HEAT STRESS
Awareness Guide

2024 EDITION

HEAT STRESS Toolkit

About this Guide

OHCOW partnered with CROSH to review and update the existing *Heat Stress Awareness Guide* that was developed by OHSCO back in 2009. With the support of the Ontario Health and Safety Prevention System partners (through the Occupational Illness Prevention Steering Committee) and local labour unions, we identified areas that required improvement or revision and the concept of a toolkit was born!

Land Acknowledgment

The writers and contributers of this guide recognize that our work takes place on traditional Indigenous territories across the province. We acknowledge that there are 46 treaties and other agreements that cover the territory now called Ontario. We are thankful to be able to work and live in these territories. We are thankful to the First Nations, Métis and Inuit people who have cared for these territories since time immemorial and who continue to contribute to the strength of Ontario and to all communities across the province.

Funding Acknowledgment

This guide was funded by the Ontario Ministry of Labour, Immigration, Training and Skills Development (MLITSD). The views expressed in this guide are those of the contributors and do not necessarily reflect those of the MLITSD.

Citation

Dorman, S.C. & Lessel, C. (2024, May). *Heat Stress: Awareness Guide* (Eds. Gagnon, D. & Kanya-Forstner, M.). Centre for Research in Occupational Safety and Health (CROSH): Sudbury, Ontario.

Disclaimer

The information in this reference guide is for information and reference purposes only and not intended as legal or professional advice. Laurentian University (LU), the Centre for Occupational Safety and Health (CROSH), and Occupational Health Clinics for Ontario Workers (OHCOW) recognize that individual companies must develop heat stress policies and plans that apply to their workplaces and comply with appropriate legislation. While information provided is current at the time of printing, including references to legislation and established practice, it may become out of date or incomplete with the passage of time.

No warranty, guarantee, or representation is made by LU, CROSH, or OHCOW as to the absolute correctness or sufficiency of any information contained in this guide. LU, CROSH, and OHCOW assume no responsibility in connection therewith; nor can it be assumed that all acceptable safety measures are contained in this material, or that other or additional measures may not be required in particular or exceptional circumstances.

OHCOW assumes no responsibility for how the information is used.

ISBN: 978-1-7383931-0-7

TABLE OF CONTENTS

INTRODUCTION

Introduction

In Canada, the growing need to combat heat exposure in workplaces, is becoming an increasingly important issue. Unfortunately, due to the consistent deterioration in environmental conditions, caused by global warming, the number of people becoming ill, or dying from heat stress, continues to grow. "Annual and seasonal mean temperatures across Canada have increased, with the greatest warming occurring in winter. Between 1948 and 2016, the best estimate of mean annual temperature increase is 1.7°C for Canada as a whole and 2.3°C for northern Canada" *(Zhang et al., 2019: p.116)*. Additionally, the Ontario Provincial Climate Change Impact Assessment report states that, between 1980 and 2010, "Regionally, Extreme Hot Days are already prevalent in Southwest, Central and Eastern Ontario (all averaging around 8.6 to 9.1 [days/year with maximum daily temperature over 30°C])" *(CRI, 2023: p.42)*. Figure 1, below, illustrates critical increase for this prevalence for the years 2022 and 2023.

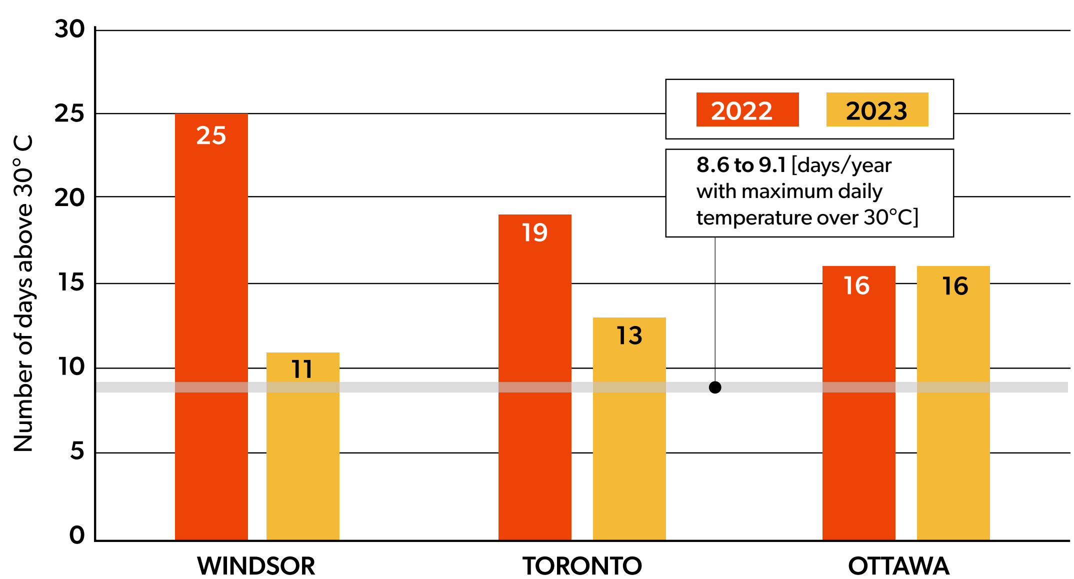


Figure 1. Number of days with a maximum daily temperature above 30℃ in three cities in Ontario, where the yellow line indicates the average of 8.6-9.1 days/year with the maximum daily temperature over 30℃ (CRI, 2023).

Additionally, urbanization and the Heat Island Effect in cities exacerbate the problem by trapping heat and making urban areas even hotter. On a sunny day, paved surfaces can be a remarkable 27-50°C hotter than the air *(EPA, 2023)*. The difference is especially noticeable at night when the heat captured by pavement and buildings during the day continues to warm the city after the sun goes down. Large cities can be as much as 12°C warmer than their surrounding environments in the evening *(Health Canada, 2020)*.

Based on a synthesis of the literature, by Kipp and others *(2019)*, the increase in environmental temperature has and will continue to result in increased risk of health effects (frequency and severity) for workers (in both indoor and outdoor work settings). Furthermore, the literature highlights Indigeneity, age, sex, socioeconomic status, and the increased number of people employed in outdoor occupations as key factors influencing worker and workplace vulnerability to climate change in Ontario, particularly in Northern Ontario (*Northwestern Health Unit, 2022*).

Heat Stress

Heat is already a recognized concern in many workplaces, including, but not limited to:

- In foundries, steel mills, smelters, glass factories, and furnaces, where extremely hot or molten material is the main source of heat.
- In outdoor occupations, such as construction, road repair, open-pit mining, wildland firefighting, tree-planting and agriculture, where radiant sunlight is the main source of heat.
- In laundries, restaurant kitchens, bakeries, and canneries, where high humidity adds to heat stress.

Today, the only occupational reports collected about heat stress are when a heat exhaustion or heat stroke event occurs. However, we know that workers in high-risk occupations regularly experience heat strain and heat illness, which are not reported, but could be used to predict or prevent the onset of heat exhaustion or heat stroke.

...an estimated 220 workers in Canada die annually from occupational heat stress.

In fact, an estimated 220 workers in Canada die annually from occupational heat stress and an estimated 15% of workers who typically or frequently worked under heat stress (minimum of 6 hours per day, 5 days per week, for 2 months of the year) experienced serious heat-related illnesses (e.g., kidney disease or acute kidney injury) *(Flouris et al., 2018: review)*.

Why is this guide necessary?

Under the Occupational Health and Safety Act (OHSA), the workplace must take every reasonable precaution for the protection of a worker. For hot workplaces due to process heat (e.g. bakeries or smelters), they are required to follow the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLVs) for heat stress and set up a heat stress control plan in consultation with the workplace's joint health and safety committee or worker health and safety representative. The purpose of the heat-related TLVs is to prevent unacclimatized workers' core temperatures from rising above 38°C (*ACGIH, 2022*). TLVs are given separately for heat-acclimatized workers who are adequately hydrated and for unacclimatized workers; called Action Limit (AL) values. TLV and ALs are determined by considering the level of physical activity performed by the worker, in the context of the environmental temperature and humidity and applying a series of graphs to interpret the estimated level of metabolic output (physical activity), which can be accomplished for a set period of time, given ambient conditions and personal protective equipment (PPE) requirements. Importantly, many workplaces face challenges in implementing the ACGIH guidelines from lacking the technical expertise needed to accurately implement them.

The previous iteration of the *Heat Stress Awareness Guide*, produced by the Occupational Health and Safety Council of Ontario (OHSCO) in 2009, translated the ACGIH guidelines into a Humidex Based Heat Response Plan, which provided workplaces with a practical, and simplified way to assess and control heat in their workplace. In *The Heat Stress Toolkit* an update of these materials can be found in *Heat Stress Prevention Tools and Strategies Guide*, including the Humidex Based Heat Response Plan.

This guide will examine:

- Workers' physiological response to heat stress;
- Factors that affect workers' response to heat stress;
- Recognizing the signs and symptoms of heat illnesses.

Who is this guide for?

This guide was primarily developed to provide Occupational Health and Safety Specialists with a comprehensive heat stress resource to inform decision-making within their organizations related to Heat Illness Management. Although comprehensive, this reference guide cannot encompass all possible information around heat stress, or management of heat stress, and therefore is intended to be used in conjunction with other resources (e.g., confidential interviews with trained health and safety professionals) to address all concerns in this area. The material contained in this reference guide is not intended as legal or professional advice. The adoption of practices described in this reference guide may not meet the needs, requirements, or obligations of all employees or individual workplaces.

Law

Employers have a duty under Section 25(2)(h) of the OHSA to take every precaution reasonable in the circumstances for the protection of a worker. For compliance purposes, the Ministry of Labour, Immigration, Training and Skills Development (MLITSD) recommends the current TLV for heat stress and heat strain, published by the ACGIH. See the MLITSD web document "Managing heat stress at work" for details. Additionally, as of August 1st, 2023 a new heat stress regulation was proposed (Proposal No. 23-MLITSD003) in Ontario; the proposal is for a stand-alone heat stress regulation, under the OHSA, with specific requirements that would apply to all of the workplaces where the OHSA applies. The proposed heat-stress regulation is currently undergoing a Regulatory Impact Analysis.

HEAT STRESS, HEAT STRAIN, AND HEAT-RELATED ILLNESS

Thermoregulation and the physiology of heat stress

Core temperature is considered to be the temperature of the deepest structures of the body (e.gs., heart and brain). The human body maintains a homeostatic core temperature of approximately 37°C under optimal conditions (*Kenney et al., 2015; Taylor et al., 2014*). Variations, typically of less than 1°C occur over any given day. A change of more than 1°C usually only occurs during illness or when environmental conditions are such that the body is unable to compensate for heat accumulation (*CCOHS, 2016*). Specifically, a deviation of + 3.5°C from 37°C, results in physiological malfunctions and possibly death (*Lim et al., 2008*). Moderate increases in body temperature can benefit physical performance, as they enhance the speed at which chemical reactions occur, such as nerve conduction, cellular metabolism, and muscle contractions (*Nybo, 2008*). However, if hyperthermia occurs and core temperature increases excessively (beyond 40°C), thermoregulatory mechanisms may fail, elevating the risks of heat stroke and death. The failure of the body's thermoregulatory mechanisms causes the denaturation of body proteins, as well as systemic inflammatory responses, which can result in increased metabolic demand, hypoxia, and ultimately organ and circulatory system failure (*Khan, 2019*). The progressive signs of heat stress start with excessive sweating, dizziness, nausea, muscle cramping, and a general sense of exhaustion. If left untreated and heat stress continues, the emergence of headaches, lack of sweating, loss of consciousness, and ultimately heat stroke may then occur.

Thermoregulation is the adaptive physiological response designed to prevent the body from becoming either too cold or too hot (*Kenney et al., 2015*) and includes various homeostatic mechanisms such as: sweating, shivering, and redistribution of blood flow through vasoconstriction or vasodilation of blood vessels (*Cheung, 2010; Cramer et al, 2022; Kenney et al., 2015*). The body starts to activate heat loss/gain mechanisms when core temperature increases/decreases, respectively. When the temperature changes, a brain structure, called the hypothalamus, detects the change and activates homeostatic mechanisms. Specially designed sensory receptors, called thermoreceptors, detect temperature change and relay this information to the hypothalamus via the nervous system. The hypothalamus acts like a thermostat for the body, and is activated either indirectly, through peripheral thermoreceptors, or directly, via central thermoreceptors in the hypothalamus (*Kenney et al., 2015; McArdle et al., 2007; Périard et al., 2016*). The peripheral thermoreceptors monitor the skin temperature, which varies with changes in the environmental temperatures around the body. Central thermoreceptors are located in the spinal cord, viscera, great veins, and the hypothalamus (*Osilla et al., 2020*), and are sensitive to even small changes in the temperature of blood that passes through the spinal cord and the hypothalamus. Both types of thermoreceptors can activate a hypothalamic response to maintain the temperature of the body within the normal range (*Kenney et al., 2015; McArdle et al., 2007*).

Upon an increase in body temperature, the hypothalamus detects the increase and initiates a series of responses to lower the body's temperature to maintain homeostasis and dissipate the excess heat. The increase in body temperature triggers a response that will attempt to decrease body temperature. When an individual is exposed to a hot environment, first, a nervous signal is sent to the smooth muscles in the walls of the skin arterioles, causing them to vasodilate (get wider). This will bring more warm blood from the centre of the body towards the skin, increasing transfer and dissipation of excessive heat to the environment (*Johnson et al., 2014; Kenney et al., 2015; Khan, 2019; Osilla et al., 2020; Taylor et al., 2008*). Second, eccrine sweat glands are activated when core temperature increases by 0.2-0.3°C. Sweating is the most important heat loss mechanism during heat stress and increases proportionate to elevations in temperature (*Gagge & Gonzales, 1996; Jay & Kenny, 2010*). Eccrine sweat causes heat loss via evaporation (*Hodge & Brodell, 2020*), however, sweat only cools the body when it evaporates from the skin surface, not when sweat drips from the body (*Cramer et al, 2022; Jay & Kenny, 2010*). Evaporation via sweat is compromised as the relative humidity in the environment increases. The ability to increase heat loss through evaporation is directly proportional to percent Relative Humidity (*McArdle 2007*).

Physiological monitoring

For the purposes of this guide, physiological monitoring is defined as any real-time monitoring of single or multiple physiological parameters simultaneously to detect signs and symptoms of cumulating heat strain. Physiological monitoring for heat stress should be a useful tool to protect the health and safety of individuals working in hot environments for several reasons. First, factors affecting heat stress; different workers will respond differently to the same environmental conditions. In fact, the same worker can also respond differently to the same conditions on different days. Secondly, The ACGIH guidelines were developed and tested on, young, healthy Caucasian males and do not represent the limits for all workers. Studies have shown that applying the ACGIH guidelines have not been sufficient to prevent workers from reaching excess temperatures of 38°C (*Lamarche et al., 2017*). Thirdly, some work cannot have time limits to achieve the work and lastly, some workloads fluctuate rapidly preventing accurate estimates of workload. Given the significant short and long-term effects of heat illness, and increased risk for workers due to climate change, additional efforts should be made to assess individual responses to heat stress using physiological monitoring.

The development of heat-stress-specific monitoring in workplaces is rapidly expanding, and as such, although numerous methods and systems currently exist, few have been fully tested in workplaces. Therefore, the section below provides an overview of the perceived benefits and challenges of physiological monitoring. The realization of these benefits and challenges will require individual workplaces to pioneer the implementation strategies and share their learnings. For a full discussion of methods, advantages and challenges of physiological monitoring, see the companion guide: <u>*Heat Stress Physiological Monitoring Guide*</u>.

Monitoring tools can include active or scheduled surveying for signs and symptoms, or objective measures of thermal stress (e.gs., core or skin temperature). However, novel monitoring tools include wearable technology equipped with heart rate monitors, and thermoregulatory devices, which continuously track multiple signs of heat stress including body temperature, heart rate, and more, as well as triggering alerts to the worker or workforce based on changes in these levels relative to the worker's baseline data. Worker alerts are believed to raise awareness for the individual to self-monitor and take breaks when needed. Workplace alerts are communicated when a worker has fallen or reached 'unsafe' levels of heat strain, according to the device. These tools may be particularly valuable for lone or at-risk workers in high-risk or remote environments.

The integration of these tools should improve a comprehensive *Heat Stress Management Plan*, but should not be used as a stand-alone practice to prevent heat illness. Ideally, physiological monitoring will proactively flag early signs of heat strain and alert the worker to a need for action to prevent heat strain escalation. Monitoring can flag timely interventions including rest breaks, hydration status, and recovery status, and can support self-calibration, particularly in inexperienced workers. Monitoring could also be used to track heat strain preventatively through data analysis of job tasks, durations, or locations associated with increased alerts, and ideally be used to track 'near misses' of heat exhaustion and heat stroke as well as assisting in the development of optimal heat strain recovery programs. Implementation, however, will introduce new challenges.

First, decisions must be made regarding the type of data that will be collected and its accessibility and safety. Data from any form of physiological monitoring, including survey data, are considered to be private medical data, so stringent policies are required in workplaces when monitoring is implemented to identify who has access to the data during and after monitoring; what the data can be used for; and whether the data is stored. Determining the type and volume of data will dictate the level of policy and practice that must be implemented to manage and protect the rights and confidentiality of the workers. For this reason, workplaces may choose monitoring systems that either have limited data output (e.g., alerts only) or provide complete data to the worker. The worker may then decide to share the data, for example to health care providers or third party. Of note, to date, the legal system and development of a global policy to manage the implementation of any kind of physiological monitoring does not exist and remains a barrier to implementing these types of systems.

Second, implementation of any monitoring program will also require the development and roll-out of educational programs to workers and workplaces on the use and application of these tools as well as operational changes to purchase, manage and integrate policy and practice changes. Ideally, these programs will be developed in alignment with existing educational programs for the *Heat Stress Management Plan*.

Third, technologies for evaluating both physical and psychological health are at various stages of development and are constantly evolving. As new technology and devices are released, it is important to test the device's ability to assess the intended feature compared to the highest standard of measurement. Some health monitoring devices have been independently tested to determine reliability (produces consistent results) and validity (accurately measures what it was intended to measure). However, there are a large number of devices on the market that have not been properly tested. This is primarily due to the popularity and demand of the devices, causing companies to produce and release them faster than researchers can test them. In addition, it should be noted that even though some commercially available devices have been validated, they may not generate the same results in all workplace settings. If you want to use physiological monitors in the workplace, the specific device under consideration should be assessed for its: validity; reliability; and practicality for use in the workplace setting of interest.

For a full discussion of physiological monitoring, see the *Heat Stress Physiological Monitoring Guide*.

Effects of heat stress on work function and performance

Heat stress is the total heat load a worker is exposed to and arises from the combination of: high ambient temperatures; metabolic heat production from physical work and effort; and insulation from protective clothing *(CCOHS, 2024; Cheung et al., 2016)*. Hot environments can be present in many workplaces, including areas where materials are extremely hot or molten (e.g., brick firing and ceramic plants, glass production facilities, smelters, steam tunnels, iron and steel foundries), mining sites, in outdoor occupations where there is prolonged exposure to the sun (e.g., hydro and telecommunications line-persons, construction and road workers, outdoor recreation workers), and emergency personnel (e.g., firefighters). Additionally, workers involved in physically active occupations (both indoors and outdoors) can have difficulty balancing safety with work requirements in challenging thermal conditions *(Jay & Kenny, 2010)*. As part of the body's physiological response to heat stress, individuals' performance at work can be negatively affected.

Cognitive function

Fatigue (*Rahman & Adnan, 2023)* and impairments in cognitive function, decision making, and task performance can increase the risk of accidents in the workplace *(Hancock et al., 2007; Pilcher et al., 2002)* and can be influenced by hot environments.

Small increases in core temperature can influence cognitive tasks *(Simmons et al., 2008)*. Increased sweating and hot thermal sensations can cause discomfort and sometimes distress, leading to increased distraction, irritability, and changes in behaviour *(Jay & Kenny, 2010)*. However, the degree of cognitive impairment may be based on the type of cognitive task being performed. Tasks that are less attention-demanding are typically less vulnerable to heat effects than tasks requiring greater concentration or skill, such as mathematical or perceptual tasks *(Grether, 1973; Hancock, 1982; Jay & Kenny, 2010; Pilcher et al., 2002; Ramsey, 1995; Ramsey & Morrissey, 1978)*.

With heat acclimatization, temperature may rise more slowly or start at a lower point to reduce heat-related decrements observed in cognitive performance *(Amos et al., 2000; Curley & Hawkins, 1983; Radakovic et al., 2007)*.

Physical function

Heating can reduce total work capacity and increase the risk for chronic injuries, such as repetitive strain injuries *(Cheung et al., 2016; Pienimäki, 2002)*. Although reductions in manual performance are more commonly associated with cold environments, both heat and cold can influence whole body functions and accelerate the onset of fatigue *(Jay & Kenny, 2010).*

Increased sweating can affect tasks that require grip and manual dexterity *(Meese et al., 1984)*. Like cognitive tasks, heat-related deficits in manual tasks vary depending on the type of task being performed, as well as the duration of exposure to the hot environment *(Hancock et al., 2007)*. More complex motor tasks (i.e. tasks involving coordinated effort from both muscles and the brain) have greater deficits than simple motor tasks *(Piil et al., 2017)*. Exposure to heat for less than 60 minutes is associated with greater reductions in performance than exposure durations of two hours or longer *(Pilcher et al., 2002).* This is because individuals who are exposed to heat for a long period of time may adjust to working in those conditions, improving overall performance as exposure time increases (i.e. worse performance is expected at the beginning of the day rather than later in the day) *(Pilcher et al., 2002)*.

Overall, working in heat stress conditions can lead to losses in productivity *(Flouris et al., 2018; Rahman & Adnan, 2023).* It has been estimated that 30% of workers in heat stress conditions have experienced losses in productivity, with these losses increasing by about 2.5% for every 1°C increase in wet bulb globe temperature (WBGT) beyond 24°C *(Flouris et al., 2018)*.

Other considerations

Heat exposure can be associated with temporary infertility in both males and females; however, the effects are more pronounced in males *(Levine, 1984; Radakovic et al., 2007).* Sperm density, mobility and number of normally shaped sperm decrease when the temperature of the groin area increases above normal temperatures *(Henderson et al., 1986; Jung & Schuppe, 2007; Mieusset et al., 1987; Procopé, 1965)*.

Mechanisms of heat exchange

The body exchanges heat with its surroundings through different mechanisms. Heat loss refers to the transfer of heat from the body to the environment. Heat gain refers to the combined metabolic heat production (resting metabolism, physical work, digestion), and heat gain mechanisms are important in hot environments *(CCOHS, 2024).*

External mechanisms

Radiation: Radiation accounts for a significant amount of heat loss and it operates based on the thermal gradient that exists between the skin and the ambient temperature (*Gagnon 2011, Kenny 2010 Cramer 2022; Lim et al., 2008*). The blood vessels of the skin, arterioles and smaller capillaries, first increase in diameter. Subsequently the heart starts to beat faster to maintain pressure and increases the blood flow from the core (and hottest parts of the body) to the skin. This creates a a gradient of heat, where typically, the skin temperature is higher than the environmental temperature *(Díaz & Becker, 2010; Kenney et al., 2015; Lim et al., 2008; McArdle et al., 2007)*. Heat is then lost across the gradient in infrared and electromagnetic waves, cooling the blood, before it returns to the core of the body. Under most environmental conditions experienced in Canada, the human body is warmer than its surrounding environment; therefore, radiant heat will transfer to the air and/or cooler objects in the environment. Radiation does not require direct contact between two objects, and, as such, is considered an indirect form of heat transfer. In occupations where workers may be in a hot environment, as well as those that require the wearing of protective clothing, this method of outward heat dissipation is impeded, either because the PPE interferes with the gradient or because the environmental temperature is elevated. In situations where the external environment is very hot, the thermal gradient is reversed, and heat can be transferred into the worker *(Levy & Roelofs, 2019)*.

Evaporation: Evaporation is also an important way for the body to lose heat (Díaz & Becker, 2010), and it operates based on the dissipation of heat through sweat from the skin changing from a liquid into a gas. When the skin temperature reaches 37°C, it starts to produce sweat (*Díaz & Becker, 2010; Jacklitsch et al., 2016*), and the rate of evaporation increases as the skin temperature continues to rise (*Díaz & Becker, 2010; McArdle et al., 2007*). Environmental humidity plays an important factor in the effectiveness of this method since high moisture in the air impairs water conversion from liquid to gas, thereby making sweating less or ineffective in humid environments. In contrast, in a dry ambient state, sweat evaporates quickly, assisting in rapid heat loss (*Díaz & Becker, 2010; Cheung, 2010*). The use of PPE, though vital to keeping many workers safe, severely compromises the body's ability to use evaporation to reduce overall body temperature; absorption of sweat into the material, does not allow for evaporative heat loss.

Conduction: The transfer of heat through direct contact between objects (e.g., the body and a surface) (*Cramer et al., 2022; McArdle et al., 2007*). The rate of conduction is dependent on the size of the thermal gradient between the objects, the thermal conductivity of the objects, any barriers (e.g., clothing) between the objects, and the amount of surface area in contact between the objects (*Cramer et al., 2022*). Therefore, the human body can gain heat by exchanging it through contact with any hotter surfaces in the environment. Unless a worker is coming into regular, direct contact with objects of different temperatures, conduction is generally considered to be an insignificant contributor to heat loss (*Cramer et al., 2022*). However, conduction can be a significant contributor to heat stress for workers that are in contact with hot surfaces in the workplace (e.g., sitting on a hot seat), or if a cooling device designed for this purpose is being utilized (e.g., cooling vest).

Convection: The transfer of heat with surrounding fluid (i.e. air or water) as it moves across the surface of the body *(Cramer et al., 2022)*. The body gains heat from hot air and loses heat to cold air, which comes into contact with the skin. Air conditioning is an example of the use of convection to cool workers in the workplace. The exchange of heat depends on: the rate of the flow (faster flow, higher dissipation), the size of the temperature gradient, and the thermal properties of the fluid *(Cramer et al., 2022; Kenney et al., 2015; McArdle et al., 2007)*. Convection may be a more significant contributor for heat stress for workers if they are exposed to process heat.

Internal mechanisms

In addition to external mechanisms, the body also generates its own heat through internal mechanisms.

Metabolic heat: The heat produced as a by-product of the normal function of biochemical processes in the body (e.g., chemical processes, hormone activation, digestion). This includes the energy produced during physical activity. At rest, metabolic heat production in humans is approximately 75W during sleep, 85W when sitting, and 100W when standing (*Cramer et al., 2022*). However, metabolic heat production rises with increased physical activity because both the energy expended in performing the work, and the energy transformed into heat, increase. During intense exercise, approximately 80-90% of metabolic heat is produced by muscle contractions (*Cramer et al., 2022*). For occupational tasks, metabolic heat production in humans is approximately 180W at low rates of work, e.g., light manual work; 295W for moderate rates, e.g., sustained hand and arm work; 415W for high rates, e.g., intense arm and trunk work; and 520W for very high rates, e.g., intense shovelling or digging (*Cramer et al., 2022; Gao et al., 2018*).

Metabolic heat must be released to the external environment to prevent overheating (*Cramer et al., 2022; Gao et al., 2018*). However, in conditions where the rate of heat gain is greater than the rate of heat loss, the body's temperature will begin to rise. If the core temperature rises excessively, it can increase that person's risk of a heat-related injury or illness (*Gifford et al., 2019*). For example, in hot workplace environments, the use of PPE creates a barrier between the body and the environment that compromises the body's ability to dissipate metabolic heat (*Cheung et al., 2000; Gao et al., 2018*).

Factors affecting heat stress

Environmental factors

Air temperature and velocity, relative humidity, and radiant temperature are the four main climatic factors that contribute to the rate of heat exchange between the skin and the environment (*Cramer et al., 2022*).

Air temperature: Temperature of the ambient air. Air temperature is one of the four main climatic factors that contributes to the rate of heat exchange between the skin and the environment *(Cramer et al., 2022)*. Individuals tend to feel most comfortable when the air temperature is between 20°C, with daily clothes, to 27°C with minimal clothing *(CCOHS, 2024)*. In hot workplaces, workers should be given access to cooler areas, such as air-conditioned rooms indoors, or shaded areas outdoors.

Relative humidity: The amount of water vapour in the air determines the evaporative capacity of the environment (i.e., the ability of sweat to evaporate and reduce body heat). High humidity reduces the amount of sweat that can be evaporated from the skin in hot environments *(Jay & Kenny, 2010)*.

Air velocity: The movement of air, through indoor ventilation or outdoor winds. In hot environments, low air velocity impairs evaporative heat loss, which makes the environment feel hotter. Local ventilation and air velocity can be increased using electric fans (*Jay et al., 2015*). However, when the air temperature is greater than workers' skin temperature, air speeds should be reduced to levels that still allow evaporative heat loss, but also reduce conductive heat gain (*Jacklitsch et al., 2016*).

Radiant temperature: Objects or surfaces that are very hot radiate that heat to other objects or people in the surrounding area, contributing to the overall environmental temperature. The sun is the largest source of radiant heat, but there are also sources of radiant heat in workplaces, such as: process heat, engines, ovens, etc. (*Cramer et al., 2022*). Radiant heat transfer is affected by the amount of heat that is radiated, the amount of time that the worker is exposed to the radiant heat, and clothing insulation (*Cramer et al., 2022*).

Climate change: According to scientists at NASA's Goddard Institute for Space Studies (GISS) in New York, 2019 was 0.98°C (1.8°F) warmer than the mean baseline established from 1951 to 1980 *(NASA GISS/Schmidt, 2020)* (Figure 2). In Canada specifically, temperatures have increased at almost double the global mean rate, with the greatest amount of warming

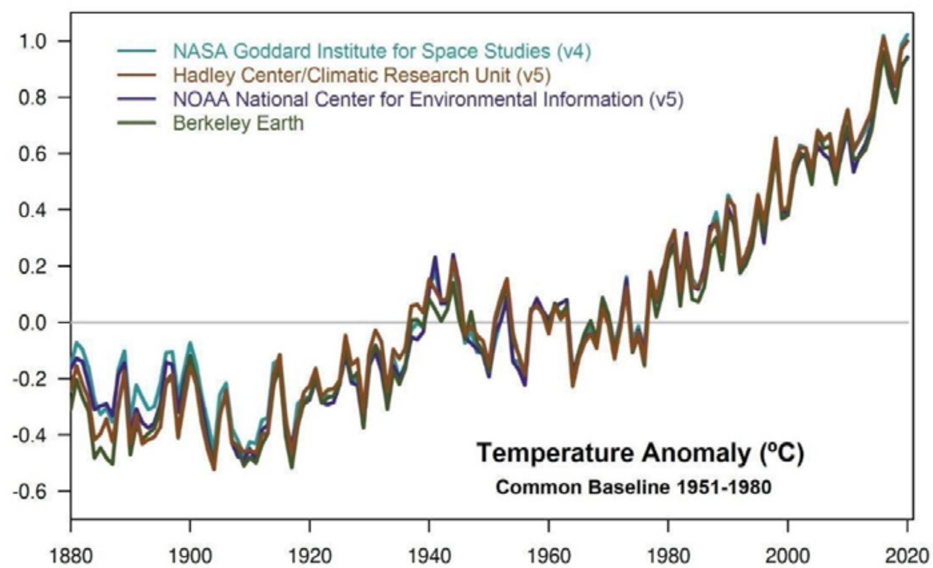


Figure 2. "This plot shows yearly temperature anomalies from 1880 to 2019, with respect to the 1951-1980 mean, as recorded by NASA, NOAA, the Berkeley Earth research group, and the Met Office Hadley Centre (UK). Though there are minor variations from year to year, all four temperature records show peaks and valleys in sync with each other. All show rapid warming in the past few decades, and all show the past decade has been the warmest" (Figure extracted from: NASA GISS/Schmidt, 2020).

observed in the winter *(Zhang et al., 2019)*. It is estimated that between 1948 and 2016, the mean annual temperature increased 1.7°C for Canada as a whole, and 2.3°C for northern Canada (north of 60° latitude) *(Zhang et al., 2019)*. In addition to the increased mean temperatures, extreme warm temperatures have also increased *(Zhang et al., 2019)*. Increasing temperatures due to climate change will contribute to an increased risk for heat related illnesses in workers. For an full report see the 2023 report of the Lancet Countdown on health and climate change (The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms (*Romanellow et al., 2023*).

Individual and job-related factors

A person's general health, and their work conditions, impact how well they can adapt to hot environments. Certain characteristics or conditions can influence individual's heat storage capacity, which is determined by anthropometric characteristics such as lean and fat mass, thermal tolerance, and their body's response to thermal stress. These factors may increase the risk of heat-related injury.

Clothing and PPE: Clothing should be selected to suit the ambient temperature, weather conditions (e.g., wind, rain), the job design, and the level and duration of activity *(CCOHS, 2024)*. Choosing clothing according to these factors can help regulate the amount of heat and perspiration produced and retained during work in hot and cold conditions. However, when you consider the high demands of some occupations, wearing PPE is essential to the health and safety of the worker. Though protective for the worker, PPE can cover most-to-all of the workers' skin, reducing airflow to skin and enhancing air trapping; both of which impair heat loss through evaporation and radiation *(Angerer et al., 2008; Foster et al., 2020; Gao et al., 2018; Rodríguez-Marroyo et al., 2012; Ruby et al., 2002; Smith et al., 2001)*. In general, PPE has a negative effect on the ability of the body to thermoregulate, leading to an estimated 13-18% increase in internal heat production and metabolic rates *(Almario, 2019; Cheung, 2010; Cheung, et al., 2000)*. Multiple layers of protection make exchanging heat with the environment even more difficult, with the potential for heat loss decreasing relative to increasing insulation and evaporative capacity of the clothing and PPE combination *(Foster et al., 2020)*.

The following guidelines should help provide some suggestions for suitable clothing for hot environments:

- Light coloured clothing is suggested when exposed to the sun.
- When safe to do so, clothing should be loose fitting.
- Wear reflective clothing when in high radiant-heat environments.
- Cover your head when exposed to direct sunlight.
- Inner layers should "wick" moisture away from the skin - "breathable." Materials that have this property include polyesters or polypropylene.
- When physical work rate, protective equipment, or the environment cannot be modified, auxiliary cooling garments can be used. These include but are not limited to: ice vest systems and circulating liquid or air-cooling systems.

Shift duration and number of consecutive shifts: The length of workers' shifts, and the number of consecutive shifts they work, can impact the effect of heat stress on those workers. Across work-rest cycles, individuals' physical work capacity has been found to be lower in moderate, hot, and very hot environments, with the reduction in capacity being proportional to both the severity of the heat stress and the length of the exposure (5(± 4)%, 7(± 6)%, and 16(± 7)% decrease in physical work capacity respectively)(*Smallcombe et al., 2022*). Long shift hours, which consequently cause an increase in work demands, have also been identified as a risk factor in increasing blood pressure (*Choi et al., 2016*), and core temperature (*Raines et al., 2015*) in workers. Additionally, a positive correlation has been found between shift duration/working hours and experiencing one or more symptoms of heat stress in workers, specifically headache, dizziness, muscle cramps, and confusion (*Kim et al., 2019*).

Across consecutive days, workers' core temperatures have been observed to increase *(Notley et al., 2018ab).* However, worker's ages may contribute to the magnitude of the effect, as this increase in core temperature has been observed in older males *(Notley et al., 2018ab)*, while in younger males, core temperature didn't significantly increase, though their ratings of perceived exertion, perceived fatigue levels, and perceived energy were lower on consecutive days *(Notley et al., 2018c)*. This has not been measured in women.

When continuous work is being completed in hot temperatures, frequent rest periods should be taken *(Kjellstorm et al., 2009)*, and cooled spaces should be provided for workers. For example, cooled observation booths can allow workers to cool down and monitor equipment simultaneously *(CCOHS, 2024)*. Implemented work-rest cycles are important to limit accumulation of body heat in hot environments.

Acclimatization: The development of resistance to, or enhanced tolerance for, an environmental change with repeated exposure to that environment (*CCOHS, 2024; Gosling, et al., 2014; Jay & Kenny, 2015*). Heat acclimatization, described as the enhancement of the thermoregulatory responses to increase heat loss under heat stress, occurs when people are repeatedly exposed to heat. New employees should be given enough time to acclimate to the new thermal conditions before assuming a full workload (*CCOHS, 2024*). To become acclimatized, workers may benefit from following an acclimatization schedule (*Jacklitsch et al., 2016*). These schedules can be used to increase work ability, decrease the risk for heat-related illness, and enhance heat tolerance times (*Jay & Kenny, 2015*). During the scheduled period, workers gradually increase their exposure time in hot environmental conditions over a 7-10 day period. (*Ashley et al., 2015; Cheung et al., 2016; Sawka et al., 2003; Taylor, 2014*) A decrease in skin and core temperatures, as well as heart rate, is observed during shorter acclimatization protocols. Longer protocols (e.g.s 14 days) will further improve sweat rate, thermal comfort and general work capacity. However, time and magnitude of these responses to acclimatization may vary significantly across individuals. Workplaces should consider the integration of acclimatization assessment tools when possible (*Armstrong & Maresh, 1991; Cheung et al., 2000; Gao et al., 2018; Lam & Lau, 2018; Nielsen, 1998; Périard et al., 2016a; Taylor, 2014*). Collectively, these physiological adaptations allow the body to dissipate heat more efficiently, thereby increasing the capacity to buffer changes in core body temperature.

Of note, unless workers purposefully maintain their acclimatization when they are away from the job, this effect is lost rapidly, during "off-workdays." A decrease in thermal tolerance, specifically to heat stress, can occur in as short as 3-4 days *(CCOHS, 2024)*. De-acclimatization can occur with absence from the thermal environment for a week or longer *(Jacklitsch, 2016)*. Physically fit individuals maintain heat acclimatization to a greater degree than less fit individuals *(Pandolf et al., 1977).* Consequently, workers may need to re-acclimatize if they are absent from thermal conditions for an extended period of time. Additional caution should be taken on the first day of a shift change as the individual may have diminished acclimation during days off *(Jacklitsch, 2016)*. However, re-acclimatization can usually be regained more rapidly in 3-5 days upon return to the thermal environment, depending on the amount of time away from the thermal stress *(Ashley et al., 2015; Lind & Bass, 1963; Wyndham, 1973).* Various organizations and agencies have put forth industry-specific recommendations for exposure and acclimatization (e.g., ACGIH), but the general recommendation for individuals returning to the same job after a prolonged leave (~9 days or longer) is as follows: 50% of usual duration of work under thermal stress on Day 1, 60% on Day 2, 80-90% on Day 3, and 100% on Day 4 *(Jacklitsch, 2016)*.

The summer season in Ontario is generally not hot enough for workers doing light work (sitting/standing, doing light arm work) to be considered acclimatized for the ACGIH Heat Stress/Heat Strain TLV. Workers doing moderate work are only considered acclimatized in Ontario if they regularly work around heat sources (e.g., in foundries, around ovens, etc.).

Hydration status: Consumption of water is essential for a number of bodily functions (e.g., temperature regulation via sweat production, urine production, respiration)*(Benelam & Wyness, 2010; Montain & Coyle, 1992; Raines et al., 2015; Taylor et al., 2014).* When possible, fluid intake should equal fluid loss; however, thirst is a poor indicator of hydration status and normal thirst mechanisms are often not sensitive enough to ensure sufficient water intake under heat stress (*Greenleaf & Harrison, 1986; McArdle et al., 2010*). Hydration can decrease rapidly due to high occupational physical activity demands, which enhance sweating and respiration rate, causing greater water loss, especially at higher ambient temperatures *(Fehling et al., 2015; Raines et al., 2015).* The consequence of these physiological processes may be exaggerated when workers are exposed to excessive heat, as excess sweating contributes to accelerated water losses. Individuals who are more active, or are exposed to heat stress, require greater water intake than those who are sedentary or are in thermoneutral (neither hot nor cold) conditions.

A lack of water intake can lead to dehydration, low blood pressure, confusion, headache, nausea, and in extreme cases muscular weakness and kidney failure (*Ritz & Berrut, 2005*). Conversely, consumption of too much water can lead to hyperhydration, accompanied by nausea, confusion, elevated blood pressure and edema (swelling) (*Ritz & Berrut, 2005*). Individuals need to be encouraged to drink fluids in small quantities, at frequent intervals (*McArdle et al., 2010*). It is important not to overdrink water in hot and humid environments. Overdrinking water, in combination with significant salt loss from sweating, can decrease the concentration of sodium in the blood. This is known as hyponatremia, which further exaggerates sodium imbalance (*Almond et al., 2005; Benelam & Wyness, 2010; Cheung et al., 2016; Lee et al., 2011*). Lower blood sodium levels can cause mental confusion, swelling of the brain, neurologic dysfunctions, gait problems and possibly falls, all of which are work safety related. This is a primary concern for individuals working in hot environments for prolonged periods of time (*Rosner & Kirven, 2007*). When water and electrolytes are lost at a rapid rate in the heat through sweat evaporation, loss of water, salt, and potassium should be compensated for by increasing both food and fluid intake. Salt and potassium in a normal diet should be sufficient to maintain electrolyte balance in acclimatized individuals, however, additional salt and potassium-rich foods may need to be added for unacclimated workers (*CCOHS, 2024; Sawka et al., 2003*).

Moreover, a decline in hydration leads to lower total blood volume. The combination of low blood volume from sweating and blood vessel vasodilation to enhance heat loss, may lead to decreases in blood pressure in some workers *(Crandall et al., 2015).* Furthermore, dehydration lowers sweating capacity and consequently heat loss which leads to further increases in temperature. To compensate for the drop in blood pressure and increase in temperature, the heart rate will increase further to maintain cardiac output and adequate oxygen transport across the body *(Cheung et al., 2000; Raines et al., 2015; Ruby et al., 2003; Cheung, 2010)*. Therefore, maintaining the hydration status is a protective measure specifically with regards to heat stress by keeping blood volume steady and decreasing the cardiovascular load on the body.

Age and work experience: Older individuals (~40 years or older) may be more susceptible to the effects of thermal stress and have more difficulty during acclimatization *(CCOHS, 2024; Jacklitsch, 2016)*. In a sample of individuals aged 31-70 years old, almost one-third of them were screened as being susceptible to heat strain *(Flouris et al., 2018)*. Beyond the age of 50, the body's thermoregulatory capacity progressively declines *(Robertshaw, 1981)* in part due to reduced responses and functions of sweat glands *(Taylor et al., 2008)*. Higher levels of aerobic fitness in older adults can help maintain their cardiovascular fitness to help protect against heat stress *(Foster et al., 2020; Notley et al, 2020);* however reductions in the sweat response will persist *(Foster et al., 2020)*. Older individuals may also be more susceptible to dehydration, due to reduced thirst perception, or blunted thirst *(Stookey, 2005; Toffanello et al., 2010)*. The prevalence of indirect hazards in the workplace may be magnified due to age-related decreases in strength, proprioception, motor control, and/or cognitive function *(Cheung et al., 2016)*.

In the workplace context, the age-related risk of developing heat-related illness (HRI) symptoms, may also be moderated by the amount of work experience individuals have. Rates of HRI, or symptoms of HRI, tend to be higher in younger, less experienced workers, compared to older, more experienced workers *(Gifford et al., 2019; Heinzerling et al., 2020; Spector et al., 2015; Taggart et al., 2024)*. An assessment of workers' compensation data for HRIs in California, found that almost 10% of cases occurred within the first two weeks of the worker's hire date, with almost 3% of cases being on the worker's first day of work *(Heinzerling et al., 2020)*. It is likely that individuals with more work experience, who also tend to be older, are better able to recognize when they are experiencing heat stress and implement behavioural controls to reduce their risk, while younger workers do not have the level of experience necessary to do this.

Sex: At the population level, males are generally more heat tolerant than females *(Foster et al., 2020).* Females tend to have a lower sweat rate *(Foster et al., 2020; Gagnon & Kenny, 2011),* and a higher heart rate *(Foster et al., 2020)* than males of equal size, and fitness. Though this difference does not persist if the males and females are both acclimatized *(Foster et al., 2020)*. However, there is disagreement on whether this difference in tolerance is driven by sex-specific differences or morphological differences (e.g., surface area). Notley and colleagues *(2017)* found that in matched work and heat conditions, when males and females were matched for morphological characteristics, neither their sweat response, nor their cutaneous vascular response differed. Instead, 10-48% of the inter-individual variation in thermal response was accounted for by differences in skin surface area, while sex only accounted for 5% of the variation after accounting for skin surface area *(Notley et al., 2017)*. Nonetheless, females have a tendency to carry more adipose tissue whereas males carry more muscle mass. Muscle tissue is more dense and can store more heat, offering males greater heat storage capacity and thereby additional protection in regard to heat stress. In general, when heat production exceeds heat loss, females tend to be more at risk of hyperthermia, while males are at greater risk of dehydration due to their increased sweat rate (*Wickham et al. 2021; Foster et al., 2020*).

Physical fitness: High intensity physical activities are associated with an elevated heart rate, which can contribute to heat stress. An elevated heart rate that is accompanied by an elevation of core temperature is indicative of heat strain (physiological response of the body to heat stress) *(Cheung, et al., 2000; Coker et al., 2019; Logan & Bernard, 1999; Ruby et al., 2002).*

Low aerobic and/or muscular fitness may further decrease physical work capacity when performing physically demanding tasks in hot environments. Lower fitness reduces an individual's ability to manage the cardiac demands of thermal stress *(Buskirk et al., 1965)*. Low fitness levels may also make individuals less heat tolerant, more susceptible to feelings of extreme heat, and increase the incidence of thermal injury and illness *(Alele et al., 2021; CCOHS, 2024; Foster et al., 2020; Pandolf et al., 1977; Tipton et al., 2008; Yeargin et al., 2006).*

Research has shown that maintaining aerobic fitness, provides protection against heat stress (Cheung, et al., 2000). Benefits of aerobic fitness are largely derived from the resultant increase in cardiovascular fitness, improved peripheral circulation, and sweat rates (*Foster et al., 2020*). At a fixed work pace, aerobically fit individuals tend to be at lower risk of hyperthermia and loss of productivity than unfit individuals (*Foster et al., 2020*). For self-paced work, individuals with higher aerobic fitness tend to have higher work output; though in unacclimatized or inexperienced workers, this can still lead to a higher core temperature (*Foster et al., 2020*). Therefore, monitoring workers for heat illness symptoms should continue independently of fitness status. Table 1 provides maximal oxygen consumption rates (VO_2max) risk thresholds for higher core temperature at moderate and heavy work intensities (*Foster et al., 2020*).

Table 1. VO_2 max risk thresholds for higher core temperature, by work intensity (from: Foster et al., 2020)

Work Intensity	VO_2max (mL/kg/min)
Heavy work	< 35.6
Moderate work	< 30

Body shape: Different factors associated with body shape affect how individuals dissipate heat. Notley and colleagues (*2017*) found that during compensable heat stress (i.e. when the body is not in a state of continuous heat gain), people with a larger surface area (i.e., more available skin surface) relied on cutaneous vasodilation, while individuals with a smaller surface area (i.e., less available skin surface) relied more on sweating for heat loss. Additionally, body composition also plays a role in heat dissipation, as there are differences in heat storage capacity between lean and fat mass (muscle stores more heat: 3.65 vs 2.51 J per g per °C), suggesting that more lean individuals are more heat tolerant since muscles can store more heat (*Cramer and Jay 2016*).

An increased amount of body fat on an individual can cause difficulty in maintaining heat balance: heat transfer to the environment is slowed from the added fat tissue *(Selkirk & McLellan, 2001)*. This can be detrimental in hot environments as the insulative effect of fat contributes to heat storage in the body *(Hanna & Tait, 2015)*. Alele and colleagues *(2021)* found that individuals who were more heat intolerant had higher BMIs, higher body fat percentage, and a lower body surface area relative to mass, compared to more heat tolerant individuals. Extra weight carried by an individual can also result in increased heat production from the added metabolic energy required to perform a task compared to a lean individual, increasing the risk of a HRI *(Khogali & Hales, 1983)*. Body fat percentage is a predictor of heat tolerance outcomes, including core temperature and heart rate *(Alele et al., 2021)*.

Overall, the relative weight of any individual factor is dynamic, and their weight can be affected by: work type (e.g., fixed pace or self-pace), work intensity (i.e. low, moderate, high), and the environmental climate (e.g., temperature, humidity) *(Foster et al., 2020)*. Flouris and colleagues *(2018)* defined a list of criteria (Table 2) to help screen individuals (aged 31-70 years) for possible susceptibility to heat stress, where individuals who meet two or more criteria are considered to be more susceptible to heat stress during work in hot environments. These criteria are limited, and not diagnostic for workers, but may provide a general guideline to help workplaces define thresholds for their heat management plans.

Table 2. Sex-specific screening criteria for susceptibility to heat stress during work and leisure activities in hot environments in individuals aged 31-70 years (from Flouris et al., 2018*). Individuals meeting two or more of these criteria are at risk for susceptibility to heat stress.*

	Males	**Females**
Age	⇢ 53.0 years	⇢ 55.8 years
Body mass index	⇢ 29.5 kg/m^2	⇢ 25.7 kg/m^2
Body Fat percentage	⇢ 28.8%	⇢ 34.9%
Body surface area*	⇠ 2.0 m^2	⇠ 1.7 m^2
Peak oxygen uptake**	⇠ 48.3 mlO_2/kg fat free mass/min	⇠ 41.4 mlO_2/kg fat free mass/min

**See https://www.calculator.net/body-surface-area-calculator.html to estimate body surface area for a given worker.*
***Peak VO_2 is the highest value of VO_2 attained on a particular test, most commonly a graded or other high-intensity test*

Pre-existing medical conditions: Some pre-existing medical conditions can affect individual tolerance to heat stress, specifically, any chronic diseases that affect blood circulation, sweat production, cardiac capacity (*Tait, 2011*), or any other factors predominately affecting thermoregulation. Some common examples of these medical conditions include heart disease (*Kenny et al., 2010; Tait, 2011*), high blood pressure (*Kenny et al., 2010; Tait, 2011*), and uncontrolled diabetes (*Foster et al., 2020; Kenny, Sigal, & McGinn, 2016; Kenny et al., 2010; Tait, 2011*). While more research is needed, there is also emerging evidence that heat stress response may be affected by active COVID-19 infection, as well as long-COVID pathologies (e.g., *López-Carr et al., 2022*).

Please speak to a medical care provider if you are concerned about whether any pre-existing conditions you have may affect your susceptibility to heat stress in the workplace.

Medications: Many prescribed and over the counter drugs can interfere with the regulation of body temperature *(Gauer & Meyers, 2019; Khogali & Hales, 1983; Sorensen & Hess, 2022)*, and are capable of decreasing an individual's ability to cope with heat stress *(CCOHS, 2024; Tait, 2011)*. Table 3 provides a list of some common medication types and their associated thermoregulatory effects. The medications listed in this table is not exhaustive, and not all medications will impact all people in the same way.

Speak to a medical care provider if you are concerned about whether any pre-existing conditions you have may affect your susceptibility to heat stress in the workplace.

Table 3. Common medications (over the counter and prescription) and their associated effects on heat regulation.

Medication	Effects On Heat Regulation
Drugs with anticholinergic activity	Altered central thermoregulation, sedation, and cognitive impairment, leads to dry mouth and/or skin, fever, cessation of sweating *(Sorensen & Hess, 2022)*, hypotension and reduced cardiac output may increase risk of fainting and falls. E.g., atropine, antihistamines, tricyclic antidepressants, phenothiazines, butyrophenones
Blood pressure medication	Decrease heart rate and cardiac contractility, which may impair heat loss through vascular mechanisms *(Sorensen & Hess, 2022)*. E.g., Beta-blockers, calcium-channel blockers
Hypotensive drugs and diuretics	Increase dehydration, impaired cardiac output, impaired blood volume (hypovolemic), postural hypotension increases risk of fainting or falls, reduced thirst sensation, renal impairments *(Sorensen & Hess, 2022; Tait, 2011; Westaway, 2015)*. E.g., Chlorothiazide, bumetanide, triamterene

Medication	Effects On Heat Regulation
Sedatives and anti-anxiety drugs	Impaired behavioural responses to temperature, such as drinking fluids or taking cooling/heating actions *(Sorensen & Hess, 2022),* these drugs may also reduce the threshold for shivering *(Tait, 2011)*. E.g., Benzodiazepines,barbiturates, zolpidem, eszopiclone
Antipsychotics	Interference with hypothalamic thermoregulation *(Sorensen & Hess, 2022)*. Additionally, impaired sweating, reduced thirst sensation, hypotension, and reduced cardiac output may increase risks of fainting or falls, sedation and cognitive impairment, such as reduced alertness, judgement, and perception can occur *(Cuddy, 2004; Westaway, 2015)*. E.g., Phenothizines, risperidone, olanzapine, quetiapine, haloperidol
Antidepressants	
1. Tricyclic antidepressant	May impair radiant cooling through peripheral vasoconstriction *(Sorensen & Hess, 2022)*. They have strong anticholinergic effects, and hypotension and reduced cardiac output may increase risk of fainting and falls *(Westaway, 2015)*. E.g., Amitriptyline
2. Selective serotonin reuptake inhibitors (SSRIs)	Interference with hypothalamic thermoregulation *(Sorensen & Hess, 2022)*. Impaired sweating, can be associated with hyponatraemia, increased cholinergic heat production, and inhibition of heat loss pathways *(Epstein et al., 1997)*, sedation and cognitive impairment, such as reduced alertness, judgement and perception can occur (*Westaway, 2015)*. E.g., Sertraline, citalopram, escitalopram
3.Serotonin and noradrenaline reuptake inhibitors (SNRIs)	Impaired sweating, enhanced cholinergic heat production, and inhibition of heat loss pathways *(Epstein et al., 1997)*. E.g., Venlafaxine, duloxetine, desvenlafaxine
Amphetamines	Increased metabolic rate within the central nervous system *(Cuddy, 2004; Ely et al., 2011; Sorensen & Hess, 2022)*, decreased blood flow and limited heat dissipation *(Cuddy, 2004)*. E.g., Dextroamphetamine, methylphenidate, dextroamphetamine/ Amphetamine combinations

Speak to a medical care provider if you are concerned about whether any medications you take can affect your ability to cope with heat stress.

Alcohol and illicit substances may also impair thermoregulatory functions. Behaviourally, the use of alcohol and illicit substances can impair alertness and judgement around individuals' perception of heat *(Sorensen & Hess, 2022)*. Additionally, alcohol use may impair heat loss via vasodilation and cardiac contractility by exacerbating dehydration, while illicit substances can increase metabolic heat production *(Sorensen & Hess, 2022)*.

Heat-related injury and illness

Heat stress is defined as the net load to which a worker may be exposed to heat, and heat strain is the physiological response to that stress (*Donoghue, 2004; WSN, 2014; Xiang et al., 2014*). Maintaining a core temperature of approximately 37°C is crucial for normal physiological processes as cells and organs function within a narrow thermal range around this temperature. High increases in core temperature: disrupt chemical reactions, increase molecular movement, and cause protein and molecular degradation; all impairing normal physiological processes leading to heat strain illnesses (*Carballo-Leyenda et al., 2019; Cuddy & Ruby, 2011*).

Heat illness is a collective term for a spectrum of heat disorders, which include: heat rash/edema, heat cramps (dehydration), heat syncope (fainting), heat exhaustion, and heat stroke; as the body is trying to control an increasing core temperature. Heat illness occurs when the body loses its thermally neutral environment and the core temperature starts to increase above 37°C. A meta-analysis by Faurie and colleagues (*2022*) found that for every 1°C increase in environmental temperature, the risk of suffering from a heat-related illness increased by 18%, while the risk of mortality increased by 35%.

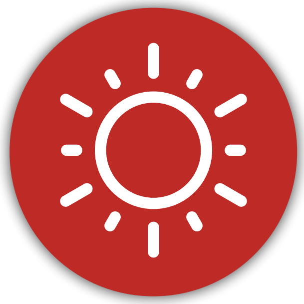
Thermally related occupational injuries and illnesses occur when the thermal load of the environment, and metabolic demands, exceed the capacity of the body to maintain a constant core temperature (*Jacklistsch, 2016*). Many workers in high-temperature environments (e.g., mine workers, crop workers) report experiencing at least one heat-related symptom (*Spector et al., 2015; Taggart et al., 2024*), with a meta-analysis by Flouris and colleagues (*2018*) indicating that 35% of individuals who worked a single shift under conditions of heat stress experienced occupational heat strain. Overall, high temperatures contribute to increases in heat-related injury claims (*Fortune et al., 2013; Xiang et al., 2014*).

It is important to be aware of heat-related illnesses, how to recognize their symptoms, and know what steps can be taken to avoid incidents of thermal-related injuries in the workplaces, to keep yourself and those around you safe. Individuals may be unable to notice their own symptoms, so it often falls to their coworkers to recognize the symptoms and seek timely first aid or medical help (*CCOHS, 2024*).

Short-term illnesses

Acute heat-related injuries and illnesses are listed in Table 4 from mildest to most severe.

Table 4. Descriptions of heat-related illnesses, and their associated signs and symptoms, and pathways for acute treatment.

Description	Signs / Symptoms	First Aid
SUNBURN Burning of the skin due to too much exposure to the sun.	Red and painful skin, may be blistered or peeling. 	Applying an aloe or calamine lotion or a dampened towel to the area may be soothing. Use skin lotions to treat peeling skin. Cover affected area to prevent further burning, work in covered or shaded areas. **If skin blisters, seek medical assistance.**
HEAT EDEMA The pooling of fluid in the hands and legs by gravity due to heat induced expansion (dilation) and permeability of blood vessels. It can be exacerbated by an increase in salt due to heavy sweating *(Gauer & Meyers, 2019; Khan, 2019; Sorensen & Hess, 2022)*.	Swelling of the soft-tissue, most notably in the ankles, and hands/fingers. 	Move to a cooler temperature area, and elevate the affected body part. Compression sleeves can be worn to promote drainage. Will resolve with acclimatization. **Do not treat with diuretics.**
HEAT RASH A rash on the skin due to inflammation of plugged sweat glands with prolonged exposure to humid heat and skin that is continuously wet with sweat *(Jacklitsch et al., 2016; Khan, 2019; Sorensen & Hess, 2022)*.	Skin becomes reddened, with clusters of bumps or blisters, and may itch, feel prickly or hurt. Primarily occurs on the neck, upper extremities, trunk, and around the groin *(Gauer & Meyers, 2019)*. 	Practice good personal hygiene, and keep skin clean and pores unclogged. Wear loose clothing to help increase ventilation, avoid direct heating of skin, and keep the rash area dry. **See a doctor if the rash persists, or an infection occurs in the affected area.**

Description	Signs / Symptoms	First Aid
HEAT CRAMPS (dehydration) Sharp muscle pains, spasms, or cramps that occur during high exertional work/exercise or working in hot and/or humid environments that cause the body to sweat heavily. Consequently, the body loses its salt (electrolyte) balance causing the muscles to jerk involuntarily *(Donoghue, 2004; Gauer & Meyers, 2019; Jacklitsch et al., 2016; Khan, 2019; MLITSD, 2021; Sorensen & Hess, 2022)*. It may also occur with large amounts of water intake without sufficient salt (electrolyte) replacement. It often occurs early in the heat stress season when the worker is unacclimatized.	Sharp muscle cramps, pains, or spasms in either active (arms, legs) or involuntary (usually abdominal) muscles, or both. An elevated heart rate, and increased body temperature may occur in combination with muscle cramps *(Khan, 2019)*. 	Move the worker to a cool area, loosen/remove excess clothing, have them drink water and have a snack, or drink fluids with electrolytes. **Avoid salt tablets**. Gently stretch the affected area. In heat stress conditions, workers need to drink about a cup of water every 20 minutes, more than just relying on satisfying your thirst. Stay away from caffeinated, carbonated, diet drinks, and alcohol.
HEAT SYNCOPE (fainting) Occurs when the body tries to cool itself through dilation of blood vessels when an individual is standing. Systemic vasodilation, combined with the effects of gravity, decrease the total supply of blood to the brain, which can cause light-headedness and syncope (fainting), particularly if dehydrated *(Bouchama & Knochel, 2002; Donoghue, 2004; Gauer & Meyers, 2019; Jacklitsch et al., 2016; Khan, 2019; Kenney et al., 2015; MLITSD, 2021; Sorensen & Hess, 2022)*. It often occurs in unacclimatized individuals, or in combination with other risk factors such as: standing/sitting in one position for a long time; after eating; or in combination with other risk factors such as viral infection, or circulatory health conditions.	Cool moist skin, weak pulse, feelings of dizziness, headache, nausea, and light-headedness. Sudden loss of consciousness after at least two hours of work. 	**Get medical aid immediately.** Lay the individual down in a cool area, and assess breathing and heart rate. Loosen or remove tight or restrictive clothing. If the person regains consciousness, offer sips of cool water.

Description	Signs / Symptoms	First Aid
HEAT EXHAUSTION A medical emergency caused by prolonged exposure to, or heavy exertion in, high temperatures, causing the body to overheat. It causes extreme salt or water loss through heavy sweating and includes rapid heart rate associated with a reduced blood volume, resulting in dizziness, anxiety, intense thirst, pale and clammy skin, and fainting *(Bouchama & Knochel, 2002; Jacklitsch et al., 2016; Khan, 2019; McArdle et al., 2007; MLITSD, 2021; Sorensen & Hess, 2022)*. **Heat exhaustion can progress to heat stroke**. A person who has experienced heat exhaustion or heat stroke previously will be more sensitive, and less tolerant to the heat. Recurrence of a second heat-stress event is common during this time.	Pale and clammy skin, heavy sweating, weakness, fatigue, dizziness, irritability, blurred vision, body temperature 38-40°C, intense thirst, decreased urine output, nausea, headache, vomiting, diarrhea, muscle cramps, breathlessness or fast/shallow breathing, heart palpitations, hypotension, numbness of hands and feet, and possible loss of consciousness. 	**This is a MEDICAL EMERGENCY as heat exhaustion can progress to heat stroke and long-term illnesses.** Move to a cooler or shaded location, and remove as much clothing as possible (e.g., layered PPE, socks, footwear). Apply cool, wet cloths, or ice, to the head, neck, armpits, and groin. Spray with water, and encourage fluid intake if the person is conscious.

Description	Signs / Symptoms	First Aid
HEAT STROKE **The most serious type of heat illness.** Heat stroke occurs at core temperatures greater than 40°C; at this level, the body's ability to dissipate heat will fail *(Donoghue, 2004; Khan, 2019; MLITSD, 2021; WSN, 2014)*. Death can occur in minutes. Classical heat stroke: the increase in body temperature occurs as a result of high environmental temperatures. More commonly occurs among younger and older individuals *(Cheshire, 2016; Khan, 2019; Sorensen & Hess, 2022)*. Exertional heat stroke: the increase in body temperature occurs as a result of a failure to dissipate excess heat gained through high metabolic heat production, due to heavy exertion, in high temperatures or in individuals with encapsulating clothing (e.g., PPE). Exertional heat stress more commonly affects healthy individuals performing high physical exertions *(Cheshire, 2016; Gifford et al., 2019; Khan, 2019; Sorensen & Hess, 2022)*. A person who has experienced heat exhaustion or heat stroke previously will be more sensitive, and less tolerant to the heat. Recurrence of a second heat-stress event is common during this time.	Classical heat stroke: hot, dry, red skin with little to no sweating. Exertional heat stroke: sweating is usually present due to strenuous exercise or work. High/rapid heart rate, erratic breathing, core temperature greater than 40°C, confusion, upset or acting strangely, dizziness, weakness, slurred speech, seizures or convulsions, complete or partial loss of consciousness, and multi-organ failure *(Jacklitsch et al., 2016; Khan, 2019)*. A worker heading into heat stroke will not realize what's happening to them. It's vital that co-workers be able to recognize what's happening quickly and intervene. Without quick attention, the worker may die! 	**This is a MEDICAL EMERGENCY, seek medical attention immediately.** Follow first aid treatment for heat exhaustion, with immediate, aggressive cooling of the person's body, until medical team/first responders arrive. Apply cold to the person's head, neck, armpits, and groin; wet their skin and clothing with cool water; increase air circulation; do not try to force the person to drink liquids.

Long-term illnesses

In addition to short-term heat illnesses, heat stress, heat exhaustion, and heat stroke can also have long-term effects, with the severity of heat strain correlating positively with the severity of long-term symptoms and damage (*Bouchama & Knochel, 2002; Jacklitsch et al., 2016*). While heat is accumulating in the body, it is causing damage to cells in the brain, heart, kidneys, liver, and even muscles (*Cheung, et al., 2000; Jacklitsch et al., 2016; McArdle et al., 2007*). Cellular damage may cause inflammation and requires time to repair; this is why workers may, in part, describe muscle pain and body aches after heat exposure. However, there are also cases when cellular damage may require years to heal, if at all. For example, following heat stroke, damage to the cerebellum, an area of the brain responsible for movements and balance, as well as other critical parts of the brain have been observed (*Albukrek et al., 1997; Lee et al., 2009; McLaughlin et al., 2003*). In the majority of cases, people recover fully from acute cognitive dysfunction. However some people are left with persistant changes in attention, memory or personality, which may be mild or severe and have been reported after heat stroke and heat stress (*reviewed in Walkter & Carraretto 2016*).

Evidence also suggests that individuals with long-term exposure to heat stress during work may be more prone to developing Chronic Kidney Disease or acute kidney injury (*Chapman et al., 2021; Flouris et al., 2018; Oppermann et al., 2021; Tawatsupa et al., 2012*). Chronic Kidney Disease (CDK) is a condition in which the kidneys are damaged and cannot filter blood as well as they should. This causes excess fluid and waste products to build up in the body and may cause other health problems such as heart disease and stroke. While more information is needed, it is hypothesized that repetitive kidney injury due to physical work under heat stress conditions may contribute to the development of chronic kidney disease of nontraditional origin (CKDnt) (*Chapman et al., 2021; Wesseling et al., 2020*). While CKDnt is currently of greater prevalence in South America, there is growing concern that increased extreme heat events, as a result of climate change, may put workers in North America at greater risk of developing CKDnt in the future.

Heat intolerance can also develop, even as a result of mild heat illness, signalling an impairment in the temperature regulation process by the hypothalamus and increasing a person's risk for recurring heat illness events (*McArdle et al., 2007; Nelson et al., 2018*). Heat intolerance symptoms may last for 8-12 weeks beyond the event, but may increase risk of future heat stroke events permanently (*Wang, et al., 2019*).

Recognizing the early signs/stages of heat illness are critical for the prevention of heat stroke and illnesses, but also to mitigating the long-term damage of heat stress. Acting quickly and efficiently can save the life of the worker, and this is the paramount effort of any organization.

APPENDIX A: DEFINTIONS

Acclimatization: The process by which bodily changes occur in a worker in response to heat stress exposure over time; these changes improve the worker's ability to tolerate heat stress *(ACGIH, 2022; Gosling et al., 2014)*.

Action limit (AL): The heat conditions at which healthy, unacclimatized workers can reach thermal equilibrium, under the ACGIH guidelines *(ACGIH, 2022)*.

Compensable heat stress: When enough heat can be lost to the environment so that the body is not in a continuous state of heat gain.

Cognitive function: Mental processes, or brain-based skills, that allow us to carry out tasks such as decision making, memory, orientation, attention, learning, reasoning, and problem solving.

Conduction: The transfer of heat through direct contact with a surface or object. The body gains heat from surrounding hot objects and loses heat to cold objects.

Convection: The transfer of heat with the surrounding air, or fluid, as it moves across the surface of the body. The body gains heat from hot air/water and loses heat to cold air/water, which comes into contact with the skin. The exchange of heat increases with greater air or fluid movement (i.e. wind, current).

Dehydration: Loss or deficiency of water in body tissues caused by sweating, vomiting, or diarrhea. Symptoms include excessive thirst, nausea, and exhaustion.

Evaporation: The most effective way to lose heat from the body from the conversion of liquid (sweat) to gas. The evaporation of sweat from the skin surface dissipates heat from the body and occurs more quickly with low humidity and high wind speeds. The ability to evaporate sweat is a major determinant in heat balance and thermal injury risk.

Heat balance: The balance between the rate of heat production and heat loss determining whether core temperature will increase or decrease.

Heat gain: The amount of heat that is transferred from the environment to and produced by the body.

Heat loss: The amount of heat that is transferred from the body to the environment.

Heat strain: The body's physiological response to heat stress *(ACGIH, 2022; Donoghue, 2004; WSN, 2014; Xiang et al., 2014)*.

Heat stress: The net load of heat to which a worker may be exposed, taking into account metabolic heat production, environmental heat, and clothing and personal protective equipment (PPE) *(ACGIH, 2022; Donoghue, 2004; WSN, 2014; Xiang et al., 2014)*.

Heat Stress Management Program (HSMP): Written plans that outline workplace policies around managing heat stress including, but not necessarily limited to: training, hygiene practices, monitoring, event documentation, and an emergency response plan. HSMP should include general controls, and job specific controls that are triggered when heat stress exceeds exposure limits, for example those in the threshold limit value (TLV) or AL *(ACGIH, 2022)*.

General controls: Actions that are taken, as part of the HSMP, to protect workers when heat stress as an expected hazard. These are broad actions that apply to general workplace settings *(ACGIH, 2022)*. Examples of general controls include: training and policies related to recognizing heat-related symptoms, alerts for high risk periods or activities, and learning first aid.

Job specific controls: Actions that are taken, as part of the HSMP, that are applied to control heat stress under specific exposure conditions. These actions are used to reduce heat stress exposure levels and include the application of the hierarchy of controls (e.g.,, engineering controls, administrative controls, personal cooling) *(ACGIH, 2022)*.

Heat-related illnesses: A spectrum of disorders, including heat cramps, heat exhaustion, and heat stroke and long-term conditions (e.g., kidney disease); caused by environmental exposure to heat.

Acute illnesses: Sudden-onset heat-related illnesses that result immediately, or within a definite time-frame, of environmental exposure to heat and resolve within days.

Chronic illnesses: Heat-related illnesses that result from severe, prolonged, repeated, or continuous environmental exposure to heat, and either take longer than 3 months to resolve, or never resolve.

Metabolic heat: The heat produced by biochemical processes in the body as a by-product of cellular energy production. As metabolic activity increase during physical work, so does heat production.

Metabolic rate: Rate of energy (and, consequently, heat) production of the body which varies between people and with the level of their activity *(ACGIH, 2022)*. If the rate of metabolic heat production is equivalent to the rate of heat lost, core body temperature does not change, as no heat is stored *(Cramer et al., 2022)*. If the rate of metabolic heat production exceeds the rate of heat loss, core body temperature increases as heat is stored *(Cramer et al., 2022)*.

Radiation: The transfer of heat, due heat waves being emitted from an object exposed to a temperature gradient, without the object coming into contact with any surface or object. The body gains heat from nearby hot objects that emit heat waves and loses heat in the same way to nearby cold objects.

Relative humidity: The ratio of water vapour content of air to the maximum possible water vapour content of air at the same temperature and barometric pressure.

Thermoregulation: A process that allows the body to maintain its core internal temperature by tightly controlled self-regulation, even under changes in environmental conditions.

Threshold limit value (TLV): The heat conditions at which healthy acclimatized individuals can reach thermal equilibrium under the ACGIH guidelines. For the purpose of the TLV, workers are considered acclimatized if they had recent heat stress exposures of at least two continuous hours, for five of the previous seven days *(ACGIH, 2022)*.

Uncompensable Heat Stress: when heat production exceeds heat loss potential in that climate and as such, the body is in a state of continuous heat gain.

Wet bulb globe temperature (WBGT): A measure of environmental heat that takes into account: air temperature, humidity, air movement, and radiant heat *(ACGIH, 2022)*.

APPENDIX B: REFERENCES

Albukrek, D., Bakon, M., Moran, D.S., Faibel, M., & Epstein, Y. (1997). Heat-stroke-induced cerebellar atrophy: Clinical course, CT and MRI findings. *Neuroradiology, 39*(3), 195–197. https://doi.org/10.1007/s002340050392

Alele, F.O., Malau-Aduli, B.S., Malau-Aduli, A.E.O., & J Crowe, M. (2021). Individual Anthropometric, Aerobic Capacity and Demographic Characteristics as Predictors of Heat Intolerance in Military Populations. *Medicina (Kaunas, Lithuania), 57*(2), 173. https://doi.org/10.3390/medicina57020173

Almario, D.R. (2019). The Ability of the U.S. Military's WBGT-based Flag System to Recommend Safe *Heat Stress Exposures* (Publication No. 13811179) [Master's Thesis, University of South Florida]. ProQuest Dissertations & Theses Global. https://digitalcommons.usf.edu/cgi/viewcontent.cgi?article=8924&context=etd

Almond, C.S.D., Shin, A.Y., Fortescue, E.B., Mannix, R.C., Wypij, D., Binstadt, B.A., Duncan, C.N., Olson, D.P., Salerno, A.E., Newburger, J.W., & Greenes, D.S. (2005). Hyponatremia among runners in the Boston Marathon. *The New England Journal of Medicine, 352*(15), 1550–1556. https://doi.org/10.1056/NEJMoa043901

American Conference of Governmental Industrial Hygienists (ACGIH). (2022). P*hysical Agents—Thermal Stress: Heat stress and strain*. In 2023: TLVs and BEIs (pp. 239–247). Cincinnati, OH: ACGIH. ISBN: 978-1-607261-58-2

Amos, D., Hansen, R., Lau, W.M., & Michalski, J.T. (2000). Physiological and cognitive performance of soldiers conducting routine patrol and reconnaissance operations in the tropics. *Military Medicine, 165*(12), 961–966. https://doi.org/10.1093/milmed/165.12.961

Angerer, P., Kadlez-Gebhardt, S., Delius, M., Raluca, P., & Nowak, D. (2008). Comparison of cardiocirculatory and thermal strain of male firefighters during fire suppression to exercise stress test and aerobic exercise testing. *The American Journal of Cardiology, 102*(11), 1551–1556. https://doi.org/10.1016/j.amjcard.2008.07.052

Armstrong, L.E., & Maresh, C.M. (1991). The induction and decay of heat acclimatisation in trained athletes. *Sports Medicine (Auckland, N.Z.), 12*(5), 302–312. https://doi.org/10.2165/00007256-199112050-00003

Ashley, C.D., Ferron, J., & Bernard, T.E. (2015). Loss of heat acclimation and time to re-establish acclimation. *Journal of Occupational and Environmental Hygiene, 12*(5), 302–308. https://doi.org/10.1080/15459624.2014.987387

Benelam, B., & Wyness, L. (2010). Hydration and health: A review. *Nutrition Bulletin, 35*(1), 3–25. https://doi.org/10.1111/j.1467-3010.2009.01795.x

Bouchama, A., & Knochel, J.P. (2002). Heat stroke. *The New England Journal of Medicine, 346*(25), 1978–1988. https://doi.org/10.1056/NEJMra011089

Buskirk, E.R., Lundegren, H., & Magnusson, L. (1965). Heat acclimatization patterns in obese and lean individuals. *Annals of the New York Academy of Sciences, 131*(1), 637–653. https://doi.org/10.1111/j.1749-6632.1965.tb34827.x

Canadian Centre for Occupational Health and Safety (CCOHS). (2024, February 10). *Hot environments Fact Sheets*. https://www.ccohs.ca/oshanswers/phys_agents/heat

Carballo-Leyenda, B., Villa, J.G., López-Satué, J., & Rodríguez-Marroyo, J.A. (2019). Characterizing Wildland Firefighters' Thermal Environment During Live-Fire Suppression. *Frontiers in Physiology, 10*, 949. https://doi.org/10.3389/fphys.2019.00949

Chapman, C.L., Hess, H.W., Lucas, R.A.I., Glaser, J., Saran, R., Bragg-Gresham, J., Wegman, D.H., Hansson, E., Minson, C.T., & Schlader, Z.J. (2021). Occupational heat exposure and the risk of chronic kidney disease of nontraditional origin in the United States. *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology, 321*(2), R141–R151. https://doi.org/10.1152/ajpregu.00103.2021

Cheshire Jr, W.P. (2016). Thermoregulatory disorders and illness related to heat and cold stress. *Autonomic Neuroscience, 196*, 91-104. https://doi.org/10.1016/j.autneu.2016.01.001

Cheung, S. (2010). *Advanced Environmental Exercise Physiology*. Human Kinetics.

Cheung, S.S., Lee, J.K., & Oksa, J. (2016). Thermal stress, human performance, and physical employment standards. *Applied Physiology, Nutrition, and Metabolism, 41*(6 Suppl 2), S148-S164. https://doi.org/10.1139/apnm-2015-0518

Cheung, S.S., McLellan, T.M., & Tenaglia, S. (2000). The thermophysiology of uncompensable heat stress. Physiological manipulations and individual characteristics. *Sports Medicine (Auckland, N.Z.), 29*(5), 329–359. https://doi.org/10.2165/00007256-200029050-00004

Choi, B., Schnall, P., & Dobson, M. (2016). Twenty-four-hour work shifts, increased job demands, and elevated blood pressure in professional firefighters. *International Archives of Occupational and Environmental Health, 89*(7), 1111–1125. https://doi.org/10.1007/s00420-016-1151-5

Climate Risk Institute (CRI). (2023). *Ontario Provincial Climate Change Impact Assessment: Technical Report*. https://www.publications.gov.on.ca/CL32819

Coker, R.H., Murphy, C.J., Johannsen, M., Galvin, G., & Ruby, B. C. (2019). Wildland Firefighting: Adverse Influence on Indices of Metabolic and Cardiovascular Health. *Journal of Occupational and Environmental Medicine, 61(3)*, e91–e94. https://doi.org/10.1097/JOM.0000000000001535

Cramer, M.N., Gagnon, D., Laitano, O., & Crandall, C.G. (2022). Human temperature regulation under heat stress in health, disease, and injury. *Physiological Reviews, 102*(4), 1907–1989. https://doi.org/10.1152/physrev.00047.2021

Cramer, M. N., & Jay, O. (2016). Biophysical aspects of human thermoregulation during heat stress. *Autonomic Neuroscience: Basic & Clinical, 196*, 3–13. https://doi.org/10.1016/j.autneu.2016.03.001

Cuddy, J.S., & Ruby, B. C. (2011). High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake. *Wilderness & Environmental Medicine, 22*(2), 122–125. https://doi.org/10.1016/j.wem.2011.01.008

Cuddy, M.L.S. (2004). The effects of drugs on thermoregulation. *AACN Clinical Issues, 15*(2), 238–253.DOI: 10.1097/00044067-200404000-00010

Curley, M.D., & Hawkins, R.N. (1983). Cognitive performance during a heat acclimatization regimen. Aviation, Space, and Environmental Medicine, 54(8), 709–713. PMID: 6626079

Díaz, M., & Becker, D.E. (2010). Thermoregulation: Physiological and Clinical Considerations during Sedation and General Anesthesia. *Anesthesia Progress, 57*(1), 25–33. https://doi.org/10.2344/0003-3006-57.1.25

Donoghue, A.M. (2004). Heat illness in the U.S. mining industry. *American Journal of Industrial Medicine, 45*(4), 351–356. https://doi.org/10.1002/ajim.10345

Ely, B.R., Ely, M.R., & Cheuvront, S.N. (2011). Marginal effects of a large caffeine dose on heat balance during exercise-heat stress. *International Journal of Sport Nutrition and Exercise Metabolism, 21*(1), 65–70. https://doi.org/10.1123/ijsnem.21.1.65

Epstein, Y., Albukrek, D., Kalmovitc, B., Moran, D.S., & Shapiro, Y. (1997). Heat intolerance induced by antidepressants. *Annals of the New York Academy of Sciences, 813*, 553–558. https://doi.org/10.1111/j.1749-6632.1997.tb51746.x

Faurie, C., Varghese, B.M., Liu, J., & Bi, P. (2022). Association between high temperature and heatwaves with heat-related illnesses: A systematic review and meta-analysis. *The Science of the Total Environment, 852*, 158332. https://doi.org/10.1016/j.scitotenv.2022.158332

Fehling, P.C., Haller, J.M., Lefferts, W.K., Hultquist, E.M., Wharton, M., Rowland, T.W., & Smith, D.L. (2015). Effect of exercise, heat stress and dehydration on myocardial performance. *Occupational Medicine (Oxford, England), 65*(4), 317–323. https://doi.org/10.1093/occmed/kqv015

Flouris, A.D., Dinas, P.C., Ioannou, L.G., Nybo, L., Havenith, G., Kenny, G.P., & Kjellstrom, T. (2018). Workers' health and productivity under occupational heat strain: A systematic review and meta-analysis. *The Lancet. Planetary Health, 2*(12), e521–e531. https://www.thelancet.com/action/showPdf?pii=S2542-5196%2818%2930237-7

Fortune, M.K., Mustard, C.A., Etches, J.J.C., & Chambers, A.G. (2013). Work-attributed illness arising from excess heat exposure in Ontario, 2004-2010. *Canadian Journal of Public Health. 104*(5), e420-426. https://doi.org/10.17269/cjph.104.3984

Foster, J., Hodder, S.G., Lloyd, A.B., & Havenith, G. (2020). Individual Responses to Heat Stress: Implications for Hyperthermia and Physical Work Capacity. *Frontiers in Physiology, 11*, 541483 https://doi.org/10.3389/fphys.2020.541483

Gagge, A.P., & Gonzales, R.R. (1996). Mechanisms of heat exchange. *Handbook of physiology. Environmental physiology*. Bethesda, MD: American Physiological Society. pp. 45-84

Gagnon, D., & Kenny, G.P. (2011). Sex modulates whole-body sudomotor thermosensitivity during exercise. *The Journal of Physiology, 589*(24), 6205–6217. https://doi.org/10.1113/jphysiol.2011.219220

Gao, C., Kuklane, K., Östergren, P.-O., & Kjellstrom, T. (2018). Occupational heat stress assessment and protective strategies in the context of climate change. *International Journal of Biometeorology, 62*(3), 359–371. https://doi.org/10.1007/s00484-017-1352-y

Gauer, R., & Meyers, B.K. (2019). Heat-Related Illnesses. *American Family Physician, 99*(8), 482–489. PMID: 30990296

Gifford, R.M., Todisco, T., Stacey, M., Fujisawa, T., Allerhand, M., Woods, D.R., & Reynolds, R.M. (2019). Risk of heat illness in men and women: A systematic review and meta-analysis. *Environmental Research, 171*, 24–35. https://doi.org/10.1016/j.envres.2018.10.020

Gosling, S.N., Bryce, E.K., Dixon, P.G., Gabriel, K.M.A., Gosling, E.Y., Hanes, J.M., Hondula, D.M., Liang, L., Bustos Mac Lean, P.A., Muthers, S., Nascimento, S.T., Petralli, M., Vanos, J.K., & Wanka, E.R. (2014). A glossary for biometeorology. *International Journal of Biometeorology, 58*(2), 277–308. https://doi.org/10.1007/s00484-013-0729-9

Greenleaf, J.E., & Harrison, M.H. (1986). Water and Electrolytes. In Nutrition and Aerobic Exercise (Vol. 294, pp. 107–124). *American Chemical Society*. https://doi.org/10.1021/bk-1986-0294.ch008

Grether, W.F. (1973). Human performance at elevated environmental temperatures. *Aerospace Medicine, 44*(7), 747–755. PMID: 4715089

Hancock, P.A. (1982). Task categorization and the limits of human performance in extreme heat. *Aviation, Space, and Environmental Medicine, 53*(8), 778–784. PMID: 7181809

Hancock, P.A., Ross, J.M., & Szalma, J.L. (2007). A meta-analysis of performance response under thermal stressors. *Human Factors, 49*(5), 851–877. https://doi.org/10.1518/001872007X230226

Hanna, E.g., & Tait, P.W. (2015). Limitations to Thermoregulation and Acclimatization Challenge Human Adaptation to Global Warming. *International Journal of Environmental Research and Public Health, 12*(7), 8034–8074. https://doi.org/10.3390/ijerph120708034

Health Canada. (2020). *Reducing Urban Heat Islands to Protect Health in Canada: An introduction for public health professionals* (Publication No. 180919). Ottawa, ON: Health Canada.

Heinzerling, A., Laws, R.L., Frederick, M., Jackson, R., Windham, G., Materna, B., & Harrison, R. (2020). Risk factors for occupational heat-related illness among California workers, 2000-2017. *American Journal of Industrial Medicine, 63*(12), 1145–1154. https://doi.org/10.1002/ajim.23191

Henderson, J., Baker, H.W., & Hanna, P.J. (1986). Occupation-related male infertility: A review. *Clinical Reproduction and Fertility, 4*(2), 87–106. PMID: 3527400

Hodge, B.D., & Brodell, R.T. (2020). A*natomy, Skin Sweat Glands*. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK482278/

Jacklitsch, B., Williams, J., Musolin, K., Coca, A., Kim, J.-H., & Turner, N. (2016). *NIOSH criteria for a recommended standard: Occupational exposure to heat and hot environments*. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2016-106. https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf

Jay, O., Cramer, M.N., Ravanelli, N.M., & Hodder, S.G. (2015). Should electric fans be used during a heat wave? *Applied Ergonomics, 46* Pt A, 137–143. https://doi.org/10.1016/j.apergo.2014.07.013

Jay, O., & Kenny, G.P. (2010). Heat exposure in the Canadian workplace. *American Journal of Industrial Medicine, 53*(8), 842–853. https://doi.org/10.1002/ajim.20827

Johnson, J.M., Minson, C.T., & Kellogg Jr, D.L. (2014). Cutaneous vasodilator and vasoconstrictor mechanisms in temperature regulation. *Comprehensive Physiology, 4*(1), 33–89. https://doi.org/10.1002/cphy.c130015

Jung, A., & Schuppe, H.-C. (2007). Influence of genital heat stress on semen quality in humans. *Andrologia, 39*(6), 203–215. https://doi.org/10.1111/j.1439-0272.2007.00794.x

Kenney, W.L., Wilmore, J., & Costill, D. (2015). *Physiology of Sport and Exercise 6th Edition*. Human Kinetics.

Kenny, G.P., Sigal, R. J., & McGinn, R. (2016). Body temperature regulation in diabetes. T*emperature: Multidisciplinary Biomedical Journal, 3*(1), 119–145. https://doi.org/10.1080/23328940.2015.1131506

Kenny, G.P., Yardley, J., Brown, C., Sigal, R.J., & Jay, O. (2010). Heat stress in older individuals and patients with common chronic diseases. *CMAJ: Canadian Medical Association Journal, 182*(10), 1053–1060. https://doi.org/10.1503/cmaj.081050

Khan, A.A. (2019). Heat related illnesses. Review of an ongoing challenge. *Saudi Medical Journal, 40*(12), 1195–1201. https://doi.org/10.15537/smj.2019.12.24727

Khogali, M., & Hales, J.R.S. (Eds.). (1983). *Heat stroke and temperature regulation*. Academic Press.

Kim, S., Kim, D.-H., Lee, H.-H., & Lee, J.-Y. (2019). Frequency of firefighters' heat-related illness and its association with removing personal protective equipment and working hours. I*ndustrial Health, 57*(3), 370–380. https://doi.org/10.2486/indhealth.2018-0063

Kipp, A., Cunsolo, A., Vodden, K., King, N., Manners, S., & Harper, S.L. (2019). At-a-glance Climate change impacts on health and wellbeing in rural and remote regions across Canada: A synthesis of the literature. *Health Promotion and Chronic Disease Prevention in Canada: Research, Policy and Practice, 39*(4), 122–126. https://doi.org/10.24095/hpcdp.39.4.02

Kjellstrom, T., Holmer, I., & Lemke, B. (2009). Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. *Global Health Action, 2*(1), 2047. https://doi.org/10.3402/gha.v2i0.2047

Lam, C.K.C., & Lau, K.K.-L. (2018). Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: A comparative study between Melbourne and Hong Kong. *International Journal of Biometeorology, 62*(7), 1311–1324. https://doi.org/10.1007/s00484-018-1535-1

Lamarche, D.T., Meade, R.D., D'Souza, A.W., Flouris, A.D., Hardcastle, S.G., Sigal, R.J., … & Kenny, G.P. (2017). The recommended Threshold Limit Values for heat exposure fail to maintain body core temperature within safe limits in older working adults. *Journal of Occupational and Environmental Hygiene, 14*(9), 703-711. https://pubmed.ncbi.nlm.nih.gov/28609164/

Lee, J.K.W., Nio, A.Q.X., Ang, W.H., Johnson, C., Aziz, A.R., Lim, C.L., & Hew-Butler, T. (2011). First reported cases of exercise-associated hyponatremia in Asia. *International Journal of Sports Medicine, 32*(4), 297–302. https://doi.org/10.1055/s-0030-1269929

Lee, J.S., Choi, J.C., Kang, S.-Y., Kang, J.-H., & Park, J.-K. (2009). Heat Stroke: Increased Signal Intensity in the Bilateral Cerebellar Dentate Nuclei and Splenium on Diffusion-Weighted MR Imaging. *AJNR: American Journal of Neuroradiology, 30*(4), e58. https://doi.org/10.3174/ajnr.A1432

Levine, R.J. (1984). Male fertility in hot environment. *JAMA, 252*(23), 3250–3251.

Levy, B.S., & Roelofs, C. (2019). Impacts of Climate Change on Workers' Health and Safety. In *Oxford Research Encyclopedia of Global Public Health*. https://doi.org/10.1093/acrefore/9780190632366.013.39

Lim, C.L., Byrne, C., & Lee, J.K. (2008). Human thermoregulation and measurement of body temperature in exercise and clinical settings. *Annals of the Academy of Medicine, Singapore, 37*(4), 347–353. PMID: 18461221

Lind, A.R., & Bass, D.E. (1963). *Optimal exposure time for development of acclimatization to heat*. Federation Proceedings, 22(3), 704–708.

Logan, P.W., & Bernard, T.E. (1999). Heat stress and strain in an aluminum smelter. *American Industrial Hygiene Association Journal, 60*(5), 659–665. https://doi.org/10.1080/00028899908984488

López-Carr, D., Vanos, J., Sánchez-Vargas, A., Vargas, R., & Castillo, F. (2022). Extreme Heat and COVID-19: A Dual Burden for Farmworkers. *Frontiers in Public Health, 10*, 884152. https://doi.org/10.3389/fpubh.2022.884152

LoVecchio, F., Pizon, A.F., Berrett, C., & Balls, A. (2007). Outcomes after environmental hyperthermia. *The American Journal of Emergency Medicine, 25*(4), 442–444. https://doi.org/10.1016/j.ajem.2006.11.026

McArdle, W.D., Katch, F.I., & Katch, V.L. (2007). *Exercise physiology: Energy, Nutrition, and Human Performance (6th Edition)*. Philadelphia, PA: Lippincott, Williams & Wilkins.

McArdle, W.D., Katch, F.I., & Katch, V.L. (2010). *Exercise Physiology: Nutrition, Energy, and Human Performance* (7th Edition). Philadelphia, PA: Lippincott Williams & Wilkins.

McLaughlin, C.T., Kane, A.G., & Auber, A.E. (2003). MR imaging of heat stroke: External capsule and thalamic T1 shortening and cerebellar injury. *American Journal of Neuroradiology, 24*(7), 1372–1375. http://www.ajnr.org/content/24/7/1372

Meese, G.B., Lewis, M.I., Wyon, D.P., & Kok, R. (1984). A laboratory study of the effects of moderate thermal stress on the performance of factory workers. *Ergonomics, 27*(1), 19–43. https://doi.org/10.1080/00140138408963461

Mieusset, R., Bujan, L., Mansat, A., Pontonnier, F., & Grandjean, H. (1987). Effects of artificial cryptorchidism on sperm morphology. *Fertility and Sterility, 47*(1), 150–155. https://doi.org/10.1016/S0015-0282(16)49951-6

Ministry of Labour, Training, Immigration, and Skills Development (MLITSD). (2021, August 19). *Managing heat stress at work* | ontario.ca. Ministry of Labour, Training, Immigration, and Skills Development (MLITSD).

Montain, S.J., & Coyle, E.F. (1992). Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *Journal of Applied Physiology (Bethesda, Md.: 1985), 73*(4), 1340–1350. https://doi.org/10.1152/jappl.1992.73.4.1340

NASA GISS. (2021, January 14). NASA GISS: NASA News & Feature Releases: 2020 Tied for Warmest Year on Record, NASA Analysis Shows (Release 21-005). National Aeronautics and Space Administration: Goddard Institute for Space Studies. https://www.giss.nasa.gov/research/news/20210114/

Nelson, D.A., Deuster, P.A., O'Connor, F.G., & Kurina, L.M. (2018). Timing and Predictors of Mild and Severe Heat Illness among New Military Enlistees. *Medicine and Science in Sports and Exercise, 50*(8), 1603–1612. https://doi.org/10.1249/MSS.0000000000001623

Nielsen, B. (1998). Heat acclimation—Mechanisms of adaptation to exercise in the heat. *International Journal of Sports Medicine, 19 Suppl 2*, S154-156. https://doi.org/10.1055/s-2007-971984

Northwestern Health Unit. (2022). *Climate Change and Health in Northern Ontario*. https://www.nwhu.on.ca/wp-content/uploads/2022/10/Climate-Change-and-Health-in-Northern-Ontario-August-2022.pdf

Notley, S.R., Meade, R.D., D'Souza, A.W., Friesen, B.J., & Kenny, G.P. (2018a). Heat Loss Is Impaired in Older Men on the Day after Prolonged Work in the Heat. *Medicine and Science in Sports and Exercise, 50*(9), 1859–1867. https://doi.org/10.1249/MSS.0000000000001643

Notley, S.R., Meade, R.D., D'Souza, A.W., McGarr, G.W., & Kenny, G.P. (2018b). Cumulative effects of successive workdays in the heat on thermoregulatory function in the aging worker. Temperature: *Multidisciplinary Biomedical Journal, 5*(4), 293–295.

Notley, S.R., Meade, R.D., Friesen, B.J., D'Souza, A.W., & Kenny, G.P. (2018c). Does a Prolonged Work Day in the Heat Impair Heat Loss on the Next Day in Young Men? *Medicine and Science in Sports and Exercise, 50*(2), 318–326.

Notley, S.R., Meade, R.D., & Kenny, G.P. (2020). Effect of aerobic fitness on the relation between age and whole-body heat exchange during exercise-heat stress: A retrospective analysis. *Experimental Physiology, 105*(9), 1550–1560.

Notley, S.R., Park, J., Tagami, K., Ohnishi, N., & Taylor, N.A.S. (2017). Variations in body morphology explain sex differences in thermoeffector function during compensable heat stress. *Experimental Physiology, 102*(5), 545–562. https://physoc.onlinelibrary.wiley.com/doi/full/10.1113/EP086112

Nybo, L. (2008). Hyperthermia and fatigue. *Journal of Applied Physiology (Bethesda, Md.: 1985), 104*(3), 871–878. https://journals.physiology.org/doi/full/10.1152/japplphysiol.00910.2007

Oppermann, E., Kjellstrom, T., Lemke, B., Otto, P., & Lee, J. (2021). Establishing intensifying chronic exposure to extreme heat as a slow onset event with implications for health, wellbeing, productivity, society and economy. *Current Opinion in Environmental Sustainability, 50*, 225-235. https://doi.org/10.1016/j.cosust.2021.04.006

Osilla, E.V., Marsidi, J.L., Shumway, K.R., & Sharma, S. (2020). *Physiology, Temperature Regulation*. In StatPearls. StatPearls Publishing.

Pandolf, K.B., Burse, R.L., & Goldman, R.F. (1977). Role of physical fitness in heat acclimatisation, decay and reinduction. *Ergonomics, 20*(4), 399–408. https://doi.org/10.1080/00140137708931642

Périard, J.D., Travers, G.J.S., Racinais, S., & Sawka, M.N. (2016). Cardiovascular adaptations supporting human exercise-heat acclimation. *Autonomic Neuroscience: Basic & Clinical, 196*, 52–62.https://doi.org/10.1016/j.autneu.2016.02.002

Pienimäki, T. (2002). Cold exposure and musculoskeletal disorders and diseases. A review. *International Journal of Circumpolar Health, 61*(2), 173–182. https://doi.org/10.3402/ijch.v61i2.17450

Piil, J.F., Lundbye-Jensen, J., Trangmar, S.J., & Nybo, L. (2017). Performance in complex motor tasks deteriorates in hyperthermic humans. *Temperature (Austin, Tex.), 4*(4), 420–428. https://doi.org/10.1080/23328940.2017.1368877

Pilcher, J.J., Nadler, E., & Busch, C. (2002). Effects of hot and cold temperature exposure on performance: A meta-analytic review. *Ergonomics, 45*(10), 682–698. https://doi.org/10.1080/00140130210158419

Procopé, B.J. (1965). Effect of repeated increase of body temperature on human sperm cells. *International Journal of Fertility, 10*(4), 333–339. PMID: 5891617

Radakovic, S.S., Maric, J., Surbatovic, M., Radjen, S., Stefanova, E., Stankovic, N., & Filipovic, N. (2007). Effects of acclimation on cognitive performance in soldiers during exertional heat stress. *Military Medicine, 172*(2), 133–136. https://doi.org/10.7205/milmed.172.2.133

Rahman, M.N.A., & Adnan, A.A. (2023). A Review on Heat Stress Issues Among Workers at Automotive Service Centre. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 32*(3), 334-341. https://doi.org/10.37934/araset.32.3.334341

Raines, J., Snow, R., Nichols, D., & Aisbett, B. (2015). Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days. *The Annals of Occupational Hygiene, 59*(5), 554–565. https://doi.org/10.1093/annhyg/meu113

Ramsey, J.D. (1995). Task performance in heat: A review. *Ergonomics, 38*(1), 154–165. https://doi.org/10.1080/00140139508925092

Ramsey, J.D., & Morrissey, S.J. (1978). Isodecrement curves for task performance in hot environments. *Applied Ergonomics, 9*(2), 66–72. https://pubmed.ncbi.nlm.nih.gov/15677254/

Ritz, P., & Berrut, G. (2005). The importance of good hydration for day-to-day health. *Nutrition Reviews, 63*(6 Pt 2), S6-13. https://pubmed.ncbi.nlm.nih.gov/16028567/

Robertshaw, D. (1981). Chapter 11 Man in Extreme Environments, Problems of the Newborn and Elderly. In K. Cena & J. A. Clark (Eds.), *Bioengineering, Thermal Physiology and Comfort* (*Vol. 10*, pp. 169–179). Elsevier.

Rodríguez-Marroyo, J.A., López-Satue, J., Pernía, R., Carballo, B., García-López, J., Foster, C., & Villa, J.G. (2012). Physiological work demands of Spanish wildland firefighters during wildfire suppression. *International Archives of Occupational and Environmental Health, 85*(2), 221–228. https://doi.org/10.1007/s00420-011-0661-4

Romanello, M., Di Napoli, C., Green, C., Kennard, H., Lampard, P., Scamman, D., ... & Costello, A. (2023). The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. *The Lancet, 402*(10419), 2346-2394. https://doi.org/10.1016/S0140-6736(23)01859-7

Rosner, M.H., & Kirven, J. (2007). Exercise-associated hyponatremia. *Clinical Journal of the American Society of Nephrology: CJASN, 2*(1), 151–161. https://doi.org/10.2215/CJN.02730806

Ruby, B.C., Schoeller, D.A., Sharkey, B.J., Burks, C., & Tysk, S. (2003). Water turnover and changes in body composition during arduous wildfire suppression. *Medicine and Science in Sports and Exercise, 35*(10), 1760–1765. https://pubmed.ncbi.nlm.nih.gov/14523317/

Ruby, B.C., Shriver, T.C., Zderic, T.W., Sharkey, B.J., Burks, C., & Tysk, S. (2002). Total energy expenditure during arduous wildfire suppression. *Medicine and Science in Sports and Exercise, 34*(6), 1048–1054. https://pubmed.ncbi.nlm.nih.gov/12048336/

Sawka, M.N., Wenger, C.B., Montain, S.J., Bettencourt, B., Flinn, S., Gardner, J., Matthew, W.T., Lovell, M., & Scott, C. (2003). *Technical Bulletin: Heat stress control and heat casualty management (Report No. MSIC 04-13)*. Washington, DC: Departments of the U.S. Army, Navy, and Air Force. https://apps.dtic.mil/sti/tr/pdf/ADA433236.pdf

Selkirk, G.A., & McLellan, T.M. (2001). Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. *Journal of Applied Physiology (Bethesda, Md: 1985), 91*(5), 2055–2063. https://doi.org/10.1152/jappl.2001.91.5.2055

Simmons, S.E., Saxby, B.K., McGlone, F.P., & Jones, D.A. (2008). The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. *European Journal of Applied Physiology, 104*(2), 271–280. https://doi.org/10.1007/s00421-008-0677-y

Smallcombe, J.W., Foster, J., Hodder, S.G., Jay, O., Flouris, A.D., & Havenith, G. (2022). Quantifying the impact of heat on human physical work capacity; part IV: Interactions between work duration and heat stress severity. *International Journal of Biometeorology, 66*(12), 2463–2476. https://doi.org/10.1007/s00484-022-02370-7

Smith, D.L., Manning, T.S., & Petruzzello, S.J. (2001). Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. *Ergonomics, 44*(3), 244–254. https://doi.org/10.1080/00140130121115

Sorensen, C., & Hess, J. (2022). Treatment and Prevention of Heat-Related Illness. The New England Journal of Medicine, 387(15), 1404–1413. https://doi.org/10.1056/NEJMcp2210623

Spector, J.T., Krenz, J., & Blank, K.N. (2015). Risk factors for heat-related illness in Washington crop workers. *Journal of Agromedicine, 20*(3), 349–359. https://doi.org/10.1080/1059924X.2015.1047107

Stookey, J.D. (2005). High prevalence of plasma hypertonicity among community-dwelling older adults: Results from NHANES III. *Journal of the American Dietetic Association, 105*(8), 1231–1239. https://doi.org/10.1016/j.jada.2005.05.003

Taggart, S.M., Girard, O., Landers, G.J., & Wallman, K.E. (2024). Symptoms of heat illness and water consumption habits in mine industry workers over the summer months in Australia. *Industrial Health*. https://doi.org/10.2486/indhealth.2023-0139

Tait, P.W. (2011). Medicine use, heat and thermoregulation in Australian patients. *The Medical Journal of Australia, 195*(6), 327. https://doi.org/10.5694/mja11.10289

Tawatsupa, B., Lim, L.L.-Y., Kjellstrom, T., Seubsman, S., Sleigh, A., & Thai Cohort Study Team. (2012). Association between occupational heat stress and kidney disease among 37,816 workers in the Thai Cohort Study (TCS). Journal of Epidemiology, 22(3), 251–260. https://pubmed.ncbi.nlm.nih.gov/22343327/

Taylor, N.A.S. (2014). Human heat adaptation. *Comprehensive Physiology, 4*(1), 325–365. https://doi.org/10.1002/cphy.c130022

Taylor, N.A.S., Kondo, N., & Kenney, W.L. (2008). The physiology of acute heat exposure, with implications for human performance in the heat. In Taylor NAS, Groeller H, eds. *Physiological bases of human performance during work and exercise* (1st edition, pp. 341–358). Elsevier. https://shop.elsevier.com/books/physiological-bases-of-human-performance-during-work-and-exercise/taylor/978-0-443-10271-4

Taylor, N.A.S., Tipton, M.J., & Kenny, G.P. (2014). Considerations for the measurement of core, skin and mean body temperatures. *Journal of Thermal Biology, 46*, 72–101. https://doi.org/10.1016/j.jtherbio.2014.10.006

Tipton, M., Pandolf, K., Sawka, M., Werner, J., & Taylor, N. (2008). Physiological adaptation to hot and cold environments. In Taylor NAS, Groeller H, eds. *Physiological bases of human performance during work and exercise* (1st edition, pp. 379-400). Elsevier.

Toffanello, E.D., Inelmen, E.M., Minicuci, N., Campigotto, F., Sergi, G., Coin, A., Miotto, F., Enzi, G., & Manzato, E. (2010). Ten-year trends in dietary intake, health status and mortality rates in free-living elderly people. *The Journal of Nutrition, Health & Aging, 14*(4), 259–264. https://doi.org/10.1007/s12603-010-0058-1

U.S. Environmental Protection Agency (EPA). (2014, June 17). *Heat Island Impacts* [Overviews and Factsheets]. EPA: Heat Islands.

Wang, D., Lau, K.K.-L., Ren, C., Goggins, W.B.I., Shi, Y., Ho, H.C., Lee, T.-C., Lee, L.-S., Woo, J., & Ng, E. (2019). The impact of extremely hot weather events on all-cause mortality in a highly urbanized and densely populated subtropical city: A 10-year time-series study (2006-2015). *The Science of the Total Environment, 690*, 923–931. https://doi.org/10.1016/j.scitotenv.2019.07.039

Wesseling, C., Glaser, J., Rodríguez-Guzmán, J., Weiss, I., Lucas, R., Peraza, S., da Silva, A.S., Hansson, E., Johnson, R.J., Hogstedt, C., Wegman, D.H., & Jakobsson, K. (2020). Chronic kidney disease of non-traditional origin in Mesoamerica: A disease primarily driven by occupational heat stress. *Revista Panamericana de Salud Pública, 44*, e15. https://doi.org/10.26633/RPSP.2020.15

Westaway, K., Frank, O., Husband, A., McClure, A., Shute, R., Edwards, S., Curtis, J., & Rowett, D. (2015). Medicines can affect thermoregulation and accentuate the risk of dehydration and heat-related illness during hot weather. *Journal of Clinical Pharmacy and Therapeutics, 40*(4), 363–367. https://doi.org/10.1111/jcpt.12294

Workplace Safety North (WSN). (2014). Mine Rescue Heat Stress Report. Workplace Safety North. https://www.workplacesafetynorth.ca/sites/default/files/resources/Mine_Rescue_Heat_Stress_Report_2014.pdf

Wyndham, C.H. (1973). The physiology of exercise under heat stress. *Annual Review of Physiology, 35*(1), 193–220. https://doi.org/10.1146/annurev.ph.35.030173.001205

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., & Sullivan, T. (2014). Association between high temperature and work-related injuries in Adelaide, South Australia, 2001-2010. *Occupational and Environmental Medicine, 71*(4), 246–252.

Yeargin, S.W., Casa, D.J., Armstrong, L.E., Watson, G., Judelson, D.A., Psathas, E., & Sparrow, S.L. (2006). Heat acclimatization and hydration status of American football players during initial summer workouts. *Journal of Strength and Conditioning Research, 20*(3), 463–470. https://pubmed.ncbi.nlm.nih.gov/16937956/

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V. V. (2019). *Changes in Temperature and Precipitation Across Canada*. In Chapter 4 in Bush, E. and Lemmen, D.S. (Eds.) Canada's Changing Climate Report (pp. 112–193). Ottawa, ON: Government of Canada.

APPENDIX C: RESEARCH AND SUPPORT

Training & technical support is available from your Health and Safety Association. Workplace-specific information, as well as training and consulting services for illness and injury prevention, are provided by the Health and Safety Associations of Ontario, the Workers Health and Safety Centre, and the Occupational Health Clinics for Ontario Workers. All OHS System Partners are part of the Occupational Illness Prevention Steering Committee that supported this project.

- Centre for Research Expertise in Occupational Disease
- Centre for Research in Occupational Safety and Health
- Infrastructure Health and Safety Association
- Institute for Work and Health
- Occupational Cancers Research Centre
- Occupational Health Clinics for Ontario Workers
- Ontario Ministry of Labour, Immigration, Training and Skills Development
- Public Services Health & Safety Association
- Workers Health & Safety Centre
- Workplace Safety North
- Workplace Safety & Prevention Services
- Workplace Safety and Insurance Board

Other sources of information on heat stress can be found in the list of additional resources from various sources at the bottom of the *Heat Stress Toolkit* page.