. V. (2013). On the Measurement of Heat Waves. *Journal of Climate*, *26*(13), 4500–4517. https://doi.org/10.1175/JCLI-D-12-00383.1

Perkins, S. E., Alexander, L. V., & Nairn, J. R. (2012). Increasing frequency, intensity and duration of observed global heatwaves and warm spells. *Geophysical Research Letters*, *39*(20). https://doi.org/10.1029/2012GL053361

Perkison, W., Schaefer, C., Roy, R., Green Mckenzie, J., Shofer, F., & McCarthy, R. (2024). Outcomes for a Heat Illness Prevention Program in Outdoor Workers: A Nine-Year Overview. *Journal of Occupational & Environmental Medicine*, *66*. https://doi.org/10.1097/JOM.0000000000003051

Rakesh, A., Sreedharan, R., Shumake-Guillemot, J., Jacob, D., Murray, V., & Ebi, K. (2025). Extreme heat: A global call to action. *Bulletin of the World Health Organization*, *103*(8), 466-466A. https://doi.org/10.2471/BLT.25.293342

Robine, J.-M., Cheung, S. L. K., Roy, S. L., Oyen, H. V., Griffiths, C., Michel, J.-P., & Herrmann, F. R. (2007). Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus. Biologies*, *331*(2), 171–178. https://doi.org/10.1016/j.crvi.2007.12.001

Romanello, M., Walawender, M., Hsu, S.-C., Moskeland, A., Palmeiro-Silva, Y., Scamman, D., Ali, Z., Ameli, N., Angelova, D., Ayeb-Karlsson, S., Basart, S., Beagley, J., Beggs, P. J., Blanco-Villafuerte, L., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J. D., Chicmana-Zapata, V., … Costello, A. (2024). The 2024 report of the Lancet Countdown on health and climate change: Facing record-breaking threats from delayed action. *Lancet (London, England)*, *404*(10465), 1847–1896. https://doi.org/10.1016/S0140-6736(24)01822-1

Roossien, C. C., Hodselmans, A. P., Heus, R., Reneman, M. F., & Verkerke, G. J. (2021). Evaluation of a Wearable Non-Invasive Thermometer for Monitoring Ear Canal Temperature during Physically Demanding (Outdoor) Work. *International Journal of Environmental Research and Public Health*, *18*(9). https://doi.org/10.3390/ijerph18094896

Russo, S., Sillmann, J., & Fischer, E. (2015). Top ten European heatwaves since 1950 and their occurrence in the coming decades. *Environmental Research Letters*, *10*, 124003. https://doi.org/10.1088/1748-9326/10/12/124003

Seichi Horie. (2013). *Prevention of Heat Stress Disorders in the Workplace*. *56*(3), 186–192.

Siegler, J., Butterick, B., Freire, R., Specht, J., & Amorim, F. (2025). Exploring the effects of outdoor physical work in the heat, with or without sodium bicarbonate supplementation, on markers of acute kidney injury.

Physiological Reports, *13*(14), e70472. https://doi.org/10.14814/phy2.70472

Sinclair, WH., & Brownsberger, JC. (2013). *Wearing long pants while working outdoors in the tropics does not yield higher body temperatures Australian and New Zealand Journal of Public Health—Wiley Online Library*. https://onlinelibrary.wiley.com/doi/10.1111/1753-6405.12013

Stott, P. (2016). How climate change affects extreme weather events. *Science*, *352*(6293), 1517–1518. https://doi.org/10.1126/science.aaf7271

Su, Y., Cheng, L., Cai, W., Lee, J. K. W., Zhong, S., Chen, S., Li, T., Huang, X., & Huang, C. (2020). Evaluating the effectiveness of labor protection policy on occupational injuries caused by extreme heat in a large subtropical city of China. *Environmental Research*, *186*, 109532. https://doi.org/10.1016/j.envres.2020.109532

Thompson, L., Sugg, M., & Runkle, J. (2018). Report-back for geo-referenced environmental data: A case study on personal monitoring of temperature in outdoor workers. *Geospatial Health*, *13*(1). https://doi.org/10.4081/gh.2018.629

Tigchelaar, M., Battisti, D. S., & Spector, J. T. (2020). Work adaptations insufficient to address growing heat risk for U.S. agricultural workers. *Environmental Research Letters*, *15*(9), 094035. https://doi.org/10.1088/1748-9326/ab86f4

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., ... Straus, S. E. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, *169*(7), 467–473. https://doi.org/10.7326/M18-0850

Tustin, A., Sayeed, Y., Berenji, M., Fagan, K., McCarthy, R. B., Green-McKenzie, J., McNicholas, J., Onigbogi, C. B., Perkison, W. B., & Butler, J. W. (2021). Prevention of Occupational Heat-Related Illnesses. *Journal of Occupational & Environmental Medicine*, *63*(10), e737–e744. https://doi.org/10.1097/JOM.0000000000002351

UNDRR. (2015, June 29). *Sendai Framework for Disaster Risk Reduction 2015-2030*. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

United States Department of Labor. (2016). *Heat: Standards. Occupational Safety and Health Administration*. https://www.osha.gov/heat-exposure/standards

Wang, L., Chen, Z., Zou, H., Huang, D., Pan, Y., Cheang, C.-F., & Li, J. (2024). A deep learning-based high-temperature overtime working alert system for smart cities with multi-sensor data. *Nondestructive Testing and Evaluation*, *39*(1), 164–184. https://doi.org/10.1080/10589759.2023.2274008

Wegman, D. H., Apelqvist, J., Bottai, M., Ekström, U., García-Trabanino, R., Glaser, J., Hogstedt, C., Jakobsson, K., Jarquín, E., Lucas, R. A., Weiss, I., Wesseling, C., & Bodin, T. (2018). Intervention to diminish dehydration and kidney damage among sugarcane workers. *Scandinavian Journal of Work, Environment & Health*, *44*(1), 16–24. https://doi.org/10.5271/sjweh.3659

WHO. (2008). *Heat-health action plans: Guidance*. https://www.who.int/publications/i/item/9789289071918

WHO & WMO. (2016). *Heatwaves and health: Guidance on warning-system development*. https://www.who.int/publications/m/item/heatwaves-and-health--guidance-on-warning-system-development

World Bank. (2026). *World Bank Country and Lending Groups*. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

World Health Organization, & World Meteorological Organization. (2025). *Climate change and workplace heat stress: Technical report and guidance*. https://www.who.int/publications/i/item/9789240099814

XIANG, J., BI, P., PISANIELLO, D., & HANSEN, A. (2014). Health Impacts of Workplace Heat Exposure: An Epidemiological Review. *Industrial Health*, *52*(2), 91–101. https://doi.org/10.2486/indhealth.2012-0145

Zhao, Y., Yi, W., Chan, A. P. C., & Chan, D. W. M. (2017). Comparison of heat strain recovery in different anti-heat stress clothing ensembles after work to exhaustion. *Journal of Thermal Biology*, *69*, 311–318. https://doi.org/10.1016/j.jtherbio.2017.09.004

Zhao, Y., Yi, W., Chan, A. P. C., & Wong, D. P. (2018). Impacts of cooling intervention on the heat strain attenuation of construction workers. *International Journal of Biometeorology*, *62*(9), 1625–1634. https://doi.org/10.1007/s00484-018-1562-y

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. https://doi.org/10.1093/annweh/wxx055

Appendices

Appendix 1 data extraction table of the included studies

Author	Year	Country	Study type	Target population	Outcome	Rating
Haynes E.	2018	Canada	Qualitative Observational	Electrical utilities and municipal workers	Morbidty: skin cancer incidence and heat stress implication	Moderate +
Wang L	2024	China	Quantitative Observational	Outdoor Cleaning and sanification workers	Morbidity:Heat stress related physiological implication	Moderate +
Choi Y.	2024	South Korea	Quantitative Experimental	Outdoor Construction workers (simulated by healthy male participants)	Morbidity: Heat stress risk (core body temperature heart rate and maximun exposure time)	Good ++
Li J.	2025	China	Quantitative Experimental	General outdoor workers whose work implicates long hours of direct sunlight and high (simulated by healthy male and female participants in a lab setting)	Morbidity: heat related stress, early phisiological and perceptual markers	Good ++
Dean A.	2025	USA	Quantitative Observational	Outdoor workers in the state of California covered by California's heat standard law	Mortality: heat-related death among outdoor workers	Good ++
Lee J	2026	South Korea	Quantitative Observational	Construction workers	Morbidity: observed heat strain and predicted heat strain with temperature threshold	Good ++
Dillane D.	2020	USA	Quantitative Observational	Agricultural workers	Morbidity: Heat strain risk (heat exposure and workload intensity)	Good ++
Zhao Y.	2017	China	Quantitative Experimental	Construction workers (simulated in a temperature controlled chamber by healthy male participants)	Morbidity: physiological and perceptual heat strain	Good ++
Del Ferraro S.	2021	Italy	Quantitative Experimental	Agricultural and construction workers (simulated by a manikin in a controlled temperature chamber	Morbidity: Heat strain mitigation by vesr dry heat loss and total thermal insulation	Good ++
Chicas R.	2021	USA	Qualitative Observational	Agricultural workers	Morbidity: Heat strain and heat exposure with perceived cooling effectiveness	Moderate +
Ishikawa T	2010	Japan	Quantitative Experimental	Airport workers in aircraft ground handling operations	Morbidity: Hydratation levels in hot environment and work related fatigue	Moderate +
Ding R.	2025	China	Quantitative Experimental	Power Grid outdoor workers	Morbidity: incidence (and prevention?) of Occupational heat-related illness such as nausea significantly increased heart rate, and oliguria	Good ++
Zhao Y.	2017	China	Quantitative Experimental	Construction workers (simulated in a temperature controlled chamber by healthy male participants)	Morbidity: physiological and perceptual heat strain such as core temperature, skin temperature, mean body temperature, heart rate	Good ++
Roossien CC.	2021	The Netherlands	Quantitative Experimental	Outdoor workers with phisically demanding tasks such as maintenance workers	Technical and effectivness evaluation fot the device	Good ++
Miura K.	2017	Japan	Quantitative Experimental	Construction workers (simulated by a thermal manikin in a temperature controlled chamber)	heat loss / cooling effect, clothing insulation (clo), duration/endurance of cooling effect	Moderate +
Idris MA.	2024	USA	Qualitative Observational	Natural gas construction workers	perceived effectiveness of the heat stress prevention intervention on worker safety and well-being	Moderate +
Morabito M.	2025	Italy	Quantitative Observational	Outdoor workers with a special focus on agricultural ones	Morbidity: occupational injury rates under high heat-risk conditions / during implementation of the heat-prevention policy	Moderate +
Siegler J	2025	USA	Quantitative Experimental	Construction worker (in a simulated outdoor setting by healthy adults)	Morbidity: Occupational heat related urinary biomarkers of acute kidney injury	Good ++

Author	Year	Country	Study type	Target population	Outcome	Rating
Kim A.	2023	South Korea	Quantitative Observational	(road) Construction workers	Morbidity: high heat strain (HHS) ed extreme heat strain (EHS) base on the worker's heart rate	Poor -
Perkinson WB.	2024	USA	Quantitative Observational	Municipal workers in Streets and Traffic, Parks and Recreation, Utilities, and Solid Waste departments	Morbidity: heat-related illness (HRI) frequency/rate	Moderate +
McCarthy RB.	2019	USA	Quantitative Observational	Municipal workers in Streets and Traffic, Parks and Recreation, Utilities, and Solid Waste departments	Morbidity: heat-related illness (HRI) frequency/rate	Moderate +
Thompson L.	2018	USA	Mixed-methods Observational	Ground maintenance workers	workers' interpretation of personal heat-exposure report-back and intended willingness to modify behaviour to reduce occupational heat exposure	Moderate +
Lee SW	2020	South Korea	Quantitative Observational	Outdoor workers	Morbidity: occurrence of heat-stress conditions associated with occupational heat-related illness in order to establish a spatio-temporal pattern for rest time	Moderate +
Fazel SS.	2023	Canada	Mixed-methods Observational	Landscaping, transportation and municipal workers	creation of evidence-based, expert-approved, and stakeholder-workshopped tailored sun safety messages aimed at reducing occupational solar UVR exposure and preventing skin cancer, eye damage, and heat stress.	Moderate +
Marquez D.	2023	USA	Quantitative Experimental	Agricultural workers	Heat related knowledge	Moderate +
Chavez Santos	2022	USA	Quantitative Experimental	Agricultural workers	Morbidity: physiological heat strain	Good ++
Sinclair WH	2013	Australia	Quantitative Experimental	Regional Council workers	Morbidity: physiological heat strain	Moderate +
Bodin T	2016	El Salvador	Mixed-methods Observational	Agricultural workers	Morbidity: physiological heat strain and self report water intake	Moderate +
Wegman DH	2018	El Salvador	Quantitative Observational	Agricultural workers	Morbidity: Occupational heat stress and kidney functions relations	Good ++
Kawakami R.	2024	Japan	Quantitative Observational	Construction (rebar) workers	Morbidity: physiological heat strain and heat stress	Good ++
Tigchelaar M.	2020	USA	Quantitative Observational	Agricultural workers	Projected heat exposure and heat-related occupational risk	Good ++
Zhao Y.	2018	China	Quantitative Experimental	Construction workers	Morbidity: physiological heat strain	Good ++

Leicester Real World Evidence Unit

Assessment of Real World Observational Studies (ArRoWS)

Author (date):
Journal:
Title:

OVERALL RATING: Good / Moderate / Poor

1. Research question/objective(s)

Is the research question or objective(s) clear?

□ Good ++ □ Moderate + □ Poor -

Consider

Clinical importance of the question

2. Representativeness

Is the study sample representative of its target population?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

Consider

Whether the target population is clearly defined

Inclusion/exclusion criteria

Data source

Recruitment methods

Response rate

3. Sample size, power and measures of uncertainty

Has a sample size, power calculation or measure of uncertainty (e.g. confidence intervals, standard errors) been provided?

□ Yes ++ □ No - □ Unclear -

4. Exposure measures

Are the exposure measures clearly defined and appropriate?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

Consider

Potential for misclassification of exposure variables

Reliability of variables (e.g. patient-reported)

5. Outcomes

Is/Are the outcome(s) clearly defined and appropriate?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

<u>Consider</u>

Has the outcome been defined? Is there potential for misclassification?
Do the outcomes relate to the research question?
Have the authors justified choice of outcomes?
Could the researchers be missing any important outcomes?

6. Confounders

Are confounders clearly defined and appropriate?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

<u>Consider</u>

Are the confounders defined and identified a priori? Are any key (measurable) confounders missing?
Have the authors attempted to control for confounders in the analysis?

7. Statistical analyses

Are the statistical analyses clearly defined and appropriate?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

<u>Consider</u>

Have baseline characteristics of the study population been described?
Loss to follow up
Missing data
Has a sensitivity analysis been conducted?

8. Limitations

Are the limitations of the study defined and appropriate?

□ Good ++ □ Moderate + □ Poor - □ Unclear -

<u>Consider</u>

Whether all of the limitations have been adequately addressed
Recognition and minimisation of potential sources of bias
Limits for inferences based on observational data

9. Conclusions

Have the authors drawn appropriate conclusions from their results?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

Consider
Whether causality is inappropriately inferred from an association
Over-generalisation of results beyond the target population

Additional design-specific questions

Cohort studies

Are the methods of follow up defined and appropriate?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

Is the length of follow up sufficient to ascertain outcomes?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

If the authors are measuring treatment effects, is the analysis appropriate (e.g. matching, instrumental variables)?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

Case-Control Studies

Have the authors explained their choice of cases and controls?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

If a matched case-control study, have the authors described their matching criteria?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

If a matched case-control study, was matching taken into account in the analysis?
□ Good ++ □ Moderate + □ Poor - □ Unclear –

Electronic database studies

Code sets
Have the authors listed/referenced (from previous literature) a code set for relevant tests, procedures, treatments and clinical events (e.g. ICD codes, Read codes)?
□ Good ++ □ Moderate + □ Poor - □ Unclear -

Consider
Whether the authors have cited relevant literature
Whether the authors have presented the sensitivity and specificity of the codes used