World Health Organization

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Climate change and workplace heat stress

technical report and guidance

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ISBN (WHO) 978-92-4-009981-4 (electronic version)
ISBN (WHO) 978-92-4-009982-1 (print version)
ISBN (WMO) 978-92-63-11376-4

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Suggested citation. Climate change and workplace heat stress: technical report and guidance. Geneva: World Health Organization and World Meteorological Organization; 2025. Licence: CC BY-NC-SA 3.0 IGO.

Cataloguing-in-Publication (CIP) data. CIP data are available at http://apps.who.int/iris.

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Cover photo and credit: Silhouette of construction workers on scaffolding under a hot sun. © Dreamstime.com / Andreas Karelias

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Foreword

Increasing temperatures and temperature extremes caused by climate change means that occupational heat stress has become a global societal challenge, which is no longer confined to countries located close to equator. This World Health Organization (WHO) and WMO Technical Report is a much-needed update of the important technical report published in 1969 by the World Health Organization (WHO) and makes an important contribution to our understanding of occupational heat stress and its consequences.

In the present report, experts in the field provide an up-to-date overview of the spread and consequences of intensified environmental heat stress, how it affects workers' health, and how it impacts individual and national economies. They also outline strategies for occupational heat action plans and how to implement practical solutions to reduce the risks associated with heat stress to ensure workers live healthy and productive lives.

Evidence-based guidance towards creating supportive environments with safe work practices and occupational heat action plans are crucial for effective prevention and treatment of occupational heat stress, particularly for workers undertaking hard manual labor. Billions of people are already exposed to heat stress that elevates the risk for a range of illnesses and diseases and the impact on health and well-being will aggravate with global warming if occupational heat stress is not effectively addressed.

Nations have set ambitious targets to promote safe and secure working environments; reduce the exposure and vulnerability of poor and those in vulnerable situations to climate-related extremes; strengthen the capacity of countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks by 2030 thanks to the Sustainable Development Goals planning process. The present report provides the scientific background to support these ambitious aims and informs the actions that governments need to take to prevent and control occupational heat stress, especially in light of climate change.

Based on the evidence presented in this report it is clear that greater mobilization is needed from many sectors of government and civil society as well as from workers themselves, and also employers and experts in occupational and environmental health.

The report reminds us that effective mitigation of occupational heat stress takes a collective consensus and public investment in interventions that are affordable, cost-effective, and based on the best available evidence.

Please join me in ensuring that the findings of this report are taken up and its recommendations implemented so that we may truly prevent the consequences of occupational heat stress.

Dr. Maria Neira
Director for Environment,
Climate Change and Health
World Health Organization

Ko Barrett
Deputy Secretary-General
World Meteorological Organization

Prelude

This comprehensive report represents a significant step forward in our collective efforts to address one of the most pressing challenges of our time: protecting workers from the escalating risks associated with extreme heat in the context of climate change.

The report offers an in-depth analysis of the multifaceted impacts of rising heat levels on occupational safety and health. It details the physiological, socioeconomic and productivity-related consequences of heat stress across a diverse range of work environments. Its evidence-based recommendations resonate strongly with the International Labour Organization's (ILO's) mandate and ongoing commitment to provide safe and healthy working environments as a fundamental labour right of all working people.

The report and the technical guidance of WHO and WMO complement the findings of the recent ILO reports Ensuring safety and health at work in a changing climate and Heat at work: Implications for safety and health (1, 2) which highlight that more than 2.4 billion workers are exposed to excessive heat globally, resulting in more than 22.85 million occupational injuries. We join the WHO and WMO in underscoring the urgency of adopting proactive measures that protect workers in vulnerable situations, especially those in sectors where exposure to heat is a daily reality.

In this light, the current report reinforces our shared objectives, as articulated under the recent United Nations Secretary-General's Call to Action on Heat. By harmonizing efforts and drawing on the best available scientific evidence, we can accelerate the implementation of practical interventions that reduce heat-induced risks, improve work conditions, and contribute to sustainable development.

Policymakers, employers as well as workers and their organizations and representatives will benefit from this report as a framework to anticipate, assess and manage the adverse effects of workplace heat stress.

The ILO reaffirms its commitment to supporting national and international efforts aimed at enhancing occupational safety and health. We are confident that the actionable strategies presented herein will not only strengthen our collective response to climate-induced hazards but also serve as a catalyst for transformative change in workplace practices worldwide.

Together, through sustained collaboration and innovation, we can build safer, healthier and more resilient work environments for all.

Joaquim Pintado Nunes
Branch Chief, Occupational Safety and Health and Working Environment Branch (OSHE)
International Labour Organization (ILO)

Acknowledgments

WHO and WMO would like to convey their gratitude to the HEAT-SHIELD project and its consortium that spearheaded thispublication, as well as to all those whose endeavours have helped facilitate the creation of this publication. The quality of this technical guidance is attributed to the invaluable input from international experts who contributed to its conceptual development, evaluated its technical content, and participated in the peer review process.

The development of this publication was guided and overseen by the following editors: Andreas D. Flouris (University of Thessaly, Greece), Lars Nybo (University of Copenhagen, Denmark), Tord Kjellstrom (Health and Environment International Trust, New Zealand), Joy Shumake-Guillemot (WHO/WMO Joint Office for Climate and Health Office), and Ivan Dimov Ivanov (WHO Occupational and Workplace Health Programme).

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The following reviewers provided feedback, guidance and input in developing this publication: Christian Schweizer (Department of Environment, Climate Change and Health, WHO), Dorothy Ngajilo (Ministry of Health, Community Development, Gender, Elderly and Children, United Republic of Tanzania), Leonidas G. Ioannou (Jožef Stefan Institute, Slovenia), Tiago Sotto Mayor (University of Porto, Portugal), and George A. Gourzoulidis (Ministry of Labour and Social Affairs, Greece).

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The editors are indebted to the HEAT-SHIELD project and its consortium, which spearheaded this publication.

Funding for the development of this guidance has been provided by the European Union's Horizon 2020 research and innovation programme (project HEAT-SHIELD; Grant agreement No 668786) as well as WHO and WMO corporate funds. Funding for the layout, graphic design and translations of this publication has been provided by the WHO Beat the Heat Flagship Initiative kindly supported by Fédération Internationale de Football Association (FIFA).

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Executive **Summary**

Climate change implies that the health challenge associated with environmental heat stress will increase in intensity, and its direct as well as indirect negative effects will spread geographically.

Adverse consequences of high environmental temperatures are currently experienced by approximately half the global population.

They particularly affect health and quality of life for the most vulnerable citizens in developing countries, with children, older adults, and people living in poverty at highest risk of death and disease during extreme heat events. However, it is important to address the major negative health and productivity effects experienced by millions of manual workers exposed to workplace heat stress on a daily basis. These effects may affect not only individual livelihoods, but also family income and jeopardize the reduction of poverty – particularly in regions highly dependent on manual work, such as the agriculture, construction and fishing sectors.[1]

Available evidence

The present guidance provides an overview and update of relevant evidence generated since 1969, when the technical guidance Health factors involved in working under conditions of heat stress was published by the World Health Organization.

The World Meteorological Organization has reported that 2024 was the warmest year on record, with the global temperature averaging 1.45°C above pre-industrial levels. The past ten years (2015–2024) have been the warmest on record, underscoring the continuing long-term trend of rising global temperatures due to climate change. The rise in global temperatures and especially the increased frequency of extreme heat events during the five decades since the publication of that seminal guidance underscore the need to update stakeholders. This guidance describes increased exposure risks, new discoveries and novel methodologies in the area of workplace heat stress, and evidence on solutions to prevent or minimize its negative consequences.

In the last decade, many studies have provided conclusive evidence that workplace heat stress directly threatens workers' ability to live healthy and productive lives, and leads subsequently to worsening poverty and socioeconomic inequality. The World Health Organization and the World Meteorological Organization recognize the undeniable increased exposure of workers to warmer conditions. In response, they have supported the development of this guidance as a frame of reference for managing workplace heat stress and mitigating its impacts on health and productivity. The guidance aims to summarize the latest scientific evidence and provide examples of effective interventions and practices for public health policymakers, employers, workers and health service providers.

Global burden – health and wealth implications

Billions of working people already experience significant threats to their health, but those who frequently work in hot indoor and outdoor conditions suffer additional physiological strain as well as an increased risk of ill health.

These include hyperthermia, abnormal kidney function, dehydration and neurological dysfunction. In addition, worker productivity decreases by 2–3% for every degree increase beyond 20°C in wet-bulb globe temperature (WBGT).

Avoiding heat exposure or reducing physical activity may lower health risks, but this is not compatible with the ability to live healthy and productive lives. It also has implications for individual income as well as national economies and wellbeing. These impacts are highest for countries, industries and individuals directly dependent on manual work, but there are indirect and broader geographical and economic impacts on distal sectors, such as those relying on stable food prices and value chains affected by primary sector productivity.

Prevention of heat stress in the workplace

Public heat-health warning systems, national or city-scale prevention programmes, and specific personal behaviours are designed to protect vulnerable populations in the general public from excess morbidity and mortality during periods of extreme heat.

However, these approaches often have limited relevance for workers who must generally sustain some level of productivity to prevent the halt of economic activity. Additional, tailored measures and regulations are required to protect workers.

This guidance provides information on the design of occupational heat action programmes and how they can be translated into specific actions (for a given industry/type of job) with the dual aim of mitigating the excess risks for morbidity and mortality, and preventing or minimizing productivity losses.

Occupational heat action programmes should be created through collaboration among key stakeholders, including but not limited to employers, business and industrial associations, workers and their representatives, trade unions, health-and-safety experts and representatives of local authorities. The action programmes should mitigate workplace heat stress, while considering practical feasibility, economic viability and environmental sustainability.

Workplace heat stress monitoring

Assessment of workplace heat stress should evaluate a range of job and personal risk factors, while also considering issues related to a worker's return to work after severe health outcomes associated with heat illness.

Employers, public agencies or work groups can make a qualitative judgment about the risk of workplace heat stress as an initial step towards recognizing the problem.

This initial assessment can be further confirmed by quantitative methods that provide detailed data on whether a workplace or task presents a high risk of workplace heat stress. This may then trigger the development and implementation of an occupational heat action programme designed to mitigate it.

A construction worker wiping sweat from his forehead on a hot worksite.
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Conclusions and recommendations

This guidance underscores the importance of the workplace heat stress problem and provides evidence-based guidance to reverse current trends. Sustainable Development Goals no. 1 (no poverty), no. 3 (good health and well-being), no. 8 (decent work and economic growth) and no. 13 (climate action) all provide a strong basis for developing much-needed policies to address this complex challenge.

This guidance can support countries and organizations by informing more effective policies and action programmes for protecting health and productivity in the context of climate change.

Public health policymakers, employers, workers as well as health and meteorological service providers can take a series of important actions to manage workplace heat stress and alleviate its negative impacts on human health and productivity.

A group of people including construction workers and officials, gathered at a building site. © iStockphoto.com / Joa_Souza

These include the following:

- Develop occupational heat-health policies, plans and advisories to address local weather characteristics as well as job and worker specificities.
- Give particular attention to certain population groups such as middle-aged and older individuals, those who are physically unfit, and people with chronic health conditions. These populations are more vulnerable to the physiological strain caused by workplace heat stress.
- Train first responders, health experts, employers and workers about the mild and severe health outcomes associated with workplace heat stress. While the treatment for most of these conditions is well known, they are often misdiagnosed or go unrecognized, and this can have serious negative effects on patient health.
- Co-create occupational heat-health policies and programmes with key stakeholders, including managers and employers, workers, trade unions, representatives of self-employed persons, experts in environmental, physiological, ergonomic safety, health and safety representatives, occupational health experts, and representatives from local authorities. Engagement with the general public is also important.
- Design occupational heat-health policies and programmes that mitigate workplace heat stress, while taking into account the practical feasibility, economic viability and environmental sustainability of the recommended strategies.
- Adopt technological solutions to augment both work safety and productivity.
- Support the implementation of research on the efficacy of occupational heat-health advisories and relevant policies to ensure the highest level of protection for workers.

Introduction

Since its publication in 1969, the WHO technical report series no. 412, titled *Health factors involved in working under conditions of heat stress: report of a WHO Scientific Group (3)*, has been a valuable framework for national and subnational governments and stakeholders responsible for planning or implementing prevention programmes to address heat stress for working people.

The rise in global temperatures and the increased frequency of extreme heat events since the publication of the original guidance underscore the need to update stakeholders. In 2019, five decades after the publication of that seminal publication, the HEAT-SHIELD consortium proposed to WHO and WMO an update of the original 1969 guidance. Members of the HEAT-SHIELD consortium were joined by experts from across the world to form a Working Group and initiated an in-depth synthesis of evidence on recent physiological, epidemiological, ergonomics and environmental research and lessons learned from the implementation of heat-health action plans in occupational settings. (The methodology used for the review of the evidence is described in the annex.) The present technical guidance presents the review's findings in the form of an overview of relevant recent evidence with clear implications for the prevention of health effects caused by exposure to heat stress in the workplace. It is intended for public health policymakers, employers, workers and health service providers, as well as other relevant stakeholders to support their own processes or procedures.

The technical guidance is based on the findings of a number of literature reviews, focusing on:

- climate change and the future of work
- assessment, monitoring and management of workplace heat stress
- global burden of workplace heat stress
- work productivity and heat
- acclimatization and adaptation to heat
- occupational heat-health action plans
- heat-health governance
- risk perception.

A farmer leading a horse through ploughed fields in a rural landscape. © iStockphoto.com / Nailotl Mendez

Beyond a thorough appraisal of the extant scientific literature, this technical guidance also encompasses elements of so-called "grey literature", such as technical documents and studies published by governmental and international entities. This inclusion is strategic, essential for understanding the pragmatic and operational implications for preventative measures at national and regional levels. Taken together, the sources of evidence used in the present technical guidance constitute a much broader foundation from which to look at occupational heat-health action planning than was available when the 1969 WHO guidance was published.

This technical guidance also considers the empirical data accumulated especially over the past decade, and new findings related to the links between climate change, workplace heat exposure and health. Large compilations and efforts, such as the Intergovernmental Panel on Climate Change (IPCC) Working Group II's contribution to the sixth assessment report, document both ongoing and expected climate change and its impacts. These reports project more frequent and severe heat stress problems for people in a number of occupations. They also extensively cover actual and potential links between climate change adaptation and health, including occupational heat-health risks *(4)*.

Part 1: Climate Change and Heat Exposure at Work

Key Messages

- Climate change results in **increasing temperature** of the near-surface air and **more frequent heatwaves** affecting workers indoors and outdoors.
- Under typical temperate conditions, healthy individuals at rest regulate their core body temperature between 36.5°C and 37.5°C. However, **this balance is easily disturbed during exposure to hot environments and/or physical work** – both of which are often observed in occupational settings.
- The term workplace heat stress describes circumstances under which a worker's **body accumulates heat** due to the combined effects of metabolic heat, environmental factors and clothing worn.
- Workplace heat stress **causes physiological heat strain** in the body that can lead to exhaustion, pathological conditions and death.
- To sustain an eight-hour work shift, core body temperature should not exceed 38°C. **Sustaining higher core body temperatures will lead to shortening of the work shift** and an increase in the risk of heat-related health outcomes.
- The principal mechanism for heat loss during work in warm/hot environments is **sweat evaporation from the surface of the skin**, a process that is undermined when the level of humidity is high and/or when multiple, insulating, impermeable layers of clothing are worn.

Climate change has far-reaching consequences that go beyond the immediate physical effects on the environment. A key impact of climate change is that it undermines the health of working people by increasing the temperature of workplaces, creating conditions that can be dangerous to workers' health.

Changes in temperature can also reduce people's ability to work, affecting economic activity in many industries. These effects of climate change are primarily felt by those who work outdoors, making it difficult to perform their work adequately and leading to increased rates of absenteeism. Potential disruptions in productivity affect millions of people in heat-vulnerable sectors such as agriculture and construction *(5)*, but also undermine primary production and trade, while creating significant spillover effects on the economy *(6, 7)*.

A group of firefighters walking through grassy terrain toward a large wildfire, with heavy smoke and the sun glowing through the haze.
© iStockphoto.com / Tony Bendele

1.1. Climate change and the future of work

Climate change is impacting everyone, but workers are the largest vulnerable group. Workers in nearly every sector can be affected by increasing ambient temperatures. Outdoor workers and first responders are particularly vulnerable to heat, but indoor workers can also be at risk, particularly if they work in heat-intensive industries or perform intense physical work *(5, 8, 9)*.

Extreme heat events, commonly known as heatwaves, are prolonged periods of abnormally hot weather, lasting from several days to months, when both daytime and nighttime temperatures exceed typical regional averages *(10)*. High nighttime temperatures are particularly concerning because they prevent essential cooling and prolong heat accumulation into the next day *(10-12)*. Local factors such as geography, urbanization and climate strongly influence heatwave characteristics *(10)*. High humidity, low wind and urban heat islands can intensify heatwaves and their health impacts *(13)*.

Global climate change is the primary driver behind the increasing frequency and severity of heatwaves, which are now spreading into new regions and seasons. The Intergovernmental Panel on Climate Change (IPCC) projects that every additional 0.5°C of global warming significantly raises the risk of longer and more severe heatwaves *(14)*.

The IPCC reports document ongoing and expected climate change and its impacts, projecting more frequent and severe heat stress problems for people in a number of occupations *(4)*. These projections show the expected differences between four representative concentration pathways (RCPs) used to calculate global mean temperature within an array of climate models *(15)*:

- RCP8.5 is a projection with no actions to reduce greenhouse gas emissions (so-called business as usual), causing a likely increase of 2.6°C to 4.8°C in global mean near-surface air temperature by the year 2100. The global mean temperature change would then double in the 22nd century.
- RCP6.0 is a pathway that fits with many existing national climate change projection policies; it would cause an estimated 1.4°C to 3.1°C increase of global mean temperature during this century, and there would be some additional increase in the next century.
- RCP4.5 approximately fits the recommendation from the 2015 Paris Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC/COP) (16) to maintain the global mean temperature increase below 2°C.
- Finally, RCP2.6 would limit the global mean temperature to a maximum increase of 1.7°C, with a decreasing trend in the second half of the 21st century.

A warehouse worker in a reflective vest sitting with eyes closed, resting his head in his hand. © iStockphoto.com/ FG Trade

Even in the case of RCP2.6 (the most optimistic scenario with the lowest level of climate change imaginable), the IPCC reports project significant changes in regional climate, both on land and in the oceans *(17)*. In relative terms, the regions where the climate will shift the most towards dangerous heatwaves are the mid-latitudes *(17)*, which include the Earth's subtropical and temperate zones that lie between the tropics and the polar circles (between the Tropic of Cancer and Arctic Circle, and between the Tropic of Capricorn and Antarctic Circle). Heatwaves are expected to become more frequent in these regions, particularly in central and eastern North America, central and southern Europe, the Mediterranean region, western and central Asia, and southern Africa *(17)*. The tropics – the hottest regions of the planet with the greatest workplace heat stress problems at present *(18)* – will also experience a rise in the frequency of heatwaves *(17)*.

Recent calculations for a large number of regions and countries *(5, 19, 20)* and occupation types indicate significant losses of work capacity (expressed as lost work hours) at different hourly workplace heat stress levels *(6, 21)*. Based on RCP6.0 (the pathway aligning with current national climate change policies around the world), occupations involving moderate-intensity work in the worst-affected countries currently experience annual work hour losses ranging from 2% to 4%. By the end of this century, losses will increase to between 8% and 11%. These losses assume that workers take breaks to rest and reduce their work pace as needed to avoid clinical health effects *(22)*. These work losses will be induced by the physiological and cognitive consequences of heat strain as well as behavioural thermoregulation as people make conscious decisions to maintain a stable body temperature, based on feelings associated with thermal comfort and discomfort *(23–25)*. Examples include taking breaks or working at lower intensities, removing/changing clothing, moving into shaded areas, or adjusting indoor temperatures via air conditioning or ventilation *(23, 24)*. If physiological heat strain is not reduced, the risks for morbidity and mortality rise dangerously *(8, 26)*.

The sizes of the populations around the planet exposed to high levels of heat currently and in the future are shown in Table 1.1 *(27)*, using two well-known indices of heat stress: the wet-bulb globe temperature (WBGT) and the universal thermal climate index (UTCI) (details on these indices are provided in Sections 4.1.2 and 4.1.3) *(28)*. These estimates suggest that 0.3 million people around the planet were exposed to "moderate" (based on WBGT) or "very strong" (based on UTCI) heat stress during the 1981–2010 period. If countries achieve the recommendation from the 2015 UNFCCC/COP in Paris *(16)* to keep the global mean temperature increase below 2°C (that is, RCP4.5), the number of people affected by the end of the 21st century will rise to 318 million. This number will further rise to 540 million people if countries only implement existing national policies (RCP6.0). If no actions to reduce greenhouse gas emissions are introduced (RCP8.5), more than a billion people will be living in areas with high heat stress by the end of the 21st century.

It is important to note that future projections have inherent uncertainty and there is a need to further improve the robustness and reliability of models related to workplace heat stress, health risks and adaptation *(29)*. Many predictions about workplace heat stress do not take into account potential changes in technology, exposure duration, activities, clothing and behaviour, given the inherent difficulty in predicting such changes *(30)*. Moreover, many of the models used to date have not considered solar infrared radiation due to the lack of such data. This considerably undermines the overall assessment of workplace heat stress, particularly for industries such as agriculture and construction, where a large part of the work is performed outdoors *(31–33)*. Adopting thermal stress indicators such as the WBGT that take into account exposure to thermal radiation can address this limitation *(34–37)*.

Table 1.1 shows the number of people living in areas of increased heat currently and in the future according to varying levels of climate change, as described in the different RCPs. This information can also be shown via global or regional maps that identify the areas most affected by heat. A picture of the current situation (Fig. 2.6) and future trends (Fig. 1.1) can be provided by dividing the planet into grid cells, each measuring 0.5° by 0.5°, and using the estimated mean monthly WBGT values for the hottest month of the year in each cell. The map in the bottom panel of Fig. 1.1 shows clearly the high heat predicted in areas close to the equator and the extreme heat that will emerge in large parts of West and Central Africa as well as in South, East and Southeast Asia, based on RCP6.0. The southern parts of the USA, as well as large parts of South America, southern Europe and Japan will also experience monthly mean afternoon heat levels that affect jobs not protected by active cooling strategies. The locations of the hottest areas are similar based on RCP2.6, but heat levels are lower in this case (top panel of Fig. 1.1).

Time period		1981–2010	2071–2099			
Global mean temperature change and associated RCP		0.7	1.5 RCP2.6	2.0 RCP4.5	2.6 –3.1 RCP6.0	4.0 RCP8.5
WBGT	**UTCI**					
Moderate [30°C]	Very strong [38°C]	0.3	48 [31 –65]	318 [104–534]	540 [377–703]	1440 [1139–1740]
High [31°C]	Very strong [39°C]	0	16 [6.5 –25]	133 [40–225]	225 [152–297]	1104 [779–1430]
High [32°C]	Very strong [40°C]	0	3.3 [0.7 –6]	35 [8–63]	64[28–101]	798 [523–1073]
Extreme [33°C]	Very strong [42°C]	0	0	2.3 [0–4.6]	12[0–21]	251 [188–314]
Extreme [34°C]	Very strong [44°C]	0	0	0.4 [0–0.8]	0.7[0–1.4]	31 [16–45]
Extreme [35°C]	Extreme [46°C]	0	0	0	0.4[0–0.8]	4.2 [2.2–6.2]

0–349	**350–699**	**700–1049**	**1050–1399**	**1400–1749**

Table 1.1: Millions of people living in areas of increased heat currently and in the future, according to varying levels of climate change, as described in the different RCPs

Note: Values reflect the average (range in brackets) number of people living in grid cell areas at different monthly heat levels indicated by two different models: the Geophysical Fluid Dynamics Laboratory (GFDL) model and the Hadley Centre Global Environment Model (HadGEM). The calculations assume that heat levels described are in the shade and accompanied by air movement over the skin at 1m/s. Source: See Traore Chazalnoel et al. (27) Estimates for the period 1981–2010 are based on data from the Climatic Research Unit, University of East Anglia, United Kingdom of Great Britain and Northern Ireland. Estimates for the period 2071–2099 are based on data from the Inter-sectoral Impact Model Intercomparison Project of the Potsdam Institute for Climate Impact Research

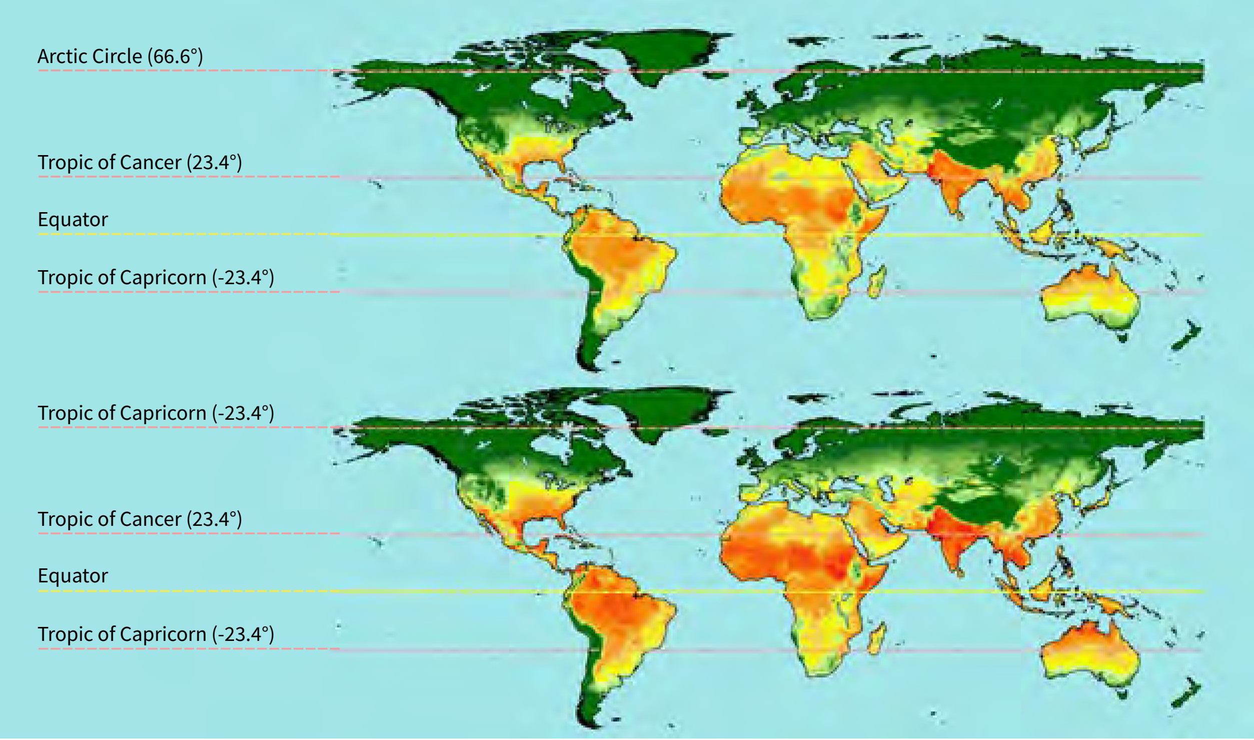


Fig. 1.1: Monthly mean WBGT in the shade during the hottest month of the year around the world (0.5° × 0.5° grid cells) for the end of the century (2071–2099) if aggressive measures are taken to reduce greenhouse gas emissions to keep the global mean temperature at a maximum 1.5°C increase with a decreasing trend in the second half of this century (RCP2.6, top panel), or if countries implement existing national policies (RCP6.0, bottom panel). Source: International Labour Organization, Working on a warmer planet *(5)*

1.2. Heat stress in occupational settings

The exposure to heat in occupational settings can severely undermine workers' health as it will be detailed in Part 2). A number of early warning systems exist to protect the general population during heatwaves *(38)*.

But the characteristics, needs and exposure to heat of the general population are very different from those of workers who often perform physical work, have a limited capacity to adapt their behaviour, position/location or clothing, and are frequently surrounded by additional sources of heat from machinery and surroundings, all of which increase their vulnerability to heat and limit their adaptative capacity.

Under normal environmental temperature conditions, healthy individuals at rest maintain their core body temperature at about 37°C.

This is done by adjusting the rate of dry heat loss (by increasing skin blood flow) and evaporative heat loss (by increasing sweating) to the environment to balance the rate at which heat is produced within the body through metabolism (Fig. 1.2a) *(39)*.

However, this balance is easily disturbed during exposure to hot environments and/or physical work – both of which are often observed in occupational settings.

For instance, increased air temperature limits the capacity for heat loss by means of skin vasodilation such that, when the environment is warmer than the skin, the body begins to gain heat, increasing the need for sweating and circulatory adjustments to achieve heat balance.

Likewise, the increased metabolic heat produced during physical work raises the need for sweat evaporation, which is the main avenue of heat loss during muscular activity (Fig. 1.2a).

In addition to these thermoregulatory challenges, factors such as increasing age, the presence of chronic disease, poor fitness, lack of heat acclimatization and reduced hydration *(40–42)* can further compromise the body's ability to lose heat.

The term **workplace heat stress** refers to the increased heat storage in the body of a worker as a result of excessive heat exposure in the workplace due to one or more of the following factors (Fig. 1.2a):

1. Hot environmental conditions (for example, increased air temperature and humidity, radiant heat sources, limited air flow);
2. Increased metabolic heat production from performing physically demanding tasks;
3. Requirement to wear impermeable and/or insulative protective clothing, which limits the ability to dissipate heat to the environment.

The body's physiological response to workplace heat stress includes elevated core body and skin temperatures as well as increases in other parameters, including skin blood flow, heart rate and sweat rate, which induce cardiovascular strain. In total, the observed impact of workplace heat stress on the body is termed physiological heat strain, and it can lead to exhaustion and pathological conditions when it exceeds the body's tolerance level.

This is exemplified in Fig. 1.2b, illustrating the relationship of core body temperature to the incidence of heat exhaustion *(43)*. This data suggests that the risk of heat exhaustion is increased when core body temperature rises beyond 38°C, supporting a long-established safety threshold set by the 1969 WHO guidance on the topic of working in conditions of heat stress *(3)*.

The guidance concludes that "it is considered inadvisable for the deep body temperature to exceed 38°C for prolonged daily exposures in heavy work". Since then, these thresholds have been adopted in guidelines and recommendations by many organizations *(5, 10, 44–51)* to enhance health and safety during work with higher levels of physical activity.

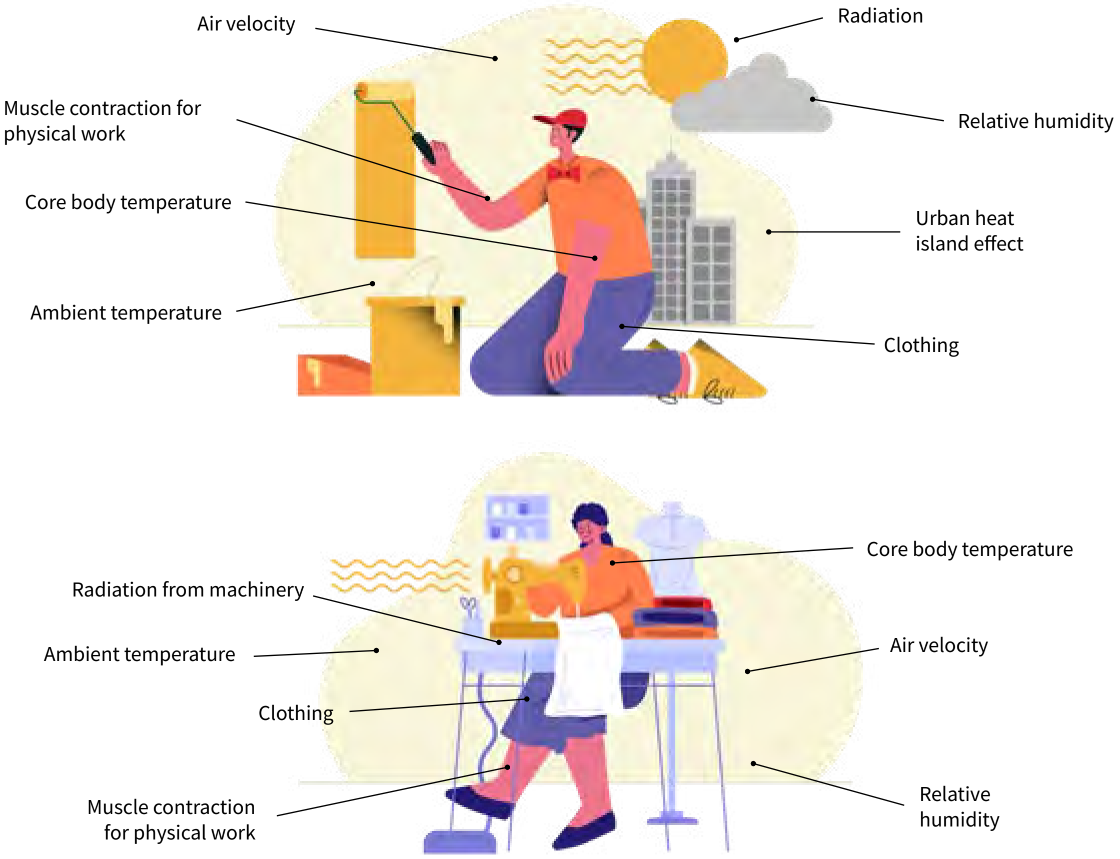


Fig. 1.2a: Illustration of the interaction of different occupational factors that can increase heat stress. Work demands dictate the internal metabolic rate, which is the major source of heat gain. Environmental factors and clothing determine the remaining avenues of heat exchange. The asterisk indicates that conduction and convection can lead to heat gain or loss; under most conditions, these are relatively minor avenues of heat exchange

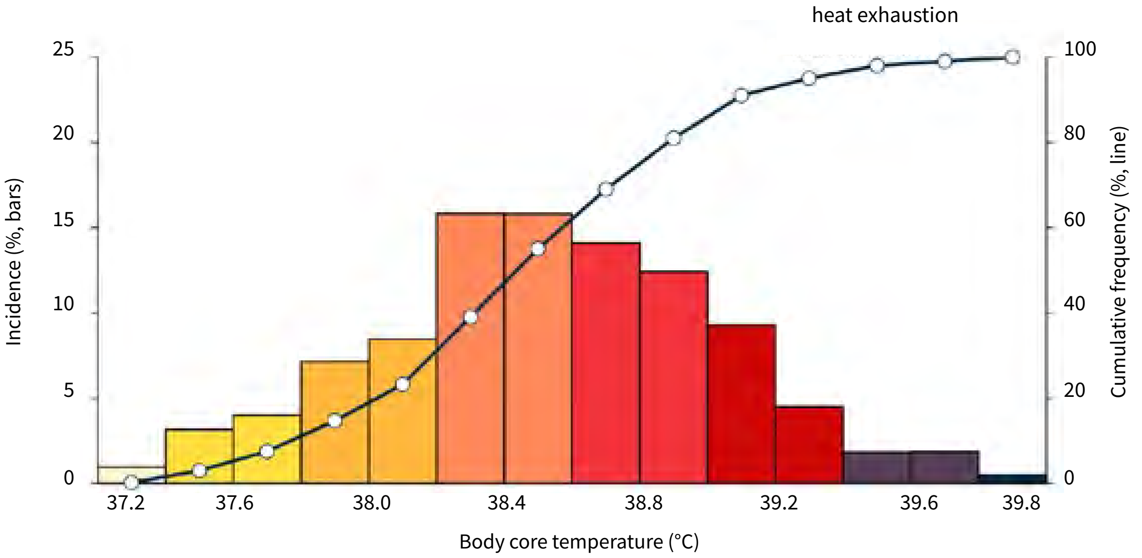


Fig. 1.2b: The incidence and cumulative frequency of heat exhaustion cases occurring for each 0.2°C rise in core body temperature while individuals perform moderate-intensity physical work under extreme heat stress conditions. Redrawn from Sawka and Pandolf *(43)*. The white circles and black line indicate the cumulative incidence of heat exhaustion

The rather conservative threshold of 38°C provides a safety margin, since it is difficult to accurately assess core body temperature or environmental and metabolic heat loads in workplace settings.

Core body temperature can also vary within a group of people due to different factors (see Part 2), even if they perform similar tasks and are exposed to the same environment. Previous research confirmed the 38°C criterion as a population-based goal *(52, 53)*. In a group of workers who perform the same tasks in a given environment and have an average core body temperature of 38°C, the probability for a particular individual to have a core body temperature of 39.2°C is less than one in 10 000 workers (less than 0.0001). In the same scenario, the probability for an individual worker to have a core body temperature of 42°C is less than one in 10 million workers (less than 0.0000001) *(52)*.

In recent decades, it has become less common for workers to experience dangerous elevations in physiological heat strain because the work intensity in many jobs has been reduced due to automation and mechanization, at least in higher-income countries. However, it has become more common for workers to be exposed to increased workplace heat due to climate change.

Furthermore, many workers still wear protective clothing that restricts the evaporation of sweat, and they continue to be exposed to solar radiation or radiant heat sources that cause heat gain. Consequently, even light to moderate work performed in a hot environment can lead to high physiological heat strain and compromise health *(8)*. Performing back-to-back days of prolonged, arduous work in workplace heat stress conditions is also common for workers in many industries, mainly in the hot regions of the planet.

This can cause adverse next-day effects (particularly if recovery and fluid/electrolyte replacement are inadequate) that impair work capability in the following day(s) *(54–56)*, increasing the risk of heat-related morbidity *(57, 58)* and mortality *(59, 60)*. However, if the exposure to workplace heat stress is not extreme and if adequate recovery is provided, consecutive days of exercise/work in workplace heat stress will induce physiological and behavioural adaptations of the individual – called heat acclimatization – which reduce the physiological strain and enhance work performance *(40, 61)*.

1.3. Production and loss of heat during physical work

In simple terms, heat stress reflects the degree to which heat is generated internally via the metabolic demands of the work and the ability to dissipate that heat to the environment, which depends on the ambient conditions and the clothing worn.

Converting chemical energy into mechanical work in the muscles is inefficient, resulting in substantial heat generation. As a consequence, humans have a rather low mechanical efficiency – a term used to describe the proportion of metabolic energy that they are able to utilize for work, out of all the energy available in the nutrients that they metabolize *(62, 63)*.

The most efficient physical task is believed to be cycling on a stationary cycling ergometer, where approximately 20% of the available energy is used to actually move the pedals *(64)*.

The mechanical efficiency of humans in most occupational tasks typically ranges between 12% and 18% *(62, 63)*. The remaining 82–88% of the energy contained in the chemical bonds of nutrients is converted to heat in the muscles and organs and is either dissipated to the external environment or accumulated within the muscle and gradually distributed and stored throughout the body via the circulatory system *(64)*.

In cases where heat is stored in the body, it will raise core body temperature and induce physiological strain, which can lead to fatigue, exhaustion or serious heat-related health outcomes.

For core temperature regulation to work, the environment must allow sufficient heat transfer from the body. The principal mechanism for heat loss during work in warm/hot environments is sweat evaporation from the surface of the skin.

Multiple layers of clothing, non-woven fabrics, laminates, or impermeable materials commonly worn by workers restrict evaporative cooling and heat dissipation through radiation and conduction, thereby limiting the body's maximum cooling capacity *(65)*.

A smiling worker in overalls holding a tablet outdoors.
© iStockphoto.com / Dobri Dobrev

Part 2: Global Burden Of Workplace Heat Stress

Key Messages

- Climate change projections suggest that the prevalence of workplace heat stress and the associated adverse health and productivity **consequences will increase** during the 21st century, affecting more and more people, particularly in the less developed parts of the world.
- More than one third of all persons who frequently work in hot conditions experience **physiological heat strain**, which is associated with signs and symptoms such as hyperthermia, syncope, impaired kidney function, dehydration and neurological dysfunction. This often results in **increasing poverty and socioeconomic inequality**.
- The **health outcomes** related to workplace heat stress range from mild to severe. **Mild conditions** induce no chronic effects, and the worker can return to activity the following day, once normal core body and skin temperature and/or fluid and electrolyte balance have been restored. **Severe conditions** require immediate attention and emergency care since they can induce tissue/organ damage that may persist for weeks, months or longer, or never resolve. Severe health problems related to workplace heat stress can be **fatal**.
- Older individuals, those who are physically unfit and people with some chronic health conditions are **more vulnerable** to the physiological strain caused by workplace heat stress, but **unfavourable consequences** have been observed even in **low-risk individuals** who follow sound heat mitigation procedures.
- Workplace heat stress can undermine an individual's **ability to remain productive** and negatively affect national economies and public health. The effects are most pronounced in countries, industries and individuals **directly dependent on manual labour**, but there are indirect and broader geographical and economic impacts on distal sectors or areas that **rely on stable food prices** and other value chains impacted by primary sector productivity.
- Occupations that involve **work outdoors** in the sun during the hot hours of the day are at particular risk of workplace heat stress. In addition, jobs with intense physical activities and/or require wearing personal protective equipment and special clothing are likely to induce greater **physiological heat strain**.

A person raking patterns into a large expanse of drying grains.
© Unsplash.com/ Dibakar Roy

2.1. Morbidity and mortality associated with workplace heat stress

Workplace heat stress has become an everyday or seasonal problem for the 30% of the global population who reside in climates where high environmental temperatures affect daily activities *(66)*.

In addition, more than one third of all persons who frequently work in hot conditions experience physiological heat strain, which is associated with clinical symptoms such as hyperthermia, syncope, impaired kidney function, dehydration and neurological dysfunction –and is often linked with worsening poverty and socioeconomic inequality *(8)*.

The ILO estimates show that worldwide more than 2.4 billion workers are exposed to workplace heat stress, while every year, 22.85 million occupational injuries, 18 970 fatalities, and 2.09 million disability-adjusted life years are directly linked to exposure to excessive heat at work *(1)*. In 2020, there were an estimated 26.2 million persons living with chronic kidney disease attributable to workplace heat stress *(1)*.

In addition to impaired work capacity, workplace heat stress markedly increases the risk of morbidity and mortality for a number of health outcomes *(25, 67–69)*, especially among outdoor workers *(8, 58, 70)*. Heat exhaustion and sometimes fatal heatstroke have been repeatedly reported among coal miners *(71)*, surface miner workers *(72)* and gold miners *(61)*, as well as workers in agriculture *(73)* and construction *(74)* workers in the United States of America. Furthermore, accumulating evidence shows that heat stroke may induce long-term health consequences in some victims *(75, 76)*. For instance, victims of heat stroke are reported to be at greater risk of dying of ischaemic heart disease (rate ratio: ~2.2) and of other cardiovascular diseases (rate ratio: ~1.7) within 30 years of hospitalization *(75)*. Moreover, a study showed that heat stroke victims had a higher incidence of a major cardiovascular event (hazard ratio: ~3.9), ischaemic stroke (hazard ratio: ~5.5), and atrial fibrillation (hazard ratio: ~15) during a 14-year follow-up period *(76)*.

The likelihood of experiencing health problems related to workplace heat stress among clean-up workers in the Gulf of Mexico increased by 58% for each degree increase above 20°C in wet bulb globe temperature (WBGT) *(58)*. Likewise, the incidence for health outcomes related to workplace heat stress (see section 2.2) increases sevenfold when WBGT exceeds 23°C *(77)*. Among military recruits undergoing training, there is a fourfold increase in the odds ratio for workplace heat stress health outcomes when WBGT increases from 23°C (odds ratio: 1.5) to 32°C (odds ratio: 6.0) *(57)*. A systematic review and meta-analysis of 111 studies covering 30 countries, including more than 447 million workers from over 40 different occupations, estimated that 35% of individuals who frequently work under workplace heat stress experience heat-related illnesses, including heat exhaustion and heat stroke *(8)*. In this analysis, individuals working a single shift under heat stress were on average four times more likely (95% confidence interval 2.5–6.6 times) to experience heat-related illnesses than individuals working in normal environmental conditions.

A sweaty auto mechanic working on a car in a workshop.
© iStockphoto.com / skynesher

Workplace heat stress has also been suggested as one potential risk factor for kidney diseases of unknown origin *(78–80)*. Meta-analytic data suggest that 15% (95% confidence interval 11–19%) of individuals who typically or frequently work under heat stress (minimum of six hours per day, five days per week, for two months of the year) experience kidney disease or acute kidney injury *(8)*.

However, there is not yet scientific consensus regarding the role of workplace heat exposure in the etiology of these kidney diseases *(81)*.

It remains unclear if these renal issues are caused by chronic heat stress alone or whether other concurrent factors, such as exposure to toxic chemicals, are also involved. Workplace heat stress is also associated with accidents and acute injuries because it induces cognitive impairments that affect alertness, decision-making and other factors leading to unsafe behaviours *(82)*.

People working in conditions near the workplace heat exposure limits demonstrate unsafe behaviours (e.g. risk-taking) more often, even on days when the prevailing environmental conditions are considered normal *(58, 83–85)*.

Furthermore, occupational accidents have been associated with dehydration, which often accompanies workplace heat stress *(8, 86)*. Nevertheless, a meta-analysis of eight studies of fatal and non-fatal occupational injuries found only a limited increase due to rising temperatures and increased heatwaves subsequent to climate change *(87)*.

As shown in Fig. 2.1, the exposure scenarios and factors that create workplace heat stress, contributing to increased morbidity and mortality, can vary greatly around the globe.

These factors include environmental and climate conditions (hot and dry, hot and humid, constant/seasonal/sudden heat, etc.) *(18)*; relevant industries (indoor or outdoor; how the workplace is affected by confounding factors such as heat from machinery and surroundings, wearing of personal protective equipment, ability to cool the microclimate around the worker, ability to adjust working schedules, etc.) *(44, 88, 89)*; and the individuals involved (and their specific work tasks and associated endogenous/metabolic heat production, clothing/safety requirements, individual characteristics, etc.) *(40, 90, 91)*.

These topics are discussed in the following sections.

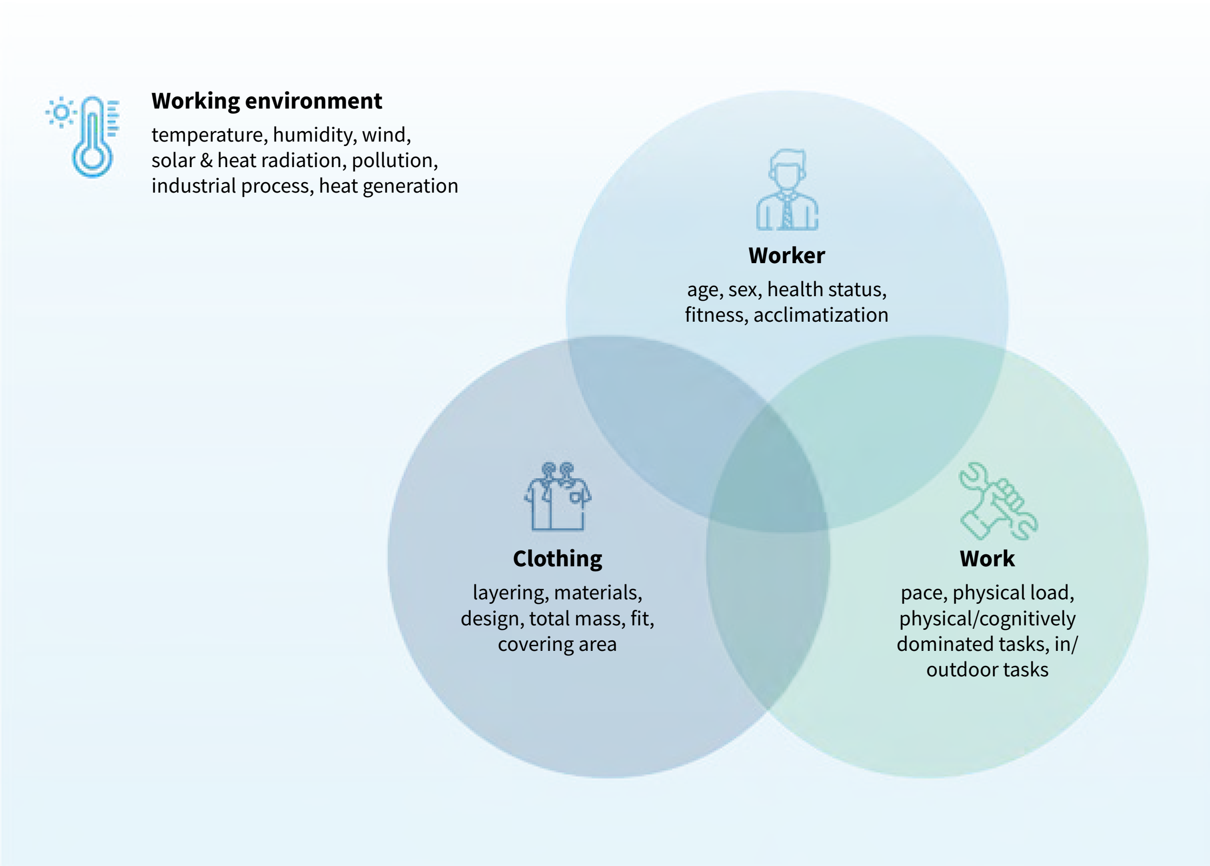


Fig. 2.1: Interconnections between factors related to work, environment, clothing and individual worker characteristics in relation to workplace heat stress

2.2. Specific health outcomes associated with workplace heat stress

During work in hot conditions, the body's primary challenge is to provide enough blood flow to support both the muscles (for the metabolic processes involved in physical work) and skin circulation (for dissipating the heat generated in the muscles) as well as to ensure perfusion of essential internal organs and the brain *(92, 93)*.

As workplace heat stress increases, the need to raise sweat secretion becomes more important for heat removal, which can lead to high fluid and electrolyte losses *(92–95)*. If fluid losses are not adequately replaced, dehydration will occur, which reduces plasma volume and further elevates physiological heat strain, impairing work capacity and increasing the risk of morbidity and mortality *(92, 93, 96)*. Moreover, low electrolyte levels compromise nervous system function and can have severe consequences such as heat stroke that may lead to death *(8, 94, 96–98)*.

To provide enough blood flow to both the skin and working muscles during workplace heat stress, the body diverts blood from the gastrointestinal and renal circulation *(93)*. Depending on the level of physiological heat strain as well as on individual factors that make some people more or less vulnerable to workplace heat stress (see Section 2.5), this adaptation may allow continued physical work with no health risks *(93)*. But when these compensatory responses are insufficient, skin, muscle and even brain blood flow are compromised, which can lead to pathological conditions *(92, 93, 96)*. Under increased heat strain and dehydration, neuromuscular function can be affected *(99, 100)*, contributing to a greater risk of occupational accidents *(85, 101)*.

The following sections provide an overview of health outcomes related to workplace heat stress to enable countries to evaluate its impact on public health, design effective public health policies and measure their effectiveness. To facilitate the systematic recording, reporting, analysis, interpretation and comparison of morbidity and mortality data related to workplace heat stress, this guidance uses the 11th revision of the International Classification of Diseases (ICD-11) *(102)*, published by WHO to standardize all disease definitions and coding of health conditions and accidents. The ICD-11 includes 19 codes for injuries, health effects, conditions and illnesses which are related to workplace heat stress. It is important to note that the health outcomes analysed below are not specific to workplace heat stress, as they can also be caused by non-occupational exposures. The recommended treatments for these health outcomes are described in Section 4.4. A key parameter to highlight is that the listed health outcomes can occur even during work in temperate environments because of high work intensity, protective clothing worn and/or underlying risk factors that make some workers more vulnerable to physiological heat strain *(93, 96, 98, 103)*. Taken together, the health outcomes listed in the following sections may lead to loss of productivity and income, which in many cases can be a much worse problem than the specific health problems. While the present guidance uses the existing classifications adopted by WHO, it is important to note that emerging science *(93, 96, 98, 103)* has resulted in the creation of serious heat illness classifications, including heat exhaustion, heat injury and heat stroke.

A construction worker lying on the ground at a worksite, with a safety helmet lying on the ground nearby. © iStockphoto.com / sorn340

2.2.1. Mild health outcomes associated with workplace heat stress

The following health outcomes related to workplace heat stress, as listed in the ICD-11, are typically mild and present with acute symptoms/effects:

- **Heat fatigue** (code NF01.3) is a transient condition that commonly occurs when working under workplace heat stress. The body directs a high volume of blood towards the peripheral skin circulation in an effort to dissipate heat, leaving less blood available to support the working muscles. A given level of physical effort is therefore perceived as more strenuous and fatigue occurs sooner *(24)*.
- **Miliaria** (heat rash; code EE02) is a common skin disorder resulting from occlusion of eccrine sweat ducts. It is precipitated by hot, humid conditions. Symptoms range from superficial blisters to an itchy red papular rash.
- **Heat syncope** (dizziness/fainting; code NF01.1) develops when there is a temporary insufficiency of blood flow to the brain because the body has directed a high volume of blood towards the peripheral skin circulation in an effort to dissipate heat *(98, 104, 105)*. Heat syncope is often associated with sudden/rapid posture changes (for example, standing up abruptly after sitting or lying down for a while). It may also be caused by standing still for a prolonged period of time. In this case, the return of venous blood to the heart is impeded by a lack of leg skeletal muscle contraction and increased blood flow to the skin due to heat.
- **Other mild effects of heat** (code NF01.Z) typically include heat cramps and heat oedema. Heat cramp is a painful muscle spasm in the leg, arm and/or torso. Its physiological mechanism is unknown, but dehydration and electrolyte losses likely play a role *(10)*. Heat oedema is a vascular condition characterized by heat-induced swelling of peripheral blood vessels in the hands, arms, feet, ankles and legs *(106)*.

Two healthcare workers wearing full protective gear, holding bottled water and medical supplies. © WHO / Rob Holden

2.2.2. Severe health outcomes associated with workplace heat stress
(often referred to as serious heat illness)

Of the health outcomes related to workplace heat stress that are listed in the ICD-11 *(102)*, fluid and electrolyte imbalances and heat exhaustion may be mild or severe, while heat stroke involves severe health effects that require immediate attention and hospitalization.

The sun's ultraviolet radiation can also have severe chronic long-term effects on the skin. These health outcomes are described below:

- Heat exhaustion (code NF01.2) is associated with physical effort and describes a spectrum of increasing severity, including mild, moderate and severe illness. It is characterized by cardiovascular dysfunction (inability to sustain cardiac output and blood pressure) caused by high skin blood flow requirements and/or dehydration that may or may not be combined with marked hyperthermia *(13, 93, 98)*. In cases where marked hyperthermia is present (usually ≥39°C core body temperature), there is an increased likelihood of damage to organs (such as kidney and liver) and/or tissues (such as gut and skeletal muscle) *(13, 93, 96, 98, 103)*.
- Heat stroke (codes NF01.0 and NF06.0) is a life-threatening condition defined by profound central nervous system dysfunction (such as severe disorientation, aggressiveness, seizures, coma), severe hyperthermia (usually ≥40°C core body temperature), organ/tissue damage, and often coagulopathy and systemic inflammatory response syndrome *(93, 96, 98, 103, 104)*. The condition is categorized as heatstroke (code NF01.0) or exertional heat stroke (code NF06.0), with the former observed primarily in elderly people or otherwise sick and frail individuals, and the latter observed typically in apparently healthy individuals (such as workers, military personnel and athletes) during or following intense and/or prolonged physical work *(10)*.
- Fluid and electrolyte imbalances (codes 5C71, 5C72, MG43.4Y, PB58) often accompany both mild and severe health outcomes related to workplace heat stress *(107)*.

  The term euhydration is used to describe the state of having normal total body water content. However, determining how much fluid people should drink to stay euhydrated is not straightforward because total water loss fluctuates markedly between individuals and even for the same person across different days *(108)*. Hypohydration refers to an uncompensated loss of body water whereas dehydration is the process of losing a large volume of total body water. Individuals who experience an acute loss (that is, within a few hours) of body mass greater than 1% (indicating a total body water deficit of >600–900 mL/day for most male and female workers) are considered to be in a hypohydrated state *(108)*. Clinical health effects typically arise when body mass is reduced by 2% or more *(94, 109, 110)*. Both hypohydration and dehydration have been associated with occupational accidents *(8, 86)*. During work, especially in hot environments, the loss of water is typically larger than the loss of electrolytes, which may lead to hypernatraemia, a condition characterised by a rise in serum sodium concentration (in excess of 145 mmol/L). At the opposite end of the spectrum, hyponatraemia (serum sodium less than 135 mmol/L) is a potentially fatal condition. For workers in hot weather, it is caused by inadequate replacement of sodium lost through sweat and/or from overconsumption of hypotonic beverages, which are often used by athletes to accelerate intracellular hydration *(94, 111)*. When performing sustained physical work in warm/hot weather, hyponatraemia can develop over many hours. While hyponatraemia and dehydration share symptoms such as confusion, headache and lethargy, the presence of repeated vomiting is often a discriminating symptom of hyponatraemia *(104)*. Often, individuals with hyponatraemia are initially incorrectly treated for dehydration, which typically resolves fairly rapidly. If the individual has gained weight, is vomiting repeatedly or has not responded quickly to fluid intake, they should be transported for medical evaluation for hyponatraemia *(104)*.
- Other effects of heat (codes NF01.Y, XE00Z, EJ1Y, PB15, SA91, SB0Y, GB7Z, 5C8Z) may include dermatoses *(112–114)*, acute/chronic kidney injury *(8, 115, 116)*, kidney stones (urolithiasis) *(8, 115, 116)*, heat-induced dyslipidaemia *(117, 118)* and other conditions.

2.2.3. Chronic health consequences

Mild health outcomes related to workplace heat stress induce no chronic effects and, after restoration of a normal core body temperature and/or fluid and electrolyte balance, the worker can return to activity the following day.

However, if the individual has three episodes of heat exhaustion within two years, they should be referred for a medical evaluation *(104)*. When such cases emerge, employers should consider ways of mitigating the workplace heat stress without delay.

Severe heat exhaustion can induce tissue/organ damage that may persist for several weeks, while heatstroke often induces skeletal muscle, organ (liver, kidney, cardiac, central nervous system) and systemic pathologies (coagulopathy, systemic inflammatory response syndrome) *(93, 96)* that may take months, or longer, to resolve *(104, 119)*. This suggests that heat stroke often causes residual tissue/organ damage that is not readily detectable but linked to an increase in long-term morbidity and mortality.

2.3. Mental health effects associated with workplace heat stress

The link between heat stress and mental health is well established *(120, 121)*. However, the impact of workplace heat stress on mental health has received less attention.

Epidemiological and experimental research demonstrates that working in hot environments can increase fatigue, irritability and lethargy, as well as cause impairments in judgment, concentration, vigilance, dexterity and coordination *(122-125)*.

A large-scale study using questionnaires mailed to about 25 000 workers in Thailand reported that workplace heat stress is associated with increased psychological distress (adjusted odds ratio: 1.84) *(126)*.

Furthermore, meta-analytic evidence suggests that environmental heat undermines human information processing and psychomotor capacities by about 10% *(127)*. These cognitive and emotional states may cause individuals to overlook safety procedures or to divert attention while performing their duties *(85)*.

2.4. Loss of labour productivity due to workplace heat stress

In addition to raising morbidity and mortality, workplace heat stress causes discomfort and fatigue *(128)*, which can lead to labour productivity losses by compromising workers' ability to perform both physical and mental work *(129, 130)*.

Recent systematic review and meta-analytic data from about 8 000 workers showed that 30% (95% confidence interval: 21–39%) of those frequently working under workplace heat stress conditions report labour productivity losses *(8)*.

In this analysis, workplace heat stress-induced productivity loss was defined as any loss of productivity and/or loss of labour time or performance and/or absence from work due to heat-related morbidity. The analysed studies investigated working conditions with WBGT ranging from 21°C to 52°C. The same systematic review and meta-analysis reported an average 2.6% productivity decline (range 0.8–5.0%) for every degree increase beyond 24°C WBGT in ambient workplace conditions (details on the WBGT index are provided in Section 4.1.2) *(8)*. Similar findings have been reported in other regional *(6)* and global *(21)* analyses. More recent meta-analytic data demonstrate that labour productivity is reduced at even lower levels of workplace heat stress, suggesting that the optimum environment to work in is at 15°C WBGT, beyond which there is an average 2.4% productivity decline for every degree increase in WBGT *(21)*.

2.5. Groups of workers at higher risk for morbidity and mortality related to workplace heat stress

Risk factors for morbidity and mortality related to workplace heat stress include lack of heat acclimatization, low physical fitness, dehydration, older age, high body mass index, underlying medical health conditions and certain medications *(42, 91, 93, 96, 98, 104, 131)*.

Table 2.5 provides individual, health, medication and environmental factors predisposing persons to severe health outcomes related to workplace heat stress *(98)*. Importantly, these health outcomes can develop even in low-risk individuals (young, healthy adults with no history of heat-related health outcomes) who practise sound heat mitigation procedures.

For example, performing successive days of strenuous work under workplace heat stress can impair an individual's capacity to dissipate heat from their body to the environment (even in heat-acclimatized workers), placing them at greater risk of heat-related health outcomes *(55, 132)*.

Exertional heat stroke (described in Section 2.2.2) is often observed even when the affected individual has previously tolerated similar heat conditions or when other individuals are simultaneously exposed without adverse effects. This pattern suggests that the individual experiencing heat-related health outcomes may be more vulnerable on that particular day, or that a unique event may trigger the underlying pathophysiological mechanism(s) involved *(133)*.

For example, several sources of evidence suggest that some victims of exertional heat stroke were unwell on the day before the incident *(93, 96, 98, 119)*. Moreover, exertional heat stroke often occurs very early during a physical work session, suggesting that the individual began work in a compromised state on that particular day *(93, 96, 98, 119, 133)*.

The common observation of rapidly developing hyperthermia suggests that fever from a pre-existing illness or inflammation may amplify the normal immune/hyperthermic response to physical work or compromise molecular protection mechanisms *(93, 119, 134)*.

Individual factors	Environmental factors	Medications	Health conditions
• Lack of heat acclimatization • Low physical fitness • Increasing age • Pregnancy • Dehydration • High body mass index	• Heavy/impermeable clothing • Physical work/ exercise • High temperature • High relative humidity • Little air movement • Sources of radiant heat (sun and/or machinery) • Heatwave	• Anticholinergics • Antiepileptic, antipsychotic and neuroleptic drugs, tricyclic antidepressants, amphetamines, cocaine, ecstasy • Heart and antihypertensive drugs (e.g. diuretics, nitrates, antihistamines, beta-blockers) • Ergogenic stimulants	• Acute illness (e.g. inflammation with fever, gastroenteritis) • Cardiovascular disease • Diabetes mellitus • Skin rash, sunburn, prior burns to large skin areas • Malignant hyperthermia Haemoglobin diseases (sickle cell trait) • Diseases of the central nervous system and mental illnesses • Chronic liver disease • Kidney disease • Disability • Chronic respiratory diseases

Table 2.5: Factors predisposing to severe heat-related disease during work under workplace heat stress conditions.
Source: Table developed based on information presented in references *(13, 91, 98, 135)*

An occupational group that warrants special attention is international migrant workers *(136, 137)*. Upon arrival, these individuals tend to be younger and healthier than the domestic workforce *(138)*.

However, they often have less work experience and poorer perception of health risks *(139)*. In addition, migrant workers are not acclimatized to the local environment. They are more likely to work in manual labour occupations that require working outdoors and exposure to environmental hazards *(136, 137, 140, 141)*. They consistently show a higher prevalence of work injuries, and they experience poorer occupational health compared to domestic workers *(136, 137, 142)*.

With regard to heat exposure, the few studies on the topic suggest that migrant workers are more likely to be exposed to workplace heat stress, particularly in the agriculture and construction industries. They are typically engaged in more physically demanding tasks and work outdoors more often than native workers *(51, 137, 139, 141–144)*.

A recent observational study among farm workers in Cyprus showed that migrant workers experience higher levels of workplace heat stress, as compared to domestic workers, because they take fewer unplanned breaks during work; they work at a higher intensity and wear more clothing. *(140)*.

2.6. Regions most affected by workplace heat stress

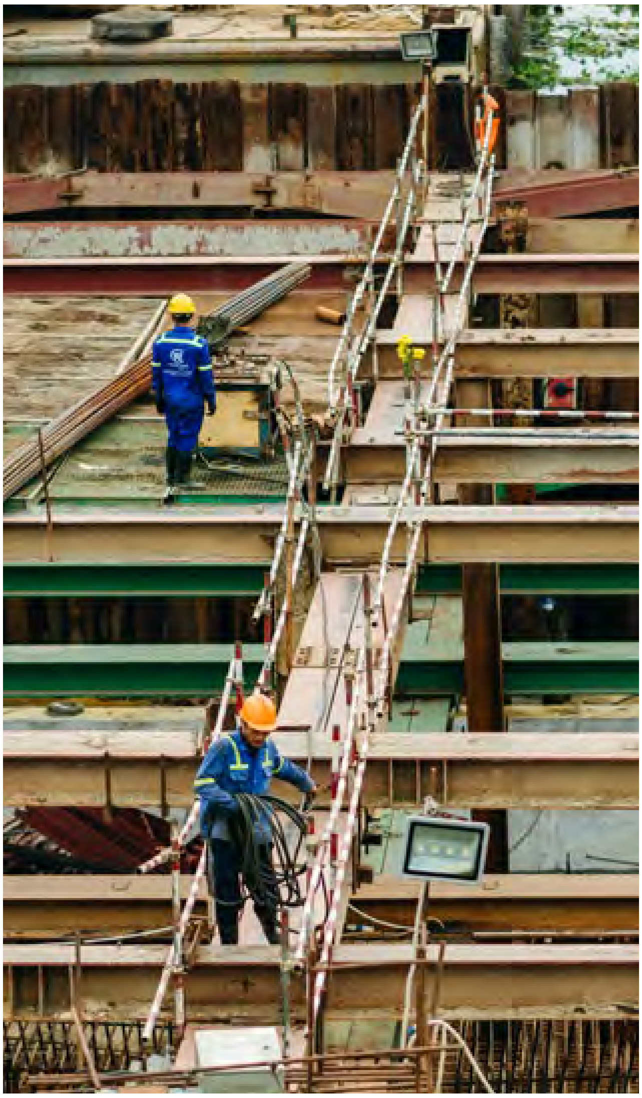
The physiological heat strain caused when working under conditions of workplace heat stress may undermine an individual's ability to remain productive and negatively impact national economies and public health *(8, 19, 145)*.

The effects are highest for countries, industries and individuals directly reliant on manual labour *(2, 8, 21)*, but there are also indirect and broader geographical and economic impacts on sectors or regions that rely on stable food prices and other value chains, which are influenced by the productivity of primary sectors.

Fig. 2.6 shows the heat conditions in the hottest month of the year around the world *(19)*. Many of the hottest parts of the world are also locations with very high population density. Of note, heatwaves and urban heat island phenomenon increase the concentration of heat within the urban fabric, leading to temperature differences of sometimes more than 10°C between central and suburban areas *(146)*.

In the event of extreme weather episodes, urban heat islands – influenced by factors such as the shape and distribution of developed and undeveloped areas, the presence and size of green spaces, as well as the materials covering the waterproofed surfaces of the urban area – increase the negative effects of heat, maintaining nighttime temperatures at levels that are hard to tolerate for human health *(146)*. This emergence of higher temperatures during the night caused by urban heat islands has occupational relevance because of the frequent practice of shifting manual outdoor work to nighttime, particularly in construction.

In such cases, the added radiant heat release may be significant enough that workplace heat stress remains high even during the night *(147)*.



Two construction workers in safety gear working on a large steel framework at a building site. © Unsplash.com / Tuân Nguyễn Minh

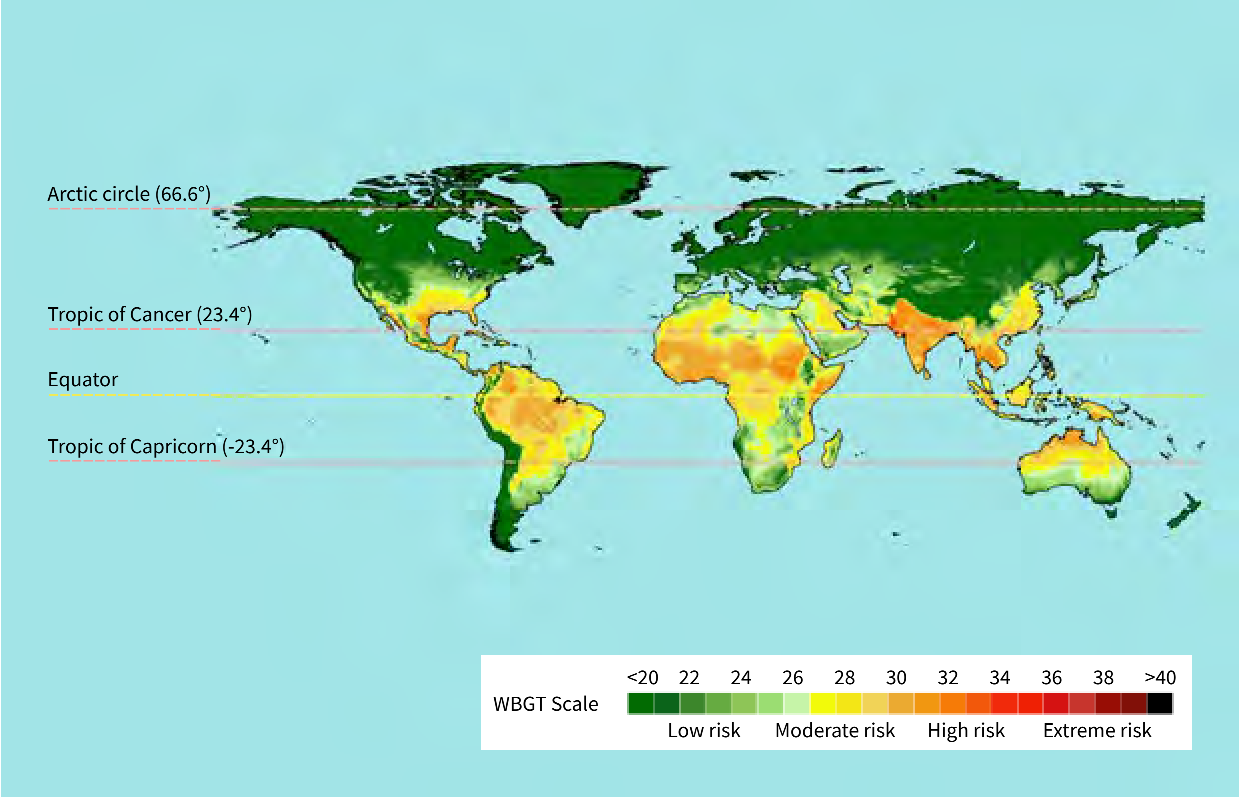


Fig. 2.6: Monthly mean wet-bulb global temperature (WBGT) in the shade during the hottest month of the year around the world (0 .5° × 0 .5° grid cells) for the period 1981–2010. Source: See Kjellstrom et al. *(19)*

2.7. Most affected workplaces

Workplace heat stress is significantly higher when working in the sun, where WBGT typically increases by 2°C to 3°C, compared to working with shade protection *(5)*.

Occupations that involve working outdoors in the sun during the hot hours of the day are therefore at particular risk of workplace heat stress and physiological heat strain *(5, 51)*.

Outdoor construction and agricultural work during the hot season are often regarded as the highest-risk occupations for experiencing morbidity and mortality associated with workplace heat stress *(5, 51, 148, 149)*.

In addition to direct solar radiation, thermal radiation from the ground or surrounding machinery further exacerbates the associated heat stress.

For example, asphalt road surfaces can exceed 60°C in the hot season when the air temperature is around 30°C to 35°C *(150)*. Steel workers, too, are often exposed to high radiant heat *(151)*, while foundry workers *(152)* experience high heat radiation along with steam and chemical explosions.

Likewise, occupations in mining, quarrying stone, glass production, ceramic production, melted metal operations, laundering of clothes and others are also considered to be at high risk of workplace heat stress *(153)*.

Occupational tasks requiring intense physical effort involve high metabolic rates and generate much greater metabolic heat (Table 2.7). Jobs that include such intense tasks are therefore likely to require a higher rate of heat dissipation by workers to offset potentially dangerous increases in core body temperature *(154)*.

Work intensity	Average work intensity (W)	Task examples	Occupation examples
Rest	115	Sitting	Office jobs
Light	180	Sitting, standing, light arm/hand work and occasional walking	Office jobs with more activity, health workers
Moderate	300	Normal walking, moderate lifting	Low intensity factory work, retailing and restaurant work, garden work
Heavy	415	Heavy material handling, walking at a fast pace	Construction, agricultural work, warehouse physical work
Very heavy	520	Pick and shovel work	Physical mining, road maintenance, heavy agricultural or construction work

Table. 2.7: Metabolic rate for different work intensities, with associated physical task and occupation examples. Source: Modified from International Organization for Standardization (ISO) standard no. 7243 *(155)*

In addition to environmental factors and work intensity (metabolic rate), clothing insulation also affects the degree of workplace heat stress. The thermal insulation provided by clothing can increase the physiological heat strain even in cases of low-intensity work.

Wearing personal protective clothing with insulation and/or low vapour permeability leads to less efficient sweat evaporation *(65, 156, 157)*. In addition to the physiological strain, wearing insulated clothing adds psychological distress because wet skin (caused by lack of sweat evaporation) is associated with perception of greater thermal discomfort for a given skin temperature *(158)*. Hence, jobs that require wearing such personal protective clothing are likely to induce physiological heat strain with added discomfort, and the applied heat-protection thresholds should be adjusted in these cases *(158)*.

Farmers who manually spray pesticides during the summer often experience heat exhaustion because of their protective clothing, which includes respiratory masks *(159)*. Livestock farmers who work indoors during the summer face the combined challenge of heat stress and noxious odours, for which respiratory masks are necessary *(160)*. Radiation decontamination workers wear impermeable protective clothing and work in areas where the air temperature is typically around 80°C. At the Fukushima Daiichi nuclear power plant in Japan, 60% of these workers experienced heat exhaustion symptoms *(161)*. To mitigate this risk, work shifts ended at 14:00 to prevent exposure to the high ambient temperatures between 14:00 and 17:00 *(162).*

One example of physiological heat strain due to protective clothing was the response to the Ebola epidemic in West Africa, where the risk of infection required working in full PPE. This was possible only over short time and imposed very frequent breaks with donning and doffing of the PPE, which posed health risks for the workers and slowed down the Ebola response *(163)*.

This demonstrates that indoor or low-intensity work that requires wearing coveralls, whether in manufacturing or service sectors, should not be assumed to be protected, even when air conditioning or electric fans are in place *(164)*. In addition, during the COVID-19 pandemic, large numbers of healthcare workers and civil protection workers were required to wear full PPE (typically consisting of a hazmat suit or impermeable apron, face mask, visor/goggles and latex gloves) to safely treat and interact with patients *(165-168)*.

Moreover, the use of facemasks during work has been advised for millions of workers around the world. While facemasks do not appear to impact thermoregulation *(169)*, wearing full-PPE, including facemasks, can increase workplace heat stress, especially in warm or hot conditions *(168, 170, 171)*.

2.8. Seasonal and diurnal variations of workplace heat stress exposure

Changes in the weather within a day, from day-to-day or between seasons can have significant impacts on work capacity and human health. Hourly increases in WBGT during the day are associated with lower work capacity in heat-exposed jobs, particularly for outdoor work (Fig. 2.8) *(25, 130)*.

Diurnal temperature range (24-hour variations between maximum and minimum temperatures) is an important indicator for weather stability and global climate change, and has been linked with mortality and morbidity *(172)*. Short-term exposure to large diurnal temperature ranges has been associated with an increased burden of premature death, particularly from cardiovascular causes, among women and among elderly individuals *(172)*. Changes in a population's susceptibility to heat may also occur over longer timescales, such as within seasons.

Within-season studies have shown that risks are substantially higher when excess temperatures occur at the start of summer compared to the end *(173, 174)*. These risks also affect workers, as excess heat contributes to daily total mortality incidence across different occupational groups *(175, 176)*.

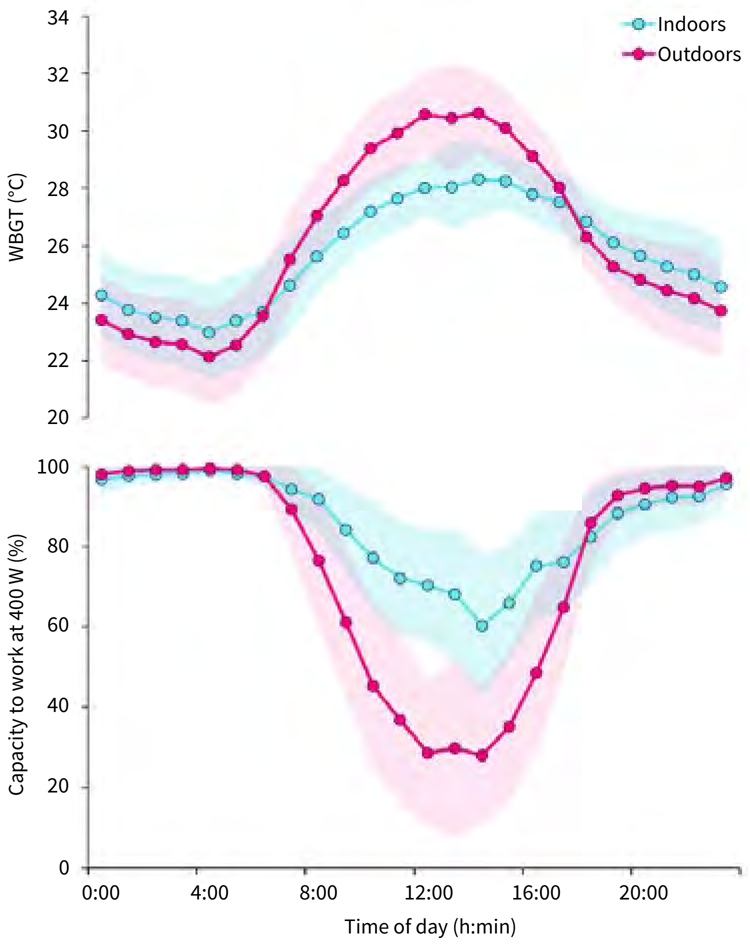


Fig. 2.8: Outdoor and indoor WBGT (top graph) and resulting ability to perform work (bottom graph) at a moderate to heavy pace (percentage of time that an individual can work at 400 W metabolic rate) during different hours of the day in Delhi, India, in May 1999. Lines indicate the monthly average and shaded areas indicate monthly standard deviation. Source: Graphs based on previously published data *(25)*; estimates based on hourly weather data from the United States National Oceanic and Atmospheric Administration database

2.9. Compound environmental hazards

It is vital to acknowledge that workers are not only exposed to workplace heat stress but also to increased levels of air pollution, dust, chemicals, ultraviolet (UV) radiation, and other environmental and occupational hazards.

These compound exposures may affect each other and drastically increase the overall severity of health risks for workers.

For instance, workplace heat stress is accompanied by an increased respiratory rate, which can intensify the inhalation of air pollutants and dust (Fig. 2.9) *(177)*.

Workplace heat stress also leads to cardiovascular strain, which may exacerbate the morbidity and mortality risks of air pollution. It is vital, therefore, to adopt a comprehensive environmental risk framework where all hazards and their synergies are taken into consideration when assessing workplace heat stress.

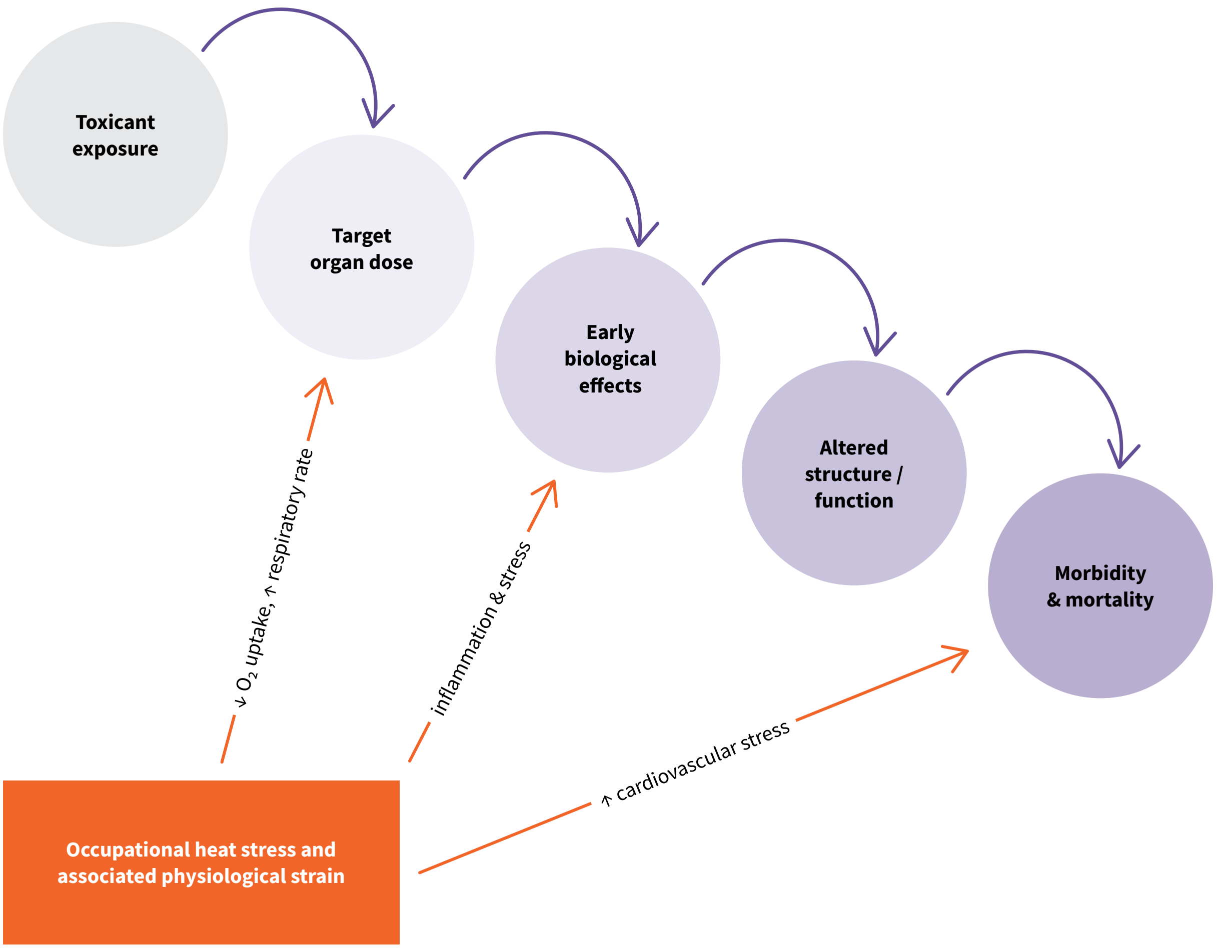


Fig. 2.9: Impacts of workplace heat stress and its associated physiological strain on the biological response to and consequences of air pollution. Note: O2 = oxygen. Source: Inspired by the idealistic exposure-dose effect continuum published by Gordon & Leon *(177)*

An African woman sweating and using a fan against the summer heat.
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Part 3: Preventing and Mitigating Workplace Heat Stress

Key Messages

- Actions to prevent and mitigate workplace heat stress **go beyond** what is typically included in public heat-health warning systems and prevention plans. Specifically designed Occupational Heat Action Programmes (OHAPs) are needed to **optimize work capabilities and reduce the excess risks** for morbidity and mortality associated with workplace heat stress in specific work settings.
- **Key stakeholders** to be involved in the development of local OHAPs include managers/employers, workers, trade unions, representatives of self-employed persons, experts in environmental/physiological/ergonomic safety, health-and-safety representatives, occupational health experts, and representatives of local authorities. Engagement with the **general public** is also crucial and encouraged.
- OHAPs should **reduce workplace heat stress** and also consider practical feasibility, economic viability and environmental sustainability. They should include **elements** related to workplace heat stress prevention policy, heat acclimatization, environmental and medical monitoring, training and education, and emergency response planning, as well as job-specific controls.
- **Engineering and administrative controls** can introduce tailor-made effective, practical and cost-effective changes to mitigate workplace heat stress.
- The contribution of **work settings** to mitigate climate change and reduce future increases in environmental heat levels is a fundamental way to prevent heat stress in a broad manner. It will **reduce the health and productivity risks** due to heat for all people, which may create particular benefits for economically disadvantaged people with a limited ability to adapt.

A woman holding a glass of water close to her face, gazing out of a window in soft natural light. © Unsplash.com / Ba Ba

3.1. From public health prevention to occupational heat action programmes

Public heat-health warning systems and prevention programmes are mainly focused on protecting the general population, and particularly vulnerable persons, from excess morbidity and mortality during extreme heat events [for an overview and links to examples of national programmes and systems, see Ebi et al. *(178)* and Casanueva et al .*(38)*] *(179-182)*.

For general guidance on public heat-health prevention programmes and issues surrounding the general heat-health problems of biometeorology, epidemiology, public-health and risk-communication aspects of heat as a hazard, readers are referred to Heatwaves and health: guidance on warning-system development (WMO-No. 1142), a guidance publication developed jointly by WMO and WHO *(10)*.

However, the actions typically considered in these heat warning systems concern only outdoor workers, though indoor workers are also at risk of heat stress. Specifically designed OHAPs are therefore needed to optimize work capacities and mitigate the excess risks of morbidity and mortality associated with workplace heat stress. These action programmes must consider how workers can sustain productivity (with adjusted or maintained activity levels) without jeopardizing their health or increasing the risk of work accidents/injuries.

Importantly, OHAPs should also be designed to address individual risk factors (see Section 2.5) that may make certain workers more vulnerable to heat-related health outcomes. Importantly, a significant portion of vulnerable workers, particularly in agriculture, construction and fishing sectors, operate in self-employed or informal arrangements. Therefore, OHAPs should also consider the unique needs of self-employed and informal workers.

Several national and international occupational safety and health authorities, trade as well as business associations and stakeholders for specific industrial sectors, have developed technical guidance documents that include instructions on the development of OHAPs and other solutions to mitigate workplace heat stress *(2)*.

Some of these programmes offer general considerations, while others provide detailed solutions and guidance tailored to a specific industrial sector or geographical area, and aligned to national requirements/legislation.

Given the large variability around the globe in terms of exposure scenarios and combinations of parameters that may increase workplace heat stress, a general three-step approach is proposed for the development of OHAPs:

1. Analyse potential issues, risk factors, potential prevention programmes/solutions/strategies, and the associated considerations for different components of the OHAP, using the checklist provided in Table 3.2.
2. Develop and describe the OHAP, securing effective information (in the local language(s)) and the involvement of relevant stakeholders. This is important for all three steps of the process to facilitate progression from one step to the next.
3. Act and translate the programme into practice, ensuring that a given solution/strategy becomes habitual behaviour when workplace heat stress rises. This facilitates seasonal adaptation and the implementation of OHAP elements. This step also involves careful preparation as some procedures and practical solutions may require substantial time and resources to install/buy/implement.

3.2. Development of OHAPs with involvement of workers and relevant stakeholders

Employers, managers and health and safety officers should collaborate with workers and their representatives, and other stakeholders to develop OHAPs. When a workplace is used by several employers and contractors they should collaborate in the development and implementation of OHAPs.

The programmes should include adequate information (education and training programmes) on workplace heat stress management and promote collaborations with workers and their representatives, including self-employed and sub-contracted workers. This process should assess each relevant component of workplace heat stress (condition of the worker, environmental heat stress and task requirements) as outlined in Table 3.2 (left column) and consider how the analysis translates into well-defined solutions, strategies and actions (outlined in centre and right columns).

The analytical part, in particular, may benefit from consultant/advisory assistance by environmental, physiological and/or ergonomic experts and also draw inspiration from other OHAPs.

Involving experienced workers and their representatives, health-and-safety officers, occupational health experts and line managers is important to tailor the solutions to specific regional/industry/company needs and to facilitate implementation, especially in the initial phase.

The OHAPs should bear in mind other compound exposures, such as air pollution, UV radiation, and chemical hazards.

	Workplace heat stress factors	Prevention programme/solution/ strategy	Benefits and practical perspectives
Environmental heat load	• Air temperature • Humidity • Solar radiation • Wind/air movement	Air cooling/conditioning or reducing humidity in very humid environments. Shading with sun sails/shades/hats, etc. Fanning/ventilation when low air movement limits heat dissipation at air temperature below ~35°C (above that, use with caution).	In all scenarios where a single parameter or combination of factors can be reduced, this should be considered along with the economic and ecological footprint. Creation of “cooling oases” or individual workplace solutions may be considered as alternatives.
Forecasting information/	• Use of climate info and weather warnings • Integrated information for risk assessment and “action alerts” • Timely heatwave warning • Periods with cooler weather	Link to national/local weather warnings for timely alert. Warning and precaution during sudden events, acknowledging that heat-health effects are highest at heatwave onset. In areas with large diurnal variation, identify if entire work shift or specific work tasks can be rescheduled.	Short-term forecasts mainly relevant in areas where heat can vary considerably week to week – or during the day. For areas with constant yearly/ seasonal heat load, consider the prolonged weather/climate scenarios and be prepared in due time.
Specific industrial settings	• Factors affecting the microclimate around workers • Machinery/industrial heat production • Thermal insulation of protective clothing	Consider solutions that may reduce heat generated by machinery or facilitate dissipation of that heat. Optimize heat dissipation of protective clothing without compromising safety requirement/protective effects.	Solutions are typically highly scenario-specific, based on practically, feasibility and economic viability.
Individual factors	• Work rate • Activity-break ratio • Workers’ individual capacity	Lowering of the work intensity (more breaks or reduced average work pace). Respect individual workers’ capacity and allow time for acclimatization during the onset of the heat period.	Heat stress will eventually force workers to take longer or more frequent breaks, or to reduce their work rate. Planning of work and breaks to minimize health risks and using breaks actively/proactively should be evaluated over the long term

Recovery between work periods	• Options to lessen workplace heat stress during a given work shift • Cooling and hydration breaks • Pacing and planning	Breaks in “cooling oases” where workers can hydrate and benefit from extra cooling. If no rooms/areas are available, use places away from hot machinery or out of the sun (for example, equipped with electric fans or locations with natural air flow and (cool) fresh water). Pacing and planning of most physically intense tasks during cool parts of days, allowing maintenance of safe work over the entire day.	Easy/natural to implement in industries with an intermittent work structure; may disturb procedures for workers with continuous tasks. Educate, discuss and involve workers for optimized integration with their tasks.
Recovery day-to-day	• Exposure outside working hours • Sleep quality	It is equally important to consider recovery from day to day, and inform/educate workers on how to secure rehydration and recovery from consecutive workdays with workplace heat stress. This should include both instruction on heat exposure outside working hours, with particular emphasis on the potential impact of nighttime temperature and sleep quality, and the re-establishment of water and electrolyte balance.	Many workers may fail to rehydrate and compromise recovery from one work shift to the next (128). Poor sleep quality may be a sign of subclinical illness and may subsequently impair recovery and work capacity. Air conditioning is important to improve sleep quality and quantity.
Hydration and hygiene facilities	• Dehydration • Hypohydration • Nutrition	Information and facilitation of procedures to secure hydration and access to toilet facilities. Installation of drinking water stations close to active workers. Hydration guidance and self-monitoring (e.g. via urine colour) *(183)*. Provision of scheduled and dedicated breaks long enough to ensure replenishment of energy and fluid.	Industries with limited clean water access (e.g. agriculture) should provide workers with water bottles and inform them about hydration and the need for electrolytes in fluid and food. Access to toilet facilities is key, as workers may not hydrate if they lack access *(184)*.
Medical emergency procedures	• Be prepared in case of emergency (see graded symptoms of heat-health outcomes in Part 2)	Information for all workers, health/safety managers and employers. Information materials supported by preparedness at the local workplace and emergency rooms (see Section 3.5). Educate workers on: minimizing the risk of heat casualties, maintaining a so-called buddy system, implementing daily heat-health habits, and being ready to act if colleagues show signs of heat illness.	All strategies and solutions are intended as habitual hot-season daily procedures, to benefit workers’ health, maintain their ability to function and prevent heat illness.

Table 3.2: Issues and risk factors to be considered; potential prevention programmes/solutions/ strategies; and the associated considerations for different components of the OHAP. Source: Developed based on information provided in the present guidance

3.3. From plan to implementation – considerations on effectiveness, feasibility and sustainability

Actions in an OHAP should aim to eliminate workplace heat stress or exposure to it (for example, by automation and mechanization).

In cases where this is not possible, actions in an OHAP should apply engineering controls to reduce exposure to workplace heat stress. It is also very important to consider aspects such as practical feasibility, economic viability and sustainability for the successful implementation of an OHAP.

For example, lowering the air temperature and relative humidity in an industrial area via air conditioning would eliminate workplace heat stress.

However, in many sectors, this is either practically impossible or would be so costly and energy consuming for the employer that this solution would not be economically sustainable. Instead, the creation of smaller cooling areas, where workers can rest, cool and hydrate during breaks, is an attractive, often more feasible and less expensive alternative to cooling the entire workplace

Likewise, there are several effective cooling interventions directly targeting the individual worker [for an overview, see Part 4 and Morris et al. *(89)*], directly targeting the individual worker. However, tailored OHAPs are needed to ensure that the proposed solutions do not compromise safety and are feasible to implement.

For instance, some intermittent or pre-activity cooling solutions are so time-consuming or may disturb work routines to such an extent that the benefits of cooling are outweighed by the complications it introduces to normal work procedures. It is therefore recommended to involve experienced workers and managers in the identification and implementation process to ensure that solutions comply with specific occupational settings.

3.4. Designing suitable, specific and sustainable OHAPs

The choice of the most suitable solution (effective and feasible) or combination of methods to mitigate workplace heat stress will be based on the population and workplace scenario.

When developing a local (specific) OHAP, it should adhere to national legislation, sector-specific safety requirements and the evidence supporting its effectiveness in terms of improved heat-health for the worker.

In addition, to ensure effective translation into sustainable actions, an OHAP should also be developed within a framework that integrates social, economic and environmental sustainability, along with feasibility considerations for both indoor and outdoor settings, to provide practitioners as well as health and occupational advisors with evidence-based guidelines *(89)*.

In addition to mitigation actions which focus on eliminating workplace heat stress or exposure to it, an effective OHAP should include adaptation actions focused on improving the individual worker's capacity to perform physical work in the heat, thereby reducing the risk of heat-related illnesses.

Fig. 3.4 illustrates some of the main heat adaptation strategies *(22)*. Table 3.2 outlines the main issues/ factors to be considered and provides examples of how environmental parameters (from the regional weather conditions to the microclimate around the worker) as well as solutions targeting the individual worker may help prevent negative heat-health effects and also support safe and effective work.

An elderly man sitting under the shade of a tree in a rural village, with a person seated on the ground nearby. © iStockphoto.com / poco_bw

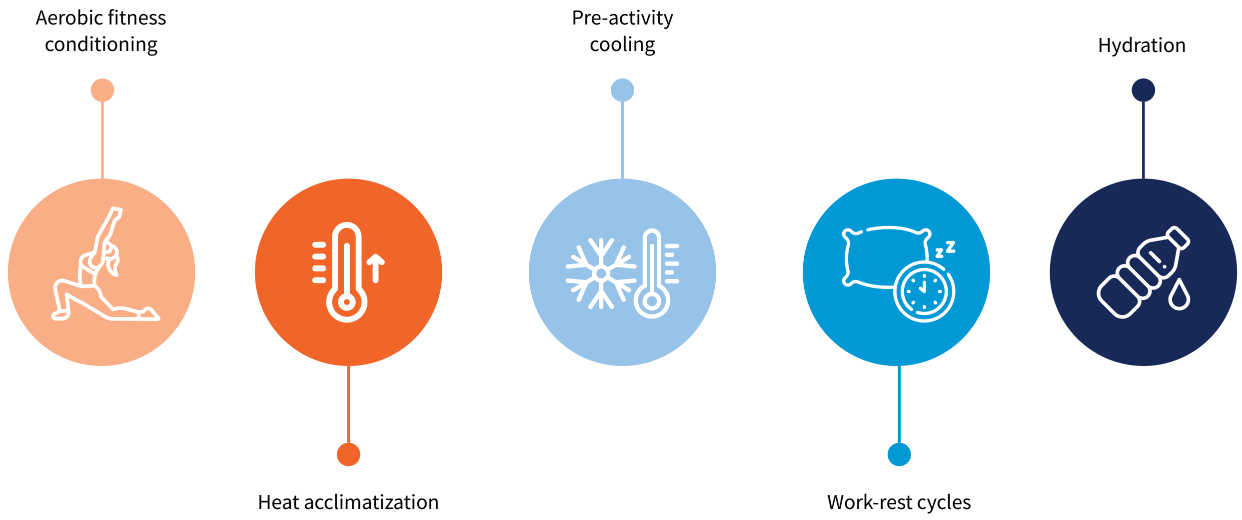


Fig. 3.4: Important heat adaptation strategies for reducing the risk of workplace heat stress

3.5. Elimination/substitution of workplace heat exposure

Reducing future exposure to workplace heat stress on a broad scale can be achieved through climate change mitigation actions at local, national and international levels, aimed at reducing atmospheric greenhouse gas levels.

The means to achieve this are outside the scope of this guidance but have been elaborated in several documents published previously by international organizations *(185-189)*.

As efforts to reduce workplace heat stress are made in workplaces, technologies and practices that also minimize greenhouse gas emissions should be sought. For instance, using air conditioning (AC) on factory roofs powered by solar panels and radiative cooling panels that reflect heat into the atmosphere are emerging strategies to combat heat stress in industrial setting while promoting energy efficiency and sustainability.

An OHAP provides the framework for the prevention and management of workplace heat stress. It should include at least six written key elements: *(1)* an workplace heat stress prevention policy; *(2)* a heat acclimatization plan; *(3)* environmental surveillance; *(4)* medical monitoring, training and hydration; *(5)* an emergency response plan; and *(6)* job-specific controls, following a recognized preference hierarchy to optimize work capabilities.

Information on these elements is provided in the following subsections.

3.5.1. Training and awareness

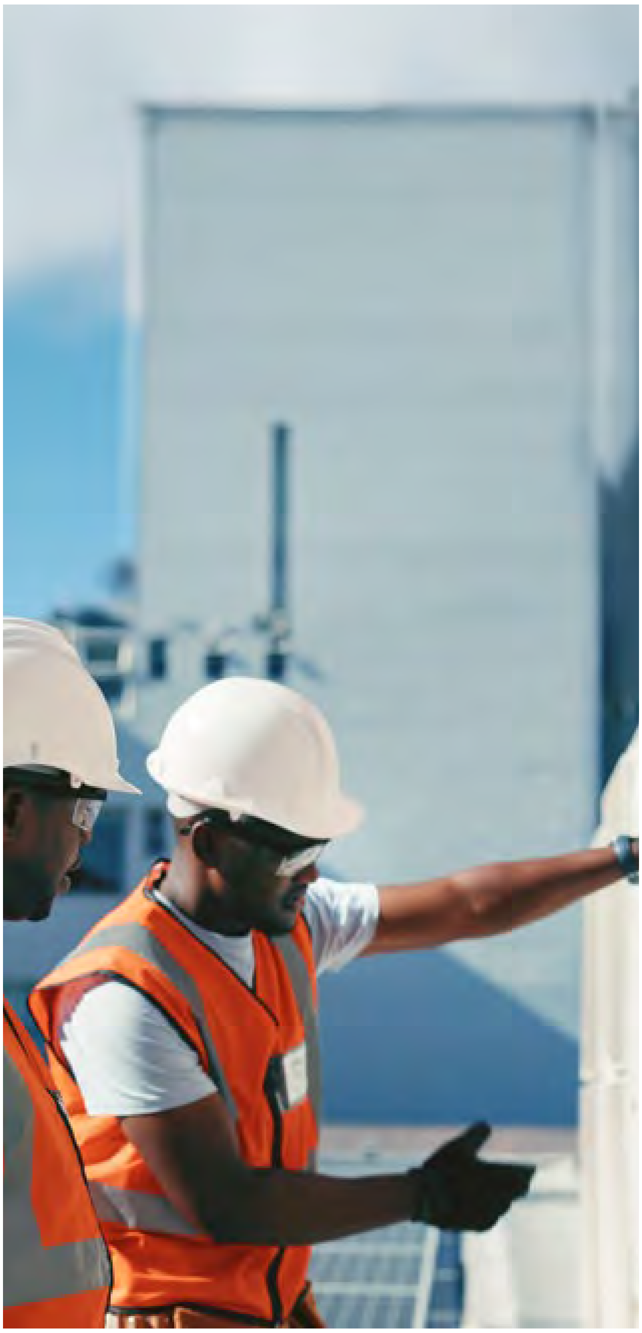
Training is the key to good work practices. It ensures that workers and supervisors understand workplace heat stress hazards and how to prevent them, using new work practices or updating old ones.

Training must be conducted periodically (especially at the start of hot seasons) to bring about awareness of signs and symptoms of workplace heat stress-related health outcomes. As a preventive approach, infographics (posters with pictorial descriptions) and signs can be displayed in high-risk and rest areas.

Training supervisors and workers to recognize the signs and symptoms of physiological heat strain is vital, and so is training them to take immediate first aid steps when these signs are identified. It is also crucial that supervisors understand the importance of allowing workers to acclimatize to hot conditions and to regulate their work pace during periods of high risk of workplace heat stress *(22)*. Training must include at least the following components:

- Knowledge of the hazards of heat stress, to promote self-protection;
- Education regarding hydration and assessing urine colour in appropriate charts (see examples in Fig. 4.4.2b) displayed in all workplace toilets, to help workers improve their fluid intake (190);
- Recognition of predisposing factors, signs and symptoms that empower workers to help themselves and their co-workers (see classifications of workplace heat stress-related health outcomes in Section 2.2);
- Worker responsibilities in avoiding workplace heat stress;
- Dangers of using recreational drugs and alcohol in hot working environments;
- Use of medications to manage health conditions when work involves exposure to workplace heat stress;
- Purpose and scope of environmental and medical surveillance programmes along with the benefits of worker participation in such programmes.

Training should also increase awareness and build capacity to recognize the early effects of heat on themselves and their co-workers. This includes providing first aid to those affected, as well as the use of a buddy system. It should further include a well-designed and applied acclimatization programme for all workers *(191)* (see Section 4.3.2), which can significantly reduce the risk of workplace heat stress-related health outcomes. This method is particularly useful to protect newly-hired workers or those returning from sick/injury leave or holidays (see Section 4.3.3).



Construction workers wearing hard hats and high-visibility vests, inspecting equipment at a worksite. © iStockphoto.com / Hiraman

3.5.2. Fluid and electrolyte replacement/hydration

The importance of hydration is well-known and workers exposed to workplace heat stress are typically aware of its key role for health, but many workers fail to ensure that they are adequately hydrated – and OHAPs often fail to facilitate adequate hydration (128).It is therefore important to ensure that workers exposed to workplace heat stress start work in a hydrated state, which entails rehydrating from the previous day as well as ingesting approximately 500 mL fluid with electrolytes about 1 h before starting work *(131, 132)*.

It is equally important that they maintain proper hydration by drinking regularly throughout the work shift *(89, 107)*. Workers should therefore have convenient access to cool potable and potable fluids throughout the day in all parts of a worksite – including relatively remote areas – to encourage them to drink adequate amounts frequently *(192, 193)*. Ample supplies of fluids should be placed close to the work areas, but away from chemical contaminants *(194)*. When workers are sweating profusely, they also lose considerable amounts of electrolytes (such as sodium and potassium) and healthy workers should be encouraged to add salt to their food if their diet is low in sodium. However, excessive salt consumption is not recommended, especially for workers who are on medication or have heart conditions or hypertension. Such workers should consult their physician on how to match dietary salt intake to their daily/work-related loss *(195)*. If possible – and particularly during breaks – cooling the fluids by refrigeration, or better yet by the addition of ice slurry or shaved/crushed ice, will help lower discomfort and physiological heat strain and improve work performance *(89, 193, 196)*. Providing beverages during meal breaks is critical for rehydration, as this is the time during the work shift when workers will normally fully rehydrate.

3.5.3. Hygiene facilities

It is important to ensure access to facilities such as toilets, washrooms and changing rooms (hygiene aspects related to the ability to wash hands and clean the skin to avoid excessive salt accumulation). Lack of access to toilet facilities may lead workers (females, in particular) to abstain from sufficient drinking *(184)* and prevent them from taking cooling breaks to splash water over their bodies *(194)*. Displaying urine colour charts (see examples in Fig. 4.4.2b) in toilets and providing a scale to monitor body mass changes helps workers assess their hydration status.

3.5.4. First aid and emergency response plan

While occupational exposure limits presented in Section 4.1 protect most healthy workers, they may not protect all workers all the time, and will provide less protection for workers with personal risk factors and vulnerabilities listed in Section 2.5. For this reason, employers need to have an emergency plan for the early recognition of workplace heat stress-related health outcomes, and steps for immediate and aggressive cooling (for example, ice/cold water immersion) *(197)*, along with provisions for securing emergency transport to a healthcare facility that is capable of diagnosing and treating heat stroke (see Section 4.4).

The emergency response plan should include the ability to recognize early symptoms of the health outcomes related to workplace heat stress (described in Section 2.2) by first-line supervisors and workers. In the event of a suspected heat pathology, the treatment methods described in Section 4.4 should be applied.

The buddy system is important for the recognition of health outcomes related to workplace heat stress, particularly since the person affected may not have the cognitive ability to understand the risk and take necessary protective steps. In this system, two individuals (the buddies) work together as a team, allowing them to monitor and help one other. Importantly, these actions require training. Table 3.5.4 exemplifies the information that might be provided to workers to identify serious heat-related disorders along with appropriate first aid and other actions. Further detail is also offered in Section 4.4 on the first aid treatment of mild and severe health outcomes related to workplace heat stress, together with issues surrounding return to work.

Observations	Suspected diagnosis	Actions
Person may say they feel: • Tired/fatigued • Thirsty • Weak • Dizzy • Lightheaded • Faintness when changing posture or after prolonged standing • Muscle cramps	**Mild heat exhaustion**	Inform supervisor. Move to cool area for recovery. Encourage the consumption of water and/or electrolyte drinks. If symptoms persist after 15 min, treat as severe heat exhaustion.
Signs: • Wobbly walking • Slow reaction time • Severe fatigue • Severe muscle cramps • Vomiting or collapse without any signs of heat stroke Person may say they feel: • Severe fatigue • Loss of appetite • Nausea • Headache • Blurred vision	**Severe heat exhaustion**	Move to air-conditioned space, encourage the consumption of water/electrolyte drinks if able, and allow to lie down. Cover head and shoulders with a towel soaked in ice water. Watch for signs of heat stroke. If there is little improvement in 15 min, arrange for medical treatment and continue to watch for possible heat stroke.
Signs: • Vomiting • Erratic/irritable behaviour • Confusion/disorientation • Garbled/gibberish speech • Hysteria/delirium/apathy • Collapse • Shivering • Convulsions • Loss of consciousness Person may say they feel: • Severe fatigue • Nausea	**Heat stroke**	This is a situation requiring an emergency response. Begin aggressive cooling (cover 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. Call emergency services and advise them that this is a heat stroke case.

Table 3.5.4: Response guidelines for health outcomes related to workplace heat stress. Presented in order of decreasing severity/urgency. One or more observations for a given diagnosis indicate a positive determination for that diagnosis. Source: created based on information presented in Sawka, Leon et al. 2011, Leon and Bouchama 2015, Leon and Kenefick 2017, Kenny, Wilson et al. 2018, Sawka and O'Connor 2020

3.5.5. Environmental surveillance

Following an assessment determining that workplace heat stress is a potential hazard (see Section 4.1), environmental monitoring with appropriate triggers should be implemented so that workers and supervisors are aware of the level of risk at any given time. In this case, the choice of system is important to ensure that the tracking of environmental parameters adheres to the required standards of validity and reliability.

3.5.6. Medical surveillance

Medical surveillance encompasses conducting medical examinations and monitoring sentinel health events *(191)* to evaluate an individual's capacity to deal with workplace heat stress both before starting the job and periodically during employment.

These examinations should include a comprehensive medical and work history, a comprehensive physical examination, tests, and an assessment of prescription drug use. It is considered best practice to provide a written opinion on the suitability of exposing the individual to heat stress. Monitoring sentinel health events includes monitoring individual cases as well as population trends. Relevant events include heat-related disorders (Section 2.2) as well as patterns of accidents, absenteeism and chronic fatigue.

As an alternative to medical examinations, the employer may want workers with chronic diseases to consult their personal healthcare provider/physician and clearly inform them that workplace heat stress is part of their job. The employer should track sentinel events, including reports of heat fatigue and heat exhaustion, first aid events and recorded illnesses.

If the employer finds that some workers have a lower heat tolerance than others, based on sentinel events or advice from a health care provider, they can implement tailored interventions. These might include adjusting work requirements during high levels of heat stress, providing personal cooling devices or implementing personal monitoring. This may involve heat acclimatization and/or exercise training, which can be effective in improving the cooling capacity of older adults with chronic conditions during physical work *(131)*.

3.5.7. Summary of controls of heat exposure

To protect workers from workplace heat stress, the optimal approach to minimizing risks and optimizing work capabilities involves making changes to the factors contributing to environmental heat stress, as well as to workload, clothing and personal factors. A logical and systematic way of addressing the risk of workplace heat stress is to address these contributing factors, using a hierarchy of controls applicable to different stakeholders. In this approach, the most effective method (for example, engineering controls) would be the first priority, and then changes would be introduced – working down to the lowest priority (for example, personal protection). The process would therefore begin by eliminating or engineering out the hazards, and then by implementing administrative controls, such as policies and procedures, to manage worker exposure to risks.

Lastly, if the first two lines of defence proved to be inadequate or not feasible, personal cooling systems can be used as the last resort *(88, 198)*. Personal cooling systems can be used in conjunction with engineering controls, administrative controls and sound manufacturing practices as an additional line of defence to reduce worker exposure to heat. Interventions may be passively communicated through mass media or feature active elements tailored to specific stakeholders, such as warnings for outdoor and indoor workers, as well as sector-specific warnings. It is imperative to warn individuals, industries and the public early to allow for proper planning and action to be taken, depending on the type and severity of the warning.

A summary of the recommended workplace heat stress prevention responses for individual workers, public organizations and employers is provided in Table 3.5.7. Individuals can mitigate risk by adjusting behaviours and by knowing which actions to take to protect themselves and fellow workers. The local community plays a vital role through public service announcements and providing infrastructure in support of individuals and employers. The principal focus of this approach is on employer actions. It should also be emphasized that most of the world is experiencing an upward trend in temperatures and heat exposure in many jobs due to ongoing climate change. The protection of workers from workplace heat stress includes taking actions and supporting efforts to reduce future climate change.

Individual worker level responses	Public level responses	Employer level responses
• Avoid workplace heat stress whenever possible. • Remaining in the shade, wear a hat with neck covering made of reflective fabric. • Avoid extreme physical exertion during hot periods. • Wear light-coloured, loose-fitting clothes that do not restrict sweat evaporation. • Taking a cool shower, bath or body wash, sprinkling water over skin or clothing, or keeping a damp cloth on the back of the neck. • Move into cooler areas whenever possible, especially when resting; electric fans may provide some relief, especially if temperatures are below 35°C. • Know the signs and symptoms of workplace heat stress health outcomes and acting accordingly. • Resting immediately in a cool place when experiencing muscular spasms (particularly in the legs, arms or abdomen). • Seek medical attention if heat cramps persist, or in case of repeated vomiting, sustained syncope or marked neuro-cognitive impairments occur.	• Prepare and strengthening community health centres and clinics during hot seasons, including in relation to diagnosis and treatment of health outcomes related to heat. • Carry out awareness raising campaigns on workplace heat stress consequences before the beginning of hot seasons, along with educational campaigns for health workers in identifying the signs, symptoms and medical management of the health outcomes of workplace heat stress. • Train healthcare providers and dealing with emergency situations. • Ensure preparedness by the health system for a coordinated response to be developed across ambulance and emergency services, hospitals, and other health facilities providing care at the community level. • Provide daily warning advisories on extreme heat stress conditions in the local language. • Issue heat alerts or warnings from local authorities or meteorological departments. • Post emergency numbers in public places to call for help in case of an emergency. • Ensure proper maintenance of ambulances and cooling capabilities. • Arrange for community supply of drinking water and	• Develop an OHAP that includes policies and procedures including heat acclimatization, fluid/electrolyte replacement, cooling stations, training, surveillance and emergency response. It should also address engineering controls, administrative controls and personal protection. • Engineering controls should be the first choice of the industry as they deliver the most effective protection against workplace heat stress at the source: • Cooling indoor workplaces by using air conditioning or increased ventilation and provide portable ventilation whenever possible. • Install local exhaust ventilation, such as exhaust hoods, in hot and moist workplaces such as laundry rooms to vent the heat and humidity. • Redirect heat with reflective shields and insulating surfaces, such as furnace walls, and decrease humidity (for example, by sealing steam leaks and keeping floors dry). • Seek specialized advice in worksites where high ambient temperatures typically occur (for example, foundries, steel mills) to evaluate the extent of the heat exposure and to make recommendations to prevent workplace heat stress-related health outcomes. • Administrative controls must be the second choice as they change the way people work: • Integrate OHAP in the occupational safety and health management system of the undertaking. • Develop and enforce an OHAP with seasonal adaptations as needed, as workers' exposure to heat may vary based on the season, work processes and the context in which tasks are carried out. • Provide adequate welfare facilities that include resting, hygiene, rehydration and cooling facilities (such as arm immersion cooling). • Rotate jobs between hot and cooler environments, and alternate between jobs with high and low physical exertion. • Establish work-rest cycles and buddy systems, empower workers to self-pace. • Modify work schedules to reduce workers' workplace heat stress. Schedule physically

• Drink oral rehydration solutions containing electrolytes, with medical advice. • Regularly drink water and non-alcohol, caffeine free beverages, regardless of the activity level, and eat cold foods, particularly salads and fruits with high water content. • Add salt to foods as advised by health professionals. Whenever possible, quantify (and replace) individual changes in body mass lost through sweat. • Self-pace the work to prevent heat strain. • Ensure adequate nutrition and replacement of electrolyte losses.	beverages at resting areas. • Provide community-level training to social workers and residents on first aid and immediate action for health-related outcomes.	strenuous work in the cooler parts of the day. If not possible, provide workers with cool rest areas or stay indoors (preferably in air-conditioned rooms) during breaks. Even short periods spent in a cooler place can reduce heat strain and reduce risk when the workers go back into the heat. • Allow workers to acclimatize or gradually get used to working in hot conditions. • Train workers to monitor themselves and their co-workers for signs and symptoms of workplace heat stress-related health outcomes and to provide first aid when necessary. • Provide physiological monitoring of workers, especially in very hot areas, periodically or when necessary. • Promote rehydration and rest and encourage workers to use shady areas in outdoor work activities. • Personal protection such as work wear and personal cooling systems are the last resort against workplace heat stress, following engineering and administrative controls: • Wearing light-coloured, breathable clothing/ uniforms. • Putting on broad-brimmed hats with neck flaps and safety glasses with tinted, polarized lenses. • Use water-, air-, phase change- or vortex-cooling garments, and wetted overgarments. • Dressing in reflective clothing and infrared-reflecting face shields when exposed to high radiation or flame *(199)*. • Wearing thermally conditioned clothing (for example, a garment with a self-contained air conditioner in a backpack). • Use plastic jackets with pockets filled with dry ice or containers of ice for workers in high-heat areas.

Table 3.5.7: Summary of heat stress prevention measures at various levels

3.6. Engineering controls

Engineering controls are changes to equipment or the technology that reduce/eliminate or isolate hazards. Apart from reducing the physical demands of the job, the best way to prevent workplace heat stress-related health outcomes is to make the work environment cooler.

There are a variety of engineering controls that address the actual source of heat and eliminate the worker's workplace heat stress exposure. Engineering controls can also be used to increase the rate of heat loss from workers to their surrounding environment.

Active cooling (turning on a fan or air conditioning system, immersion of body parts using cool water, application of cooling packs or jackets) is often more effective than passive cooling (resting, removing clothes, natural ventilation) *(200, 201)* for jobs such as firefighting. Some standard engineering controls are as follows:

- **Active ventilation** refers to supplying external air inside the workplace by mechanical systems, usually followed by an air purifier, with the aim of reducing workplace heat stress. In this method, the external air maintains a fresh and cool indoor environment. However, this method is less effective as temperature increases and is inadvisable in hot and wet environments. In these environments, the outside air can be cooled before dilution, but this can be very energy intensive *(202)*. New technologies using solar energy on factory roofs as an energy source for cooling indoor air may provide an efficient solution to this challenge.
- Two types of **local air cooling** can be useful in reducing air temperature in specific areas. The first type is a cold room that can be used to enclose a particular workplace or to offer a recovery area near hot jobs *(203)*. The second type is a portable blower with a built-in air chiller, which has the advantages of portability and minimal set-up time *(204)*.
- Installing **evaporative cooling devices** and **altering the roof pattern** for natural ventilation reduces heat inside the building and improves ventilation *(205)*.
- **Personal air-cooled garments** are an effective personal cooling system which directs compressed air inside impermeable garments or double cotton overalls to enhance sweat evaporation *(206)*.
- **Water sprays with fans**: Increasing the airflow using fans in the work area (as long as the air temperature is less than the worker's skin temperature) can help workers stay cooler by increasing both the convective heat exchange and the rate of evaporation *(207)*. Fans combined with sprays/mists of cold water are a cheap, cost-effective and portable solution *(208)*. However, their efficacy in reducing workplace heat stress is limited in workplaces with high relative humidity in the air.
- **Automation/robots/mechanical aids**: Heat reduction can also be achieved by using power assists and tools that reduce the physical demands placed on a worker. However, for this approach to be successful, the metabolic effort required for the worker to use or operate these devices must be lower than that needed without them *(209)*.
- **Radiation reflective/absorptive surfaces**: The emission of heat radiation can be controlled by installing reflective or absorptive barriers in the main workstations *(210)*. These surfaces vary in complexity and can include insulated furnace jackets, reflective metal shields, reflective clothing or light-coloured external surfaces, and reflective paint coatings on the roofs and walls as passive and sustainable options to minimize the surface temperature and heat load of the building or vehicle *(211–214)*.
- **Use of alternative building materials**: Materials with lower thermal conductivity, thermal diffusivity and absorptivity may be suitable as building envelopes, especially for workspaces that are occupied primarily during the day. Certain materials with excellent thermal properties (such as vacuum insulation panels, shape-memory polymers, phase-change materials, window glazing, polymer skin) can be incorporated in different parts of the building to reduce indoor temperatures from process heat *(215, 216)*.

3.7. Administrative controls and work practices

Administrative controls include measures aimed at reducing worker exposure to hazards by altering work practices.If it is not possible or practical to reduce exposure to workplace heat stress by engineering controls, establishing work policies and procedures to reduce the length of workers' exposure to heat is the second most effective way to control the hazard.

There are several intervention mechanisms with a physiological basis to mitigate physiological heat strain, such as increasing workers' fitness and fluid ingestion as well as heat acclimatization. Other administrative controls include the following:

- Job rotation: Persons working in hot areas of the worksite must also be stationed in colder zones within the shift to avoid exposure to a high heat load. Rotating workers for physically demanding jobs is a simple administrative control with minimal cost and proven results *(5)*.
- Job schedules: Physically strenuous jobs and activities in hot areas should be scheduled for the cool part of the day, and routine maintenance and repair work in hot areas should be scheduled for the colder seasons of the year *(204)*. Using shifts (for example, early morning, cool part of the day, or night) for physically intensive work and work that typically involves being in open sunlight reduces workers' heat exposure. However, it is also important to consider the social impacts of such changes in working hours to ensure the well-being of all workers and their families.
- Adjusting the work-rest schedule to include more frequent breaks allowing workers to leave hot areas of the worksite. Carefully designed work-rest schedules have shown positive effects on mitigating physiological heat strain without impacting worker productivity *(51, 89)*. The regular alternation between work and rest breaks also helps limit the physiological heat strain and allows the body time to dissipate excess heat *(51, 217)* for both outdoor *(22, 51)* and indoor *(51, 218)* work. Industry recommendations *(45)* as well as the international standards *(219)* for worker heat protection are based on the fact that longer breaks during hot hours protect workers' health.
- Worker monitoring programmes: Individuals who work in extraordinary conditions that increase the risk of workplace heat stress, such as wearing semi-permeable/impermeable protective clothing at high temperatures and/or working at very high intensities (greater than 500 W) should be personally monitored (heart rate, recovery heart rate, core body temperature, level of dehydration and extent of body water loss) in consultation with an expert in occupational medicine/physiology or ergonomics *(135, 204)*. Another monitoring approach is the buddy system, where co-workers intermittently monitor each other for excessive fatigue and signs of health outcomes related to workplace heat stress.

A woman wearing overalls and a hat sitting in a cabin, gazing outside.
© iStockphoto.com / DragonFly

3.8. Personal protective equipment and cooling systems

Personal cooling systems can play an important role as the last line of defence for mitigating workplace heat stress, by providing a barrier between the worker and the heat source. In their simplest forms, personal cooling systems can be part of personal protective equipment aiming to maximize body heat loss and minimize heat gain from the environment.

Examples for outdoor workers include hats and long, loose-fitting, lightweight, breathable clothing with light colour or reflective fabrics. For these workers, reflective tents and shade are also very effective for reducing workplace heat stress.

For indoor workers, ventilation patches can be applied in less exposed areas (for example, inside the elbows and behind the knees) in cases where whole-body protection (for example, against chemicals or diseases) is not required. More sophisticated personal cooling systems include cooling hats, sweatbands and hard hat cooling products such as neck shades, bandanas, sun shields and cooling pad inserts. Advanced forms of personal cooling systems include reflective clothing, cooling garments that use phase-change materials, and microclimate liquid cooling garments *(88, 198)*.

When applying personal cooling systems to address workplace heat stress-related issues, it is important to consider that these systems can sometimes restrict heat loss and be associated with greater work effort depending on practicality and equipment mass. Reducing the exposure time to workplace heat stress and integrating intermittent cooling in breaks between exposures is therefore an advisable low-cost and often more feasible solution. A list of good practices regarding personal cooling systems is provided below:

- Selection and use of personal cooling systems and equipment should be tailored to the location, profile and type of work *(88, 198, 220)*.
- Cold air-cooled garments and liquid cooling garments provide the highest level of protection but are less practical and more costly than phase-change cooling vests *(88, 198, 221–224)*.
- Local body cooling using ice gel packs and other phase-change materials is the most practical and cost-effective option. Workers use local body cooling packs made from refrigerant cooling gel or non-toxic polymer ice gel placed inside purpose-designed pockets of the garments.
- Extremity immersion cooling: Installing stations where workers can immerse their arms in cool water near high workplace heat stress areas of the worksite is a low-cost and effective method to reduce physiological heat strain *(225).*

A metal fan sitting on top of a table. © Unsplash.com / Beaumont Yun

A small desert town at sunset, with golden light casting long shadows over the arid landscape. © iStockphoto.com / vkp-australia

Part 4: Assessment, Monitoring and Management of Workplace Heat Stress

Key Messages

- A workplace heat stress assessment should **evaluate job and personal risk factors** and should also consider issues related to the return to work after severe health outcomes associated with workplace heat stress.
- Countrywide workplace adoption of **thermal stress indicators** such as the wet-bulb globe temperature (WBGT) can support evidence-based decision-making, improve worker health and safety, and reduce disease burden.
- A **qualitative judgment** on the risk of workplace heat stress can be made by an employer, public agency or work group as an initial step of recognition. Quantitative methods can confirm whether a workplace or task is at high risk of workplace heat stress, which should then trigger the **development and implementation of an OHAP**.
- In most cases, mild health outcomes associated with workplace heat stress can be treated at the worksite. However, most of the **severe health outcomes** associated with workplace heat stress require immediate and aggressive cooling as well as evacuation for medical care.

A construction worker in a safety vest and ear protection resting his hard hat against his head, appearing fatigued. © iStockphoto.com / coffeekai

4.1. Assessment methods for workplace heat stress

Any evaluation of heat stress must consider key occupational risk factors. At a minimum, this includes environmental conditions such as air (dry-bulb) temperature, air movement (velocity), relative humidity and infrared radiation, along with job-specific elements like work intensity (metabolic rate) and type of clothing worn.

To illustrate this, Box 4.1 presents an example of effective strategies for assessing workers' exposure to workplace heat stress.

Most assessment methods are grounded in either empirical data or biophysical principles. Some approaches may also incorporate additional environmental indicators, such as air speed, and take clothing characteristics into account.

When a male construction worker (body stature: 170 cm; body mass: 65 kg) is shovelling materials at a heavy work intensity (metabolic rate of 460 W in Table 2.7) *(226)*, the actual external work that he is producing is 69 W (assuming a 15% efficiency); the remaining 391 W is released within his body as heat.

This heat must be dissipated to the environment to avoid hyperthermia. If this hypothesized worker performs a non-stop 8-hour shift while wearing a normal construction uniform (coverall, shirt, underpants, socks and shoes; total clothing insulation: 0.8 m2·°C/W) during a typical autumn day in a temperate climate (air temperature: 18°C; relative humidity: 40%; wind speed: 1 m/s; solar radiation: 400 W/m2) his body temperature is not expected to surpass 37.8°C and he can remain hydrated by consuming a relatively low volume of fluids (3 L; that is, 0.4 L per hour).

However, if this worker performs the same task on a typical summer day (air temperature: 30°C; relative humidity: 40%; wind speed: 1 m/s; solar radiation: 500 W/m2), his core temperature will reach nearly 38°C and he will need to drink a greater volume of fluids (5.5 L; that is, 0.7 L per hour) during his work shift to remain hydrated, while his total salt loss is expected to be substantial because of anticipated high sweat production.

If he performs this job during a very hot day (air temperature of approximately 39°C), his core body temperature is expected to surpass 38°C within about 1 h of starting work and he will be forced to markedly reduce his work intensity and/or take frequent breaks to avoid heat exhaustion. In addition, his fluid needs will be very high, reaching close to 10.5 L (that is, 1.3 L per hour) during his work shift.

Box 4.1: An example of workplace heat stress exposure, created using the freely available Predicted Heat Strain calculator *(63)* which follows ISO standard No. 7933

4.1.1. Professional judgment and qualitative assessments

Often, there is a shared agreement among employers, workers and other stakeholders that a workplace or job task has a risk of heat-related health outcomes. This shared judgment might be based on local experience, experience at other similar workplaces and tasks, or records gathered by public agencies or professionals. Questions that may facilitate this informed judgment include:

- Is there obvious sweating among the workers?
- Is the environment perceived as warm or hot by the observer?
- Does work under cool conditions require a break at least every 2 h?
- Would wearing regular work clothes be more comfortable?
- Are there reports of fatigue, weakness, loss of coordination, dizziness, headaches, nausea, heat exhaustion or cramps among the workers?
- Are there reports of absenteeism, worker irritability or worsening worker relations associated with the work conditions?
- Are there reports of increases in accidents and injuries or decreases in productivity or quality indices associated with the work conditions?

If the answer to any of the above questions is yes, then workplace heat stress may be present and the development of an OHAP should be considered. Another qualitative workplace heat stress exposure assessment is presented in Table 4.1.1 using category assessments for air temperature, humidity, thermal radiation, air movement, workload, clothing and worker opinion *(53)*.

When a decision is based on professional judgment (shared agreement), the implementation of controls specific to the job becomes more difficult. In the context of occupational safety, health and wellness, this judgment would be the initial step of recognition or anticipation of risk, to be followed by evaluation of risk (that is, exposure assessment) and controls. Once a workplace or task is confirmed as having a potential exposure to heat stress, then an OHAP should be implemented (see Part 3).

A construction worker in a hard hat and orange safety vest shielding her eyes from the bright sunlight. © iStockphoto.com / Wormphoto

Factor	All factors within these categories = low risk of workplace heat stress			One or more factors within these categories = high risk of workplace heat stress	
Air temperature	Generally <18°C	Generally 18–25°C	Generally 25–32°C	Generally 32–40°C	Generally >40°C
Humidity	Dry throat and/or eyes after 2–3 hours	Normal	Moist skin	Skin completely wet	
Thermal radiation	Feels cold on the face after 2–3 min	No perceptible radiation	Feels warm on the face after 2–3 min	Unbearable on the face after >2 min	Immediate burning sensation
Air movement	Cold air	No noticeable air movement	Light movement of warm air	Strong movement of warm air	
Work effort	Light		Moderate	Heavy	Very heavy
Clothing	Light and flexible; no interference with work		Long and heavier; slight interference with work	Clumsy and heavy; specially designed barrier for radiation and/or water vapour	Special coveralls with gloves and hoods
Feels	Slight, local cool discomfort	No thermal discomfort	Slight sweating and discomfort; thirst	Heavy sweating; strong thirst; modified work pace	Excessive sweating; very strong thirst; very tiring work; special clothing

Table 4.1.1: A qualitative method to assess workplace heat stress based on category assessments. If any single factor falls into either of the two far-right categories, workplace heat stress may be present. Source: See Malchaire et al. *(53)*

4.1.2. Wet-bulb globe temperature (WBGT)

The WBGT is a widely recognized index for evaluating environmental heat stress and its impact on health *(45, 155, 191)*. It takes into account: temperature, humidity, wind speed and thermal radiation. Practically speaking, it represents the maximum ability of the environment to support evaporative cooling as reflected in the natural wet-bulb temperature (Tnwb) and the heat exchange by radiation and convection reflected in the globe temperature (Tg).

In conditions with no direct sun, WBGT = 0.7 Tnwb + 0.3 Tg. In the special case of direct exposure to the sun, WBGT = 0.7 Tnwb + 0.2 Tg + 0.1 Tair, which accounts for the exaggerated effect of the sun on Tg by adding air temperature (Tair). The weighting towards the natural wet-bulb temperature recognizes the importance of cooling by sweat evaporation compared with dry heat exchange by radiation and convection. The values of WBGT under different conditions can also be calculated from data on temperature, humidity, air movement and heat radiation, which avoids the need to use specialized equipment for monitoring *(227)*.

The goal of different WBGT thresholds is to limit heat stress exposure to a sustainable level that can be tolerated over hours without unfavourable health effects, allowing healthy adults to remain at an acceptable and sustainable level of physiological heat strain.

When combined with a category of metabolic rate (see Table 2.7), the WBGT has been recommended by a number of national and international organizations for assessing heat stress (Table 4.1.2a). According to a recent large-scale multi-country evaluation of all thermal indicators developed to date, WBGT has also been recommended as the most effective thermal stress indicator for assessing the physiological strain experienced by individuals working in heat *(34–37)*.

The thresholds of WBGT adopted by different regulatory agencies and expert organizations are illustrated in Fig. 4.1.2 as a function of work intensity (metabolic rate) and acclimatization state *(155)*. The figure shows that the WBGT exposure limit decreases with work intensity. This is due to the need to reduce the humidity and air temperature reflected in WBGT to facilitate the additional cooling required by the higher metabolic rate.

The figure also shows the effect of the acclimatization state, where an acclimatized person can sustain a higher WBGT than an unacclimatized person at the same work intensity.

Practically speaking, workplace heat stress assessment formally includes whether workers are acclimatized (i.e. adapted) to heat because of the importance of this personal risk factor and also because most healthy people can acclimatize to heat stress. Importantly, the “safe” heat exposure curves by metabolic rate presented in Fig. 4.1.2 are based on work clothing comprising long trousers and long-sleeved shirt worn over modest clothing (for example, shorts and T-shirt).

Several of the organizations listed in Table 4.1.2a allow for clothing adjustment values (CAVs) that can be added to the ambient WBGT to account for the effects of clothing (Table 4.1.2b) *(45, 155)*.

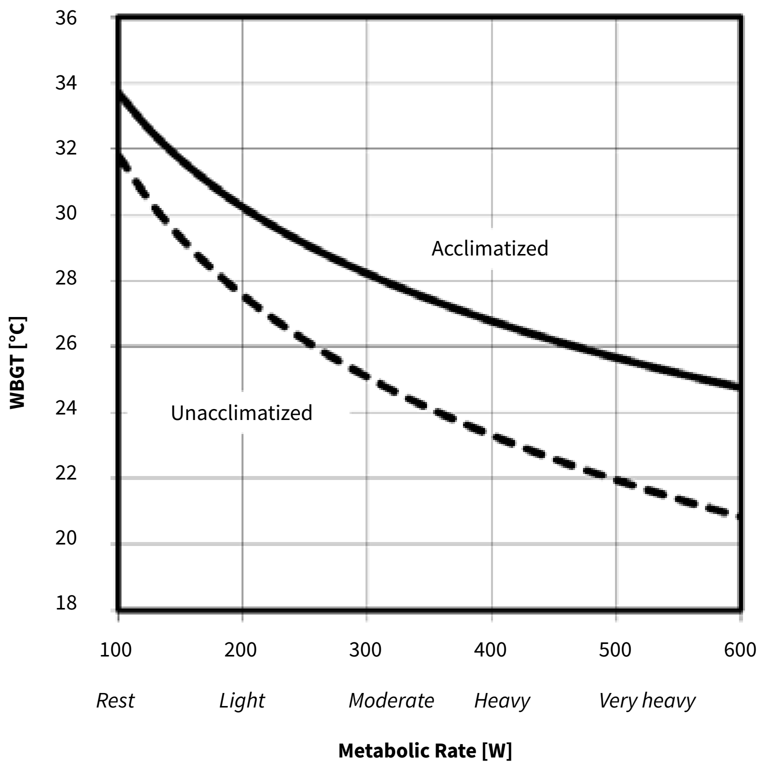


Figure 4.1.2: WBGT exposure limits adjusted for metabolic rate (work effort) for healthy persons. Source: See ISO standard no. 7243 *(155)*

	Level of physical effort			
Organization	**Light**	**Moderate**	**Heavy**	**Very heavy**
Canadian Centre for Occupational Health and Safety *(228)*	31.0	28.0	---	---
Cyprus Ministry of Labour, Welfare and Social Insurance *(229*)	30.0	26.7	25	---
Greece Ministry of Labour and Social Affairs *(230, 231*)	31.0	28.0	---	---
ISO 7243:2017 *(155)*	30.0	28.0	26.0	25.0
Japan Ministry of Health, Labour and Welfare *(232)*	32.5	29.0	26.5	---
Malaysia Ministry of Human Resources *(233)*	31.0	28.0	---	---
NATO *(50)*	32.2	31.1	29.4	27.7
United States National Institute for Occupational Safety and Health *(191)*	30.0	28.0	26.0	25.0
Qatar Ministry of Labour *(234)*	30.0	28.2	---	---
Singapore Workplace Safety and Health Council (235)	31.0	28.0	---	---

Table 4.1.2a: Values of WBGT (in °C) used as upper thresholds for continuous work at different levels of work effort (average metabolic rate), proposed by different regulatory agencies and expert organizations. Above these thresholds, no work should be done at the given level of work intensity.

Note: --- = threshold not designed for continuous work because the associated metabolic demands are not physiologically sustainable for most workers regardless of the environment. The metabolic rate (W) for each work intensity varies across the different organizations, but generally falls within ±30 W of that presented in Table 2.7

The National Institute for Occupational Safety and Health (NIOSH) criteria for a recommended standard relating to workplace heat stress *(191)* as well as many textbooks on occupational health and safety provide some guidance for using WBGT-based exposure limits. An important aspect of heat stress assessments is the selection of the averaging period for calculating the time-weighted average WBGT and work intensity (metabolic rate).

Although exposure limits are designed for prolonged exposure over several hours, the recommended averaging period should be between 1 and 2 hours, and should not exceed 2 hours.

The weaknesses of WBGT for assessing heat stress and physiological strain include: *(1)* overestimation of evaporative capacity at high humidity and at low air speeds; *(2)* potential use of instruments that do not meet minimum standards; and *(3)* the need to account for metabolic rate with more accuracy than usual (in the case of WBGT thresholds) *(236, 237)*. Moreover, some studies have questioned the validity of time-weighted averages to specify work and recovery cycles (238–240).

The instruments to measure WBGT recommended in the international standard *(155)* are typically expensive, and cheaper instruments may not have sufficient accuracy. An alternative to expensive instrumentation is to estimate the WBGT using local weather data or local air temperature and humidity with some adjustment for sunlight *(227, 241–243)*.

Some regions have smartphone applications that allow timely updates for at least air temperature and humidity. However, in many low-resource settings, this method may not be feasible.

Ensemble	**CAV* (°C WBGT)**	**Comments**
Work clothes	0	Work clothes made from a woven fabric is the reference ensemble
Cloth coveralls	0	A non-proprietary process to make non-woven fabrics from polypropylene
Non-woven SMS coveralls as a single layer	0	Coveralls made from polyethylene
Non-woven polyolefin coveralls as a single layer	2	Two layers of woven clothing (generally taken to be coveralls over work clothes)
Double layer of woven clothing	3	Apron configuration designed to protect the front and sides of the body against spills from chemical agents
Vapour-barrier apron (long length and long sleeves) over cloth coveralls	4	The real effect depends on the level of humidity and in many cases the effective CAV is lower
Vapour-barrier coveralls as a single layer without hood	10	The real effect depends on the level of humidity and in many cases the effective CAV is lower
Vapour-barrier coveralls as a single layer with hood	11	---
Vapour-barrier over cloth coveralls without hood	12	Wearing a hood of any fabric with any clothing ensemble
Hood†	+1	

Table 4.1.2b: Clothing adjustment values (CAV) in terms of WBGT for selected clothing ensembles. Source: ISO standard no. 7243 *(155)*

Note: * = Clothing Adjustment Values (CAVs) are added to the measured WBGT to calculate the effective WBGTeffective. For clothing with high vapour resistance, there the CAV depends on relative humidity. The values represent the likely upper limit. † = This value is added to the CAV of the ensemble without hood or respirator. SMS = spunbond meltblown spunbond (a fabric commonly used in protective clothing)

4.1.3. Universal thermal climate index (UTCI)

The Universal Thermal Climate Index (UTCI) is a scientifically developed index used to assess the perceived temperature of outdoor environments, taking into account how the human body responds to various weather conditions. It integrates air temperature, wind velocity, humidity and mean radiant temperature (sunlight and surrounding surfaces) to reflect how hot or cold it feels to an individual, not just the air temperature. The UTCI is based on a dynamic model of human thermoregulation, simulating how the body maintains its core temperature under different conditions, along with a mathematical or biophysical representation of how clothing affects the body's ability to exchange heat with the environment. *(244–247)*. The UCTI is based on the concept of an equivalent temperature.

It takes the real climate conditions and matches the dynamic physiological model response predictions for that climate to the temperature under reference conditions (relative humidity fixed at 50%, calm air and mean radiant temperature equal to air temperature) that produces the same physiological response.

The temperature under those reference conditions is the UTCI value. For all simulations, the model assumes a fixed activity level and behavioural adjustment of clothing insulation by a general urban population based on the actual temperature *(245, 248)*.

Regarding workplace heat stress, the UTCI presents the advantage of combining environmental heat stress with physiological heat strain in a dynamic manner. This elegant dynamic integration provides very accurate results in most situations *(249*). On the other hand, a noteworthy limitation is that the UTCI assumes fixed levels of exposure duration (2 h) and a moderate metabolic rate of 135 W/m2 as well as free behavioural adaptations in terms of clothing.

That is, the adaptive clothing model incorporated in the UTCI adapts the outcome while taking into account the clothing habits of the general urban population and their choice of clothing insulation related to the environmental temperature *(245, 249)*. However, workers in many industries wear protective clothing and/or are not allowed to adjust their clothing if the environmental temperature fluctuates.

Though work clothing is typically adapted based on the season of the year, there is very little day-to-day variability. Furthermore, it is often not possible for workers to change their clothing during a work shift. In addition to the clothing issues, workers often work at higher work intensity (metabolic rate) than that assumed in the UTCI estimations. Simulations using the flexibility of the thermoregulation and clothing models *(245, 247)* to extend UTCI to varying levels of activity, clothing and exposure duration are therefore ongoing *(248)*.

Despite these limitations, a recent large-scale validation study of all available heat stress indicators for use in occupational settings ranked the UTCI as the second most effective workplace heat stress indicator available *(34–36)*.

4.1.4. Heat index

The heat index is an indicator of the environmental contribution to heat stress. It has received attention because it is readily accessible via weather reports and smartphone applications *(44)*.

The heat index accounts for air temperature and concurrent humidity expressed as relative humidity *(250, 251)*, and there are at least five different formulas to calculate it *(35, 250–256)*.

Overall, the heat index correlates well with WBGT *(242)*. While it is often used for heat stress recommendations, it does not account for solar radiation, which effectively adds about 3.5°C to the heat index value *(242)*.

United States OSHA investigators have assessed the use of heat index for exposure assessment *(70, 257)*, reporting that a heat index threshold of 27°C would protect most outdoor workers from heat stress *(257)*, although they earlier supported a somewhat higher level of 29°C *(70)*.

There is no direct experimental evidence of heat index thresholds adjusted for work intensity or clothing. The following heat index threshold has been proposed for occupational exposure in healthy acclimatized adults: heat indexthreshold (°C) = 49 − 0.026 M (where M is the metabolic rate in W) *(258)*.

Just like the WBGT exposure threshold, this heat index threshold decreases with metabolic rate. The unacclimatized heat index threshold would be about 5.5°C lower

Table 4.1.4 provides the proposed exposure limits based on the work intensity categories outlined in Table 2.7, whether the work takes place in the direct sun or not, and also based on the workers' acclimatization state *(258)*.

Likewise, heat index clothing adjustment values were reported as 1.5°C for particle-barrier coveralls, 6°C for water barrier coveralls and 18.5°C for vapour-barrier coveralls *(258)*.

Illustration of a medical worker holding a thermometer, isolated on a white background. © Dreamstime.com / Cgpictures

	Work intensity	Rest (115 W)	Light (180 W)	Moderate (300 W)	Heavy (415 W)	Very heavy (520 W)
Sun	Acclimatized	43	41	38	35	32
	Unacclimatized	37	35	32	29	26
No Sun	Acclimatized	46	44	41	38	35
	Unacclimatized	41	39	36	33	30

Table 4.1.4: Heat index (°C) exposure limits based on work effort (average metabolic rate) categories with reference metabolic rate for each category. Source: See Garzon-Villalba et al. (258)

The heat index can be determined in occupational settings using relatively inexpensive instruments, and it is reported via local weather broadcasts and mobile apps in some countries, making it a readily accessible index for workplace heat stress assessment and management. However, two commonly cited disadvantages of exposure assessment based on the heat index are that it does not account for radiant heat and airflow.

It has been argued that adding 3.5°C to the heat index for solar radiation is reasonable *(242)*, and this is supported by inspecting the graphs showing the correlation between the heat index and WBGT from United States OSHA investigators *(257)*.

Airflow is less critical because WBGT does not change much with air velocity once the normal motion of the body during work is accounted for. Another disadvantage of the heat index is that the guidance provided is not well supported with evidence beyond the threshold to start a programme for heat stress management.

Moreover, this support is based on United States OSHA citations, which represent a limited data set. The heat index threshold equation proposed above is based on only one laboratory study that is comprehensive in scope; there are no other studies to confirm the results. A recent large-scale validation study *(36)* of all available heat stress indicators for use in occupational settings ranked one of the versions of the heat index *(252)* as the 13th most effective workplace heat stress indicator available.

4.1.5. Predicted heat strain

The predicted heat strain (PHS) model estimates core body temperature rise, total water loss through sweating, and time until critical limits are reached (e.g., core temperature of 38°C–39°C or 5% body mass through sweat core body temperature) *(53, 219)*.

The PHS model is defined in ISO 7933:2023 standard, and is applicable to woven clothing (with a permeability index of 0.38), but not for special protective clothing.

The predicted heat strain can be used to determine if the exposure is sustainable when the predicted core body temperature is less than 38°C after four hours.

The added value of the predicted heat strain is that it accounts for duration of work, an important job risk factor, and provides a safe time threshold for the combination of environmental conditions, metabolic rate and clothing.

Overall, the predictions made with the predicted heat strain have been shown to effectively protect most healthy workers.

While the calculations required to derive the predicted heat strain are complex and require advanced technical knowledge, a recently published and freely available software package provides a practical way to calculate this index. Nonetheless, it is important to note that the predicted heat strain should be used by qualified professionals.

4.1.6. Comments on assessment methods

In summary, there are several features to consider when employing the different methods presented in this section to assess the level of workplace heat stress. At a minimum, a qualitative assessment of the risk of workplace heat stress should be made by employers, public authorities, or occupational health and safety committees using the criteria in Table 4.1.1. High risk of workplace heat stress triggers the need to have an OHAP in place (see Part 3).

The quantitative assessment methods of WBGT, UTCI and the heat index, which are presented in this section, evaluate the basic job risk factors of environmental conditions, work intensity and clothing. In addition, the predicted heat strain includes duration of work as a fourth job risk factor. All these indices provide a stratified evaluation of the level of heat stress. That is, once the occupational exposure limit is exceeded, the risk associated with the exposure increases as the index rises above the limit. This risk relates to both the proportion of the population who cannot sustain the exposure and the potential severity of the exposure.

It is important to consider that the methods presented in this section were developed for healthy, well-hydrated individuals and make allowances for their heat acclimatization state. Recognizing high inter- and intra-individual variability *(40)* and following a public health model, the quantitative assessments have thresholds that are designed to be protective for more than 95% of exposures.

The trade-off involves an increased likelihood of false-positive determinations for exposures that marginally exceed the established threshold. This elevated false-positive rate can undermine the perceived credibility of the assessment among health professionals, supervisors, workers, and policymakers. Nevertheless, irrespective of how exposure thresholds are applied, the inherent uncertainty and variability in individual susceptibility to heat stress necessitate the inclusion of an emergency response component within any comprehensive heat stress management strategy (refer to Section 2.5).

4.1.7. An existing occupational heat-related warning system

Established knowledge, together with emerging evidence, was recently used to develop an occupational heat-related warning system within the framework of the HEAT-SHIELD project, funded by the European Commission. This is the first operational web-based platform providing short-term (weekly) and long-term (monthly) heat warnings to safeguard workers' health and productivity on a continental scale *(259)*. Smartphone apps have also been recently introduced to inform workers about current workplace heat stress and provide them with customized mitigation strategies, but without the ability for short-term or long-term forecasting. The OSHA–NIOSH Heat Safety Tool *(260)*, ClimApp *(261)* and the WBGT app developed by the University of Thessaly for the Greek Ministry of Labour and Social Affairs *(231)* are three examples of such applications.

The HEAT-SHIELD platform is based on the extended-range ensemble forecasts of the European Centre for Medium-Range Weather Forecasts, which enables customized heat stress risk assessment for up to a month (Fig. 4.1.7) *(259)*. By providing accurate workplace heat stress risk information several weeks in advance, the HEAT-SHIELD platform allows workers, employers, and other relevant stakeholders in various industries to determine ahead of time the most appropriate adaptation measures to be implemented *(259)*.

The HEAT-SHIELD platform provides users with weekly maps for the next four weeks illustrating the maximum daily probability of exceeding 27°C outdoor WBGT across Europe. These forecasts are generic and accessible to everyone without registration *(259)*. The aim is to motivate users to register on the platform to obtain customized information based on workplace and individual characteristics. These tailored recommendations relate to clothing, hydration, and work/break schedule (259). Moreover, the platform uses email alerts and push messages to notify users and stakeholders of future risks related to workplace heat stress, for safeguarding workers' health and productivity *(259)*.

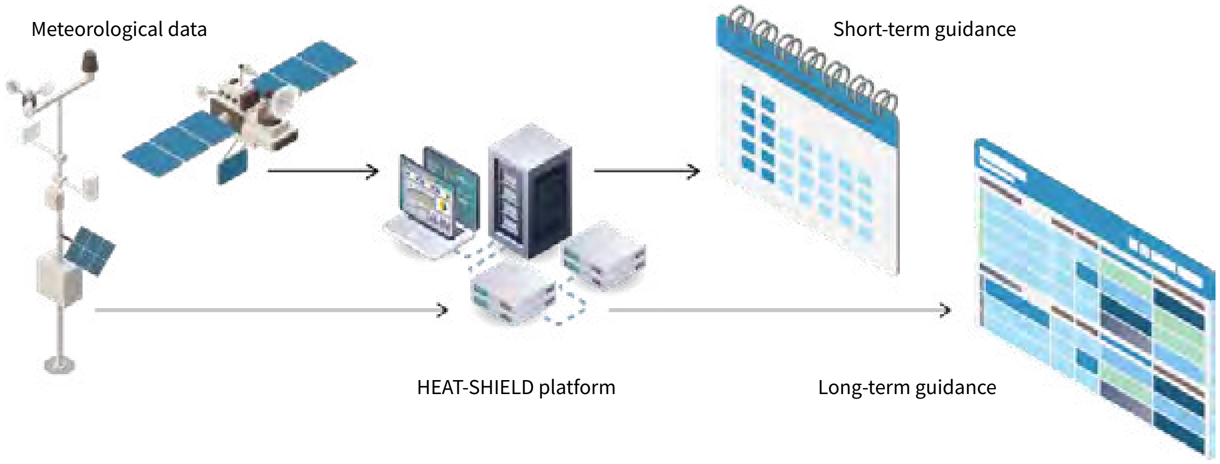


Figure 4.1.7: Graphical representation of the main components of the HEAT-SHIELD platform, where meteorological data are used to generate short-term (weekly) and long-term (monthly) forecasts for workplace heat stress risk, which is then translated into short-term and long-term heat mitigation guidance for workers, employers and stakeholders

4.2. Physiological heat strain monitoring

Monitoring heat strain can serve two purposes: *(1)* demonstrating that physiological heat strain is adequately managed by an OHAP, and *(2)* providing information to workers so that they can manage their individual workplace heat stress exposure (an administrative control) *(135)*.

The most accessible physiological response to workplace heat stress is heart rate, which reflects the overall cardiovascular response to the combination of work demands and peripheral blood flow needed to dissipate heat. There are recommendations for average daily heart rate, peak sustained heart rate, and percentage heart rate reserve, but large-scale validation of these thresholds has been performed mostly in athletes.

Moreover, heart rate is affected by age and chronic disease, and its relevance diminishes as a person becomes dehydrated. To date, the adoption of heart rate thresholds in occupational settings has been only observed in small-scale occupational field studies *(262, 263)*.

Monitoring core body temperature provides insight into the amount of heat stored in the body and the potential for heat-related health outcomes. Oral and aural temperatures are long-standing, socially acceptable methods, yet their validity is limited, and they require care in terms of calibration and use in occupational settings *(135)*.

Direct measurement of gastrointestinal temperature via a transmitting pill is a valid method to accurately assess core body temperature. However, this method is expensive for routine use, and its acceptability varies across different regions of the world. Skin temperature is easily measured, and many investigators have tried to use skin temperature as a surrogate for core body temperature *(135)*.

The physiological strain index has received considerable attention as a method to combine the core body temperature and heart rate into one metric *(262–264)*. Unfortunately, its usage in occupational settings is limited, as heat-related health outcomes can occur over a wide range of core body temperatures (particularly when skin temperature is high), and an individual's heart rate can be elevated by body movements not related to work.

Sweat loss is another approach to assessing the physiological impact of workplace heat stress. Urine specific gravity and urine colour are often used in the management of dehydration in OHAPs *(51, 191)*.

Charts of urine colour (see Fig. 4.4.2b) are available, and progressively darker colours indicate an increasing need for rehydration *(265, 266)*. While this method is practical and cost-effective, it is important to remember that whole-body sweat losses can vary significantly between individuals during a given workday *(195)*.

Overall, physiological heat strain monitoring is often difficult and requires specialised, costly technology. It is recommended that any physiological monitoring be directed by professionals who understand the underlying physiology and the strengths and limitations of each method to assess heat strain. Just as individual factors influence heat tolerance, individual factors may similarly influence the performance of physiological monitoring.

4.3. Risk factors in workplace heat stress assessment

Workplace heat stress assessment by practitioners and researchers is vital to reduce the associated risks for morbidity and mortality and to help employers and policymakers understand how heat-related risks occur.

4.3.1. Job risk factors

Job risk factors are job characteristics – including work demands, environmental conditions, and clothing requirements – that contribute to workplace heat stress (Fig. 2.1).

These are the factors to consider in the exposure assessment for workplace heat stress, and they are generally modifiable to help reduce the level of physiological heat strain.

As a person performs physical work (such as lifting, pushing or shovelling) or moves their body against gravity (for example, walking up a hill, climbing stairs or ladders), the metabolic rate increases and heat is produced *(267)*.

Thus, different occupations and different job tasks place workers at different levels (or doses) of workplace heat stress.

Likewise, a worker who rapidly or frequently changes body posture may be at greater risk of heat syncope. An office worker who primarily conducts desk-based work in an air-conditioned room may be at low risk of workplace heat stress, whereas a construction worker labouring in the sun without shade during the summer may experience high levels of workplace heat stress.

4.3.2. Heat acclimatization/adaptation

There are substantial differences among people in their ability to tolerate a given workplace heat stress exposure (e.g., due to age, health status, fitness or hydration; see Section 2.5), and this should be considered in the context of workplace heat stress assessment. A person who has either an unknown history or no recent history of workplace heat stress exposures should be considered heat unacclimatized.

During heat stress exposures of two or more hours per day, the individual will likely experience improving tolerance to heat over the first week or two *(268–271)*. This physiological adaptation is called acclimatization and leads to an earlier onset of sweating as well as to increased sweat output, combined with improved water and electrolyte management, and molecular adaptations to protect tissues *(93, 269, 270)*.

The improved tolerance leads to lower cardiovascular demands and risk for hyperthermia during workplace heat stress *(268–271)*. However, acclimatization slowly fades over a period of two or more weeks with no exposure to heat stress *(270, 272)*. The loss of acclimatization is accelerated by illnesses such as bacterial or viral infections, and those associated with fever, nausea, vomiting or diarrhoea.

Table 4.3.2 provides guidance on re-acclimatization following routine absence (e.g., for vacation, work assignment or recovery from injury) or illness. It should be emphasized that there is likely to be considerable “specificity” of heat acclimatization in how workers adapt to the specific environmental conditions (e.g., wet or dry heat), intensity of environmental heat stress, and required physical work. The procedures used to induce heat acclimatization should therefore mimic, as much as possible, the conditions of the job.

Occupational exposure limits for heat stress assume that workers are healthy and well-hydrated, with no residual physiological deficits from previous exposures. While the exposure limits are adjusted for acclimatization state, other personal risk factors (see Section 2.5) are not considered. The exposure limits may therefore not protect those with a temporary or permanent intolerance to heat stress.

Days away from heat exposure		**Percentage of full work assignment after worker has returned to duty**			
Routine absence	Illness	**Day 1**	**Day 2**	**Day 3**	**Day 4**
<4	---	100			
4–5	1–3	R/E	100		
6–12	4–5	80	100		
12–20	6–8	60	80	100	
>20*	>8*	50	60	80	100

Table 4.3.2: Re-acclimatization schedule for work involving heat stress exposure after routine absence or illness

Note: R/E = Reduced expectations with no specific reduction in heat stress exposure; * treat as unacclimatized. Newly hired workers in cognitively demanding or high-skill jobs may require a more gradual schedule over five days of 20%, 40%, 60%, 80% and 100% assignment, respectively

4.3.3. Return to work after severe health outcomes associated with workplace heat stress

The decision on returning to work after experiencing a severe workplace heat stress-related pathology is typically left in the hands of the attending physician *(191)*. It is a complex and challenging decision-making process that also requires input from the manager, health and safety expert, and worker.

Despite the prevalence of severe workplace heat stress-related diseases in the workforce (8), the available evidence on the timing of return to work remains scarce, and all previous recommendations were designed for athletes and armed forces personnel based on anecdotal observation and caution *(273–275)*.

These guidelines recommend that athletes and armed forces personnel who experience heat-related illness should return to full activity in no less than one week, while up to 15 months may be needed following serious heat-related health outcomes *(104, 273, 274, 276–278)*.

For workers, it is recommended that no physical activity beyond that required for daily living be permitted for two weeks following a heat stroke or severe heat exhaustion incident *(279)*.

The patient should be medically re-evaluated weekly (including clinical and biochemical examination, and diagnostic imaging of the affected organs, if needed), and once all symptoms and signs have resolved, a physical rehabilitation programme should be initiated, consisting of gradual increases in physical exercise (not to exceed 60 mins per day), supervised by an exercise specialist.

When exercise is well tolerated and no symptoms of work or heat intolerance are observed (such as unexplained increases in heart rate or core body temperature, or abnormal liver and muscle enzyme levels), the patient can be medically evaluated for return to work *(279)*.

A return to work for workers who have experienced severe heat exhaustion or heat stroke should be reviewed after a complete clinical assessment and on an individual basis, guided by the following requirements:

- an asymptomatic state (i.e. an absence of symptoms);
- an unremarkable clinical examination (i.e. no abnormal findings);
- an unremarkable laboratory examination; and
- a carefully planned and progressively graded physical heat-load challenge under close supervision. The physical challenge should simulate to the highest degree possible the worker’s job tasks as well as the environmental conditions in which the job is performed. Tolerance to the physical work and the heat loadshould be evaluated, together with cardiovascular stability and blood chemistry biomarkers *(279)*.

4.4. Managing health outcomes associated with workplace heat stress

4.4.1. Managing mild health outcomes associated with workplace heat stress

The most up-to-date recommendations for treating mild health outcomes related to workplace heat stress, as described in Section 2.2.1 and listed in the ICD-11, are as follows:

- Workers experiencing **heat fatigue** (code NF01.3) should be advised to wear light-coloured, loose-fitting clothing, take frequent breaks, replace fluids and electrolytes lost in sweat, and avoid, if possible, sunny, hot, and humid environments *(13)*. When possible, strenuous physical activities should be performed out of direct sunlight, or planned for the cooler parts of the day (or year), and carried out away from hot machinery *(13)*. Acclimatization to heat stress, improved physical fitness, and maintaining hydration can reduce the impact of heat fatigue *(13)*.
- Treatment for **heat oedema** (code NF01.Z) should follow the recommendations for heat fatigue. Additionally, placing the individual in a recumbent position in a cool environment and using supporting objects to raise the swollen area(s) or performing gentle exercise (such as walking) can alleviate the symptoms. Individuals with frequent symptoms should reduce the amount of salt in their diet.
- **Miliaria** (heat rash; code EE02) is treated through the cooling and drying of affected skin, avoiding conditions that induce sweating, controlling infection, and relieving itching *(104)*. Prevention includes proper skin hygiene, wearing clean, loose-fitting clothes, and avoiding talc and creams.
- **Heat syncope** (dizziness/fainting; code NF01.1) typically resolves rapidly once the affected person sits or lies supine in a cool environment, or with skin cooling and ingestion of fluids (preferably with electrolytes or salt) *(104)*.
- **Heat cramp** (code NF01.Z) treatment should follow the recommendations for heat syncope, with the addition of stretching and muscle massage to reduce discomfort. Intravenous rehydration can be can be used in cases of intractable cramping or for workers who are vomiting. Serum sodium levels should be examined for hyponatraemia in cases of prolonged cramping *(104)*.
- **Heat oedema** (code NF01.Z) treatment should follow the recommendations for heat fatigue. Additionally, placing the individual in a recumbent position in a cool environment and using supporting objects to raise the swollen area(s), or performing gentle exercise (such as walking), can alleviate the symptoms. Individuals with frequent symptoms should reduce the amount of salt in their diet.

4.4.2. Treating severe health outcomes associated with workplace heat stress

The most up-to-date recommendations for treating the severe health outcomes related to workplace heat stress, as described in Section 1.2.2 and listed in the ICD-11, are as follows:

For workers experiencing **heat exhaustion** (code NF01.2), placing them in a recumbent position in a cool environment, applying rapid and aggressive skin cooling, and administering oral fluids (preferably containing electrolytes or salt) are typically sufficient to lead to recovery. In severely dehydrated individuals, intravenous fluid replacement may be required. Skin cooling not only lowers core body temperature, but perhaps more importantly redirects blood from the skin back to the heart to support circulation. Heat exhaustion victims should therefore be rapidly cooled using the methods proposed below for heat stroke. Individuals with heat exhaustion will usually improve rapidly with active whole-body cooling *(13, 197, 276, 280, 281)*; subsequently, water and electrolyte imbalances can be corrected by administering oral fluids and salted foods or intravenous saline. Workers with heat exhaustion who do not rapidly improve with cooling, or who deteriorate, need to be evacuated for medical care as rapidly as possible.

Until proven otherwise, **heat stroke** (codes NF01.0 and NF06.0) should be the initial working diagnosis in anyone who has a heat incident and displays altered mental status (ranging from unconsciousness to erratic or aggressive behaviour) *(96, 98, 282, 283)*. Rapidly cooling the skin of the entire body (e.g. in a bath with water temperature as low as possible, down to 2°C) shifts the distribution of blood from the skin to the central circulation and the internal organs, interrupting cell and tissue damage and re-establishing near-normal cardiovascular function (blood pressure regulation) *(93, 119)*.

The highest priority should therefore be given to starting active whole-body cooling by the most effective means available to lower core body temperature below 39°C, if possible within 30 min of collapse *(197, 276, 280, 281, 284, 285)*. Concomitant support of airways, breathing, and circulation is also paramount for the individual's survival and prognosis.

Delaying active whole-body cooling (e.g., to assess whether the individual can cool spontaneously) may lead to morbidity and mortality *(286, 287)*, as the amount of time that core body temperature remains above critical levels is linked with the severity and reversibility of multisystem organ failure in heat stroke *(287–289)*.

Field data confirm a greater number of fatalities when cooling treatment is delayed *(287, 289)*, as well as increased organ dysfunction, longer hospitalization and/or a prolonged period of return to activity in individuals who survive despite delays in treatment *(287, 289–291)*.

		Practicality	
		Less	More
Effectiveness	Less	Cold water (~2°C) immersion	Fan with ice water-soaked sheets
		Cool water (~20°C) immersion	Ice water-soaked sheets
		Fans with ice water-soaked sheet with cold packs	Rest in shade and keep skin wet using water
	More	Water spray and fans	Remove clothes, rest in shade or coolest place

Table 4.4.2: Relative effectiveness and practicality of whole-body cooling methods for use in field workplaces, based on information provided in *(197, 284, 285, 292, 294-297)*

Note: More practical methods are less effective than less practical methods

Management of heat stroke in occupational settings includes (in order of decreasing importance): cooling, rehydration, and monitoring.

Immersing the body in cold water is the most effective form of cooling to treat heat stroke *(197, 284, 285, 292, 293)* and can be used even when the individual has been severely hyperthermic for a significant amount of time (e.g., due to failure to recognize the presence or seriousness of heat stroke, absence of medical personnel, or lack of on-site equipment) *(284, 285)*.

While cold water immersion can induce shivering, it is usually not sufficient to elevate core body temperature, so shivering should not be treated *(98, 284)*. Nevertheless, it is not always feasible to have ice or cold water baths in occupational settings.

Methods of active whole-body cooling are listed in Table 4.4.2 in their relative order of effectiveness, as some methods may be more or less practical than others in work environments *(98, 103, 119, 284, 285, 294)*.

Priorities for monitoring during cooling include mental status, neuromuscular function, vomiting, and core body temperature (rectal or oral). In occupational environments, the monitoring of core body temperature is generally considered a lower priority compared to the immediate initiation of whole-body cooling for individuals suspected of experiencing heat exhaustion or heat stroke

The end point for whole-body cooling should be based on evidence of clinical improvement, such as resolution of cognitive or behavioural symptoms.

To date, it has not been possible to estimate the required cooling time based on practical information such as the individual's physical characteristics *(298)*.

Research on this topic suggests that cooling can be safely continued until core body temperature is reduced to approximately 38°C *(119, 284, 285, 299)*; however, even mild hypothermia can have adverse consequences (98).

Real-time monitoring of rectal temperature is the standard of care to accurately diagnose and treat exertional heat stroke, avoiding adverse health outcomes associated with under- or over-cooling, and for implementing "cool first, transport second" exertional heat stroke policies *(277, 300305)*.

Recent meta-analytical evidence suggests that, in cases where assessment of rectal temperature is not available (e.g., field settings or emergency situations), exertional heat stroke patients should be immersed for 11–12 min when water temperature is ≤9°C, and for 18–19 min when water temperature is 10 to 26°C *(285)*.

Workers who demonstrate the signs of heat stroke need to be cooled on site before being evacuated for medical care as rapidly as possible, while keeping in mind that active whole-body cooling remains the highest priority *(283)*. Once hyperthermia has been addressed, treatment should focus on other heat stroke complications. This is because, even with rapid cooling, one in three individuals with heat stroke may display core body temperature regulation abnormalities and multiorgan system dysfunction or failure *(96, 306, 307)*.

Heat stroke cases therefore require hospitalization with clinical and biochemical markers of end-organ injury monitored over several weeks until complete resolution *(308)*. In relation to fluid and electrolyte imbalances (codes 5C71, 5C72, MG43.4Y, PB58), Fig. 4.4.2a provides estimates of daily water needs (litres per day) for healthy individuals performing work at different intensities (metabolic rates) *(195)*.

A variety of measures are used to assess hydration status in laboratory and athletic settings (most commonly, first morning urine specific gravity ≥1.020) *(94)*, but the best-practice approach for day-to-day assessment in occupational settings involves monitoring body weight, urine output and thirst, known as the "WUT" approach *(94, 309)*. If two of these factors are present (weight loss, dark urine and/or thirst), an individual is likely to be dehydrated.

The decision-aid diagram and urine colour scale shown in Fig. 4.4.2b provide a simple tool that can be used to detect hypohydration and determine the adequacy of day-to-day water loss replacement in healthy, active, low-risk populations of workers.

For dehydrated workers, it is critical to replace lost electrolytes (for example, sodium, potassium) by combining eating with ingesting fluids (e.g., water, juice) *(94, 104)*.

For workers demonstrating symptoms of dehydration (dizziness, malaise, rapid heart rate, exhaustion), the use of oral rehydration drinks is warranted *(309, 310)*; these contain substantially higher sodium and potassium concentrations than sports drinks.

Replacement of these electrolyte losses is critical to re-establishing the intracellular and extracellular fluid volumes *(309, 310)*.

Paramedics carrying a person on a stretcher.
© Dreamstime.com / Bobex-73

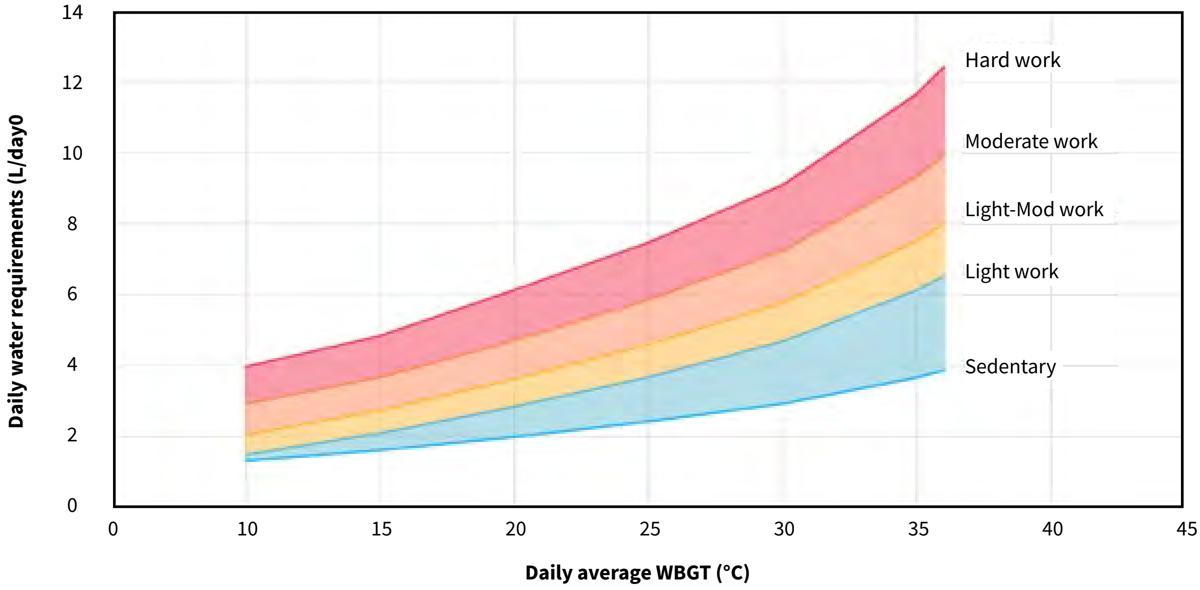
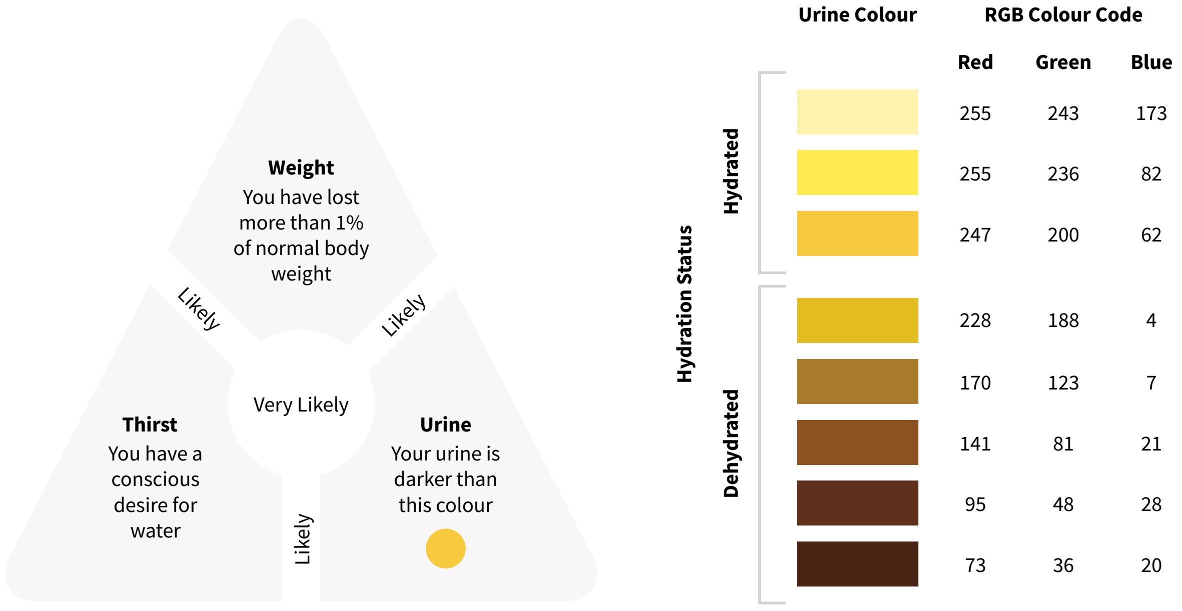


Figure 4.4.2a: Approximate daily water requirements as a function of climate (WBGT) and average daily energy expenditure. Source: Redrawn from Reference *(195)*



Hydration Status		Urine Colour	RGB Colour Code		
			Red	Green	Blue
Hydration Status	Hydrated	🟨	255	243	173
		🟨	255	236	82
		🟨	247	200	62
	Dehydrated	🟨	228	188	4
		🟫	170	123	7
		🟫	141	81	21
		🟫	95	48	28
		🟫	73	36	20

Figure 4.4.2a: Simple tools for detecting hypohydration and determining the adequacy of day-to-day water loss replacement in healthy, active, low-risk populations of workers. The triangle in the left panel illustrates a simplified approach for assessing daily fluid intake adequacy based on three criteria: body weight loss greater than 1%, a conscious desire for water, and urine colour darker than colour #3 on the scale provided in the right panel. Hypohydration is likely when two out of three factors are present and very likely when all three factors are present. The urine colour scale in the right panel illustrates the likely diagnosis regarding hydration status based on the urine colour. The RGB colour code provided can be used to recreate the image, as the colours may vary depending on the printer or screen.

A farmer in overalls and a straw hat standing among tall crops, squinting in the bright sunlight while holding a tablet.
© iStockphoto.com / Gabrijelagal

Part 5: Conclusions and Recommendations

Exposure to heat has become a common problem for almost half the global population, as they live in areas where high environmental temperatures affect nearly all daily activities. In the context of climate change, exposure to workplace heat stress will further increase. Workers are at high risk of adverse consequences from global warming of 1.5°C or more *(311)*.

The present guidance provides practical information on both gaps and priorities in research, legislation, and practices. More importantly, it identifies the roles of the health, labour and meteorological services in identifying risks and protecting workers.

To manage workplace heat stress and mitigate its impacts on health and productivity, public health policymakers should collaborate with scientists, meteorological services, health service providers, as well as organizations of employers and workers, while considering and acting on the following issues:

Close-up of hands writing on a clipboard with blurred construction workers in the background. © Dreamstime.com / Bundit Minramun

- A combination of interventions for **preventing exposure** and health surveillance of workers can **reduce** workplace heat stress exposure, manage physiological heat strain, and prevent short- and long-term health effects.
- **Reducing the risks** of physiological heat strain caused by workplace heat stress requires developing and implementing specific programmes for workers and workplaces at risk.
- To enhance the specificity of prospective guidelines related to workplace heat stress, heat-health advisories should be designed to address not only the **weather conditions** but also **clothing**, as well as the type, **intensity, and duration of work.** Another work-related factor of importance is whether the work is paid by piece or by the hour, as this determines **workers' motivation** to continue working despite higher heat stress. Finally, heat-health advisories should also consider the adaptive strategies available to the workers. These factors should also help shape the **direction of future research**.
- Certain population groups, such as middle-aged and older individuals, those who are physically unfit, and people with common chronic health conditions, are **more vulnerable** to the physiological strain caused by workplace heat stress. Relevant advisories and legislation must **address the increased vulnerability** of these populations.
- Many mild and severe health outcomes are associated with workplace heat stress. While the **treatment** for most of these conditions is well known, they are often misdiagnosed, which can have serious **negative effects** on the patient's health. It is vital that the pathophysiology and treatment for these conditions receive **greater emphasis** in medical and health-related education.

- The development of occupational heat-health recommendations and policies must **involve key stakeholders**, including managers and employers, workers, trade unions, representatives of self-employed persons, experts in environmental, physiological, ergonomic safety, health and safety representatives, occupational health experts and representatives from local authorities. Engagement with the **general public** is also highly desirable.
- The overall aim of occupational heat-health recommendations and policies should be to **reduce workplace heat stress**. However, it is also imperative to consider the **practical feasibility, economic viability, and environmental sustainability** of the recommended strategies. These should include elements related to workplace heat stress prevention policy, heat acclimatization, environmental and medical monitoring, training and education, and emergency response planning, as well as job-specific controls.
- The use of **technological solutions** should be researched further to augment both workplace safety and productivity.
- Future research should **evaluate the efficacy** of occupational heat-health advisories and relevant policies to ensure the highest level of protection for workers.
- Policies and actions to **reduce the extent of climate change** will significantly contribute to protecting working populations from excessive heat in the future.

A glass bottle labeled "Not A Plastic Bottle," between two glasses of water and the ocean in the background. © Unsplash.com / Bundit Minramun

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Annex

This publication was developed from a project Working Group (WG) which included representatives from HEAT-SHIELD consortium, the WMO and WHO, as well as selected highly cited experts on this topic from academic institutions. The criteria for selecting experts included consideration for geographical and gender balance within the WG.

The WHO Secretariat proposed a WG Chair (Andreas Flouris) and Co-Chair (Lars Nybo) who were selected from the WG members. The objective of the WG was to perform an in-depth analysis of the available evidence and develop the report, ensuring the required diversity of viewpoints in producing the final document. The list of WG members, their affiliations and areas of expertise are included in Table A1.

The WG performed an in-depth synthesis of evidence on recent physiological, epidemiological, ergonomics, and environmental research as well as the lessons learned from implementation of heat-health action plans in occupational settings. This synthesis was based on the findings of a series of narrative literature reviews, focusing on climate change and the future of work, assessment, monitoring and management of workplace heat stress, the global burden of workplace heat stress, work productivity, acclimatization and adaptation to heat, occupational heat-health action plans, heat–health governance, as well as risk perception. The review also encompassed elements of grey literature, including technical documents and studies disseminated by governmental and international stakeholders.

This was essential for understanding the practical implications of preventative measures at both national and regional levels. Empirical data, especially from the past decade, were considered. This included new findings related to the links between climate change, workplace heat exposure, and health. Large compilations and reports, such as those from the IPCC Working Group II, were also reviewed to document ongoing and projected climate change impacts.

Regular group meetings were organized to facilitate collaboration and discussion among the WG members. In addition to these large group meetings, smaller, focused group meetings were held as needed to discuss specific chapters or topics within the report.

Chapters were assigned to specific authors who were experts in that particular area and were responsible for drafting the initial content and ensuring the accuracy and comprehensiveness of their sections. A team of Editors (of whom A. Flouris and L. Nybo also acted as authors) oversaw the entire report and were responsible for the final draft, coordinating with the authors to refine the content and ensure consistency and quality. The Editors provided additional layers of review and supervision to ensure coherence and integration of the various chapters. The draft report underwent multiple rounds of review, from WHO and WMO as well as external independent reviewers (listed in the acknowledgments) from different parts of the world.

An elderly man wearing a straw hat, looking into the camera with a gentle expression. © iStockphoto.com / poco_bw

Name	Gender	Organization	Country	Expertise
1. Andreas Flouris	Male	Univ. of Thessaly	Greece	Thermal physiology & epidemiology (applied, mechanistic, genetic aspects)
2. Lars Nybo	Male	Univ. of Copenhagen	Denmark	Exercise & thermal physiology
3. Tord Kjellstrom	Male	Health & Envir. International Trust	New Zealand	Environmental & occupational health
4. Joy Shumake-Guillemot	Female	WHO/WMO Climate and Health Office	USA	Environmental health policy & programming for climate adaptation & risk mgt.
5. Ivan Dimov Ivanov	Male	World Health Organization	Bulgaria	Occupational and environmental health
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8. Janvier Gasana	Male	Kuwait University	Kuwait	Environmental & Occupational Health
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13. Mike Sawka	Male	Georgia Institute of Technology	USA	Exercise, thermal & cardiovascular physiology
14. Ken Tokizawa	Male	National Institute of Occupational Safety and Health	Japan	Occupational ergonomics
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Table A1: Members of the Working Group on workplace heat stress who prepared this report.

Close-up of cupped hands catching splashing water.
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