International Labour Organization

Heat at work: Implications for safety and health

A global review of the science, policy and practice

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List of abbreviations

AI	Artificial intelligence
BWI	Building and Wood Workers' International
CKDnt	Chronic kidney disease of non-traditional origin
DALY	Disability-adjusted life year
EU	European Union
GDP	Gross domestic product
ILO	International Labour Organization
NGO	Non-governmental organization
OSH	Occupational safety and health
PAF	Population attributable fraction
PPE	Personal protective equipment
WBGT	Wet bulb globe temperature
WHO	World Health Organization

> When heat comes, it’s invisible. It doesn’t bend tree branches or blow hair across your face to let you know it’s arrived. The ground doesn’t shake. It just surrounds you and works on you in ways that you can’t anticipate or control. You sweat. Your heart races. You’re thirsty. Your vision blurs. The sun feels like the barrel of a gun pointed at you. Plants look like they’re crying. Birds vanish from the sky and take refuge in deep shade. Cars are untouchable. Colors fade. The air smells burned. You can imagine fire even before you see it.

▶ **Jeff Goodell,** Author “The Heat Will Kill You First”

Executive summary

The world is warming at a rapid rate. 2023 was the hottest year on record, with July 2023 being the hottest month ever recorded (NASA 2024). These trends have continued into 2024, as May 2024 became the twelfth consecutive hottest month on record (Copernicus 2024).

Climate change is already having serious impacts on the safety and health of workers - higher daily temperatures, and more frequent and severe heatwaves, are now affecting workers in all regions of the globe (Mora et al. 2017). Workers are among those most exposed to temperature extremes, yet frequently have no choice but to continue working despite the huge risks.

Heat stress is an invisible killer. It can immediately impact workers on the job, by leading to illnesses such as heat exhaustion, heatstroke, and even death, as has already been witnessed in many regions of the world. In the longer term, workers are developing serious and debilitating chronic diseases, impacting the cardiovascular and respiratory systems, as well as the kidneys. The mental health impacts must also be considered, as well the numerous accidents and injuries occurring due to reduced cognitive performance, slippery and heated surfaces and unsuitable personal protective equipment (PPE). While workers in all sectors may be adversely affected, some face unique exposure situations placing them at higher risk, including, migrant and informal workers, pregnant women, indoor workers in unventilated environments, and those working outdoors in physically demanding roles.

> While climate-related mitigation efforts will necessitate concerted action over time, workers are being injured and dying now, and therefore heat stress preventative measures should be implemented as a matter of urgency.

The number of workers suffering the consequences of excessive heat is alarming and occupational safety and health (OSH) protections have struggled to keep up. The ILO report, "Ensuring safety and health at work in a changing climate" (ILO 2024), showed that at least 2.41 billion workers – 71 per cent of the working population – are exposed to excessive heat, resulting in 22.85 million injuries and 18,970 deaths annually.

The intensification of excessive heat not only jeopardizes the safety and health of workers, but also undermines the resilience of economies and the potential for decent work on a global scale. While climate-related mitigation efforts will necessitate concerted action over time, workers are being injured and dying now, and therefore heat stress preventative measures should be implemented as a matter of urgency.

What do we know?

This report sought to delve deeper into this growing crisis, to gain an enhanced understanding of the impact of excessive heat on OSH. The main results were as follows:

- Workplace exposures to excessive heat in Africa, the Arab States, and Asia and the Pacific were above the global average (71 per cent) - at 92.9 per cent, 83.6 per cent and 74.7 per cent of the workforce, respectively.
- Europe and Central Asia region had the greatest increase in excessive heat exposure, with a 17.3 per cent increase from 2000 to 2020. This is almost double the global average increase (8.8 per cent from 2000 to 2020).

- The Africa and Americas regions have the greatest proportion of occupational injuries attributable to excessive heat, at 7.2 per cent and 6.7 per cent of all occupational injuries, respectively.
- The Americas, along with the Europe and Central Asia region, were found to have the most rapidly increasing proportion of heat-related occupational injuries since the year 2000, with increases of 33.3 per cent and 16.4 per cent respectively.
- Nine out of ten worker exposures to excessive heat, and eight out of ten occupational injures linked to excessive heat, occur outside of a heatwave.
- Globally, 26.2 million people are living with chronic kidney disease attributable to heat stress at work. The cases attributed to heat exposure at work constitute about 3 per cent of all chronic kidney disease cases, ranging from 3.34 per cent in Africa to 1.8 per cent in the Americas.
- Implementing OSH measures to prevent occupational injuries related to excessive heat could save over US$361 billion globally.

What response measures exist?

In most countries, provisions referring to excessive heat in existing OSH laws are often general and do not adequately address the intensifying climate change-related dangers many workers face daily, however some countries are now revising their laws or developing new specific regulations to address heat. These commonly include maximum temperature limits and guidelines for adaptive measures at the workplace level. In line with the ILO List of Occupational Diseases, a number of countries recognize excessive heat-related diseases as occupational diseases.

An analysis of national legislation to address heat stress from 21 countries across the world showed some common provisions for workplace level measures:

- Participatory risk assessment in the working environment integrating excessive heat.
- Identification of and targeted strategies for worker groups at high risk, including outdoor and indoor workers, those in informal economies and micro, small and medium enterprises (MSMEs), among others.
- Use of the wet bulb globe temperature (WBGT) as a potential heat stress indicator to assess the level of heat exposure, with varying safety thresholds based on work intensity.
- Hydration strategies, including adequate sanitation facilities, especially for female workers.
- Rest, breaks or modified work schedules to limit or avoid exposure to excessive heat, including the ability to self-pace.
- Provision of cool, shaded and ventilated rest areas.
- Heat acclimatization measures for workers without recent heat exposure.
- Personal protective equipment (PPE) designed to protect workers from heat stress.
- Education and awareness on heat stress and heat-related illnesses.
- Regular medical check-ups and health monitoring.

What are the key lessons learned?

1. **Prevention and control strategies for heat stress in the working environment need to be strengthened as a matter of urgency.** Existing strategies to combat heat stress are proving inadequate, especially in the context of rising temperatures and changing weather patterns. Despite the presence of laws and regulations aimed at safeguarding workers from heat stress many of these provisions were established in the past, often with basic requirements that fail to address the complexities of contemporary heat stress challenges.
2. **Heat action plans and public health campaigns should integrate OSH protections.** Workers should be at the heart of heat action plans, early warning systems and other heat related public health efforts. Excessive heat and heatwaves should be treated as OSH hazards. OSH considerations should be incorporated into broader strategies and action on climate change and just transition.
3. **The safety and health of workers should be protected during all periods of excessive heat, not only during heatwaves.** As the majority of worker exposures and injuries linked to excessive heat occur outside heatwaves, protective measures should be applied whenever excessive heat poses a risk to worker safety and health, not just during heatwaves. A rights-based approach for workers is needed, which includes the fundamental right to a safe and healthy working environment, the right to know about heat stress and the right to remove themselves from dangerous situations.
4. **Tailored strategies for different sectors, and both indoor and outdoor workers, should be developed and implemented.** Heat stress disproportionately impacts certain sectors and occupations, which are both in outdoor settings but also indoor, with some in particularly vulnerable situations such as in factories (e.g., female workers in the garment sector). Tailored strategies that are practical and low-cost should be made available for informal and MSME settings.
5. **OSH management systems should integrate heat stress prevention and control measures.** Workplace-level risk assessments and preventive and control strategies should explicitly incorporate heat stress considerations and require direct input from workers.
6. **Workplace protection practices can be simple and affordable.** Scientific evidence has shown that many effective ways to protect workers are inexpensive and easy to implement. These include the provision of adequate hydration; work breaks with cool, shaded and ventilated rest areas; modified work schedules; and heat acclimatization programmes.
7. **Social dialogue must be the foundation for action.** Stakeholders at all levels must prioritize social dialogue as a fundamental component of developing and implementing OSH policies and strategies on heat stress, with workers and their representatives trained and empowered to participate in these processes. A number of critical collective bargaining agreements have been adopted to address specific conditions for different sectors, detailing procedures and protocols to deal with excessive heat in the workplace.
8. **International, inter-governmental and cross-sector collaboration should be a priority.** Collaboration between governments, employers and workers' organizations, international organizations, OSH networks and non-governmental organizations (NGOs) is essential to share knowledge, resources and best practices addressing workplace heat stress. Policy coherence should be ensured on heat stress-related issues that concern the world of work, especially between Ministries of Labour, Ministries of Health, Ministries of Environment and Ministries of Climate Change, as they begin to become established.
9. **Targeted empirical research and global knowledge exchanges are urgently needed.** There are pressing needs at the national level, including the monitoring and evaluation of policies, and at the workplace place level, to assess the effectiveness of practical and low-cost interventions. Strengthened global collaboration among experts on heat stress and OSH is necessary to avoid ad hoc and isolated assessment methodologies and interventions. Experts can then work together to propose harmonized and evidence-informed heat stress assessment, and intervention models and protocols. Such a coordinated effort will serve to enhance the science-policy interface and recommendations.

Globally

2.41 billion workers

70 per cent of the working population

are exposed to excessive heat

This results in

22.85 million non-fatal injuries

and

18,970 deaths annually

Regions with the **highest** workforce exposure to excessive heat:

Africa
92.9% of the workforce

The Arab States
83.6% of the workforce

Asia and the Pacific
74.7% of the workforce

Regions with the **highest proportion** of occupational injuries attributable to excessive heat:

Africa
7.2% of all occupational injuries

The Americas
6.7% of all occupational injuries

Region with the **most rapidly increasing** workforce exposure to excessive heat since 2000:

Europe and Central Asia
17.3% increase

Regions with the **most rapidly increasing** heat-related occupational injuries since 2000:

The Americas
33.3% increase

Europe and Central Asia
16.4% increase

US$361 billion

could be saved globally

if OSH measures to prevent occupational injuries related to excessive heat were implemented.

9/10

worker exposures to excessive heat occur **outside of a heatwave.**

8/10

occupational injuries linked to excessive heat occur **outside of a heatwave.**

26.2 million

people living with **chronic kidney disease** attributable to heat stress worldwide.

Introduction

The record-breaking trend of rising temperatures seen for much of 2023 has continued into 2024 (Copernicus 2024). As global temperatures continue to soar due to climate change, more frequent and severe heatwaves are predicted, leading to increased mortality, reduced productivity and damage to critical infrastructure (Mora et al. 2017). Countries previously unaccustomed to extreme heat will face unfamiliar threats which they may be ill-equipped to deal with, while conditions in regions already contending with sustained high temperatures will only deteriorate.

Excessive heat poses a significant threat to worker safety, health and well-being, both for indoor and outdoor workers. Already workers in all regions of the world are suffering from serious heat-related health conditions, often with irreversible consequences. This is only going to get worse. Aside from the impacts on individuals, their families and communities, jobs will be threatened, economies will be weakened, and the planet will suffer irreparable harm.

The time to act is now. By the end of this century, it is likely that workers in all regions of the world will face serious and life-changing health risks associated with extreme heat, with the poorest regions affected more than others. While some Member States have already started to adopt new policies to safeguard workers from this evolving hazard, most existing strategies do not properly address the complexities of changing weather patterns and their impacts on the working environment. There is an urgent need for new, evidence-based and comprehensive measures to protect the health and lives of all workers, in all sectors, and in all regions of the world, with the overall goal of advancing social justice and promoting decent work for all.

Aim of the report

This report presents key findings related to excessive heat from both academic and technical sources, as well as data from the ILO, outlining the main occupational safety and health (OSH) challenges and providing evidence-based solutions to address excessive heat at work and create safe and healthy working environments. Its objectives are to:

- Provide a foundational understanding of key concepts and background information related to heat stress and its connection to OSH for the benefit of ILO constituents.
- Explore the extent and trends of the global burden of disease attributed to heat stress.
- Present the key components of both global- and national-level actions concerning heat stress and the essential elements of a workplace-level OSH programme designed to protect the health and well-being of workers.

Structure of the report

Part A: What do we know?

- **Chapter 1. Occupational heat stress -** An overview of how excessive heat at work impacts the safety and health of workers, and a consideration of worker groups in vulnerable situations.
- **Chapter 2. Global burden of disease from excessive heat at work -** The most recent ILO data regarding occupational exposures and health impacts, including injuries and deaths according to region, as well as economic impacts.

Part B: What can we do?

- **Chapter 3. Global and national action on heat stress at work -** The key ILO international labour standards pertaining to heat stress and an analysis of national legislation from 21 countries to identify best practices to protect workers from excessive workplace heat.
- **Chapter 4. Workplace action on heat stress at work -** Workplace heat stress prevention and control practices, with a detailed description of protective measures to be applied according to the "hierarchy of controls".

Part C: Where do we go from here?

- **Chapter 5. Key findings and lessons learned -** An overview of the main conclusions from the report and key takeaways for policymakers, employers and workers going forward.

PART A

What do we know?

1. Heat stress at work

Temperatures are warming and they are affecting everyone, especially workers. Workers in both indoor and outdoor workplaces are among those most at risk from excessive heat, as they are often exposed for longer periods and at greater intensities than the general population. Furthermore, they frequently have no choice but to continue working, even when conditions are dangerous. In recent years, evidence of the negative impacts of excessive heat on the safety and health of workers has become increasingly alarming. Workers have been dying from excessive heat exposure in all regions, even those previously not impacted by this hazard. Many more are sustaining heat-related injuries or developing serious illnesses.

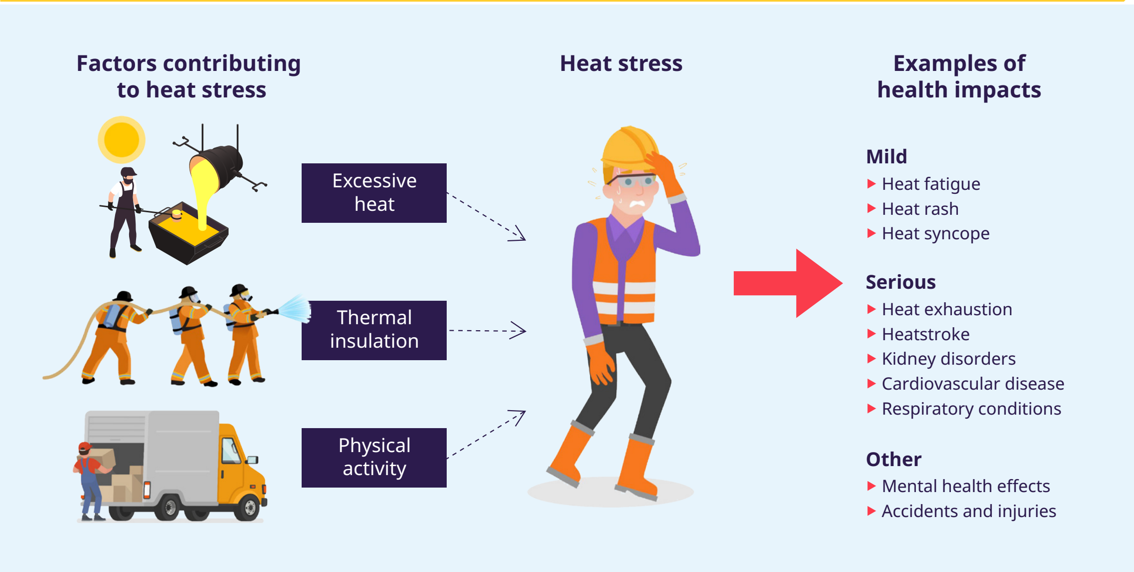
1.1 Excessive heat and heat stress

Maintaining a core body temperature of around 37°C is essential for continued normal body function. Heat-related risks for workers are influenced by the contributions of a number of factors, acting alone or in combination:

1. **Excessive heat -** the combined interaction of increased air temperature/humidity, limited air flow and radiant heat sources (for example, heat-emitting sources and machinery).
2. **Thermal insulation -** the impact of clothing and personal protective equipment (PPE).
3. **Physical activity -** metabolic heat is generated when performing physical tasks.

Workplace heat stress refers to the state in which excess heat is stored in a worker's body, which, if not released to the environment, will raise core body temperature, leading to potential health risks and reduced productivity (Flouris et al. 2018b; Ioannou et al. 2022a). The consequences of heat stress on the human body include, among others, elevated core body and skin temperatures as well as increases in skin blood flow, heart rate and sweat production. If body temperature rises above 38°C, physical and cognitive functions are impaired; if it rises above 40.6°C, the risk of organ damage, loss of consciousness and, ultimately, death increases sharply (Smith et al. 2014). Various adverse health impacts have been associated with heat stress in the workplace, including heat syncope, heat exhaustion and heatstroke (figure 1).

Figure 1. Factors leading to heat stress and examples of resulting health impacts



How do we define heat stress and how is it measured?

A variety of definitions exist for heat stress in academic literature and in national policies. In some cases, heat stress is treated as an exposure and is synonymous with excessive heat. However, the common understanding is that excessive heat is the exposure, which, in combination with other factors (for example, humidity, radiant heat and physical exertion), leads to the risk of heat stress. In this report, excessive heat is treated as the exposure and the risk of heat stress as the intermediary, which in turn causes heat-related illnesses (figure 1).

Most countries use an indicator to assess heat in the working environment. In the majority of cases, this is the **wet bulb globe temperature (WBGT)**, which is also the most well-known and commonly adopted indicator for heat stress used by scientists and OSH professionals (Canadian Centre for Occupational Health and Safety 2005; NATO 2013; NIOSH 2016; ISO 2017; ACGIH 2020; Ioannou et al. 2022b; Ioannou et al. 2022c; Ioannou et al. 2022d). The WBGT considers temperature, humidity, wind speed, and thermal radiation. Moreover, the guidance derived from the WBGT also takes into account work intensity and PPE. The objective of establishing various WBGT thresholds is to keep heat stress within a manageable range that can be sustained over several hours, thus allowing healthy adults to maintain a level of core body temperature increase that is both tolerable and sustainable. A series of large-scale multi-country evaluations of all the available indicators reported that the WBGT is the most effective heat stress indicator for evaluating the risk of heat- related illnesses for people who work in conditions of excessive heat (Flouris et al. 2022; Ioannou et al. 2002b; Ioannou et al. 2002c; Ioannou et al. 2002d).

The **Heat Index** is another indicator used by some countries to evaluate the level of workplace heat stress. In general, there is a good correlation between the Heat Index and the WBGT (Bernard and Iheanacho 2015). In occupational environments, the Heat Index can be easily measured using cost-effective instruments, making it a convenient tool for analysing the risk for heat stress. Nonetheless, its limitations must also be taken into account, including the lack of consideration for radiant heat and airflow and the limited empirical evidence supporting the adjustment of Heat Index thresholds according to work intensity or clothing. A further drawback of the Heat Index is that the guidance it offers for initiating a heat stress prevention programme is not robustly backed by evidence.

Workers in all sectors are susceptible to heat stress, but workers in some sectors may be at particular risk. For example, there is a high incidence of heat-related illnesses and accidents in outdoor workers in occupations that involve work in the sun during the hottest hours of the day, such as in agriculture or construction (Devi 2014; Xiang et al. 2015; Harari Arjona et al. 2016; Beck et al. 2018; Flouris et al. 2019; Piil et al. 2020; Ioannou et al. 2021a).

Heat radiation from the ground or surrounding machinery can also intensify heat exposures. For instance, asphalt surfaces can reach temperatures of over 60°C in the summer when ambient temperatures are 30-35°C (Higashiyama et al. 2016). Steel workers are often exposed to intense radiant heat (Parameswarappa and Narayana 2014), while foundry workers face high heat radiation along with steam and chemical exposures (Safe Work Australia 2013). Workers in mining, stone quarrying, glass production, ceramic production, molten metal operations, laundering of clothes and recreation and sport-related professions are also at high risk (Nag et al. 2009).

Moreover, those working indoors in various occupations can be significantly affected by heat stress, especially in environments where there is limited ventilation, no air conditioning, or where machinery generates additional heat. The move to energy efficient buildings, for example, doesn't always ensure air quality and safe temperatures for workers.

Those working indoors in various occupations can be significantly affected by heat stress, especially in environments where there is limited ventilation, no air conditioning, or where machinery generates additional heat.

The prevalence of heat stress is also high in occupations where workers wear clothing and/or PPE with thermal insulation, which can increase the risk of having higher core body temperature even during low-intensity work. Wearing PPE with thermal insulation and/or low vapour permeability leads to less efficient sweat evaporation (Holmér 1995; Poirier et al. 2015b; Watson et al. 2019; Foster et al. 2022). For instance, some forms of personal protective clothing can cause the body temperature to rise 40 per cent faster (Havenith et al. 2011), resulting in significant risks to OSH.

In addition, workers in occupations involving heavy physical work are particularly vulnerable, as tasks requiring intense physical effort involve high metabolic rates and generate high amounts of metabolic heat. The average metabolic rate for different work intensities is provided in table 1. Those in the most physically demanding occupations include agricultural workers (Ainsworth et al. 2011; Poulianiti et al. 2019), outdoor recreation workers (Uejio et al. 2018; Christman 2023), athletes (Gamage et al. 2020), soldiers (Sawka et al. 2003) and firefighters (Cheung et al. 2016).

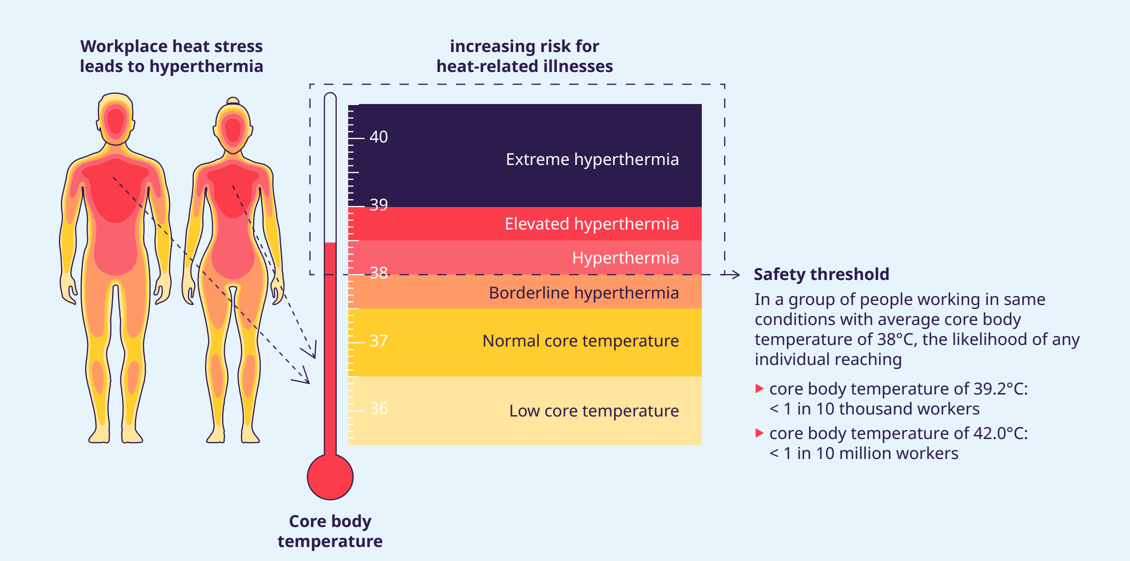
▶ Table 1. Metabolic rate for different work intensities, with associated physical task and occupation examples.

Work intensity	Typical work intensity (W)	Task example	Occupation examples
Rest	100 – 125	Sitting	Office jobs
Light	125 – 235	Sitting, standing, light arm/hand work and occasional walking	Office jobs with more activity, health workers
Moderate	235 – 360	Normal walking, moderate lifting	Low-intensity factory work, retail and restaurant work, garden work
Heavy	360 – 465	Heavy material handling/lifting, walking at a fast pace	Construction, agriculture, warehouse physical work
Very heavy	>465	Pick and shovel work	Physical mining, road maintenance, heavy agricultural or construction work

Source: Recreated based on information from ISO (2017).

Core body temperature should not exceed 38°C for prolonged daily periods, either intermittent or continuous, during manual work (WHO 1969). This long-standing and well-accepted safety threshold was originally introduced in a 1969 World Health Organization (WHO) report (WHO 1969). The rather conservative threshold of 38°C illustrated in figure 2 serves as an early warning, given the difficulty of accurately measuring core body temperature in occupational settings. Previous research has validated the 38°C criterion as a population-based benchmark (Malchaire et al. 2000; Malchaire et al. 2001) and it has been adopted in guidelines and recommendations by many organizations to ensure safe and healthy working environments (Occupational Health and Safety Council of Ontario 2009; NATO 2013; McGregor et al. 2015; Jacklitsch et al. 2016; Flouris et al. 2019; ILO 2019a; Ontario Ministry of Labour, Immigration, Training and Skills Development 2019; Republic of Cyprus Department of Labour Inspection 2020; Gourzoulidis et al. 2023; Hellenic Republic Ministry of Labour and Social Affairs 2023).

▶ Figure 2. The impact of excessive heat on core body temperature - a safety threshold of 38°C serves as an early warning to protect all workers.



Case study. A real-life example of heat balance during work, illustrating the elements of heat stress.[1]

When a female agriculture worker is harvesting crops at a moderate work intensity (for example, picking apples or grapes (Costa et al. 1989; Ioannou et al. 2017; Poulianiti et al. 2019)), her body is generating an enormous amount of heat that must be dissipated to the environment to avoid hyperthermia. If this worker performs an 8-hour shift in the Champagne region, France, while wearing typical clothing during a cool autumn morning, her core body temperature is not expected to surpass the WHO safety threshold of 38°C and she can remain adequately hydrated with a total fluid intake of 1.8 litres during her shift. If this worker performs the same task during midday on a typical summer day, she will still experience core body temperature below 38°C but she will need to drink about 4 litres of fluids per shift to remain hydrated and her total salt loss will be substantial. And if this work is done during a heatwave with air temperature of 40°C, her core body temperature will surpass 38°C within just 35 minutes of work and continue to rise. In this situation, to maintain her core body temperature below 38°C she will be forced to reduce her work intensity markedly and/or take more breaks to avoid dangerous hyperthermia. If she does not, she will reach extreme levels of hyperthermia and would need to drink 9.5 litres of water during her shift to remain hydrated in theory. However, in practice this high water consumption surpasses the ability of her gut to absorb water, making it impossible to remain hydrated.

1 Simulation performed with the FAME Lab Predicted Heat Strain model (Ioannou et al. 2019). Data: height: 170 cm; body mass: 65 kg; metabolic rate: 320 W; clothing worn in autumn: hat, long-sleeve shirt, t-shirt, bra, denim overalls, underwear, socks, shoes; clothing worn in the summer: hat, short-sleeve shirt, bra, denim overalls, underwear, socks, shoes; autumn weather: 18°C air temperature, 40 per cent humidity, 1 m/sec wind speed, 290 W/m^2 solar radiation; summer weather: 30°C air temperature, 60 per cent humidity, 1 m/sec wind speed, 865 W/m^2 solar radiation.

1.2 Impact of heat stress on worker safety and health

Mild effects

- **Heat fatigue** arises because the body diverts a significant amount of blood flow to the skin circulation in an effort to remove heat. This reduces the blood available to support the working muscles, making a given level of physical exertion be perceived as more arduous, causing an earlier onset of fatigue (Flouris and Schlader 2015; Kenny et al. 2018).
- **Miliaria** or **heat rash** or prickly heat is a skin disorder triggered by the blockage of sweat ducts when an individual is exposed to hot and humid conditions. It manifests as red lumps or superficial blisters on the skin. Various dermatoses may occur (Schmitt et al. 2011; Reinau et al. 2013; Trakatelli et al. 2016).
- **Heat syncope** is a heat-related illness characterized by fainting or sudden dizziness. Similarly to heat fatigue, it is caused by the body's response to heat stress, which can cause blood to pool in the extremities, leading to a reduction of blood pressure (Sawka et al. 2003; Schlader et al. 2016; Sawka and O'Connor 2020).
- **Heat cramp** is a type of heat-related muscle spasm or contraction that occurs during or after physical exertion in hot conditions. The cause has not been fully understood to date, but it is often accompanied by dehydration and loss of electrolytes due to excessive sweating (McGregor et al. 2015).
- **Heat oedema** is a disorder affecting the blood vessels that often occurs in response to prolonged exposure to hot and humid conditions. It is characterized by the retention of fluid in the body, resulting in swelling, typically in the hands, ankles and legs (Gauer and Meyers 2019**).**

Serious effects

- **Heat exhaustion** results from cardiovascular strain when the body has to send blood to both the muscles, to produce work, and the skin, to remove heat (Sawka et al. 2011; Kenny et al. 2018; Sawka and O'Connor 2020). When core body temperature rises to 39°C or higher, there is an elevated risk of potential damage to organs (such as the kidneys and liver) and tissues (such as the gut and skeletal muscles) (Sawka et al. 2011; Leon and Bouchama 2015; Leon and Kenefick 2017; Kenny et al. 2018; Sawka and O'Connor 2020).
- **Heatstroke** is a life-threatening condition, characterized by core body temperature often, but not always, greater than 40.5°C with concomitant central nervous system anomalies (for example, confusion, delirium, convulsions, coma) and/or signs of organ system failure, coagulopathy, and systemic inflammatory response syndrome (Sawka et al. 2003; Leon 2008; Sawka et al. 2011; Casa et al. 2015; Leon and Bouchama 2015; Sawka and O'Connor 2020; DeGroot et al. 2022). It is often associated with intense and prolonged physical exertion or work and it is typically identified in apparently healthy individuals, including workers, military personnel and athletes (McGregor et al. 2015).
- **Fluid/electrolyte disorders** can range in severity from mild to severe. Individuals who lose more than 1 per cent of their body mass within a few hours are considered to be hypohydrated, meaning that they have lost a significant amount of body water (Cheuvront and Kenefick 2016). Up to 70 per cent of manual labourers arrive at work in a hypohydrated state, and a similar proportion finish their work in this condition (Piil et al. 2018).

- **Cardiovascular impacts/disease** may be exacerbated through exposure to excessive heat and may limit the ability of the body to thermoregulate. As the body works to regulate its internal temperature, strain is put on the heart and circulatory system, through increases in heart rate and other factors (WHO 2021).
- **Respiratory impacts/diseases**, such as chronic obstructive pulmonary disorder (COPD), may be aggravated in patients who are exposed to excessive heat. This may be due to excess heat being associated with an increased risk of inflammation in the airways and strain on the cardiovascular system due to the body's attempt to thermoregulate (WHO 2021).
- **Acute/chronic kidney injury** (Menon and Resnick 2002; KDIGO 2012; Glaser et al. 2016; Flouris et al. 2018b; Schlader et al. 2019) can be induced by heat stress in occupational settings. Importantly, an epidemic of chronic kidney disease of non-traditional origin (CKDnt) is affecting workers who engage in physically demanding outdoor work in hot conditions (Chatterjee 2016; Glaser et al. 2016; Flouris et al. 2018b; Johnson et al. 2019; Schlader et al. 2019). Kidney stones (urolithiasis) have also been linked to work in hot environments (Menon and Resnick 2002; KDIGO 2012; Flouris et al. 2018b; Schlader et al. 2019).

▶ Chronic kidney disease of non-traditional origin (CKDnt) in tropical countries

Sugar cane workers in Central America are at greater risk of heat stress, leading to a drastic increase in the risk for CKDnt. The aetiology of CKDnt is currently unknown, however the leading hypothesis suggests that it may be a form of kidney injury related to heat stress in the workplace (Glaser et al. 2016; Flouris et al. 2018b; Schlader et al. 2019; Hansson et al. 2020). Other lines of evidence suggest that heat stress may be only an exacerbating factor, among other factors such as exposure to chemicals and environmental pollutants, socio-economic conditions, genetics, other pathologies that can affect renal function, maternal undernutrition and low birth weight (Herath et al. 2018).

Photo credit: Ed Kashi/Redux. Permission required for reproduction.

- **Mental health** effects arising from excessive heat have been frequently reported. For instance, construction workers report psychological distress caused by working in hot conditions (Jia et al. 2016; Flouris et al. 2019), while firefighters report increased anxiety levels (Smith et al. 1997). A large-scale study of 41,000 workers from various occupations in Thailand reported an 84 per cent increase in the likelihood of experiencing heightened psychological distress when exposed to occupational heat stress compared to non-heat stress conditions (Tawatsupa et al. 2010). Excessive heat can also increase workers' mental workload and reduce their focus and concentration (Hancock and Vasmatzidis 2003). For example, car industry workers have shown cognitive performance impairments and increased levels of stress biomarkers when exposed to heat at work (Vangelova et al. 2002; Mazlomi et al. 2017).

- **Accidents and injuries** are more likely to occur when people are working in hot environments (Yi et al. 2016; Canetti et al. 2022; Karthick et al. 2023). A recent systematic review and meta-analysis of epidemiological evidence based on a total of 22 studies representing almost 22 million occupational injuries showed that the overall risk of occupational injuries increased by 1 per cent for every 1°C increase in temperature above reference values, and by 17.4 per cent during heatwaves (Fatima et al. 2021). When mental performance decreases, workplace accidents can increase (table 2) due to worker irritation, anger, and other emotional states provoked by heat stress (Bates and Schneider, 2008; Sultana et al. 2015). Furthermore, moist hands, hot metal surfaces and equipment, as well as fogged safety glasses, all while rushing to complete tasks, can result in accidents such as slips, falls, collisions with objects and burns (Nunfam et al. 2019; Han et al. 2021). Finally, when PPE is not designed for hot conditions, it further contributes to heat stress. As a result, workers become uncomfortably hot and may wish to remove their PPE or disregard safety protocols, increasing their exposure to accidents and injuries (Lundgren et al. 2013; Rowlinson et al. 2014).

▶ Table 2. Mental health challenges faced by people working in excessive heat.

Mental health challenge caused/amplified by excessive heat	Workplace effect
Mental fatigue	Errors in work output
Distraction from work	Increase in accidents
Increased irritation	More workplace conflicts
Decreased perception level	Limited decision-making ability
Confusion	Inability to make judgements
Emotional stress	Low worker morale
Anxiety	Reduced work performance
Anger	Negative co-worker relations
Depression	Workplace absenteeism
Increased suicide rate	Low worker morale and reduced number of manual labour workers

Developed based on information presented by Karthick et al. (2023).

People working in excessively hot conditions often face other occupational risks from climate change, including ultraviolet radiation, extreme weather events and air pollution, resulting in a more complex and potentially dangerous work environment (ILO 2024). This cocktail of hazards has created serious health risks for 70 per cent of the world's workers (ILO 2024). For example, performing physical work in hot conditions is well-known to cause increases in respiration (Hayashi et al. 2006) even in workers acclimatized to heat (Fujii et al. 2012). Consequently, when combined with exposure to air pollution (Katsouyanni et al. 1993; Rainham and Smoyer-Tomic 2003), harmful chemicals (Gordon 2005; Gordon and Leon 2005; Leon 2008; Weisskopf et al. 2013), metals and/or dusts (such as silica) (Dorevitch and Babin 2001), heat exposure can increase their absorption and the severity of acute or chronic health problems. Additionally, a decrease in urinary output due to heat-induced dehydration can result in chemicals accumulating in soft tissues (Leon 2008). These chemical agents may also impair the body's ability to regulate its temperature, thus diminishing a worker's ability to cope with heat stress (Truchon et al. 2014). For instance, vasoconstricting substances, such as lead and inorganic compounds, can impede the body's ability to release heat to the environment (Vyskocil et al. 2005). Exposure to organophosphorus compounds and carbamates can inhibit acetylcholinesterase, altering physiological responses crucial for thermoregulation, such as skin blood circulation, heart rate, breathing and sweat secretion (Leon 2008). Exposure to pentachlorophenol can lead to increased metabolism, elevated body temperature and excessive sweating (Gordon and Leon 2005). Lastly, more intense heatwaves can destabilize the components of munitions, particularly where explosives are not properly stored (ILO 2023a). Extreme temperatures and humidity can cause munitions to self-ignite, leading to deaths and injuries from explosions.

Surveillance of heat-related illnesses and injuries is not optimal, while morbidity and mortality arising from excessive heat at work is under-reported (Rosenman et al. 2006; Taiwo et al. 2010; Gubernot et al. 2014; Gubernot et al. 2015; Schmeltz et al. 2015; Sabrin et al. 2021). Diagnosing heat-related illnesses in the workplace can be challenging due to reasons such as the resemblance in clinical presentation and underlying mechanisms between illnesses arising from occupational and non-occupational exposures, the time lag that sometimes occurs between heat exposures and the appearance of symptoms, the complex and multifaceted origins of many heat-related illnesses, and the potential lack of communication regarding work-related hazards between doctors and patients (Taiwo et al. 2010; Gubernot et al. 2014). These factors, alongside a lack of awareness on the part of both workers and healthcare providers, are likely to contribute to the under-reporting and under-diagnosis of morbidity and mortality arising from heat stress (Rosenman et al. 2006; Gubernot et al. 2015).

▶ The dangers of excessive heat are intimately familiar to delivery workers.

Mail and package delivery workers have experienced first-hand the perils of excessive heat. This issue is alarmingly common, with multiple records showing workers becoming seriously ill or dying from severe heat-related illnesses (Tannis 2020; Noor 2023). These workers face challenging conditions including hot weather, labouring in confined spaces that trap heat and often lack air conditioning, generating metabolic heat through activities such as walking and lifting packages, and limited access to restrooms which can often lead to hypohydration. During heatwaves, young workers in their 20s have reported feeling ill while delivering mail and packages, unable to drive themselves home, and having to recuperate for hours in customers' homes or offices where they seek refuge, then requiring weeks to recover (Noor 2023).

Harvesting hazard: the impact of extreme temperatures on European vineyard workers.

Vineyard workers in Europe (Ioannou et al. 2017; Grimbuhler and Viel 2021; EEA 2022) and elsewhere (Wagoner et al. 2020) are already being affected by heatwaves. A number of deaths of grape harvesters have been reported during intense heat, many of which involve workers in their early 20s (Jackson and Rosenberg 2010; Pianigiani 2017; Mobley 2021; EEA 2022; Camut 2023). At summer's end each year, millions of seasonal labourers move to wine-producing regions to harvest grapes. Without enough time to get acclimatized to the environmental conditions and the job requirements, these workers must also often endure long shifts, which have been shown to cause cardiac strain among grape harvesters (Grimbuhler and Viel 2021). In addition, these seasonal workers are frequently assigned with the heaviest physical tasks, such as lifting and carrying (Ioannou et al. 2023). Combined with the high environmental heat, the limited access to restrooms which can often lead to hypohydration and the often exploitative nature of the informal sector which necessitates over-working to make ends meet, these conditions increase the risk of severe heat-related illnesses.

1.3 Worker groups in vulnerable situations

Heat-related health risks disproportionately impact workers in precarious situations who have a lower capacity to adapt, making them more susceptible to heat-related illnesses. There are a number of factors that make an individual more prone to experiencing serious or severe heat-related illnesses and accidents (Sawka et al. 2003; Sawka et al. 2011; Leon and Bouchama 2015; Kenny et al. 2016a; Flouris et al. 2018a; Notley 2019a; Sawka and O'Connor 2020) (table 3). It is important to note that these illnesses can arise even in individuals deemed low-risk (such as young, fit adults with no history of heat-related illnesses) who follow effective heat prevention strategies. For instance, engaging in consecutive days of intense labour in conditions of excessive heat can undermine an individual's ability to release heat from their body to the environment, even if they are heat-acclimatized (Notley 2018a; Notley 2018b). Also, the use and abuse of many prescription or recreational drugs can increase metabolism causing increased body heat production, can impair the body's capacity to dissipate heat, and can affect cognitive function and judgement, or have all these effects combined.

Table 3. Factors increasing the risk of serious/severe illnesses during work in excessive heat conditions.

Individual

- Pregnancy
- Disability
- Lack of heat acclimatization
- Low physical fitness
- Hypohydration
- Advanced age
- High body mass index
- Limited work experience

Environmental

- Heavy/impermeable clothing
- Physical work/exercise
- Heatwave
- High temperature
- High relative humidity
- Little air movement
- Sources of radiant heat (sun and/or machinery)

Pharmacological

- Antiepileptic, antipsychotic and neuroleptic drugs, tricyclic antidepressants, amphetamines, cocaine, “ecstasy”
- Anticholinergic substances
- Heart and antihypertensive drugs: (diuretics, nitrites, vasodilators and calcium ion channel blockers)
- Hormones (including insulin)
- Alcohol
- Ergogenic stimulants

Pathological

- Acute illness (e.g., infection with fever or gastroenteritis)
- Diseases of the central nervous system and mental illnesses
- Cardiovascular diseases
- Malignant hyperthermia
- Diabetes mellitus
- Kidney diseases
- Skin rash, sunburn and/or previous burns on large skin areas
- Haemoglobin diseases (sickle cell anaemia)
- Chronic liver diseases
- Chronic respiratory diseases

While workers all over the world may be adversely impacted by excessive heat, some face unique exposure situations, placing them at higher risk:

- **Migrant and informal workers -** These workers are more likely to be employed in physically demanding outdoor jobs in construction and agriculture than native workers (Orrenius and Zavodny 2009; Boschetto et al. 2016; Sterud et al. 2018; Flouris et al. 2019; Messeri et al. 2019; Alahmad et al. 2020; Flouris et al. 2021), but tend to take fewer work breaks, work at a higher work intensity and their clothing is often not adapted to the local conditions (Ioannou et al. 2023). They often lack access to OSH training, are typically unacclimatized to the local environment, and are more frequently employed in manual labour roles involving outdoor work and exposure to environmental hazards (Orrenius and Zavodny 2009; Flouris et al. 2021; Onarheim et al. 2021; Ioannou et al. 2023).
- **Women and pregnant workers -** On average, women have a higher percentage of body fat and lower aerobic fitness than men, both of which increase their risk of having higher core body temperature during physical work in hot conditions (Flouris et al. 2018a; Kazman et al. 2015). In addition, women tend to sweat less than men and therefore have a lower capacity to dissipate heat to the environment, increasing the risk of having higher core body temperature (Gagnon and Kenny 2011; Gagnon and Kenny 2012; Gagnon et al. 2013; Flouris et al. 2018a; D'Souza et al. 2020) and, potentially, heat-related illnesses. Evidence has shown that women are 3.7 times more likely to be heat intolerant than men during physical work (Kazman et al. 2015).

Pregnant workers are particularly vulnerable to heat-related illnesses. This is important since women make up more than 43 per cent of the workforce globally in agriculture (FAO 2011) and this figure reaches 50 per cent in agriculture-intensive countries such as the developing countries in Africa (FAO 2011). In these parts of the world, many women continue to undertake manual work during pregnancy. They perform much of the subsistence farm-work and many strenuous manual tasks, struggling with physical symptoms, long and heavy workloads and limited options for prevention in cases of heat stress (Spencer et al. 2022). Evidence from West Africa (Bonell et al. 2022) and North America (Flocks et al. 2013) has shown that pregnant subsistence farmers are exposed to excessive heat in 20 per cent of their normal work shifts and that they report high rates of heat-related illnesses. Also, pregnant farmers have increased maternal core body temperature, as well as reduced placental blood flow and increased foetal heart rate (Bonell et al. 2022). A recent study of 800 pregnant women in India showed that 47 per cent of them were exposed to excessive heat at work and that this was associated with a higher maternal core body temperature and moderate dehydration (Rekha et al. 2024). More importantly, pregnant women working in heat stress conditions had twice or more the risk of miscarriage, adverse pregnancy and foetal outcomes, as well as adverse outcomes at birth (Rekha et al. 2024).

▶ Informal waste pickers in Brazil

A mapping of climate change impacts in Brazil undertaken by the Women in Informal Employment: Globalizing and Organizing (WIEGO) network documented how waste pickers are impacted by climate change in the workplace. A majority (85 per cent) of waste pickers surveyed had experienced abnormal heat or heatwaves while working. Most waste pickers work in direct exposure to the sun, with those who work indoors still experiencing high temperatures due to poor air circulation. Due to their informal working conditions and socioeconomic status, they may feel pressured to continue working even during very hot conditions in order to collect enough materials to support their survival, risking their safety and health in the process. In this WIEGO study, workers often reported adverse effects such as dehydration, heatstroke and fatigue.

- **Older adult workers -** The ability to perform physical work in a hot environment is significantly reduced in older adults (Ellis 1972; Semenza et al. 1996; Semenza et al. 1999; Kenny et al. 2016a). This is particularly true for those with concurrent conditions including type 2 diabetes (Notley et al. 2019a; Notley et al. 2021), obesity (Bar-Or et al. 1969; Havenith et al. 1998) and cardiovascular disease (Semenza et al. 1996; Semenza et al. 1999; Ishigami et al. 2008), due to the pathophysiology of these conditions as well as the medications taken to address them, which can often affect thermoregulation (Westaway et al. 2015). Also, studies have documented that older workers are more vulnerable to occupational accidents during heatwaves (Xiang et al. 2014; Rameezdeeen and Elmualim 2017), and that the injuries that they sustain in these accidents are often more severe compared to their younger counterparts, reaching more than double the healthcare cost (Rameezdeen and Elmualim 2017). Overall, the human capacity to handle heat stress diminishes with age (Larose et al. 2013a; Larose et al. 2013b; Larose et al. 2013c; Stapleton et al. 2015a; Stapleton et al. 2015b; Kenny et al. 2016b). This thermoregulatory impairment begins as early as 40 years old (Larose et al. 2013b) and by 55 years of age is escalated and increases the risk of hyperthermia when engaging in physical work (Flouris et al. 2018a). Importantly, the risk of having higher core body temperature for older workers is mainly evident during high- or very high-intensity work, while light- or moderate-intensity work seem to be well tolerated (Stapleton et al. 2015a; Stapleton et al. 2015b).
- **Workers with disabilities -** These workers have an increased risk of adverse health impacts as certain physical limitations might affect the body's ability to thermoregulate efficiently. For example, spinal cord injuries can disrupt the normal vasodilation and sweating process, which are crucial for cooling the body (Yamasaki et al. 2001; Tsoutsoubi et al. 2023). In addition, certain disabilities require medications that can impair sweating or affect the cardiovascular system, hindering the body's natural cooling mechanisms (Westaway et al. 2015). Many disabilities are associated with underlying health conditions that can be exacerbated by heat stress, such as cardiovascular disorders or respiratory conditions. Also, workers with disabilities may use adaptive equipment or prosthetics, which can sometimes inhibit heat dissipation or add to thermal load (Ghoseiri et al. 2018). Finally, it is important to note that some disabilities may impact communication or mobility, making it difficult for workers to express discomfort or move to cooler environments.

2. Global burden of disease from excessive heat at work

Summary of key figures

A previous report by the ILO, "**Ensuring safety and health at work in a changing climate**" (ILO 2024), showed that each year 2.41 billion workers are exposed to excessive heat. This equates to more than 70 per cent of all workers globally. The impacts on worker safety and health are alarming. For example, during 2020 alone, excessive heat was linked to 22.85 million injuries and 18,970 deaths.

This report further investigates the global burden, looking at regional differences, the additional dangers faced by workers during heatwave periods and occupational chronic kidney disease attributable to heat stress. The main results were as follows:

1. The Africa, the Arab States, and Asia and the Pacific regions were above the global average of the workforce exposed to excessive heat (71 per cent), at 92.9 per cent, 83.6 per cent and 74.7 per cent respectively.

2. Europe and Central Asia region had the greatest increase in excessive heat exposure, with a 17.3 per cent increase from 2000 to 2020. This is almost double the global average increase (8.8 per cent from 2000 to 2020).

3. The Africa and Americas regions have the greatest proportion of occupational injuries attributable to excessive heat, at 7.2 per cent and 6.7 per cent of all occupational injuries, respectively.

4. The Americas, along with the Europe and Central Asia region, were found to have the most rapidly increasing proportion of heat-related occupational injuries since the year 2000, with increases of 33.3 per cent and 16.4 per cent respectively. This may be due to quickly increasing temperatures in mildly temperate regions, where working populations are largely not acclimated to periods of excessive heat.

5. In 2020, 231 million workers were exposed to excessive heat during a heatwave, which is a 66 per cent increase from 2000 (from 139 million). Therefore, one in ten workers who were exposed to excessive heat in 2020 were exposed during a heatwave, while nine out of ten workers were exposed outside of heatwaves.

6. Heatwaves in 2020 caused more than 4,200 fatal occupational injuries globally. This implies only two in ten injuries attributable to excessive heat actually occurred during heatwave periods, which means that 80 per cent of occupational injures linked to excessive heat occurred during periods outside of heatwaves.

7. The Arab States and Africa regions have the highest proportion of occupational injuries attributable to excessive heat during heatwaves, at 1.7 per cent in both regions. The Americas, along with the Africa region, have seen the most rapidly increasing proportion during heatwaves, with the percentage of heat-related injuries increasing by 142 per cent and 29 per cent respectively since 2000.

8. Globally approximately 26.2 million people are living with chronic kidney disease attributable to heat stress at work.

9. Implementing OSH measures to prevent occupational injuries related to excessive heat could save over US$361 billion globally. In low- and middle-income economies, which are frequently the most impacted by excessive heat, this equates to about 1.5 per cent of the national gross domestic product (GDP).

2.1 Number of workers exposed to excessive heat

To estimate the size of the global labour force that is exposed to excessive heat, an analysis of climate patterns, future temperature forecasts and labour force numbers was performed at a spatial resolution of 0.5°×0.5° (see methodology in Annex I). The analysis estimated the number of person-days of work exposed to excessive heat. These were defined as "a single person exposed during their working day within one year". It was crucial to include the entire labour force in this assessment, capturing all workers across formal and informal sectors, various occupations and economic activities, including the self-employed. The numbers from the year 2020 were compared with those from 2000, focusing on the different regions of the world as defined by the ILO: Africa, the Americas, the Arab States, Asia and the Pacific, and Europe and Central Asia.

In 2020, approximately 881 billion person-days of work, or nearly 71 per cent of the global total, were impacted by excessive heat, marking a 9 per cent rise in the proportion of affected workdays since 2000. There was significant variability between countries and regions, as impacts are predominantly driven by local temperature patterns (table 4). The Africa region had the highest rate of person-days of work affected by excessive heat (about 93 per cent), while Europe and Central Asia had the lowest (under 29 per cent). Workers in Europe and Central Asia, however, faced the biggest increase in excessive heat exposure (17.3 per cent) worldwide over the 20 years from 2000 to 2020. It is also important to note the high prevalence in many low- and lower-middle-income countries, often exceeding 90 per cent, highlighting their vulnerability to excessive heat-related hazards.

Assuming that each worker works every day throughout the year, which is an overestimation, to derive a conservative estimate of the number of exposed workers, the findings suggest that at least 1.8 billion full-time workers were exposed to excessive heat in 2000, and this number rose to 2.41 billion full-time workers in 2020, an increase of 34.7 per cent.

▶ Table 4. Percentage of workers exposed to excessive heat.

Region	Global	Africa	The Americas	The Arab States	Asia and the Pacific	Europe and Central Asia
Percentage of workers exposed to excessive heat in 2020 (%)	71.0	92.9	70.0	83.6	74.7	29.0
Percentage change in exposure from 2000 to 2020 (%)	8.8	2.7	5.4	6.2	6.7	17.3

2.2 Global burden of occupational injuries attributable to excessive heat

Given the projected inevitability of climate change in the coming decades (IPCC 2018; Cissé et al. 2022) and the exposure of an estimated 2.41 billion full-time workers to excessive heat, there is a pressing need to gain an understanding of the associated global morbidity and mortality. This is essential for developing comprehensive strategies to prevent the adverse health impacts of heat exposure, including the number of injuries and deaths caused by heat stress.

The ILO defines occupational injury as "any personal injury, disease, or death resulting from an occupational accident" (ILO 1996). This includes any health-related event occurring as a result of a one-time exposure but excludes occupational illnesses with long latency periods, such as chronic kidney disease, which is analysed separately in Section 2.5.

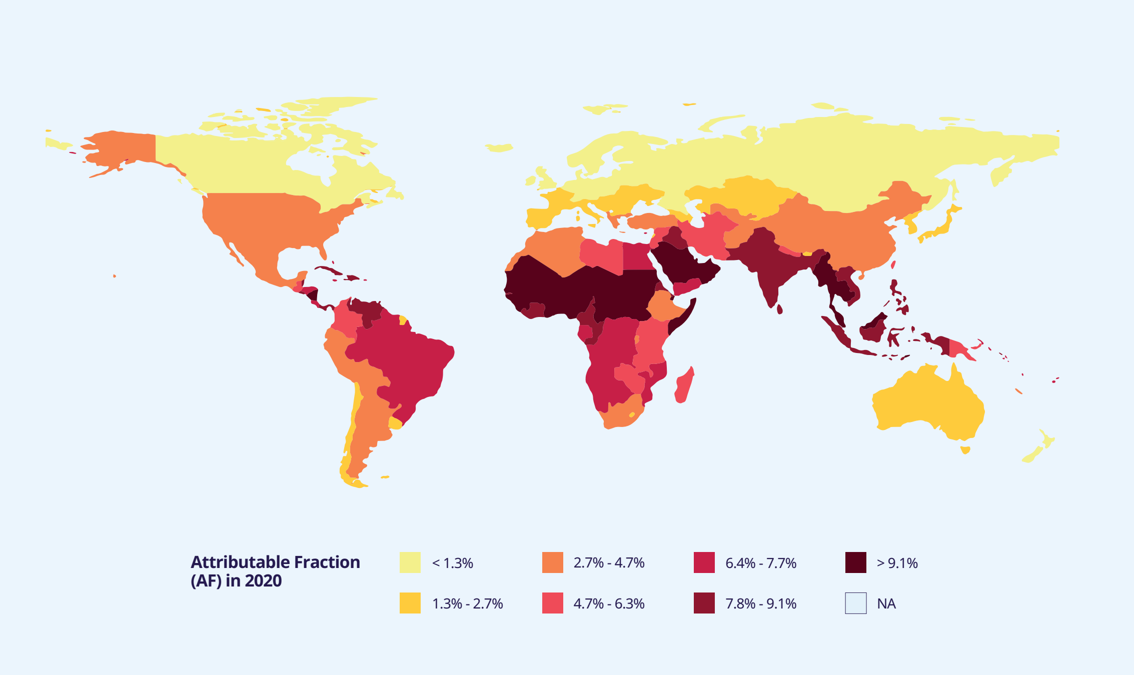
To assess the global, regional, and national burden of occupational injuries and deaths attributed to exposure to excessive heat, the present report combined the estimates of exposed workforce presented in Section 2.1 with occupational injury data and compared the estimates for 2020 with those for 2000 across the five ILO regions: Africa, the Americas, the Arab States, Asia and the Pacific, and Europe and Central Asia (ILO 2023b; ILO 2023c). The findings showed that, in 2020, exposure to excessive heat was linked to an estimated 22.85 million non-fatal occupational injuries, 18,970 deaths, and 2.09 million disability-adjusted life years (DALYs) worldwide. Globally, 6.1 per cent of fatal workplace injuries and 6.3 per cent of DALYs lost could have been avoided if exposure to excessive heat was eliminated. This is comparable to the number of workers who die from drowning (WHO/ILO 2021).

The impact of exposure to excessive heat varied across regions (table 5). In Africa, 7.2 per cent of fatal occupational injuries could have been avoided if exposure to excessive heat was eliminated, compared to 1.7 per cent in Europe and Central Asia. Lower-middle-income economies were disproportionately burdened with occupational injuries attributable to excessive heat, with over 7.8 per cent injuries occurring due to this risk. From 2000 to 2020, there was a 2.9 per cent global increase of fatal occupational injuries that could have been avoided if exposure to excessive heat was eliminated. This increase was highest in the Americas, followed by Europe and Central Asia (33.3 and 16.4 per cent respectively). Figure 3.a illustrates the global prevalence of fatal occupational injuries attributable to excessive heat while figure 3.b shows the percentage change in prevalence between 2000 and 2020.

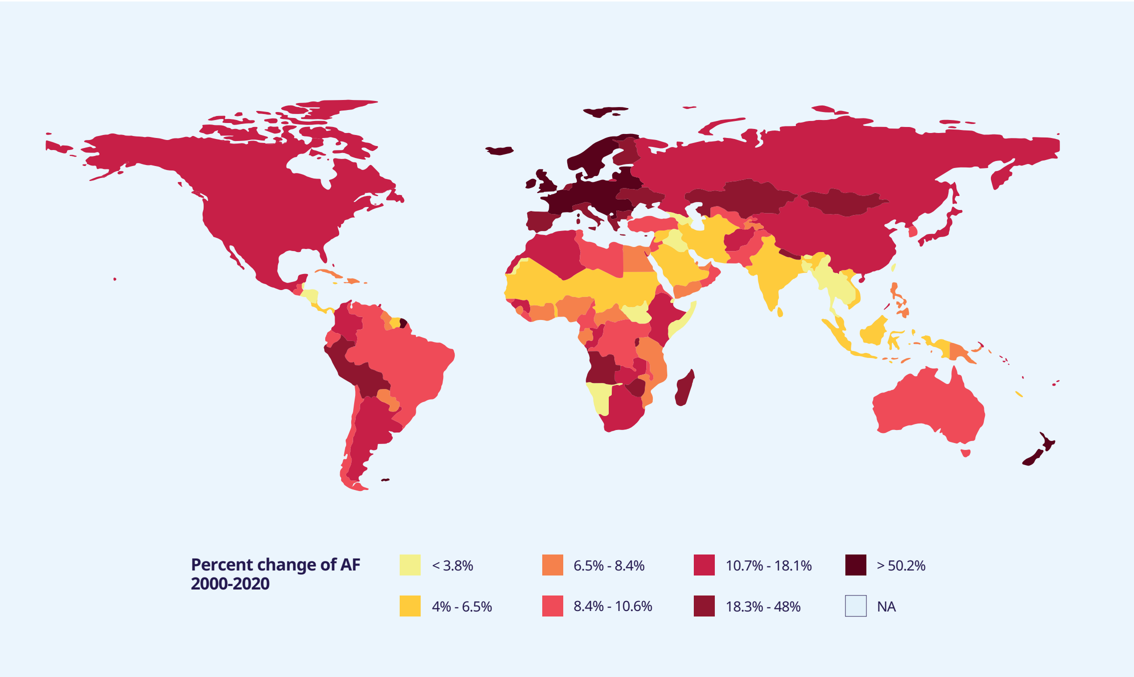
▶ Table 5: Occupational injuries attributable to excessive heat.

Region	Global	Africa	The Americas	The Arab States	Asia and the Pacific	Europe and Central Asia
Number of occupational injuries attributable to excessive heat in 2020	22,852,671	7,454,041	2,801,704	1,771,890	10,548,088	276,930
Percentage of fatal occupational injuries attributable to excessive heat in 2020 (%)	6.1	7.2	6.7	6.4	5.8	1.7

▶ **Figure 3.a. Prevalence of fatal occupational injuries attributable to excessive heat by country in 2020.**



▶ **Figure 3.b. Change in prevalence of fatal occupational injuries attributable to excessive heat in 2020 relative to 2000.**



2.3 Number of workers exposed to excessive heat during heatwaves

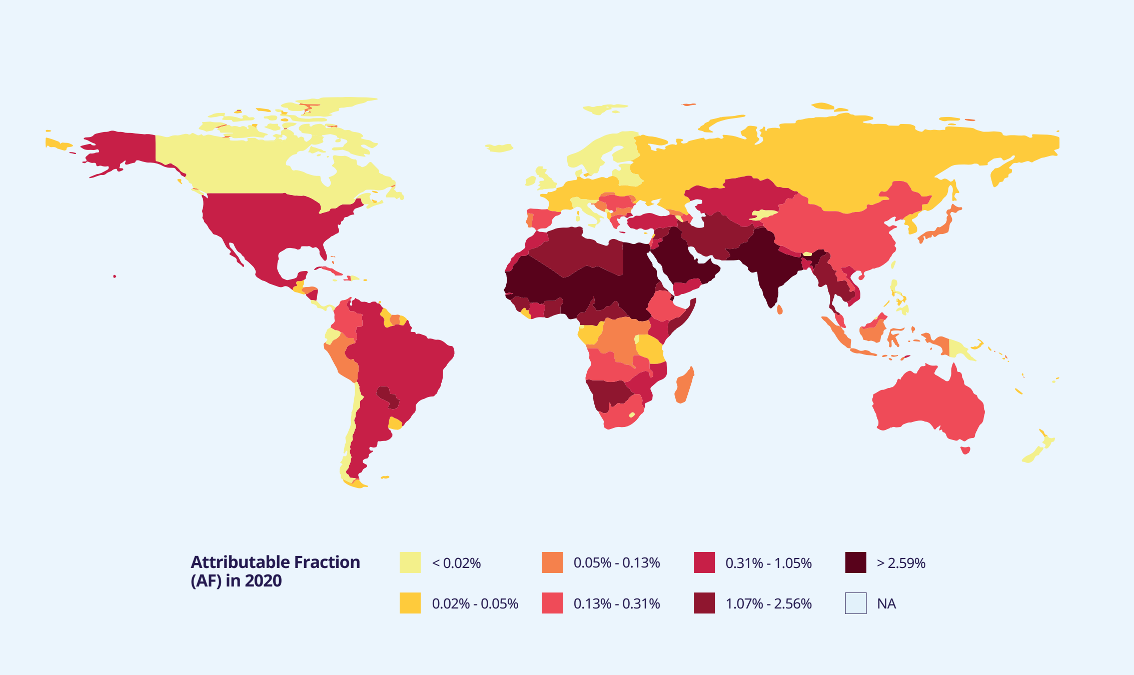
Heatwaves significantly increase global mortality, but estimates of their impact vary based on how heatwaves are defined (Xu et al. 2016). In epidemiological studies, heatwaves have previously been characterized as extended periods of hot temperatures, typically defined as three or more days with temperatures exceeding 35°C. Based on this definition it was estimated that in 2020, there were 84 billion person-days of work exposed to excessive heat during heatwaves, accounting for 9.6 per cent of all exposed person-days of work, a 23 per cent increase since 2000. This translates to about 231 million full time workers in 2020, which is a 66 per cent increase since 2000 (from 139 million). Compared to overall exposure to excessive heat, about 10 per cent of cases occurred during heatwaves specifically, marking a 23 per cent increase since 2000. In the Arab States, over 38 per cent of excessive heat exposure occurred during heatwaves, followed by Africa at 11.3 per cent. Meanwhile Europe and Central Asia (78.6 per cent) and the Americas (78.5 per cent) experienced the fastest increases in exposure to excessive heat during heatwaves. The slowest increase was seen in the Asia and the Pacific region (22.4 per cent).

2.4 Global burden of occupational injuries attributable to excessive heat during heatwaves

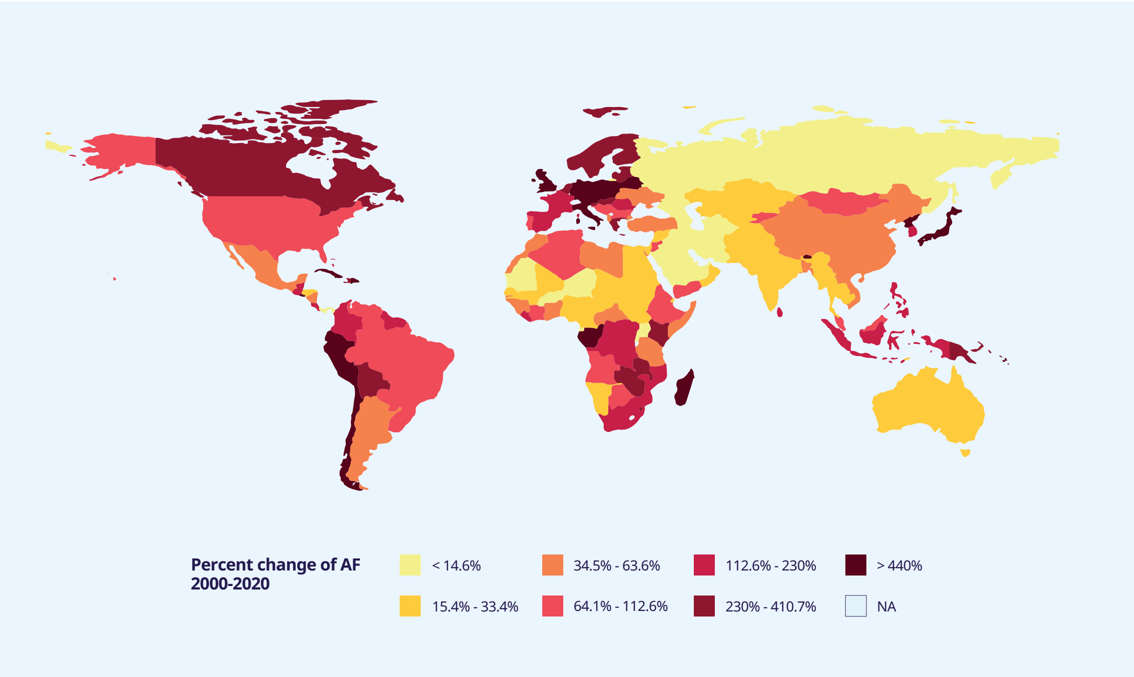
A significant proportion of occupational injuries, deaths, and DALYs caused by exposure to excessive heat occurs during heatwaves. For example, in 2020, heatwaves were responsible for 5.1 million injuries, more than 4,200 deaths, and significant health impacts indicated by 0.5 million DALYs. This represents 22.1 per cent of all occupational injuries attributable to exposure to excessive heat. Considering that approximately 10 per cent of excessive heat exposure accounts for this burden, the risk of occupational injury on a heatwave day is over 230 per cent higher compared to a regular hot day. Globally, 1.4 per cent of fatal workplace injuries and 1.9 per cent of DALYs lost could be avoided if exposure to excessive heat during heatwaves was eliminated. Over 22.1 per cent of the excessive heat-related occupational injuries are avoidable by eliminating the health burden of heatwaves specifically.

Over the 20 years from 2000 to 2020, both the number of deaths and the health impact of exposure to excessive heat during heatwaves increased by 10.4 per cent. The impact of exposure to excessive heat during heatwaves showed significant geospatial variation, as illustrated in Figures 4.a and 4.b. The Arab States and Africa regions have the highest proportion of occupational injuries attributable to excessive heat during heatwaves, at 1.7 per cent in both regions. Some regions experienced much faster growth. The Americas, along with the Africa region, have seen the most rapidly increasing proportion due to heatwaves, with the percentage of heat-related injuries increasing by 142 per cent and 29 per cent respectively since 2000.

▶ **Figure 4.a. Prevalence of fatal occupational injuries attributable to excessive heat *during heatwaves* in 2020.**



▶ **Figure 4.b. Change in prevalence of fatal occupational injuries attributed to excessive heat *during heatwaves* in 2020, compared to 2000.**



2.5 Global burden of chronic kidney disease attributable to heat stress

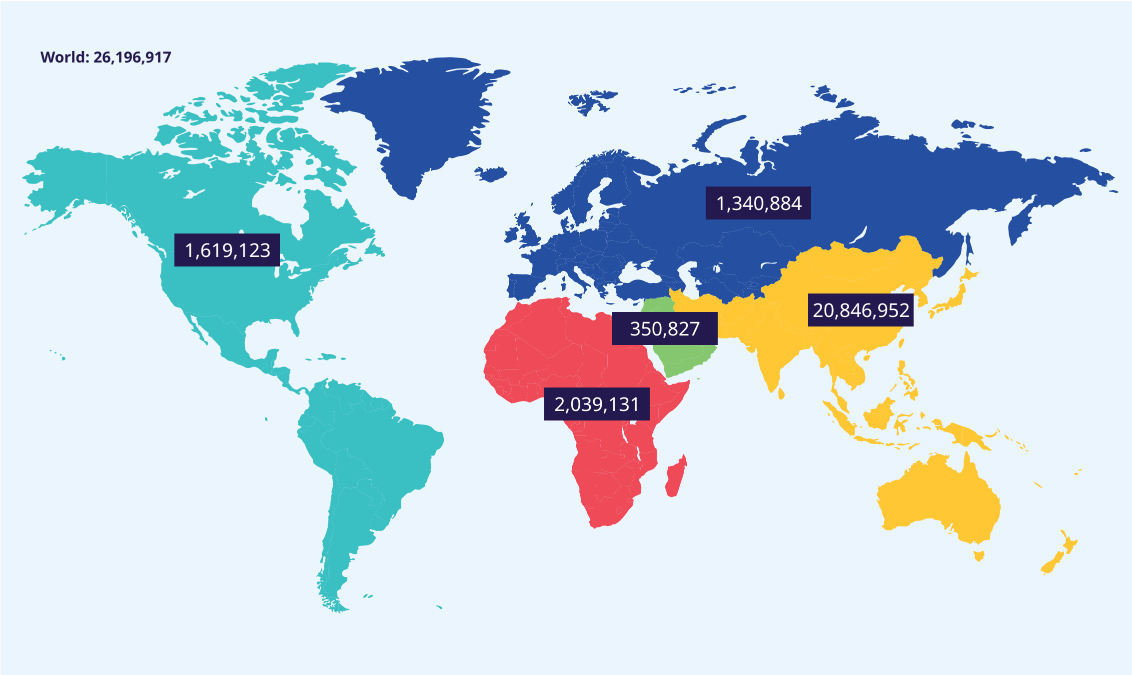
Repeated days of work under heat stress can increase the risk of hyperthermia (Notley 2018a; Notley 2018b), therefore raising the risk of heat-related illnesses. Working under heat stress can also lead to occupational illnesses with long latency periods, such as chronic kidney disease, which is not considered in the global analysis of injuries presented in Section 2.2. Globally, chronic kidney disease affects over 10 per cent of the general population, amounting to more than 800 million people (Kovesdy 2022).

To assess the global, regional and national burden of chronic kidney disease of non-traditional origin (CKDnt) attributed to heat stress, the present report combined global climate models, labour force data and estimates of exposed workforce at a spatial resolution of 0.25°×0.25° (see methodology in Annex I) across the five ILO regions: Africa, the Americas, the Arab States, Asia and the Pacific, and Europe and Central Asia. The analysis used the "population attributable fraction" (PAF) for CKDnt based on previous meta-analytic evidence encompassing data from nearly 22,000 workers, which showed that 15 per cent of individuals who typically or frequently work in heat stress conditions develop CKDnt (Flouris et al. 2018b). The population attributable fraction is the estimated fraction of all chronic kidney disease cases that would not have occurred if there had been no heat stress exposure.

The analysis showed that, in 2020, there were 26.2 million people living with chronic kidney disease attributable to heat stress worldwide (figure 5), constituting approximately 3 per cent of all chronic kidney disease cases. The regions with the highest percentage of chronic kidney disease cases due to excessive heat were Africa (3.34 per cent) and Asia and the Pacific (3.33 per cent). Conversely, the Americas region accounted for 6 per cent of the cases, however only 1.8 per cent of cases were attributed to excessive heat specifically.

> The analysis showed that, in 2020, there were 26.2 million people living with chronic kidney disease attributable to heat stress worldwide, constituting approximately 3 per cent of all chronic kidney disease cases.

▶ **Figure 5. Number of people living with CKDnt attributable to heat stress in the five ILO regions during the year 2020.**



▶ 2.6 Financial impacts of heat stress at work

Global GDP is generated by the global workforce. If a worker dies or experiences temporary or permanent incapacity for work due to exposure to excessive heat, the potential contribution of that worker to the GDP is lost. Additionally, treating injured workers incurs costs. Combined, these factors account for a loss of over US$361 billion globally. However, at the regional and country level, this ranges in terms of GDP from 0.004 per cent in Europe and Central Asia to 0.1 per cent in Africa, with some countries experiencing national GDP losses exceeding 1.5 per cent. Notably, the largest national cost burden is observed in low- and lower-middle-income economies.[2]

2 The figures in this section describe the economic costs of heat stress related to health loss. The impacts of heat stress on productivity loss are described in the following section.

2.7 Loss of labour and productivity due to heat stress

Working under conditions of heat stress can significantly impair an individual's productivity, with broader implications for national economies and public health (Nybo et al. 2017; Flouris et al. 2018b; Kjellstrom et al. 2018; Flouris et al. 2022). The effects are most marked in countries, industries and individuals reliant on manual labour. Additionally, there are indirect, wider geographic and economic impacts on sectors and regions dependent on stable food prices and other supply chains linked to the productivity of primary industries. These repercussions extend beyond the immediate areas and industries directly affected by heat stress, influencing various interconnected economic and social elements (Flouris et al. 2018b; García-León et al. 2021; Ioannou et al. 2022a; Zhao et al. 2022; Wen et al. 2023).

Importantly, emerging evidence suggests that these effects are much more widespread than previously thought. As an example, it was previously thought that workers' productivity is reduced when the WBGT rises above 28°C (Kjellstrom et al. 2014; Bröde et al. 2018). However, more recent studies performed as part of the HEAT-SHIELD project in both field (Ioannou et al. 2022a) and laboratory (Foster et al. 2021) settings showed that productivity reductions emerge in environments as cool as 16°C WBGT and rise exponentially with every 1°C increase in WBGT (Foster et al. 2021; Ioannou et al. 2022a). This means that there are significant productivity losses in countries that were previously thought to be spared from climate change. It also means that the impacts of heat stress on productivity are not concentrated in only a few countries and are much more widespread. This is in line with the findings presented in Section 2.1, showing that 2.41 billion full-time workers around the world are currently working in heat stress conditions.

We need to redefine how we think about heat. The last ten years have been the hottest on record. It’s not a slow progression into a warmer world. It’s extreme heat spikes. It’s getting hotter faster. We’re in a new climate and we’re not going back to the way it was.

▶ **Jeff Goodell,** Author “The Heat Will Kill You First”

PART B

What can we do?

3. Global and national action on heat stress at work

3.1 Global normative instruments relevant to workplace heat stress

The ILO's fundamental Conventions on OSH, the Occupational Safety and Health Convention, 1981 (No. 155) and the Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187) and their accompanying Recommendations No. 164 and No. 197, include provisions for the development of national OSH policies, systems and programmes as well as measures to be implemented at the workplace level. All ILO Member States, regardless of ratification status, are expected to respect, promote, and realize the principles of these fundamental Conventions, as "a safe and healthy working environment" is recognized as a fundamental principle and right at work. The Occupational Safety and Health Recommendation, 1981 (No. 164), specifically mentions that measures should be taken regarding the "temperature, humidity and movement of air in the workplace" (Article 3(c)).

The Hygiene (Commerce and Offices) Convention, 1964 (No. 120) states that "as comfortable and steady temperature as circumstances permit shall be maintained in all premises used by workers" (Article 10). The Protection of Workers' Health Recommendation, 1953 (No. 97) provides that measures should be taken by employers so that suitable atmospheric conditions are maintained so as to avoid excessive heat or cold (Article 2(d)).

The ILO further has several sectoral instruments which provide guidance in relation to excessive heat at work. The Safety and Health in Agriculture Convention (No. 184) and its Recommendation, 2001 (No. 192) cover OSH measures to be implemented in the agricultural sector. Recommendation No. 192 includes mention of the establishment of a national system of OSH surveillance, including risk assessment, and where appropriate, preventive and control measures in respect to "extreme temperatures" (Paragraph 4(1)(g)). The Safety and Health in Mines Convention (No. 176) and its Recommendation, 1995 (No. 183) provide measures on OSH in mining. Recommendation No. 183 includes "extreme temperatures" (Paragraph 20(h)) as one of the hazards that Article 9 of Convention No. 176 may refer to.

The List of Occupational Diseases Recommendation, 2002 (No. 194) includes in its Annex, under the section on Diseases caused by physical agents, "1.2.6. Diseases caused by exposure to extreme temperatures".

The ILO Ambient factors in the workplace code of practice (ILO 2001) has formed the basis for eliminating or controlling workplace heat stress. Developed through the ILO's tripartite approach, it ensures a balanced representation of the views, needs, and perspectives of the three key stakeholders in the world of work: governments, employers and workers. This code underscores the pivotal roles and responsibilities of competent authorities, employers' obligations, and the duties and rights of workers and others with regard to the prevention of heat-related illnesses and accidents. Specifically, it focuses on establishing legal, administrative and practical procedures and structures for evaluating heat stress, its risks and control strategies. It covers the objectives and processes for recognizing and mitigating or managing excessive heat, monitoring the health of workers and the work environment and providing necessary information and training to the workforce.

ILO Code of practice on ambient factors in the workplace: Chapter 8 Heat and cold: *Excerpt*

The scope of this chapter covers conditions in which temperatures and/or humidity are unusually high, workers are exposed to high radiant heat, or high temperatures and/or humidity occur in combination with protective clothing or high work rate. The chapter outlines assessment, prevention and control, health surveillance and training and information.

8.3.1. Where assessment shows that the workers may be at risk from heat stress, employers should, if practicable, eliminate the need for work in hot conditions or, if elimination is not practicable, take measures to reduce the thermal load from the environment.

8.3.4. Where the assessment shows that health or discomfort conditions arise from increased air temperature, the employer should implement means to reduce air temperature, such as a ventilation system. The design should take into account seasonal and sudden temperature changes in make-up air brought from outside. If the air temperature is below about 36 °C, increasing air movement (for example by fans) will cool the workers; above that temperature it will heat them further.

8.3.6. The air may be cooled by evaporation, for example by water sprays, in addition to or instead of ventilation. The design of such a system should first be checked by a technically competent person to ensure that, in the circumstances of use, the increase in humidity does not counteract the effect of the temperature decrease on the working environment.

8.3.8. Where part of the risk arises from the metabolic heat produced during work, and other methods of eliminating the risk are impracticable, employers should arrange a work-rest cycle for exposed workers, either in the workplace or in a cooler restroom. The rest periods should be as prescribed by the competent authority and/or sufficient to allow the worker to recover (see paragraph 8.2 of the annex). Employers should ensure that appropriate mechanical aids are available to reduce workloads and that tasks performed in hot environments are well designed ergonomically to minimize physical stress.

8.3.9. Where other methods of controlling thermal risk, including a work-rest regime, are not practicable, employers should provide protective clothing. In the selection of such clothing, consideration may be given to the following:

(a) reflective clothing where heat gain is mostly by radiation;

(b) insulated clothing with reflective surfaces during simultaneous exposure to high radiant heat and hot air (allowing freedom of movement to perform tasks);

(c) air-, water- or ice-cooled clothing in other instances and as a possible complement to (a) and (b) above.

8.3.11. For hydration maintenance, employers should make water at low salt concentration or dilute flavoured drinks readily available to workers, and should encourage them to drink at least hourly, by providing a close source or arranging for drinks to be brought to the workers. Drinks at 15 to 20°C are preferable to iced drinks. Alcohol, caffeine, carbonated drinks or drinks with a high salt or sugar content are unsuitable, as are drinking fountains because they are too difficult to drink from in sufficient volume.

8.3.12. Where a residual risk of heat stress remains even after all the control measures have been taken, workers should be adequately supervised so that they can be withdrawn from the hot conditions if symptoms occur. Employers should ensure that first-aid facilities and staff trained in the use of such facilities are available.

▶ 3.2 National policy responses

In many countries, OSH laws and regulations traditionally refer to heat and extreme temperature as a physical hazard, but these provisions are often quite general and inadequate to respond to the challenges of a warming planet. Judiciously, many countries are revising their laws or developing new specific regulations to deal with workplace heat stress, and this section of the report aims to highlight those examples.

A literature review[3] was conducted to identify countries with comprehensive legislation dealing with workplace heat stress. Twenty-one examples of comprehensive national legislation were selected (figure 6) and are presented by region in the following subsections. The key aspects of the twenty-one legislative frameworks analysed are summarized in Section 3.3 to identify best practices as well as the main building blocks for developing effective measures. It is important to note that **this review presents a snapshot of what currently exists and is not exhaustive**.

▶ **Figure 6. Countries included in this review with national legislation aiming to address heat at work across the five ILO regions**

3 The literature review adopted a comprehensive approach to gather, analyse and synthesize information from a variety of sources including internet-based research (i.e. using academic databases, professional websites and search engines), insights from international conferences and information obtained through informal discussions with subject matter experts, professionals in the field, union representatives, policymakers, workers, researchers and other relevant stakeholders.

Africa

Algeria

The Algerian Law No. 83-13 of July 2 1983, relating to accidents at work and occupational diseases, contains provisions that mandate employers to protect workers in conditions like excessive heat. For example, workplaces must have adequate ventilation, cool areas for rest, PPE and a supply of drinking water. Regular risk assessments must also be carried out. Furthermore, the law pays special attention to female workers and workers with special needs. The same provisions encourage maximising the physical and mental well-being of workers to increase their productive and creative abilities. In addition, in 2016, the Algerian Ministry of Labour, Employment and Social Security established an agreement to protect workers from the impacts of excessive heat. Under the agreement, compensation was granted for unemployment caused by extreme temperatures for workers in the construction, public works and irrigation sectors. The compensation was distributed first in the southern states, due to the climatic conditions in these regions, and expanded to the high plateau states in 2017. The Ministry of Labour, Employment and Social Security aims to extend the compensation to all states of the country. It was reported that the number of beneficiaries of this agreement at the national level is about 50,000 workers from the specified sectors.

South Africa

South Africa has implemented the Occupational Health and Safety Act: No. 85 of 1993 to protect its workforce from excessive heat, with a particular focus on those involved in heavy manual labour (Republic of South Africa 1993). The provisions stipulate that employers must take steps to mitigate heat stress if the average hourly WBGT exceeds 30°C (Republic of South Africa 1993). In situations where it is not possible to relocate work to a cooler environment, it is recommended that workers undergo medical assessment by a registered physician to ensure they are fit to work above this threshold. Furthermore workers must be acclimatized to the work environment and should drink at least 600 millilitres of water for every hour of work. The legislation mandates training for workers on how to avoid heatstroke and requires employers to facilitate immediate access to first-aid treatment for any worker who suffers from heatstroke (Republic of South Africa 1993).

The Americas

Brazil

The Brazilian Regulatory Standards regulate and provide guidance on mandatory procedures related to OSH for all Brazilian companies. Regulatory Standard No. 15 (Annex 3) sets workplace exposure tolerance limits based on the WBGT, considering the type of work activity (Federative Republic of Brazil 2019). However, these limits are applied only to calculate the additional hazard pay.

Complete work interruption is a general right set by the Regulatory Standard No. 1, which is complemented by specific provisions from the other Regulatory Standards.

Regulatory Standard No. 9 (Annex 3) sets workplace exposure tolerance limits based on the WBTG that require the adoption of the preventive or corrective measures.

In cases where WBGT exceeds 31.7°C for very low intensity work (100 W), and 20.7°C for very high-intensity work (602 W), the employer must take preventive measures. The preventive measures provided are: providing fresh drinking water (or other suitable replacement fluid) and encouraging its ingestion; planning high intensity work preferably in periods with milder thermal conditions; providing heat-protective clothing when the activity is performed in closed environment or with artificial heat sources.

In cases where WBGT exceeds 33.7°C for very low intensity work (100 W), and 24.7°C for very high-intensity work (606 W), the employer must take corrective measures, aiming at reducing the temperature levels. The corrective measures provided are: adapting work processes or operations; alternating activities with low and high exposure to heat to reduce the overall exposure levels; providing access to a milder environment for breaks and thermal recovery during the outdoor work.

If the employer does not fulfil this duty, or if the preventive and corrective measures adopted are not enough to reduce the heat stress risk, the work should be interrupted.

Complete work interruption is also foreseen if the Ceiling Limits are reached. The Ceiling Limits are used to determine total heat loads where a worker could not achieve thermal balance but might sustain up to a 1 degree Celsius (1°C) rise in body temperature in less than 15 minutes. This provision is set by the Occupational Hygiene Standard NHO-06 (2nd edition - 2017) from FUNDACENTRO, mentioned by the Regulatory Standard No. 9, based on the NIOSH parameters.

Employers are advised to measure WBGT at the workplace during the hottest part of the day using appropriate validated equipment, as well as to perform a risk assessment which should include the control measures adopted to mitigate heat related illnesses.

Chile

Chile's new National OSH Policy 2024-28 includes the implementation of policies aimed at preventing "occupational risks derived from exposure to extreme temperatures". In the context of heat events related to high and extreme temperatures resulting from climate change and the El Niño phenomenon, the Chilean Superintendency of Social Security instructed occupational accidents and diseases insurance organizations to adopt preventive measures against exposure to high temperatures in the workplace (Republic of Chile 2023). Technical assistance from these organizations must include:

1. training for employing entities on the definitions, scope and effects on human health of the different types of heat events that may occur due to high and extremely high temperatures within the framework of meteorological alerts;
2. technical assistance to employers for the preparation and implementation of emergency and contingency plans which include risk assessments for each task and/or job;
3. identification of the main disorders and diseases associated with heat events (heatstroke, heat exhaustion, heat cramps, heat fainting or syncope, heat oedema, heat rash, among others);
4. identification of risk groups or especially vulnerable people and preventive measures to be implemented for their protection;
5. preparation and dissemination of information outlining prevention measures.

In 2020, the Institute of Public Health reviewed the Protocol for Heat Stress Measurement and established a standardized methodology for the use of heat stress monitoring equipment in occupational heat exposure assessment. Also, in December 2023, following the declaration of a preventive early warning for high temperatures by the National Disaster Prevention and Response Service, the Chilean Chamber of Construction launched a risk management protocol for high temperatures with 15 preventive measures, including planning work with greater physical effort for the hours of the day with lower temperatures, the provision of areas protected from direct sun and hydration points for workers, and training to recognize the symptoms of heatstroke (Chilean Chamber of Construction 2023).

Costa Rica

In 2015, the Costa Rican Ministry of Labour and Social Security and Ministry of Health adopted a regulation specifically aimed at protecting outdoor workers from heat stress (Republic of Costa Rica 2015). This law was a response to studies highlighting the prevalence of chronic kidney diseases among farmworkers in Central America. It requires employers to implement several protective measures, including educating their workers on the health effects of heat stress, supplying PPE, allowing time for workers to acclimatize to high temperatures, providing rehydrating drinks and ensuring shaded areas for rest. Additionally, workers are required to be part of a health surveillance programme, which focuses on monitoring kidney health and function. The legislation's approach uses levels of risk for heat-related illnesses based on the Heat Index Score as follows: <91: low risk; 91-102: moderate risk; 103-124: high risk; ≥125 extreme risk. Employers are also allowed to adopt the WBGT index for their heat stress risk assessment.

Mexico

In 2014, Mexico adopted the Federal Regulation of Occupational Health and Safety, which outlines measures for employers to protect employees from heat stress (United Mexican States 2014). Employers are required to identify work areas with hazardous heat conditions and implement appropriate risk reduction strategies. These strategies include placing safety signs to limit access to areas with thermal hazards, executing heat reduction actions when needed and providing workers with PPE. Additionally, the regulation mandates that employers conduct regular medical examinations for their workers, educate them about the dangers of heat stress and provide specialized training for those working in extreme heat conditions. The regulation also explicitly forbids the assignment of pregnant workers to tasks in environments with unsuitable thermal conditions or extreme outdoor conditions that pose significant health hazards (United Mexican States 2014). In addition, the Mexican Government has just updated the standard focused on OSH care for agricultural workers, which now includes measures to prevent agricultural workers from being exposed to environmentally high temperatures, not only those related to mechanical sources[4].

The Arab States

Bahrain

In Bahrain, the Ministry of Labour has established protocols to shield workers from the hazards of excessive heat during the summer months. According to Order No. 3 for 2013 Regulating Working Hours Outdoors, workers are not allowed to work outdoors between 12 p.m. and 4 p.m. from 1 July to 31 August each year (Kingdom of Bahrain 2013a). In addition, employers are required to set a work schedule in accordance with these “prohibited work hours” and place it where all workers can see it and labour inspectors can review it during inspection visits. Workers in oil and gas installations, as well as those in emergency maintenance, are excluded from these rules, but employers must take the necessary precautions to protect them (Kingdom of Bahrain 2013a). Furthermore, employers are mandated to provide the appropriate safety equipment and ensure the safe use and storage of materials, as well as to educate their workforce about the dangers of workplace heat stress (Kingdom of Bahrain 2013b).

Kuwait

In Kuwait, the Public Authority for Manpower has implemented the “midday work ban,” as per Ministerial Decision No. 535 of 2015, to protect workers from severe heat and direct sunlight during the hottest part of the year (State of Kuwait 2015)]. This regulation, effective from 1 June to 31 August annually, forbids all workers, including those in jobs such as street cleaning, construction and delivery, from outdoor labour between 11 a.m. and 4 p.m. However, it does not include a specific heat stress threshold (for example WBGT) and does not cover workers in the country’s oil and gas sectors, or those in closed-in vehicles or structures.

Oman

In Oman, Ministerial Resolution No. 286 of 2008, amended by Resolution No. 322 of 2011, has introduced a “midday work stoppage”. This regulation prohibits outdoor labour, especially in construction, from 12.30 p.m. to 3.30 p.m. during the period from 1 June to 31 August (Sultanate of Oman 2008a; Sultanate of Oman 2008b; ILO 2019b). Again, the legislation does not include a specific heat threshold. The Ministry of Labour directs employers to educate their workers about various occupational risks, including heat stress, and corresponding protective strategies (Sultanate of Oman 2008b; Sultanate of Oman 2012). Additionally, the Ministry of Health has introduced guidelines to prevent heatstroke, emphasizing hydration and the avoidance of prolonged exposure to heat and sun.

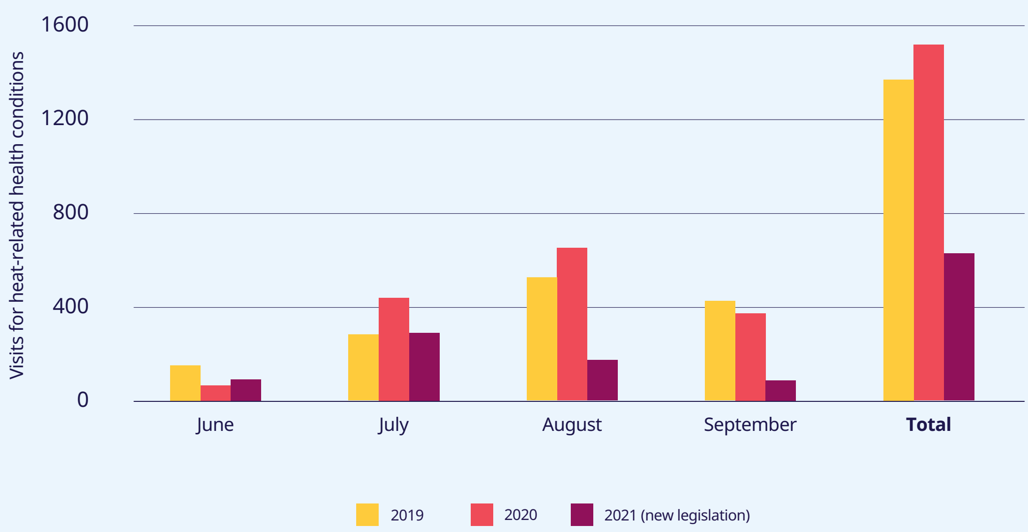
4 NORMA Oficial Mexicana NOM-003-STPS-2023, Actividades agrícolas-Condiciones de seguridad y salud en el trabajo.

Qatar

In 2019, with the support of scientists and the ILO, Qatar's Ministry of Administrative Development, Labour and Social Affairs conducted large-scale research into the exposure of workers to excessive heat (Flouris et al. 2019). The research provided a scientific basis on which to propose amendments to Qatar's previous legislation to further protect workers from heat stress. In 2021, the Government of Qatar announced Ministerial Decision No.17, which replaced previous legislation and introduced additional measures (State of Qatar 2023). The new legislation introduced an expansion of summertime working hours during which outdoor work is prohibited. Under these rules, workers cannot work outside between 10 a.m. and 3:30 p.m. from 1 June to 15 September. In addition, regardless of the time, all work must stop if the WBGT rises above 32.1°C in a particular workplace. Furthermore, it also mandates that employers provide workers with annual health checks, educate them about the dangers of heat stress and provide specialized training for those working in extreme heat conditions. Based on data collected by the Qatar Red Crescent during the first summer after implementation of the new legislation, hospitalizations associated with workplace heat stress in Qatar were reduced by more than half after adoption of Ministerial Decision No.17 (figure 7) (ILO 2021a).

The example from Qatar provides a good practice of evidence-based policy making, leveraging the strength of academic research towards effective legislative measures. Such practices can be replicated on a larger scale. For more information, please see the 2019 ILO report "Assessment of occupational heat strain and mitigation strategies in Qatar".

▶ Figure 7. Total number of initial patient visits to Qatar Red Crescent clinics for heat-related illnesses before (2019 and 2020) and after (2021) the adoption of Ministerial Decision No.17.



The image has been redrawn from data appearing in a previous ILO report (ILO 2021a).

Saudi Arabia

In Saudi Arabia, the Ministry of Human Resources and Social Development has instituted regulations to safeguard workers from excessive heat in the hottest months of the year. Ministerial Decree No. (3337), effective from 15 June to 15 September each year, prohibits outdoor work between 12 p.m. and 3 p.m. (ILO 2021b; Kingdom of Saudi Arabia 2023; Kingdom of Saudi Arabia 2021). The Ministry has also developed a guide with strategies to mitigate heat stress, including breaks, rest areas, hydration every 15 to 20 minutes, working in teams and immediate response to health symptoms. The guide further stresses the need for workers to take breaks and wear light coloured clothing that minimizes heat absorption (Kingdom of Saudi Arabia 2021). The legislation's approach uses levels of risk for heat-related illnesses based on the Heat Index as follows: 25-29°C: low risk; 30-38°C: moderate risk / 25 per cent of work time should be spent on breaks; 39-51°C: high risk / 50 per cent of work time should be spent on breaks; ≥52°C extreme risk / 75 per cent of work time should be spent on breaks. Work should be suspended when the Heat Index reaches 56°C or more. Based on the legislation, employers must provide temperature- and humidity-measuring devices, ensure water availability, adjust work schedules to reduce exposure to excessive heat, create designated rest zones and conduct annual health checks to identify workers at greater risk of heat-related illnesses (Kingdom of Saudi Arabia 2023; Kingdom of Saudi Arabia 2021).

United Arab Emirates

In the United Arab Emirates, the Ministry of Labour has implemented a midday break under Ministerial Decree No. 401 of 2015 (United Arab Emirates 2015). This legislation, aiming to reduce heat stress and prevent heat-related illnesses, prohibits outdoor work from 12.30 p.m. to 3 p.m. from 15 June to 15 September annually (United Arab Emirates 2015). Additionally, the United Arab Emirates Government has launched the "Safety in the Heat" programme in collaboration with the Abu Dhabi Public Health Centre (United Arab Emirates 2023). This programme focuses on educating about 800,000 workers and employers on effective strategies for managing the risks of excessive heat, such as hydration, salt intake, rest breaks, gradual adjustment to heat, reduced work demands and monitoring for at-risk individuals. It also includes training on handling heat-related illnesses (Joubert et al. 2011; Grivna et al. 2012).

Asia and the Pacific

China

China's Administrative Measures on Heatstroke Prevention, issued in 2012, require employers to provide protective measures for outdoor and indoor workers (People's Government of Guangdong Province 2012). These include carrying out health checks on employees working in high temperatures and adapting the work of workers suffering from heart, lung and cerebrovascular diseases, tuberculosis, diseases of the central nervous system and other physical conditions unsuited to a hot working environment. Article 8 lays down more specific provisions for the summer season: "during the period of high temperatures, the employer shall [...] adopt reasonable arrangements for working hours, rotation of operations, appropriate increases in rest periods for workers in high temperature working environments and reductions in work intensity" (EUROGIP 2023). Furthermore, for outdoor work, employers must comply with the following: (1) If the temperature reaches 40°C, outdoor activities must be stopped for the day; (2) If the temperature is between 37°C and 40°C, the employer must ensure that employees do not work outdoors in the open air for more than 6 hours in total in a day and during the 3 hours of the highest temperature period of the day; (3) If the temperature is between 35°C and 37°C, the employer must adopt measures such as rotating shifts to shorten workers' continuous working time (EUROGIP 2023). Furthermore, employers are required to conduct training on heat-related illnesses and provide cooling measures such as rest areas, free cool drinks and air conditioning in indoor workplaces. Workers who suffer from heatstroke and other heat-related complications must be given workers' compensation and, in workplaces that cannot reduce temperatures below certain thresholds, employers must pay high-temperature subsidies to their workers (EUROGIP 2023).

India

In 1950, India issued the Factories Act (No. 63 of 1948) (Republic of India 1948; Republic of India 1950) to safeguard the health and well-being of factory labourers. These provisions require employers to ensure that the wet bulb temperature does not exceed 30°C in factory workrooms. In addition to the above rule for factories, the Indian National Disaster Management Authority, in collaboration with the Ministry of Home Affairs, has published the National Guidelines for Preparation of Action Plan - Prevention and Management of Heatwave to protect the Indian workforce in the face of heat extremes (Republic of India 2019). These guidelines emphasize the importance of: (1) educating workers, (2) ensuring proper hydration, (3) regulating work schedules and (4) providing necessary medical facilities. The same guidelines highlight the importance of acclimatizing workers to high temperatures and the need for employers to provide access to cool drinking water during work, as well as encouraging workers to consume traditional beverages that will help them to stay hydrated throughout their shifts (Republic of India 2019). It is recommended that physically demanding jobs should be rescheduled to cooler times of day, and the frequency and duration of work breaks increased during periods of extreme temperatures (Republic of India 2019). In addition to the above, special attention is given to pregnant workers and workers with underlying medical disorders. Lastly, the same guidelines advise workers to take measures against sun exposure by wearing breathable light-coloured clothing as well as by using hats and/or umbrellas (Republic of India 2019).

Japan

The Japanese Industrial Safety and Health Act mandates that employers should implement the necessary measures to prevent health impairments due to heat stress and recommends regular medical check-ups and environment monitoring during hazardous work operations. In addition, the Ministry of Health, Labour and Welfare has produced the Workplace Heatstroke Prevention Measures Manual (Japan 2021a), a relevant Circular (Japan 2021b) as well as other documents and campaigns (Japan 2023) which include extensive guidance for avoiding heat stress at work. This guidance uses WBGT to provide recommended upper thresholds for different work activities, with very high-intensity work not recommended beyond 25°C, high-intensity work not recommended beyond 26°C, moderate-intensity work not recommended beyond 28°C, low-intensity work not recommended beyond 30°C, and all forms of work being inadvisable beyond 33°C. These values are meant for acclimatized workers, while the respective thresholds for unacclimatized workers are 20, 23, 26, 29 and 32°C WBGT. To complement these measures, the provisions highlight the importance of controlling the workplace environment, shortening work hours during hot periods, ensuring regular hydration and promoting health management (Japan 2021a). In addition, the Climate Change Adaptation Law issues heatstroke alerts based on WBGT forecasts (Japan 2018a). Moreover, guidelines have been developed to address heat-related risks during specific scenarios, such as radioactive clean-up work (Japan 2018b; Japan 2018a).

Singapore

The Singaporean Ministry of Manpower in collaboration with the Ministry of Health has published a comprehensive set of measures designed to safeguard outdoor workers from the adverse impacts of excessive heat. These recently updated provisions (Republic of Singapore 2023a; Republic of Singapore 2023b) are based on a four-point approach: acclimatization, hydration, rest and shade. Specifically, a gradual heat-acclimatization period is essential for workers who are new to Singapore or those who are returning to the country after a long absence. Equally important is the emphasis on hydration: workers are encouraged to drink at least 300 millilitres of water hourly and take regular work breaks in shaded areas (Republic of Singapore 2023a; Republic of Singapore 2023b). When the WBGT exceeds 32°C, people who perform intense manual labour should take a minimum 10-minute break in the shade every hour and when the WBGT reaches or exceeds 33°C, these breaks should be extended to 15 minutes per hour (Republic of Singapore 2023a; Republic of Singapore 2023b). Moreover, workers with underlying health disorders should take extended breaks, tailored to their medical needs. To ensure real-time responsiveness, employers, particularly from the construction sector, shipyards, and the processing industry, are directed to use WBGT meters for hourly temperature monitoring. For broader applicability, other industries can use dedicated mobile applications for the assessment of workplace thermal conditions. To ensure quick identification of any heat-injury symptoms, the use of a buddy system (two or more workers working together) is encouraged (Republic of Singapore 2023a; Republic of Singapore 2023b).

Thailand

The Thai Occupational Standard to protect workers from excessive heat mandates that there should be complete work interruption in cases where the WBGT rises beyond 34°C for low intensity work, 32°C for moderate intensity work, and 30°C for very high intensity work (Kingdom of Thailand 1976; Kingdom of Thailand 2006; Phanprasit et al. 2021). Additionally, the Standard underlines that employers should use engineering controls, such as cooling fans, to reduce the risk of heat stress, post warning notices in excessive heat exposure areas and provide workers with effective PPE. Workers that may be at risk of heat stress should receive health check-ups.

Europe and Central Asia

EU Directive 89/391/EEC (Council of the European Union 1989) mandates the protection of workers' health and safety from all risks, including emerging ones. Nevertheless, the European Union (EU) currently lacks binding legislation specifically safeguarding workers from heat stress. Various EU Member States have independently formulated plans to protect their workforce from excessive heat exposure by providing maximum temperature limits, yet there is considerable variation in the strategies used, even for neighbouring Member States with similar climates and types of industries. The thresholds are determined through a mix of statutory laws, collective bargaining or both (ETUC 2020). For instance, in Germany, the standard workplace temperature is set at 26°C, with mandatory "cool down" measures foreseen when the temperature exceeds 35°C. Hungarian labour laws mandate thresholds of 31°C for light work, 29°C for moderate work, and 27°C for heavy work. In Latvia, the indoor work temperature limit is set at 28°C, while Slovenia has set an air temperature threshold of 28°C for work areas (ETUC 2020; ETUI 2021; ETUC 2022). These variations reflect the diverse approaches within the EU to addressing the challenge of heat stress and ensuring worker safety. The following subsections review some of the most comprehensive national legislation in the region.

Belgium

The Belgian legislation regarding heat stress is the Royal Decree of 4 June 2012 on thermal environmental factors (Kingdom of Belgium 2013). This legislation mandates a risk analysis of technical and environmental thermal factors considering the specific characteristics of the workplace and the nature of the work performed. The risk analysis should not be limited to industrial factors but should also include environmental factors such as heatwaves and sun exposure. Employers are encouraged to determine preventive measures for different types of activities proactively, before the occurrence of extreme weather conditions. Employers are obligated to strive for thermal comfort standards, taking into account technological advancements and available scientific methods. Compliance with the industry standards on thermal comfort (for example ISO 7933 and ISO 9886) is required. The legislation uses the WBGT to determine action values for heat stress, with complete work interruption for non-acclimatized workers foreseen when WBGT rises above 29°C for low-intensity work, 26°C for moderate-intensity work, 22°C for high-intensity work, and 18°C for very high-intensity work (Kingdom of Belgium 2013). Employers are required to have a written strategy detailing the specific measures to be taken in response to heat stress, including measures that are immediately applicable when the above action values are exceeded.

Cyprus

The primary legislative documents that address excessive heat in Cyprus are the Safety and Health at Work (Code of Practice for the Protection of Workers from Heat Stress) Order of 2014 (P.I. 291/2014) and its 2020 amendment (P.I. 206/2020), along with the Minimum Requirements for Safety and Health at the Workplace Regulations of 2002 (P.I. 174/2002 and P.I. 494/2004) (Republic of Cyprus 2020). These regulations apply to employers and self-employed people and include specific requirements for managing heat stress, considering the work/rest cycles and physical effort required. Employers are obligated to take appropriate measures, both organizational and technical, for lowering temperatures to within acceptable limits to ensure that the core body temperature of their workers remains below 38°C. These measures are based on WBGT levels, with complete work interruption for acclimatized workers foreseen when the WBGT rises beyond 32.2°C for low-intensity work, 31.1°C for moderate-intensity work or 30.0°C for high-intensity work. For non-acclimatized workers, these values are reduced by 2.5°C (Republic of Cyprus 2020). Below these levels, the measures also include work-rest cycles for both acclimatized and non-acclimatized workers. Also, employers are advised to monitor weather conditions and adjust work accordingly, while the National Meteorological Service provides WBGT forecasts. Employers are required to document their efforts in monitoring and mitigating heat stress (Republic of Cyprus 2020).

Greece

In the period 2017 - 2023, collaboration between the Ministry of Labour and Social Affairs, workers' and employers' organizations, OSH inspectors, occupational physicians, the Hellenic National Meteorological Service and scientists resulted in the development of an integrated protection framework to protect workers from heat stress (Gourzoulidis et al. 2023). This was based on evidence gathered in the country's workplaces, as well as a synthesis of relevant international evidence (Gourzoulidis et al. 2023). Protective practices included adaptations to work schedules and PPE, technical and organizational measures to limit work stress and considerations for non-acclimatized workers and a range of vulnerable worker groups (Gourzoulidis et al. 2023). Complete work interruption occurs when the WBGT rises above 32.5°C for low-intensity work, 31.5°C for moderate-intensity work, 30.5°C for high-intensity work, and 30°C for very high-intensity work (Gourzoulidis et al. 2023). Below these levels, the measures also include work-rest cycles for both acclimatized and non-acclimatized workers. Employers are advised to measure the WBGT using appropriate validated equipment, while the simplified version of the WBGT (incorporating only air temperature and relative humidity) is suggested as an alternative for micro-businesses that may not be able to purchase sophisticated equipment to perform comprehensive WBGT assessments (Gourzoulidis et al. 2023). A pilot phase of the above-described framework was launched in the summer of 2021 by the Ministry of Labour and Social Affairs along with collaborating partners (workers' and employers' organizations and the FAME Lab) which included adopting the proposed measures, assessing heat stress in small and large worksites and education and training for workers and OSH professionals (Gourzoulidis et al. 2023). In the summer of 2023, Ministerial Decision No. 65581 was adopted to address a specific heatwave which lasted 14 days in July that year (Hellenic Republic 2023). The permanent legal integration of the developed framework is the next crucial step.

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Collaboration between research institutions and the Government in Greece to protect workers from heat stress

The Greek experience serves as a valuable model for other countries and regions facing similar challenges from excessive heat. Expanding this model of collaboration between research institutions, government bodies and other stakeholders can lead to more effective, evidence-based OSH policies globally. It underscores the need for ongoing research, technological innovation and stakeholder engagement in addressing occupational health challenges in the face of climate change and evolving workplace environments. Key points of this model include:

- **Evidence-based approach:** The development of an integrated protection framework based on both national workplace evidence and international studies showcases how research can directly inform policy. This approach ensures that measures are not only theoretically sound, but practically applicable in the specific context of a country's workforce.
- **Technical expertise:** Scientists and occupational physicians provided the technical expertise necessary to understand the physiological impacts of heat stress and to design appropriate prevention strategies. This expertise is crucial in translating complex scientific data into actionable policy measures.
- **Innovative solutions:** The collaboration led to innovative solutions, such as the development of a model by the Hellenic National Meteorological Service to forecast the WBGT across the country. Additionally, the creation of a smartphone application by University of Thessaly scientists for assessing current and future WBGT demonstrates how technology can be deployed to support OSH initiatives.
- **Pilot implementation and validation:** The pilot phase launched as part of the collaboration allowed for real-world testing and validation of the proposed measures. This step is critical in evaluating the effectiveness of policy recommendations and making necessary adjustments before wider implementation.
- **Stakeholder engagement:** Engaging a wide range of stakeholders, including workers, employers and government bodies, ensured that the policies developed were comprehensive and addressed the needs and concerns of all parties involved. This inclusive approach facilitates greater acceptance and adherence to the implemented measures.
- **Education and training:** The emphasis on education and training for workers and OSH professionals about heat stress and the measures to mitigate it highlights the role of knowledge dissemination in policy implementation. Effective training programmes are essential for the successful adoption of safety measures.

Spain

In Spain, Law 31/1995 on Occupational Risk Prevention, together with Royal Decrees 1561/1995 and 486/1997, form the cornerstone of legislation protecting workers from heat stress (Kingdom of Spain 1995; Kingdom of Spain 1997). Key aspects include managing extreme temperatures and humidity, preventing sudden temperature shifts, eliminating drafts, reducing irradiation and curbing solar radiation through transparent surfaces (Kingdom of Spain 1995; Kingdom of Spain 1997). The regulations stipulate that for outdoor work, particularly in areas that cannot be enclosed, employers must implement adequate safeguards to protect workers from adverse weather conditions, including extreme temperatures. This includes suspending certain tasks during hazardous weather if other protective measures are insufficient and the provision of adequate rest areas with refreshment facilities, including showers for jobs inducing heavy sweating (Kingdom of Spain 1995; Kingdom of Spain 1997).

Furthermore, should the Meteorological Agency issue weather warnings, employers are required to alter work conditions, potentially including changes to work hours, to ensure worker safety (Kingdom of Spain 1995; Kingdom of Spain 1997). In enclosed working premises the following conditions in particular shall be complied with (Kingdom of Spain 1995; Kingdom of Spain 1997):

a) The temperature of premises where sedentary work is carried out, typical of offices or similar, shall be between 17 and 27°C. The temperature of premises where light work is carried out shall be between 14 and 25°C.

b) The relative humidity shall be between 30 and 70 per cent, except in rooms where there are risks due to static electricity, where the lower limit shall be 50 per cent.

c) Workers shall not be frequently or continuously exposed to air currents whose velocity exceeds 0.25 m/sec when working in non-heat stress conditions, 0.5 m/sec when doing sedentary work in heat stress conditions, and 0.75 m/sec when doing active work in heat stress conditions. These limits do not apply to air currents expressly used to mitigate heat stress, nor to air conditioning currents, for which the limit shall be 0.25 m/sec in the case of sedentary work and 0.35 m/sec in other cases.

Royal Decree-Law 4/2023, enacted in May 2023, introduced urgent measures to address issues caused by weather conditions and prevent labour risks during high temperatures. It requires protective measures for outdoor workers, based on occupational risk assessments, job characteristics and workers' personal or health conditions. Measures include restricting certain tasks during extreme weather and altering work conditions if hot weather warnings are issued, ensuring that salary is not reduced if work is interrupted. The regulation also expanded coverage to include environments such as fishing boats and agricultural fields, acknowledging their significant heat exposure risks (Kingdom of Spain 2023).

3.3 Summary of national legislative measures to address workplace heat stress

Overall, the analysis indicates a lack of a standardized policy approach to address excessive workplace heat. As the impacts of climate change intensify and grow, countries must often develop policies and legislation quickly, in order to address rapidly evolving risks. This may lead to ineffective policies and, more importantly, to significant threats to workers' health and safety.

To contribute towards a standardized approach to address heat stress, the laws identified were analysed for their main components (table 6) and the methods for developing measures to adapt to higher temperatures in work environments. The analysis revealed the following:

- **Countries often use heat stress indicators and in most cases this is the WBGT:** 15 of the 21 national frameworks analysed in this report (71 per cent) use a heat stress indicator to assess the level of exposure (table 7). Ten out of the 15 countries that use a heat stress indicator have adopted the WBGT. Costa Rica uses both the WBGT and the Heat Index, Saudi Arabia uses the Heat Index, India uses wet bulb temperature, China uses air temperature, while Spain uses air temperature, relative humidity and air flow. Overall, information from the present analysis as well as the available research evidence suggests that WBGT is the most well-known and commonly adopted indicator to evaluate the risk of heat-related illnesses for people who work in conditions of excessive heat (Canadian Centre for Occupational Health and Safety; NATO 2013; NIOSH 2016; ISO 2017; ACGIH 2020; Ioannou et al. 2022b; Ioannou et al. 2022c; Ioannou et al. 2022d).
- **Maximum temperature thresholds vary according to work intensity:** The thresholds adopted in the legislations analysed are typically 29-30°C for high-intensity work, 30-31°C for moderate-intensity work, and 31.5-32.5°C for low-intensity work. Nevertheless, for countries with relatively cool climates such as Belgium and Japan, these safety thresholds are more conservative, being 22-25°C for high-intensity work, 26-28°C for moderate-intensity work, and 29-30°C for low-intensity work (table 7). This is because people living in cooler climates are less acclimatized to higher temperatures and therefore would be at risk for heat-related illness even at lower exposure levels. It is important to note that having different safety thresholds based on work intensity is valuable and contributes significantly to protecting workers from heat stress.
- **Other common protective measures include rest areas, hydration, education**

and training and PPE: 33 per cent of the legislative measures addressing heat stress require employers to provide cool, shaded and ventilated rest areas for workers. 67 per cent of the legislation analysed included provisions for hydration, 57 per cent for rest, breaks or modified work schedules to avoid excessive heat, while 48 per cent included provisions for periodic health checks. 57 per cent included provisions for education and training, while 62 per cent included provisions for PPE designed to limit and/or protect workers from heat stress (table 6). Finally, written risk assessment, acclimatization and identification of worker groups in vulnerable situations are mandatory in many countries worldwide.

Overall, the analysis of the legislative measures identified from selected countries reveals the following characteristics, which could be used as guidance for developing effective workplace action plans:

- Participatory risk assessment in the working environment integrating excessive heat.
- Identification of and targeted strategies for worker groups at high risk, including outdoor and indoor workers, those in informal economies and micro, small and medium enterprises (MSMEs), among others.
- Use of the WBGT as a potential heat stress indicator to assess the level of heat exposure, with varying safety thresholds based on work intensity.
- Hydration strategies, including adequate sanitation facilities, especially for female workers.
- Rest, breaks or modified work schedules to limit or avoid exposure to excessive heat, including the ability to self-pace.
- Provision of cool, shaded and ventilated rest areas.
- Heat acclimatization measures for workers without recent heat exposure.
- PPE designed to protect workers from heat stress.
- Education and awareness on heat stress and heat-related illnesses.
- Regular medical check-ups and health monitoring.

These measures are explained in detail in Chapter 4: Workplace action on heat stress.

▶ Table 6. Key aspects of national legislation addressing excessive heat in the workplace.

ILO region	Country	Provisions							Other
		Exposure threshold*	Cool rest areas	Hydration	Rest / Breaks	Health checks	Education & Training	PPE	
Africa	Algeria		X	X	X	X		X	Risk assessment requirement; Identification of worker groups in vulnerable situations.
Africa	South Africa	X		X		X	X		Risk assessment requirement; Provision for acclimatization and first-aid treatment.
The Americas	Brazil	X							Risk assessment requirement.
The Americas	Chile	X	X	X	X	X	X	X	Requirements: risk assessment, emergency response plan, ventilation, buddy system; Identification of worker groups in vulnerable situations.
The Americas	Costa Rica	X	X	X		X	X	X	Provision for acclimatization.
The Americas	Mexico					X	X	X	Identification of worker groups in vulnerable situations.
The Arab States	Bahrain						X	X	Outdoor work is prohibited during midday; Exemption: oil and gas industry, emergency maintenance.
The Arab States	Kuwait								Outdoor work is prohibited during midday; Exemption: oil and gas industry, workers in closed-in vehicles/structures.
The Arab States	Oman			X			X		Outdoor work is prohibited during midday.
The Arab States	Qatar	X	X	X		X	X	X	Outdoor work is prohibited during midday; Includes workers' right to remove themselves from excessive heat situations.
The Arab States	Saudi Arabia	X		X	X	X	X	X	Outdoor work is prohibited during midday; Provision for acclimatization; Requirements: risk assessment, emergency response plan, buddy system; Exemption: workers in closed-in vehicles / structures, shaded areas or remote areas where no shade is available.
The Arab States	United Arab Emirates			X	X		X	X	Outdoor work is prohibited during midday; Provision for acclimatization; Identification of worker groups in vulnerable situations; Additional allowance for overtime work in excessive heat.

ILO region	Country	Provisions							Other
		Exposure threshold*	Cool rest areas	Hydration	Rest / Breaks	Health checks	Education & Training	PPE	
Asia and the Pacific	China	X	X	X	X		X		Requirement for early warning system; Identification of worker groups in vulnerable situations; Monthly high-temperature allowance for workers exposed to excessive heat.
	India	X		X	X		X	X	Requirement for medical facilities; Provision for acclimatization; Identification of worker groups in vulnerable situations.
	Japan	X		X	X	X			Provision for alerts based on WBGT forecast from national meteorological service.
	Singapore	X	X	X	X				Provision for acclimatization; Identification of worker groups in vulnerable situations; Requirements: emergency response plan, buddy system.
	Thailand	X				X		X	Requirements: risk assessment and ventilation.
Europe and Central Asia	Belgium	X			X			X	Workers' core body temperature should not exceed 38°C; Requirements: risk assessment, emergency response plan, ventilation.
	Cyprus	X		X	X			X	Workers' core body temperature should not exceed 38°C; Provision for alerts based on WBGT forecast from national meteorological service; Requirements: risk assessment, emergency response plan; Identification of worker groups in vulnerable situations; Provision for acclimatization.
	Greece	X	X	X	X	X	X	X	Workers' core body temperature should not exceed 38°C; Provision for alerts based on WBGT forecast from national meteorological service; Real-time WBGT estimate via smartphone application; Requirements: risk assessment, emergency response plan; Identification of worker groups in vulnerable situations; Provision for acclimatization.
	Spain	X			X				Provision for alerts based on air temperature forecast from national meteorological service; Requirements: risk assessment; Identification of worker groups in vulnerable situations.

* maximum value beyond which work should be terminated

An important policy effort is the setting, implementation and enforcement of maximum exposure limits. Table 7 provides a comprehensive summary of exposure limits established by the 21 countries analysed in this review, as well as some additional countries and other expert organizations which have also set limits.

▶ Table 7. Examples of legislation regarding maximum temperature thresholds in the workplace.

This includes the 21 countries analysed in the literature review, as well as additional countries identified in the ILO report, "Ensuring safety and health at work in a changing climate" (ILO 2024).

ILO region	Country	Heat stress assessment	
		Heat stress indicator	Safety threshold (work intensity / risk)
Africa	Mozambique*	Air temperature	33°C (mining operations only)
Africa	South Africa	WBGT	30°C
The Americas	Brazil	WBGT	31.7-33.7°C (very low intensity work) 20.7-24.7°C (very high intensity work)**
The Americas	Chile	WBGT	32.2°C (low) 31.1°C (mod.) 30.0°C (high)
The Americas	Costa Rica	Heat Index and WBGT	<91 (low risk) 91-102 (mod. risk) 103-124 (high risk) ≥125 (extreme risk)
The Arab States	Qatar	WBGT	32.1°C
The Arab States	Saudi Arabia	Heat Index	25-29°C (low risk) 30-38°C (mod. risk) 39-51°C (high risk) ≥52°C (extreme risk)
Asia and the Pacific	China	Air temperature	37-39°C (high risk) >39°C (extreme risk)
Asia and the Pacific	India	Wet Bulb Temperature	30°C
Asia and the Pacific	Japan	WBGT	33.0°C (sedentary) 30.0°C (low) 28.0°C (mod.) 26.0°C (high) 25.0°C (very high)
Asia and the Pacific	Singapore	WBGT	32°C (mod. risk) 33°C (high risk)
Asia and the Pacific	Thailand	WBGT	34.0°C (low) 32.0°C (mod.) 30.0°C (very high)
Asia and the Pacific	Vietnam*	Air temperature (indoor only)	34°C (light) 32°C (medium) 30°C (heavy)

ILO region	Country	Heat stress assessment	
		Heat stress indicator	**Safety threshold (work intensity / risk)**
Europe and Central Asia	Armenia*	Air temperature	40°C
	Austria*	Air temperature	25°C (low physical stress) 24°C (normal physical effort)
	Belgium	WBGT	29.0°C (low) 26.0°C (mod.) 22.0°C (high) 18.0°C (very high)
	Cyprus	WBGT	32.2°C (low) 31.1°C (mod.) 30.0°C (high)
	Greece	WBGT	32.5°C (low) 31.5°C (mod.) 30.5°C (high) 30.0°C (very high)
	Hungary*	Air temperature	31.0°C (intellectual) 31.0°C (light) 29.0°C (medium) 27.0°C (heavy work)
	Latvia*	Air temperature (indoor only)	28°C
	Portugal*	Air temperature	22°C (commercial, office and service establishments only)
	Slovenia*	Air temperature	28°C
	Spain	Air temperature	27°C (sedentary work) 25°C (light work)
		Relative humidity	70 per cent (all other rooms) 50 per cent (rooms with risk of static electricity)
		Air flow	0.25 m/sec (normal conditions) 0.75 m/sec (active work in excessive heat)

Expert organization	Heat stress assessment	
	Heat stress indicator	**Safety threshold (work intensity / risk)**
Canadian Centre for Occupational Health and Safety (CCOHS 2005)	WBGT	31.0°C (low) 28.0°C (mod.)
ISO 7243:2017 (ISO 2017)	WBGT	30.0°C (light) 28.0°C (mod.) 26.0°C (heavy) 25.0°C (very heavy)
NATO (NATO 2013)	WBGT	32.2°C (light) 31.1°C (mod.) 29.4°C (heavy) 27.7°C (very heavy)
United States National Institute for Occupational Safety and Health (NIOSH 2016)	WBGT	30.0°C (light) 28.0°C (mod.) 26.0°C (heavy) 25.0°C (very heavy)

* Data from the ILO report "**Ensuring safety and health at work in a changing climate**" (ILO 2024). Full analysis of heat-specific legislation for these countries is not covered in this report.

**For both very low intensity work and very high intensity work, different measures need to be implemented at two assigned temperature thresholds. For more detail, see the section on Brazil on page 32.

Other national level actions

Aside from policies and strategies, other national level actions exist and have been implemented by countries globally:

- A number of international and national OSH bodies and authorities have developed **technical guidelines** specifying the measures to be adopted in the workplace for protecting workers from heat stress. For example, in New Zealand, WorkSafe has a number of online tools for work in hot environments[5]. Working Safely in Extreme Temperatures, concerned with any outdoor work during summer, provides advice on risk assessment in the event of extreme temperatures, as well as preventive measures, for example health checks. Two further sources of practical information are Working in Extreme Heat - a Guide for Businesses and Working in Extreme Heat – a Guide for Workers.
- In some countries, public authorities and other bodies have developed **training programmes and advisory initiatives** to educate and assist employers and workers in addressing hazards related to heat and preventing the risks of heat stress at work. For example, the Social Security Superintendence Authority (SUSESO) of Chile instructed occupational accidents and diseases insurance organizations to adopt preventive measures against exposure to high temperatures in the workplace. Technical assistance from these organizations must include items such as training for employers on the health impacts of heat events, technical assistance to employers for the preparation and implementation of emergency planning, identification of the main heat-related illnesses and high risk groups, and provision of information outlining prevention measures.
- **Awareness-raising campaigns** are important for spreading information and knowledge and stimulating action on OSH issues. Such initiatives can be organized by public authorities, OSH bodies, trade unions and employers and business membership organizations. Awareness campaigns can address groups of workers in a region affected by a particular climate threat, workers in specific sectors, employers or the public in general. For example, in Australia, the Victorian Chamber of Commerce and Industry's Health, Safety and Wellbeing team have published guidance for employers to raise awareness of the dangers of excessive heat in the workplace. The guidance explains how heat load may impact workers and the types of workplace controls that can be implemented to protect them. Businesses can also seek advice from the team on how to prepare, review and improve procedures and practices for working in hot conditions and methods of skilling staff in these complex safety management needs.
- In some instances, **dedicated committees** have been set up between government ministries and other agencies to promote the development of policies, programmes and initiatives in a comprehensive and systematic manner. For example, in Japan, the Committee for the Promotion of Heatstroke Control was established in 2021. The Committee meets 3-4 times a year to discuss the reporting of heatstroke cases, the weather forecast and estimated risks, and joint initiatives on the prevention of heatstroke such as National Plans, updating the legal framework, targeted campaign activities, and awareness materials.

Further examples can be found the ILO report, "**Ensuring safety and health at work in a changing climate**" (ILO 2024).

5 Working safely in extreme temperatures

▶ Heat-related illnesses recognized as occupational diseases

In line with the ILO List of Occupational Diseases Recommendation, 2002 (No. 194), which includes in its Annex at 1.2.6. Diseases caused by exposure to extreme temperatures, certain countries recognize heat-related illnesses as occupational diseases.

- For instance, in Mauritius[6], notifiable occupational diseases include "1.2.7 Diseases caused by extreme temperature (for example sunstroke, frostbite)", in Malaysia[7] they include "Conditions resulting from severe heat exposure, such as heat cramps or heatstroke", and in Namibia[8] "Diseases caused by hot or cold work environments, and all work involving exposure to the risk concerned".
- In Tunisia[9], several maladies caused by work in temperatures greater than 28°C, such as muscle cramps with profuse sweating and oliguria, are included in table 83 of the list of occupational diseases.
- In France[10], table 58 lists occupational diseases caused by working at high temperatures, including muscle cramps, oliguria and urinary chloride equal to or less than 5 g/litre.
- The list of occupational diseases provided in Decree 14229 (art. 4.2.1) in Lebanon includes occupational diseases that result from exposure to extreme heat or any work that exposes the worker to extreme heat that exceeds the national averages.

6 Occupational Safety and Health Act 2005 (Act No. 28 of 2005). List of Notifiable Diseases point 1.2.7.

7 Factories and Machinery Act 1967. No. 12.

8 Regulations relating to the health and safety of employees at work (Government Notice No. 156 of 1997). Notifiable Occupational Diseases, page 92.

9 Joint Ministerial Decree of the Ministers of Health and Social Affairs on 10 January 1995 defining the list of occupational diseases.

10 Tableaux des maladies professionnelles, Tableau n°58 du régime général : Affections professionnelles provoquées par le travail à haute température.

▶ 3.4 The importance of social dialogue

In designing global, national and workplace-level actions to mitigate heat stress, the roles of workers and employers, along with social dialogue, are integral for creating effective and sustainable strategies.

In line with Convention No. 155, employers are responsible for addressing heat-related illnesses arising from excessive heat exposures to ensure the health and safety of workers. This responsibility entails a comprehensive approach to managing heat-related hazards in the workplace. Employers are responsible for conducting thorough risk assessments to identify situations where workers may be exposed to excessive heat. Results from risk assessments can guide employers in implementing workplace level measures following the hierarchy of controls.

Employers are furthermore responsible for ensuring that workers receive proper training and education on recognizing the signs of heat-related illnesses and understanding the importance of hydration and other protection measures. This may involve conducting regular training sessions and disseminating informational materials to raise awareness among employees about heat-related illnesses and strategies for prevention.

Workers have the right to a safe and healthy work environment and to be protected from heat-related illnesses. They are entitled to receive clear and comprehensive information about the dangers of excessive heat exposures and the measures in place to mitigate them. Additionally, workers have the right to participate in the development and implementation of prevention strategies, including providing feedback on the effectiveness of existing measures and advocating for additional protections if necessary. Workers also have the right to remove themselves from a situation in which there is imminent and serious danger from excessive heat.

Workers face the burden of heat-related illnesses arising from heat stress, and their experiences offer invaluable insights into the effectiveness of existing measures and the need for new ones (Morris et al. 2020; Morris et al. 2021a; Morris et al. 2021b). Their participation in the design of prevention policies and programmes ensures that the strategies developed are grounded in the realities of those most affected by heat stress. Their feedback on existing conditions, effectiveness of current measures and suggestions for improvements provide critical data for shaping effective heat stress prevention strategies. Workers can be powerful advocates for encouraging the development of global, national and workplace-level standards on heat stress. One example is the Adaptation to Climate Change and the World of Work guide and the associated toolkits developed by the European Trade Union Confederation (ETUC 2020). These resources were developed to assist European trade unions in actively participating in the formulation and execution of national adaptation strategies and to place adaptation at the forefront of industrial relations discussions. Similar strategies and educational programmes as well as workers' involvement in co-designing heat stress prevention strategies, programmes and legislation have been also implemented in other countries (NRDC 2022).

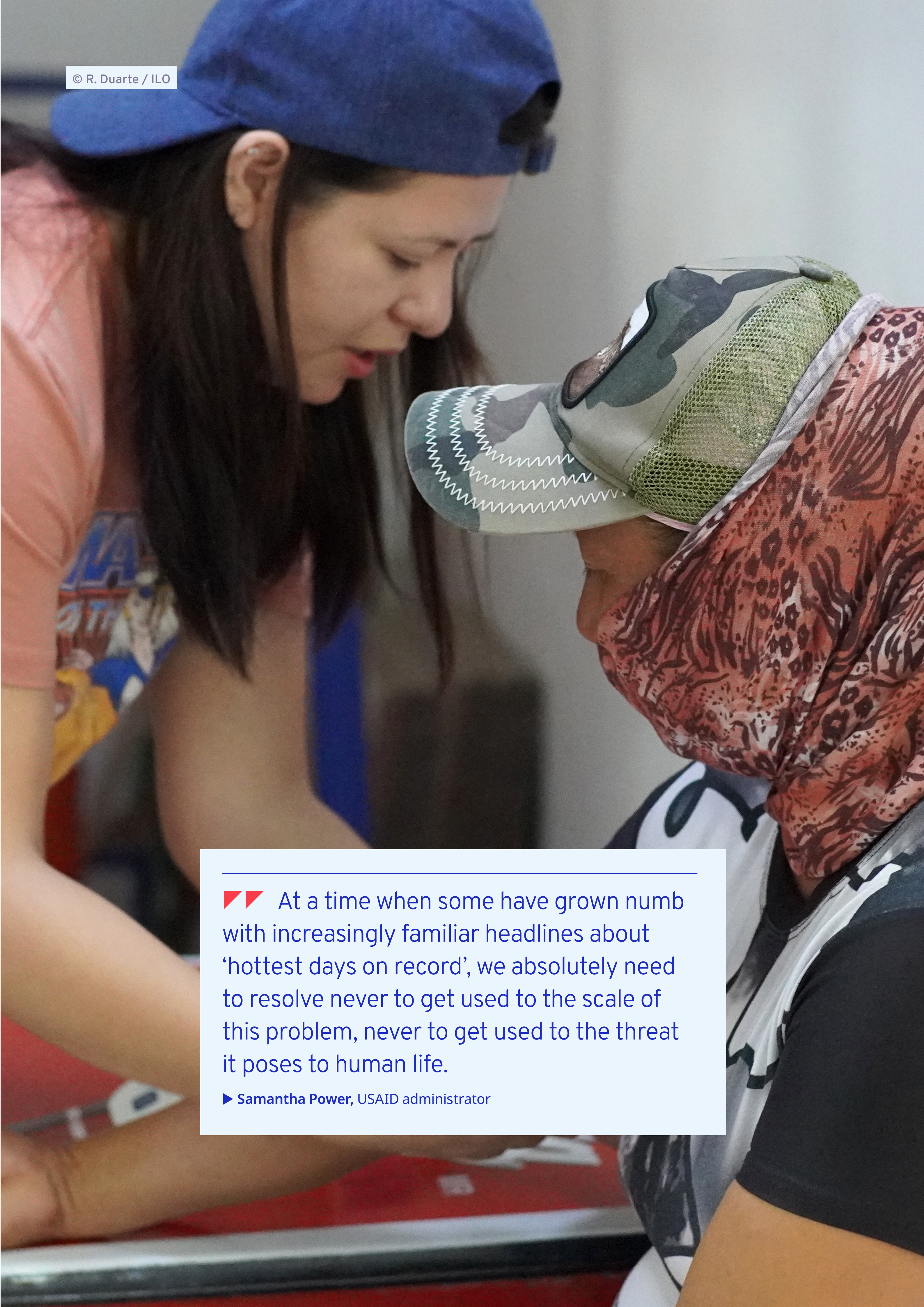
By adhering to the guidelines set out in Convention No. 155, employers can fulfil their duty to protect workers from heat-related illnesses arising from excessive heat exposure. Through collaboration and cooperation between employers and workers, a safe and healthy work environment can be maintained, even in challenging conditions such as extreme heat.

Collective bargaining agreements, resulting from negotiations between employers (and their organizations) and workers (and their organizations), have been adopted to address the specific conditions of different sectors, detailing procedures and protocols to deal with excessive heat in the workplace.

Examples of social partner initiatives

- In 2023, the Teamsters, one of the largest unions in the United States, negotiated the "2023-2028 UPS Teamsters National Master Agreement" with the shipping company UPS to add air conditioning, exhaust heat shields, fans and improved ventilation to UPS trucks (Roscoe 2023). Concerns had previously been raised regarding the dangers UPS drivers face from heat, which can reach nearly 50°C inside trucks.
- Phoenix City Council in Phoenix, the United States, passed a new ordinance in 2024 to protect workers from the dangers of extreme heat, after a citywide campaign involving Service Employees International Union, UNITE HERE Local 11 and other worker and community organizations. City contractors of outdoor workers in construction, engineering, airport and other services to the city, will be required to provide easy access to rest, shade and potable water, access to air conditioning in vehicles with enclosed cabs, and training on how to recognize and prevent heat injury and illness.
- Also in the United States, the Coalition of Immokalee Workers, a non-profit organization representing farmworkers, negotiated the Fair Food Program, in which farms must put in place safeguards to protect workers from heat in order to be certified (Rivero and Uzcategui 2024). The rules include the requirement of available shaded rest areas from 15 April to 15 November, electrolyte supplements for drinking water and increased breaks (Rivero and Uzcategui 2024).
- The International Framework Agreement of Building and Wood Workers' International (BWI) with Belgian construction company BESIX aims to protect the safety and health of construction workers in the Middle East from extreme temperatures (BWI 2023). The agreement states that sites must contain basic welfare elements, which include an adequate supply of wholesome drinking water, washing facilities and sufficient shelter. Furthermore, regular information should be given to workers on how to avoid climate-related diseases such as heatstroke and sunburn (BWI 2023).
- The OSH committee of the Bahrain Free Labour Unions Federation conducted a health and safety awareness campaign aimed at outdoor workers who are required to work in direct sunlight in the middle of the day (BFLUFBH 2018). The campaign provided information on the dangers of sun exposure and how to prevent heatstroke during working hours. The Federation also conducted checks on constructions sites and gave on-site advice to workers about staying hydrated and wearing light clothing.
- The International Trade Union Confederation has been working with the care sector to raise awareness of how climate change concerns can impact workers in the sector and how workers in care homes can advocate for safe and healthy working environments (ITUC 2022). Coping with Climate Change in the Care Sector is a guide for workers produced by the International Trade Union Confederation outlining the role workers can play in creating policies to adapt the care sector to climate change (ITUC 2022). These include awareness-raising campaigns, social dialogue between employers and workers, and advocacy by unions at local, regional and national levels (ITUC 2022).

Policies and strategies addressing excessive heat at work that are developed through social dialogue are more likely to be relevant to the actual working conditions and challenges faced by workers (Morris et al. 2020; Morris et al. 2021a, Morris et al. 2021b). This relevance enhances the effectiveness of the actions taken to mitigate heat stress, and also builds trust and cooperation among the key stakeholders. This is vital for the successful implementation and enforcement of policies and measures designed to tackle heat stress. Through dialogue, stakeholders can share experiences, best practices, and innovative approaches from different sectors and regions. This sharing can lead to more adaptive and innovative solutions that are tailored to specific contexts. Importantly, social dialogue also provides a platform for addressing conflicts or disagreements that may arise between different stakeholders. As a result, policies developed through a participatory process are more likely to be supported and complied with by all parties, thus improving the likelihood of successful policy enforcement. Finally, in the face of climate change and evolving work environments (for example digitalization), social dialogue allows for policies to be updated and adapted to changing conditions. This ensures that prevention strategies remain relevant over time.



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> At a time when some have grown numb with increasingly familiar headlines about ‘hottest days on record’, we absolutely need to resolve never to get used to the scale of this problem, never to get used to the threat it poses to human life.
>
> ▶ **Samantha Power,** USAID administrator

4. Workplace action on heat stress

OSH laws implemented at the national level must then be applied in practice at the workplace level. The following sub-sections describe in detail the key concepts of an OSH management system intended to protect workers from heat-related illnesses and injuries.

4.1 Workplace-level risk assessment

In a number of countries, national OSH legislation stipulates that employers must assess the various health and safety risks associated with their workplace (including those arising from excessive heat), in order to reduce, and whenever possible, prevent them. A workplace risk assessment is one of the key tools for protecting the safety and health of workers who may be exposed to excessive heat.

Effective risk management encompasses the identification of the hazard(s) related to excessive heat exposure, the assessment of the associated risks and the implementation of practices to prevent and control them, all grounded in reliable and proven methodologies. It requires a comprehensive understanding of the relevant national and international legal framework (described in Section 3). Conducting a written risk assessment for excessive heat at the workplace involves a systematic and participatory process, which should be recorded in a written document outlining the findings.

The risk assessment should follow these five steps[11]:

- **Step 1: Identify the hazards -** This involves surveying the workplace and identifying possible heat-related hazards and their specific risks to safety and health. Workers may face a range of exposure scenarios depending on their job sector and specific tasks performed. This approach typically starts with observations and the gathering of information about the work environment. It should consider various factors such as the type of work being performed, the duration and intensity of the tasks, the work-rest cycle(s) and the availability of drinking water, as well as environmental conditions such as ambient temperature, humidity, air movement and radiant heat sources. It also includes evaluating the adequacy of ventilation, the nature of work uniforms and PPE used by workers and any direct exposure to sunlight or other heat sources. The workers' feedback about their comfort levels and any heat-related illness symptoms they might be experiencing should be given serious consideration.

11 See A 5 Step Guide for employers, workers and their representatives on conducting workplace risk assessments. ILO 2014.

Consider these key questions when assessing if there is a risk of heat stress

- Do workers exhibit noticeable sweating?
- Does the observer feel that the environment is warm or hot?
- In cooler conditions, is there a need for a break every two hours during work?
- Would it be more comfortable for workers to wear less insulative work clothes?
- Have there been any reports among workers of symptoms such as weakness, fatigue, dizziness, muscle cramps, loss of coordination, headaches, nausea, heat exhaustion or heatstroke?
- Are there cases of absenteeism, increased irritability among workers or deteriorating worker relations that can be linked to working conditions?
- Have there been an increased number of accidents and injuries, or are there indications of reduced productivity or output/product quality related to the working conditions?

- **Step 2: Identify who might be harmed and how -** Next, the risk assessment should recognize the different heat stress susceptibilities among workers, such as varying levels of acclimatization, individual health conditions, and particular vulnerabilities due to age, medication or pre-existing medical conditions. Workers in specific industries, such as those employed outdoors in farming and construction, may be at greater risk of the adverse health effects associated with excessive heat.
- **Step 3: Evaluate the risk -** The evaluation of the risks associated with excessive workplace heat involves calculating both the likelihood of the risk occurring and the severity of its potential consequences. This classification serves as the foundation for choosing preventive actions to implement and determining the urgency for enacting control measures. Based on the identified hazards and potential routes of exposure for workers, the hierarchy of controls should be applied to eliminate hazards or minimize risks associated with heat-related hazards. There are five categories in the hierarchy: elimination, substitution, engineering controls, administrative controls and PPE, with control methods at the top of the hierarchy (elimination) being more effective than those at the bottom (PPE) (see Section 4.2).
- **Step 4: Record who is responsible for implementing which control measure, and the timeframe -** Once control measures have been decided upon, it should be determined who will be responsible for implementing and overseeing these new measures, as well as an appropriate timeline for their implementation. If resources are limited, control measures should be prioritized based on degree of risk. A plan of action may also include worker training and regular checks to ensure the appropriate measures are still in place.
- **Step 5: Record the findings, monitor and review the risk assessment and update when necessary -** Risk assessment findings should be recorded and made available to supervisors, workers and labour inspectors. Arrangements will be needed to monitor the effectiveness of the control measures, for example through workplace inspections. Importantly, the written risk assessment must be regularly reviewed and updated to reflect any changes in the workplace, work practices or climate conditions. These may result in new potential exposure pathways that put workers' safety and health at increased risk. This document should detail the hazards identified, the results of the risk assessment and the proposed measures to mitigate the risk. It should be accessible to all workers and used as a basis for training and awareness programmes about heat stress and heat-related illnesses.

4.2 Heat stress prevention and control practices

Preventing heat-related illnesses involves the identification and implementation of measures to prevent or minimize risks from excessive heat, with a focus on safeguarding the safety and health of workers, as well as monitoring these measures over time. These actions should effectively protect all individuals exposed to excessive heat, however additional or alternative measures may be necessary specifically to safeguard workers in high-risk exposure situations.

The hierarchy of controls encompasses several stages: elimination, substitution, engineering controls, administrative controls, and the use of PPE, with control methods at the top of the hierarchy (elimination) being more effective than those at the bottom (PPE). When developing a workplace-level action plan for heat stress prevention and control, it is crucial to weigh factors such as practical feasibility, economic viability and sustainability for its effective execution. For example, using air conditioning to lower air temperature and humidity in an industrial setting can eliminate excessive heat, but in many industries this approach may be impractical or too costly and energy-intensive to be economically sustainable. A more practical and cost-effective alternative could be creating smaller cooling areas where workers can rest, cool off and hydrate during breaks, rather than cooling the entire workspace.

Elimination

Prioritizing elimination to remove excessive heat exposure completely is the most effective risk-control method in reducing the incidence of heat-related illnesses and accidents; however, it may be very difficult to accomplish. Fully eliminating excessive heat as a hazard would include options such as moving enterprises to regions less prone to high environmental temperatures.

Substitution

Substitution involves replacing a traditional process, piece of equipment, material or method with alternatives that cause no or less heat stress. If it is not possible to avoid it by replacing or altering procedures, equipment, methodologies or substances that contribute to it, the option of permanently discontinuing the activity should be considered. Substituting one process, material or technology with another should not introduce new or increased risks.

Engineering controls

If neither elimination nor substitution are achievable due to technical limitations, engineering controls, involving the use of technology, can be a viable and effective method to either eliminate heat stress or lessen the probability of its occurrence (de Castro 2003; Morris and Cannady 2019). The aim of engineering controls is to address heat stress at its source, thereby enabling workers to perform their duties without facing the OSH risks arising from excessive heat (de Castro 2003).

The most effective method for preventing heat stress is to introduce engineering controls that can cool down the work environment. Such controls can also enhance the dissipation of heat from the worker's body to their environment. Active cooling methods, such as using a fan or air conditioning system, or immersing body parts in cool water are often more effective than passive cooling methods such as resting, removing clothing or PPE or relying on natural ventilation, especially in physically demanding jobs such as firefighting, mining, construction and agriculture (Selkirk et al. 2004; Colburn et al. 2011).

Some common examples of engineering controls to address excessive heat exposure are:

- **Incorporating alternative building materials** with lower thermal conductivity, diffusivity and absorptivity can be effective, particularly for buildings that are mainly used during the daytime. Utilizing materials with superior thermal characteristics, such as vacuum insulation panels, shape memory polymers, phase-change materials, window glazing and polymer skin, in various parts of the building or in vehicles can help reduce internal temperatures, especially where machinery generates a lot of heat (Latha et al. 2015; Ramakrishnan et al. 2017; Vale et al. 2021; Alves et al. 2022).
- **Controlling the emission of heat radiation** can be achieved by installing surfaces that either reflect or absorb radiation at key workstations (Giahi et al. 2015). Such surfaces come in various forms and complexities, ranging from insulated furnace jackets and reflective metal shields to light-coloured external surfaces and reflective paint coatings on roofs and walls. These passive and sustainable options help to reduce surface temperatures and the overall heat burden of buildings or vehicles, thereby reducing workers' exposure to excessive heat (Ran and Tang 2018; Westex 2019; Vale et al. 2021; Alves et al. 2022).
- **Utilizing automation, robots or mechanical aids** is another strategy to minimize the physical exertion required from a worker (Ioannou et al. 2021a; Ioannou et al. 2022b). For this method to be effective, the metabolic effort necessary to use or operate these devices should be less than the effort required to perform the tasks manually (CCOHS 2023).
- **Adopting nature-based solutions** can offer a sustainable approach using the cooling and shading benefits of natural elements. Planting trees and vegetation in and around workplaces can reduce ambient temperatures through shading and evapotranspiration, providing cooler environments for outdoor workers and reducing heat absorption by buildings, thus benefiting indoor workers as well. Green roofs and walls also contribute to urban cooling, making cities more resilient to heatwaves. Moreover, these solutions foster biodiversity, improve air quality and enhance the mental well-being of workers, presenting a multifaceted approach to combating heat stress.

- **Active ventilation** involves the use of mechanical systems to bring outside air into the workplace, often coupled with an air purifier, to reduce workplace temperatures. This approach helps to keep the indoor environment fresh and cool by circulating external air. However, the effectiveness of this method diminishes as outdoor temperatures rise, and it is not recommended in hot and humid conditions. In such environments, cooling the external air before introducing it indoors is an option (Jay et al. 2015).
- **Local air cooling** can be effectively implemented to lower air temperature in specific areas using two different methods. The first is the use of a cold room, which can either enclose a particular work area or serve as a recovery space close to jobs that involve excessive heat (Anderson and De Souza 2017). The second approach involves using a portable blower equipped with an air chiller. This method offers the benefits of easy mobility and quick set-up but can be energy-intensive (OSHA 2017).
- **Implementing evaporative cooling systems** and modifying the roof design to enhance natural ventilation can effectively lower the heat within a building and enhance air circulation (De Angelis et al. 2017).
- **Utilizing water sprays** in conjunction with fans can enhance airflow in the workspace, which is beneficial if the air temperature is lower than the worker's skin temperature. This combination assists in keeping workers cooler by boosting both convective heat exchange and the rate of evaporation (Reese 2018). Fans paired with cold water sprays or mists present an affordable, efficient and easily movable option (Farnham et al. 2017; Meade et al. 2024).

Administrative controls

Administrative controls consist of policies aimed at reducing workers' exposure to excessive heat and are typically achieved via work assignments. These controls primarily involve strategies such as training and job rotation, though they may not always directly target the specific vulnerabilities and risks caused by heat (Morris and Cannady 2019). Examples of effective administrative controls include increasing workers' fitness, adopting work-rest cycles and hydration strategies, limiting or prohibiting work at certain times of the day, providing acclimatization and sufficient training, instructions or information to minimize the likelihood of heat-related illnesses, as well as supervision to ensure that such controls are effectively implemented.

Common examples of administrative controls to address excessive heat exposure include:

- **Elimination of job risk factors** that contribute to excessive heat exposure. For instance, a construction worker labouring outdoors in the sun during summer who frequently changes body posture rapidly might be at a higher risk of heat syncope (Carillo et al. 2013; Schlader et al. 2016). In contrast, a dry-cleaning worker working in a hot-humid indoor environment may be more prone to fluid and electrolyte imbalances (see Section 1.2).
- **Improving workers' physical fitness** can help minimize the likelihood of heat-related illness. Specifically, individuals who are physically fit have a more efficient cardiovascular system, which facilitates distributing heat away from the body's core to the skin where it can be dissipated (Notley et al. 2019c; Notley 2019b). Also, cardio-respiratory fitness enhances the body's capacity to sweat, which is the most important method of heat dissipation during physical work, especially in hot environments (Flouris 2019).
- **Ensuring adequate hydration** is key. While the significance of hydration for maintaining health is widely recognized (Han et al. 2021), many workers still struggle to stay adequately hydrated (Piil et al.2018). Workers should have easy access to potable water throughout the day in all areas of the worksite, even in remote locations, to encourage frequent consumption (Tan and Lee 2015; NIOSH 2017). Ample supplies of potable water should be conveniently located near work areas but away from any chemical contaminants (Nerbass et al. 2017). Individual water bottles carried by the workers at all times are a very effective means to ensure adequate hydration (Flouris et al. 2019). General guidance on water consumption based on WBGT levels and acclimatization status is provided in table 8.

▶ Table 8. Recommended water intake based on WBGT levels and acclimatization state.

It is essential for workers exposed to excessive heat to start their workday well-hydrated, which includes rehydrating from the previous day and consuming roughly 500 millilitres of fluid with electrolytes about an hour before beginning work (Notley et al. 2018b). It is equally important for workers to sustain water balance by drinking regularly based on their sensation of thirst throughout their shift (Kenefick and Sawka 2007; Morris et al. 2020).

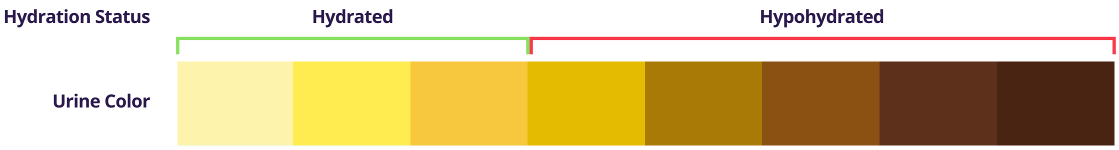
	Water intake (litres/hour)		
WBGT	**Low-intensity work**	**Moderate-intensity work**	**High-intensity work**
25.0-28.0	0.35	0.55	0.65
28.0-29.4	0.40	0.55	0.70
29.5-30.9	0.40	0.60	0.75
31.0-32.4	0.45	0.65	0.80
≥32.5	0.50	0.70	0.85

Note: Work intensity follows levels provided in Table 1 of ISO 7243:2017; Simulation performed with the FAME Lab Predicted Heat Strain model (Ioannou et al. 2019). Simulation data - height: 170 cm; body mass: 70 kg; clothing worn: hat, short-sleeve shirt, bra, denim overalls, underwear, socks and shoes.

When workers sweat heavily, they lose significant amounts of electrolytes such as sodium and potassium. Healthy workers should be encouraged to add salt to their food if their diet is low in salt. However, overconsumption of salt should be avoided, particularly for workers on medication or with heart conditions or hypertension, who should consult a physician about balancing dietary salt with their daily and work-related loss (Institute of Medicine 2005). If feasible, especially during breaks, consuming cooling drinks, ice slurry or shaved or crushed ice can help alleviate discomfort, reduce core body temperature and enhance productivity (Tan and Lee 2015; Morris et al. 2020; Alhadad et al. 2021).

- **Ensuring the availability of sanitary facilities** such as toilets, washrooms and changing rooms is crucial. Inadequate access to restroom facilities can cause workers, particularly females, to avoid drinking adequate water (Venugopal et al. 2016) and may deter them from taking breaks for cooling purposes, such as splashing water on themselves (Nerbass et al. 2017). Placing urine colour charts (figure 8) in toilets can assist workers in evaluating their hydration levels.

▶ Figure 8. Urine colour scale to evaluate the level of hydration status.



- **Introducing work-rest cycles** to include more frequent breaks enables workers to leave hot areas of the worksite. Implementing well-planned work-rest schedules has been effective in reducing heat stress, without adversely affecting worker productivity (Flouris et al. 2019; Morris et al. 2020). Alternating regularly between work periods and rest breaks, for both outdoor (Flouris et al. 2019; Ioannou et al. 2021b) and indoor (Attia and Engel 1980; Flouris et al. 2019) work not only helps to move workers away from sources of heat, but also provides them with opportunities to rehydrate and for their body to remove excess heat (Berry et al. 2011; Flouris et al. 2019). For moderate intensity work, breaks of 10-15 minutes every hour can prevent rises in core body temperature for exposures up to 29°C WBGT, but longer breaks are needed in higher temperatures. Importantly, when used as a stand-alone strategy, work-rest cycles cannot always prevent rises in core body temperature (Meade et al. 2016; Lamarche et al. 2017; Notley et al. 2020). Therefore, while work-rest cycles can reduce the risk of heat stress, they do not eliminate the need for other prevention strategies and controls.
- **Implementing job rotation and schedules** allows individuals who perform physically demanding tasks and/or work in hot areas of a worksite to spend time doing less intense work and in cooler areas during their shift. When feasible, work that is physically demanding and takes place in hot environments should be planned for cooler times of the day and regular maintenance or repair work in these hot areas should be arranged during the cooler seasons of the year (OSHA 2017). However, it is also crucial to consider the social implications of changes in work hours, such as introducing night shifts, to ensure the overall well-being of workers and their families. In hot urban areas, the urban heat island effect causes significant radiant heat release at night, which can maintain high levels of heat even during night-time hours (Hua et al. 2021). Also, night shifts may reduce workers' exposure to excessive heat, but the potential adverse effects of night shifts on health, safety and productivity have been widely reported (Bohle et al. 2010; Jun and El-Rayes 2010; Kenny et al. 2016a). Performing consecutive night shifts can nearly double the risk of accidents at work (Wagstaff and Sigstad Lie 2011) and can affect all tasks (Raslear et al. 2011), causing an increase of up to 53 per cent in absenteeism and up to 92 per cent in compensation for absenteeism (d'Errico and Costa 2012). Also, workers labouring at night under hot conditions report getting insufficient sleep during the day, skipping meals to catch up on their sleep and missing shifts due to lack of sleep (Flouris et al. 2019).
- **Introducing heat acclimatization** regimes is essential for workers who are not yet acclimatized. People vary widely in their capacity to withstand a certain level of heat stress, depending on whether their body has been adapted to these conditions (Arbury et al. 2016; Flouris 2019). Individuals with no or no recent (in the last 3 weeks (Flouris et al. 2014; Poirier et al. 2015a; Périard et al. 2021)) exposure to excessive heat should be regarded as not acclimatized to heat. During exposures to excessive heat for two or more hours daily, workers will typically show an increasing tolerance across the initial week or two (Brearley et al. 2016; Périard et al. 2016; Périard et al. 2021; Brown et al. 2022). This process, known as acclimatization, induces adaptations that lead to reduced cardiovascular strain and a lower risk of hyperthermia during periods of excessive heat (Brearley et al. 2016; Périard et al. 2016; Périard et al. 2021; Brown et al. 2022). However, acclimatization can gradually diminish over a period of two or more weeks without heat exposure (Flouris et al. 2014; Poirier et al. 2015a; Périard et al. 2021) and can be lost more quickly due to illnesses, particularly those causing fever, nausea, vomiting or diarrhoea.

▶ Return to work after severe heat-related illnesses.

Typically, the decision about when an individual can return to work after suffering a serious heat-related illness is made by the treating physician. This decision is complex and challenging, often requiring contributions from the manager, the OSH professional and the worker themself. Despite the global burden of disease arising from heat stress (see Section 2), there is limited evidence available on the appropriate timing for returning to work. Previous recommendations, mainly intended for athletes and military personnel, have been based on anecdotal evidence and a cautious approach (McDermott et al. 2007; O'Connor et al. 2007; Depenbrock et al. 2018). These guidelines typically suggest that athletes and military personnel who have suffered heat-related illnesses should not resume full activity for at least one week, and in cases of serious heat-related illnesses, a recovery period of up to 15 months may be necessary (Sawka et al. 2003; American College of Sports Medicine et al. 2007; McDermott et al. 2007; O'Connor et al. 2007; O'Connor et al. 2010; Casa et al. 2015).

For workers who have experienced heatstroke or severe heat exhaustion, it is advised that they refrain from any physical activities beyond those necessary for daily living for a period of two weeks (United States Army 2019). During this time, the worker should undergo weekly medical re-evaluations, which may include clinical and biochemical examinations and, if necessary, diagnostic imaging of any affected organs. Once all symptoms and signs have cleared, the worker should undergo a physical rehabilitation programme, guided by an exercise specialist. This programme should involve a gradual increase in physical exercise, not exceeding 60 minutes per day. If the exercise is well-tolerated and the worker shows no adverse reaction to physical work or heat (such as unexplained increases in heart rate or core body temperature, or abnormal liver and muscle enzyme levels), they can then be medically assessed for their readiness to return to work (United States Army 2019). For workers who have experienced heatstroke or severe heat exhaustion, the decision to return to work should be made on an individual basis following a thorough clinical assessment. This decision should be based on several key criteria:

- The worker should be symptom-free.
- The clinical examination should reveal no abnormalities.
- Laboratory tests should show no abnormal findings.

There should be a well-structured, progressively challenging physical heat-load test conducted under close monitoring. This test should closely mimic the worker's actual job tasks and the environmental conditions in which they work. The worker's ability to tolerate both the physical work and the heat, as well as their cardiovascular stability and blood chemistry biomarkers, should be evaluated (United States Army 2019).

The table below shows an example of a re-acclimatization schedule after routine absence or illness for occupations involving excessive heat. Once assignment has reached 100 per cent, workers can continue with their normal schedule.

Proposed schedule of re-acclimatization for work involving heat exposure following routine absence or illness.

	Days away from heat exposure due to routine absence (or illness)					Days after returning to work
	<4 (---)	4-5 (1-3)	6-12 (4-5)	12-20 (6-8)	>20* (>8*)	
Percent of full assignment	100	R/E	80	60	50	1
		100	100	80	60	2
				100	80	3
					100	4

Note: R/E = Reduced workload expectations with no specific reduction in excessive heat exposure; * treat as unacclimatized.

- **Implementing job/task monitoring programmes** to identify jobs and tasks that significantly increase exposure to excessive heat, such as those that are performed in high environmental heat, and/or require wearing semi-permeable or impermeable PPE and/or involve tasks of very high intensity (exceeding 500 W). This monitoring includes tracking heart rate, recovery heart rate, core body temperature and hydration levels, as well as the degree of body water loss, and should be carried out in collaboration with a specialist in occupational medicine, physiology, or ergonomics (OSHA 2017; Notley 2018c). Another method is the buddy system, where two colleagues (the "buddies") work closely together as a unit, allowing them to keep watch over and assist each other in identifying signs of excessive fatigue and heat-related illnesses during their shifts. To implement this approach, workers and supervisors must first undergo a comprehensive heat stress education and training programme.

Personal Protective Equipment (PPE)

PPE is only to be used in cases where it is not possible to implement any other control measure to prevent heat stress. Simpler forms of PPE often show increased practicality, cost-effectiveness, and capacity to reduce the risk of heat stress for both outdoor and indoor workers (table 9).

> Simpler forms of PPE often show increased practicality, cost-effectiveness, and capacity to reduce the risk of heat stress for both outdoor and indoor workers

Advanced PPE technologies such as personal garments with liquid/ventilation technologies or phase-change materials can help maintain normal core body temperature during work in certain excessive heat conditions (Flouris and Cheung 2006; Kenny et al. 2011; Chan et al. 2015; Morris et al. 2020; Ioannou 2021b; Tokizawa 2023). However, some PPE solutions designed to reduce heat stress may occasionally impede heat loss and could lead to increased work effort, depending on their ease of use and weight. Such PPE approaches may also interfere with a worker's senses (for example by generating noise or moisture) and potentially impair performance in some situations (Teunissen et al. 2014; Zhao et al. 2015). Furthermore, it is important to note that these technologies are not always helpful in preventing rises in workers' core body temperature (Teunissen et al. 2014; Chan et al. 2018; Flouris et al. 2019) and, in some cases, workers may find them to be challenging and stressful (Zhao et al. 2015).

Best practices for the use of advanced cooling systems as part of PPE include selecting, applying, and, if necessary, adapting these systems to the work environment, the nature of the job and the characteristics of the workers (Ha et al. 1996; Flouris and Cheung 2006; Chan et al. 2015). While cold air-cooled and liquid cooling garments offer the highest level of protection, they are less practical and more expensive compared to phase-change cooling vests or hats (Flouris and Cheung 2006; Reinertsen et al. 2008; Gao et al. 2011; Gao 2014; Chan et al. 2015; Parameswarappa and Narayana 2017). Local body cooling with ice gel packs or other phase-change materials is a more practical and cost-effective approach.

▶ Table 9. Examples of simple but effective PPE for outdoor and indoor workers.

Outdoor workers	Indoor workers
Hats	Cooling hats/caps with active ventilation or made of phase-change materials
Neck covers	Hard hat cooling accessories e.g. neck shades, bandanas, sun shields and cooling pad inserts
Long, loose-fitting, lightweight and breathable clothing	Sweatbands
Reflective tents and shade structures	Ventilation patches in work uniforms or PPE (elbows, between the legs, and/or behind the knees) when full-body protection is not necessary

Heat stress and heavy personal protective equipment (PPE)

Excessive heat poses a significant challenge for individuals who wear PPE when exposed to hazardous chemicals. Havenith and et al. (2011) examined various improvements in PPE to reduce hyperthermia without compromising chemical protection. The study compared selectively permeable membranes with low vapour resistance against textile-based outer layers of similar vapour resistance, as well as against layers with enhanced air permeability. The findings revealed that thermoregulatory indicators including core body temperature, skin temperature and heart rate were notably higher when wearing selectively permeable membranes, as opposed to air-permeable ensembles. The study concluded that enhancing the air permeability of chemical protective clothing could effectively lower heat strain levels, depending on the required level of protection. Another study by Grimbuhler and Viel (2018) assessed the cardiac strain of vineyard workers wearing three different types of PPE during vine-lifting in vineyards around Bordeaux, south-western France. The results showed that cardiac strain was related to the type of PPE worn by workers. Surprisingly, a very light, thin and permeable type of PPE resulted in the highest cardiac strain because, under the very humid conditions of the field study, the thinness and breathability of this PPE led to undergarment humidity in the forearms, thighs and legs, causing added physiological burden on the workers (Grimbuhler and Viel 2018).

4.3 Education and awareness on heat stress

A significant portion of the workforce is not well-informed about effective strategies to counteract heat stress. In one survey, 60 per cent of workers from Slovenia and 50 per cent from Greece (mainly in construction, agriculture, and manufacturing) indicated they were not adequately informed about the health impacts of heat stress (Pogačar et al 2019). A similar survey in Italy showed that 83 per cent of workers (mainly among technical and scientific personnel in the construction, public administration and manufacturing sectors) did not receive heat warnings from their employer (Bonafede et al. 2022). In a study of 326 construction workers in China, 89 per cent of the workers agreed that education was needed to reduce the risk of heat-related illnesses and accidents (Han et al. 2021). Importantly, as remote work becomes increasingly prevalent, there is likely to be a growing need for regulations and their enforcement to safeguard the physical and mental health of home-based workers (Eurofound 2020).

Effective training on the risks of excessive heat should be carried out regularly, particularly before the onset of warmer seasons, to raise awareness of the signs and symptoms of heat-related illnesses. The use of administrative controls such as infographics and posters, and the placement of signs in high-risk and rest areas can serve as preventive measures.

A heat stress training programme should encompass, at a minimum, the following components:

- Knowledge of the risks of excessive heat and the factors that contribute to heat stress (see Section 1).
- Information regarding hydration and assessing urine colour in appropriate charts (see figure 8) in all workplace lavatories to help workers improve their fluid intake (Kavouras et al. 2010).
- Recognition, treatment, and predisposing factors, signs and symptoms of heat-related illnesses (see classifications of heat-related illnesses in Section 1.2).
- Employer responsibilities and worker duties in preventing heat stress (see Section 4.2).
- Guidance on workers' rights for self-regulation of work pace and for removing oneself from a dangerous situation (for example by taking breaks or reducing the intensity of work), and awareness that these should form the foundational basis of any heat stress prevention plan.
- Dangers of using recreational drugs and alcohol in hot working environments (see Section 1.3).
- Use of medications to manage health conditions when work involves exposure to excessive heat (see Section 1.3).
- Purpose and coverage of environmental and medical surveillance programmes and the advantages of worker participation in such programmes (see Section 4.4).

The training should further include a properly designed and applied acclimatization programme for all workers (NIOSH 2016), which can significantly decrease the risk of heat-related illnesses.

▶ 4.4 Worker health monitoring for heat-related illnesses or accidents

While prevention and control measures can eliminate or reduce the risk of heat stress, "inter-individual" (between people) and "intra-individual" (same person at different times) factors can raise the chances of heat-related illnesses or accidents (Kenny et al. 2016a; Notley et al. 2019b; Notley et al. 2019c). Regular medical check-ups and personalized fitness programmes are recommended for workers in heat-intensive jobs. These involve conducting medical examinations and tracking key health indicators (NIOSH 2016). In line with the Occupational Health Services Convention, 1985 (No. 161), occupational health services, which are entrusted with essentially preventive functions and responsible for advising employers, workers and their representatives (Article 1(a)), should conduct surveillance on factors in the working environment and working practices that may affect workers' health (Article 5(b)), as well as surveillance of workers' health in relation to work (Article 5(f)).

In relation to heat stress, it is recommended that an individual's ability to cope with heat stress is assessed both before they start a job and periodically thereafter, especially before the onset of the year's hot season. These examinations should encompass detailed medical and occupational histories, a thorough physical examination with relevant tests, and an evaluation of any prescription medication usage. Best practices recommend providing a written assessment regarding the individual's suitability for exposure to excessive heat. Monitoring for health events should focus on the health of both individual workers and the workforce as a whole. Important indicators to monitor include heat-related illnesses (as described in Section 1.2), first aid events, chronic health conditions and the prevalence of accidents, absenteeism and chronic fatigue.

Should an employer discover, based on sentinel events or recommendations from a healthcare provider that a worker has a reduced tolerance to excessive heat compared to others, tailored interventions can be implemented for that individual. These may include modifying work demands during tasks or periods of intense heat, providing personal cooling devices or conducting personal monitoring, acclimatization and physical fitness programmes (see Section 4.2 Administrative controls) (Flouris et al. 2019; Notley et al. 2019a; Morris et al. 2020).

An emergency preparedness and response plan should be developed to equip workers and supervisors with the skills to promptly identify early signs of heat-related illnesses, as detailed in Section 1.2. The buddy system (described in Section 4.2 Administrative controls) plays a key role in the rapid recognition of heat-related illnesses, particularly because the affected individual might not be cognitively able to recognize the risk or take protective measures. Table 10 can serve as a resource for workers to identify serious heat-related illnesses and to understand the appropriate first aid and other necessary actions.

▶ Table 10. Response guidelines to identify heat-related illnesses.

These are presented in order of increasing severity/urgency. One or more observations for a given diagnosis indicate a positive determination for that diagnosis.

Mild heat exhaustion	**Worker may say they feel:** Tired/fatigued Thirsty Weak Dizzy Lightheaded Likely to faint with change in posture or prolonged standing Muscle cramps	**Actions to follow:** Inform supervisor Move worker to cool area for recovery Encourage worker to drink water and consume electrolytes If symptoms persist after 15 min., treat as severe heat exhaustion
Severe heat exhaustion	**Signs:** Wobbly walking Slow reaction time Severe fatigue Severe muscle cramps Vomiting or collapse without any signs of heatstroke (see below) **Person may say they feel:** Severe fatigue Loss of appetite Nausea Headache Blurred vision	**Actions to follow:** Move worker to cool / air-conditioned area for recovery Encourage worker to lie down, drink water and consume electrolytes Cover head, neck, and shoulders with towels soaked in ice water and ensure the towels remain cold by re-soaking them every 2-3 min. If no ice/cold water is available, cool the worker's body with the most effective method available Watch for signs of heatstroke If there is little improvement in 15 min., arrange for medical treatment and continue to watch for possible heatstroke
Heatstroke	**Signs:** Collapse/fainting Loss of consciousness Vomiting Erratic/irritable behaviour Confusion/disorientation Garbled/gibberish speech Hysteria/delirium/apathy Shivering Convulsions **Person may say they feel:** Severe fatigue Nausea	**Actions to follow:** This is a situation requiring emergency response. Begin aggressive cooling (cover the worker's body in ice or place in cold/ice water bath). If ice-cold water or ice is not available, flush water over person from hose or shower, or keep the skin wet and fan. It is vital to cool the worker's body with the most effective method available Call emergency services and advise them that it is a heatstroke case

4.5 Role of workplaces in the mitigation of climate change impacts

Mitigating heat stress on a large scale can be achieved through various actions at the local, national and international levels aimed at reducing greenhouse gas emissions in the atmosphere, thereby addressing climate change. The specifics of these methods are not the primary focus of this report and have been detailed in many publications by international organizations (IPCC 2014a; IPCC 2014b; WHO 2020; WMO 2020; WHO 2021). However, it should be highlighted that, in their efforts to control heat stress, enterprises should adopt technologies and practices that also contribute to lowering greenhouse gas emissions in the framework of a just transition. Examples include:

- **Solar-powered cooling systems:** implementing air conditioning and cooling systems powered by solar energy helps maintain comfortable temperatures in workplaces without relying on fossil fuels, thereby reducing greenhouse gas emissions (Desideri et al. 2009; Al-Yasiri et al. 2022).
- **Green roofs and living walls:** installing green roofs and living walls can help regulate building temperatures naturally. Plants absorb sunlight and improve insulation, reducing the need for artificial cooling (Fernández-Cañero et al. 2013).
- **Energy-efficient ventilation:** upgrading to energy-efficient ventilation systems can improve air circulation and reduce excessive heat in industrial settings. These systems use less energy and emit fewer greenhouse gases compared to traditional ventilation systems (Zhao et al. 2023).
- **Smart building management systems:** utilizing smart technology to optimize building temperature and air quality can significantly reduce energy consumption and greenhouse gas emissions. These systems can adjust cooling based on occupancy and weather conditions (Eini et al. 2021).
- **Reflective or white roofing:** using reflective materials for roofing reflects sunlight away from buildings, reducing temperatures and the need for air conditioning (Bartesaghi Koc et al. 2018).
- **Insulation upgrades:** improving insulation in industrial buildings can mitigate heat stress more efficiently, reducing reliance on cooling systems and the associated greenhouse gas emissions (Ijjada and Nayaka 2022).
- **Natural cooling strategies:** designing buildings to maximize natural ventilation and cooling can reduce reliance on artificial cooling systems for mitigating heat stress. This includes strategic window placement, thermal mass construction and using shading devices (Bhamare et al. 2019).
- **Water recirculation and cooling systems:** implementing water-based cooling systems that recirculate water can be more energy-efficient and emit fewer greenhouse gases compared to traditional air conditioning systems (Al-Hadban et al. 2018).

Examples of workplace heat stress prevention and control plans

A number of heat stress prevention plans have been implemented in recent years. Selected examples from different regions across the world are summarized below.

Vision Zero Fund in Mexico and Viet Nam

ILO's Vision Zero Fund (or the Fund), a G7 initiative, aims to eliminate severe or fatal work-related accidents, injuries and diseases in supply chains. In 2002, the G7 tasked the fund to address the impact of climate change on OSH.

In Mexico, the Fund is working with the University of Colorado and the Mexican Institute for Social Security to establish a methodology to measure heat exposure and heat stress among greenhouse workers in the tomato and chili pepper sectors.

Stage 1 of the methodology entails observations, collection and analysis of data. Qualitative assessments will include discussing existing measures to address heat in the workplace as well as other potential solutions. Quantitative assessments on a subset of workers identified as having greater risk of heat stress will include data collection on environmental conditions, activity level and workload, hydration, potential heat associated symptoms and illnesses, heart rate, BMI, and skin and core body temperatures. Heat associated conditions monitored during Stage 1 include (but are not limited to): symptoms linked to heat exhaustion/heat stress/heatstroke, dehydration, metabolic rate/work intensity, acute kidney function change, inflammation, cognitive function, work injuries and near misses, mental health and well-being, and productivity.

Stage 1 findings will inform Stage 2, in which workplace adaptation measures will be designed, implemented and monitored. Key health indicators will be evaluated pre-, during and post-intervention to assess impact and inform next steps. Findings of the project will be used to recommend national regulatory improvements to address occupational heat stress, and to develop workplace-level guidance for employers.

In Viet Nam, the Fund commissioned research to identify opportunities for OSH adaptations to climate change in agricultural supply chains. The study included a comprehensive literature review, mixed-methods data collection in three provinces, and a synthesis of study results with evidence from global contexts. It had three main objectives:

1. Identify the main climate change-induced OSH hazards to which agricultural workers are exposed.
2. Understand worker perspectives on climate and health.
3. Recommend adaptive strategies to protect workers' safety and health.

Four primary climate change-related hazards were identified as impacting workers' safety and health, including increasing temperatures and heatwaves; extreme weather events; rising sea levels and salinity intrusion; and biological hazards.

Three key opportunities emerged during the analysis:

1. Adaptive strategies can address multiple climate hazards but should be tailored to agricultural sector and region.
2. Scientific rigour in implementation and evaluation design should seek to reduce inequities in climate impacts.
3. Adaptive strategies should address both physical and mental health impacts of climate change-related hazards.

The study recommended that pilot studies of adaptative strategies engage workers throughout their design, implementation and evaluation. A community-based participatory research approach is recommended to support uptake of recommendations and to facilitate understanding of the feasibility, effectiveness, sustainability and scalability of interventions.

Addressing indoor heat in Cambodian apparel and footwear factories

For workers in the apparel and footwear industries in Cambodia, heat stress is a daily reality. The ILO's Better Factories Cambodia[12] programme has been at the forefront of addressing this issue, implementing rigorous assessments to ensure safe working conditions across local exporting apparel and footwear factories.

From 2015 to 2022, the Better Factories Cambodia programme conducted nearly 3,000 assessments, setting a threshold of 32°C for acceptable indoor temperatures. Advanced dry globe temperature sensors were used to obtain consistent and reliable data, which highlighted the severity of heat conditions inside these factories. A recent analysis conducted by Cornell ILR Global Labor Institute and Schroders (2023), using Better Factories Cambodia's temperature data from 2015 to 2022, revealed striking findings:

- One in five factories experienced days with indoor temperatures exceeding 35°C.
- Nearly two-thirds of the assessments showed temperatures above the 32°C threshold.
- More than two-thirds of the factories violating the heat standard had indoor temperatures higher than the concurrent outdoor temperatures.
- Seasonal variations were observed, with indoor temperatures peaking during the hottest months from March to May. During this period, 80 per cent of assessments showed violations of the 32°C standard. The challenge was further compounded during the rainy season, when high humidity levels exacerbate heat stress, despite slightly lower average temperatures.

Despite these challenges, there are promising signs. The data indicates gradual improvement over time, with the percentage of factories violating the 32°C threshold decreasing from a high of 74 per cent in 2019 to 54 per cent in 2022. This progress, though slow, is a testament to ongoing efforts to improve working conditions.

A significant insight from the Better Factories Cambodia programme is the potential impact of improved cooling systems. For example, a large-scale apparel manufacturer near Phnom Penh managed to keep its indoor temperatures within the 32°C threshold by employing a combination of evaporative water-cooling systems, exhaust fans, high ceilings, and a heat shield on the roof.

The story of Better Factories Cambodia is one of gradual progress amidst persistent challenges. It highlights the critical role of consistent data collection and innovative solutions in creating safer and more sustainable working environments. Integrating wet-bulb temperature readings, which consider both temperature and humidity, could provide a more accurate picture of the heat stress faced by workers, particularly during the most humid months. As the industry continues to evolve, our commitment to better working conditions remains strong, aiming for a future where every factory is safe and productive.

12 Jason Judd, Angus Bauer, Sarosh Kuruvilla and Stephanie Williams (2023). Higher Ground? Report 1: Fashion's Climate Breakdown and its Effect for Workers. ILR Global Labor Institute and Schroders.

The HEAT-SHIELD warning platform in Europe

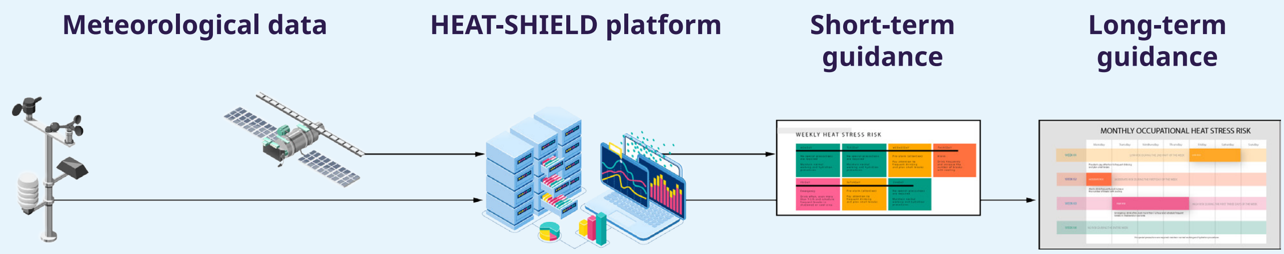
Well-established knowledge was used alongside emerging evidence to develop a heat stress warning system within the framework of the HEAT-SHIELD project, funded by the EU's Horizon 2020 research and innovation programme. The outcome was the first web-based platform offering both short-term (weekly) and long-term (monthly) guidance to protect the health and productivity of workers across an entire continent (Morabito et al. 2019).

The HEAT-SHIELD platform brings together data from the European Centre for Medium-Range Weather Forecasts to offer tailored excessive heat alerts for periods of up to a month (Morabito et al. 2019). By delivering precise information well in advance, the HEAT-SHIELD platform enables workers, employers, and other key stakeholders across different industries to plan and implement the most suitable prevention measures (Morabito et al. 2019).

The HEAT-SHIELD platform offers its users weekly maps for the upcoming four weeks, displaying the highest daily probability of surpassing a 27°C outdoor WBGT throughout Europe. These forecasts are general in nature and available to non-registered users (Morabito et al. 2019). The platform is designed to encourage users to sign up in order to receive customized information tailored to their specific workplace and individual needs. These personalized recommendations cover aspects such as appropriate clothing, hydration strategies and work/rest schedules (Morabito et al. 2019). Additionally, the platform utilizes email alerts to inform users and stakeholders about upcoming excessive heat exposures, thereby helping to protect the health and productivity of workers (Morabito et al. 2019).

▶ Graphical representation of the main components of the HEAT-SHIELD platform.

Meteorological data is utilized to create both short-term (weekly) and long-term (monthly) predictions for excessive heat exposures. These forecasts were subsequently converted into practical guidance for heat stress prevention over both short-term and long- term periods, aimed at workers, employers and other relevant stakeholders.



▶ The Adelante Initiative in Central America

The Adelante Initiative[13] was founded in 2017 to improve working conditions for sugarcane workers facing extreme heat and its consequences, including heatstroke and impaired kidney function. Ingenio San Antonio (a sugar plantation in Chichigalpa, Nicaragua), La Isla Network (a research and advocacy NGO), and Bonsucro (a sustainability certification platform) united to take action. The mechanics of the workplace heat stress prevention plan developed through the Adelante Initiative were conceptually simple:

1. Mandated breaks throughout the day across the entire year.
2. Mobile tents for accessible shaded rest during the mandated breaks.
3. Accessible purified water as well as isotonic solution made of purified water, electrolytes and carbohydrates.
4. Sanitation facilities in the field, to account for needs related to increased fluid intake.

Despite its conceptual simplicity, the heat stress prevention plan required innovative management and logistical solutions to function effectively on a 750 square kilometre (75,000 hectare) sugar plantation. To achieve this, Ingenio San Antonio and La Isla Network set a series of priorities (known as "the PREP methodology"):

- **Prevention:** Heat exposure and organizational systems are assessed, gaps addressed with employers and workers, and protocols implemented to prevent heat-related illnesses and accidents arising from excessive heat.
- **Resilience:** Measured through (1) the contribution of occupational interventions on the resilience of communities supplying the labour force, and (2) the impact that the reduction of incidence of heat-related illness has on the public health and social security systems.
- **Efficiency:** The use of physiological insights to ensure worker productivity is essential as employers are unlikely to adopt programmes that impair production targets.
- **Protection:** Careful assessment of excessive heat exposure and health outcome data informs impactful and achievable public and private sector policy recommendations to protect workers from heat-related illnesses.

In the first three years, the methodology reduced harm with a sharp decline (94 per cent) in cases of acute kidney injury arising from excessive heat, eliminated fatal incidences of heatstroke, increased productivity by 10-20 per cent and provided a 22 per cent positive return on investment as accidents, staff turnover and absenteeism were reduced.

The Adelante Initiative has emerged as a centre of excellence where sugar mills and other industries in the region learn to better protect their workforce, while researchers with La Isla Network assess new organizational and technical innovations.

▶ A group of sugar cane workers in Nicaragua.

Taking a mandated cooling break in a mobile tent as part of the heat stress prevention plan developed through the Adelante Initiative.

Photo credit: Ed Kashi/Redux. Permission required for reproduction.

13 https://adelanteinitiative.org/

The HeatSafe project in Singapore

Project HeatSafe[14] was a collaborative, multi-disciplinary research project seeking to understand how our warming climate affects the health, well-being and productivity of workers in Southeast Asia, as well as identify sustainable preventive policies and actions that can reduce these impacts. HeatSafe commenced in October 2020 and was funded by the National Research Foundation, Prime Minister's Office, Singapore.

An intervention study was conducted at an outdoor construction site in Singapore during May 2023. Findings from previous phases of the project, such as physiological and ethnographic profiling of outdoor construction workers, and the survey responses of site managers were taken into consideration when designing the heat stress prevention plan. Recommendations by the Singapore Workplace Safety and Health Council were also incorporated.

Participating workers were monitored for one day while they did their jobs following the typical process (normal work routine, practices and attire). The workers were then monitored one week later for another day, on which they were supported by a multi-component heat stress prevention plan designed to be scalable, sustainable and economically viable, consisting of:

1. Heat stress education: to increase supervisors' and workers' awareness of heat stress and heat-related illnesses through an educational video delivered in workers' native languages.
2. Scheduled breaks: three additional 15-minute rest breaks under shade during the workday.
3. Provision of cold water: increased access to cold water points and the use of an insulated bottle sleeve to keep workers' bottles cold.
4. Optimised work attire: provision of a set of work attire with enhanced heat dissipation properties.

Overall, the thermo-physiological and self-reported challenges faced by the workers were similar between the typical workday and the intervention day. However, on the intervention day workers clocked a 10 per cent higher step count and a 14 per cent higher step rate, suggesting a possible increase in productivity. Findings from the focus group discussions revealed positive perceptions of the prevention plan and workers were supportive of its implementation. Also, the findings demonstrated the feasibility and potential benefits of implementing this multi-component heat stress prevention plan at construction sites across Singapore.

▶ A group of construction workers in Singapore.

Taking a mandated cooling break as part of the workplace heat stress prevention plan developed through the HeatSafe project.

14 https://www.heatsafe.org/

▶ The Sri Ramachandra Institute workplace heat stress prevention plan in India

A study funded by the Government of India's Department of Science and Technology and executed by the Sri Ramachandra Institute of Higher Education and Research has shed light on the alarming consequences of excessive heat on workers in brick kilns. The study assessed 200 brick kiln workers in Chennai, Tamil Nadu, evaluating the workload across various jobs and classifying heat stress levels. Results showed that 53 per cent of workers were working in conditions above the recommended limits for workplace heat stress even during the cooler parts of the year. About 83 per cent of workers reported adverse heat-related illness symptoms, while 72 per cent of them were hypohydrated at the end of their shift. Regarding kidney health, 21 per cent of workers showed a low estimated glomerular filtration rate (<90 mL/min/1.73 m^2), an important marker of kidney function.

The research team worked alongside the brick kiln owner to implement a multi-component heat stress prevention plan within a 4-year period to reduce the exposure of workers to excessive heat and improve their overall health and well-being. Key aspects of the intervention included:

- Implementing shaded areas in the brick-making and drying sections to protect workers from prolonged exposure to direct sunlight.
- Enhancing sanitation facilities for workers, including improving toilet access.
- Introducing electric vehicles for carrying heavy loads to reduce manual workload and alleviate the physical strain on workers.
- Introducing health insurance schemes that support workers in accessing medical care and addressing health concerns.

After implementing these interventions, the owner of the brick kiln reported a 57 per cent increase in the productivity of his establishment, from 3.5 to 5.5 million bricks annually. He stated that this high level of productivity allowed his company to surpass the benchmark set by the local industry in productivity and efficiency. More importantly, measurements performed by the research team showed a significant reduction in the heat stress and thermoregulatory challenges experienced by workers and recorded significant improvements in their heat-related illness symptoms, including improved kidney function. The kiln-owner further acknowledged that, at the end of the prevention plan, the prevalence of worker attrition had been considerably reduced due to the company becoming a reputable employer. Based on this experience, he intended to hold out his kiln as a model for other proprietors of brick kilns, setting a benchmark for how the well-being of workers and favourable business outcomes can complement one another.

▶ Brick kiln labourers in India.

Working under the sun in the brick-making section of the worksite (top left) and after the area had been covered to provide shade (bottom left), as well as during manual carrying of the bricks (top right) and after the provision of electric vehicles for carrying heavy loads (bottom right) as part of the heat stress prevention plan developed through the project.

Photo credit: India - Heat Team Research at the Sri Ramachandra Institute of Higher Education and Research.

PART C

Where do we go from here?

5. Key findings and lessons learned

Heat is an invisible force - a silent killer. As record-breaking temperatures continue across various regions, more workers than ever before are losing the fight against excessive heat. The intensification of excessive heat not only jeopardizes the safety and health of workers, but also undermines the resilience of economies and the potential for decent work on a global scale.

This hazard leaves both indoor and outdoor workers at increased risk of health impacts such as heat exhaustion, heatstroke, cardiovascular and respiratory conditions, and death. This is not to mention the various mental health effects and increased risk of workplace accidents and injuries. Moreover, when it comes to chronic health impacts such as kidney disease and others, we may only be seeing the tip of the iceberg.

What we know is that across the world, at least 2.41 billion workers were exposed to excessive heat in 2020 (more than 70 per cent of the workforce), leading to more than 22.85 million occupational injuries and 18,970 deaths.

Excessive heat transcends geographical boundaries and impacts regions differently. It is now affecting countries previously unaccustomed to such extreme heat exposure, while exacerbating conditions in regions already grappling with high temperatures.

In regard to excessive heat exposures:

- The Africa, the Arab States, and Asia and the Pacific regions were ***above the global average*** of the workforce exposed to excessive heat (71.0 per cent), at 92.9 per cent, 83.6 per cent and 74.7 per cent respectively.
- Europe and Central Asia region had the greatest ***increase*** in excessive heat exposure, with a 17.3 per cent increase from 2000 to 2020. This is almost double the global average increase (8.8 per cent from 2000 to 2020).

When it comes to occupational injuries attributable to excessive heat:

- The Africa and Americas regions had the ***greatest proportion*** of occupational injuries attributable to excessive heat, at 7.2 per cent and 6.7 per cent of all occupational injuries, respectively.
- The Americas, along with the Europe and Central Asia region, were found to have the most rapidly ***increasing proportion*** of heat-related occupational injuries since the year 2000, with increases of 33.3 per cent and 16.4 per cent respectively. This may be due to quickly increasing temperatures in usually temperate regions where working populations are largely not acclimated to periods of excessive heat.

Occupational exposures and injuries occur during and outside of heatwaves. This report found that:

- Nine out of ten workers were exposed to excessive heat outside of the time of a heatwave.
- Eight of ten occupational injuries linked to excessive heat occurred outside of the time of heatwaves. This indicates the importance of preventative safety and health measures for workers during hot periods and not only during heatwaves (when crisis response plans are usually activated).

From a financial perspective:

- Implementing OSH measures to prevent occupational injuries related to excessive heat could save over US$361 billion globally. In the most impacted low- and middle-income economies, this is equivalent to about 1.5 per cent of the national GDP.

Given these staggering figures, what has been the global OSH response?

In most countries, provisions referring to heat in existing OSH laws are often general and do not adequately address the intensifying climate change-related dangers many workers face daily. However some countries are now revising their laws or developing new specific regulations to address heat. These commonly include occupational exposure limits in the form of temperature thresholds and guidelines for adaptive measures at the workplace level. In line with the ILO List of Occupational Diseases, a number of countries recognize heat-related diseases as occupational diseases.

In this report, an analysis of national legislation to address heat stress from 21 countries showed some common provisions for workplace level measures:

- Participatory risk assessment in the working environment integrating excessive heat.
- Identification of and targeted strategies for worker groups at high risk, including outdoor and indoor workers, those in informal economies and MSMEs, among others.
- Use of the WBGT as a potential heat stress indicator to assess the level of heat exposure, with varying safety thresholds based on work intensity.
- Hydration strategies, including adequate sanitation facilities, especially for female workers.
- Rest, breaks or modified work schedules to limit or avoid exposure to excessive heat, including the ability to self-pace.
- Provision of cool, shaded and ventilated rest areas.
- Heat acclimatization measures for workers without recent heat exposure.
- PPE designed to protect workers from heat stress.
- Education and awareness on heat stress and heat-related illnesses.
- Regular medical check-ups and health monitoring.

Key takeaways

- **Prevention and control strategies for heat stress in the working environment need to be strengthened as a matter of urgency.** Existing strategies to combat heat stress are proving inadequate, especially in the context of rising temperatures and changing weather patterns. Despite the presence of laws and regulations aimed at safeguarding workers from heat stress many of these provisions were established in the past, often with basic requirements that fail to address the complexities of contemporary heat stress challenges.
- **Heat action plans and public health campaigns should integrate OSH protections.** Workers should be at the heart of heat action plans, early warning systems and other heat related public health efforts. Excessive heat and heatwaves should be treated as OSH hazards. OSH considerations should be incorporated into broader strategies and action on climate change and just transition.

- **The safety and health of workers should be protected during all periods of excessive heat, not only during heatwaves.** As the majority of worker exposures and injuries linked to excessive heat occur outside heatwaves, protective measures should be applied whenever excessive heat poses a risk to worker safety and health, not just during heatwaves. A rights-based approach for workers is needed, which includes the fundamental right to a safe and healthy working environment, the right to know about heat stress and the right to remove themselves from dangerous situations.
- **Tailored strategies for different sectors, and both indoor and outdoor workers, should be developed and implemented.** Heat stress disproportionately impacts certain sectors and occupations, which are both in outdoor settings but also indoor, with some in particularly vulnerable situations such as in factories (e.g., female workers in the garment sector). Tailored strategies that are practical and low-cost should be made available for informal and MSME settings.
- **OSH management systems should integrate heat stress prevention and control measures.** Workplace-level risk assessments and preventive and control strategies should explicitly incorporate heat stress considerations and require direct input from workers.
- **Workplace protection practices can be simple and affordable.** Scientific evidence has shown that many effective ways to protect workers are inexpensive and easy to implement. These include the provision of adequate hydration; work breaks with cool, shaded and ventilated rest areas; modified work schedules; and heat acclimatization programmes.
- **Social dialogue must be the foundation for action.** Stakeholders at all levels must prioritize social dialogue as a fundamental component of developing and implementing OSH policies and strategies on heat stress, with workers and their representatives trained and empowered to participate in these processes. A number of critical collective bargaining agreements have been adopted to address specific conditions for different sectors, detailing procedures and protocols to deal with excessive heat in the workplace.
- **International, inter-governmental and cross-sector collaboration should be a priority.** Collaboration between governments, employers and workers' organizations, international organizations, OSH networks and non-governmental organizations (NGOs) is essential to share knowledge, resources and best practices addressing workplace heat stress. Policy coherence should be ensured on heat stress-related issues that concern the world of work, especially between Ministries of Labour, Ministries of Health, Ministries of Environment and Ministries of Climate Change, as they begin to become established.

- **Targeted empirical research is urgently needed to improve knowledge and fill policy gaps.**

At the national level, more evidence is needed on the effectiveness of specific interventions by sector and occupation, taking into account geographical specificities. The roll out and implementation of new national policies should be systematically monitored and periodically re-evaluated to ensure that they reflect the latest research findings and address emerging risks and heat stress trends.

In regard to data collection, heat-related illnesses arising from excessive heat are significantly under-reported. It is crucial to standardize recording and notification systems, in order to develop comprehensive databases that integrate heat stress data and occupational health information.

At the workplace level, the design and evaluation of novel technologies is urgently needed, especially when it comes to artificial intelligence (AI) assisted interventions, alert systems and effective cooling techniques. There must be a balance between practicality and cost implications for informal and low-resource settings.

Strengthened global collaboration among experts on heat stress and OSH is necessary to avoid ad hoc and isolated assessment methodologies and interventions. Experts can then work together to propose harmonized and evidence-informed heat assessment and intervention models and protocols. Such a coordinated effort will serve to enhance the science-policy interface and recommendations.

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Annex I

Methodology for the estimates of population exposed to workplace heat stress and the global burden of occupational injuries attributable to workplace heat stress

To assess the impact of heat stress on occupational injuries, this methodology integrated climate models, global temperature projections, labour force data and occupational health information. Overall, the methodology aimed to assess the global, regional, and national number of people exposed to excessive heat, as well as the numbers for injuries and excess deaths associated with excessive heat, using the latest data available to the ILO and a two-stage analysis strategy.

Climate data

The first step of the study included analysing global temperature changes using climate models, which divide the world into small geographical areas known as grid cells. Each grid cell covers an area of approximately 55 km x 55 km at the equator (0.5° x 0.5°), resulting in a total of 58,843 grid cells across the Earth's surface. Daily maximum temperatures at a height of 2 metres were collected from various climate models, which were accessed through the Copernicus Climate Change Service. These climate models include:

- Essential climate variables for water sector applications derived from climate projections (Copernicus Climate Change Service 2018a).
- Agrometeorological indicators from 1979 to the present derived from re-analysis (Copernicus Climate Change Service 2018b).
- CMIP6 climate projections (Copernicus Climate Change Service 2018c).
- CMIP5 daily data on single levels (Copernicus Climate Change Service 2018d.)

For each of these climate projection experiments, both the 4.5 and 8.5 representative concentration pathways (RCP) and several independent climate simulation runs were considered.

- The RCP 4.5 represents a scenario in which greenhouse gas emissions, particularly carbon dioxide (CO_2), increase at a moderate rate throughout the 21st century and then start to decline by mid-century. This pathway is characterized by efforts to reduce emissions through various policies and technologies, resulting in a radiative forcing of approximately 4.5 W/m^2 by the year 2100. RCP 4.5 is associated with a global temperature rise of between 2°C and 3 °C by 2100.
- The RCP 8.5 represents a high emissions scenario where greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases continue to rise significantly throughout the 21st century. RCP 8.5 is often used as a high-end emissions scenario in climate modelling to assess the potential impacts of unchecked greenhouse gas emissions on the global climate system. It is associated with a significant increase in global temperatures. This scenario predicts a global average temperature increase of around 4.5°C or more by the end of the century compared to pre-industrial levels.

Population data

The analysis utilized population data from the Gridded Population of the World, v4 which is based on United Nations population estimates (CIESIN 2016). These data provide population estimates for the years 2000, 2005, 2010, 2015 and 2020. To align with the climate data grid, the population data were grouped into 0.5° x 0.5° grid cells. For grid cells spanning multiple countries, population figures were calculated based on the land area occupied by each country within the cell, using bilinear extrapolation.

Labour force and occupational injuries data

Data on the labour force were sourced from the ILO's statistical database (ILOSTAT 2023). National estimates of labour force-to-population ratios were applied to the population data for each grid cell relevant to the country under analysis. National estimates of occupational injuries were obtained from the ILO's Global Estimates of Occupational Accidents and Work-Related Illnesses for the year 2023 (ILO 2023c) and were subsequently applied to the labour force data for each grid cell.

Relative risk data

The relative risk data were adopted from a recent systematic review and meta-analysis of epidemiological evidence based on a total of 22 studies representing almost 22 million occupational injuries. The analysis reported that the overall risk of occupational injuries increased by 1 per cent (RR 1.010, 95 per cent CI: 1.009 –1.011) for 1°C increase in temperature above reference values and 17.4 per cent (RR 1.174, 95 per cent CI: 1.057–1.291) during heatwaves (Fatima et al. 2021).

The analysis also used the "population attributable fraction" (PAF) for occupational injury based on previous large-scale meta-analytic data (Fatima et al. 2021). This is the fraction of all occupational injuries in the workforce that is attributable to exposure to excessive heat. It is calculated as the observed number of occupational injuries minus the expected number of occupational injuries under no exposure to excessive heat, all divided by the observed number of occupational injuries. In other words, the PAF is the estimated fraction of all occupational injuries that would not have occurred if there had been no exposure to excessive heat.

Burden of disease calculations

The correlation between projected temperature, heat stress and the occupational burden of disease was estimated by employing a combination of data sources and a model within the framework of the global Comparative Risk Assessment (Ezzati et al. 2002). The Comparative Risk Assessment framework organizes risk factors and health outcomes, allowing the quantification of exposure to specific risk factors and the associated disease burden (Ezzati et al. 2002).

Combining information on prevalence of exposure to a defined risk factor with information about the increased risk of the incidence of or mortality from a defined health outcome among people exposed to the risk factor allows the calculation of the PAF for this pair of risk factor and health outcome (i.e. the proportional reduction in death or disease from this health outcome that would occur if exposure to the risk factor were removed or reduced to a counterfactual exposure distribution).

Population attributable fractions

The PAFs were calculated using prevalence estimates from the gridded climate models and risk ratios for exposure to high temperatures and heatwaves, based on previous methodology (Fatima et al. 2021). The formula used for calculating the PAF^i for each geographic cell *i* was as follows:

$$PAF^i = \frac{P_e^i(RR^i - 1)}{1 + P_e^i(RR^i - 1)}$$

where, P_e^i represents the proportion of the workers exposed to high temperatures, RR^i is the relative risk at geographic cell *i*.

Attributable burden

Applying the PAF to the total burden of the health outcome allowed the determination of the total number of deaths, DALYs and injuries attributable to excessive heat.

Uncertainty range calculations

To account for potential bias and errors in our estimates, uncertainty ranges were calculated for exposure, death, DALYs and incidence estimates using Gaussian error propagation. It was assumed that uncertainties followed a normal distribution, with the 2.5 per cent and 97.5 per cent quantities defining the lower and upper limits of the uncertainty range respectively.

Sensitivity analyses

The following sensitivity analyses were conducted to test the robustness of the findings:

1. Calculating estimates based on different climate predictions.
2. Using the WHO/ILO Joint estimates (WHO/ILO 2021) and Global Burden of Disease estimates for the years when available for burden envelope calculations.
3. Using various temperature threshold values.

Methodology for the estimates of the global burden of chronic kidney disease attributable to excessive heat

Working under excessive heat can lead to occupational illnesses with long latency periods, such as chronic kidney disease. The present report combined meta-analytic findings with global climate models, temperature projections and labour force data at a spatial resolution of 0.25°×0.25° to estimate the global, regional and national burden of chronic kidney disease attributable to excessive heat.

Population data

Population data were obtained from the Gridded Population of the World (v4) which is based on United Nations population estimates (CIESIN 2016) (offering estimates for the years 2000, 2005, 2010, 2015 and 2020 at a resolution of 2.5 arc-minute (approximately 5km). The analysis utilized the 2020 population count estimates.

Labour force

Labour force data were sourced from the ILO's statistical database, specifically the annual modelled estimates in thousands of employment by sex and economic activity of 2023 (ILOSTAT 2023). These data were combined with population data to determine labour force distributions. In our analysis, we utilized the 2022 values for each country, categorized by detailed economic activity.

Climate data

Global temperature projections were obtained using the ssp1-1.9 climate model at a resolution of 35 arc-minutes (approximately 70 km) from the CMIP6 climate projections provided by the Copernicus Climate Change Service (Copernicus Climate Change Service 2018c). For the present analysis, the monthly average temperatures at the 1000hPa level were utilized.

Burden of disease calculations and population attributable fraction

A recent systematic review and meta-analysis of epidemiological evidence based on a total of 22 studies representing almost 22 million occupational injuries identified reference values for temperature beyond which occupational injuries rise (Fatima et al. 2021). Also, previous meta-analytic data encompassing data from nearly 22 thousand workers showed that 15 per cent of individuals who typically or frequently work in excessive heat conditions develop chronic kidney disease (Flouris et al. 2018b). The burden of disease was estimated by combining information on the prevalence of exposure to excessive heat with information about the increased risk of the incidence of chronic kidney disease when working in a hot environment.

This estimate is also in line with data from the WHO and Sri Lanka Ministry of Health (Elledge et al. 2014) and is the fraction of all chronic kidney disease cases in the workforce that is attributable to heat stress alone, excluding any other potential causes or contributing factors. The PAF is calculated as the observed number of chronic kidney disease cases minus the expected number of chronic kidney disease cases under no heat stress exposure, all divided by the observed number of chronic kidney disease cases.

Sensitivity analyses

The following sensitivity analyses were conducted to test the robustness of the findings:

1. Using the WHO/ILO Joint estimates (WHO/ILO 2021) and Global Burden of Disease estimates for the years available for burden comparisons.

2. Using various temperature threshold values.

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